

Utilization efficiency analysis on renewable energy for cooling and heating in green buildings

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Abstract: In this study, two evaluation indices of energy level equilibrium coefficient and primary exergy efficiency are explored in a bid to analyze the utilization efficiency of the green building cooling and heating sources. The three-star office green building and one-star library green building are analyzed with the proposed indices. Results show that the higher the primary exergy efficiency, the higher the energy sources utilization efficiency. The smaller the energy level equilibrium coefficient, the higher the matching of energy system and rational use of energy. For the three-star office green building, given the two evaluation indices, the renewable-energy ground-source VRF (variable refrigerant flow) air conditioner is better than the conventional-energy air-source VRF air conditioner. For the one-star library green building, the two evaluation indices of the water cooling chiller (WCC) show better effects than those from the ground source heat pump (GSHP) for cooling, which indicates that the utilization efficiency of the WCC is higher than the GSHP for cooling, but for heating the two evaluation indices of GSHP suggest much better performance. Consequently, when analyzing the utilization efficiency of the green building renewable energy for cooling and heating, both the cooling and heating efficiency should be taken into account as a whole for analytical purposes.

Key words: renewable energy for cooling and heating; green building; primary exergy efficiency; energy level equilibrium coefficient

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1 Introduction

At present, the consumption energy sources of the building's cooling and heating system accounts for a large amount in the heating, ventilation and air conditioning system. The relevant literatures^[1-4] had investigated the building energy system from primary energy to the building envelop, which had shown that the largest exergy destruction occurred in the primary energy transformation and cooling/heating production stage. Therefore, the building cooling and heating

sources play a crucial role in the overall amount of energy consumption. In recent years, the green building in China has developed rapidly, renewable energy for cooling and heating are widely used in green building, such as the ground source heat pump, the solar hot water, etc. The utilization of renewable energy in buildings is not completely cost-free, needing to consume additional conventional energy sources. In some cases, if it consumes more additional conventional energy, the utilization efficiency could be less than that the conventional energy system. As such, it is of great

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importance to evaluate the renewable energy utilization efficiency scientifically in green buildings.

In the previous studies, Gong et al^[5] had presented an analysis method of product exergy cost for scheme-selection optimization of building cooling and heating sources. Li et al^[6] had comparably analyzed the two different systems of the building cooling and heating source with annual cost and net present value method from economic, energy consumption and environmental aspects. Liu et al^[7] had proposed a photovoltaic thermal-compound thermo-electric ventilator system and also evaluated its performance. Yildiz et al^[8] had evaluated the three different building heating sources with system energy and exergy efficiency from source to sink. Hepbasli^[9] had analyzed the performance of three greenhouse heating sources from power plant to envelope using exergy efficiency and sustainability index. Goncalves et al^[10] had compared the performance of eight space heating options through the indicators of primary energy ratio and primary exergy ratio.

Although the above papers have evaluated the building cooling and heating sources from economic, energy consumption, environmental and optimal control model aspects, the exergy analysis with cooling and heating sources from system process can only evaluate the system thermodynamic perfection, without solving the problem of energy match between supply and usage. To address this problem, this paper exploits the utilization efficiency evaluation indices of energy level equilibrium coefficient and primary exergy efficiency to comparatively analyze the renewable and conventional energy for cooling and heating in green buildings.

2 System descriptions

A three-star office green building and a one-star university library green building are chosen to conduct this study. The office green building is 39.5 m high, and the total floor area is about 12 400 m², including 9 over ground floors and 1 under ground floor. The university library building is 23.5 m high, and the total floor area is about 40 100 m² with 5 over ground floors and 1 under ground floor.

For the three-star office green building, ground source VRF air conditioner with 825 kW cooling and 926 kW heating capacity (input power about 158 kW) is chosen for renewable cooling and heating sources. Air source VRF air conditioner with 462 kW cooling and 518 kW heating capacity (input power about 123 kW) is chosen for conventional cooling and heating sources, as show in Table 1.

For the one-star library green building, two ground source heat pump units with 1 000 kW cooling capacity (input power 195 kW) per unit and one water cooling chiller unit with 2000 kW cooling capacity (input power 356 kW) are chosen for renewable and conventional cooling sources. Only the two ground source heat pump units with heat capacity 1 100 kW (input power 220 kW) per unit are chosen for the renewable heating source as shown in Table 1. The supply and return temperature of chilled water for summer is 7/12 °C, and those of hot water for winter is 45/40 °C.

