DEVELOPMENT OF HEAT PUMP SYSTEM USING TOGETHER WITH COLD STORAGE AND FLOOR PANEL HEATING WITH THERMOBANK

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Abstract: This paper is to develop heat pump system can use cold storage together with floor panel heating. The system stores the wasted heat with thermobank during refrigeration cycles and its heat is used floor panel heating and hot gas defrost. This system reduces condensation load and its room maintains the constant temperature for working with cold storage, and then changes over heat pump for floor panel heating. Reducing defrosting time with thermobank the system can prevent temperature increasing in the cold storage. Heat pump system is investigated experimentally and analysed under cold storage and floor panel heating. The average performances of the refrigerator with cold storage and the heat pump with floor panel heating, under some test conditions, are shown a good COP of 3.0 and 4.0, respectively.

Key Words: heat pump systems, cold storage, floor panel heating, thermobank, hot gas defrost

1 INTRODUCTION

The rural communities have over 9 thousand small size cold storage warehouse under 20 M/T that can preserve and trade agricultural products in their nearby areas in Korea(Suhyup, Monthly newsletter, 2010). All of them are located inside or outside of house is built about 5 m distance from oil boiler equipment for rooms heating (floor panel heating) in individual house. A refrigeration unit in cold storage warehouse operates with electric power and heating of rooms are heated with using oil boiler. Therefore, spaces of those occupy much larger in small house and energy is wasted doubly in spite of saving them in rural. And the oil boiler exhausts CO_2 that increase Global Warming Potential(GWP). To overcome these problems, it need to develop heat pump system that can be used to keep preservation of agricultural products in cold storage warehouse together with floor panel heating for room in rural house. Various computer or numerical models with thermobank have been developed based on physical equations, empirical correlations using the curve fitting method, or combination of both. This model uses physical equations combined with the curve fitting empirical correlations to develop a model with simple and minimum input requirements. Based on the system operating conditions, refrigeration unit models can be divided into steady-state (Hoffenbecker et al. 2005, Jolly et al. 2000 and Ardiyansyah et al. 2007) and transient models. The steady-state model is used because in the refrigeration systems of small size cold storage warehouse, the equipment is mainly intended to keep the refrigerated room in steady-state conditions within the set temperature range. Preservation of agricultural

