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ENERGY ANALYSIS REGARDING THE USE OF A HYBRID BUILDING HEATING SYSTEM

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Abstract: The heating system proposed to be analyzed in this paper is a hybrid system composed of a heat pump working with mechanical vapor compression and a thermal power plant, each of them providing the thermal power needed for heating volumes, in an accumulation tank where the heat agent is circulated in the heating installation of the consumer.

In this context, the analysis of energy efficiency is appropriate because it has a significant impact on technology, taking into account the accelerated depletion of conventional resources, that leads us to the objective of the paper witch is to quantify and compare different installation configurations using heat pumps in order to partially replace conventional energy resources.

The analysis refers to the values of thermal and electrical energy used annually by the heat pump and is taking in consideration 3 categories of parameters: the climatic zone in which the building is located, thermal parameters used in the sizing of the central heating installation and the installed capacity of the heat pump used. The obtained results were processed and presented graphically.

Keywords: heating system, heat pump, energy, degrees of coverage, installation system

1. Introduction

Conducted specialized studies play an important role in designing and developing future strategies for alignment with the laws and directives developed, which have an impact on the quality of the life of people and also on the environment.

Replacing conventional systems has been an ongoing issue, including the imposition of a quota of renewable resources used at national level by Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, which states that renewable resources should be in the amount of 32% of total resources for energy production in EU member states by 2030.

The operation of the heating system consists of the transfer of energy provided by a thermal agent using the energies from external temperatures and inside of accumulation tank and cope it with the one in the space that is going to be heated.

As shown in Fig. 1, the system represents the assembly consisting of a condenser, an evaporator, an accumulation tank, an auxiliary source that ensures the heat requirements using conventional fuel, static heat radiators, water and refrigerant circuit pipes, as well as a compressor and the supply valve.

The consumer's central heating installation has a classic structure with static heaters. The dimensioning process of the heating installation has important consequences regarding the performance of the heat pump [1]. Another parameter with important energy implications is the capacity of the installed heat pump [2], capacity represented primarily by the maximum value of the electrical power absorbed from the national system grid by the heat pump compressor [3].

In this paper, the value of the maximum electrical power was reported to the thermal transfer [4] capacity of the building, Pel/H. A third parameter analyzed was the climatic zone in which the building is located, which means different heat requirements.

2. Studies on heat pump systems

Through the article *"A New Modeling Approach for Low-Carbon District Energy System Planning"* by Abolfazl Rezaei, Bahador Samadzadegan, Hadise Rasoulian, Saeed Ranjbar, Soroush Samareh Abolhassani, Azin Sanei and Ursula Eicker" a new thermal energy supply system for a district in Canada was modeled using heat pumps to cover the energy needs for 6 types of buildings, which found that the centralized mode of heat transmission requires fewer heat pump modules with a lower electricity requirement compared to the distributed system, even if the last one has hydraulic and heat losses due to circulation through pipes.

Also, through the work *"Life Cycle Assessment of District Heating Systems in Europe: Case Study and Recommendations"* by Camille Jeandaux *, Jean-Baptiste Videau and Anne Prieur-Vernat, efficiency is analyzed in 12 countries (3 for each cardinal region – North, South, East, West) from the point of view of introducing renewable resources, using 8 energy supply scenarios. In terms of sustainability, the use of renewable resources in combination with the use of natural gas can increase the impact on climate change by 38-78%, but replacing it with biomass can lead to up to 75% of the impact. The centralized form of thermal energy supply can reduce the harmful impact of natural gas by 5% to 90%, compared to decentralized systems. At the same time, according to the same document, it was found that centralized heating is more cost-effective.

The article *"Influence of heat pumps on renewable electricity integration: Germany in aEuropean context"* written by Christiane Bernath, Gerda Deac and Frank Sensfuß, presents a possible integration of heat pumps in thermal energy supply systems but also the transfer of electrical power to the local electricity grid in case of their failure, in Germany. They concluded that the use of heat pumps has an important role in the evolution of the price of CO_2 but also on other fuels as well. In addition to these, the rise of renewable resources in the energy sector can significantly increase competition with other sources of thermal energy production.