3 Method

The energy sources inputting to the building

Table 1 Renewable and conventional energy supply system of the two green buildings kW

Energy	Three-star office building				One-star library building			
	Cold sources		Heat sources		Cold sources		Heat sources	
	Type	Capacity	Type	Capacity	Type	Capacity	Type	Capacity
Renewable energy	Ground source VRF	825	Ground source VRF	926	Ground source heat pump	2 000	Ground source heat pump	2 200
Conventional energy	Air source VRF	462	Air source VRF	518	Water cooling chiller	2 000	—	—

cooling and heating equipment are not only electricity, but also can be steam, natural gas and renewable energy etc., which are different kinds of energy sources. In order to scientifically analyze different quality level of the building energy sources consumption, the evaluation indices of energy level equilibrium coefficient and primary exergy efficiency are used to analyze the green building renewable energy utilization efficiency for cooling and heating with exergy method.

3.1 Energy level equilibrium coefficient

According to the definition of exergy^[11], energy level coefficient (λ) refers to the proportion of available energy (W) in the total quantity of energy (Q), that is

$$\lambda = W / Q. \quad (1)$$

Electricity is the highest-grade energy source and can be completely converted into work. The energy level coefficient of electricity is 1.

3.1.1 Energy level coefficient of heating and cooling

The energy level coefficient of heating (λ_{he}) and cooling (λ_{co}) capacity is defined as^[12]:

$$\lambda_{he} = 1 - T_o / T_{in}, \quad (2)$$

$$\lambda_{co} = T_o / T_{de} - 1, \quad (3)$$

where T_o is the environment reference temperature, T_{in} is the indoor air temperature in heating mode. T_{de} is the dew-point temperature of indoor air in cooling mode.

3.1.2 Energy level coefficient of hot and chilled water

Energy level coefficient of hot (λ_{hot}) and chilled (λ_{ch}) water can be calculated by^[13]:

$$\lambda_{hot} = 1 - T_o \ln(T_s / T_r) / (T_s - T_r), \quad (4)$$

$$\lambda_{ch} = T_o \ln(T_s / T_r) / (T_s - T_r) - 1, \quad (5)$$

where T_s and T_r are the supply and return temperature of the hot/chilled water, respectively, and T_o stands for the environment reference temperature.

3.1.3 Equivalent energy level coefficient

For the building cooling and heating energy supply system, there are a variety of type of energy sources inputting to the system, and the energy level coefficients of each are different. The equivalent energy level coefficient (λ_e) of different energy sources can be defined as^[14]:

$$\lambda_e = \sum E_i / \sum Q_i = \sum (Q_i \lambda_i) / \sum Q_i, \quad (6)$$

where λ_i is the energy level coefficient of one kind of energy sources, and Q_i is the total quantity of one kind of energy sources.

3.1.4 Energy level equilibrium coefficient

Supposing the system energy level coefficient of input and output is λ_1 and λ_2 respectively, when the two are equivalent, the difference ($\Delta\lambda$) is zero, which indicates that the system energy level is balanced. When the two are not equal, which means the energy level of the system is unbalanced. The energy level difference can be used as a criterion for assessing the building cooling and heating energy system performance. Energy level equilibrium coefficient (ζ) can be used to evaluate and analyze the rationality of the system, and also can reflect the system relative energy level changing, which can be calculated by^[15]:

$$\zeta_\lambda = (\lambda_1 - \lambda_2) / \lambda_1 = 1 - \lambda_2 / \lambda_1. \quad (7)$$

3.2 Primary exergy efficiency

Primary exergy efficiency (η) is defined as the ratio of the total effective income exergy (E_{out}) to the total primary exergy input ($E_{pr,in}$)^[11].

$$\eta = E_{out} / E_{pr,in}, \quad (8)$$

where E_{out} stands for income exergy, $E_{pr,in}$ is the primary exergy consumed to obtain income exergy.