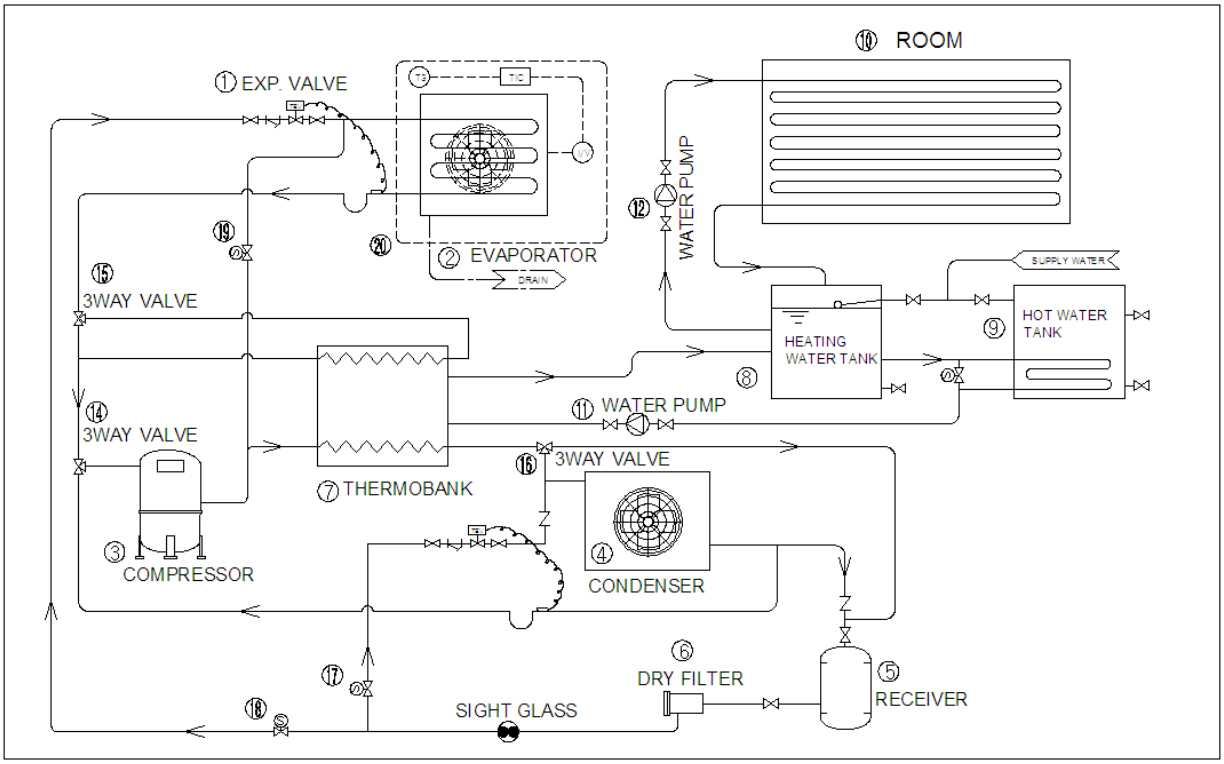


Figure 1: Schematic of heat pump system equipped with thermobank and heating room

products from producing district to the market and consumer forms an important parts of the product's cold chain which is mainly distributed in markets which is located at small, medium and large cities. Korea, more than 642 units of cold storage warehouse over 50M/T are in operation for food preservation and its total capacity is over 3.58 million M/T (Suhyup, Monthly newsletter, 2010). The performance and efficiency of such refrigeration unit is essential to maintain good quality of the agricultural products and fishery foods, saving energy and minimize environmental impacts. The objective of this study is to develop heat pump system with a pre-condenser and stores a portion of refrigerant heat rejection that can be used to keep around agricultural products with the set temperature in cold storage warehouse together with floor panel heating for room heating in rural house.

2 HEAT PUMP SYSTEM

Figure 1 shows the schematic of a heat pump system equipped with thermobank and heating room. The thermobank equipment uses water or brine which stores the heat. During the defrost process, the system directs hot refrigerant from compressor through the heat storage (bypassing the condenser) to the evaporator for defrosting the evaporator coils. The refrigerant ejects its heat and condenses into liquid. It then flows back into the heat storage equipment. The refrigerant is re-evaporated by the storage heat of thermobank before entering the compressor and circulates again. A steady state energy balance equation over the entire system is described in equation (1).

$$q_c = p + q_e - q_{th} \tag{1}$$

The compressor is modeled based on published manufacturers' specification data and empirical correlations from previous study (Mun et al. 2010). The direct-expansion evaporator is modeled based on the single zone heat transfer process with the two-phase refrigerant heat transfer process, between the refrigerant inside the evaporator coils and the

air flow. It is derived from the e-NTU relation for two-phase heat exchanger (Incropera and DeWitt 1990). A quasi-steady state approach is applied to the heat transfer process in the heat storage area. For a determined period of time, the heat storage temperature increases by (Boeis et al. 2005):

$$\Delta T_w = (T_2 - T_w)\frac{\dot{m}.c_p}{M.c_v}\left(1-\exp\left[-\frac{UA}{\dot{m}.c_p}\right]\right).\Delta t \tag{2}$$

The air-cooled condenser used in this study is modeled based on two-zone analysis, namely super cooling and condensation zones. The refrigerant leaving the condenser is assumed to be in a saturated liquid phase. The heat transfer within the super cooling is obtained from equation (3-4) where ε_c is the heat transfer effectiveness.

$$q_{c,sp} = \dot{m}_r\, c_r (T_3 - T_{b,in})\varepsilon_c \tag{3}$$

$$\varepsilon_c = 1 - \exp\left(-\frac{\dot{m}_a.c_a}{\dot{m}_r.c_r}\left(1-\exp\left(\frac{U_{c,sp}A_{c,sp}}{\dot{m}_a.c_a}\right)\right)\right) \tag{4}$$

The two-phase heat transfer for the condensation zone is given in (5).

$$q_{c,tp} = \dot{m}_b\, c_b (T_c - T_{b2}).\left[1-\exp\left(-\frac{U_{c,tp}A_{c,tp}}{\dot{m}_b.c_b}\right)\right] \tag{5}$$

The corresponding overall heat transfer coefficient for each zone is obtained from heat exchanger equation similar to equation (3) for the condenser. The refrigerant R-404A properties used in the analysis are obtained from data generated by REFPROP 8.0 software (Lemmon et al. 2007).

