Efficiency Evaluation of Packaged Air-Conditioning System with Different Patterns of Compressor Operation

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ABSTRACT
It is important to develop the practical evaluation method of energy efficiency of packaged air conditioning system for estimation of electric power consumption of a building. The relationship between electric power consumption and partial load ratio of the air conditioning system is sometime not unique, especially in case of the low thermal load operation. In this paper, we examined the effect of compressor operation patterns on the efficiency of packaged air conditioning system which has one outdoor and one indoor unit. We found that the efficiency of the air conditioning system was different with compressor operation pattern even though partial load ratio was the same.

KEYWORDS
Efficiency evaluation, Simulation, Frequency of Compressor, Packaged Air-Conditioning System

INTRODUCTION
Recently, the multiple packaged air-conditioning unit system begins to be introduced into not only the small and medium size scale building but also the large-scale building instead of the central air-conditioning system. That system has high flexibility to design due to the variety of combination of outdoor unit and indoor unit. To estimate the energy consumption of the air-conditioning system accurately for the building design, it is necessary to understand the relationship between input power and heat load that an air-conditioning system processes.
In a practical situation, air-conditioning systems does not always operate with rated condition. It operates with low load condition, generally. Under such condition, the

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system operates intermittently because of the difficulty in the continuous running of the compressor. Therefor it is difficult to develop the evaluation method of the actual energy efficiency of the system because of a variety of operating conditions.

In this paper, to get basic knowledge for the development of the actual energy efficiency, we examined the effect of compressor operation patterns on the efficiency of packaged air conditioning system by using numerical value simulation. Especially, we examined the effect of compressor frequency and duration of compressor operation when the compressor operates intermittently at partial load condition.

ANALYSIS METHODS

Systems

We studied about the air-conditioning system which has one outdoor and one indoor unit. The schematic view of this system is shown in figure 1. This system has a scroll-type compressor, fin-tube type heat exchanger unit, electric expansion valve, accumulator and pipes.

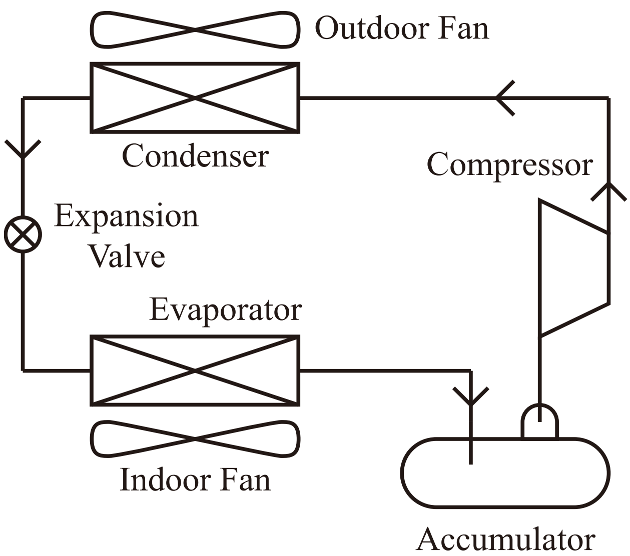

Figure 1. *Schematic view of heat pump*

Simulator

To simulate an operation of air-conditioning system, we used the “ENERGY FLOW +M” which is a simulator that Saito Laboratory of Waseda Univ. has been developed (Ohno and Saito 2012, Ohno et al. 2013). Ohno et al. (2013) examined the accuracy of this simulator by comparing calculated data with actual operation data of air-conditioning system and they showed that the difference between them was less than ten percent. The basic logic of this simulator is modular analytical method. At first, quantity of the fluid which flow in and out of component, pressure and enthalpy were calculated for each component of the air-conditioning system based on the mathematical model. Equations of the whole system could be described by giving boundary condition at the point where an element is connected. To obtain a solution, the simulator processes convergence calculation for provided equation group by using Newton-Raphson method.

ANALYSIS CONDITIONS

Condition of air

In this paper, we examined the efficiency of cooling mode. Inlet air temperature and relative humidity of outdoor unit were kept constant at 35 degrees C and 45% respectively. And those of indoor unit were also kept constant at 27 degrees C and 46.6% respectively.

Pattern of compressor operation

We examined efficiency difference between the case of continuous operation of compressor and the case of intermittent operation with a constant frequency. In the case of continuous operation, the rotation speed of the compressor was set every 5 rps from 10 to 60 (rated speed). In the case of intermittent operation, the rotation speed of the compressor was varied as a square wave. The duration of one cycle is 30 minutes. In one cycle, duration of compressor running (ON duration) and speed of compressor are shown in table 1.

Table 1. *Pattern of compressor operation*

Comp. Speed [rps]	30, 45, 60
ON Duration [min]	7.5 (only for comp. speed of 60 rps), 15, 22.5

Control of expansion valve

With continuous operation, the opening rate of expansion valve was adjusted to keep a degree of super heat of refrigerant at evaporator outlet as 5 degrees C for each compressor speed. With intermittent operation, the opening rate of expansion valve was set at same as the case of continuous operation. For example, when a compressor speed of ON duration was 60 rps, the opening rate was same as continuous operation of 60 rps. The opening rate was kept constant even for OFF duration.

