Load Distribution of Semi-Central Evaporative Cooling Air-Conditioning System Based on the TRNSYS Platform

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Abstract: Evaporative cooling is a green, energy-efficient cooling technology adopted in hot and dry regions, which has wider application in the field of air-conditioning systems. Outdoor meteorological parameters have a great influence on the operation mode and control strategy of evaporative cooling air-conditioning systems, and the system load distribution and system configuration will be affected. This paper aims at investigating the load distribution of semi-central evaporative cooling air-conditioning systems under the condition of hourly outdoor meteorological parameters. Firstly, this paper introduced the design partition, operation mode, controlling strategy and load distribution method on semi-central evaporative cooling air-conditioning system. Then, taking an office building in Lanzhou (China) as an example, the evaporative cooling air-conditioning system was divided into five regions and the load distribution was simulated by TRNSYS (The Transient Energy System Simulation Tool) under the condition of hourly outdoor meteorological parameters. Finally, the results have shown that the evaporative cooling air-conditioning system can provide 25.46% of the building loads, which was of great significance to reduce the energy consumption of air-conditioning system.

Keywords: semi-central evaporative cooling air-conditioning system; design partition; operation mode; controlling strategy; load distribution

1. Introduction

HVAC (Heating, ventilation and air conditioning) systems play an increasingly important role in fulfilling human comfort requirements and indoor air quality [1,2]. However, up to 2010, it was estimated that greenhouse gas emissions resulting from HVAC system energy consumption accounted for approximately 33% of all global greenhouse gas emissions [3,4]. Energy consumption in buildings accounted for about 20–40% of the total energy consumption, while HVAC systems accounted for about 60–70% of the energy consumption in buildings in developed countries [5,6]. With the increase of energy needs, costs and related environmental issues, energy saving air-conditioning would be a promising development [7]. In summer, the relative humidity of outdoor air was high in many regions of China and latent heat loads account for about 30–50% of the total heat loads. Therefore, the energy consumption generated by dehumidification would also account for about 30–50% of the total energy consumption for air-conditioning system, and humidity control is a challenging task [8–11].

In recent years, many studies have focused on temperature and humidity independent control air-conditioning systems, while there have been few studies on the problem of dynamic load distribution. Researchers in Tsinghua University first proposed a temperature and humidity
independent control air-conditioning system based on the control of the indoor environment [12],
which consisted of temperature control and humidity control subsystems [13]. Temperature
and humidity independent control air-conditioning systems have the advantage of reducing
air-conditioning energy consumption and improving the indoor environment, and are an effective
way to match the energy structure [14]. Huang et al. drew on the concept of the traditional
semi-central air-conditioning system and proposed a semi-central evaporative cooling air-conditioning
system for hot and dry areas, as an energy-efficient temperature and humidity independent control
air-conditioning system, which had been widely used in northwest China [15]. Liu et al. compared
the performance analysis between the evaporative cooling composite air-conditioning system and the
traditional semi-central air-conditioning system in a middle-humidity area, and indicated that the
combination of evaporative cooling and the traditional air-conditioning mode could reduce the cooling
capacity of the chiller and the running time, thereby saving operation costs and improving the energy
efficiency, which provided a basis for the development of evaporative cooling air-conditioning systems
in the middle-humidity areas [16]. Chen et al. investigated fresh air processed by solar assisted liquid
dehumidifiers and evaporative cooling systems, and indicated that the energy savings rate of the
system was between 22.4% and 53.2% when the optimal ventilation ratio was determined with different
fresh air conditions under the influence of solar heat collecting area, dehumidifier and evaporative
cooling system [17]. Jiang et al. introduced a new type of evaporative cooling air-conditioning system,
which consisted of a solid dehumidification heat pump and variable refrigerant flow air-conditioning
system, and indoor sensible heat loads and latent heat loads were respectively processed. Furthermore,
the study compared the energy efficiency of the new type of evaporative cooling air-conditioning
system with the experimental device of joint heat recovery ventilation equipment and variable
refrigerant flow air-conditioning system (JHVS), and concluded that the new type of evaporative
cooling air-conditioning system could achieve energy savings of 17.2% and the indoor relative humidity
was maintained at about 50% [18]. Zhao et al. analyzed the operation performance of a temperature
and humidity independent control air-conditioning system in an office building located in Shenzhen
(China). The results showed that temperature and humidity independent control air-conditioning
system could achieve good indoor environment, which made the indoor temperature, humidity and
\( \text{CO}_2 \) concentration meet the requirements of human comfort. Therefore, the air system would be
more energy-saving and efficient compared with traditional air-conditioning system [19]. Xuan et al.
analyzed the performance of evaporative cooling air-conditioning systems. The results showed that
an evaporative cooling air-conditioning system had a higher potential of practical application and
energy saving in northwest China. In addition, it could be applied as a secondary cooling system in
south China. They also performed an analysis of heat and mass transfer in evaporative cooling air
conditioning systems, and these studies indicated that most theoretical models had been validated
by experimental results, which could provide some references for the design on air-conditioning
around the world [20]. Han et al. carried out performance tests on the new type of evaporative
cooling air-conditioning system in different climate zones. The results indicated that the energy saving
effect of the new type in evaporative cooling air-conditioning system was greatly affected by the
outdoor meteorological parameters in different climate zones. The new system would save 31.31%
of energy consumption in cold and dry areas while energy saving would reach 13.66% in warm and
humid areas [21]. Evaporative cooling air-conditioning systems were very promising compared with
conventional compressed air-conditioning systems [22], which could remove latent heat loads and
pollutants from the air, and reducing electricity and energy consumption [23–25].

