HCR OF HEAT PUMP ROOM AIR CONDITIONER IN CHINA

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ABSTRACT

Definition of heating/cooling capacity ratio (*HCR*) of the heat pump air conditioner has been put forward in this study, and the relationship between supply *HCR* (HCR_S) and demand *HCR* (HCR_D) has been illustrated. Based on the simulated hourly loads of a typical residential building in Haerbin, Beijing, Shanghai and Shenzhen faced to different directions and with different air conditioner running schedules along with the performance of the heat pump air conditioner under varied conditions, the demand heating capacity, cooling capacity and HCR_D in different climate subareas have been ascertained. Secondly, a simulation model was built to study the effect of different physical parameters, include the parameters of the indoor heat exchanger, outdoor heat exchanger and compressor, on *HCRs* of the conventional fixed speed heat pump system to research the possibility to match the HCR_D and *HCRs* in China.

KEYWORDS

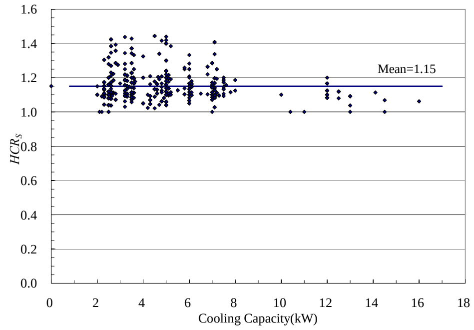
Heating/cooling capacity ratio, Simulation; Heat pump, Room air conditioner, Cooling/Heating load

INTRODUCTION

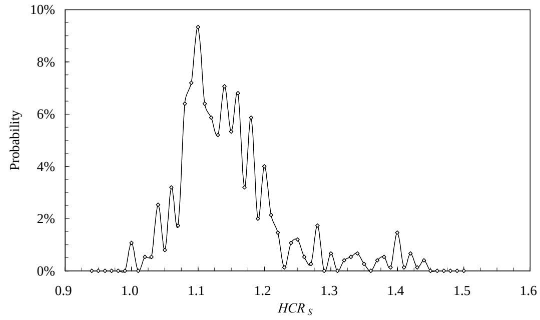
China has a wide territory and the different places have quite different climates, so China is divided into 5 different climate subareas in Chinese national standard (1993). Because of the diversity of climate, envelop of the building, the operation habits, and thermal comfort of the user, the cooling and heating load of the building in different areas is obviously different. Hereby, the heat pump air conditioner selected according to the cooling capacity maybe does not satisfy the heating need of the room. Vice versa. The heating/cooling capacity ratio (*HCR*) conception is brought forward under this situation.

Yu (1998) and Wang (2001) defined *HCR* as the ratio of the rated heating capacity to the rated cooling capacity of a room heat pump air conditioner. They pointed out that because the general heat pump room air conditioner is designed under its cooling working condition, the air conditioner can satisfy the cooling demand but sometimes can't satisfy the heating demand in actual operation.

The authors investigated 683 different constant speed heat pump air conditioners sold in Chinese market, and the conclusion is the *HCR* of the constant speed



(a) HCRs VS. Cooling Capacity



(b) HCRs distribution

Fig.1 HCRs of room air conditioner in Chinese market heat pump air conditioners varies in a small range, from 1.0 to 1.23 (Fig.1), and the average is about 1.15. Thereby, it is necessary to research whether the heat pump air conditioners sold in Chinese market can satisfy both the cooling demand and heating demand of different buildings in different climate sub areas and if there is opportunity to develop air conditioners with different *HCRs* to satisfy the different HCR_D of different room.

DEFINITION OF SUPPLY *HCR* AND DEMAND *HCR*

In actual, there are two different conceptions of *HCR*: the first one is the *HCR* which can be provided by the air conditioner. It is the ability of the machine and defined as supply *HCR* (HCR_S). The second one represents the ratio of the required heating and cooling capacity of the room. It is the property of the room and defined as demand *HCR* (HCR_D). The definitions are as following.

(1) HCR_S (Supply Heating/Cooling capacity Ratio): the ratio of the rated heating capacity and the rated cooling capacity of the heat pump room air conditioner.

$$HCR_S = Q_{h,rated} / Q_{c,rated} \tag{1}$$

Where, the rated capacity is measured under the rated conditions of the national standard (2004). It can be found that the HCR_S is a performance parameter of the air conditioner and connected with the heat exchangers, compressor and other accessories.

