Study on regional applicability of dehumidification air conditioning system with different stage regeneration modes

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Abstract. This article also put forward staged-regeneration wheel of the air conditioning system with condensing heat recovery technology, according to the climate zones in China, using the DesT software simulation in different areas of thermal and moisture load in a villa, and regeneration of the runner desiccant air conditioning system performance calculation, the results show that the compared with the two area runner desiccant air conditioning system, hierarchical regeneration runner desiccant air conditioning system performance are improved, the system of the refrigerant mass flow is reduced, the cooling load of the evaporator is reduced, the total load also significantly reduce energy consumption, air conditioning systems exergy efficiency improved; For regions with low temperature, low humidity or moderate humidity, the desiccant air conditioning system of three-areas graded regeneration wheel is more energy saving. In temperature and humidity relatively moderate areas, classification of renewable energy saving effect of the wheel were similar, but the four-areas wheel exergy efficiency obviously is higher than other wheel; For regions where both temperature and humidity are relatively high, the energy saving of the air conditioning system of the rotary wheel in the three-areas is not obvious, and the energy saving effect of the two-stage rotary wheel is the most significant.

1. Introduction
In recent years, the rotary dehumidification air conditioning system as a new air conditioning system in the operating mode, using the adsorption principle of the adsorbent, can separately handle the heat load and the wet load of the air conditioning system, not only fundamentally reducing the energy consumption of the air conditioning system, but also it solves the problem of mold contamination of fresh air in traditional air conditioning systems and has gradually received attention. However, higher temperatures are required during the regeneration of the adsorbent, which is also the most important energy consumption in the runner dehumidification purification process.

The graded regeneration method has been proven to reduce the regeneration temperature requirements of the runner and improve the thermal performance of the system [1]. At present, domestic and foreign scholars have studied the graded regenerative dehumidification air conditioning system. Compared with the two-zone rotary dehumidification air conditioning system, the graded regenerative dehumidification air conditioning system has obvious energy-saving effect. Collier and Cohen [2] proposed the concept of a graded regenerative wheel. The principle is to add a preheating zone in front of the regeneration zone.

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The system uses silica gel as a desiccant. After simulation and experimental research, the system can significantly improve the air conditioning system COP. Meckler [3] designed a system in which a two-stage runner is coupled to a conventional air conditioner. The system first uses the full heat exchange runner to cool the treated air, and bears part of the latent heat load, and then sends the treated air to the dehumidification runner for further dehumidification. The research results show that the dehumidification capacity of the full heat exchange runner can reach 30% to 50%, and no extra heat is needed during processing; Henning [4] also studied a similar two-stage rotor dehumidification system. In China, Ge Tianshu [5] proposed the concept of a two-rotor two-stage dehumidification air conditioning system. Compared with the ordinary runner, the two-stage runner has better adsorption performance, and under standard operating conditions, both the regeneration temperature and the helium efficiency of the two-stage system are improved; Wang Han [6] proposed a new hybrid air-conditioning system that combines a graded regenerative rotor and evaporative cooling technology.

Compared with the general composite air-conditioning system, the regenerative energy consumption of the graded regenerative composite system is reduced by about 42%, COP increased by about 78%. This paper intends to construct three dehumidification air conditioning systems that couple the grading regeneration runner with the condensing heat recovery technology. According to China's building climate zoning, seven typical cities are selected, and DesT software is used to calculate the heat and humidity load of a villa in different regions.

The performance parameters of three kinds of graded regenerative dehumidification air conditioning systems are calculated separately. Compared with the two-zone rotary dehumidification air conditioning system, the regional applicability of different graded regenerative dehumidification air conditioning systems is analyzed.

2. Workflow of graded regenerative dehumidification air conditioning system

![Figure 1. The dehumidifying air-conditioning systems of two-areas rotating wheel.](image1)

![Figure 2. The dehumidifying air-conditioning systems of three-areas rotating wheel.](image2)
The figure above shows the working principle of the staged regenerative dehumidification air conditioning system. Among them, DEH is a Wheel dehumidifier, EVAP is an evaporator, COND is a condenser, and HTR is a regenerative heater. The treatment air first enters the runner on the dehumidification side to perform dehumidification and temperature rise, and then is sent to the sensible heat exchanger to cool down, and after that the cooled air is sent to the Wheel dehumidifier again, and is processed to the Supply air condition by the evaporative cooler.

