Multi-connected Air-Conditioning System Standards Analysis and Annual Operating Performance Evaluation

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Abstract Problems and limitations of existing multi-connected air-conditioning unit standards are analyzed in this chapter. Based on irrationality of the existing evaluation criteria, the evaluation index and method for evaluating whole year energy consumption and efficiency of multi-connected air-conditioning system are studied. The evaluation index, calculation formula, weights, and testing condition parameters are proposed. The correctness of the evaluation method is verified. The results show that eight region average classification method based on dynamic load is feasible to evaluate seasonal energy efficiency ratio of multi-connected air-conditioning system. The evaluation method is applicable to evaluate DVM or variable frequency-controlled multi-connected air-conditioning system. The evaluation method can be applied to evaluate annual energy consumption and annual integrated energy use efficiency of multi-connected air-conditioning system in the building, as well as to compare energy efficiency among different air-conditioning systems.

Keywords Multi-connected air-conditioning system · Performance evaluation · Standards analysis

1 Introduction

Multi-connected air-conditioning (heat pump) unit has been widely used and rapidly developed due to its several advantages, such as easy maintenance, wide range capacity output, precise capacity control, and high seasonal energy efficiency ratio (SEER). It has become one of the most commonly used central air-conditioning

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systems in small commercial buildings and civil buildings. Compared with centralized or semi-centralized air-conditioning system, multi-connected air-conditioning system is simpler in structure and easier to install. Outdoor unit is smaller and occupies less space than that of centralized or semi-centralized air-conditioning system. Each indoor unit of multi-connected air-conditioning system is independently controlled. And its energy loss is lower than that of the other two systems due to its only once heat exchange in heat transfer process.

At present, there have been several studies relevant to multi-connected air-conditioning system. Goetzler et al. (2004) analyzed energy saving potential and market factors of refrigerant systems that vary flow and volume. Zhang et al. (2009, 2011) and Zhao (2009) addressed experimental study on performance of digital variable multiple air-conditioning system under part load conditions. Huang et al. (2008) conducted an experimental study on operating characteristics of ducted air-conditioning unit with digital scroll compressor and conventional scroll compressor under refrigerating and heating condition. Hu and Yang (2005) discussed the relationship between the opening degree of electronic expansion valves and the compressor output ratio. Zhou et al. (2008) developed a simulation module for variable refrigerant volume (VRV) air-conditioning system on the basis of EnergyPlus. Several papers addressed control strategy of VRV air-conditioning system by Shi (2000), Shi et al. (2003a, b, c). Kim et al. (1999) applied fuzzy logic to control refrigerant distribution for the multi-type air conditioner. Wu et al. (2005) and Xia (2005) studied control scheme and optimization control of VRV air-conditioning system. And evaluation standard for multi-connected air-conditioning (heat pump) unit (GB/T 1883; JRA4048-2006; Office of Energy Efficiency and Renewable Energy Department of Energy 2006; ANSI/AHRI 2010) has been formulated.

The studies above are mainly focused on operating characteristics, control strategies, and evaluation method of multi-connected air-conditioning system. However, up to now, seldom researches have been conducted on standards analysis and annual operating performance evaluation of multi-connected air-conditioning system. In this chapter, problems and limitations of existing multi-connected air-conditioning unit standards are analyzed and the existing evaluation criteria, the evaluation index, and the method for evaluating multi-connected air-conditioning system annual energy consumption and integrated efficiency are studied.

2 Multi-connected Air-Conditioning Unit Standards Analysis

2.1 Chinese Multi-connected Air-Conditioning Unit Standard

The first multi-connected air-conditioning unit standard GB/T18837-2002 was born in China in 2002. In this standard, IPLV(C/H) (Refrigerating or Heating Integrated Part Load Value) is used to evaluate refrigerating or heating performance of multi-connected air-conditioning unit.