3 EXPERIMENTAL INVESTIGATION

A prototype heat pump system is developed and installed. The cooling capacity tests are performed on a 3,225 x 1,740 x 1,640 mm full-scale small size cold storage warehouse. The operation, including electrical valves, time and box temperature set, is controlled by microprocessor-based controller designed specifically for the system. The temperature sensor setting, position and measurement during cooling capacity and heating room (panel) tests are based on the calibrated-box method of transport refrigeration unit described in ARI 1110-2006 (ARI 2006). Along with temperature sensor at the compressor, condenser, evaporator and heat storage in thermobank, the temperature measurement are recorded simultaneously by Darwin DA 100 data acquisition unit. The air flow from evaporator and condenser and box humidity are measured using Solomat MPM 100 environmental meter.
The Figure 2 is a heat pump system using together with cold storage and floor panel heating with thermobank and the system specifications and test conditions are described in Table 1.



Figure 2: Heat pump system using together with cold storage warehouse and floor panel heating with thermobank.

Table 1: System specification and test conditions

Component	Specification
Compressor	ZB15KQ-PFV-524,
Refrigerant	R 134a
Evaporator	Aluminum finned, 4 rows, 9.53 mm diameter Cooper tube, total area 8.52 m^2, frontal area 0.17 m^2; Fan: 2x250 mm diameter, 80 W, 33.8CMM, 3.4 m/s
Condenser	Aluminum finned, 6 rows, 9.53 mm diameter Cooper tube, total area 13.635 m^2, frontal area 0.44 m^2; Fan: 3x250 mm diameter, 80 W, 79.8 CMM, 3.04 m/s
Floor panel	2400 x 2100 mm, 10 mm diameter Heating tube, Water
Expansion valve	TEN 2-1.5/NO-3
Heat storage	5 rows x10 circuit Cooper tube immersed in 75L of water
Heater	10 kW heater element with single fan
Test condition	Case 1 : Cooling operation, Heat storage, thermobank temperature = 50℃, FCU on, Condenser Fan off Case 2 : Heating operation, Heat storage, thermobank temperature = 60℃, FCU on, Heat pump system

4 RESULTS AND DISCUSSION

The inputs for the computer simulation include evaporator and condenser model, air flow and temperature, ambient and cold storage set point temperature, and heat storage model. The comparison of simulation and experimental investigation are performed for cooling capacity and heat storage temperature for three different operating conditions. The experimental investigation also measures the system power input and system COP. The average heat transfer 14.39 W/℃ of cold storage warehouse at 15℃ambient temperature is obtained from the heat leak tests prior to the cooling capacity tests. The system power input and system COP is depicted in Figure 3. The measured power input includes compressor's motor, evaporator and condenser fans and control operations and other losses. The simulation and

experimental comparison of compressor power draw values, which is different from the total power input, is not presented here. From Figure 3, the compressor power is more required at higher cold storage warehouse set point temperature, to achieve the balance point of the system; hence the system power input increases with the increase of the cold storage warehouse set point temperature. Given the COP is directly proportional to cooling capacity, the COP increases as the cold storage warehouse temperature increases.

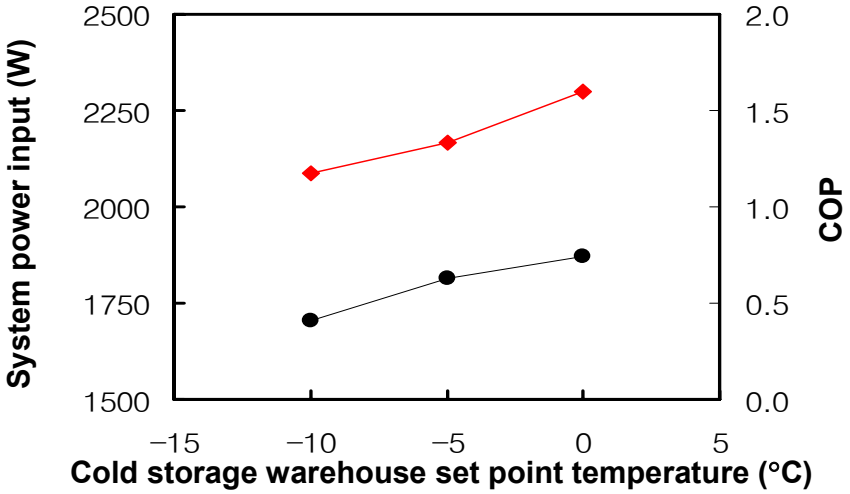


Figure 3: Experimental results of power input and COP with cold storage set temperature.