On the regeneration side, for the three-zone runner, the air passing through the condenser is divided into two strands, one is sent to the preheating zone of the runner, and one is sent to the regenerative heater to be heated to the regeneration temperature required by the system; for the four-zone and two-stage runners, the regeneration air is divided into two stands. One is heated by the condenser and sent to the regenerative heater for heating, and the other is heated by the sensible heat exchanger and sent to the regenerative heater for heating. In this paper, the dehumidification air conditioning system chooses R22 as the refrigeration cycle working medium. It has been shown that the outlet air temperature of the condenser of the system is not higher than 55’C, which cannot meet the requirements of adsorbent regeneration. Therefore, an auxiliary heat source is needed to heat the regeneration air [7].

3. Mathematical description of system performance parameters

Mixed state point of fresh air and return air:

\[ h_i = \frac{G_w h_w + G_N h_N}{G_w + G_N} \]  \hspace{1cm} (1)

\[ d_i = \frac{G_w d_w + G_N d_N}{G_w + G_N} \]  \hspace{1cm} (2)
In the formula:

- $G_W$ - mass flow of fresh air outside, kg/h;
- $G_N$ - mass flow of indoor return air, kg/h;
- $h_W$ - the enthalpy of fresh air outside, kJ/kg;
- $h_N$ - the enthalpy of indoor return air, kJ/kg;
- $d_W$ - moisture content of fresh air outside, g/kg;
- $d_N$ - moisture content of indoor return air, g/kg.

**Sensible heat exchanger:**

**Dehumidification area:**

$$ t_{A2} = t_{A1} - ε_{hx}(t_{A1} - t_B) $$

$$ d_{A2} = d_{A1} $$

**Regeneration Zone:**

$$ t_{B2} = t_B + ε_{hx}(t_{A1} - t_B) $$

$$ d_{B2} = d_B $$

In the formula, $ε_{hx}$ - heat-transfer coefficient, value 0.9; $t_{A2}$, $d_{A2}$ - air temperature and humidity at the outlet of the sensible heat exchanger on the dehumidification side; $t_{A1}$, $d_{A1}$ - air temperature and humidity at the inlet of the sensible heat exchanger on the dehumidification side; $t_{B2}$, $d_{B2}$ - air temperature and humidity at the outlet of the sensible heat exchanger on the regeneration side; $t_B$, $d_B$ - air temperature and humidity at the inlet of the direct evaporative cooler on the regeneration side.

**Evaporation temperature and condensation temperature:**

$$ Q_{evap} = M_k(h_{A2} - h_{A1}) $$

$$ t_{cond} = t_w + 15 $$

$$ t_{evap} = t_{A2} - \frac{t_{A2} - t_{os}}{0.94E_s} $$

In the formula, $M_k$ - mass flow through the evaporator air, kg/s; $h_{A1}$, $h_{A2}$ - the air enthalpy of the inlet and outlet of the evaporator, kJ/kg; $t_w$ - outdoor air temperature, °C; $t_{cond}$ - condensing temperature of the condenser, °C; $t_{evap}$ - evaporation temperature of the evaporator, °C; $t_{A2}$, $t_{os}$ - wet bulb temperature of air inlet and outlet of evaporator, °C; $E_s$ - the wet bulb temperature efficiency of the.

**Refrigeration system:**

![Figure 5. Theoretical cycle of a refrigeration system.](image-url)
The figure shows:

Cooling capacity per unit mass refrigerant $q_0$:

$$q_0 = h_1 - h_4$$  \hspace{1cm} (10)

Condenser heat per unit mass refrigerant $q_k$:

$$q_k = h_2 - h_3$$  \hspace{1cm} (11)

Unit power consumed when compressor compresses unit mass of refrigerant $w_c$:

$$w_c = h_2 - h_1$$  \hspace{1cm} (12)

Compressor theoretical power consumption $P_{th}$:

$$P_{th} = M_r (h_2 - h_1)$$  \hspace{1cm} (13)

Condensing heat $\phi_k$:

$$\phi_k = M_r (h_2 - h_3)$$  \hspace{1cm} (14)

In the formula, $M_r$ - mass flow of refrigerant, kg/s; $h_1$ - enthalpy of refrigerant at the compressor inlet, kJ/kg; $h_2$ - enthalpy of refrigerant at the compressor outlet, kJ/kg; $h_3$ - the enthalpy of refrigerant at the condenser outlet, kJ/kg; $h_4$ - enthalpy of refrigerant at evaporator inlet, kJ/kg.