3. Description of the system and analysis method

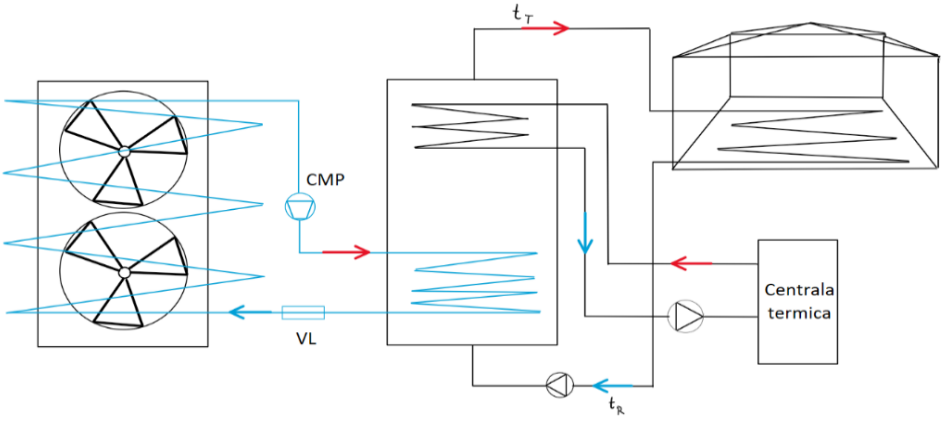

Fig. 1 - Constructive and functional scheme of the analyzed system

The heat pump for which the analysis is made is of the air-water type, characterized by a variable COP value depending on the external air temperature and by the temperature value of the heat agent circulated in the heating installation. If the thermal power delivered by the heat pump condenser in the accumulation tank is insufficient, then a supplement of thermal power is made through the heat exchanger supplied by the heating plant. In situations where the thermal power delivered by the heat pump is sufficient, the correlation of the thermal power with the variable demand of the consumer is done by using of a frequency converter so that only an absolutely necessary value of electrical power is used to be absorbed by heat pump compressor. Continuous monitoring of the state of the heat pump, whether or not it can cope alone to meet the needs of the consumer, was considered. See the model in Fig. 1

The determination of the values procedure was based on the preliminary evaluation of BINs of outdoor temperatures for each month of the cold season, then the group of thermal powers was to be established on each BIN separately and then the group of energies and degrees of energy coverage on each BIN. Next, the energy values from the same category were collected for each month separately and finally for the whole year. As mentioned, the analysis followed 3 categories of parameters namely:

- The relative capacity of the heat pump related to to the heat transfer capacity of the building: PEL/H; 3 values were considered for the mentioned ratio: P_{EL}/H = 11-16 $\left(\frac{W}{W/_K}\right)$, P_{EL}/H = 7-8 $\left(\frac{W}{W/_K}\right)$, P_{EL}/H = 4 $\left(\frac{W}{W/_K}\right)$;
- The size of the parameters of the building's heating system: t_{T0}/t_{R0} = 90/70 ºC, t_{T0}/t_{R0} = 70/50 ºC, t_{T0}/t_{R0} = 50/30 ºC,
- The climatic zone where the building is located: Reșița, zone 1 – te0 = -12 ºC, Slatina, zone 2 – te0 = -15 ºC, Zalău, zone 3 – te0 = -18 ºC, Bistrița, zone 4 – te0 = -21 ºC, Sfântu Gheorghe, zone 5 – te0 = -24 ºC.

The size of the parameters of the consumer's heating installation are important for the energy performance of the heat pump, but they also requires different surfaces of the heating installation, translating into a greater investment in the situation where a lower level of heating agent temperatures is chosen in the installation of heating. The size of the heat pump installed has decisive importance on the degree of energy coverage of the consumer. As for the climatic zone in which the building is located, it implies a different heat requirement for the consumer, which of course also influences the capacity of the installed heat pump. However, it must be stated that a number of parameters involved in the energy results presented have been fixed, these parameters are:

- The heat transfer capacity of the building has the value H = 14200 W/K, which means a building with approx. 100 residential apartments;
- The electrical efficiency of the motor that drives the heat pump compressor has the value $\square_{EL}$ = 0.9;
- The isentropic efficiency of the heat pump compressor has the value η_{IZ} = 0.8.

It is important to state that the ratio PEL/H is related to the external equilibrium temperature, t_E, according to the relation (3):

$$P_{inc} = H \cdot (t_{i0} - t_E) \quad (1)$$

$$P_{inc} = COP_E \cdot P_{EL} \quad (2)$$

From (1) and (2) results :

$$\frac{P_{EL}}{H} = \frac{t_{i0} - t_E}{COP_E} \quad (3)$$

The analysis we proposed, the annual energy consumption according to the 3 types of parameters took into account only the couple of temperatures of the thermal agent, t_{T0}/t_{R0}, fixing the value of the PEL/H ratio at the value of 4. This means that the maximum electrical power is not too high, so a medium heat pump was chosen that partially covers the thermal needs of the consumer, the rest of the required power being covered by the thermal plant.

Below are some related figures that will be analyzed and reflect the performances of the various hybrid system structures.

4. Data analysis

The fixed parameter is the P_{EL}/H ratio, which has the value 4.

