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EVALUATION OF ALTERNATIVERS TO R404 – THE MOST COMMON REFRIGERANT IN SWEDISH GROCERY STORES

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Abstract

The F-Gas Regulation, which came into force on 1st of January 2015, in practice leads to a phase out of the refrigerant R404A within a few years. In this study a theoretical model was used to investigate alternative refrigerants for R404A in a freezer application in a grocery store. The model was based on commercially available compressor data. Investment costs and operating cost (energy use) was analyzed for R407F DX, R448A DX, Indirect R290 (propane) and R744 (CO2) DX. The results indicate that energy consumption will be reduced with all the different alternatives but the different options spread considerably when comparing the investment costs.

R407F and R448A are sometimes called drop-in refrigerants, and that means that R404A in principle can be exchanged directly to those, resulting in low investment costs. However, R407F and R448A are likely to be phased out because of the F-Gas Regulation just as R404A, due to an increased price for the refrigerant when the quotas are decreased. Probably this will happen slightly later since their GWP is less than that of R404A.

The two other alternatives examined, R290 and R744 have GWP of 3 and 1 respectively and will therefore not be affected by the F-Gas Regulation. These alternatives, however, come with completely different investment costs than the other two options but can be economically beneficial in the long run. The results from this study should be valuable for owners of grocery stores when analyzing what refrigerant and freezer system they should use in the future.

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1. Introduction

1.1. Background

In grocery stores in Sweden, two types of cooling systems are used, direct expansion and indirect systems. Both of these systems require refrigerants to drive the refrigeration process. Today R404A is the most commonly used refrigerant in Swedish grocery stores. R404A is an HFC refrigerant that is covered by the F-Gas Regulation, which entered into force on 1 January 2015. The aim of the new F-Gas Regulation is to reduce the climate impact of refrigerants and uses different policies to guide the market towards refrigerants and system solutions with lower Global Warming Potential (GWP).

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There are refrigerants that are not covered by the F-Gas Regulation and therefore are suitable as an alternative to R404A, some of these are: HFO, carbon dioxide, ammonia and hydrocarbons. There will also be mixtures of HFC-HFO that will be used in existing systems during a transition period, but the cost of these refrigerants will increase in line with the phase-out. The other refrigerants available - carbon dioxide, ammonia and hydrocarbons - requires in most cases a complete reinstallation of the refrigerant circuit. It means large investments for the stores, investments that may nonetheless be economically feasible.

This study aimed to evaluate some of these options from an economic view. This was done by estimating the investment costs and by analyzing the energy consumption of the various options using a theoretical model. Only freezing systems were analyzed in this study.

1.2. Scope

The scope of this study was to define the investment cost and operating cost of a few types of freezing systems with other refrigerants than R404A.

1.3. Limitations

In this project, the following limitations were used:

- Only freezing systems were analyzed. Refrigeration units were excluded from the analysis to reduce the number of systems to be tested.
- Energy consumption was estimated using a theoretical model based on other models and experiences of the project participants, as well as expertise in the area.
- The annual cost was only based on the energy consumption of refrigeration systems and not on maintenance costs etc.
- Optimized condensing and evaporating temperatures were assumed which resulted in optimized operation of the freezer system.

2. F-gas Regulation and Alternatives to R404A

2.1. F-gas regulation

In January 1, 2015, the new F-Gas Regulation (EU Regulation 517/2014) came in force [1]. The main purpose of the regulation is to protect the environment by reducing the emissions of fluorinated greenhouse gases (F-gases) in Europe. The regulation includes a quota system as tiered according to Table 1 that will reduce the use of F-gases. In 2030, consumption will be reduced to 21% compared with the 2015 level. This will very soon lead to a shortage of refrigerants with high GWP such as R404A, which is one of the common refrigerants in refrigeration units. Also refrigerants that have a medium level GWP will likely be too expensive as soon as the phase down passes the level of the refrigerant (e.g. year 2023 for a refrigerant with a GWP of 1035). F-Gas Regulation will also mean greater demands on leakage control and stop on refill of refrigerants with a GWP over 2500 in 2020. In practice this will mean that systems with R404A cannot be maintained after year 2020.

Table 1. Phase down rate of F-gases.

Year	Phase down %	Average GWP
2015	100	2300
2016-17	93	2139
2018-20	63	1449
2021-23	45	1035
2024-26	31	713
2027-30	24	552
2030	21	483

2.2. Possible alternatives to R404A

In this project a number of refrigerant alternatives to R404A have been studied. This section briefly describes the characteristics of the options and the rebuilding required for a change from R404A. Table 2 present some of the properties of the alternative refrigerants.

Table 2. Properties of different alternative refigerants to R404A.

