2010

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Poland, Joe; Groll, Eckhard A.; and Horton, W. Travis, "Energy Consumption and Performance of Supermarket Refrigeration Systems" (2010). *International Refrigeration and Air Conditioning Conference.* Paper 1151.
http://docs.lib.purdue.edu/iracc/1151

Energy Consumption and Performance of Supermarket Refrigeration Systems

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ABSTRACT

Over the past decade, the use of alternative technologies to the HFC direct expansion system for supermarket refrigeration has continued to gain interest. The market for such alternative systems has been thriving for several years in Europe and is beginning to gain some momentum in North America. One of the major unresolved issues with use of novel refrigeration systems is obtaining an accurate measurement of the energy consumption for system comparison. The motivation for having accurate energy consumption is discussed, along with field results which have been published. Low-temperature systems are the main focus of the discussion due to the larger energy consumption. However, the issues discussed also pertain to medium-temperature systems. The factors necessary to formulate a proper comparison of systems are presented as well as a discussion of the need to perform testing to determine the impact of these factors.

1. INTRODUCTION

Several driving factors in conjunction with a growing public concern towards the environment have begun to encourage establishments which are known to be significant emitters of HFC refrigerants towards the use of natural refrigerants. While much of Europe has legislative factors and incentives for the use of low green house gas emission systems, North America has not seen any such driving forces yet. For the supermarket industry, carbon dioxide has become very popular as an HFC alternative and is well suited for both low-and medium-temperature cooling. In the past, there was a lack of suppliers of CO_2 components suited for supermarket capacities. However, this is no longer a major issue for rack manufacturers.

Currently, one of the barriers slowing the use of alternative refrigeration systems, in particular, low-temperature systems, is the yet unresolved energy consumption comparison of the various types of alternative systems to an equivalent HFC direct expansion system. Typical profit margins in supermarkets float around 3 %. Of that 3 %, 1 % goes towards electricity, and the electricity cost for refrigeration makes up 39 – 50 % of the total electricity cost (Energy Star 2003). With such small profit margins, systems which have higher energy requirements, and hence a higher electricity cost, are not attractive.

Based on field experience from manufacturers it is known that many factors influence the energy consumption of a supermarket refrigeration system. While computer models are relatively cheap and readily accessible, not all of the factors which are known to have a significant effect on energy consumption are necessarily included in many modeling tools leaving their accuracy in question. This paper discusses the factors which can have a significant impact on the energy consumption of a supermarket refrigeration system. Additionally, the need to support further investigation into such factors for the purpose of being able to accurately compare various system types is presented.

2. POPULAR ALTERNATIVE SYSTEMS

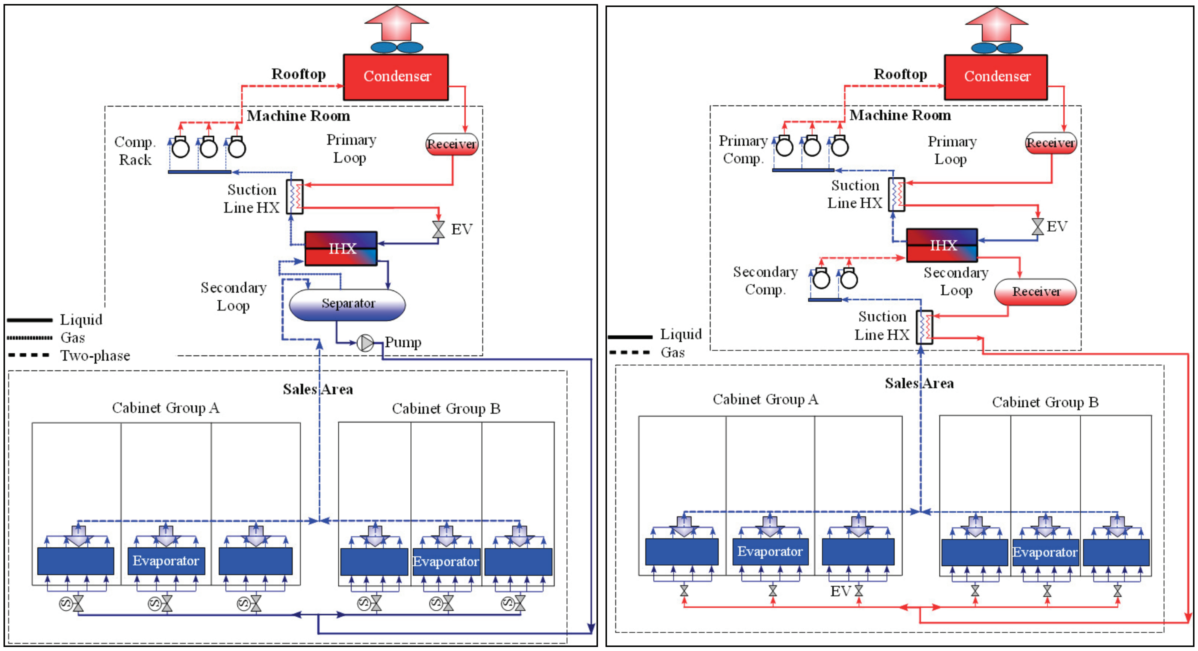
The most well known and widely used supermarket refrigeration system is the HFC direct expansion system, commonly referred to as a “centralized” or “multiplex” system. The HFC direct expansion system has the advantage of being less expensive in comparison to the systems exhibiting a much lower environmental impact. This is due, in part, to the large number of component suppliers, commonly available contractors, and high level of experience of rack manufacturers.

