Energy Simulation of a Heat Pump System with Thermal Storage according to Control Strategies

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Abstract -- A comparative analysis was performed on the energy consumption and cost of heat pump system with thermal storage for various control strategies according to cooling and heating load variations. Simulation models of heat pump and thermal storage are developed to obtain energy consumption for cooling and heating of a building in Seoul during summer and winter season. Energy simulation has been conducted for the zone control as well as existing control strategies such as heat pump priority and thermal storage priority. Power consumption and energy cost has been evaluated based on electricity pricing in Korea. When the cooling and heating loads increase, the heat pump priority method is more effective. Whereas, when the low cooling and heating loads are demanded, the thermal storage priority method is more economical than heat pump priority method. Zone control strategy is found to be comparable to the heat pump priority method for large loads, while it is also economic for small loads compared to the heat pump and heat storage priorities control strategies.

Keywords: heat pump, thermal storage, heat pump priority, thermal storage priority, zone control

1. Introduction

Recent energy issue has been caused by increasing energy demands, shortages of energy resources and environmental problem. Especially, building sectors occupies considerable energy consumption and CO₂ emission. In order to reduce energy consumption and improve energy performance of air conditioning system in building, lots of studies have been conducted. Heat pump system with thermal storage as shown in Fig. 1 is one of the promising technologies and can be operated under various control strategies according to electricity pricing and cooling or heating load variation. The most widely used conventional methods are heat pump priority and storage priority strategies.

![Fig. 1. Schematic of a heat pump system with thermal storage](image-url)
In the heat pump priority method, heat pump maintains rated operation and thermal storage is responsible for the remainder of load. This method can keep the high efficiency by minimizing the part load operation of heat pump. But, according to the load decrease, the utilization ratio of thermal storage is gradually reduced. In the thermal storage priority method, thermal storage is responsible for base of the cooling or heating load, and heat pump is in charge of the rest. Thus, regardless of changes in load, maximum utilization of the thermal storage is possible. However, due to part load operation of the heat pump in daytime, the operation efficiency decreases. A zone control strategy was proposed considering load variations (Lee et al.). When load is lower than rated capacity of thermal storage, thermal storage only operates coping with load, and when load is between rated capacity of thermal storage and optimum capacity of heat pump, heat pump only operates according to load variation. Thermal storage and heat pump operate concurrently as load exceeds the optimum capacity of heat pump.

In this study, physical models of heat-pump and thermal storage have been presented, and the performance simulations have been conducted for the heat pump priority, thermal storage priority, and zone control strategies. A comparative analysis was carried out on energy consumption and operation costs considering electricity pricing in Korea.

2. Simulation Models

In this study, simulation models of heat pump and thermal storage system are developed, and energy consumptions of heat pump system are obtained considering cooling and heating load variations of building in Seoul. Meteorological data provided by the Solar Energy Society of Korea has been used for the simulation. And cooling and heating loads are calculated using an energy simulation tool TRNSYS. The building is an office building consisted of 10th floor and located in Seoul, Korea. Details of the simulation have been designed based on the existing study (Seok et al.).

Heat pump model used in this study is a static model and consists of sub-components that are compressor, condenser, and evaporator. In the compressor model, discharge temperature is calculated regarding polytropic process and refrigerant mass flow rate is obtained by volumetric efficiency, compressor frequency, and refrigerant inlet density.

\[
\frac{T_{\text{dis}}}{T_{\text{suc}}} = \left( \frac{P_{\text{dis}}}{P_{\text{suc}}} \right)^{\frac{n-1}{n}}, \quad R_p = \frac{P_{\text{dis}}}{P_{\text{suc}}} \tag{1}
\]

\[
\dot{m}_{\text{comp}} = \eta_v \cdot \rho_i \cdot V_d \cdot RPS \tag{2}
\]

Condenser and evaporator are modelled by UA and LMTD at three-zone and two-zone according to the refrigerant phase, respectively. Mean temperature difference at condenser is calculated as in Eq. 3.

\[
\frac{1}{\Delta T_{c,m}} = \frac{1}{\dot{Q}_{c,\text{sh}}} + \frac{1}{\dot{Q}_{c,\text{sat}}} + \frac{1}{\dot{Q}_{c,\text{sc}}} \tag{3}
\]

Thermal storage is a capsule type storage tank. This model has some assumptions that a tank is divided into some virtual layers and each layer has same number of capsules. Governing equations are obtained from energy conservation as shown in Eq. 4 and 5 (Lee et al.).

\[
\rho_b V_b C_{p,b} \frac{dT_b}{dt} = U_c n A_c (T_w - T_b) + \dot{m}_{b} C_{p,b} (T_l - T_b) \tag{4}
\]

\[
h_{fg} \frac{dM_{PCM}}{dt} = \dot{m}_{b} C_{p,b} (T_l - T_p) \tag{5}
\]
results

In response to the hourly cooling load, performance simulation of heat pump and thermal storage has been conducted for various control strategies. Fig. 1 shows load sharing results of heat pump and thermal storage according to cooling load variations in a day in July when average cooling load is 80% of design cooling load. In heat pump priority strategy, heat pump operates almost in a rated condition, and comprises a large portion of cooling load, while storage usage ratio is low. On the other hand, in thermal storage priority strategy, most of the stored energy in thermal storage is consumed, and part load operation ratio of heat pump becomes greater with decrease in cooling load. Zone control strategy describe load sharing in-between heat pump and thermal storage priority strategies. Heat pump operates in a better performance condition than thermal storage priority method, and a larger amount of stored energy in the thermal storage can be utilized than heat pump priority method.

4. Conclusion

This study has been conducted for the optimal control of heat pump system with thermal storage. Physical models of the heat pump and thermal storage have been developed. And also, in response to the cooling and heating load, energy simulation for the heat pump priority, thermal storage priority, and zone control strategies were performed. For conventional control methods, when large cooling or heating load occurs, heat pump priority shows less energy consumption and operating cost. Whereas, when the low cooling or heating load is demand, thermal storage priority method is more effective. Zone control
strategy is found to be comparable to the heat pump priority method for large loads, while it is also economic for small loads compared to the heat pump and heat storage priorities control strategies.

Fig. 3. Energy simulation results during cooling period(A : heat pump priority; B : thermal storage priority; C : zone control)

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References