The effect of storage heat in thermobank with cooling operating in the small size cold storage warehouse is shown in Figure 4. The compressor outlet and the condensing temperature are 60℃ and 22℃ each at around 70 minute after the heat pump system is started. That is because the heat pump system in Fig. 1 works a condenser simultaneously. But, the compressor outlet and the condensing temperature increase steeply when it is turn off the condenser for storage heat in thermobank. A condensing temperature and storage heat temperature in thermobank show about 50℃ with slowly increasing and those illustrate about constant temperature with working floor heating panel. Therefore, heat pump system can be operated with cooling for preservation of agricultural products and heating of floor panel heating.

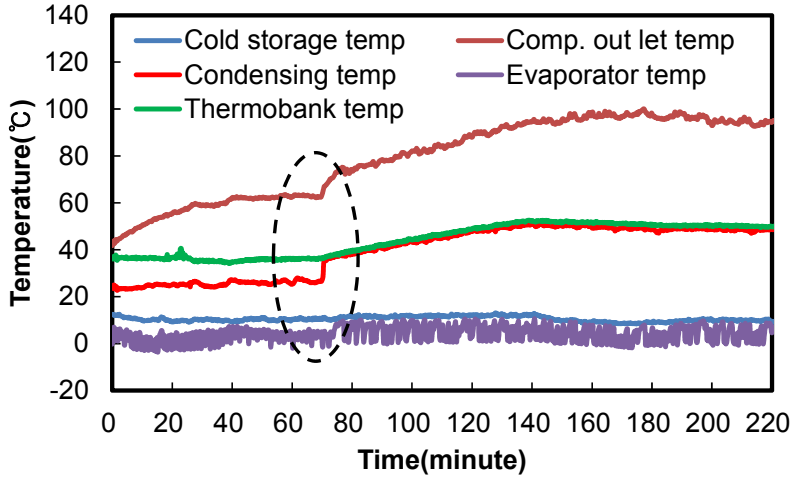


Figure 4: Temperature variation of heat pump system in cooling operation.

Figure 5 shows the power consumption, room temperature in cold storage warehouse and thermobank temperature in heating operation without working of the condenser in heat pump system. The total power consumption is 1.7 kW when the condenser worked including a

circulation pump in heat pump system, and that increases until running time is 140 minute together with thermobank temperature. But, the power consumption and thermobank decrease after the running time is 140 minute and those do not show change from 180 minute for working. Therefore, the working of heat pump system is steady-state.

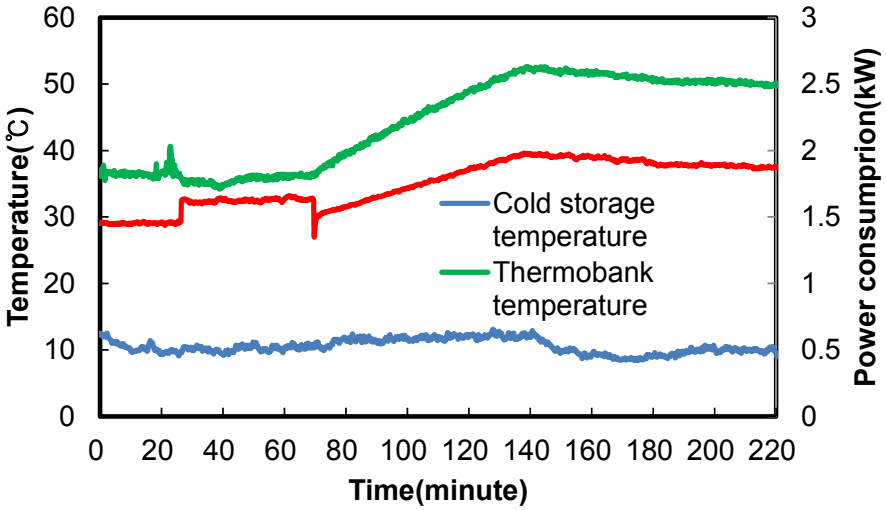


Figure 5: Temperature and electric power variation of heat pump system in heating operation.