Regeneration energy consumption of air conditioning systems:

$$Q_r = m_r c (t_2 - t_1)$$  \hspace{1cm} (15)

In the formula, $Q_r$ - regenerative energy consumption of the system, kW; $m_r$ - mass flow of regenerative air, kg/s; $c$ - specific heat of regeneration air, kJ/(kg·℃); $t_2$ - the temperature of the regeneration air at the runner outlet, ℃; $t_1$ - the temperature of the regenerated air at the runner inlet, ℃.

3.1. Exergic loss and exergic efficiency of grading rotary dehumidification air conditioning system

In this paper, the parameters in the atmospheric environment are selected as reference points for the calculation of exergic loss and the analysis of exergic efficiency. The atmospheric pressure is $P_0$, the thermodynamic temperature of air is $T_0$, and the saturated moisture content $W_0$ at air temperature is used as the reference parameter. Then the calculation formula of exergy under different wet air states (P, T, W) is as follows:

$$e = (c_{pa} + w_c p_w) T_0 \left( \frac{T}{T_0} - 1 - \ln \frac{T}{T_0} \right) + (1 + 1.608 w) R_a T_0 \ln \frac{p}{p_0}$$

$$+ R_a T_0 \left[ (1 + 1.608 w) \ln \frac{1 + 1.608 w_0}{1 + 1.608 w} + 1.608 w - \ln \frac{w}{w_0} \right]$$  \hspace{1cm} (16)

among them, $R_a$ - dry air gas constant, value in the text is 0.287 kJ/kg/K; $C_{pa}$ - constant pressure specific heat of dry air, value in the text is 1.003 kJ/kg/K; $C_{pw}$ - constant pressure specific heat of water vapor, value in the text is 1.872 kJ/kg/K.

As can be seen from the above equation, exergy of wet air can be divided into three parts, the first term is heat exergy of wet air, expressed with $e_{eb}$; the second item is mechanics exergy, expressed with $e_m$; When the system under study is open and constant pressure, this term is ignored; the third item is exergy of wet air, also known as diffusion exergy, expressed with $e_{eb}$. 
\[ e = e_{th} + e_{me} + e_{ch} \]  \tag{17}

According to the above we can know, the graded runner composite air conditioning system studied in this paper uses the state of the air in the atmosphere as a reference point to establish the exergic equilibrium equation.

Because the system inlet specific exergic is larger than the system outlet specific exergic, therefore can be expressed as:

\[ e_{in} - e_{out} \geq 0 \]  \tag{18}

The system’s specific exergic loss \( i \) is defined as:

\[ i = e_{in} - e_{out} \]  \tag{19}

The system exergic efficiency \( \eta \) is defined as:

\[ \eta = \frac{e_{out}}{e_{in}} = 1 - \frac{i}{e_{in}} \]  \tag{20}

4. Examples and analysis

4.1. Regional selection

China’s climate zoning is determined in accordance with the current national standard <Thermal design code for civil building> GB50176, taking the coldest month average temperature as the main indicator, it is mainly divided into five climatic zones: severe cold region, cold region, hot summer and cold winter region, hot summer and warm winter region, and mild region.

At present, in the severe cold and cold regions of China, according to the differences in the number of heating days (HDD18) and the number of air conditioning days (CDD26) in a year, the existing <Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones> [9] divides the two large building climate regions in detail, the severe cold regions are mainly divided into three parts, including severe cold zone A, zone B and zone C; divide the cold area into 2 parts, including cold areas A and B.

The specific division of each climate sub-area is shown in table 1. Among them, the hot summer and cold winter regions and the hot summer and warm winter regions respectively choose representative Chongqing and Guangzhou as the basis for calculation.

