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Water-Cooled Refrigeration Systems in the Food Retail Industry

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RESEARCH MOTIVATION

The need for refrigeration in the food retail industry and especially supermarkets currently accounts for 30% to 60% of the total energy consumed (Tassou, et al., 2011). A key characteristic of this consumption is the high amount of low-grade (i.e. low-temperature) heat rejected by the condensation units to the ambient air.

AIM

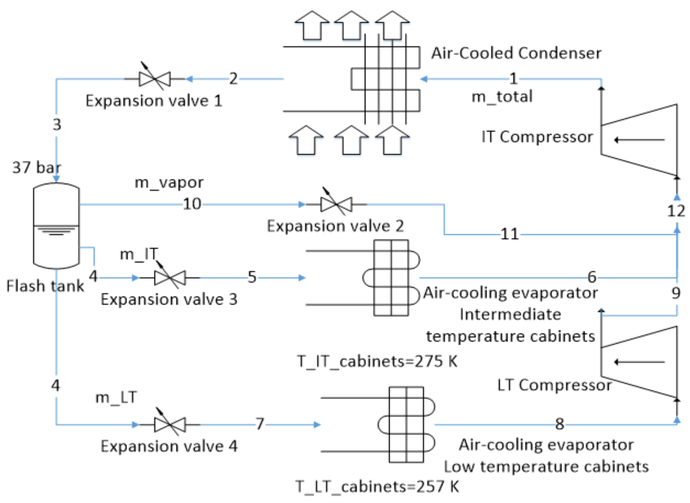
This study focuses on transcritical CO_2 (R744) refrigeration cycles which are becoming increasingly popular in industrial refrigeration applications.

The aim is to assess whether the use of a water-cooled condenser rejecting heat to the soil via an intermediate closed water-circuit can lead to a reduced energy consumption, while considering the economic implications of these modifications.

METHOD

1. Development of a detailed model simulating an existing supermarket refrigeration system
2. Validation against experimental data
3. Model modification to evaluate the performance of a similar system with a water-cooled condenser used instead of the existing air-cooled unit or in parallel to it.

Figure 1: Schematic diagram of the refrigeration system modelled



Case study: Refrigeration system of a store situated in Leicester

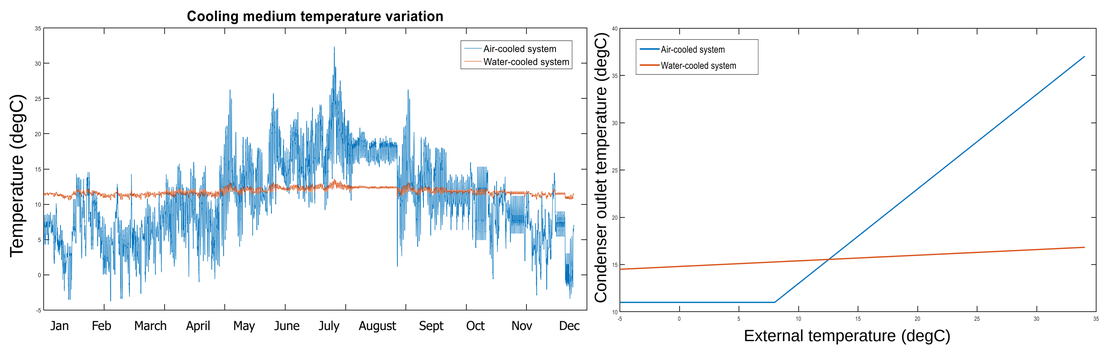
Two packs of direct-expansion CO_2 transcritical booster systems each one comprising an air-cooled condenser coupled with two sets of compressors for the provision of intermediate and low-temperature cooling

Key characteristic: The temperature of the refrigerant stream leaving the condenser (2) is 3 K higher than the temperature of the inlet air stream (external).

Alternative systems examined

1. Water-cooled condenser replacing the existing air-cooled unit
2. Hybrid system with coupled air-cooled and water-cooled condensers in parallel operation

Figure 2: Yearly temperature variations of the cooling medium and outlet temperature of the refrigerant stream in relation to external temperature



External air temperature varies significantly more than water temperature throughout the year. The condensation pressure is adjusted in order to main the temperature difference of 3 K at the condenser's outlet side (Sainsbury's, 2014).

As a result, the temperature of the refrigerant when a water-cooled condenser is employed, is not as much affected by the external conditions as it is in a system where the air-cooled condenser is employed.

RESULTS

Results indicate that the use of water-cooled condensers can reduce the amount of rejected heat by up to a factor of 5 when external temperature is high.

However, in cold ambient conditions the air-cooled unit currently employed rejects 10% less heat resulting to a better system performance.