4.1. Reșița (zone 1)

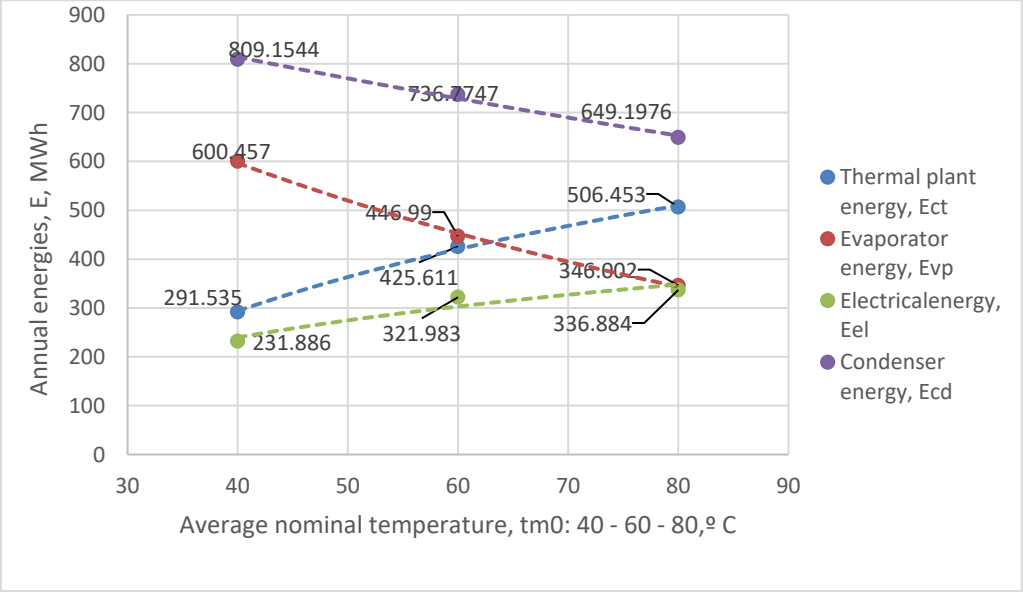

Fig. 2 - Energies – Resița - PEL/H = 4

Using the value PEL/H = 4 results in a smaller heat pump to this zone, which leads to a decrease in the thermal energy supplied by the heat pump compensated by an increase in the thermal energy supplied by the thermal plant which becomes significant. A pronounced decrease in the thermal energy absorbed at the evaporator of the heat pump is observed, and at the same time an increase in the electrical energy. See Fig. 2.

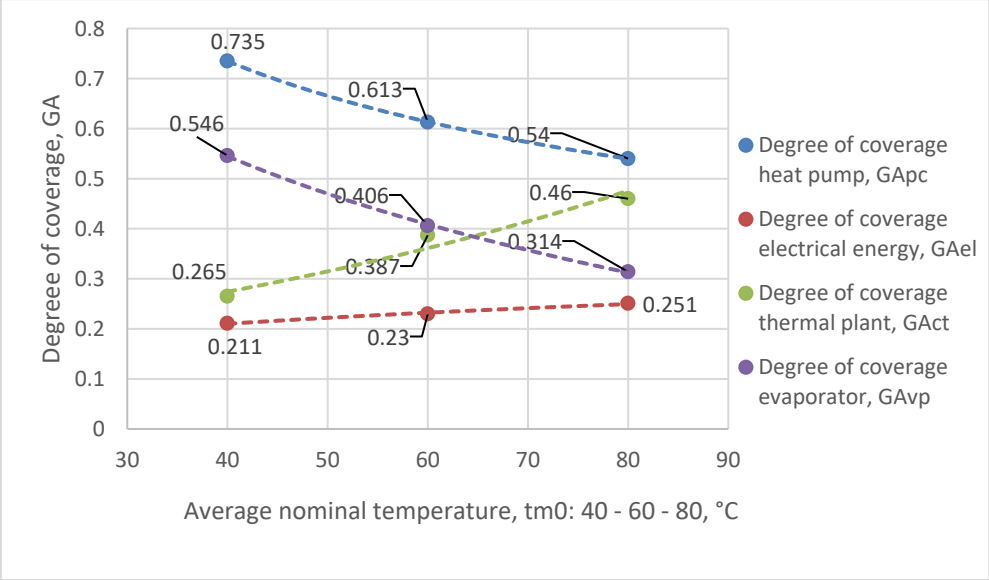

Fig. 3 - Degrees of coverage Resița $P_{EL}/H=4$

The heat pump's electrical power consumption has significantly decreased, leading to a corresponding reduction in the energy coverage provided by the heat pump. Meanwhile, the thermal power supplied by the thermal plant has increased.

