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Renewable energy utilization evaluation method in green buildings

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Abstract

Utilizing renewable energy (RE) is an important part of the design and development of green buildings. However, it is unreasonable to assess renewable energy utilization (REU) only with the net ratio of end-use energy provided by the renewable energy system to a building's total energy consumption, but ignoring the system efficiency of REU with the necessary extra conventional energy consumption, such as electricity. In this paper, the energy quality coefficient (EQC) is introduced to describe the quality of energy, while the energy conversion coefficient (ECC) is applied to evaluate energy system efficiency. The indexes and their expressions were developed based on exergy analysis. Based on these two indexes, an effective substitution ratio (ESR) was developed for the evaluation of REU. Furthermore, the ESR of utilizing RE to substitute for single type and multiple types of conventional energy is discussed. Finally, case studies were conducted and some conclusions were drawn from the results for application of RE in buildings.

Keywords: Renewable energy; Energy conversion coefficient; Energy quality coefficient; Effective substitution ratio

1. Background

The theory of green buildings includes a lower environment load, higher energy efficiency and resource saving throughout a building's whole life cycle. At the same time, green buildings should provide comfortable, safe and healthy environments for people. Renewable energy utilization (REU) is one of the most important aspects of green buildings. RE is defined as energy that is derived from natural processes and that can be replenished constantly, including energy generated from solar, wind, biomass, geothermal, hydropower and ocean resources, and biofuel and hydrogen derived from renewable resources [1].

End-use energy consumption in buildings, such as cooling energy consumption, heating energy consumption, hot water energy consumption, lighting electricity consumption as well as household appliance electricity consumption, can be supplied by conventional energy systems (CESs) or renewable energy systems (RESs). Furthermore, RESs also require the consumption of some conventional energy (CE) (Fig. 1). In other words, the REU is not totally free.

The methods to assess REU in existing green building assessment systems can be divided into two categories: one is evaluation by the index of the substitution ratio (the ratio of end-use energy acquired from the RES to the total energy demand, SR) represented by America's Leadership in Energy and Environment Design (LEED) [2] and China's Green Olympic Building Assessment System (GOBAS) [3]; the other is assessment by the index of acquiring end-use energy from RES per m^2 represented by Japan's Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) [4] and the GBTools [5] used by multiple countries.

Most of the above assessment systems, except GOBAS, ignore the extra CE consumption during the REU process. Assuming the RE earning (REE) reduction is equal to the output of extra CE consumption being applied in the CES, GOBAS (version 2003) takes the coefficient of performance (COP; COP = 5.5 for the heating system and COP = 4.5 for the cooling system) as the conversion coefficient between extra CE consumption and reduced REE [3], which ignores the difference between different CESs. Consequently, assessing the acquirement and consumption

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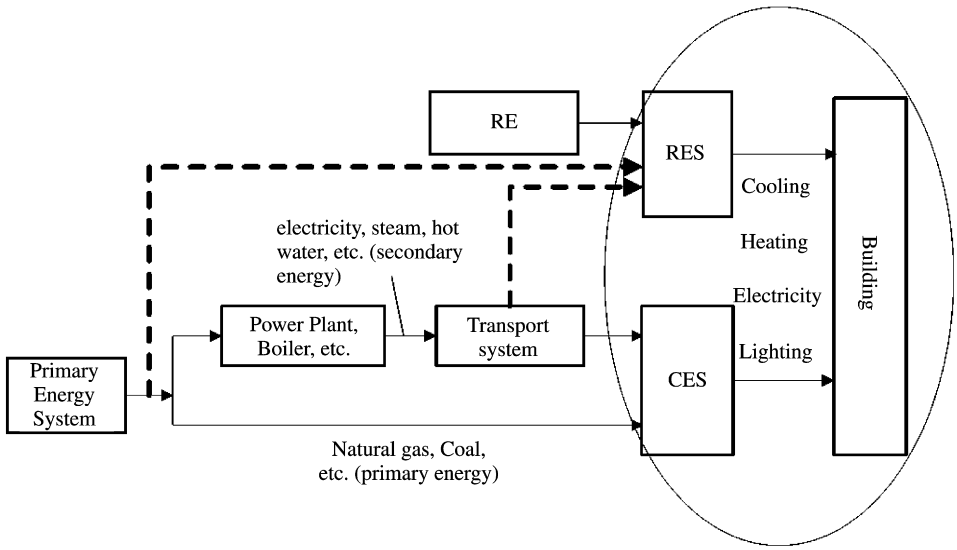

Fig. 1. Building energy consumption flowchart.

of RESs is an important issue for the development of REU in buildings.