The primary exergy of electricity is assumed as coal fired in this text. Supposing W is the inputting power of electricity, the basic value of power supply standard coal consumption is $326 \text{ gce} \cdot (\text{kWh})^{-1}$ based on Chinese grades of coal-fired power plant 600 MW domestic subcritical generating set^[15]. E_{coal} is the exergy of the coal, which is $31\,317 \text{ kJ} \cdot \text{kg}^{-1}$ in reference [14]. M_{coal} is the standard coal consumption, kg. The primary exergy of electricity ($P_E W$) can be expressed as follow^[16]:

$$P_E W = W M_{coal} E_{coal}. \quad (9)$$

3.2.1 Primary exergy efficiency of the ground source heat pump (GSHP) system

As shown in Fig. 1, the exergy equilibrium equation of the ground source heat pump in heating and cooling mode is obtained according to the following formula:

$$P_E W_{\text{comp,gshp}} + P_E W_{\text{ug}} + E_{\text{hot,in}} + E_{\text{ug}} = E_{\text{hot,out}} + \Pi_{\text{hp,h}}, \quad (10)$$

$$P_E W_{\text{comp,gshp}} + P_E W_{\text{ug}} + E_{\text{ch,in}} = E_{\text{ch,out}} + E_{\text{ug}} + \Pi_{\text{hp,c}}, \quad (11)$$

in which $E_{\text{hot,in}}/E_{\text{ch,in}}$ and $E_{\text{hot,out}}/E_{\text{ch,out}}$ are the exergy of supply and return hot/chilled water from the ground source heat pump respectively, $W_{\text{comp,gshp}}$ and W_{ug} are the power inputting to the compressor and the pump of the ground side respectively, E_{ug} is the heat absorbing/dissipation from ground to the system in heating/cooling mode, $\Pi_{\text{hp,h}}$ and $\Pi_{\text{hp,c}}$ are the exergy loss of GSHP system in heating and cooling mode respectively.

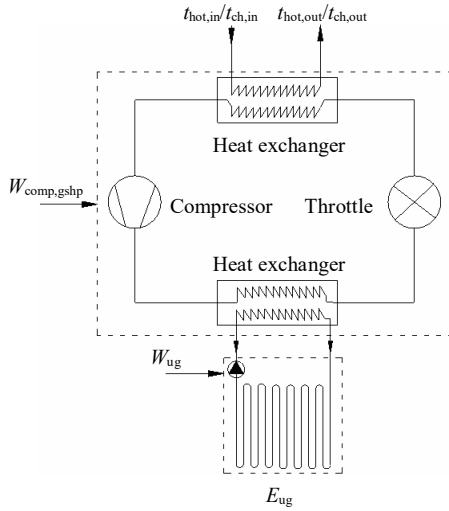


Fig. 1 Energy flow chart of the GSHP system

Ignoring the exergy (E_{ug}) of heat absorbing/dissipation from ground, the primary exergy efficiency of the GSHP system for heating ($\eta_{\text{gshp,h}}$) and cooling ($\eta_{\text{gshp,c}}$) can be calculated by

$$\eta_{\text{gshp,h}} = \frac{E_{\text{out}}}{E_{\text{in,pr}}} = \frac{E_{\text{hot,out}} - E_{\text{hot,in}}}{P_E W_{\text{comp,gshp}} + P_E W_{\text{ug}}}, \quad (12)$$

$$\eta_{\text{gshp,c}} = \frac{E_{\text{out}}}{E_{\text{in,pr}}} = \frac{E_{\text{ch,out}} - E_{\text{ch,in}}}{P_E W_{\text{comp,gshp}} + P_E W_{\text{ug}}}. \quad (13)$$

3.2.2 Primary exergy efficiency of the water cooling chiller (WCC) system

As shown in Fig. 2, the exergy equilibrium equation of the WCC system can be written as:

$$P_E W_{\text{comp,wcc}} + P_E W_{\text{ct}} + P_E W_{\text{pm,ct}} + E_{\text{ch,in}} = E_{\text{ch,out}} + \Pi_{\text{wcc}}, \quad (14)$$

in which $E_{\text{ch,in}}$ and $E_{\text{ch,out}}$ are the exergy of supply and

return chilled water from the WCC system respectively, $W_{\text{comp,wcc}}$, W_{ct} and $W_{\text{pm,ct}}$ are the power inputting to the compressor, cooling tower and circulating pump respectively, Π_{wcc} is the exergy loss of the WCC system.

