Comparative study on the electrical power consumption versus monitoring for an outdoor ice rink

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Abstract.

Our paper refers to the analysis of the variation in electricity consumption made by a removable, seasonally ice rink installed outside of a commercial building. The electricity consumption of the ice-skating installation was monitored for about six months between 2016 and 2017, during November and March period of skating season. It is described the ice rink refrigeration plant which is one with indirect mechanical compression in one step using a R134a refrigerant agent and a 30% ethylene glycol solution as a secondary agent. It is compared and analyzed the current electricity consumption with the one obtained by simulating the operation of the refrigeration plant in ideal conditions using R134a refrigerants. A comparison of the electricity consumption is made between simulating the operation of the refrigeration plant using refrigerant R134a or R410a or R507a.

Keywords: monitoring, skating rink temperature, energy performances, outdoor skating rink, analysis

1 Introduction

In this article we analyze the current real electricity consumption against the theoretic one resulted from the installation design of a seasonal ice rink with a surface of 600m^2 mounted on the land next to a commercial building, monitored for its energy consumption.
It will be performed a comparative study between the real electricity consumption and the theoretical electricity consumption by using the Pack Calculation Pro software for the designed installation using R134a as freon refrigerant agent. Supplementary, it will be compared with the similar theoretical electricity consumptions when using R410a and R507a as refrigerant agents.
The operational period of this installation is ranged from November to March, and in the off-season period, the land is used for the terraces for various commercial activities.

2. Description of the installation

The ice rink installation [1] is a mechanical compression system with indirect vaporization in a stage using freon refrigerant R134a and as secondary agent 30% ethylene glycol solution with a refrigerant power of 180kW. This is designed to create and maintain the ice layer of runway up to an outside temperature of 18°C.

The ice layer thickness should be between 2.5cm and 3.5cm [2], [8], [11], the ratio of the ice quality and ice consumption to maintain the ice is optimal at a thickness of 3 cm. Given that the ice-skating rink is discovered (thus is subject to the wind and precipitations), the ice making activities should be carried out more often.
The temperature of the ice layer varies between - 4 °C and - 8 °C depending on the exterior temperature, the number of the skaters and the opening hours when the ice skating is working.
In figure 1 is represented the ice rink assembly.

Fig. 1. The ice rink assembly

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To make these conditions it is recommendable that the ethylene glycol solution temperature which is circulating through the rink pipes to be:

- between - 9°C and -7°C at an exterior temperature between -10°C and 0°C;
- -10°C at an exterior temperature between +5°C and +15°C;
- lower than -10°C at an exterior temperature over +15°C.

When the exterior air temperature falls below -12°C and 15°C, the ice formation and its maintenance will be achieved naturally, without the use of the refrigeration system, it is mounted in a technical room (figure 2) and consists of the following equipment:

a) chiller type York JCI - model YLCS 0620 HA (*CH*) [3] with refrigerant agent freon R134a, having a capacity of 314W, power P_{abs} =131.8kW, with an evaporator for the 30%, flow solution Q_{gl} = 27.5 l/s, condenser cooled with water t_{water} =30^{0}C/35^{0}C, flow water Q_{water} = 21 l/s, with two screw compressors;

b) glycol tank with V = 1000 liters;

c) double pump Willo (*PG*) [4] for the ethylene glycol solution for the ice-skating - model DL 80/220-4/4, with an engine in operation and another engine as reserve, with flow Q = 60.4m^3/h, pumping height of H =14.2 m, NPSH 1.97 m;

d) expansion tank (*VE)* with volume V = 250 liters, pressure p_{max} =10 bars.

