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ENERGY EFFICIENCY IN CONSTANTA HARBOR- A THEORETICAL ASSESSMENT OF THE PERFORMANCE OF A HEAT PUMP FOR HEATING NEEDS, FOR A LESS POLLUTANT ADMINISTRATION OFFICE

Feiza MEMET

Constanta Maritime University, Faculty of Naval Electro-Mechanics, 104 Mircea cel Batran Street, 900663, Constanta, Romania, e-mail address: feizamemet@yahoo.com

Abstract: In accordance with the present energetic exigencies, the energy consumption in port buildings is of a vital importance. From this perspective, heat pumps are less pollutant and more energy efficient options than the traditional heating technologies. This study focuses on an air source heat pump (ASHP), operating in an administration office located in Constanta harbor, Romania, in order to supply heated water during December of 2020. Electrically driven heat pumps are seen as a successful alternative to classical expensive heating means, such as electrical heating or the one based on fossil fuels combustion. Within this research, are investigated influences of the heated water temperatures and exterior air temperatures on the theoretical Coefficient of Performance, the compression ratio and the discharge temperature. The cycle is working with R134a, with 5^0C superheating and sub cooling. It will be considered that the heated water is supplied in the range (40-50) ^{0}C, while the outdoor air temperature varies in the range (0-10) ^{0}C. Obtained results show that the highest efficiency of the ASHP is obtained for the lowest value of the heated water temperature and for the highest value of the outdoor air temperature. This situation corresponds also to the good working of the compressor of the refrigeration plant, since are seen lowest values of the compression rate and the discharge temperature, as well. This means that the compressor do not consume high amounts of energy and the oil is not damaged because of high temperatures of the refrigerant vapors.

Key words: heat pump, building, pollution, freon R134a, efficiency

1. INTRODUCTION

Heat pumps are technologies used to transfer heat from a cold source to a hot source, with energy consumption and are met in heating, refrigeration or air conditioning applications; air source heat pumps (ASHP) are used to serve heating systems, seen that the hot water supply is required all year long [1].

These systems do not produce heat, but they transfer it between sources of heat. Heat pumps (HP) do not use traditional fuels in order to produce energy in the place it is required, so that they are environmental friendly.

This important feature of HPs place them on a very good position, when talking about energy efficiency in buildings, in the global warming challenge context; also, they are interesting systems in other context: energy savings in buildings while the energy demand is on ascending trend [2].

Due to the fact that HPs are efficient and energy saving systems, hot water supply inside buildings is provided by their use on large scale, with the mention that the performance of ASHPs is directly related to the outdoor air temperature [3].

An important issue connected with HP is the refrigerant in use – which should show some features, such as: chemical stability, environmental behaviour, safety, good thermodynamic properties, compatibility with oil and materials, availability on the market or low costs [4].

Refrigerants responsible with ozone layer depletion, such as CFCs (Chlorofluorocarbons) and HCFCs (Hydrochlorofluorocarbons) are subjects of international regulations in respect with their use and production, a brief summary being given below [5]:

Montreal Protocol – 1987,
Helsinki meeting – 1989,
London revision – 1990,
Nairobi revision – 1991,
Copenhagen revision – 1992,
Bangkok revision – 1993,
Vienna revision – 1995,

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Montreal revision – 1997,
Beijing revision – 1999.

The environmental impact of refrigerants is assessed throughout ODP (Ozone Depletion Potential) – related to the depletion of the ozone layer because of chlorine based gases and GWP (Global Warming Potential) – related to the assessment of gases greenhouse effect, in connection with their radiative properties relative to carbon dioxide in a specific time setting; nowadays, HFCs (hydrofluorocarbons) are used in a wide range of refrigeration systems, R134a being one of the most common (see its main properties in Table 1 [6]).

Table 1. Main properties of R134a (CH2FCF3)

Boiling point (^{o}C)	–26.074
Critical temperature (^{o}C)	101.06
Critical pressure (MPa)	4.06
ASHRAE Safety group	A1
ODP	0
GWP (100 Years)	1430

In our modern times, it is known the fact that buildings are high energy amounts consumers, this is why heat pumps are interesting technologies for these establishments; seen that the outdoor temperatures have a major influence on heating function of HPs, the Black Sea area climate offers the opportunity of obtaining maximum efficiency of these technologies [7].

