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THE ASSESSMENT OF SEER RELATING TO CAPACITY MODULATION IN THE AIR CONDITIONER WITH TWO COMPRESSORS

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ABSTRACT

An air-conditioner driven by two compressors with different capacity was developed to improve energy efficiency through load matching. It consists of 40%, 60% capacity ratio of compressor and can run with three kinds of operating mode, namely, 100%, 40%, 60% capacity ratio. In minimum operating condition, the system runs at 40% or 60% compressor capacity ratio and the SEER is estimated.

The system operating at 40% capacity ratio obtained about 7% SEER enhancement at Cd(degradation coefficient)=0.25 as compared with the 60% capacity operating system. This is because the condenser size of 40% capacity operation is relatively larger than that of 60% capacity operation. When Cd changed to 0.1, due to the enhancement in operating efficiency, the advantage of compressor input power reduction at 60% capacity operation is bigger than that of 40% capacity operation. Therefore, the enhancement of the SEER at 40% capacity operation is reduced to about 5% compared with 60% capacity operation. From the viewpoint of SEER, 40% capacity operation is more efficient. But if the load condition is over the 60% cooling capacity or the comfortableness is more required, 60% capacity operation can be effective.

The operation mode to fully use 3 stage capacity is applied and compared with 2 stage capacity operation mode. From the results, the operation with 3 stage capacity is able to properly correspond with cooling load and it is also found to be more profitable from a energy efficiency point of view.

1. INTRODUCTION

The energy efficiency regulation of air-conditioner becomes tightened every year, because of the worldwide environmental protection movement. However, it became more difficult than ever, to reduce energy consumption without retail price increase. It is known that a variable speed compressor system shows higher efficiency, but the higher cost has not attracted consumers as many as the manufacturers expected. Therefore, a new method was developed to improve the efficiency without adopting the expensive variable speed compressor.

There are two ways in indicating the energy efficiency, COP(Coefficient of Performance) and SEER(Seasonal Energy Efficiency Ratio). The investigation for high efficiency was focused on the first method, but, in view of saving the running cost during the cooling season, the second method, SEER can be more useful. The reason is why the capacity modulation method is powerful to increase the energy efficiency of air-conditioning system. When measuring COP, the test unit operates at one rated test measuring system, but SEER considered entire cooling load conditions includes the rated and minimum condition. In COP measuring system, there is an underlying assumption that the system with higher efficiency at one test condition would show higher efficiency at other operating conditions. But this measurement omits the fact that the frequent cyclic start-and-stop operation of a compressor could lead to a sharp decrease in energy efficiency, which occurs at a minimum or low cooling loads. When the compressor stops, the refrigerant with high pressure migrates into the low pressure side to level out the pressure difference (Sano,1999). When the compressor starts, it takes time to recover the high pressure, and it is one of the main reason for the energy loss in the constant capacity air-conditioner. When the cooling load is low, the variable capacity system slows down, and reduces the number of cyclic start and stop operation of the compressor, which saves lots of energy consumption. Therefore, SEER is inevitable for evaluating system performance.

Most of the air-conditioner systems except inverter air-conditioner include 2-stage compressor for variable capacity such as Copeland Ultratech and Bristol TS in residential system. These compressors have the capacity ratio like 100-67%, 100-50%. When the cooling load is much less than the minimum capacity, it is difficult to closely correspond with the cooling load.

In this study, 2-comp system is developed to correspond with variable capacity, which is based on a previous research results in Kim *et al.* (2001). It has two kinds of 2-stage, 100-60%, 100-40% capacity ratio, and SEER is evaluated. Also, 3-stage operation is conducted with 2-comp system and is compared with 2-stage operation.

2. SYSTEM CONFIGURATION AND TEST CONDITION

2.1 System Configuration and Operating Theory

The schematic diagram of 2-comp system is shown in fig. 1. There are two compressors, check valves and a common accumulator besides condenser and evaporator. The working flow path is explained as follows. The refrigerant that is discharged from compressors, flows into condenser and then goes through expansion device like TXV. The expanded refrigerant flows into evaporator and then goes into a common accumulator and compressors. The common accumulator works as follows. A refrigerant, evaporated in evaporator, flows into a common accumulator, and there the vapor refrigerant flows into each compressor through a suction line while the liquid