In summary, previous researchers have conducted a detailed study on temperature and humidity
independent control air-conditioning systems. For different climate zones, to some extent, the
performance of evaporative cooling air-conditioning systems depended on the outdoor meteorological
parameters. The operation mode and control strategies of the system were directly affected when
these outdoor meteorological parameters changed, which resulted in different energy-saving effects
and air-conditioning system operating efficiency. After the research and analysis, the energy-saving
efficiency of the evaporative cooling air-conditioning system in hot and dry areas was higher than that in the middle-humidity areas, which has bright prospects. Therefore, this paper aimed at studying the problem of dynamic load distribution in semi-central evaporative cooling system. Taking a dry-type fan-coil unit with fresh air system in an office building located in Lanzhou (China) as an example, the present work focused mainly on determining partition of the outdoor hourly meteorological parameters area in summer and investigating the load distribution of evaporative cooling system in different climatic zones based on TRNSYS (The Transient Energy System Simulation Tool). These results could be employed as a reference on the problem of dynamic load distribution in semi-central evaporative cooling system in the northwest region of China.

2. Methods

2.1. The Layout of Evaporative Cooling Air-Conditioning System

In summer, the design parameters of evaporative cooling air-conditioning system have a great difference in different climate regions. The function sections of the evaporative cooling unit adopted were different under the conditions of different outdoor air dry and wet bulb temperature. References [26–28] divided the different summer outdoor air state points into five regions on the i-d chart as shown in Figure 1 and analyzed how to select the form of function section of evaporative cooling air-conditioning system by summer outdoor design state points in different climatic zones. Different outdoor air design dry and wet bulb temperatures in summer, air-conditioning units should adopt different forms of evaporative coolers, which calculate the loads of different sections of evaporative cooling combination by TRNSYS’s psychrometric chart module. The points N and O respectively represented the indoor design air state point, the ideal air supply state point (apparatus dew point).

![Figure 1](image)

Figure 1. Design partition of evaporative cooling air-conditioning system.

2.2. The Mode of Evaporative Cooling Air-Conditioning System

The evaporative cooling air-conditioning system was affected by the climate, so the form of evaporative cooling air-conditioning systems was different in different climate regions. The operation mode of dry areas is shown in Figure 2, while the operation mode of middle-humidity areas is shown in Figure 3. The system was composed of evaporative cooling air-conditioning unit, evaporative chiller unit, mechanical refrigeration unit and fan-coil unit. An evaporative chiller alone or or combined with a mechanical refrigeration unit provided high temperature cooling water as the cold source for a dry-type fan-coil unit when the system was running. In the evaporative cooling air-conditioning unit, the outdoor air was processed by the indirect evaporative cooling section, the surface cooling section and the direct evaporative cooling section. The cooling water was handled by the evaporative cooling high temperature chiller, the temperature of which was between the wet bulb temperature and dew point temperature, was used as the high temperature cold source of the system.
2.3. The control Strategy of Evaporative Cooling Air-Conditioning System

Evaporative cooling air-conditioning systems achieve the system operation requirements by opening different function sections of the evaporative cooling air-conditioning unit and adjusting the water temperature.