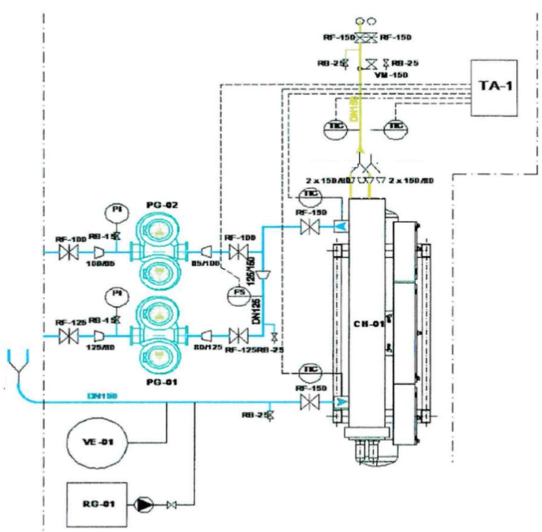

Fig. 2. The refrigeration technical room

The rink has a schedule to operate between 10.00 a.m. and 11.00 p.m. from Monday to Sunday and during the legal holiday's days and at the request of the landlord between 10.00 a.m. and 10.00 p.m.

In the table 1 and figure 3 there are presented the outdoor air parameters and the electricity consumption resulted from the monitoring of the electricity consumption from the refrigerant installations during the period of November 2016 and March 2017, consumptions related to the outdoor air parameters and skaters' number.

Table 1. Outdoor air parameters and electricity consumption for refrigeration system and lighting

Month	Outdoor air parameters		Electricity consumption (kWh)
	Temperature T_M /T_m /T_{med} (° C)	Humidity M / m/ med (%)	
November 2016	19/-3/6	100/35/84	22785
December 2016	12/-1/0	100/34/79	25382
January 2017	6/-17/-5	100/46/85	22205
February 2017	18/-10/2	100/32/80	12094
March 2017	22/-1/9	100/16/72	545

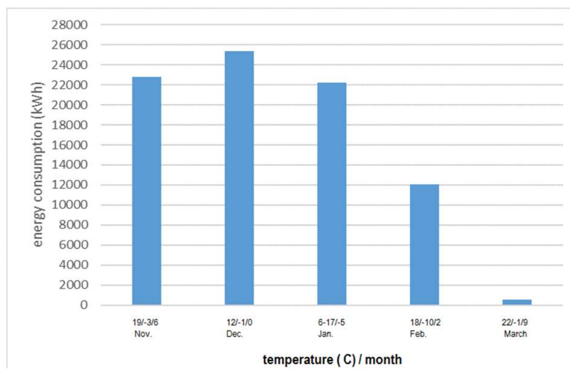

Fig. 3. Variation of the real energy consumption depending on the exterior temperatures

3. Energy consumptions analysis

Pack Calculation Pro is a software used for simulation to calculate and to compare the annual energy consumption of refrigeration systems [9].

The Pack Calculation Pro software contains a wide range of meteorological data, technical characteristics of the various equipment and refrigerants used, which allows studies on energy consumption, efficiency and environmental impact of the analyzed installation.

Using the Pack Calculation Pro software, a comparative analysis was carried out between the current consumption of the refrigerant installation using the R134a freon refrigerant agent and the theoretical consumption of the installation using as refrigerant agents such as R134a, R410a and R 507a.

R134a has the following characteristics:

a) good thermo-dynamic properties used in refrigerant installations having medium power values;

b) chemically stable;

c) hardly inflammable;

d) does not chemically react with metals used in the refrigerant installations;

e) insoluble with mineral and synthetic oils, which causes the use of special oils on the compressor;

f) water solubility is low.
R410A has the following characteristics:
a) transfer of higher heat;
b) low vaporization temperature;
c) high volume refrigeration power;
d) high compressed steam superheat temperature;
e) high adiabatic compression index.
R507A has the following characteristics:
a) stable in normal environmental conditions;
b) having good thermo-dynamic properties in normal environmental conditions;
c) inflammability,
d) miscibility with mineral oils.
For theoretical model of the refrigerant installation of the ice rink, there are used, during the simulation with Pack Calculation software, the Bitzer compressors types such as:
a) CSH7573 – 70 Y for R 134a freon refrigerant agent;
b) OSK 7441 for R 410a freon refrigerant agent;
c) 6 FE – 44Y for R 507a freon refrigerant agent.
In table 2 there are presented the real and theoretical electricity consumptions for the refrigerant installations of the ice rink using the R134a refrigerant agent.