Despite the moderate climate, in cold ones the performance of the HPs decreases massively because of the important temperature gap between the cold source and the heat sink, especially in the case of air-source HPs [8].

Based on the above mentioned, this paper deals with the theoretical assessment of the performance of a heat pump for heating needs, the HP taken into discussion being an air-source type (ASHP).

The ASHP should operate in a building located in Constanta/ Romania – a port city at the Black Sea. ASHP provides heated water during December 2020.

The refrigerant in use is R134a. Will be analysed the influence of the condensation temperature on the Coefficient of Performance and the influence of the evaporation temperature on the Coefficient of Performance, on compression ratio, on the compression discharge temperature.

2. METHODS AND MATERIALS

The thermodynamic analysis on which it is developed this study, relies on the schematic layout of the single stage vapour compression system of the ASHP and the mathematic formulation – provided below [9, 10].

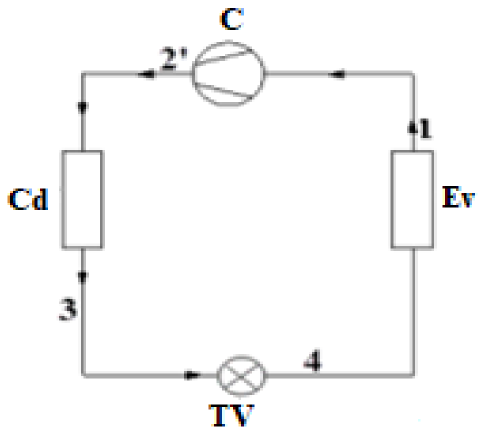

Figure 1 Schematic layout of the considered ASHP (Ev – evaporator; C – compressor; Cd – condenser; TV – throttling valve)

The theoretical Coefficient of Performance (COP) of the ASHP it is defined to be the ratio between the specific heat load in the condenser (q_{Cd}) and the specific work consumed by the compressor (l), terms given by the enthalpy differences at the outlet and inlet of each component (h).

$$COP = \frac{q_{cd}}{l} = \frac{h_{2'} - h_3}{h_2 - h_1} \tag{1}$$

The condensation temperature is assessed with:

$$t_{cd} = t_{ws} + 8^{o}C \tag{2}$$

where: t_{ws} – temperature of the supplied water.

The evaporation temperature is assessed with:

$$t_0 = t_{ea} - 8^{o}C \tag{3}$$

where: t_{ea} – temperature of the exterior air.

3. RESULTS AND DISCUSSIONS

The results are obtained for the following data:

- the evaporation temperature, t_0, varies in the range (-8; 2)^{o}C
- the condensation temperature, t_{cd}, varies in the range (48 - 58)^{o}C
- the exterior air temperature, t_{ea}, varies in the range (0 ÷ 10)^{o}C
- the water is supplied with temperatures, t_{ws}, between (40 ÷ 50)^{o}C
- superheating of vapours and sub cooling of liquid refrigerant: 5^{o}C.

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From Figure 2 can be seen the dependency between the theoretical Coefficient of Performance (COP) and the condensation temperature (t_c), for a given evaporation temperature (t_0).

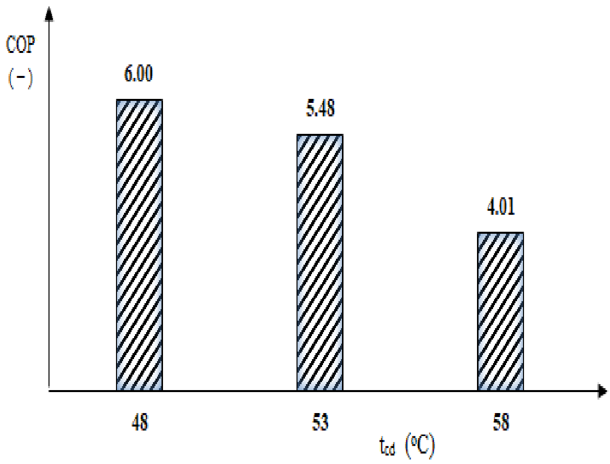

Figure 2 Dependency (t_{cd} – COP), when t_0 = 5°C

When the condensation temperature increases, the Coefficient of Performance decreases, for a given value of the evaporation temperature.

This is due to the fact that a higher difference between evaporation and condensation temperatures leads to a higher difference between pressures.

Thus more work will be requested for the operation of the compressor, resulting a lower performance of ASHP.