1) When the summer outdoor air state point \( W \) was in area I, that is \( h_{w} < h_{o}, d_{w} < d_{o} \), the evaporative cooling air-conditioning unit opened the direct evaporative cooling section to process the outdoor air. The enthalpy-humidity chart with air process and the process diagram are shown in Figure 4a.

2) When the summer outdoor air state point \( W \) was in area II, that is \( h_{w} > h_{o}, d_{w} \leq d_{o} \), the evaporative cooling air-conditioning unit opened the indirect evaporative cooling section and the direct evaporative cooling section to process the outdoor air. The enthalpy-humidity chart with air process and the process diagram are shown in Figure 4b.

3) When the summer outdoor air state point \( W \) was in areas III~V, the direct evaporative cooling was unable to meet the indoor air requirements. At this time, the indirect evaporative cooling section was opened to precool the outdoor air, and opened the surface cooling section of evaporative cooling air-conditioning unit to cool and dehumidify outdoor air. The enthalpy-humidity chart with air process and the process diagram are shown in Figure 4c.
section was opened to precool the outdoor air, and opened the surface cooling section of the evaporative cooling air-conditioning unit to cool and dehumidify outdoor air. The enthalpy-humidity chart with air process and the process diagram are shown in Figure 4c.

The fresh air unit was responsible for indoor moisture loads and partial sensible heat loads by opening different function sections. The fan-coil unit assumed the sensible heat loads caused by the indoor equipment, personnel, lights and envelope structure. The system operation mode was shown in Table 1.

![Diagram](image)

**Figure 4.** Enthalpy-humidity chart with processing air and the process diagram.

The fresh air unit was responsible for indoor moisture loads and partial sensible heat loads by opening different function sections. The fan-coil unit assumed the sensible heat loads caused by the indoor equipment, personnel, lights and envelope structure. The system operation mode was shown in Table 1.

**Table 1.** The operation mode and control strategy of the semi-central evaporative cooling system.

| Number | Equipment | Function section | Coarse filtration section | Indirect evaporative cooling section | Surface cooling section | Direct evaporative cooling section | Heating section | Cooling tower (Evaporative chiller) | Mechanical refrigeration chiller | Sensible heat terminal |
|--------|-----------|------------------|---------------------------|-------------------------------------|------------------------|------------------------------------|----------------|-----------------------------------|-------------------------------|--------------------------|
| 1      | Fresh air unit (Evaporative cooling combined air-conditioning unit) | i                  | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 2      | Cold source | ii | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 3      | Terminal   | iii | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 4      |            | iv | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 5      |            | v  | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 6      |            | vi | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 7      |            | vii | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 8      |            | viii | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
| 9      |            | ix  | √                          | √                                   | √                      | √                                  | √              | √                                | ×                             | √                       |
2.4. The Case Study for Evaporative Cooling Air-Conditioning System

The design of conventional air-conditioning systems generally adopts the method of designing outdoor air calculation parameters, while evaporative cooling air-conditioning systems require opening different function sections to achieve the system operation strategy for different outdoor meteorological parameters. Therefore, it is significant to study the load distribution of evaporative cooling air-conditioning when the outdoor meteorological parameters change continuously during summer.

