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On the activation strategy of the chiller in water-loop self-contained refrigeration systems: An experimental analysis

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ABSTRACT

Supermarkets require considerable amount of electricity and gas for refrigeration and maintenance of comfortable retail environment conditions. They are also responsible for a large amount of both direct and indirect CO_2 emissions. Nowadays advanced refrigeration systems for supermarkets can reduce both annual energy consumption and total equivalent warming impact. One of these advanced solutions is the water-loop self-contained refrigeration system, where the thermal power of each cabinet is rejected to a fluid-loop, refrigerated either by a dry-cooler or by a central chiller. In this study the performances of a real water-loop self-contained plant are analyzed to establish whether the activation of the water-loop chiller is energy effective or not varying the external air temperature. The activation strategy of the chiller is a crucial issue, which dramatically affects the energy performances of the whole system.

Stratégie d'activation du refroidisseur dans les systèmes frigorifiques autonomes à boucle d'eau : analyse expérimentale

Mots-clés : Boucle d'eau ; Boucle d'eau autonome ; Réglementation ; Supermarché

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Nomenclature

a, *b*	Constant values
BLDC	Brushless direct current motor
C_{min}	Minimum heat capacity rate (kW K^{-1})
CC	Counter-current heat exchange
CL	Closed valve
c_w	Water specific heat (kJ kg^{-1} K^{-1})
EEI	Energy Efficiency Index (as in CEN EN 16297-1: 2012)
EER	Energy Efficiency Ratio (as in UNI EN 14511-1: 2013)
EEV	Electronic Expansion Valve
EV	Electronic, pressure independent valve with flow meter integrated
F_c	Compressor frequency (Hz)
GDMD	Glass Door, Multi-Deck cabinet
K_v	Valve flow coefficient (m^3 h^{-1})
LT	Low temperature
OP	Open valve
$\dot{m}_w$	Water mass flow rate (kg s^{-1})
$\dot{m}_r$	Refrigerant mass flow rate (kg s^{-1})
MT	Medium temperature
OVMD	Open, Vertical, Multi-Deck cabinet
P_c	Cooling capacity (kW)
P_{el}	Electric power (kW)
$q_{th\ real}$	Real thermal power exchanged (kW)
q_{th}^*	Simulated thermal power exchanged (kW)
S_p	Plate heat exchange surface (m^2)
SC	Sub-Cooling value (K)
SH	Super-Heating value (K)
T_c	Saturated condensation temperature (°C)
T_e	Saturated evaporation temperature (°C)
T_{ext}	Temperature of the external air (°C)
T_{ext}^*	Simulated temperature of the external air (°C)
T_{int}	Air temperature in the room (°C)
$T_{w\ c\ in}$	Water temperature at the condenser inlet (°C)
$T_{w\ DC\ in}$	Water temperature at the dry-cooler inlet (°C)
$T_{w\ DC\ out}$	Water temperature at the dry-cooler outlet (°C)
$T_{w\ DC\ out\ g}$	Guessed water temperature at the dry-cooler outlet (°C)
$T_{w\ DC\ out\ test}$	Set point value of the water temperature at the dry-cooler outlet used in a test (°C)
$T_{w\ e\ in}$	Water temperature at the evaporator inlet (°C)
TEV	Thermostatic expansion valve
TEWI	Total Equivalent Warming Impact (kg$_{co_2}$)
V_i	Internal volume (cm^3)
WLSC	Water-Loop Self-Contained
ε	Dry-cooler effectiveness
ρ_{is}	Compressor isentropic efficiency

1. Introduction

Supermarkets require considerable amount of energy (mainly electricity and natural gas) for refrigeration and maintenance of comfortable retail environment conditions for both staff and consumers (Ge and Tassou, 2011). According to several authors (Walker, 2001; Arteconi et al., 2008) supermarkets might be considered as the largest energy users in the commercial sector in many countries. Walker (2001) estimated that 50% of the electric energy consumption in a supermarket is absorbed by the refrigeration system, which is also responsible of a large amount of both direct and indirect CO_2 emissions.

The large majority of supermarkets employ direct expansion air refrigerant coils as evaporators. Compressors and condensers are kept in a machine room, located at the back or in the roof. As a consequence, large amount of refrigerant is needed to charge the refrigeration system (Bagarella et al., 2014a). This solution is known as “multiplex refrigeration system”, where the term “multiplex” indicates that multiple compressors have a common suction line and discharge manifolds.

Nowadays advanced supermarket systems can reduce both annual energy consumption and total equivalent warming impact (*TEWI*). One of these advanced solutions is the water-loop self-contained refrigeration system (*WLSC*). In a *WLSC* system, each cabinet is equipped with its own compressor and condenser. The thermal power of each cabinet is rejected to a fluid-loop, refrigerated either in a dry-cooler or in a central chiller. Simulations carried out by Walker (2001) and Zhang (2006) assert that a *WLSC* system is less efficient if compared to a benchmark multiplex solution. However, a continuous loading–unloading capacity control was provided for the scroll compressors in those simulations. As in Bagarella et al. (2014b), if compressors optimized for variable speed operation (with high efficiency brushless direct current motors and inverters) are considered, a *WLSC* plant can allow a 16% electric energy reduction on an annual basis with respect to a traditional multiplex system (which implies AC motors, TEVs and desuperheating only heat recovery). Moreover, calculations showed that a *WLSC* plant is estimated to lead to 56%–58% 15-years *TEWI* reduction, compared with multiplex solutions. This is possible thanks to drastic reduction of both refrigerant charge and annual percentage leakages. For a correct evaluation of *WLSC* systems the reader should be aware that no sufficient analyses comparing the performances of *WLSC* plants with those of advanced multiplex systems (with BLDC inverter driven motors, EEVs and the whole condensation heat recoverable) were carried out in the past to the best Authors' knowledge.

Anyway, what past analyses certainly demonstrated is that *WLSC* systems have some crucial aspects as well. The main one is that two (or more) refrigeration cycles (in series) are needed when the water-loop chiller is activated (Bagarella et al., 2014b). The first cycle takes place inside the cabinet, the second one in the chiller. Although some studies were carried out in the past analyzing the performances of *WLSC* plants, there are no indications about the best way to regulate the chiller during summer periods (during winter periods the chiller is always activated, working as a heat-pump which provides energy for space heating using the water-loop as cold source). In fact, from one hand if the temperature of the external air is high (25 °C–35 °C) and the water-loop chiller is deactivated (the water-loop is cooled by the