For northern and central Europe, where the climate is relatively moderate and rarely exceeds 30 ^{o}C in the summer, a carbon dioxide transcritical system has become a popular choice. The CO_2 direct expansion system exhibits a lower direct emissions contribution to the total equivalent warming impact in comparison to HFC direct expansion systems due to the low GWP characteristic of CO_2. As discussed by Seinel and Finckh (2007), this system is geographically limited to more northern and central regions due to the high energy consumption that occurs with extended transcritical operation.

In North America, secondary loop systems have been implemented in many locations and using several different configurations. The paper from Kazachki and Hinde (2006) mentions that over 500 medium temperature secondary loop systems are operating in North America using glycol as a secondary fluid for medium-temperature refrigeration. The use of two-phase secondary loop systems for both low and medium-temperature refrigeration has also started being implemented.

Several published studies have concluded that use of a single phase secondary coolant for low-temperature cooling leads to higher energy cost due to the increased pumping power of what is typically a relatively high viscosity fluid (see paper by Melinder, 2000). Manufacturers in both Europe and North America have been using CO_2 as a two-phase secondary fluid for low-temperature levels with success for several years.

For the purposes of this paper, the type of secondary loop systems being discussed are systems which use loops with two different fluids that provide the cooling to the case. Specifically, systems which use a glycol loop for heat rejection, also referred to as a water cooled condenser, is not included as being a secondary loop system for clarity. Two main types of secondary loop systems have seen use in both North America and Europe. One is an indirect system where a primary loop, typically containing an HFC refrigerant, is used to cool a fluid in a secondary loop which is then circulated via a pump. A simplified depiction of an indirect system is shown in Figure (1a). The second type of secondary loop configuration is a cascade system. The cascade system uses vapor compression of a separate primary loop and secondary loop and is shown in Figure (1b).



(a) Indirect system

(b) Cascade system

Figure 1: Simplified schematics of two different secondary loop systems

For low-temperature, the use CO_2 in the secondary loop as a two-phase fluid is becoming the norm. As of spring 2010, one U.S. manufacturer has 20 indirect systems and 3 cascade systems operating in the field which use CO_2 in the secondary loop for low-temperature cooling. Europe has several times as many systems using CO_2 which are operating in the field.

3. ENERGY CONSUMPTION MEASUREMENTS

While the successful operation of field units, which exhibit lower direct refrigerant emissions impacts on the environment, has been achieved, there remains hesitation on the part of supermarkets in using these systems. Rack manufacturers, which are producing alternative refrigeration systems, are able to provide a first cost quote for the rack to the supermarket owner. It is also relatively easy for supermarket managers to account for operating costs of their refrigeration system and report this to rack manufacturers. With the first cost and annual maintenance costs known the question of electricity costs remains the only significant unknown.

For indirect systems there have been several studies, which have reported various results. Thomas (1998) compared a secondary loop using Ammonia in the primary loop and silicone heat transfer oil in the secondary loop with an equivalent R-404A direct expansion system in West Sussex, England. It was found that the Ammonia/secondary loop system consumed 3.3 % more energy than the R-404A direct expansion system. Hinde et al. (2008) compared an R-404A/CO_2 indirect system to nearby R-404A direct expansion systems in the U.S. and found 2-3 % lower energy consumption by the indirect system in the summer months, despite the direct expansion system using a dual-suction group.