Taking an office building located in Lanzhou as an example, the building was orientated southwise. The length, width and height of the building are respectively 40 m, 20 m, 3 m. The building has five floors, the indoor air-conditioning area of single floor was 800 m², the building air-conditioning area was 4000 m² and the north and south window wall area ratio was 0.4. The heat transfer coefficient of windows is 1.4 W/(m²·K). In addition, the thermal parameters of the building envelope are shown in Table 2. Climate zones and the load distribution model based on TRNSYS of the office building in Lanzhou are shown in Figure 5. The parameters of the air supply state point were determined by the hourly loads of the building in summer, the indoor design point parameters and air supply volume. Then, with the change of the air supply state point parameters, the load distribution of different function sections of evaporative cooling air-conditioning system could be determined based on indoor design state point parameters and the air supply state point parameters according to the design method of evaporative cooling system shown in Section 2.1. The specific method of the load distribution was as follows:

Table 2. Building envelope thermal parameter table.

| Structural Layer       | Thickness (mm) | Thermal Conductivity (W/(m·K)) | Specific Heat Capacity (kJ/(kg·K)) | Density (kg/m³) | Heat Transfer Coefficient (W/(m²·K)) |
|------------------------|----------------|--------------------------------|------------------------------------|-----------------|--------------------------------------|
| Floor                  |                |                                |                                    |                 |                                      |
| Cement Mortar          | 20             | 0.93                           | 1.05                               | 1800            | 0.6                                  |
| Extruded Polystyrene Board | 50         | 0.036                          | 1.38                               | 30              |                                      |
| Reinforced Concrete    | 150            | 1.74                           | 0.92                               | 2500            |                                      |
| Exterior Wall          |                |                                |                                    |                 |                                      |
| Expanded Polystyrene Board | 50         | 0.05                           | 1.38                               | 30              | 0.6                                  |
| Light Aggregate Concrete | 190       | 0.29                           | 1.05                               | 500             |                                      |
| Lime Mortar            | 15             | 0.81                           | 1.05                               | 1600            |                                      |
| Roof                   |                |                                |                                    |                 |                                      |
| Extruded polystyrene Board | 50         | 0.036                          | 1.38                               | 30              | 0.55                                 |
| Light Aggregate Concrete | 30          | 0.29                           | 1.05                               | 500             |                                      |
| Cement Mortar          | 15             | 0.93                           | 1.05                               | 1800            |                                      |
| Reinforced Concrete    | 250            | 1.74                           | 0.92                               | 2500            |                                      |

Known conditions: indoor state point N: \( h_N, \) kJ/kg; \( d_N, \) g/kg; air supply volume: \( q_m, \) kg/s; fresh air volume: \( q_{mR}, \) kg/s; fan-coil unit air volume: \( q_{mW}, \) kg/s; hourly loads: \( Q_i, \) Kw; hourly moisture loads: \( W_i, \) kg/s.

(1) Determination of the air supply state point \( O_i \):

\[
h_{ai} = h_N \cdot \frac{Q_i}{q_m}
\]

\[
d_{ai} = d_N \cdot \frac{W_i}{q_m}
\]
(2) Determination of the fresh air process state point: \( L_i \):

\[
d_L = d_{oi} + \frac{q_{mR}}{q_{mW}} (d_{oi} - d_N)
\]  (3)

(a) When the outdoor state point was in area I, the enthalpy-humidity chart of the air process, which was direct evaporative cooling, is shown in Figure 4a, then \( h_{Li} = h_{Wi} \).

(b) When the outdoor state point was in area II, the enthalpy-humidity chart of the air process, which was indirect and direct evaporative cooling, is shown in Figure 4b. It was found that the indirect evaporative cooling efficiency was 75% by calculation and consultations with the equipment manufacturers, then \( d_{wIi} = d_{wi} \). The enthalpy, which was \( h_{wIi} \) of the indirect process state point \( W_{II} \), was output by the TRNSYS psychrometer program, then \( h_{Li} = h_{WIi} \).

(c) When the outdoor state point was in areas III~V, the enthalpy-humidity chart of the air process, which was indirect evaporative cooling and mechanical refrigeration, was shown in Figure 4c.