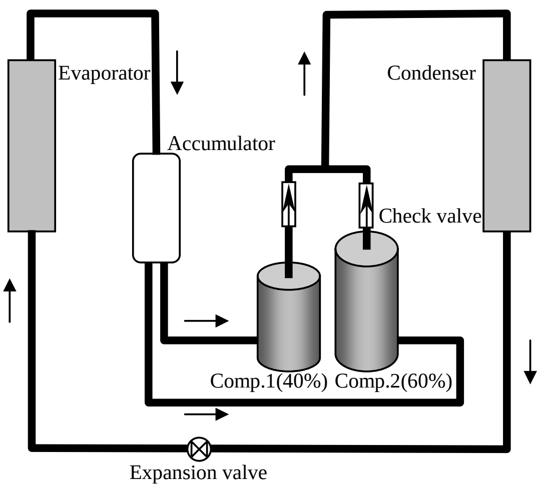


Figure 1. The schematic diagram of 2 comp system

refrigerant and oil are accumulated at the bottom of the accumulator. At this time, oil is recovered to the compressor through the oil-return hole with vapor refrigerant (Kim *et al.*, 2003). Check valve is necessary that the refrigerant prevent from flowing back to the other compressor when only one of the compressors operates.

2.2 Experimental Unit and Test Condition

Indoor unit is A-coil (3 row, 20step) with blower which has BLDC motor, and outdoor unit size is about $0.66m^3$. The expansion valve is TXV. The compressors are Matsushita rotary compressors and the ratio of capacity is about 60:40. The refrigerant is R410A. Test condition is A and B condition as follows. Outdoor fan motor is induction motor.

Table 1: Test condition (A, B) in indoor and outdoor

Condition		Indoor	Outdoor
A	DB	80°F	95°F
	WB	67°F	75°F
B	DB	80°F	82°F
	WB	67°F	65°F

3. EVALUATION OF SEER IN 2-COMP SYSTEM

3.1 Definition of SEER in 2-Comp System

SEER (Seasonal Energy Efficiency Ratio) is used as a standard to define the annual power consumption of a system. It is defined as follows for the capacity modulation system including two speed compressors or two compressors, or cylinder unloading (ARI Standard 210/240, 1994).

$$SEER = \frac{\sum_{j=1}^{8} \frac{Q(T_j)}{N}}{\sum_{j=1}^{8} \frac{E(T_j)}{N}} \qquad (1)$$

where,

$\frac{Q(T_j)}{N} =$ ratio of total cooling(Btu) in temperature bin *j* to the number of temperature bin hours.

$\frac{E(T_j)}{N} =$ ratio of Energy usage(watt-hr.) in temperature bin *j* to the number of temperature bin hours.

where *j* is temperature bin index (1~8).

2-stage system (100-60% or 100-40%) has 3 different operating regions covering the temperature, which are minimum operation, alternate operation and maximum operation. Compared with one-compressor system, the power consumption in 2-comp system is reduced when the number of repetitive on/off is decreased. It is more effective in minimum operating condition. In minimum operation mode, the capacity of condenser and evaporator is increased more than that of compressor as compared to regular operation mode. Therefore, in the operating range except maximum operating condition, SEER can be enhanced by capacity modulation.

3.2 Comparison and Analysis as to Capacity Modulation

As presented in schematic diagram (fig.1), the air-conditioner system is 2-comp system. The capacity ratio of the compressors is 40:60, which can realize 2-stage operation mode such as 100-60% and 100-40%. Operation of two