Take refrigerating condition as example, IPLV(C) is calculated by Eq. (1).

$$\begin{aligned}\mathrm{IPLV(C)} = & \frac{(\mathrm{PLF}_1 - \mathrm{PLF}_2)(\mathrm{EER}_1 + \mathrm{EER}_2)}{2} \\ & + \frac{(\mathrm{PLF}_2 - \mathrm{PLF}_3)(\mathrm{EER}_2 + \mathrm{EER}_3)}{2} \\ & + \frac{(\mathrm{PLF}_3 - \mathrm{PLF}_4)(\mathrm{EER}_3 + \mathrm{EER}_4)}{2} \\ & + (\mathrm{PLF}_4)(\mathrm{EER}_4) \end{aligned} \quad (1)$$

The above algorithm considers part load performance and on-off loss of compressor under nominal condition. IPLV(C) represents average cycle energy efficiency ratio under nominal condition. It is more reasonable to evaluate performance of multi-connected air-conditioning unit than EER. However, there exist the following two problems: (1) ±10 % part load ratio change range of test condition may affect the performance evaluation result when performance of different multi-connected air-conditioning units is compared. (2) The testing condition parameters should reflect actual operating performance and operating time of multi-connected air-conditioning system when evaluating its actual operating performance. Therefore, the evaluation index in GB/T18837-2002 cannot be used to evaluate actual operating performance of multi-connected air-conditioning system.

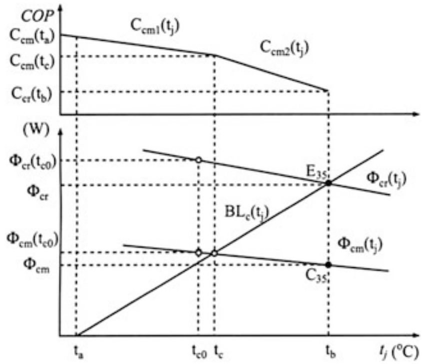
2.2 Japanese Multi-connected Air-Conditioning Unit Standard

In JRA4048 standard, cooling seasonal performance factor (CSPF), heating seasonal performance factor (HSPF), and annual performance factor (APF) are used as evaluation index. The testing condition parameters are the same as that of variable frequency-controlled air conditioner unit. When nominal refrigerating capacity of multi-connected air-conditioning unit is less than 28 kW, two indoor units with the same capacity are experimented, and nominal refrigerating capacity and energy consumption of one indoor unit and two indoor units are measured.

Take refrigerating condition as example, as shown in Fig. 1, calibration points are solid dots with 35 °C outdoor dry bulb temperature, 27 °C indoor dry bulb temperature, and 19 °C indoor wet bulb temperature.

Using variational condition characteristic modified coefficient gained from statistical average of Japanese products, refrigerating capacity and energy consumption under 29 °C outdoor dry bulb temperature may be calculated, as shown in hollow dots in Fig. 1. Considering on-off loss of compressor under low part load ratio, the model of refrigerating capacity and energy consumption was developed and combined with air-conditioning load curve of typical building and operating

Fig. 1 Typical building load line and multi-connected air-conditioning unit performance model for CSPF evaluation



time distribution with outdoor temperature, the cooling seasonal performance factor CSPF or SEER is calculated as shown in Eq. (2).

$$\text{CSPF} = \frac{\text{CSTL}}{\text{CSTE}} \tag{2}$$

where CSTL is total refrigerating capacity, and CSTE is total energy consumption during cooling season.

In JRA4048 standard, variable working condition characteristics were considered, while variable air-conditioning load performance was not included. In addition, using indirect calculation method to gain performance parameter under 29 °C outdoor dry bulb temperature condition cannot reveal differences among different products. And two points cannot reflect operating performance of product under large range operating condition. What is more, the relationship between air-conditioning load of the building and outdoor temperature is simplified as a linear in JRA4048, which also does not reflect actual air-conditioning load characteristics of the building. Therefore, CSPF or SEER in JRA4048 standard cannot reflect actual performance of multi-connected air-conditioning system.

2.3 American Multi-connected Air-Condition Unit Standard

ANSI/AHRI1230-2010 was proposed in the USA in 2010. In this standard, CSPF or HSPF is used as evaluation index when refrigerating capacity is less than 19 kW, which exists the same problem as that of JRA4048 standard. While refrigerating capacity is more than 19 kW, IEER is used as evaluation index, which is shown in Eq. (3).

$$\text{IEER} = a \times A + b \times B + c \times C + d \times D \tag{3}$$

where A, B, C, and D are the energy efficiency ratio under 100, 75, 50, and 25 % part load condition, respectively; and a, b, c, and d are the weight coefficients of the percentage of operating time corresponding to each part load ratio, respectively.