In a field study by Rasmussen et al. (2008), a variable speed pump specifically designed for CO_2 was compared to a fix speed pump which required a bypass. It was found that the energy consumption for the variable speed pump made up 1 % of the total system energy use over an extended testing period. The baseline fix speed pump made up 9.2 % of the total system energy. Baxter (2003) reported that a Danish supermarket using an HFC direct expansion system performed a retrofit, using an R-290/ CO_2 cascade system. Energy consumption for the cascade system was reported to be 10 % lower than the previous direct expansion system.

In a larger scale study, Seinel and Finckh (2007) performed a field study using a large number of stores in a small region of Switzerland. The measurements of the bottom highest 25 % energy consuming stores were eliminated in an attempt to remove any outliers. The systems examined were HFC direct expansion, HFC/glycol medium temperature with HFC/CO_2 cascade low-temperature, and CO_2 direct expansion. All of the systems were very similarly sized, in close proximity, and in stores with similar layouts. In an attempt to eliminate any variations due to dissimilar system capacity, the energy consumption was normalized by running meter of cabinet length. The results are shown in Figure (2). While the authors of the published data are conveying the potential energy efficiency of transcritical systems, the spread of data shown in Figure (2) demonstrates that despite the efforts to eliminate any biased data in addition to normalizing the energy consumption, a very large spread still exists. Figure (2) serves as a representation of why performing direct comparisons of field installations has such a large potential for inaccuracy and that there are still additional significant factors which need to be considered.

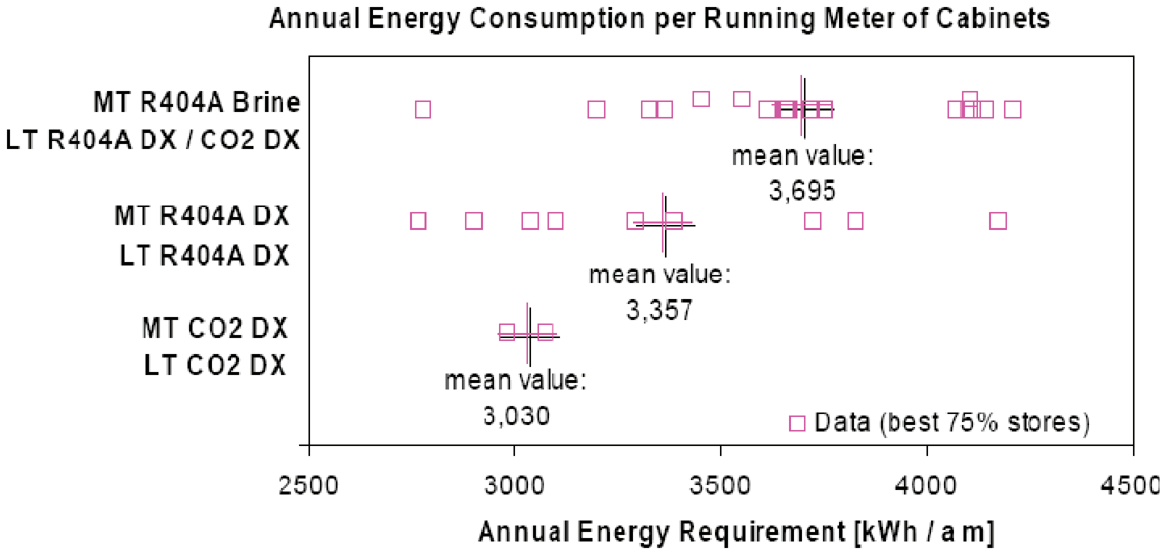


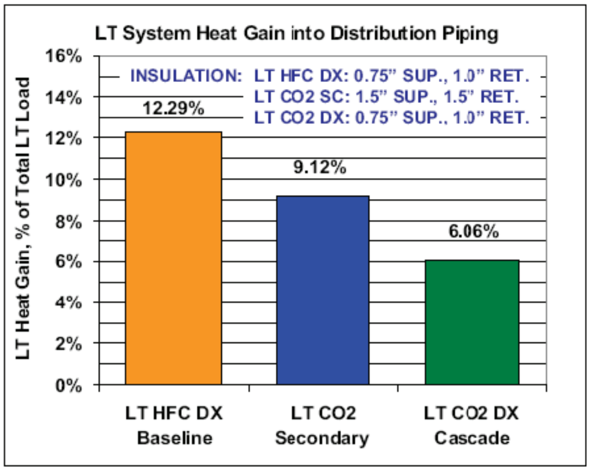
Figure 2: Normalized energy consumption (Seinel and Finckh, 2007)

While field experiments are a more practical method of determining energy consumption of a supermarket system due to the cost elimination of the refrigeration system, there are still several drawbacks of using field measurements. Measuring the actual energy consumption alone can be done without being very intrusive to the supermarket operation however; properly instrumenting merchandised display cases is not something supermarket owners will generally allow. The high cost of instrumenting all the cases and ambient locations in the store is an additional barrier which must be dealt with. This makes attributing the causes for variance in energy consumption values from one system to another difficult, if not impossible, to know.