Table 2: SEER in 100-60% and 100-40% operating mode as to different Cd

SEER		**Operating mode**	
		100-60%	**100-40%**
Cd	0.25	14.1	15.1
	0.1	14.7	15.4

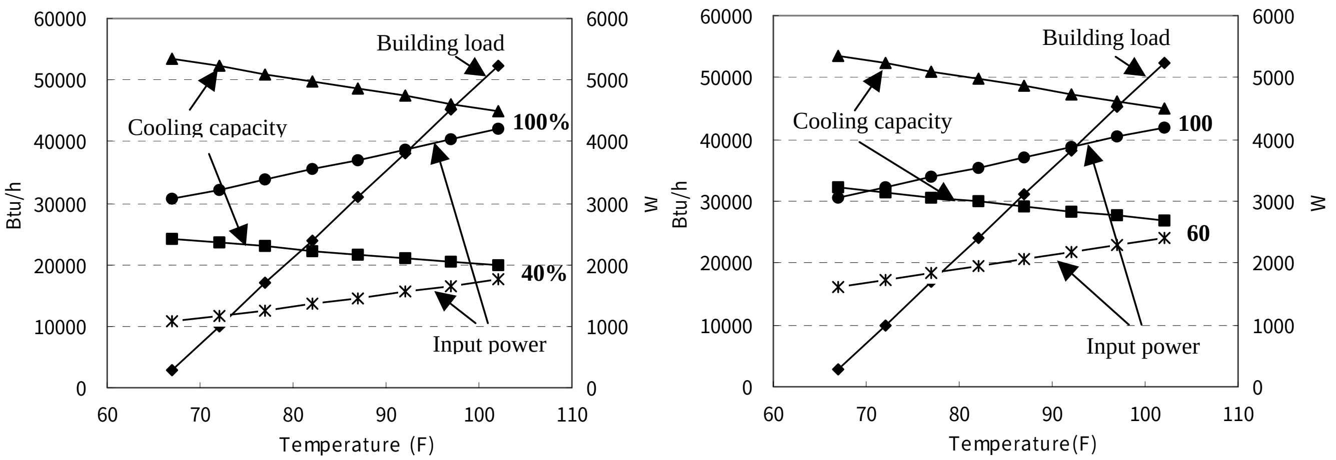
Table 3: The comparison of System capacity and comp. input compared with rated capacity and input

Operating mode	**sys. capa./comp capa.**	**comp input/rated input**
60%	111%	71%
40%	134%	75%

compressors produces full capacity, 100%, and one of the compressors produces 40% or 60% capacity. In general, 2-stage scroll compressor like Copeland Ultratech has 100% and 67% operating mode. This is similar to 100-60% in this study. But as compared with above scroll compressor or similar compressor with variable capacity, this system has other operation mode, 100-40%, and SEER is investigated in these operation modes. Cd (degradation coefficient), which means degradation of efficiency due to cyclic operation, should be considered when evaluating SEER, and the value is adopted as 0.25 and 0.1. Cd=0.25 is generally used instead of conducting C and D test (cyclic test). Cd=0.1 is also adopted because it is expected to be obtained if C and D test are conducted.

The results are presented in Table 2. When Cd=0.25 is applied, SEER in 100-60% mode and 100-40% mode is 14.1 and 15.1, which is seen that SEER is higher in 100-40% mode. The compressor with 40% capacity has an advantage of higher SEER when compared with the compressor with 60% capacity because the condenser is relatively larger for 40% compressor than 60% compressor. From a viewpoint of system capacity, 40% operation is more profitable as seen in Table 3. Large size of condenser contributes to power consumption. Minimum operation with one compressor (40% or 60% comp.) leads to lower electric input due to lower condensing temperature. This result is displayed in Table 3. Compared with rated capacity, real comp input is small, and the ratio is almost same in both operating mode. This means that the condenser size is enough large to condense the refrigerant in condenser, which has more advantage in 60% operation mode to decrease compressor input power.

The building load, cooling capacity and input power at each operating mode are shown in fig. 2. The x-axis means temperature, y-axis cooling capacity (Btu/h) and input power (W). As is seen in the figure, 100% cooling capacity in both operating mode (100-60%, 100-40%) is same, therefore the graph of building load and 100% capacity-input



(a) 100-40% (b) 100-60%

Figure 2. Building load, cooling capacity and input power as to the different capacity ratio

power are same. But the alternate operating range between maximum and minimum operating is different because the minimum operating capacity is different in each mode. In 100-40% mode, which uses 40% compressor as minimum operation, even one compressor (40%) meets the cooling load below about 81F. Taking into consideration of distribution of fractional hours in temperature bins for calculating SEER, it can be estimated to be high in 100-40% mode. The distribution of fractional hours in temperature is displayed in fig. 3.

In minimum operating range, E(T,j)/N(watt-h), that is input power, is unfavorable to 60% mode because power input is large and PLF is small as compared with 40% mode while load factor in 60% mode is smaller. E(T,j)/N(watt-h) is expressed as follows.

$$E(T, j)/N = X^{k=1} \times n_j / N \times E^{k=1}(T_j)/PLF \quad (2)$$

where $X^{k=1}$ is load factor, n_j/N fractional number of hours in temperature bin *j*, $E^{k=1}$ input power. PLF means part-load performance factor.