	HFC R404A	**HFC R407F**	**HFC-HFO R448A**	**HFO 1234ze**	**Hydrocarbon, Propane R290**	**Carbon Dioxide R744**
GWP	3922	1824	1273	6	3	1
Flammability	Non flammable	Non flammable	Non flammable	Mildly flammable	Flammable	Non flammable
Can replace R404A in existing systems	-	Yes	(Yes)	No	No	No

2.2.1. Reference system

The most common freezer system in Swedish grocery stores is a direct R404A system. Therefore, such a system is chosen as reference in this study. A freezing system in a grocery store in Borås, Sweden, has partly been used as an example to compare the performance of the chiller and freezing cabinet as well as to estimate the costs of different investment options. The chiller unit of this store consists of two parallel-connected compressors (Bitzer 6F-40.2Y) and the freezer cabinets come from the manufacturer Arneg. After installation of lids on the freezers in the store the cooling demand has declined drastically why the cooling effect of one of the compressors is most often sufficient. The authors of this report believe that this situation is representative for a large part of the Swedish grocery stores.

2.2.2. Change to R407F

When R404A is changed to R407F the existing cooling system can be used (compressors, piping, refrigerant coolers, etc.). However, the expansion valves in the cabinets have to be replaced, which in this context is a inexpensive operation. This option result in low investment costs but also entails a risk that the refrigerant have to be replace again within a 10 year period due to increased price of the refrigerant. At that time, the whole refrigerant circuit together with chillers must be replaced, which means a large investment.

2.2.3. Change to R448

According to a supplier [2], R404A can in some cases be replaced with R448A without replacing the compressor. However, this depends on the compressor model. In this project, we have assumed that the change in refrigerant requires a replacement of the compressor but that the other parts of the cooling system can be kept. This result in a slightly higher investment cost compared to R407F, but you are still facing the same problem. Probably the whole cooling system including the refrigerant must be replaced within a 10 year period due to the relative high GWP of the refrigerant.

2.2.4. System with 1234ze

There is not yet commercially available equipment (compressors) for pure HFO refrigerants such 1234ze according to the supplier [2]. Therefore this option is not evaluated further in this study.

2.2.5. Indirect system with propane (R290)

Changing from R404A to propane requires that the entire refrigerant circuit is replaced. Possibly the existing piping to the cabinets can be kept, but then the liquid line must be isolated. The system that has been analyzed in this study is an indirect system with a propane-powered chiller and a pumped CO2 system for distributing the cold to the cabinets. The reason an indirect system is used is mainly because of the flammability of propane. The energy consumption of the pump in the indirect system is very low and is assumed to be negligible in relation to the other energy using components. The freezers are modified by replacement of expansion valves and capillary tubes. Alternatively, the entire cabinets are replaced, but this result in a much higher investment cost. Changing to an indirect propane system is significantly more costly than for R407F and R448A. But on the other hand, a system like this is likely to retain over a much longer period.

2.2.6. Direct system with CO_2 (R744)

As for the propane option a change to CO2 requires that the entire cooling circuit is replaced. To achieve sufficiently high condensing temperature (above 35 ° C at times) a so-called booster system with a subcritical compressor and a trans-critical compressor (CO2 goes into the trans-critical state at 31 ° C) is required. In a CO2 system the preferred solution is a gas cooler that directly cools the gas from the trans-critical compressor (instead of an ordinary liquid cooler). As for the propane case, a switch to CO2 result in a significantly higher investment cost compared to R407F and R448A.

3. Method

Within this study, a number of different freezing systems with different refrigerants were investigated. A system with R404A was used as reference. A model was developed in order to calculate the running costs (by calculating operating energy) for the different types of systems by collaboration with a refrigeration supplier in order to obtain the necessary data. In addition, the investment cost for the various types of system solutions was investigated. A freezing system in a grocery store in Borås, Sweden was partly used as an example.

3.1. Model for energy consumption and electricity costs

The cooling requirement of a freezer cabinet is dependent on transmission losses to the surrounding air, the infiltration of air into the disk as well as lighting, fans, defrost and warm food. The air that is infiltrated needs to be cooled to the temperature of the cabinet and the moisture that the air carries is condensed. On hot days when the air contains a lot of water vapor, condensation of the vapor may account for a large part of the cooling load. Installation of doors on freezers and refrigerators result in reduced infiltration which leads to the reduced cooling need for condensation of water vapor.

The model developed in this project uses climate data from Meteonorm (simulated hourly values based on 30 years of climate data for several locations in Sweden) [3]. Outdoor temperature and humidity are converted to the climate inside the store for each hour of the year. The model assumes that any moisture present in the outdoor air reaches the air indoors and does not account for a possible air conditioning systems. Thus, the model overestimates somewhat the electricity for freezing systems in grocery stores that uses air conditioning.