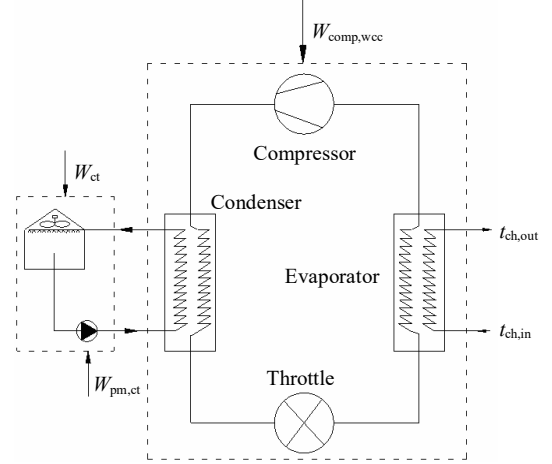


Fig. 2 Energy flow chart of the WCC system

The primary exergy efficiency (η_{wcc}) of the WCC system can be written as:

$$\eta_{\text{wcc}} = \frac{E_{\text{out}}}{E_{\text{pr,in}}} = \frac{E_{\text{ch,in}} - E_{\text{ch,out}}}{P_E W_{\text{comp,wcc}} + P_E W_{\text{ct}} + P_E W_{\text{pm,ct}}}. \quad (15)$$

3.2.3 Primary exergy efficiency of the ground source VRF

As shown in Fig. 3, the exergy equilibrium equation of the ground source VRF system can be written as below:

$$P_E W_{\text{gsvrf}} + P_E W_{\text{ug}} \pm E_{\text{ug}} = \Delta E_{\text{air,room}} + \Pi_{\text{gsvrf}}, \quad (16)$$

in which W_{gsvrf} and W_{ug} are the power inputting to the ground source VRF system and the pump of the ground side respectively, $\Delta E_{\text{air,room}}$ is the exergy increment of the

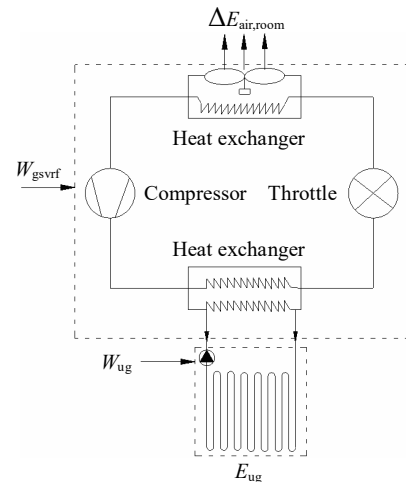


Fig. 3 Energy flow chart of the ground source VRF system

indoor room, E_{ug} is the heat absorbing/ dissipation from ground to the system in heating/cooling mode, Π_{gsvrf} is exergy loss of the system.

Ignoring the exergy (E_{ug}) of heat absorbing/ dissipation from ground, the primary exergy efficiency (η_{gsvrf}) of the ground source VRF system can be written as:

$$\eta_{gsvrf} = \frac{E_{out}}{E_{pr,in}} = \frac{\Delta E_{air,room}}{P_E W_{gsvrf} + P_E W_{ug}}. \quad (17)$$

3.2.4 Primary exergy efficiency of air source VRF

As shown in Fig. 4, the exergy equilibrium equation of the air source VRF system can be written as:

$$P_E W_{asvrf} \pm E_{air,out} = \Delta E_{air,room} + \Pi_{asvrf}, \quad (18)$$

in which W_{asvrf} is the power inputting to the air source VRF system, $\Delta E_{air,room}$ is the exergy increment of the indoor room, $E_{air,out}$ is the heat absorbing/dissipation from outdoor to the system in heating/cooling mode, Π_{asvrf} is exergy loss of the system.

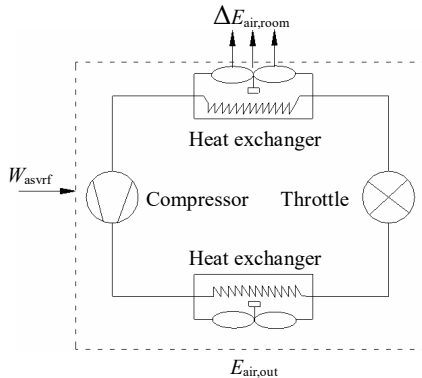


Fig. 4 Energy flow chart of the air source VRF system

Ignoring the exergy (E_{air}) of heat absorbing/ dissipation from outdoor, the primary exergy efficiency (η_{asvrf}) of the air source VRF system can be written as:

$$\eta_{asvrf} = \frac{E_{out}}{E_{pr,in}} = \frac{\Delta E_{air,room}}{P_E W_{asvrf}}. \quad (19)$$

4 Analysis

Though the environment reference temperature will affect the exergy value of energy sources, the purpose of this study is to calculate the energy level equilibrium coefficient and primary exergy efficiency, which is related to the relative exergy value of energy

sources. The environment reference temperature has little effect on the results. The reference temperature 35 °C in cooling period and 3 °C in heating period are chosen in reference [13].

