論 文 の 内 容 の 要 旨

論文題目　　Thermodynamic Analysis and Optimization of HVAC System
（空調システムにおける熱力学的解析とその最適化に関する研究）

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Under the background of global energy saving, the reduction of building energy consumption and the improvement in the system performance of HVAC (Heating Ventilation Air Conditioning) system have attracted more and more attention in recent years. In HAVC system, heat transfer equipments are the important components since any thermodynamic process is closely related to the heat transfer process. The optimization of the heat transfer equipment helps to improve the heat transfer performance and the COP of chiller or any other air conditioning equipment. On the other hand, for some large and complex HVAC system, the pumping power accounts for a considerable proportion of system total energy consumption, which has an important effect on the system performance of HVAC system. The use of some suitable system renovations and debugging and the development of assessment method of system are significant for the improvement of system performance. Therefore, the above-mentioned two points are focused on in this study, aiming at supplying some good optimization and evaluation methods and some useful conclusions.

At first, the modified number of entropy production units, Ns, represented by Xu is adopted as the objective function of heat exchanger optimization. According to the two types of losses in heat exchanger, namely heat transfer through a finite temperature difference and a pressure drop in the heat transfer fluids, Ns can be divided into Ns due to heat transfer (NsΔT) and Ns due to friction (NsΔP), respectively. In order to clarify the proportion of irreversible loss due to heat transfer and pressure loss, respectively, to make sense of the main inducement of irreversible process in the heat exchanger for different working mediums, the values of NsΔT and NsΔP of three kinds of heat exchangers (air-to-air, water-to-water, air-to-water) are compared under three kinds of inlet temperature differences, three kinds of length-to-diameter ratios, and nine kinds of inlet Reynolds numbers. It can be found that for water-to-water heat exchanger, the irreversible loss is caused by heat transfer at any Reynolds number; for air-to-water and air-to-air heat exchangers, the irreversible loss is mainly caused by heat transfer at lower Reynolds number and by pressure loss at higher Reynolds number.

Then, the optimization of a water-to-water plate-fin heat exchanger is carried out. The convective heat transfer coefficients of the plate and fin are defined as independent parameters in the optimization, and their values are calculated by applying the multiple regression analysis equation to numerical simulation results of 45 cases. $Ns\Delta T$, $Ns\Delta P$, and Ns are considered as three single objective functions. Finally, according to the single objective optimization and multi-objective optimization, the optimal structural parameters of the heat exchanger are obtained using GA. Meanwhile, the optimizations based on fixed overall dimension of an assumed heat exchanger are also carried out. After the thermodynamic optimization, the efficiency of heat exchanger increases from 30.8% to 33.0%; the heat transfer amount also increases 7.1% from 49.3 kW to 52.8 kW.

Next, in order to clarify the effects of different variable-flow control methods and supply water temperatures on the exergy budget of chilled water circuit, the exergy analysis on an assumed chilled-water circuit system under four variable-flow control modes (throttle-valve control, constant-pressure control, constant-differential-pressure control, and predictive-system-curve control) and two supply water temperatures are carried out. The pumping head, pumping power, and the input exergy rate of each case are compared and analysis. it can be found that the rates of exergy input and exergy consumption under any partial-load condition are significantly smaller than those under full-load condition; the rates of exergy input and exergy consumption under any variable-frequency control mode are smaller than those under throttle-valve control mode; in variable-frequency control mode, the rate of exergy inputs decrease in the following order: constant-pressure control, constant-differential-pressure control, and predictive-system-curve control. Moreover, regarding the effect of the supply water temperature, the rate of exergy inputs are smaller at 12°C than at 7°C. Therefore, the use of the variable-frequency control mode and a higher chilled water temperature will effectively reduce the exergy input to the system.

Finally, performance of an actual heat pump system at each step of the system renovation and debugging are compared and analysed. Meanwhile, in order to clarify the effect of chilled water temperature, operation mode of compressor and pumps, and the type of heat exchanger on the system performance, the exergy analysis based on three sets of representative operating data of heat pump system are carried out. It can be seen that, for the three sets of representative operating data, after the variable-frequency transformation of compressor and water pumps, the temperature adjustment of child water, and the replacement of heat exchanger from stainless steel plate heat exchanger to aluminium plate-fin heat exchanger, a good system performance is obtained. The COP of heat pump chiller increases from 4.2, 5.0, to 6.4; the system COP increases from 2.2, 2.9 to 3.2; the exergy efficiency of the system increases from 26.4%, 33.8% to 38.7%.

This study provides a useful optimization method of heat exchanger and a more reasonable and clear analysis method (exergy analysis) for system evaluation and renovations. By adopting these methods, more research can be carried out in future focused on different heat transfer equipments and different HVAC systems.