In summary, according to the relevant division basis, seven typical cities were selected for research, namely Mohe, Harbin, Shenyang, Dalian, Tianjin, Chongqing and Guangzhou. The outdoor design state parameters of different regions are shown in table 2.

| Climates region | Climate area       | Partition basis          | Typical city |
|-----------------|--------------------|--------------------------|--------------|
| severe cold     | Severe Cold Area A | 6000≤HDD18               | Mohe         |
| region          | Severe Cold Area B | 5000≤HDD18<6000          | Harbin       |
|                 | Severe Cold Area C | 3800≤HDD18<5000          | Shenyang     |
| cold            | Cold Area A        | 2000≤HDD18<3800          | Dalian       |
| region          | Cold Area B        | 2000≤HDD18<3800 90<CDD26 | Tianjin     |
Table 2. Outdoor design status parameters in different areas.

| Location   | Outdoor design air dry bulb temperature in summer (℃) | Outdoor design wet bulb temperature in summer (℃) | Relative humidity | Moisture content of outdoor design air in summer (g/kg) | Outdoor design air velocity in summer (m/s) |
|------------|------------------------------------------------------|--------------------------------------------------|-------------------|--------------------------------------------------------|------------------------------------------|
| Mohe       | 29.1                                                 | 20.8                                             | 57%               | 13.8                                                   | 1.9                                      |
| Harbin     | 30.7                                                 | 23.9                                             | 62%               | 16.5                                                   | 3.2                                      |
| Shenyang   | 31.5                                                 | 25.3                                             | 65%               | 18.2                                                   | 2.6                                      |
| Dalian     | 29.0                                                 | 24.9                                             | 71%               | 17.3                                                   | 4.1                                      |
| Tianjin    | 33.9                                                 | 26.8                                             | 63%               | 20.4                                                   | 2.2                                      |
| Chongqing  | 35.5                                                 | 26.5                                             | 59%               | 20.8                                                   | 1.5                                      |
| Guangzhou  | 34.2                                                 | 27.8                                             | 68%               | 22.4                                                   | 1.7                                      |

4.2. Simulation calculation
The villa has two floors above ground with a land area of 122 m², a total construction area of 198.5 m² and a building height of 6.25 m. The building simulation analysis of the project includes thermal parameters of the enclosure structure, room ventilation, room heat disturbance, etc., uses DesT software to fully simulate the hourly cooling load of buildings in different areas; the villa simulation overview is shown in Figure 6:

![Figure 6. The simulation diagram of building.](image)

Table 3 shows the heat and humidity load of air conditioners in different regions. The wet load mainly considers the moisture production of indoor personnel and equipment.

Table 3. The table of load calculation in different areas.

| Location   | Mohe  | Harbin | Shenyang | Dalian | Tianjin | Chongqing | Guangzhou |
|------------|-------|--------|----------|--------|---------|-----------|-----------|
| cooling load (kW) | 12.7  | 13.2   | 14.3     | 14.8   | 14.9    | 15.1      | 16.5      |
| humidity load (kg/h) | 11.9  | 11.9   | 11.9     | 11.9   | 11.9    | 11.9      | 11.9      |

The air treated by the runner in the air conditioning system is a mixture of outdoor fresh air and indoor return air. The ratio of return air volume to fresh air volume is 4:1, and the value of fresh air state parameters is shown in Table 2, it is assumed that the air volume to be processed is constant, the state parameter of the air supply is determined by the heat and humidity load in the building, and the return air state parameter is the indoor air design state parameter. In addition, the air distribution ratio of the heating zone and the preheating zone in the three-zone rotary dehumidification air conditioning system...
is 1:1. In order to meet the requirements of comfort air conditioning, according to the provisions of GBJ 50019-2003, the designed indoor air temperature is 26℃, and the designed indoor air humidity is 10.2 g/kg.

**Table 4. The performance comparison of air conditioning systems in different regions.**

| Zone 2 rotary air conditioning system | Mohe | Harbin | Shenyang | Dalian | Tianjin | Chongqing | Guangzhou |
|--------------------------------------|------|--------|----------|--------|---------|-----------|-----------|
| Refrigerant mass flow rate kg/s      | 0.141| 0.160  | 0.177    | 0.165  | 0.184   | 0.196     | 0.206     |
| Evaporator cooling load kW           | 21.3 | 23.5   | 26.2     | 24.8   | 29.2    | 29.5      | 31.1      |
| Compressor energy consumption        | 2.62 | 2.98   | 3.45     | 3.18   | 3.62    | 3.70      | 3.94      |
| Regenerative load                    | 11.23| 13.98  | 15.23    | 14.59  | 19.82   | 23.56     | 26.12     |
| Exergic loss                         | 1.02 | 1.33   | 1.54     | 1.47   | 1.66    | 1.84      | 1.87      |
| Exergic efficiency                   | 62%  | 61%    | 57%      | 60%    | 55%     | 53%       | 51%       |