(2) HCR_D (Demand Heating/Cooling capacity Ratio): the HCR_S of the air conditioner which satisfies the requirement of the heating and cooling of the specific room in a whole year. If the heat pump air conditioner has a HCR_S equaling to HCR_D of the room, it means that the cooling capacity of the air conditioner can fitly match the cooling need of the room and it also can fitly satisfy the heating need of the room.

According to the definition, it can be seen that the HCR_D is related with not only the load of the room but also the performance of the heat pump room air conditioner under non-rated conditions. It describes the requirement of the room. So the HCR_D can be expressed as the ratio of the demand rated heating capacity and the demand rated cooling capacity.

$$HCR_D = Q_{h,rated,D} / Q_{c,rated,D} \tag{2}$$

Where, $Q_{h,rated,D}$ is the demand rated heating capacity and $Q_{c,rated,D}$ is the demand rated cooling capacity. They are the maximums of the rated heating and cooling load in a whole year.

$$\begin{cases} Q_{h,rated,D} = \max[f_1(HL, T_{out}, T_{out,w}, T_{in}, T_{in,w})] \\ Q_{c,rated,D} = \max[f_2(CL, T_{out}, T_{out,w}, T_{in}, T_{in,w})] \end{cases} \tag{3}$$

Where, f_1 and f_2 is the transform functions. They can calculate and output the rated heating/cooling capacity of the air conditioner which can eliminate the heating load HL/cooling load CL when the outdoor temperatures are T_{out} and $T_{out,W}$ (wet bulb temperature) and the indoor temperature are T_{in} and $T_{in,W}$ (wet bulb temperature).

For the common heat pump room air conditioner suitable for T1 climate, when the outdoor temperature is under -7 ℃, its performance will decrease quickly (2005). So a assumption is raised in this research: the heating load under -7 ℃ is met by other heating methods and not considered by the heat pump room air conditioner.

CALCULATION OF HCR_D

HCR_S is a parameter based on the rated parameters of the air conditioner and can be easily obtained. However, HCR_D is related with the load of the room and performance of the air conditioner, and its calculation is more complex than HCR_S. Indeed, HCR_D can be gained according the following three steps:

(1) Calculate the hourly load of the room;

(2) Calculate the hourly rated capacity of the air conditioner satisfying the hourly load;

(3) Get the right maximum rated heating capacity and cooling capacity, get HCR_D.

The hourly load of the room can be obtained based on the simulation toolkit DeST (2005) and the calculation of HCR_D is a piece of cake after the achievement of the hourly capacity. The calculation of the rated capacity of the air conditioner based on the load under a certain environment is the most important and complex part of the calculation of the HCR_D.

As we know, for a certain heat pump room air conditioner with a rated heating capacity $Q_{h,rated}$ under the rated heating condition (temperature: indoor 20 ℃/outdoor 7 ℃; influence of humidity is neglected), the heating capacity Q_h will decrease or increase as the change of the indoor and outdoor temperature.

$$Q_h(T_{out}, T_{in}) = f_3(Q_{h,rated}, T_{out}, T_{in}) \tag{4}$$

So the function (4) can be rearranged as a function of Q_h to calculate the rated heating capacity of the air conditioner.

$$Q_{h,rated}(7,20) = f_3^{'}(Q_h, T_{out}, T_{in}) \tag{5}$$

In the same way, the rated cooling capacity can be gotten according to an hourly cooling load of the room.

$$Q_{c,rated}(35,27) = f_4^{'}(Q_c, T_{out}, T_{in}) \tag{6}$$

Based on this consideration, the hourly rated cooling or heating capacity can be calculated if the non-rated performance of the air conditioner is known. Actually, the non-rated performance of different air conditioner is quite different and hard to acquire. A simplified calculated method in the national standard (2004) is utilized in this paper to illuminate the principle.

For cooling, the transform function can be expressed as:

$$Q_{c,rated} = \frac{1+(27-T_{in})\times\alpha_c\%}{1+0.077\times\frac{35-T_{out}}{35-29}}\times CL(T_{out}, T_{in}) \tag{7}$$

Where, the numerator of the right side is the influence of the indoor temperature, which means the $Q_{c,rated}$ increases α_c % when the indoor temperature decreases 1 ℃. The denominator of the right side is the modification of the outdoor temperature.