Additionally, the thermal energy absorbed by the pump's evaporator has decreased substantially, while the electrical energy consumed by the heat pump's compressor has risen. These changes in

thermal energy at the evaporator and electrical energy at the compressor are most pronounced at the maximum values of the central heating system's sizing parameters.

It is observed that the sum of the degrees of coverage GApc and GAct for tm0=40, tm0=60 and tm0=80 are equal to 1, which suggests that the two cover the needs of the building, as can be seen in relation (4) with the data in Fig.3.

$$GApc40+GAct40 = GApc60+GAct60 = GApc80+GAct80 = 1 \quad (4)$$

4.1. Slatina zone2)

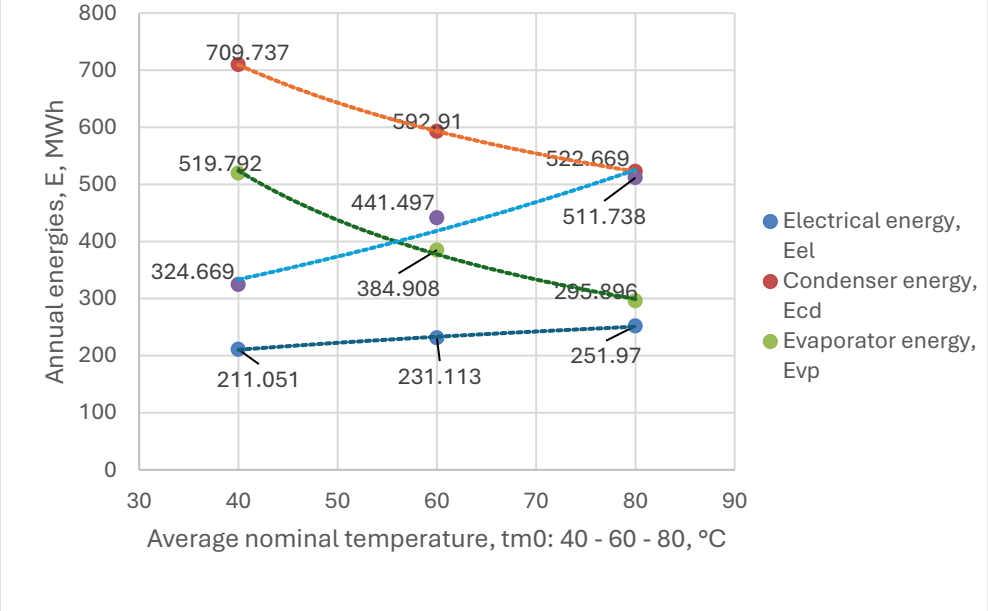

Fig. 4 - Energies Slatina PEL/H=4

And in the case of the city of Slatina in zone 2, there are energy consequences similar to zone 1, i.e. the decrease in the share of energy supplied by the heat pump with the increase in the dimensioning parameters of the central heating installation, associated with the increase in the participation share of the thermal plant.

The energy absorbed at the heat pump evaporator decreases, in the background of the increase in electrical energy absorbed by the compressor motor. As can be seen in Fig. 4.

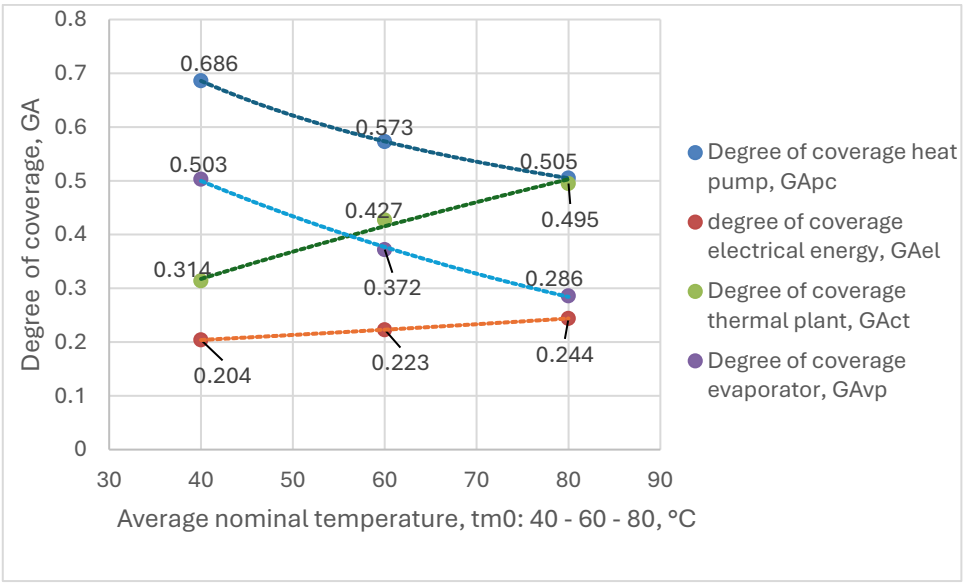

Fig. 5 - Degrees of coverage Slatina PEL/H=4

The same consequences are also found in terms of degrees of energy coverage, as in the case of the city of Reșita in zone 1. It should be noted that in the situation where the temperature level of the thermal agent in the consumer's central heating installation increases, it reduces the energy performances reflected both in the energy values as well as in the degrees of energy coverage.