| Zone 3 rotary air conditioning system | Mohe | Harbin | Shenyang | Dalian | Tianjin | Chongqing | Guangzhou |
|--------------------------------------|------|--------|----------|--------|---------|-----------|-----------|
| Refrigerant mass flow rate kg/s      | 0.134| 0.153  | 0.172    | 0.163  | 0.188   | 0.192     | 0.203     |
| Evaporator cooling load kW           | 20.3 | 23.3   | 26.1     | 24.9   | 28.6    | 29.2      | 30.9      |
| Compressor energy consumption        | 2.55 | 2.91   | 3.44     | 3.10   | 3.57    | 3.65      | 3.86      |
| Regenerative load                    | 5.74 | 7.58   | 8.54     | 7.88   | 11.02   | 13.26     | 15.18     |
| Exergic loss                         | 0.74 | 1.04   | 1.29     | 1.12   | 1.46    | 1.48      | 1.70      |
| Exergic efficiency                   | 71%  | 68%    | 62%      | 67%    | 59%     | 55%       | 52%       |

| Zone 4 rotary air conditioning system | Mohe | Harbin | Shenyang | Dalian | Tianjin | Chongqing | Guangzhou |
|--------------------------------------|------|--------|----------|--------|---------|-----------|-----------|
| Refrigerant mass flow rate kg/s      | 0.094| 0.107  | 0.118    | 0.116  | 0.133   | 0.142     | 0.153     |
| Evaporator cooling load kW           | 14.6 | 16.2   | 17.8     | 17.0   | 20.8    | 22.0      | 23.4      |
| Compressor energy consumption        | 1.78 | 2.09   | 2.34     | 2.20   | 2.56    | 2.75      | 2.98      |
| Regenerative load                    | 8.03 | 7.97   | 8.78     | 8.70   | 9.35    | 9.62      | 10.14     |
| Exergic loss                         | 0.34 | 0.35   | 0.43     | 0.37   | 0.61    | 0.78      | 0.82      |
| Exergic efficiency                   | 87%  | 86%    | 83%      | 86%    | 76%     | 73%       | 72%       |

| Two-stage rotary air conditioning system | Mohe | Harbin | Shenyang | Dalian | Tianjin | Chongqing | Guangzhou |
|-----------------------------------------|------|--------|----------|--------|---------|-----------|-----------|
| Refrigerant mass flow rate kg/s         | 0.094| 0.106  | 0.118    | 0.113  | 0.135   | 0.142     | 0.155     |
| Evaporator cooling load kW              | 14.3 | 16.1   | 17.9     | 17.1   | 20.5    | 21.9      | 23.5      |
| Compressor energy consumption           | 1.79 | 2.01   | 2.36     | 2.14   | 2.57    | 2.74      | 2.95      |
| Regenerative load                       | 7.47 | 7.88   | 8.22     | 8.20   | 8.90    | 9.57      | 9.93      |
| Exergic loss                            | 0.34 | 0.49   | 0.64     | 0.53   | 0.68    | 0.72      | 0.74      |
| Exergic efficiency                      | 83%  | 81%    | 79%      | 80%    | 79%     | 77%       | 76%       |
The above table shows the performance calculation results of the grading regenerative rotary composite air conditioning system under several typical climatic conditions in China.

Under the seven air conditioning conditions, compared with the two-zone rotary dehumidification air conditioning system, the mass flow, regenerative load and compressor energy consumption of the grading regenerative air conditioning system are significantly reduced, and the exergic efficiency is improved. In the graded dehumidification air conditioning system, all the wet loads in the air are borne by the runner, but a part of the heat is released while dehumidifying, and the heat load in the system is shared by the sensible heat exchanger and the evaporator. Therefore, the energy consumption of the compressor is significantly reduced; at the same time, due to the existence of the sensible heat exchanger, the temperature of the runner outlet is reduced, so the evaporator refrigeration load is significantly reduced.

When the indoor environmental parameters have the same value, the outlet temperature of the runner is related to the parameters of the outdoor environment. The higher the outdoor air temperature, the larger the cooling load and the higher the outlet temperature of the runner. Therefore, in order to meet the indoor air supply requirements, evaporative condensation system needs to consume more energy and can't achieve energy saving effect; when the humidity in the air is high, the capacity of the adsorbent to adsorb moisture in the runner is relatively high, and the greater the dehumidification amount of the runner, the greater the latent heat load, so the higher the required regeneration temperature, the greater the energy consumption for regeneration, at the same time, the air temperature at the exit of the runner has increased, the sensible heat load of the vapor compression system has increased, and the total load energy consumption has also increased.