From Figures 3, 4 and 5 can be seen the dependency between the theoretical Coefficient of Performance (COP) and the evaporation temperature (t_0), for different values of the condensation temperature (t_c) and supplied water temperature (t_{ws}).

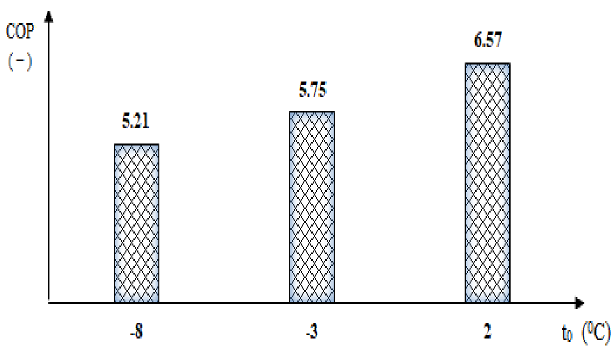

Figure 3 Dependency (t_0 – COP), for t_c = 48°C and t_{ws} = 40°C

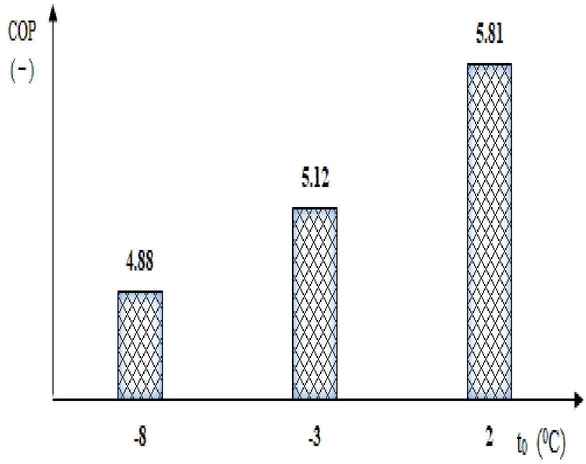

Figure 4. Dependency (t_0 – COP), for t_c = 53°C and t_{ws} = 45°C

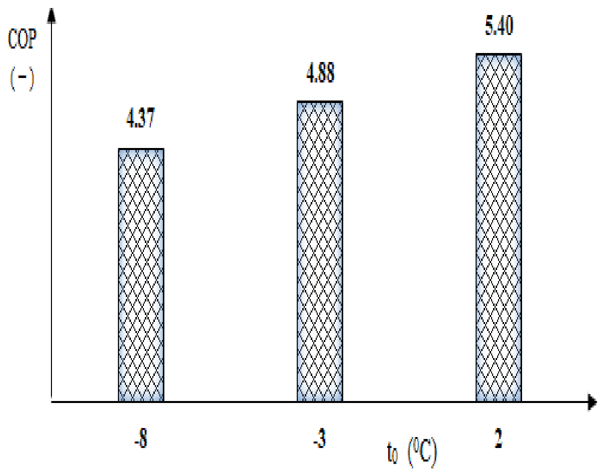

Figure 5 Dependency (t_0 – COP), for t_c = 58°C and t_{ws} = 50°C

The Coefficient of Performance increases together with the increase of the evaporation temperature due to the fact that increases the refrigeration effect and decreases the work input at the compressor.

Also, it is observed that COP values are higher when the condensation temperature and the supplied water temperatures are lower.

The ASHP performance is highest (6.57) when the supplied water temperature is at its lowest value (40°) and the outdoor temperature is at its highest value (10°).

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Figures 6, 7 and 8 indicate the influence of the evaporation temperature (t_0) on the compression ratio (β) – given by the ratio between the condensation pressure and the evaporation pressure; for each case, the condensation temperature (t_c) is kept constant.