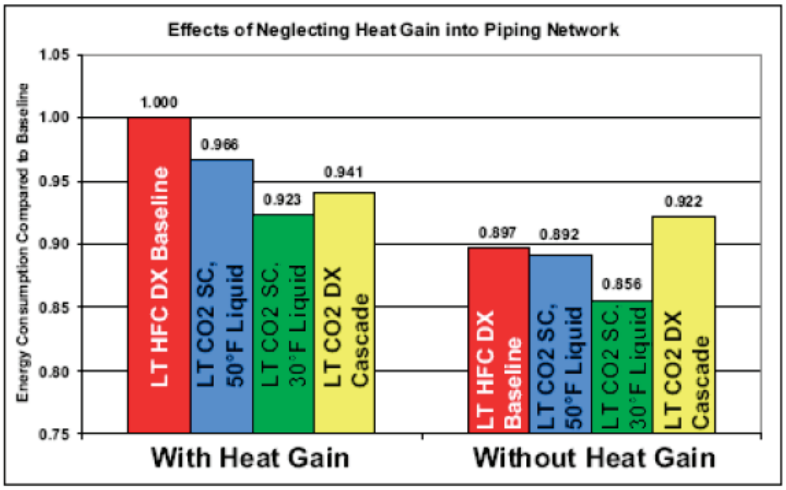
From the above literature, it can be concluded that, considering the factors commonly used to date, direct comparisons of energy consumption between two or even several systems has a significant potential for error. This is a clear indicator that variables which are significant to the energy consumption are being omitted. While it may not be easily feasible to account for some of these variables, it is necessary if the issue of addressing energy consumption of supermarket refrigeration systems is going to be resolved.

4. ACCOUNTING FOR NECESSARY FACTORS

Recent literature has shown that factors, which in the past have not typically been known to be significant, are important in assuring the accuracy and precision of energy consumption comparisons. Hinde et al. (2008) found that different system types will exhibit different levels of heat gain into the distribution piping network as seen in Figure (3a), which can be attributed to the line layout and diameter. Calculations were also performed using a model which was experimentally validated and showed that a 10 % difference in low-temperature system energy consumption for an HFC direct expansion system can exist if this heat gain into the distribution piping is not taken into account. This is reflected for each system type in Figure (3b).



(a) Heat gain for three system types



(b) Effects of neglecting heat gain in distribution piping

Figure 3: Heat gain analysis on distribution piping (Hinde et al. 2008)

In a study of three supermarkets in Sweden conducted by Arias and Lundqvist (2000) it was found that for those particular supermarkets, the use of night covers for the medium and low-temperature cases was able to save approximately 10 % more energy than by not using covers. It was also shown in the same study that at nearly the same outdoor temperature, an outdoor relative humidity approximately 9 % higher can increase indoor ambient conditions and thus, increase compressor load on the order of several percent.

Numerous papers have been published discussing the energy consumption for various defrost modes and the compressor power resulting from cabinet pull-down. The previously discussed factors are meant to be a showcase of factors which can affect the energy consumption of supermarket refrigeration systems.

Additional variables may include, but are not limited to: defrost frequency, defrost method, case infiltration rate, case lighting, customer shopping patterns, store hours, store internal ambient conditions, refrigerants/coolants used, system configuration, system control components, efficiency of major components, piping configuration, piping insulation, condensing type and configuration, heat exchanger effectiveness, medium-temperature/low-temperature capacity, annual climate, system maintenance schedule, and interactions between the refrigeration system and the store heating and cooling system.

5. CONCLUSIONS

With global environmental reform efforts increasing in most parts of the world, supermarket refrigeration has become one of the targets for change. As supermarket owners in both the U.S. and Europe move towards systems using natural refrigerants, the issue of energy consumption of the refrigeration system remains unclear. Existing available data is both limited and inconsistent and thus, makes reliable conclusions difficult to draw. This supports the need for testing to determine the factors which cause inconsistencies in energy consumption. Such testing would provide the means to make computer models of supermarket refrigeration systems much more accurate as well as more detailed for predicting energy consumption under various conditions. Additionally, testing could provide a means for supermarket owners to better determine how far from optimum their refrigeration systems are performing.

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ACKNOWLEDGEMENT

The work has been co-funded by ASHRAE and AHRTI.