ANSI/AHRI1230-2010 considers building type, meteorological parameters, and operating time, comprehensively. However, CSPF/HSPF or IEER is not available to evaluate annual energy consumption of multi-connected air-conditioning system. On the one hand, testing condition parameters cannot reveal typical condition of annual operating, which are determined by dynamic air-conditioning load characteristic and operating time distribution. On the other hand, weighted coefficient cannot reveal energy consumption characteristic of actual operating condition of multi-connected air-conditioning system. Using operating time percentage as weighting coefficient in ANSI/AHRI1230-2010 may only reflect the operating time proportion of each region, but not reflect air-conditioning load of the building. So, weighting coefficient in ANSI/AHRI1230-2010 cannot reflect seasonal energy consumption characteristic of multi-connected air-conditioning system.

3 Annual Operating Performance Evaluation Method of Multi-connected Air-Conditioning System

Algorithm of seasonal energy efficiency of multi-connected air-conditioning system is similar to IPLV index of chiller, which includes three factors, air-conditioning load characteristic of the building, operating time distribution, and part load performance. Typical operating parameters are obtained by the statistic of seasonal operating parameters of multi-connected air-conditioning system. And seasonal energy consumption performance indexes of multi-connected air-conditioning system will be expressed by weighted average value of energy efficiency ratios corresponding to several typical operating points.

Part load performance is effected by outdoor air temperature and air-conditioning load of each region. Therefore, outdoor air temperature and part load ratio are used as testing condition parameters. The specific calculation steps are as follows:

1. Calculate air-conditioning load characteristic of air-conditioning area and determine typical testing condition parameters and weighting coefficients.
2. Measure operating performance parameters of multi-connected air-conditioning system under typical testing condition and calculate corresponding EER.
3. Calculate seasonal energy efficiency and seasonal energy consumption of multi-connected air-conditioning system.
4. Accumulate seasonal cooling capacity, seasonal heating capacity, and seasonal energy consumption of each multi-connected air-conditioning system, and annual energy efficiency and energy consumption of the building are calculated.

Divide air-conditioning region into several regions, calculate weight coefficient of each region, and seasonal energy efficiency is calculated by weighting EER or

COP on weight coefficient of typical test condition in each region, which is named IPLEER or IPLCOP as shown in Eqs. (4) and (5).

$$\mathrm{IPLEER} = a \times \mathrm{EER_I} + b \times \mathrm{EER_{II}} + c \times \mathrm{EER_{III}} + d \times \mathrm{EER_{IV}} + \cdots \quad (4)$$

$$\mathrm{IPLCOP} = a \times \mathrm{COP_I} + b \times \mathrm{COP_{II}} + c \times \mathrm{COP_{III}} + d \times \mathrm{COP_{IV}} + \cdots \quad (5)$$

where a, b, c, and d are the weighting coefficient of each region, respectively.

On the basis of CSTL, HSTL, IPLEER, and IPLCOP, seasonal energy consumption and integrated energy efficiency are calculated, which are named OPC (operating power consumption) and IPF (integrated performance factor), respectively, as shown in Eqs. (6) and (7).

$$\mathrm{OPC} = \mathrm{CSTL}/\mathrm{IPLEER} + \mathrm{HSTL}/\mathrm{IPLCOP} \quad (6)$$

$$\mathrm{IPF} = \frac{\mathrm{CSTL} + \mathrm{HSTL}}{\mathrm{OPC}} \quad (7)$$

In this chapter, average region division method is used, and the typical testing condition parameters are determined by weighting outdoor air temperature and part load ratio on operating time. If the proportion of each region's operating time to total operating is taken as weighting coefficient, only operating time proportion is revealed, but air-conditioning load characteristic of the building is not considered. While the proportion of part load ratio and its corresponding operating time product of each region to total product of part load ratio and its corresponding operating time is taken as weighting coefficient, it may not only reflect operating time but also the air-conditioning load characteristic of the building, which is more reasonable.