In summary, the total load energy consumption of the composite air-conditioning system is related to the temperature and humidity of the outdoor environment. Although the graded regeneration runner has good energy-saving effects, the specific energy saving needs to be analyzed according to the outdoor environment and the dehumidification performance of the runner.

In Mohe, where the temperature and humidity are relatively low, the mass flow rate of the refrigerant in the two-zone rotary air conditioning system is 0.141 kg/s, the energy consumption of the compressor is 2.62 kW, the renewable energy consumption is 11.23 kW, exergy efficiency is 62%. Compared with the two-zone rotary dehumidification air-conditioning system, the mass flow rate of the three-zone rotary refrigerant is not much different from that of the compressor. The refrigerant mass flow rate of the four-zone and two-stage composite rotary dehumidification system is reduced by 33.3%. Compressor energy consumption decreased by 32.1% and 31.7% respectively. The exergic efficiency of the three-zone, four-zone and two-stage runners increased by 14.5%, 40.3% and 33.8% respectively, and the regeneration load decreased by 48.9%, 27.6% and 33.5% respectively.

Compared with the outdoor temperature and humidity in Mohe, Dalian, where the outdoor temperature is similar and the humidity is relatively high, the mass flow of refrigerant of the rotary air-conditioning system in zone 2 is 0.165 kg/s, the energy consumption of compressor is 3.18 kW, the regenerative energy consumption is 14.59 kW, and the exergic efficiency is 60%. Compared with the two-zone rotary dehumidification air-conditioning system, the refrigerant mass flow rate of the four-zone and two-stage composite rotor dehumidification system is reduced by about 26.7% and 31.5%, and the compressor energy consumption is reduced by 30.8% and 32.7% respectively. The exergic efficiency of the four-zone and two-stage runners increased by 11.7%, 43.3% and 33.3% respectively, and the renewable energy consumption decreased by 46.0%, 40.0% and 43.8% respectively.

From the perspective of energy consumption, the energy saving effect of the three-zone runner is more obvious when the temperature is lower, and the energy saving effect of the three-zone runner system is most significant in the region with low humidity, and with the increase of humidity, the energy saving effect of the four-zone and two-stage runners is becoming more and more obvious, according to the analysis, when the dehumidification amount is low, the grading runner can meet the dehumidification requirements at a lower regeneration temperature. For the three-zone runner, due to the presence of the preheating zone, the consumption of high-grade thermal energy is reduced, so the regeneration load is
also relatively low. Therefore, for areas with lower temperatures, lower humidity or milder temperatures, the three-zone grading regenerative air conditioning system is relatively more energy efficient.

In Harbin and Shenyang areas where temperature and humidity are relatively mild, the temperature and humidity of Harbin are lower than that of Shenyang, for the Harbin area, the mass flow rate of the refrigerant in the second-zone rotary air-conditioning system is 0.160 kg/s, the energy consumption of the compressor is 2.98 kW, the energy consumption for regeneration is 13.98 kW, and the efficiency of exergic is 61%, compared with the two-zone rotary dehumidification air-conditioning system, the mass flow rate of the three-zone rotary refrigerant is similar to that of the compressor, and the refrigerant mass flow of the four-zone and two-stage composite rotary dehumidification system is reduced by about 33.1%, compressor energy consumption decreased by 29.9% and 32.5% respectively, the exergic efficiency of the three-zone, four-zone and two-stage runners increased by 11.4%, 41.0% and 32.8% respectively, and the regeneration load decreased by 45.8%, 43.0% and 43.6% respectively.

For the Shenyang area, the mass flow rate of the refrigerant in the second-zone rotary air-conditioning system is 0.177 kg/s, the energy consumption of the compressor is 3.45 kW, the energy consumption for regeneration is 15.23 kW, and the efficiency of the exergic is 57%, compared with the two-zone rotary dehumidification air-conditioning system, the mass flow rate of the three-zone rotary refrigerant is not much different from that of the compressor, the refrigerant mass flow rate of the four-zone and two-stage composite rotary dehumidification system is reduced by 33.3%, compressor energy consumption decreased by 32.2% and 31.6% respectively. The exergic efficiency of the three-zone, four-zone and two-stage runners increased by 8.7%, 45.6% and 38.5% respectively, and the regeneration load decreased by 43.9%, 42.3% and 46.0% respectively. From the perspective of energy consumption, in the areas where the temperature and humidity are relatively mild, the energy saving effects of the three-zone, four-zone and two-level systems are not much different. The analysis suggests that in areas where the temperature and humidity are not very high, the dehumidification and energy consumption of the grading regeneration runners are not much different, but the exergic efficiency of the four-zone runners is significantly higher than that of the other runners.