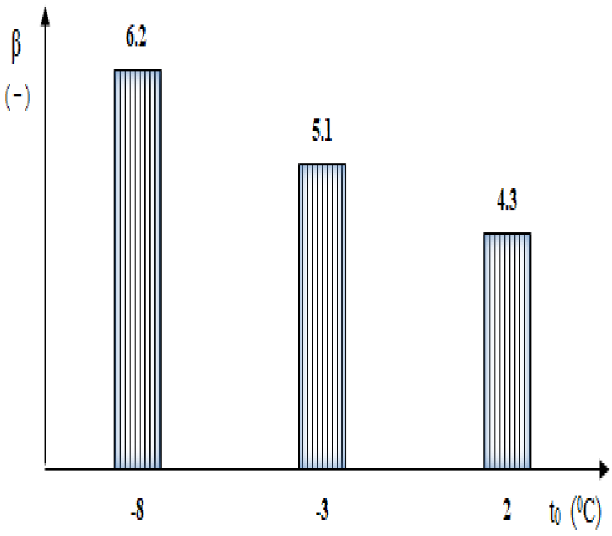

Figure 6 Dependency (t_0 – β), for t_c = 48°C and t_{ws} = 40°C

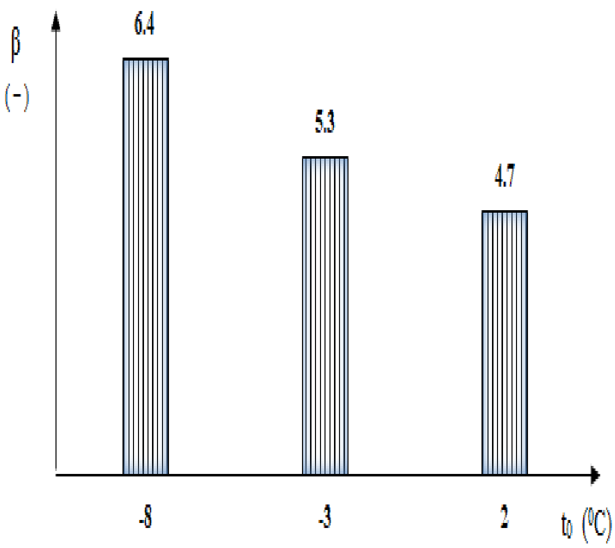

Figure 7 Dependency (t_0 – β), for t_c = 53°C and t_{ws} = 45°C

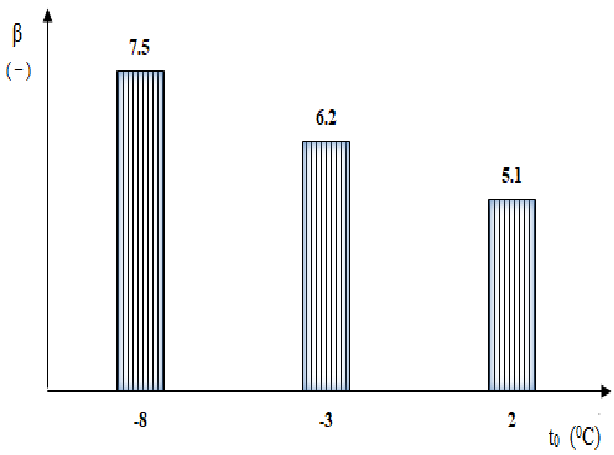

Figure 8 Dependency (t_0 – β), for t_c = 58°C and t_{ws} = 50°C

The compression ratio decreases with the increase of the evaporation temperature, when the condensation temperature is kept constant, due to the fact that the decrease in the gap of temperature values leads to the decrease in the gap of the pressure values.

Lower β values indicate a lower energy consumption at the compressor.

Since compression ratio has to have low values, the best situation results to be when the outdoor temperature is at its highest value (10°C) and the supplied water is at its lowest value (40°C), for which β = 4.3.

The influence of the evaporation temperature variation (t_0), when the condensation temperature (t_c) is kept constant, on the compressor discharge temperature ($t_{2'}$) it is given in Figure 9, Figure 10, Figure 11.