Saturation partial pressure \( P_{sLi} \) of the fresh air process state point \( L_i \):

\[
P_{sLi} = \frac{Bd_{Li}}{0.622 \varphi + d_{Li} \varphi}
\]  (4)

Dry bulb temperature \( ti \) of the fresh air process state point \( L_i \):

\[
P_{sLi} = 611.2 \times 10^{\frac{7451}{t_i}}
\]  (5)

\( h_{Li} \) was output by the TRNSYS psychrometer program according to the dry bulb temperature and moisture content.
(3) Determination of the fan-coil unit process state point $M_i$:

$$d_{Mi} = d_N$$  \hspace{2cm} (6)$$

$$h_{Mi} = h_{Oi} + \frac{q_{mW}}{q_{mR}} (h_{oi} - h_{Li})$$  \hspace{2cm} (7)$$

(4) Determination of the indirect process point $W_{Ii}$ of the fresh air unit:

(a) When the outdoor state point was in area II: the determination process of state point $W_{Ii}$ is as shown in the second method in Section 2.4 (2).

(b) When the outdoor state point was in the areas III~V, the enthalpy-humidity chart of the air process, which was indirect evaporative cooling and mechanical refrigeration, is as shown in Figure 4c. The indirect evaporative cooling efficiency was 75%, then $t_{wii} = t_{wi} - 0.75(t_{wi} - t_{wsi})$, $d_{wii} = d_N$. The enthalpy, which was the $h_{wii}$ of the indirect process point $W_{Ii}$, was output by the TRNSYS psychrometer program.

(5) Determining the operation strategy of evaporative cooling unit by TRNSYS according to each state point. At the same time, the loads which were provided by the direct evaporative cooling section, the indirect evaporative cooling section, the surface cooling section and the fan-coil unit, was respectively output.

(a) When the outdoor state point was in area I: the loads provided by the direct evaporation section:

$$Q_{_dec} = c_p \times q_{mR} \times (t_w - t_L)$$  \hspace{2cm} (8)$$

The loads provided by fan-coil unit:

$$Q_{_fancoil} = q_{mW} \times (h_N - h_M)$$  \hspace{2cm} (9)$$

(b) When the outdoor state point was in area II: the loads provided by the indirect evaporation section:

$$Q_{_indec} = q_{mR} \times (h_w - h_{w1})$$  \hspace{2cm} (10)$$

The loads provided by the direct evaporation section:

$$Q_{_dec} = c_p \times q_{mR} \times (t_{w1} - t_L)$$  \hspace{2cm} (11)$$

The loads provided by fan-coil unit:

$$Q_{_fancoil} = q_{mW} \times (h_N - h_M)$$  \hspace{2cm} (12)$$

(c) When the outdoor state point was in areas III~V: the loads provided by the indirect evaporation section:

$$Q_{\sim indec} = q_{mR} \times (h_w - h_{w1})$$  \hspace{2cm} (13)$$

The loads provided by the surface cooling section:

$$Q_{\sim ciol} = q_{mR} \times (h_{w1} - h_L)$$  \hspace{2cm} (14)$$

The loads provided by fan-coil unit:

$$Q_{\sim fancoil} = q_{mW} \times (h_N - h_M)$$  \hspace{2cm} (15)$$
3. Results and Discussion

3.1. Applicability Judgment of Evaporative Cooling Air-Conditioning Unit

The hourly cooling load of air-conditioning was simulated by TRNSYS, as shown in Figure 6. The design loads of the office building were 326.00 kW, the design moisture loads were 14.17 g/s, the heat humidity ratio \( \varepsilon \) was 23,011.79 kJ/kg, the air supply volume was 38.82 kg/s, the fresh air volume was 5.3875 kg/s, and the fan-coil unit air volume was 33.43 kg/s. Indoor state point, outdoor state point and air supply state point are shown in Table 3.