For heating, the transform function can be expressed as:

$$Q_{h,rated} = \frac{1-(20-T_{in})\times\alpha_h\%}{1-0.399\times\frac{7-T_{out}}{7-(-8.5)}}\times HL(T_{out}, T_{in}) \tag{8}$$

Where, the numerator of the right side is the influence of the indoor temperature, which means the $Q_{h,rated}$ increases α_h % when the indoor temperature increases 1 ℃. The denominator of the right side is the modification of the outdoor temperature. When the heating load is measured at the outdoor temperature -8.5 ℃, the rated heating capacity should be 1.66 (=1/(1-0.399)) times of the heating load.

When the air conditioner is heating during outdoor temperature -8.5~5.5 ℃, the evaporator will frost. A correction is done based on function (8).

$$Q_{h,rated} = (1+0.12\times\frac{T_{out}-(-8.5)}{2-(-8.5)})\times\frac{1-(20-T_{in})\times\alpha_h\%}{1-0.399\times\frac{7-T_{out}}{7-(-8.5)}}\times HL(T_{out}, T_{in}) \tag{9}$$

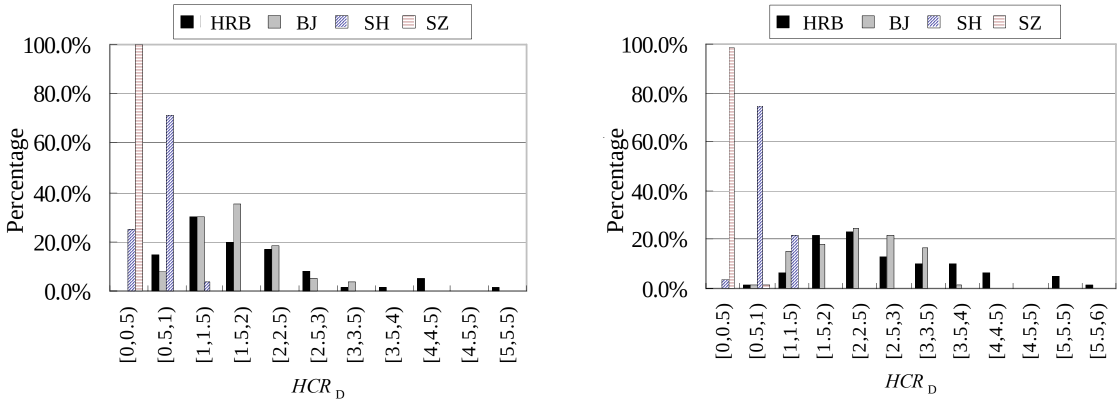
Using function (7)~(9), the hourly rated capacity of the air conditioner satisfying the hourly load can be calculated.

Based on the simulated hourly loads of a typical residential building in Haerbin, Beijing, Shanghai and Shenzhen faced to different directions and with different air conditioner running schedules along with the aforementioned calculation method, the HCR_D of 480 cases are obtained. Their ranges and distributions are showed in table 1 and Fig.2.

Table 1 HCR_D range of buildings in four major cities of China

	Haerbin	Beijing	Shanghai	Shenzhen
Energy saving Building	0.63~5.30	0.72~3.33	0.35~1.06	0~0.16
Common Building	0.96~5.76	0.97~3.58	0.48~1.24	0~0.57

As a conclusion, it can be found: (1) the HCR_D of the energy-saving building is smaller than the HCR_D of the common building, which means these energy-saving techniques have a more powerful influence on the heating than on the cooling; (2) from

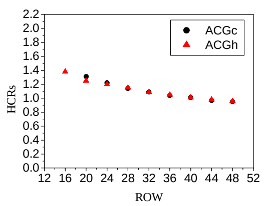
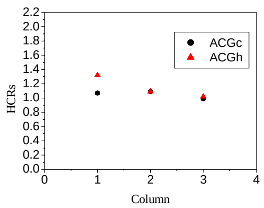
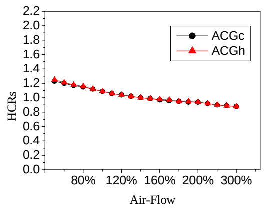


HRB: Haerbin; BJ: Beijing; SH: Shanghai; SZ: Shenzhen

(a) Energy-saving Building *(b) Common Building*

Fig.2 HCR_D distribution of buildings in four major cities of China

Table 2 Effects of parameters of indoor heat exchanger on HCR_S

		Increase Row	Increase Column	Increase Wind Speed
Heating Capacity		Increase, appreciably	Increase, appreciably	Increase, appreciably
Cooling Capacity		Increase, obviously	Increase	Increase
COP		Increase	Increase; No effect when column increases from 2 to 3	Increase
EER				
HCRs	Variation			
	Range	0.95～1.25	1.0～1.3	0.95～1.25