PLF means the energy consumption efficiency induced by on-off operation. Under the condition of same Cd, the larger load factor, $X^{k=1}$, the more PLF increases, and it leads to more efficient operation and helps to decrease power consumption.

$$PLF^{k=1} = 1 - C_D^{k=1}\left(1 - X^{k=1}\right) \quad (3)$$

Table 4: The EER in each operation range in 100-60% and 100-40% mode

Operating range	**EER(=Q/E)**	
	60%	**40%**
Low	14.8	17.1
Alternate	13.1	14.0
High	10.7	10.7

The EER in each operation range is displayed in Table 4. It is shown that EER of 40% mode in minimum operating range is much higher than that of 60% mode. This advantage gives rise to enhancement of entire system efficiency and consequently SEER becomes high in 100-40% mode.

When Cd changes 0.25 to 0.1, the rise of SEER is larger in 60% mode as seen in Table 2. As Cd decreases, PLF increases (eq. (3)). This is a great help to reduction of power consumption because load factor, $X^{k=1}$, in 60% mode is smaller than that in 40% mode.

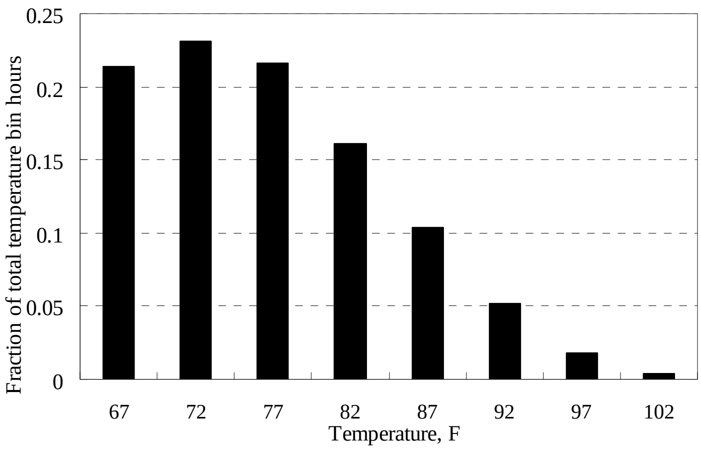


Figure 3. The distribution of fractional hours in temperature range

4. 3-STAGE OPERATION

4.1 3-Stage Operating with 2 Comp System

In general, residential unitary system adopts 2-stage thermostat for variable capacity operation. The schematic diagram of circuit with thermostat is displayed in fig. 4. Thermostat reads room temperature and gives Y1 or Y2 signal to indoor and outdoor unit. Y1 means low speed (minimum operation) compressor runs and Y2 means full operation, namely, 100% operation mode is on. The temperature set by user decides the signal, Y1, Y2. That is, if the temperature difference between room temperature and desired temperature is large, thermostat transfers Y2, otherwise, Y1. In this 2-comp system, it is able to realize 3-stage operation because of having 3 different capacities with 2 compressors. But there are only two signals from thermostat. Therefore, new operating method that is 3-stage operation with 2-stage thermostat comes out. In this study, Y1 signal transferred from 2-stage thermostat is treated for 3-stage operation. That is, Y1 signal is interpreted as 60% or 40% capacity depending on indoor cooling load. The experiment is conducted under the condition that is very similar to living condition. Outdoor condition is 33℃(about 91F) and user setting temperature is 27℃(about 80F). It is operated for 6 hours.

4.2 Analysis of 2-Stage and 3-Stage Operating

The results are shown in fig.5. There are three kinds of results as to operation mode, 100-40%, 100-60% and 100-60-40%. The figure shows room temperature, system input power and integrated power consumption. Operating pattern can be seen. Basic pattern in the thermostat is as follows. Much of the cooling load in the room is removed in first one or two cycle using 100% operation. And then the rest of cooling load is decreased by utilization of low stage cooling capacity. As seen in fig. 5 (a) and (b), the operating pattern is clearly depicted. Operating pattern is same in 100-40% and 100-60% mode. But the way of corresponding with initial cooling load is a little different. As compared with 100-40% mode, the period of 100% operation in 100-60% mode is shorter because first 60% operation causes to get rid of lots of cooling load as compared with 40% operation. This helps to comfortableness.
From the view point of cycle repetition, the number of compressor on/off in 100-40% mode is less than that in 100-60% mode. This indicates that the room temperature does not fluctuate widely and it leads to comfortableness. While the comfortableness in the latter half is favorable in 100-40% mode, the electricity consumption is not good. Compared with 100-60% mode, it is increased by about 0.4%. In the initial stage of removing cooling load, the cooling capacity of 40% compressor is smaller than that of 60% compressor and it resulted in longer 100% operation. Consequently, the input power in 100-40% mode is more increased until stable period as compared with 100-60% mode.
In 3-stage mode, it is found to be mixed pattern including 100-40% and 100-60% mode. In order to remove initial cooling load, 60% operation mode is applied and after clearing initial load, 40% on-off is applied by treating Y1 signal. When compared with 100-60% mode, the electricity consumption in 3-stage mode is reduced by about 3%. After initial cooling load being removed, 3-stage mode obtains the effective result of about 5% reduction in