Table 2. Electricity consumption for refrigeration system use R134a

Month	Electricity consumption	
	Refrigeration system real (kWh)	Refrigeration system theoretic (kWh)
November 2016	22,681	22,662.8
December 2016	25,187	23,401.2
January 2017	21,989	23,344.4
February 2017	11,878	21,129,3
March 2017	531	23,458
Total	82,266	113,995.8

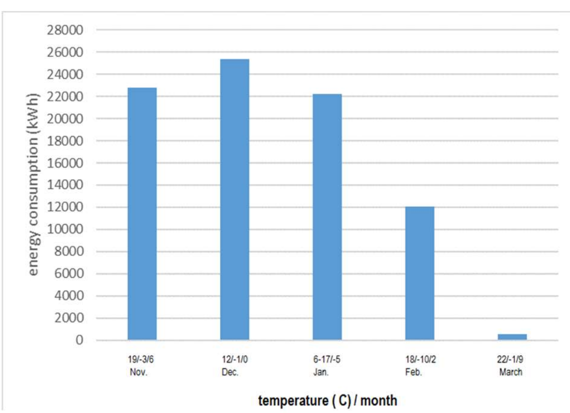

Fig. 4. Real / Theoretical energy consumption for system use R 134a

As it can be observed in the table 2 and the figure 4 the real consumptions are closed to the theoretical ones, exception is seen in the values for the month of February when the consumption is reduced due to the low number of the skaters, so that the refrigerant installation worked more to maintain the ice level and not to remake the ice. Also, in the month of March is seen when the ice rink installation is closed in the first week due to the lowest number of the skaters and to the high exterior temperatures.
The consumption differences are influenced by the parameters of the exterior air temperature, humidity and direction of the wind.
It is noted that the peak of the energy consumption is in December and January because of the higher number of the skaters during the holidays period and of the winter holiday for children.
In the table 3 and the figure 5 there are presented the theoretical electrical energy for the refrigerant installation of the ice rink using as refrigerant agents R 134a, R 410a and R507a during the period of November 2016 – March 2017.

Table 3. Energy consumption for refrigeration system use R134a, R 410a and R 507a

	R 134a theoretic	R 410a theoretic	R 507a theoretic
November	22,662.8	23,302.8	23,605.1
December	23,401.2	24,062.1	24,374.2
January	23,344.4	24,003.7	24,315.0
February	21,129.3	21,725.9	22,007.7
March	23,458.0	24,120.5	24,433.3
Total consumption	113,995.8	117,215.0	118,735.3
Medium consumption	9,499.6	9,767.9	9,984.6

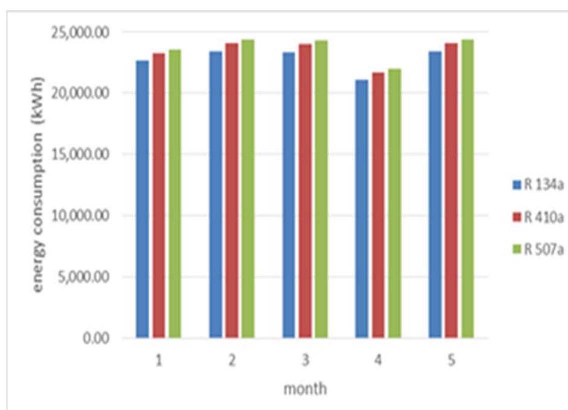

Fig. 5. Energy consumption for refrigeration system use R 134a, R 410a and R 507a

From the table 3 and figure 5 results that the refrigerant installation, which is using R134a freon as refrigerant agent, has the lowest theoretical electricity consumption.
COP for the refrigeration plant is defined as the ratio between the refrigerant output produced during the operating season and the energy consumed by the compressor, condenser, and circulation pumps for the brine.

$$COP = \frac{Q_{refrig}}{W_k + W_{pumps}} \quad (1)$$

Where:

COP – performance coefficient,
Q_{refrig} – refrigerant power (kW),
W_k – energy consumed by the compressor (kW)
W_{pumps} – energy consumed by the pumps for the brine (kW)

In the Table 4 and Figure 6 there is shown the performance coefficient (C.O.P) of the refrigerant installation of the ice rink using the three types of refrigerant agents used and studied. It results that, R 134a has the highest C.O.P. against the others refrigerant agents used.