As for the degrees of coverage from Resita, it is observed that the sum of the degrees of coverage GApc and GAct for tm0=40, tm0=60 and tm0=80 are equal to 1, which suggests that the two cover the needs of the building, as can be seen in relation (4) with the data from Fig. 5

4.3. Zalău (zone 3)

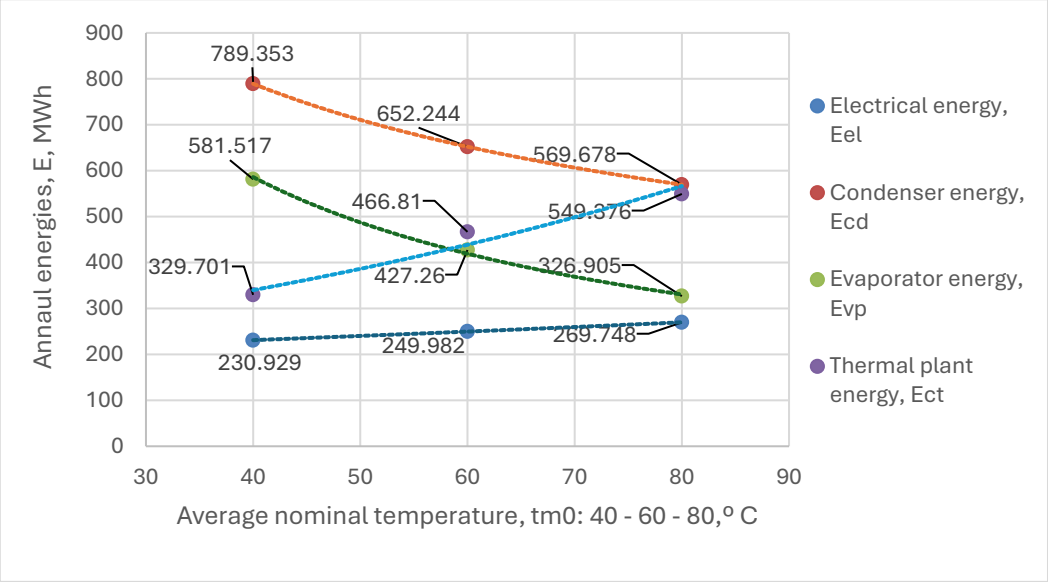

Fig. 6 - Energies - Zalău - PEL/H=4

We have a smaller heat pump. The consequence is a decrease in the thermal energy supplied by the heat pump compensated by an increase in the thermal energy supplied by the thermal plant which becomes significant. A pronounced decrease in the thermal energy absorbed at the evaporator of the heat pump is observed, and at the same time an increase in the electrical energy. See Fig. 6.