Information on the design cooling capacity of the cabinets comes from the manufacturer of cabinets Arneg and is converted from standard testing climate to the actual climate in the store. The influence of water vapor upon the cooling load of the cabinet is calculated using a method described by Howell [4] but with an adjustment because of the cabinet doors. The shop is assumed to be open between 7am and 10pm and the cabinet doors are assumed to be opened with a certain frequency during the hours the store is open and fully closed (i.e. minimized infiltration) during the hours the store is closed.

Temperature differences and temperature changes in the heat transfer step between the condenser heat transfer fluid and refrigerant coolers are based on qualified assumptions. The same applies to evaporators and cabinets. Depending on whether the system is of direct expansion or indirect type different assumptions upon temperature and pressure losses in the pipes to the cabinets are made. Climate data, infiltration and temperature differences in heat transfer steps finally lead to an evaporation and condensation temperature for the compressor.

The efficiency (COP) of the chillers was calculated using data from the compressor manufacturer Bitzer. Refrigerant, subcooling, overheating and useful overheating has been entered in Bitzer's software and a suitable compressor has been selected [5]. The software provides information of cooling capacity and electric power demand for various evaporation and condensing temperatures. This information is then used in the model and for each hour the delivered cooling energy and electricity need of the chiller is calculated. These data are then totaled for the entire year. The only exception to this method (data from Bitzer) is the trans-critical part of the CO2 system which is made up of a subcritical and a trans-critical compressor. COP of the trans-critical compressor is estimated according to a curve fit of the performance of a CO2 compressor in the trans-critical operation. The method is described in detail in a report by Arias [6].

A liquid cooler with adequate capacity from AIA was selected and its product data was used in the model to estimate the electricity use of the fan (about 1 kW nominal power output). Nominal electrical output of the pump was assumed to be 1.2 kW. Fan and pump power was assumed to vary proportionally to the capacity (part load) of the chiller.

Operating costs were finally estimated for each refrigerant (with associated cooling systems) by summing up the electricity use of the chiller, the refrigerant coolers, heat medium pump and auxiliary systems in the freezer, which consists of fans, defrost function, lighting and anti-fog function. Electricity price was assumed to be 1SEK/kWh.

3.2. Installation costs

To estimate the cost of the various refrigerant alternatives the authors of this study have been in contact with a supplier for the relevant cooling equipment. The supplier has a good knowledge of the grocery store in Boras partly used as examples in this project. The supplier has received information about the various alternative refrigerants being investigated and has subsequently provided information on the measures that needed to be done for each option along with an estimate of materials and labor costs.

4. Results

4.1. Energy Performance

With the help of the theoretical model and Bitzers compressor data, the annual energy consumption is calculated for a variety of refrigerants and related systems solutions as shown in Figure 1. The figures include energy for chillers, fans, pumps and auxiliary systems in the cabinets such as fans, defrost, lights and anti-fog function. The energy to the auxiliary systems is the same for all examined options, accounting for just over 100KWh / year and is therefore of the same size as the energy use of the chiller and fans and pumps. The difference between the different options thus consists only of the chiller system energy use.

None of the options stand out significantly from the rest, and the total consumption is in a range between 190,000 kWh and 230,000 kWh. The reference system with R404A consumes the most energy, while the direct system with CO2 consumes the least amount.

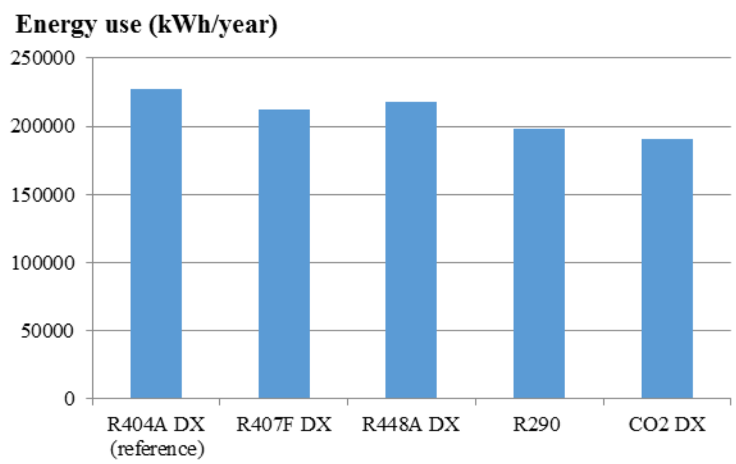

Figure 1. Yearly energy use for different systems with other refrigerants than R404A.
The energy use for a direct expansion system with R404A is used as a reference.