The compressor outlet temperature, the thermobank and evaporating temperature for heating operation of heat pump system are depicted in Figure 6. After start, when running time is 10 minute, a condensing and the thermobank temperature increase. And a condensing and the thermobank become 100℃ and 60℃ each after a running time is 90 minute. Total power consumption of heat pump system is 2.6 kW and the heat pump system is very steady-state. This can explain that the heat pump system is able to use for keeping preservation of agricultural products with the set temperature in cold storage warehouse together with floor panel heating for room heating in rural house.

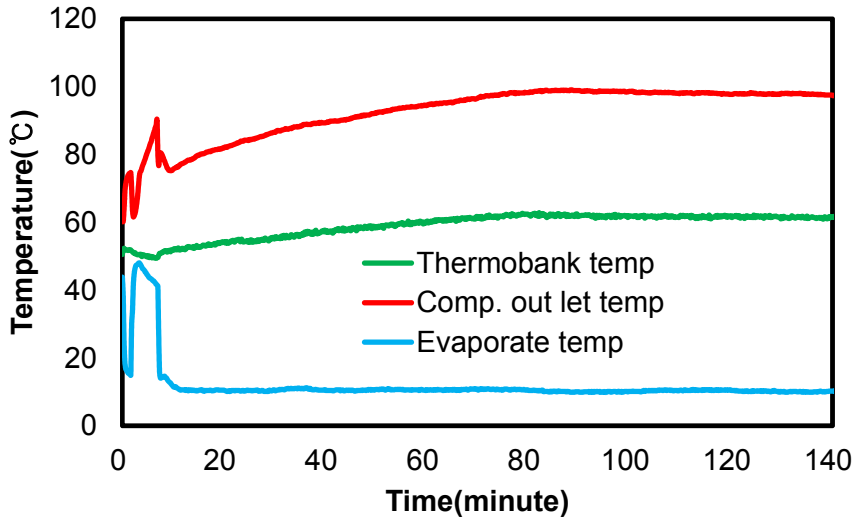


Figure 6: Temperature variation of heat pump system in heating operation.

5 CONCLUSION

The heat pump system is equipped with auxiliary condenser, thermobank and floor panel heating. The simulation value shows good agreement with the experimental result. A set temperature of room in small size cold storage warehouse is steady-state for cooling and

heating operating of the heat pump system. When a condensing and the thermobank temperature become 100℃ and 60℃ each, a storage heat of thermobank can be use heating of room in individual house together with food preservation of cold storage warehouse is keeping by set point temperature simultaneously in rural. The power consumption of heat pump system decreases because the thermobank save heating energy for floor panel heating. Therefore, the heat pump system can be alternated with refrigeration unit for preservation of agriculture products and boiler system for heating of room in individual house in rural of Korea.

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6 REFERENCES

Suhyup, 2010. " Monthly newsletter," Report of refrigeration and cold storage warehouse.

Hoffenbecker N., S.A. Klein, and D.T. Reindl. 2005. "Hot Gas Defrost Model Development and Validation," International Journal of Refrigeration 28: 605-615.

Jolly P.G., C.P. Tso, Y.W. Wong and A.M. Ng. 2000. "Simulation and Measurement on the Full Load Performance of Refrigeration System in a Shipping Container," International Journal of Refrigeration 23: 112-126.

Ardiyansyah, K.I. Choi, J.T. Oh, and H.K. Oh, 2007, "Modelling of a High Efficiency Refrigeration System with Heat Storage for Reverse Cycle Hot Gas Defrost," Int. J. of AC and Ref. 15(4), 175-179

Mun, J.C., Choi, K.I., Rifaldi, M., and Oh, J.T. 2010, Modeling and Experimental Investigation of a Transportation Refrigeration System. 1st International Conference of Cold Chain, Cambridge England.

Incropera F.P., and David P. DeWitt 1990. *Fundamental of Heat and Mass Transfer 3rd edition*, John Wiley and Son, Singapore.

Boeis A.M., K.O. Homan., J.H. Davidson., and Wei Liu 2005. A Variable Effectiveness Model for Indirect Thermal Storage Devices. Proceedings of ASME Summer Heat Transfer Conference HT2005-72711 Research 25:859-880.

Lemon, E.W., M.L. Huber, and M.O. Mc Linden. 2007. REFPROP: Reference Fluid Thermodynamic and Transport Properties -NIST Standard Reference Database 23-Version 8.0. USA.

ARI, 2006, "Performance Rating of Mechanical Transport Refrigeration Units-Standard 111011, ARI, USA.