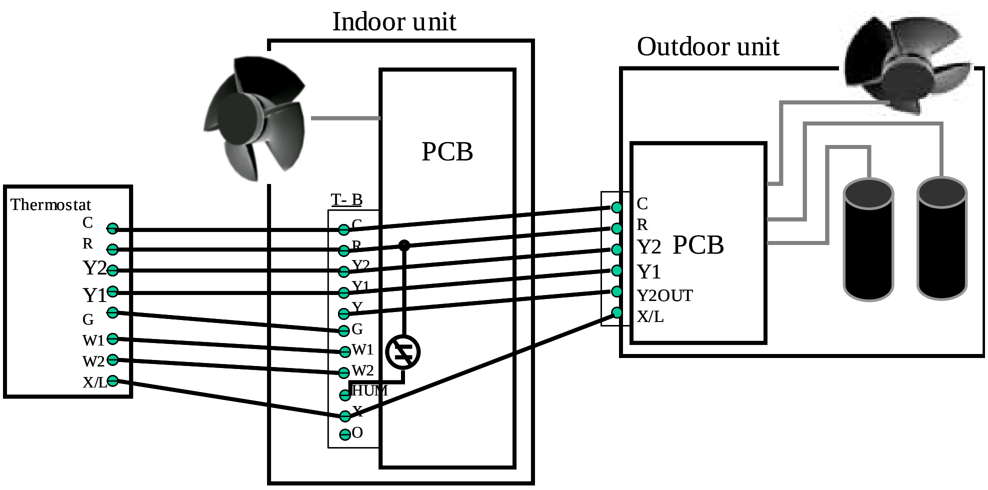
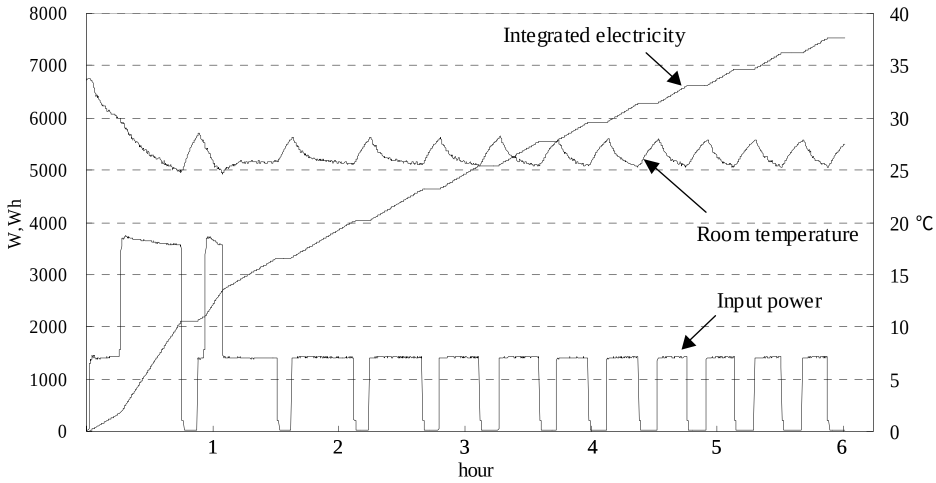
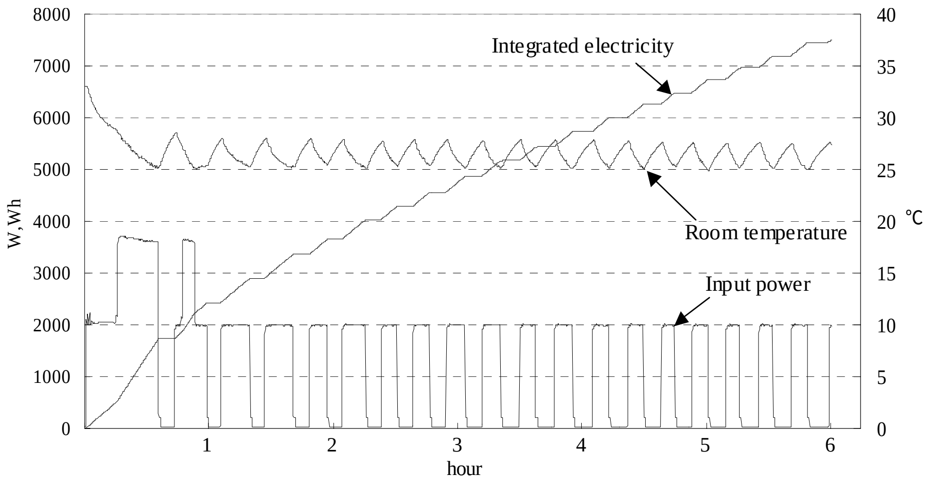