Table 4. The performance coefficient (C.O.P.) for R134a, R 410a and R 507a refrigerant agents

	R134a theoretic	R 410a theoretic	R 507a theoretic
C.O.P.	2.79	2.71	2.68

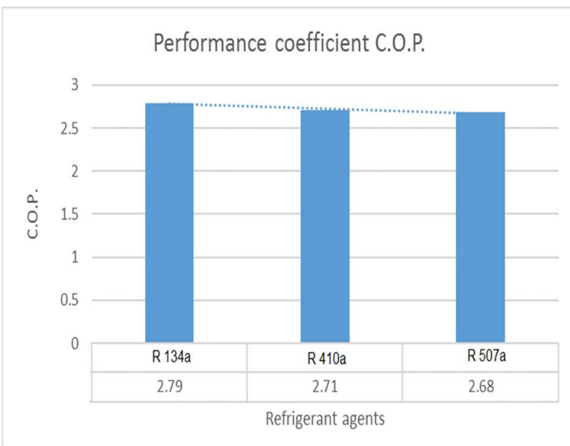

Fig. 6. The performance coefficient (C.O.P.) for R134a, R 410a and R 507a refrigerant agents

As it can be observed, in the table 5 and Figure 7, there are presented the CO_2 emissions obtained in case of the use of the three types of refrigerant agents. Thus, it results that the by using the refrigerant agent R 134a freon, it is obtained the lowest CO2 emission value for the installation.

Table 5. CO_2 emissions for the refrigerant installations of the ice rink using R134a, R 410a and R 507a refrigerant agents

	R 134a	R 410a	R 507a
Emissions Kg the eel (CO_2)	604,178	621,239	629,297

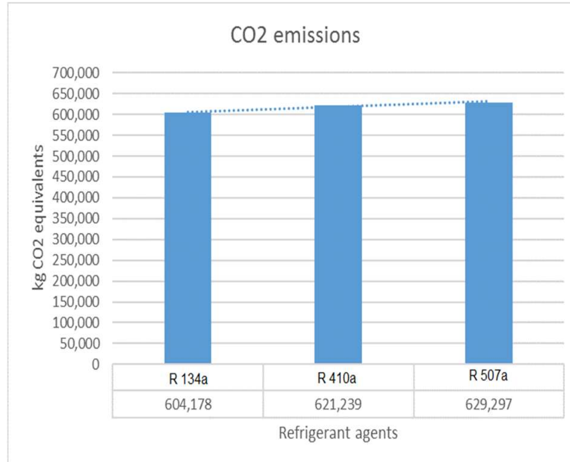

Fig. 7. CO_2 emissions for the refrigerant installations of the ice rink using R134a, R 410a and R 507a refrigerant agents

In the picture 8 there is presented a comparison between the exploitation costs for a duration of 10 years of the refrigerant installation of the ice rink plant. As it can be shown in this picture, the installation using R134a freon refrigerant agent has a higher cost in the first three years and afterwards the exploitation costs are lower versus the ones used by the installation with R410a or R507a during period of ten years in operation.

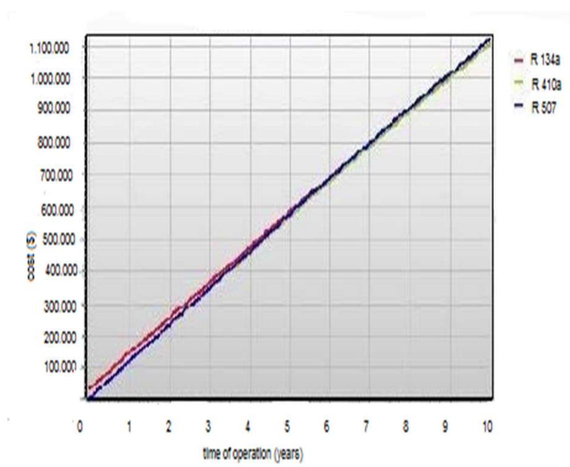

Fig. 8. Exploitation costs (energy consumptions, maintenance)

The cost of the ice rink equipment and their installation is $ 375,000, the maintenance cost per season is $ 7100 for a 10-year life span.
In Figure 9 is presented the evolution of the life cycle cost including the cost of the investment, the cost of maintenance and the cost of the energy electricity consumed.
Figure 10 shows the structure of the life cycle cost. Considering these charts, one can study what measures are indicated for the quicker depreciation of the investment.