For the Tianjin, Chongqing and Guangzhou regions where the temperature and humidity are relatively high, the specific analysis is as follows: for the Tianjin area, the mass flow rate of the refrigerant in the second-zone rotary air-conditioning system is 0.184 kg/s, the energy consumption of the compressor is 3.62 kW, the energy consumption for regeneration is 19.82 kW, and the efficiency of exergic is 55%, compared with the two-zone rotary dehumidification air-conditioning system, the refrigerant mass flow rate of the four-zone and two-stage composite rotor dehumidification system is reduced by 27.7% and 26.6%, and the compressor energy consumption is reduced by about 29.3% and 29.0%. The exergic efficiency of the four-zone and two-stage runners increased by 7.3%, 38.2% and 43.6% respectively, and the regeneration load decreased by 44.4%, 52.8% and 55.0% respectively. For the Chongqing area, the refrigerant flow rate of the second-zone rotary air-conditioning system is 0.196 kg/s, the compressor energy consumption is 3.70 kW, the regenerative energy consumption is 23.56 kW, and the exergic efficiency is 53%, compared with the two-zone rotary dehumidification air-conditioning system, the refrigerant mass flow rate of the four-zone and two-stage composite rotor dehumidification system is reduced by about 26.5%, and the compressor energy consumption is reduced by about 25.7% respectively, the exergic efficiency of the three-zone, four-zone and two-stage runners increased by 5.7%, 37.7% and 45.3% respectively, and the regeneration load decreased by 43.7%, 59.2% and 59.3% respectively.

For the Guangzhou area, the mass flow rate of the refrigerant in the second-zone rotary air-conditioning system is 0.206 kg/s, the energy consumption of the compressor is 3.94 kW, the energy consumption for regeneration is 26.12 kW, and the efficiency of exergic is 51%, compared with the two-zone rotary dehumidification air-conditioning system, the refrigerant mass flow rate of the four-zone and two-stage composite rotor dehumidification system is reduced by about 25.0%, and the compressor energy consumption is reduced by 24.3% and 25.1% respectively, the exergic efficiency of the two-stage runners increased by 5.9%, 37.2% and 49.0% respectively, and the regeneration load decreased by 41.9%, 61.2% and 61.9% respectively. For areas with relatively high temperature and humidity, the
dehumidification performance of the three-zone runner decreases. With the increase of dehumidification, the energy saving of the three-zone runner system is less obvious. The energy-saving effect of the two-stage runner dehumidification air-conditioning system is the most significant.

5. Conclusion
This paper proposes the concept of combining the regenerative runner and the condensing heat recovery technology into the composite rotor dehumidification air conditioning system. The main conclusions are as follows:

- compared with the two-zone rotary dehumidification air conditioning system, the performance of the staged regenerative dehumidification air conditioning system is improved; the refrigerant mass flow rate in the system is reduced, the refrigeration load of the evaporator is reduced, the total load energy consumption is also significantly reduced, and the exergic efficiency of the air conditioning system is also improved;
- the energy consumption of the staged regenerative dehumidification air conditioning system is greatly affected by the outdoor environment. For areas with low temperature, relatively low humidity or milder temperature, the three-zone grading regenerative air conditioning system is relatively more energy efficient than the two-zone rotary dehumidification air conditioning system.
- In areas where temperature and humidity are relatively mild, the energy-saving effect of the grading regeneration runner is not much different, but the exergic efficiency of the four-zone runner is significantly higher than that of the other runners;
- For areas with relatively high temperature and humidity, the energy saving of the three-zone rotary air conditioning system is not obvious, and the energy saving effect of the two-stage runner is the most significant.

Acknowledgments
This work is supported by the Ministry of Housing and Urban-Rural Development project (2017-R1-006). In addition, I really appreciate my tutor and my friends who really gave me so much help. I should work hard on my subject and achieve great success.

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