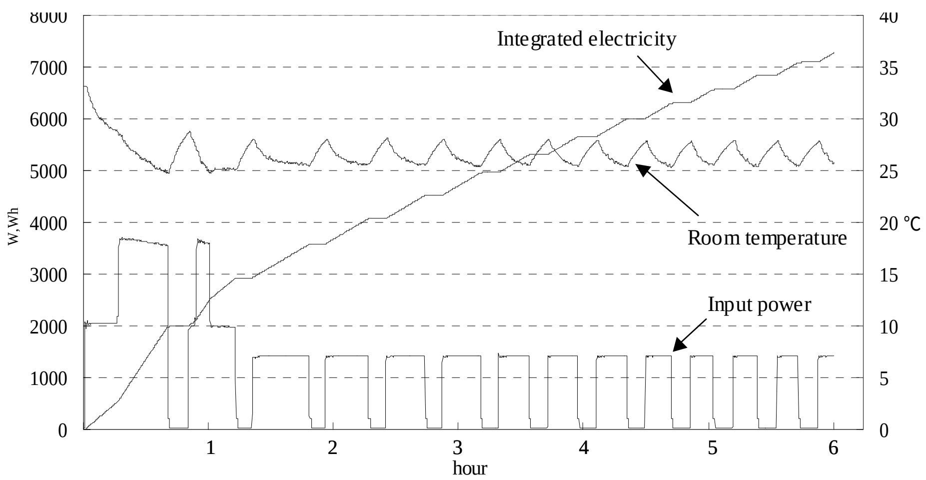
Figure 4. The schematic diagram of thermostat circuit configuration



(a) 100-40%



(b) 100-60%



(c) 100-60-40%

Figure 5. The transition of room temperature and power consumption along with time as to operation mode

electricity consumption. As seen in fig.5 (c), the operating pattern in the latter half of the graph is on-off control of the compressor with 40% capacity, which means that it is enough to maintain the desired room temperature by only 40% compressor. As mentioned in 100-40% mode, less on-off period compressor gives better comfortableness and is also favorable in electricity.

5. CONCLUSIONS

Among many methods of capacity modulation, 2-comp system is constructed and analyzed. The capacity ratio of compressors is 40:60 and can be controlled by three kinds of capacity operation mode, 100, 60, 40%. The experiment is conducted and evaluated.
The conclusions are as follows.

- 2-comp system is developed and SEER is evaluated as to the combination of the compressor capacity.
- The system operating in 100-40% mode obtained about 7% SEER enhancement (Cd=0.25) as compared with the 100-60% mode. When Cd changed to 0.1, SEER is reduced to 5%. It is because the condenser size of 40% capacity operation is relatively larger than that of 60% capacity operation. But the large increase of PLF induced by the reduction of Cd contributes to SEER of 60% operation more than 40% operation.
- 3-stage operation is introduced and compared with 2-stage operation. In view of electricity consumption, 3-stage operation is more favorable, and it can be better than 2-stage operation even in comfortableness.

NOMENCLATURE

Cd	degradation coefficient	
$E(T_j)/N$	ratio of Energy usage	(watt-hr)
j	temperature bin index	
N	number	(–)
PLF	part-load performance factor	
$Q(T_j)/N$	ratio of total cooling	(Btu)
X	load-factor	

Superscripts

k=1	low compressor speed (low capa. Operation)

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