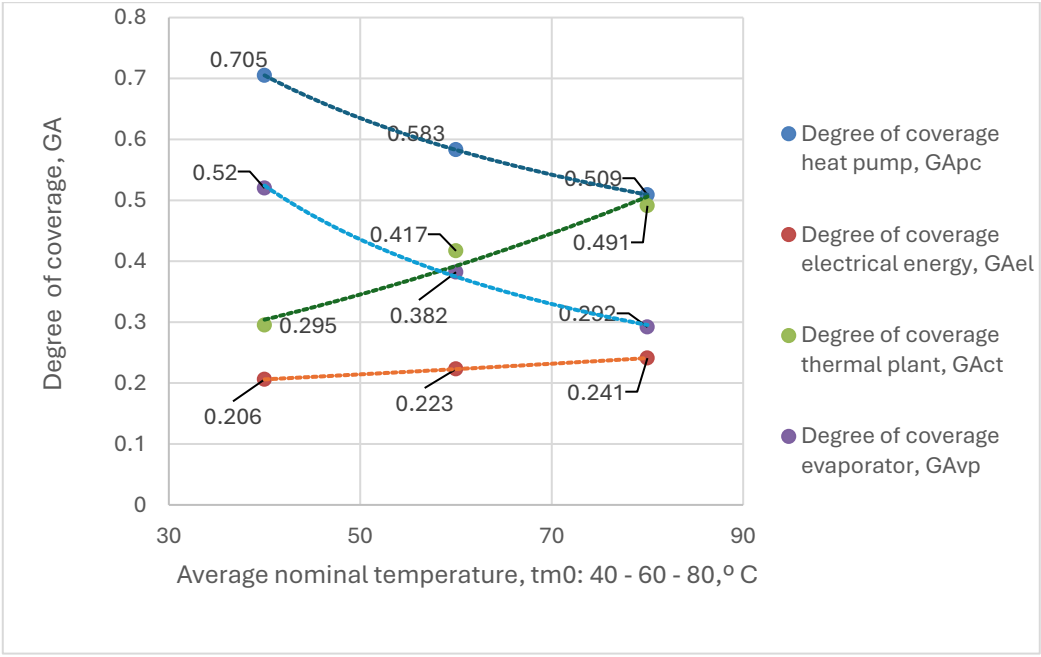

Fig. 7 - Degrees of coverage - Zalău - PEL/H=4

The heat pump's electrical power consumption has significantly decreased, leading to a reduced energy coverage contribution. Conversely, the thermal plant's thermal power output has increased. Simultaneously, the thermal energy absorbed by the heat pump's evaporator decreases notably, while the electrical energy consumed by the compressor rises. These effects are most pronounced at the maximum central heating system sizing parameters.

For Reșița and Slatina, the combined energy coverage degrees (GApc and GAct) at tm0=40, 60, and 80 sum to 1, indicating that the heat pump and thermal plant fully meet the building's energy needs, as shown in relation (4) and Figure 7.

4.4. Bistrița (zone 4)

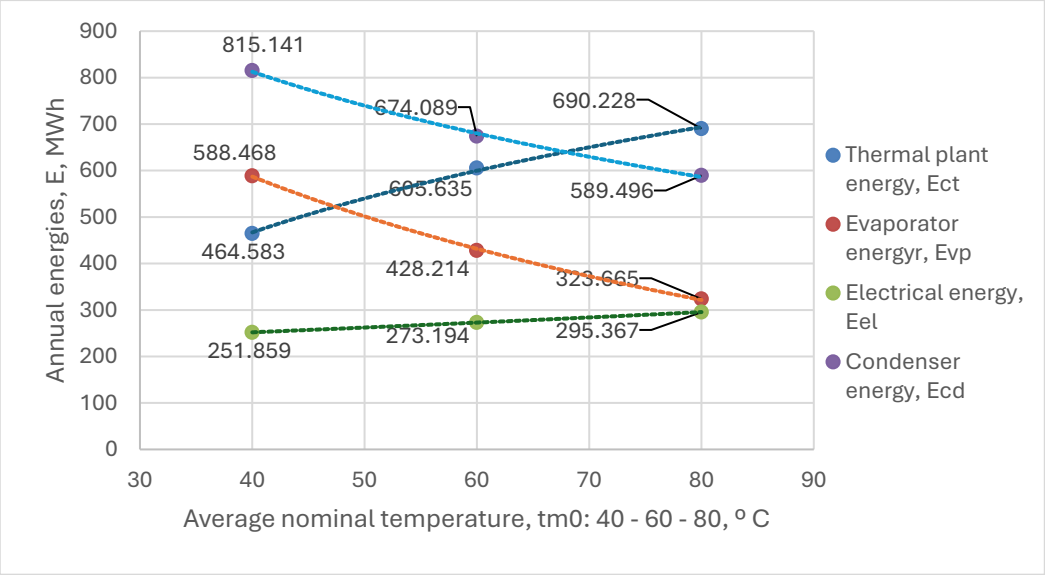

Fig. 8 - Energies Bistrița PEL/H=4

In the case of city of Bistrița zone 4, at the highest values of temperatures of the thermal agent tT0/tR0 = 90/70 ºC, it is observed that the thermal plant will have the largest contribution, surpassing that the heat pump, as seen in Fig. 8.