Fan

Air flow of indoor unit and outdoor unit were kept constant at 500 and 1000 m^3/h, respectively.

Analysis time interval

In the case of continuous operation, we calculated behavior of air-conditioning system every 10 seconds. When the refrigeration cycle is enough stable state, we got an efficiency value. In the case of intermittent operation, we calculated behavior of air-conditioning system every 5 seconds during two cycles, i.e. 60 minutes.

RESULTS AND DISCUSSIONS

The results of numerical calculation obtained for intermittent operation were shown in figure 2. These graphs represent the time course of compressor speed, electric consumption of the air-conditioning system, cooling capacity, refrigerant pressure at inlet/outlet of the compressor and degree of super heat at outlet of the evaporator. When the compressor was turn on, the pressure of refrigerant and degree of super heat were not stable so cooling capacity was low compared to the stable condition.

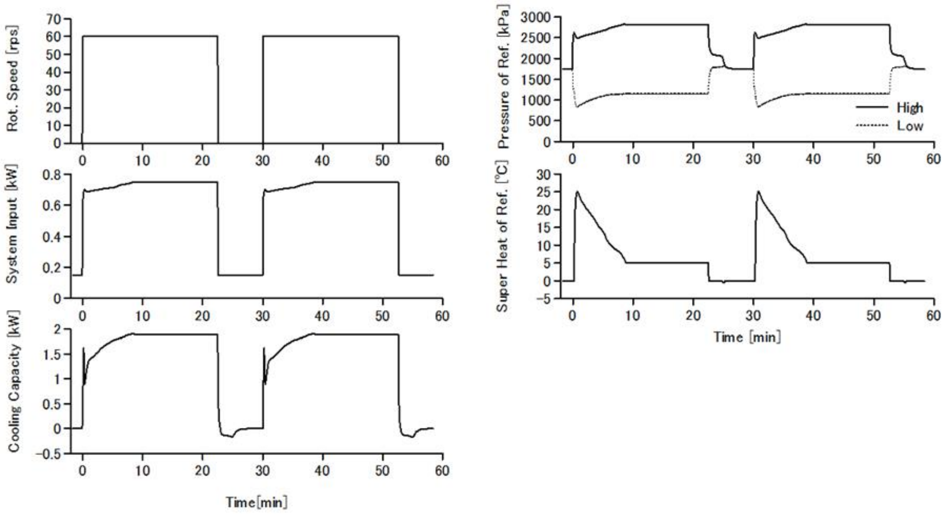

Figure 2. *Results of numerical simulation for intermittent operation*

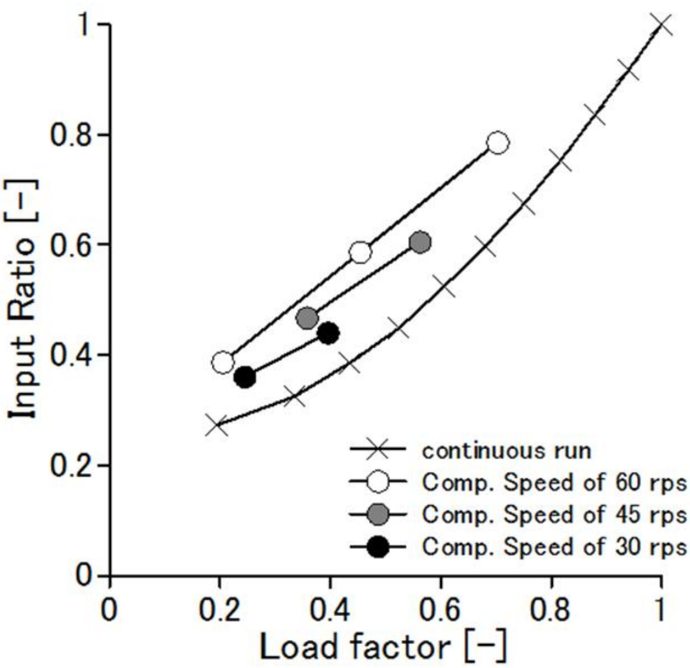

Figure 3. *The relationship between load factor and input ratio*

Figure 3 showed the relationship between the averaged cooling capacity and averaged electric consumption across one cycle of intermittent operation. The abscissa indicates the ratio of cooling capacity of each pattern of operation to rated capacity, the ordinate the ratio of electric consumption to rated wattage. The cross symbols indicate the results obtained from continuous operation. The circles indicate the results obtained from intermittent operation; white, gray and black symbols are corresponding to the compressor speed of 60, 45 and 30 rps, respectively. Although the cooling capacity was almost the same, electric consumption for intermittent operation was higher than for continuous operation. Increase of electric consumption was large if the compressor speed during ON duration was high.

CONCLUSION

We found that the efficiency of the air conditioning system was different with compressor operation pattern even though partial load factor was the same. To estimate energy consumption for the practical buildings, further study is needed to clarify what environmental factor determines the operation pattern.

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