4.1 Utilization efficiency analysis on the three-star office green building

4.1.1 Energy level equilibrium coefficient

For the ground source VRF and air source VRF, the useful energy output is cold and hot air. The indoor air temperature is 18 °C in heating period. The indoor air temperature is 26 °C and the relative humidity is 55% in cooling period. The output energy level coefficient for cooling is 0.066, and for heating is 0.052. The input energy is electricity both for ground source VRF and air source VRF. For ground source VRF, the input electricity includes the pump of the ground side consumed. The energy level coefficient of electricity is 1, because the input energy from environment is anergy, which is useless and has no capacity to do work. From the energy level analysis point of view, it is precisely the input anergy weaken the input energy level, which makes the energy utilization more rational. The equivalent input energy level coefficient of the ground source VRF is lower than that of the air source VRF, no matter in cooling or heating mode as shown in Table 2. The smaller the energy level equilibrium coefficient, the more matching the energy level and the more rational energy utilization. The minimum energy level equilibrium coefficient is ground source VRF for cooling of 0.714, followed by ground source heat pump for heating of 0.748. The energy level equilibrium coefficients of air source VRF for cooling and heating are 0.752 and 0.781 respectively.

4.1.2 Primary exergy efficiency

The effective income exergy of the cooling and heating energy source for three-star office green building is the increment exergy of the indoor cold and hot air. The main input energy is the secondary energy electricity, which should be converted to primary exergy. Primary exergy efficiency is calculated shown in Table 3. The highest primary exergy efficiency is ground source

Table 2 Cooling and heating energy level equilibrium coefficients of the three-star office green building

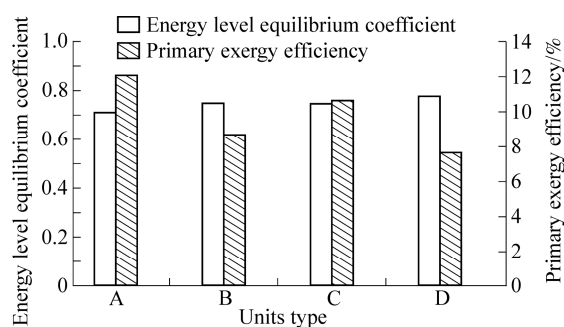
System	Input energy level		Output energy level	Difference of energy level	Energy level equilibrium coefficient
	Energy sources	Equivalent energy level			
Ground source VRF (for cooling)	Electricity	0.231	0.066	0.165	0.714
	Source water				
Air source VRF (for cooling)	Electricity	0.266	0.066	0.200	0.752
	Air				
Ground source VRF (for heating)	Electricity	0.206	0.052	0.154	0.748
	Source water				
Air source VRF (for heating)	Electricity	0.237	0.052	0.185	0.781
	Air				

VRF for cooling of 12.1%, followed by ground source VRF for heating of 10.7%, and the air source VRF for cooling and heating are of 8.7% and 7.7% respectively.

Table 3 Cooling and heating primary exergy efficiency of the three-star office green building

Units type	Effective income exergy/kJ	Exergy of input primary energy/kJ	Exergy efficiency $\eta/\%$
Ground source VRF (for cooling)	54.23	447.68	12.1
Air source VRF (for cooling)	30.36	349.13	8.7
Ground source VRF (for heating)	47.71	447.68	10.7
Air source VRF (for heating)	26.73	349.13	7.7

The energy level equilibrium coefficient and primary exergy efficiency of cooling and heating energy sources for three-star office green building are shown in Fig. 5. Considering both the energy level equilibrium coefficient and the primary exergy efficiency, the ground source VRF for cooling is the best. The higher the primary exergy efficiency, the higher the energy sources utilization efficiency.



A: Ground source VRF (for cooling); B: Air source VRF (for cooling); C: Ground source VRF (for heating); D: Air source VRF (for heating).