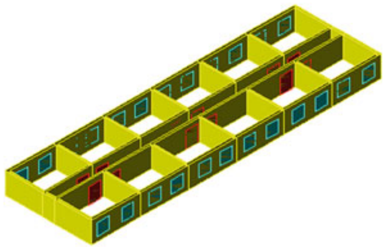
4 Verification for Annual Operating Performance Evaluation of Multi-connected Air-Conditioning System

In this chapter, annual energy consumption performance of multi-connected air-conditioning system composed of one outdoor unit (14 HP) and twelve indoor units is studied. The type and rated capacity of multi-connected air-conditioning unit are shown in Table 1. Building model is presented in Fig. 2. Boundary conditions of the model are selected in accordance with limit value of Public Building Energy Saving Design Standard GB 50189-2005.

Table 1 Indoor and outdoor unit type and rated capacity/kW

	Type	Rated refrigerating capacity	Rated heating capacity
Indoor unit	AVXCMH040EF	4	4.5
Outdoor unit	RVXVHT140GF	40	45

Fig. 2 Building model



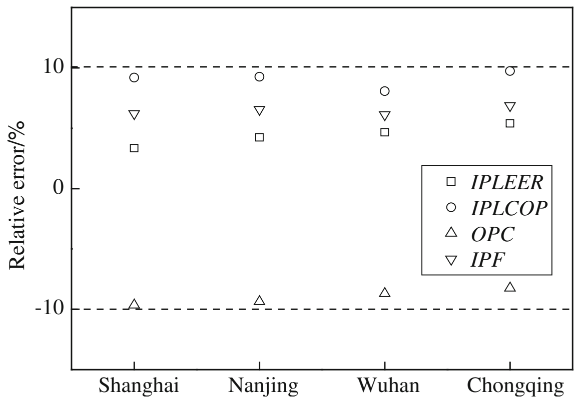
Four typical hot summer and cold winter cities, Shanghai, Nanjing, Wuhan, and Chongqing, are selected as study object. Dest software is used to calculate annual air-conditioning load of the building. And annual energy consumption characteristics are gained on the basis of annual air-conditioning load of the building and energy consumption calculation model of multi-connected air-conditioning system. The above data are the baseline of verification for annual operating performance evaluation of multi-connected air-conditioning system.

The calculation results of eight region average classification method are shown in Fig. 3. The relative error between calculation results and baseline is less ±10 %, which is in accordance with the engineering permissible precision range.

The calculation results of 12 region average classification method are shown in Fig. 4. The relative error between calculation results and baseline is less ±10 %, which is in accordance with engineering permissible precision range. The calculation accuracy of 12 region average classification method is better than that of 8 region average classification method.

Therefore, 8 region average classification method not only guarantee the precision but also is simple to implement. And due to the similarity of part load performance of multi-connected air-conditioning system, the evaluation method is applicable to evaluate DVM or variable frequency-controlled multi-connected air-conditioning system. The evaluation method can be applied to evaluate annual

Fig. 3 Relative error distribution



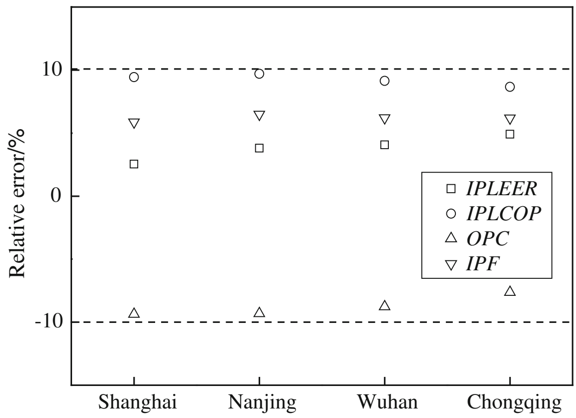


Fig. 4 Relative error distribution

energy consumption and annual integrated energy use efficiency of multi-connected air-conditioning system in the building, as well as to compare energy efficiency among different air-conditioning systems.

5 Conclusions

1. Multi-connected air-conditioning unit standards provide evaluation index and testing method for the evaluation of the performance of the product, but they are not available to evaluate the actual operating performance.
2. Eight region average classification method based on dynamic load is feasible to evaluate seasonal energy efficiency ratio of multi-connected air-conditioning system, which not only guarantee the precision but also is simple to implement.
3. The evaluation method proposed in this chapter can be applied to evaluate annual energy consumption and annual integrated energy use efficiency of multi-connected air-conditioning system in the building, as well as to compare energy efficiency among different air-conditioning systems.

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