Figure 3: Rejected heat and associated COP of the air-cooled and the water-cooled refrigeration systems in relation to the external temperature

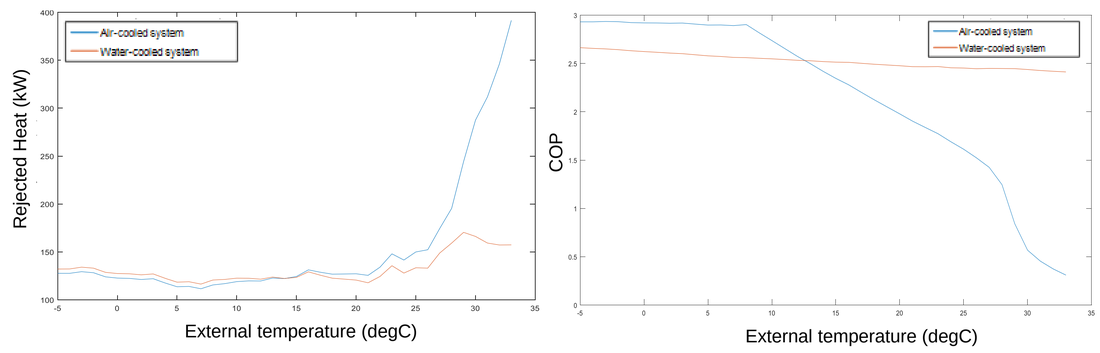
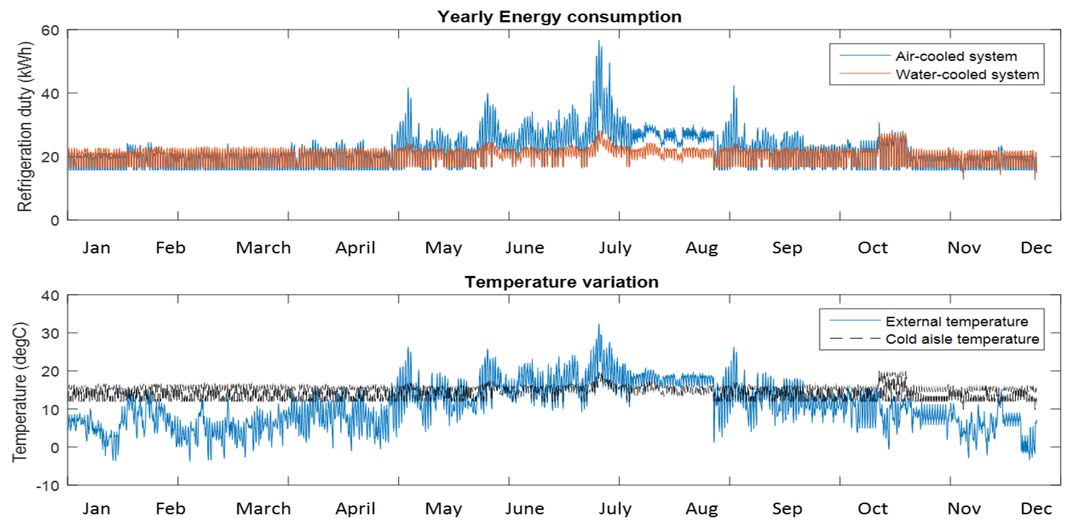


Figure 4: Energy consumption of the air-cooled and the water-cooled system and temperature variation in one year



Under these external conditions, the air-cooled system shows lower energy consumption than the water-cooled one for 65% of the year.

Table 1: Comparative results for the alternative systems examined

	Air-cooled system	Water-cooled system	Hybrid system
COP	0.50 - 2.90	2.40 - 2.65	2.40 - 2.90
Rejected heat of Pack 1	125 - 400 kW	130 - 180 kW	125 - 180 kW
Yearly energy consumption	696 MWh/year	673 MWh/year	656 MWh/year
Yearly electricity cost	£ 59,200	£ 57,500	£ 55,900
Yearly emissions	321 $tnCO_2$/year	311 $tnCO_2$/year	303 $tnCO_2$/year

FINANCIAL EVALUATION

1. **20%** higher CAPEX of a water-cooled system compared to the air-cooled one due to the high costs associated with the heat rejection system.
2. **Increased** OPEX of the water-cooled system, hence the total annual savings are less than expected.

The system is **sized down** when a water-cooled condenser is employed.

In a new store, a water-cooled condenser pays-off immediately and a hybrid system in less than 5 years.

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Tassou, S., Ge, Y., Hadawey, A. & Marriott, D., 2011. Energy consumption and conservation in food retailing. Applied Thermal Engineering, Issue 31, pp. 147-156.

Sainsbury's specifications, 2014