For some of the investigated systems the compressor capacity is insufficient during parts of the hottest and most humid days. However, the cabinets are assumed to have sufficient thermal inertia to keep the temperature inside the cabinets constant. In order to cover the cooling demand at all times one should invest in two or more parallel compressors. However, this result in a higher investment cost than what is counted for in this project.

4.2. Investment calculation

The investment cost of the various options presented in Figure 2. The investment cost comprises the cost of materials and labor for the installation. As mentioned in Chapter 2.2, the alternatives that require replacement of the entire cooling system have considerably higher investment costs than the drop-in alternatives (R407F and R448A). Both material costs and labor costs are higher for systems with propane and CO2.

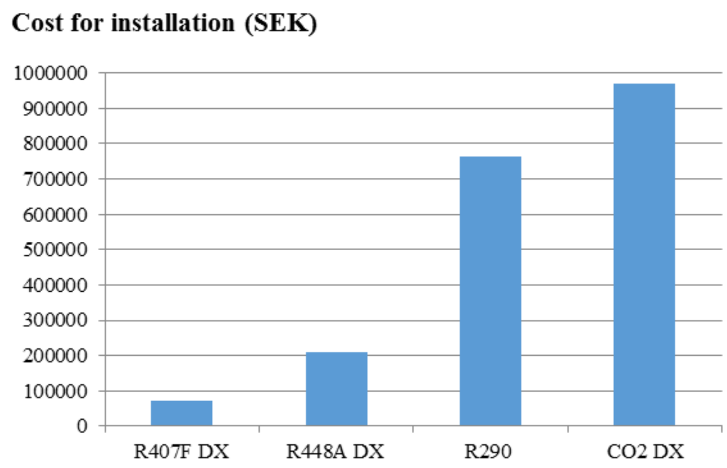

Figure 2. Cost for installation for the different freezer systems with other refrigerants than R404A.

The present value of each option was calculated with a depreciation time and cost of capital in 10 years and 3% respectively, and the results are shown in Figure 3. The present value gives a total figure on the cost of installation and operating costs during the depreciation period.

Since the energy use does not differ so much between the different options, the installation cost has a large impact. Therefore, the alternatives with high installation cost, get a high present value, and vice versa.

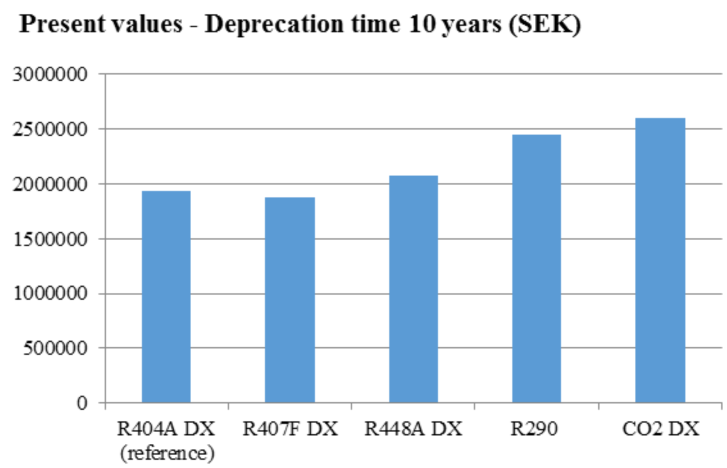

Figure 3. Present value for the different systems. Deprecation time is 10 years and cost of capital is 3%.

5. Discussion and conclusion

F-Gas Regulation, which entered into force 1 of January 2015 will in practice lead to a phase out of refrigerant R404A within a few years. This project has investigated some alternative refrigerants for R404A in a freezer application in a grocery store, and the results indicate that energy use will be reduced with all the alternatives. The different options R407F DX, R448A DX, Indirect R290 (propane) and R744 (CO2) DX spreads, however, in investment costs. The first two mentioned are sometimes called drop-in options and that means that they in practice can replace R404A without large reinstallations resulting in low investment costs. However, R407F and R448A are likely to be phased out because of the F-Gas regulation just as for R404A. The phase out will occur a few years later than R404A since their GWP is lower than that of R404A. Therefore, a switch to one of the drop in options will most likely result in a situation where the refrigerant and the associated cooling system must be replaced in a number of years.

The two other options investigated, R290 (propane) and R774 (CO_2) has a GWP of 3 and 1 and will therefore not be affected by the F-Gas Regulation. For those options, however, a larger investment is needed than for the other two options.

The authors of this report also think there is a risk that it will be a lack of personnel with the right knowledge that can perform all the re-installations that must be done in a few years. Thus, installation costs will most likely be higher compared to the levels identified in this report. For newer facilities where you want to keep the existing cooling system, drop-in refrigerants may be economic feasible alternatives. However, in that case one must be prepared to make a major investment in not too many years. For older freezer facilities it should be wise to choose one of the more long-term options with R290 or R744.

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