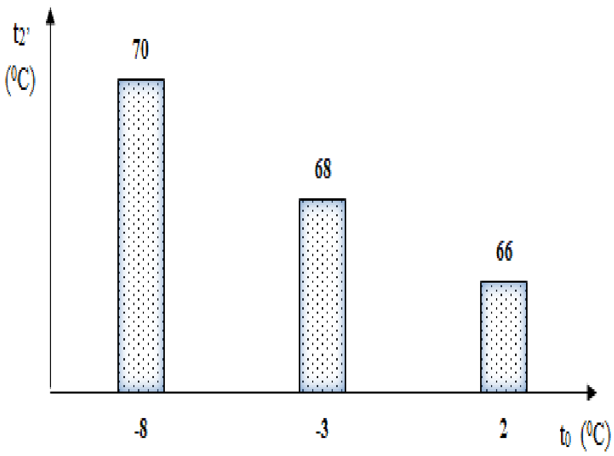

Figure 9 Dependency (t_0 – $t_{2'}$), for t_c = 48°C and t_{ws} = 40°C

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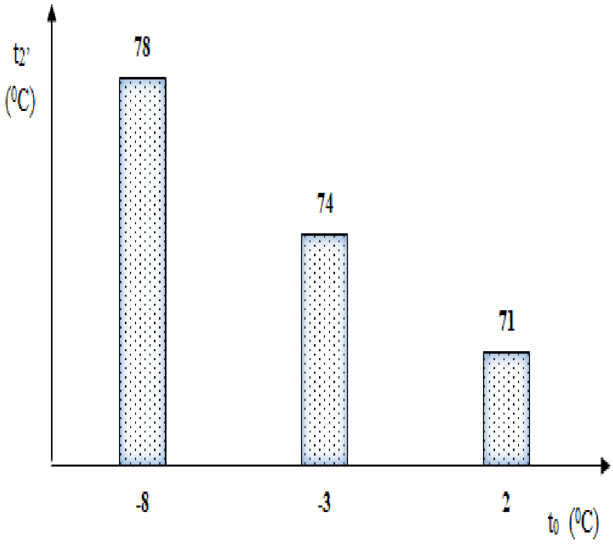

Figure 10 Dependency ($t_0 – t_{2'}$), for t_c = 53^{o}C and t_{ws} = 45^{o}C

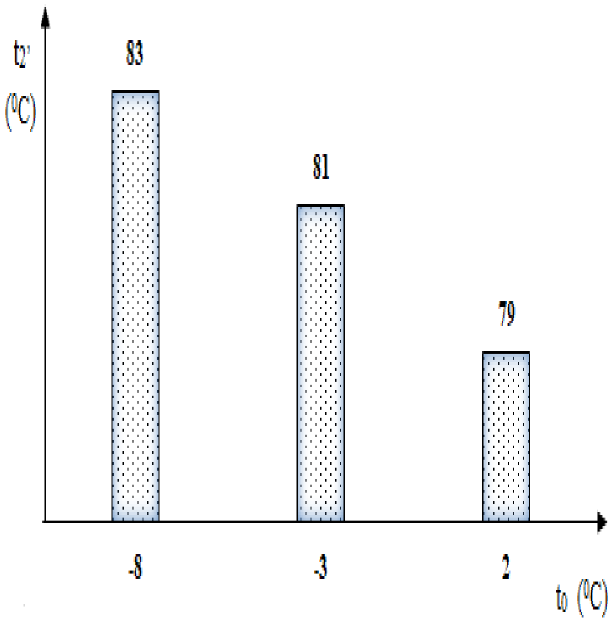

Figure 11 Dependency ($t_0 – t_{2'}$), for t_c = 58^{o}C and t_{ws} = 50^{o}C

The discharge temperature decreases with the increase of the evaporation temperature, when the condensation temperature is kept constant. This temperature should have values for a good stability of the oil and for a long life of the compressor. Thus, the best $t_{2'}$ value is 66^{o}C, obtained for the highest outdoor temperature (10^{o}C) and for the lowest value of the supplied water (40^{o}C).

4. CONCLUSIONS

Analysing the results obtained within this study, the following conclusions are formulated:

- R134a is a refrigerant suitable for the use in HPs, according to the international regulations
- The Coefficient of Performance of ASHPs depends on the temperature of the heated water to be supplied
- The Coefficient of Performance of ASHPs depends on the outdoor air temperature
- Since the above mentioned temperatures influence the values of the condensation and evaporation temperatures, results that they have influence also on the values of compression ratio and compressor discharge temperature
- The best values of the performance indicator (COP) of the analysed HP was seen in the case in which the ASHP is working when the outdoor air temperature has its highest value – from the considered range and the heated water is supplied at the lowest temperature value - from the considered range:

COP = 6.57, for t_{ea} = 10^{o}C and t_{ws} = 40^{o}C.

- The assessment of the other parameters – specific to the cycle, able to indicate an efficient operation of the considered ASHP is in the same trend: lowest values for the compression ratio (β) and the discharge temperature ($t_{2'}$) are obtained also for t_{ws} = 40^{o}C and t_{ea} = 10^{o}C:

β = 4.3 and $t_{2'}$ = 66^{o}C.

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