![Figure 6. Hourly cooling loads of an office building in Lanzhou.](image)

**Table 3. Parameters indoor state point, outdoor state point and air supply state point.**

| Classification                  | Outdoor State Point W | Indoor State Point N | Air Supply State Point O |
|---------------------------------|-----------------------|----------------------|--------------------------|
| Dry Bulb Temperature °C         | 31.2                  | 26                   | 18.05                    |
| Wet Bulb Temperature °C         | 20.1                  | 20.33                | 17.67                    |
| Relative Humidity %             | 36%                   | 60%                  | 95%                      |
| Moisture content g/kg (Dry air) | 10.16                 | 12.64                | 12.48                    |
| Enthalpy kJ/kg                  | 57.37                 | 58.20                | 49.80                    |

The air-conditioning season in Lanzhou was from 15 May to 30 September, and the entire air-conditioning added up to 3336 h. Figure 6 showed the outdoor air state point in Lanzhou. According to the design partition of evaporative cooling air-conditioning system, the outdoor hourly meteorological parameters, the design of indoor air state point and the air supply state point parameters were compared. On the psychrometric chart, the hours of the outdoor state point were respectively determined in the areas I, II, III, IV and V, which were 2640 h, 346 h, 100 h, 41 h, 244 h and accounted for 79.14%, 10.37%, 3.00%, 1.23%, 7.31% of the air-conditioning hours, which also listed in the Table 4. When the outdoor state point was in area II, two-stage evaporative cooling was implemented by opening the indirect evaporation section and direct evaporation section of fresh air unit. When the evaporative cooling air-conditioning unit was applied in Lanzhou in summer, the evaporative cooling air-conditioning unit could achieve the requirements of indoor air ventilation during the 89.51% of summer time. Therefore, it is necessary to analyze the outdoor hourly meteorological parameters pertinently and determine the air process strategy when the evaporative cooling cannot achieve the requirements of indoor ventilation.
Table 4. Partition of outdoor air state point in Lanzhou.

| Partition | I  | II | III | IV | V  |
|-----------|----|----|-----|----|----|
| Hours h   | 2640 | 346 | 100 | 41 | 244 |
| Percentage of Air-conditioning Hours % | 79.14 | 10.37 | 3.00 | 1.23 | 7.31 |

As shown in Figure 7, the summer outdoor meteorological parameters were in different climate areas I–V according to the indoor air design state and air supply design state. The evaporative cooling combined air-conditioning unit needed opening different function sections to process the outdoor air. The above analysis ignores the influence of outdoor meteorological parameters on building loads. However, the air supply point, air supply volume and air process changed with the change of building loads. In order to analyze and determine the loads provided respectively by direct evaporative cooling section, indirect evaporative cooling section, surface cooling section and fan-coil unit, the load distribution of evaporative cooling air-conditioning should be considered according to the load distribution method demonstrated in Section 2.4 under the condition of constant air volume.

![Figure 7. The enthalpy-humidity chart of outdoor air state point in Lanzhou area.](image-url)
3.2. Analysis of Load Distribution of Evaporative Cooling Air-Conditioning System

According to the load distribution method demonstrated in Section 2.4, the direct evaporative cooling loads, indirect evaporative cooling loads, surface cooling loads and fan-coil unit loads of evaporative cooling combined fresh air unit were output by TRNSYS. The load distribution of the evaporative cooling air-conditioning system in the different regions are shown in Figures 8–10, and the load distribution results are shown in Table 5.

As shown in Table 5:

(1) When the outdoor state point was in area I, outdoor fresh air was processed by opening the direct section of evaporative cooling air-conditioning unit. At the same time, the fan-coil unit handled the indoor return air. The cumulative loads provided by direct evaporative cooling section were
20,023.69 kWh, and the cumulative loads provided by fan-coil unit were 20,023.69 kWh. The loads provided by the evaporative cooling air-conditioning unit accounted for 18.65% of the total loads.

(2) When the outdoor state point was in area II, the outdoor fresh air was processed by opening the direct and indirect section of the evaporative cooling air-conditioning unit. The cumulative loads of indirect and direct evaporative cooling section were respectively 3347.36 kWh, 75.96 kWh. The loads provided by the evaporative cooling air-conditioning unit accounted for 3.19% of the total loads.

(3) When the outdoor state point was in areas III–V, the requirements of air supply could not be achieved by opening the indirect and direct evaporative cooling unit. Therefore, the indirect section and surface cooling section of air-conditioning unit needed to be opened to process fresh air. The cumulative loads provided by indirect evaporative cooling section were 3883.92 kWh and accounted for 3.62% of the total loads.