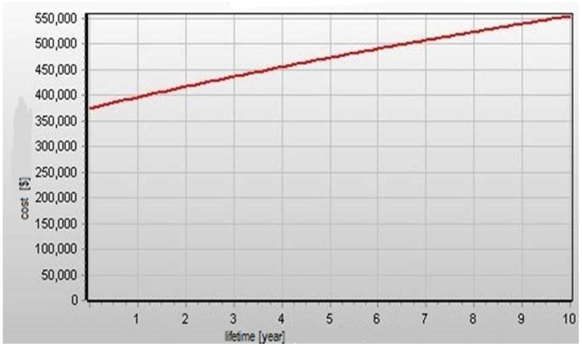

Fig. 9. The evolution of the life cycle cost of the ice rink

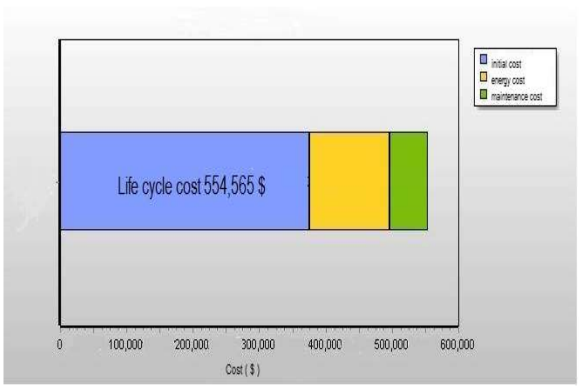

Fig. 10. Life cycle cost diagram

4. Conclusions

Analyzing the results, it is noticed that the solution adopted by the beneficiary by using the refrigerant agent R134a freon is optimal to the use of other refrigerants R410a and R507a, due to the lower energy consumption and higher COP. The refrigerant units using R134a freon are more advantageous than the reliability point.

The R134a freon has a lower purchase price than the other refrigerants studied, therefore the CO_2 emissions are less polluting.

R134a freon refrigerant agent versus R507a freon is not flammable, which is recommended when to be used in cold shops. According to the European Commission regulation 517/2014 as of 2018, it is intended to reduce and eliminate agent R507a in 2020. Between real and theoretical electricity consumption for the refrigerator of the ice rink using the freon R134a, there are small differences which determine that the installation was correctly designed and not oversized.

To produce the energy consumption during the operation of the ice skating it is required:

a) to adopt a dry cooler solution to the refrigeration installation and to lead to 65% electricity consumption savings [5];

b) to equip the electric engines of the frequency inverter equipment for different operating modes such as forming, maintaining ice, recovering ice, leads to 20% reduction of the electricity consumption [2];

c) to plant trees in the wind direction or mounting billboards [2]; the predominant direction of the winds is North-East to South West;

d) to adjust the temperature of the sole according to the outside temperature by fitting external temperature sensors which, depending on its variation and the return temperature of the sole, controls the flow temperature of the sole in the track of the skating rink;

e) to cover the night skating rink with thermal foil.

To establish the budget of the operating the ice-skating installation [6], [7], it is important to consider the monthly costs such as:

a) utility costs;

b) operating monthly fees;

c) charges for insurance policies;

d) salaries with the staff.

The ice rink installation requires permanent supervision, involving the hiring of trained personnel to monitor and maintain the installation permanently and serve the skaters on the track. Limiting the operation of the refrigeration plant to save money can result in lower quality ice, which can lead to less customers over time resulting in higher financial losses by closing the ice rink. Failure to review [6] on time and with proper parts may result in damage to the plant, and its repair is much more expensive.

The costs of opening an ice skating rink are high, they can be amortized by adopting technical solutions to allow for subsequent energy savings. In the first years of operation the percentage of investment recovery is small, the role of the skating rink being specially to attract customers to the commercial building. The owner of the ice rink installation must consider when determining the costs of recovering the investment of the tendency to limit and eliminate from the market refrigerants based on hydrofluorocarbons according to European Commission Regulation 517/2014 if the equipment using this freon is more cost-effective to be repaired or replaced, taking into account its evolution on the market.

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