2. Exergy analysis of energy system

Existing energy efficiency assessment methods always focus only on the energy quantity, but ignore the energy quality [6,7]. Based on the exergy principle [8], energy transfer includes work and heat. When work is converted into heat, the quality of energy depreciates. As a result, the ratio of work, which can be delivered to its surroundings, to total energy can be used as a measurement of the energy quality, which is defined as the Energy Quality Coefficient (EQC) in GOBAS [3] and is calculated by

$$\lambda = \frac{W}{Q}, \tag{1}$$

where Q is the total quantity of energy (GJ), and W denotes the exergy of energy (GJ).

Moreover, GOBAS developed the Energy Conversion Coefficient (ECC) as an index to assess the efficiency of HVAC systems. ECC, which considers both energy quantity and energy quality, is defined as the amount of energy acquirement from one GJ's energy consumption, and both energy quantity and quality are measured by exergy Eq. (2):

$$\mathrm{ECC}_{\mathrm{HVAC}} = \frac{Q_{\mathrm{C}}\lambda_{\mathrm{C}} + Q_{\mathrm{H}}\lambda_{\mathrm{H}} + E\lambda_{\mathrm{E}}}{\sum_i (W_{\mathrm{HVAC}_i}\lambda_i)}, \tag{2}$$

where $Q_{\mathrm{C}}/Q_{\mathrm{H}}$ is the annual cooling/heating demand of a building cluster or a single building (GJ), E is the annual electric power output from a CCHP system (GJ), W_{HVAC_i} is the annual consumption of the i type energy for the HVAC system of a building site or single building (GJ) and λ_{C}, λ_{H}, λ_{E} as well as λ_i are the EQC of the cooling demand, heating demand, electricity and the i type energy, respectively, dimensionless.

3. Renewable energy system

The essence of REU is converting RE to end-use energy with low CE consumption, which cannot always be ignored. If we deduce the principle of $\mathrm{ECC}_{\mathrm{HVAC}}$ for the cooling and heating system in GOBAS to assess any building's CES, we can obtain

$$\mathrm{ECC}_{\mathrm{CES},i} = \frac{\lambda_i Q_i}{\sum_{j=1}^{m_i} (\lambda_{\mathrm{CES\_used},i,j} W_{\mathrm{CES\_used},i,j})}, \tag{3}$$

where $\mathrm{ECC}_{\mathrm{CES},i}$ denotes the ECC of the CES to acquire Q_i, Q_i is the i type end-use energy demand (GJ), $W_{\mathrm{CES\_used},i,j}$ is the j type CE consumption of the CES to acquire Q_i (GJ), and λ_i and $\lambda_{\mathrm{CES\_used},i,j}$ are the EQC of Q_i and $W_{\mathrm{CES\_used},i,j}$, respectively.

Similar to the $\mathrm{ECC}_{\mathrm{CES},i}$, we can define $\mathrm{ECC}_{\mathrm{RES},i}$ to assess the efficiency of an RES as

$$\mathrm{ECC}_{\mathrm{RES},i} = \frac{\lambda_{\mathrm{RES},i} Q_{\mathrm{RES},i}}{\sum_{j=1}^{n_i} (\lambda_{\mathrm{RES\_used},i,j} W_{\mathrm{RES\_used},i,j})}, \tag{4}$$

where $Q_{\mathrm{RES},i}$ is the i type end-use energy demand of a building acquired by RES (GJ), $W_{\mathrm{RES\_used},i,j}$ is the extra CE consumption to obtain $Q_{\mathrm{RES},i}$ (GJ) and $\lambda_{\mathrm{RES},i}$ and $\lambda_{\mathrm{RES\_used},i,j}$ are the EQC of $Q_{\mathrm{RES},i}$ and $W_{\mathrm{RES\_used},i,j}$, respectively.

In order to assess the level of the substitution of RE for CE, we defined the ESR (effective substitution ratio) as

$$\mathrm{ESR} = \frac{\mathrm{REE} - Q_{\mathrm{RL}}}{\text{sustituted energy demand}}, \tag{5}$$

where Q_{RL} denotes the loss of REE according to the extra energy consumption of REU.