**ACG_C: charge the air conditioner according to cooling condition*

**ACG_h: charge the air conditioner according to heating condition*

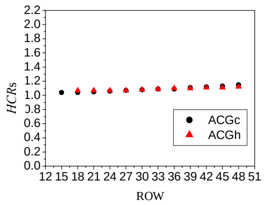
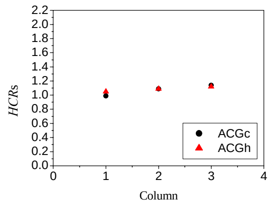
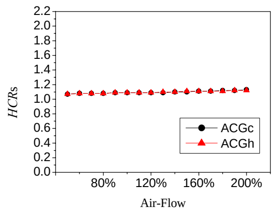
south China to north China, the HCR_D increases gradually due to the increase of heating need; (3) the HCR_D of Shenzhen is close to 0, so a single cooling air conditioner is enough; Haerbin should use other methods for heating because its HCR_D is far bigger than the HCR_S of the common heat pump air conditioner; a common or heating-enhanced heat pump room air conditioner can meet the heating and cooling need of building in Shanghai and Beijing. The research to enhance the heating capacity of room air conditioner is significant for these areas.

FACTOR ANALYSIS ON HCR_S

The ways to change the heating or cooling capacity include the inverter compressor, multi stage system, refrigerant injection, and so on. Here, we just talk about the possibility of adjusting the self parameters of the air conditioner to change the HCR_S. If it is possible, the heat pump air conditioner oriented to different areas can be easily designed to satisfy different needs of different places.

The variable parameters in the common constant speed heat pump air conditioner include the parameters of the evaporator, condenser, and compressor. The effects of these factors on the performance of the air conditioner are listed in Table 2, 3, and Fig.3.

Table 3 Effects of parameters of outdoor heat exchanger on HCR_S

		Increase Row	Increase Column	Increase Wind Speed
Heating Capacity		Increase, obviously	Increase	Increase
Cooling Capacity		Increase, appreciably	Increase, appreciably	Increase, appreciably
COP		Increase, appreciably	Increase, appreciably	No change
EER				Increase, logarithmically
HCRs	Variation			
	Range	1.05～1.15	1.0～1.15	1.07～1.12
*ACG_C: charge the air conditioner according to cooling condition				
*ACG_h: charge the air conditioner according to heating condition				

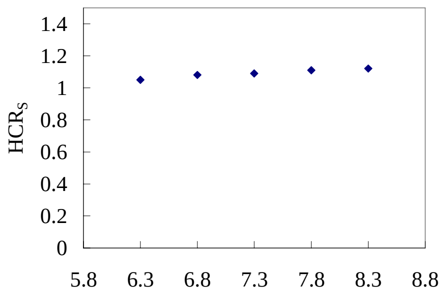


Fig.3 Effect of the compressor capacity on the HCR_S

Generally speaking, the variation of the parameters of the air conditioner has limited effect on the supply *HCR* (around 1.1, from 0.95 to 1.15). Some other technologies, such as gas refrigerant injection, must be used to make a heat pump room air conditioner with a variable HCR_S.

CONCLUSION

The definition of supply and demand heating/cooling capacity ratio (HCR_S and HCR_D) of the heat pump air conditioner has been put forward in this study, and their calculation methods are illustrated. Based on the simulated hourly loads of a typical residential building in Haerbin, Beijing, Shanghai and Shenzhen faced to different directions and with different air conditioner running schedules, the demand heating capacity, cooling capacity and HCR_D in different climate subareas have been ascertained. As a result, it is found that: the HCR_D of Shenzhen is close to 0 and a single cooling air-conditioner is enough; Haerbin should use other methods for heating because its HCR_D is far bigger than the HCR_S of the common heat pump air conditioner; a common or heating-enhanced heat pump room air conditioner can meet the heating and cooling need of building in Shanghai and Beijing. The research to enhance the heating capacity of room air conditioner is significant for these areas. Thereby, a simulation model was built to study the possibility of adjusting the self parameters of the air conditioner to change the HCR_S. However, the factor analysis shows: the variation of the parameters of the air conditioner has limited effect on the supply *HCR*. Some other technologies must be used to make a heat pump room air conditioner with a variable HCR_S.

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