(4) In summer, when the outdoor meteorological parameters change hourly, the loads provided by the direct and indirect evaporative cooling sections accounted for 25.46% of the total loads in different regions.

![Hourly loads distribution in areas III–V.](image)

**Figure 10.** Hourly loads distribution in areas III–V.

**Table 5.** The load distribution table.

| Partition                              | Peak Loads kW | Cumulative Loads kWh |
|----------------------------------------|---------------|----------------------|
| **Area I Direct Evaporation Section**  |               |                      |
| Direct Evaporation Section             | 69.72         | Cumulative Direct Evaporation Section 20,023.69 |
| Fan Coil                               | 200.57        | Cumulative Fan Coil 34,521.43 |
| **Area II Direct and Indirect Evaporation Section** | | |
| Indirect Evaporation Section           | 50.24         | Cumulative Indirect Evaporation Section 3347.36 |
| Direct Evaporation Section             | 17.47         | Cumulative Direct Evaporation Section 75.96 |
| Fan Coil                               | 233.82        | Cumulative Fan Coil 15,028.96 |
| **Area III IV V Indirect Evaporation Section and Surface Cooling Section** | | |
| Indirect Evaporation Section           | 39.94         | Cumulative Indirect Evaporation Section 3883.92 |
| Surface Cooling Section                | 125.79        | Cumulative Surface Cooling Section 13,438.61 |
| Fan Coil                               | 229.21        | Cumulative Fan Coil 17,024.51 |
| **Total Value**                        |               | 107,344.45          |
4. Conclusions

In this paper, the outdoor hourly meteorological parameters in Lanzhou, located in northwest China, were divided into five regions, and the operation mode and control strategies of evaporative cooling air-conditioning systems were determined in these different zones. Finally, the dynamic loads of different function sections in evaporative cooling air-conditioning system are obtained, and the following conclusions are drawn from the study:

(1) In summer, outdoor fresh air can be processed by evaporative cooling in Lanzhou, and the guaranteed rate of evaporative cooling air-conditioning is 89.51%.

(2) The loads provided by the direct evaporative cooling and indirect evaporative cooling account for 25.46% of the total loads in an office building located in Lanzhou, which is of great significance to reduce the energy consumption of air-conditioning systems.

(3) In the five regions divided according to the outdoor meteorological parameters in Lanzhou, the outdoor dry bulb temperature is higher, the relative humidity is smaller, and air-conditioning units can provide greater cooling loads. Therefore, the system can produce more obvious energy-saving effects.

(4) According to the hot and dry climate characteristics in Lanzhou in summer, temperature and humidity independent control principle is applied to an evaporative cooling air-conditioning system, which achieves a better energy saving effect. As a result, the air-conditioning system is suitable for application in northwest China. In addition, it should also be suitable for other areas where the climate is relatively hot and dry.

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Nomenclature

- $d_p$: ideal air supply moisture content, g/kg
- $h_W$: outdoor air enthalpy, kJ/kg
- $L$: direct evaporative cooling state point
- $M$: constant humidify cooling state point
- $\varepsilon$: heat humidity ratio, kJ/kg
- $\varphi$: relative humidity, %
- $h_{ai}$: hourly air enthalpy, kJ/kg
- $d_o$: hourly air supply moisture content, g/kg
- $d_{Li}$: hourly fresh air moisture content, g/kg
- $h_{Li}$: hourly fresh air enthalpy, kJ/kg
- $d_{fri}$: hourly fresh air moisture content, g/kg
- $d_{Wi}$: hourly outdoor air moisture content, g/kg
- $t_{wsi}$: hourly indirect evaporative cooling temperature, °C
- $c_p$: heat capacity at constant pressure, kJ/(kg·°C)
- $h_{Mi}$: constant humidify cooling state point enthalpy, kJ/kg
- $t_L$: direct evaporative cooling state point temperature, °C
- $t_M$: constant humidify cooling state point temperature, °C
- $h_o$: ideal air supply enthalpy, kJ/kg
- $t_{afr}$: hourly fresh air temperature, °C
- $t_W$: outdoor air temperature, °C
- $t_{wi}$: hourly outdoor air temperature °C
- $W_i$: hour outdoor air condition point
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