Fig. 5 Energy level equilibrium coefficient and primary exergy efficiency of the three-star office green building

4.2 Utilization efficiency analysis on one-star library green building

4.2.1 Energy level equilibrium coefficient

For the GSHP and WCC, the useful energy output is the chilled water and the hot water. The supply and return temperature of chilled water is 7 °C and 12 °C respectively, and the energy level coefficient is 0.16. The supply and return temperature of hot water is 45 °C and 40 °C respectively, and the energy level coefficient is 0.09. The input energy sources are different, taking the GSHP for cooling as example, the input energy is electricity and source water. To acquire the source water, additional electricity will be consumed by the ground side pump. According to the Eq. (6), the equivalent energy level coefficient can be calculated, which is 0.232. The energy level equilibrium coefficients of the cooling and heating energy sources for the one-star library green building are calculated by Eq. (6) and (7), as shown in Table 4.

The minimum energy level equilibrium coefficient is the ground source heat pump for heating, which input energy is electricity, including the electricity consumed of ground side pump for getting the source water. Though electricity is high grade energy, the percent of the total input energy is small. The equivalent energy level coefficient of input energy is small, which is in balance with the energy level coefficient of output energy heating water. The energy level equilibrium coefficient of the water cooling chiller is much less than that of the ground source heat pump for cooling, since the input electricity for cooling tower is small, which reduces the equivalent input energy level coefficient.

Table 4 Cooling and heating energy level equilibrium coefficients of the one-star library green building

System	Input energy		Output energy level	Difference of energy level	Energy level equilibrium coefficient
	Energy sources	Equivalent energy level			
WCC (for cooling)	Electricity	0.208	0.09	0.118	0.556
GSHP (for cooling)	Electricity	0.232	0.09	0.142	0.612
GSHP (for heating)	Electricity	0.234	0.16	0.074	0.315
	Source water				

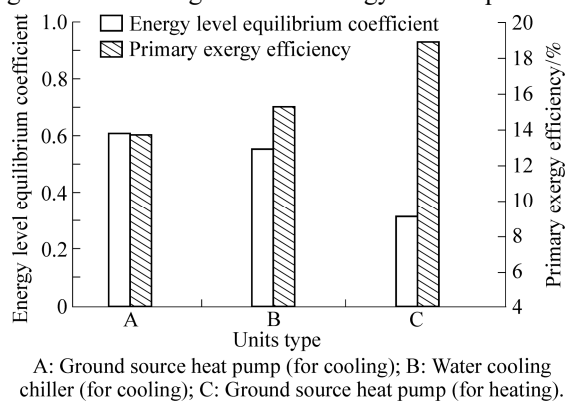
4.2.2 Primary exergy efficiency

The effective income exergy of the cooling and heating energy source for one-star library green building is the increment exergy of the chilled and hot water. The main input energy is also electricity, and the primary exergy efficiencies are calculated as shown in Table 5. The highest primary exergy efficiency is the ground source heat pump for heating of 18.9%, followed by the water cooling chiller of 15.3%. The ground source heat pump for cooling is of 13.7%.

Table 5 Cooling and heating primary exergy efficiencies of the one-star library green building

Units type	Effective income exergy/kJ	Exergy of input primary energy/kJ	$\eta/\%$
WCC (for cooling)	180.6	1 179.7	15.3
GSHP (for cooling)	180.6	1 315.9	13.7
GSHP (for heating)	275.4	1 457.7	18.9

The energy level equilibrium coefficient and the primary exergy efficiency of cooling and heating energy sources for one-star library green building are shown in Fig. 6. Considering both the energy level equilibrium

**Fig. 6 Energy level equilibrium coefficient and primary exergy efficiency of the one-star library green building**

coefficient and primary exergy efficiency, the ground source heat pump for heating is the best.

5 Conclusions

In this paper, the utilization efficiency evaluation indices of the energy level equilibrium coefficient and the primary exergy efficiency are exploited to analyze the green building cooling and heating energy sources.

For the three-star office green building, the renewable cooling and heating energy source is the ground source VRF, and conventional energy source is the air source VRF. The primary exergy efficiency of the ground source VRF is higher than the air source VRF, and the energy level equilibrium coefficient is lower for both heating and cooling. Therefore, the ground source VRF is better than the air source VRF.

