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Performance characteristics of a combined air conditioner and refrigerator system interconnected via an intercooler

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A B S T R A C T

Convenience stores and supermarkets are equipped with air conditioner and refrigeration/freezer systems that are independently operated; these systems consume approximately 50%–60% of the total electric power used by the convenience store or supermarket. In this study, a combined system that can recover the condensation heat of the refrigeration system into the air conditioner using an intercooler is developed. Experimental investigations are conducted in order to investigate the performance characteristics of the combined system. Then, the proposed combined system is installed in a convenience store and operated for one year in order to measure the annual power consumption in a real environment. The proposed combined system exhibits an increase in the operation ratio, a reduction in defrosting operations, and a 32% reduction in the annual electric power consumption. The intercooler contributes to the reduction in power consumption, as does the use of a variable speed compressor. It is also found that the flow rate of the intercooler should be optimized when the air conditioning system is operated in the cooling mode.

Caractéristiques de performance d'un conditionneur d'air combiné et interconnecté avec un système de réfrigérateur par un refroidisseur intermédiaire

Mots clés : Commerce de proximité ; Meuble de vente ; Conditionneur d'air ; Refroidisseur intermédiaire ; Système combiné

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Nomenclature

REF	refrigerator
ODU	outdoor unit
IDU	indoor unit
HEX	heat exchanger
O/S	oil separator
Sol. V/V	solenoid valve
I/C	intercooler
w	compressor work, J kg^{-1}
k	adiabatic constant
v	specific volume, $m^3\ kg^{-1}$
P	pressure, Pa

Subscripts

d	compressor discharge
s	compressor suction

1. Introduction

The electric power consumed by the air conditioner and refrigeration/freezer systems in convenience stores and supermarkets is approximately 50%–60% of their total electric power consumption. Freezing and refrigeration showcases are systems that consume significant amounts of energy, and studies are being conducted in order to reduce the electric power consumption in this field. In particular, because 24-h convenience stores are constantly operating their air conditioner and refrigeration/freezer systems (i.e. 24 h per day) and general supermarkets also constantly operate their refrigeration systems, the performance of these systems should be improved in order to reduce power consumption. Heat pumps are commonly used in convenience stores in order to cool and heat spaces. Therefore, there is significant demand for heat pumps, and numerous studies have been conducted on the performance and reliability of heat pumps (Aikins et al., 2013; Ishi and Yoshimura, 2013; Li et al., 2013; Maria et al., 2013).

For refrigeration and freezing in convenience stores and supermarkets, two temperature levels are required: approximately 2–8 °C and −18 to −22 °C are typically required for refrigeration and freezing systems, respectively. The efficiency of refrigeration showcases and freezer showcases is lower than that of air conditioners because the evaporating temperature of these showcases is lower. Accordingly, many studies have been conducted in order to improve the performance of refrigeration and freezer systems (Choi and Oh, 2009; Renato et al., 2009).

In convenience stores and supermarkets where the air conditioner and refrigeration systems are operated together, the air conditioner and refrigeration system are generally operated using independent cycles. In summer, the air conditioner and refrigeration systems perform cooling and refrigeration operations, respectively, and both discharge condensation heat to outside. In winter, the outdoor unit heat exchanger of the air conditioner works as an evaporator and absorbs heat from the outdoor air to send this heat into the indoor space. Meanwhile, the refrigeration/freezer system continues to operate in a cooling cycle in winter. That is, the evaporator of the refrigeration showcase absorbs heat from inside and sends the condensation heat outside. If the condensation heat sent outside from the refrigeration system could be used for the air conditioner during its heating operation, much energy could be saved when the characteristics of convenience stores that are open for 24 h are considered. In this study, a combined system was developed through connecting the air conditioner and refrigeration system using an intercooler, in which the heat generated by the refrigeration system is transferred to the air conditioner through the intercooler and is then used by the air conditioner.

Dopazo and Fernandez-Seara (2011) conducted a study to determine the optimum CO_2 condensation temperature depending on the changes in the CO_2 evaporation temperature through constructing a cascade refrigeration system with an evaporation temperature of −50 °C using CO_2 and NH_3 as the refrigerants. Suamir and Tassou (2013), Silva et al. (2012), Getu and Bansal (2008), Chiarello et al. (2010), Sawalha (2005), and Wang et al. (2009) also conducted research to improve the system performance of CO_2 refrigeration systems that were used in supermarkets. In the abovementioned studies, an intercooler was used to lower the condensing temperature of the bottoming cycle. In addition, Yang and Zhang (2011) analyzed subcooler designs of integrated two-temperature supermarket refrigeration systems. Yang and Zhang (2010) conducted simulations in order to improve the system performance when an intercooler was installed between the air conditioner and refrigeration systems, between the air conditioner and freezing systems, and between the refrigeration and freezing systems in supermarkets. The reported results of their study stated that the improvements in the efficiency achieved by conducting heat exchange between the refrigeration and freezer systems using an intercooler were the largest, and it was followed by the heat exchange between the air conditioner and refrigeration systems. However, they did not consider the situation where the heat rejected from the condenser was recovered and used in space heating. Recently, recovering thermal energy from CO_2 refrigeration systems in supermarkets has also attracted significant attention (Cecchinato et al., 2012; Ge and Tassou, 2014; Sawalha, 2013).

Although there have been numerous studies on cascade refrigeration systems in the past, the performance of a combined system between an air conditioning cycle and a refrigeration cycle has primarily been investigated using analytical and numerical methods. However, the real behavior of a combined system differs from the simulation results because the evaporating temperature and condensing temperature of refrigeration/freezer systems continue to fluctuate due to their repeated on-off operations. Furthermore, there are few studies on systems where the condensation heat of a refrigeration system is recovered through an intercooler and is subsequently used by the air conditioning system.