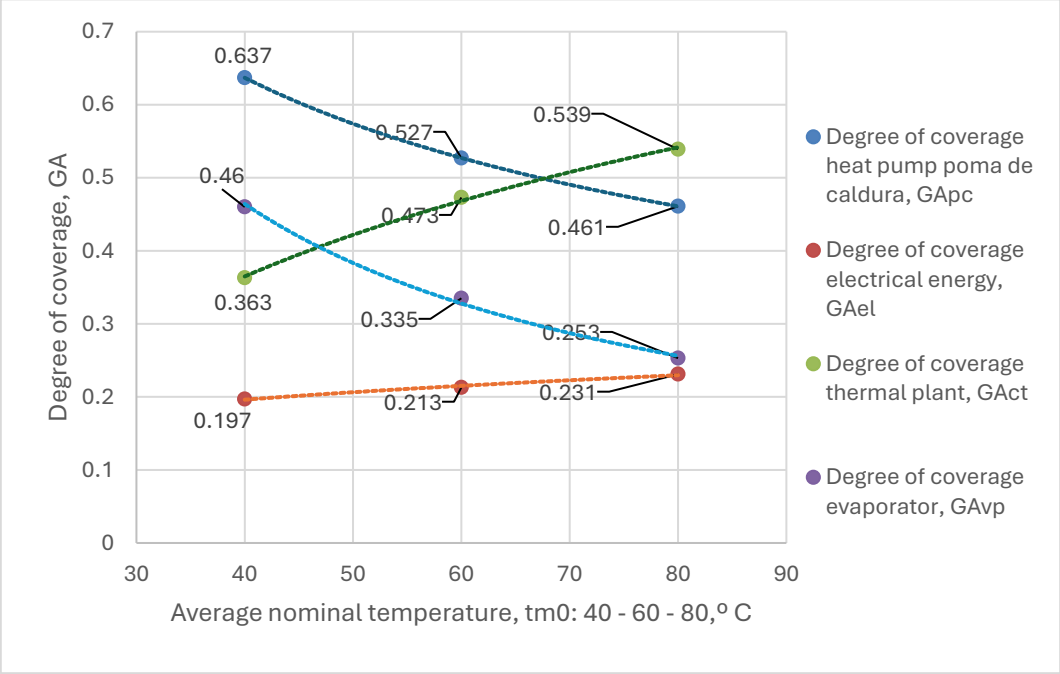

Fig. 9 - Degrees of coverage - Bistrița - PEL/H=4

The energy assessments made based on the figure in the case of energies also result from the analysis of the associated figure relating to degrees of energy coverage.

Like the degrees of coverage from Resița, Zalău and Slatina, it is observed that the sum of the degrees of coverage GApc and GAct for tm0=40, tm0=60 and tm0=80 are equal to 1, which suggests that the two cover the building's needs, as can be seen in relation (4) with the data from Fig. 9.

4.5. Sf. Gheorghe (zone 5)

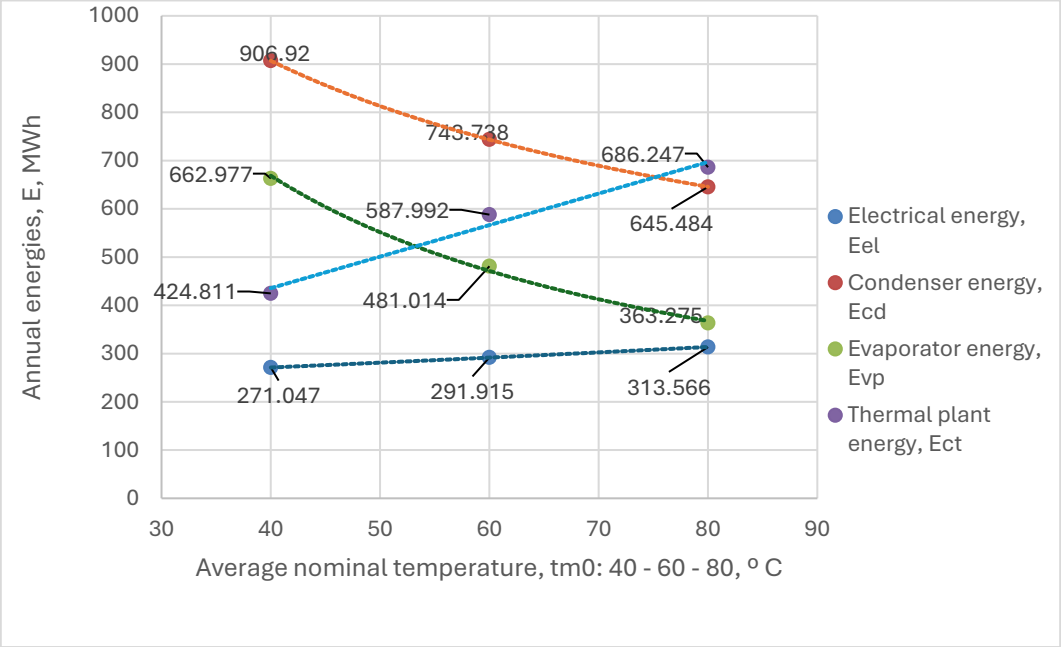

Fig. 10 - Energies - Sf. Gheorghe - PEL/H=4

In the case of the city of St. Gheorghe are generally the same energy consequences, but the energy values are significantly higher given the demand of the city's climate in zone 5. As can be seen in Fig. 10.