For the one-star library green building, the renewable energy for cooling and heating is the GSHP, and the conventional energy source WCC is only for cooling. Considering the two evaluation indices, the WCC is better than the GSHP for cooling, but the GSHP is better for heating. To analyze the green building renewable energy for cooling and heating utilization efficiency, both cooling and heating should be taken into account as a whole to analyze.

References:

- [1] Sakulpipatsin P, Itard L C. An exergy application for analysis of buildings and HVAC systems[J]. Energy and Buildings, 2010, 42(7):90-99.
- [2] Yucera C, Hepbasli A. Thermodynamic analysis of a building using exergy analysis method[J]. Energy and

- Buildings, 2011, 43(3):536-542.
- [3] Wang P, Gong G C, Wang Y, et al. Thermodynamic investigation of building integrated energy efficiency for building retrofit[J]. Energy and Buildings, 2014, 77:139-148.
- [4] Zhou Y, Gong G C. Exergy analysis of the building heating and cooling system from the power plant to the building envelope with hourly variable reference state[J]. Energy and Buildings, 2013, 56:94-99.
- [5] Gong G C, Zeng W, Chang S, et al. Scheme-selection optimization of cooling and heating sources based on exergy analysis[J]. Applied Thermal Engineering, 2007, 27:942-950.
- [6] Li Z, Lin D M, Shu H W, et al. District cooling and heating with sea water as heat source and sink in Dalian[J]. China Renewable Energy, 2007, 32:2603-2616.
- [7] Liu Z B, Zhang L, Luo Y Q, et al. Performance evaluation of a photovoltaic thermal-compound thermoelectric ventilator system[J]. Energy and Buildings, 2018, 167:23-29.
- [8] Yildiz A, Gungor A. Energy and exergy analyses of space heating in buildings[J]. Applied Energy, 2009, 86(3): 1939-1948.
- [9] Hepbasli A. A comparative investigation of various greenhouse heating options using exergy analysis method [J]. Applied Energy, 2011, 88(5):4411-4423.
- [10] Goncalves P, Gaspar A R, Silva M G. Comparative energy and exergy performance of heating options in buildings under different climatic conditions[J]. Energy and Buildings, 2013, 61:288-297.
- [11] Zhu M S, Liu Y, Lin Z Z. Engineering Thermodynamics [M]. Beijing: Tsinghua University Press, 1995:151-160. (in Chinese)
- [12] Zhou Y, Gong G C. Exergy analysis combined with LCA for building envelope energy efficiency retrofit[J]. International Journal of Exergy, 2011, 8(4):379-391.
- [13] Zhou Y. Evaluation of renewable energy utilization efficiency in buildings with exergy analysis[J]. Applied Thermal Engineering, 2018, 137:430-439.
- [14] Tang X Z. Heat Energy Conversion and Utilization[M]. Beijing: Metallurgical Industry Press, 2002:36-58. (in Chinese)
- [15] DB33/644. Thermal power plant power supply coal consumption quota and calculation methods[S]. 2007:1-10. (in Chinese)
- [16] Zhou Y. Research on the building heating and cooling system with exergy analysis[D]. Changsha: Hunan University, 2012:70-75. (in Chinese)

绿色建筑中可再生能源供暖与制冷的利用效率分析

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摘要: 为了分析绿色建筑中可再生能源供暖和制冷的利用效率, 本文提出了采用能级平衡系数和一次能源焓效率指标来评价分析可再生能源的利用效率. 采用该评价指标对某三星绿色办公建筑和某一星绿色图书馆建筑进行了分析. 结果表明, 冷热源一次能源焓效率越高, 可再生能源利用效率就越高; 可再生能源系统能级平衡系数越小, 能量系统的匹配程度就越高, 能量利用就更加合理. 对于绿色办公建筑, 供暖和制冷时, 可再生能源地源热泵多联机的能级平衡系数和一次能源焓效率均优于常规能源系统的多联机. 对于绿色图书馆建筑, 制冷时, 常规能源水冷冷水机组的能级平衡系数和一次能源焓效率均优于地源热泵, 但供暖时地源热泵的能级平衡系数和一次能源焓效率远高于制冷时. 因此, 对可再生能源同时供暖和制冷系统进行利用效率分析时, 应把两者作为一个整体进行分析.

关键词: 可再生能源供暖和制冷; 绿色建筑; 一次能源焓效率; 能级平衡系数

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