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# Investigation of heat recovery in $CO_2$ trans-critical solution for supermarket refrigeration

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ABSTRACT

Using computer simulation modeling this study investigates the performance of a $CO_2$ trans-critical system with heat recovery from the de-superheater. The influence of sub-cooling (or further cooling) in the condenser/gas cooler on system performance is investigated. Following the suggested control strategy in this study, the extra operating energy demand required to recover the needed heating energy from the analyzed $CO_2$ system is smaller than what a typical heat pump would require for the same load. This is the case for almost all ambient temperatures over a full season. When taking the simultaneous heating and cooling loads into account, the $CO_2$ trans-critical system has lower annual energy usage in an average size supermarket in Sweden when compared to a conventional R404A refrigeration system with separate heat pump for heating needs. $CO_2$ trans-critical systems are efficient solutions for simultaneous cooling and heating needs in supermarkets in relatively cold climates.



# Solution au $CO_2$ transcritique pour le froid dans les supermarchés : Étude sur la récupération de chaleur

*Mots clés :* Dioxyde de carbone ($CO_2$) ; Supermarché ; Froid ; Modélisation ; Récupération de chaleur

## 1. Introduction

Supermarkets are intensive energy consumers with constantly increasing number of installations. Simultaneous cooling and heating is often needed in a typical supermarket in northern Europe. Sometimes the amount of heating energy rejected from the refrigeration system is even higher than the supermarket's needs. The rejected heat can be utilized with proper system design and control.

Heat recovery system solutions in supermarkets are used mainly to heat up the space air. The practical experience indicated that though seemingly high quantity of heating energy is rejected by supermarket refrigeration systems, only 40–70% of the necessary heating energy can be recovered (Arias, 2005). Arias (2005) explains that in a typical Swedish supermarket HVAC and refrigeration systems are installed and operated by separate companies. Therefore, HVAC and refrigeration systems are coupled by heat exchanger which in a way separates the entities, i.e. responsibilities, so the control

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**Nomenclature**

| | |
|---|---|
| COP | coefficient of performance, – |
| COP1 | heating coefficient of performance, – |
| COP2 | cooling coefficient of performance, – |
| $\dot{E}$ | power consumption, kW |
| FC | floating condensing |
| HP | heat pump |
| HR | heat recovery |
| HRR | heat recovery ratio, – |
| HVAC | heating ventilation and air conditioning |
| $\dot{Q}$ | capacity, kW |
| $\dot{Q}_1$ | heating capacity/demand, kW |
| $\dot{Q}_{HR}$ | heating demand that can be covered by the de-superheater, kW |
| P | pressure, bar |
| T | temperature, °C |

*Subscript*

| | |
|---|---|
| amb | ambient |
| cab | cabinet |
| cond | condenser/condensing |
| de-sup | de-superheater |
| disch | discharge |
| el | electric |
| ev | evaporation |
| f | freezer/low temperature level |
| FC | floating condensing |
| GC | Gas cooler |
| HP | heat pump |
| HR | heat recovery |
| m | medium temperature level |
| opt | Optimum |
| SC | sub-cooling |
| tot | total |

of both systems is done independently. This has been cited as one of the reasons for the low heat recovery percentage.

An important parameter in the analysis of the heat recovery potential for refrigeration system is the match between the heating and cooling demands. At low outdoor temperatures the relative humidity is low and so is the cooling demand on the system, at the same time the heating demand in the supermarket increases. Therefore, the relative size/capacity of the refrigeration system to the heating needs in the supermarket and the seasonal profile must be considered to design an efficient refrigeration system for simultaneous cooling and heating needs.

Heat recovery from refrigeration systems in supermarkets has been typically done by elevating the condensing pressure to a level where the coolant fluid of the condensers has the required supply temperature to the heating system (Cecchinato et al., 2010), this method is known as fixing the head pressure. This is being mostly used with systems running with HFCs where the condensers reject the heat to a coolant loop with a dry cooler, the indirect heat rejection is mainly applied to minimize the refrigerant charge.

The environmentally friendly natural refrigerants are seen to be a long-term solution in refrigeration applications especially in supermarkets. Supermarket refrigeration systems working with natural refrigerants provide new possibilities for heat recovery. Cecchinato et al. (2012) analyzed several combinations of refrigeration and heat recovery solutions and compared their energy use to a conventional system. Some of the natural based solutions showed higher energy efficiency compared to the conventional one.

Being natural, $CO_2$ does not present unforeseen threats to the environment and it is relatively safe. Certain system solutions based on $CO_2$ as the refrigerant, cascade and trans-critical, are seen as efficient solutions for supermarket refrigeration (Sawalha, 2008).

The common heat recovery method of fixing the head pressure used in conventional refrigeration systems is not suitable for systems running with only $CO_2$ as the working fluid in the system, i.e. trans-critical systems. This is mainly because $CO_2$ trans-critical systems for supermarket applications have relatively low COP compared to conventional at high heat sink temperatures; this is why it have been installed mainly in cold climates with direct heat rejection to the ambient air where the operation is mostly sub-critical (Sienel T. and Finck O., 2007).

With $CO_2$ systems it is possible to recover heat by cooling, i.e. de-superheating, the compressor's discharge gas due to its relatively high temperature. About 55 °C for isentropic compression between −10 and 20 °C with 10 K superheat, compared to about 35 °C in case of R404A which is mostly used in conventional systems. When the $CO_2$ system operates around the critical point the potential to recover heat from discharge gas is higher and the system has to be properly controlled to obtain good system efficiency.

Reinholdt and Madsen (2010) investigated two operation strategies for maximization of refrigeration COP and for maximization of amount of recovered heat at different hot water temperature requirements. The study concluded that the heat recovered rates from the system can be increased considerably. Colombo et al. (2010) studied the energy savings when applying heat recovery in $CO_2$ trans-critical refrigeration system in an existing supermarket. Considerably energy savings have been observed and the $CO_2$ system showed lower energy consumption when compared to an existing R404A system.

Tambovtsev et al. (2010) discussed aspects related to recovering heat from $CO_2$ trans-critical refrigeration system and emphasized the importance of applying the gas cooler by-pass and an optimally tuned control algorithm. Some of the control strategies have been tested by Tambovtsev et al. (2011) and proved to be in-line with the predicted system performance.