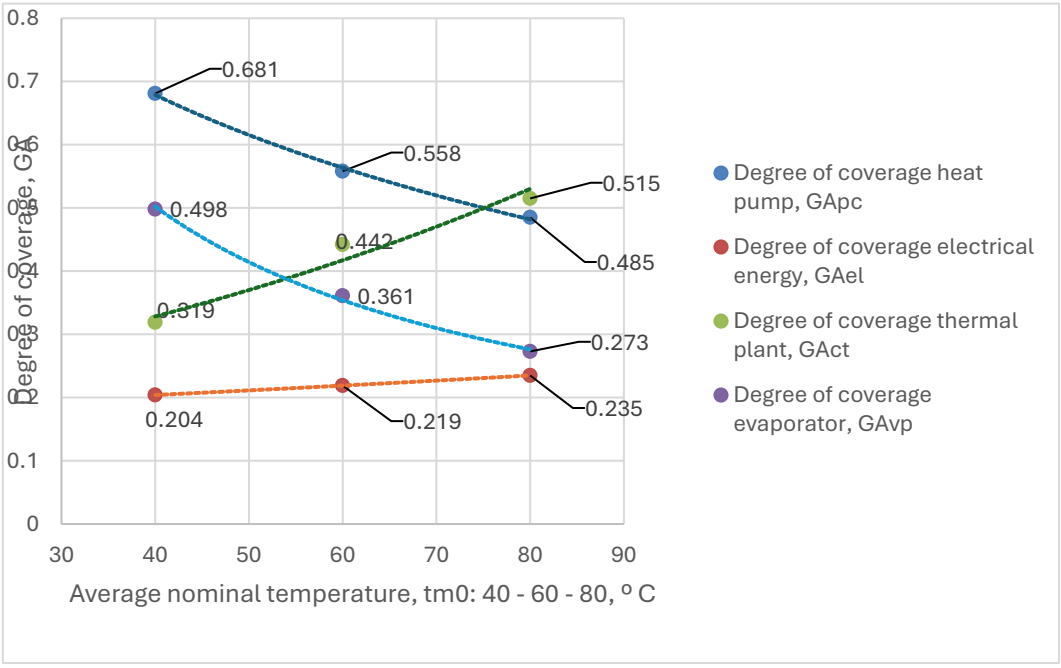

Fig. 11 - Degrees of coverage - Sf. Gheorghe - PEL/H=4

From the analysis of the degrees of energy coverage, similar conclusions emerge regarding the influence of the calculation temperatures of the heat agent: the higher level of these temperatures decreases the energy performance of the heat pump.

Like the degrees of coverage from Resița, Zalău, Slatina and Bistrița, it is observed that the sum of the degrees of coverage GApc and GAct for tm0=40, tm0=60 and tm0=80 are equal to 1, which suggests that the two cover the necessary of the building, as can be seen in relation (4) with the data in Fig. 11.

Conclusions

The energy analysis targeted in this paper refers to the importance of introducing a heat pump in the central installation system, depending on the sizing of the consumer's central heating installation. If the consumer's heating installation is dimensioned at a higher level than the design temperatures of the heating agent, it puts the heat pump exchangers in difficulty, reducing the heat flows to the evaporator and condenser and therefore the energy participation of the heat pump.

A central heating installation dimensioned at a lower level of the design temperatures tT0/tR0 = 70/50 or even 50/30 ºC gives chances to capitalize on the effect of the heat pump, its participation increasing as the level of the design temperatures of the heating agent is lower. We must not forget that a lower level of temperatures pre-established of the heating agent leads to larger surfaces of the heating installation.

If it is desired to increase the energy participation of the heat pump, it can be influenced by the size of the heat pump chosen, i.e. considering a ratio PEL/H = 7 or 11 or 16 and not 4 as chosen in the present paper.

Symbols

ti0 – interior temperature for calculation, ºC;
te0 – external temperature for calculation, ºC;

tE – external equilibrium temperature, ºC;

Pînc - required heating power, W;

H – thermal capacity of the building; W/K;

PEL - the maximum electrical power absorbed by the heat pump, W;

t_{T0}/t_{R0} – the calculation temperatures of the heat agent for sizing the central heating installation, ºC;

tm0 – the arithmetic mean of the calculation temperatures of the thermal agent, t_{T0}/t_{R0}, ºC;

η_{EL} – the efficiency of the electric motor that drives the compressor;

η_{IZ} – isentropic operating efficiency of the compressor;

COPE – coefficient of performance of the heat pump at te = t_E;

M, N – work constants in the correlation between the isentropic efficiency and the Carnot efficiency of the heat pump, ;

Ecd – condenser energy, MWh;

Evp – evaporator energy, MWh;

Ect – thermal plant energy, MWh;

Eel – electrical energy, MWh;

GApc – degree of coverage heat pump;

GAel – degree of coverage electrical energy;

GAct – degree of coverage thermal plant;

GAvp – degree of coverage evaporator.

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