EVALUATION OF RENEWABLE ENERGY SYSTEM IN CHINA'S GREEN BUILDING ASSESSMENT METHOD (GBAS)

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ABSTRACT

Utilizing renewable energy systems (RES) 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 renewable energy earning to a building's total energy consumption, while ignoring the system efficiency of RES with the additional 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, a new scoring method of RES is developed. According to a case study, the feasibility of the new index and scoring method was validated.

KEYWORDS

renewable energy; energy conservation coefficient; energy quality coefficient; effective substitution ratio

INTRODUCTION

The research of Green Building begins in the 1960s, when the theory of "Arology" combining "Ecology" and "Architecture" was firstly proposed by Paola Soleri. After the energy crisis in the 1970s, energy conservation became a critical factor for the sustainable development of the world and reducing energy consumption of buildings has attracted more and more attention. In 1980s, SBS (Sick Building Syndrome) was found in new buildings and the IAQ (Indoor Air Quality) of buildings became an important issue for human health. In 1991, integrated design considering energy, climate, material, occupancy and surrounding environment was proposed by Brenda and Robert Vale in their publication "Green architecture design for a sustainable future" (Brenda 1996). During the last 16 years, a great deal of work has been done by many architects, engineers, owners as well as researchers in the field of “Green Buildings”, the objective of which aims to reduce environment load, cut down resource consumption and improve energy efficiency throughout a building's whole life cycle. Many countries and organizations have developed green building assessment systems to assist green building design, including America’s Leadership in Energy and Environment Design (LEED) (2001), Japan’s Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) (2005), China’s Green Olympic Building Assessment System (GOBAS) (2003), multi-countries’ GBTools and so on (2002).

In the theory of “Green Building”, renewable energy system (RES) takes an important place, which applies energy deriving from natural process to maintain building’s operation. Meanwhile, the score of RES always takes high percentage in the green building assessment system. In this case, the evaluation method of RES has significant influence on the design of green building. In order to evaluate

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RES reasonably, two key factors should be taken into account in the green building assessment system:

(1) Evaluation index that can reflect performance of RES correctly.

(2) Scoring method of RES as well as the relationship between RES and other items;

In the following sections, a review of different RES evaluation method is carried out firstly, and then a new method proposed in China’s green building assessment method (GBAS), which is the development of GOBAS, is introduced. Meanwhile, several practical cases are discussed and some important conclusions are summarized.

**COMPARISON OF DIFFERENT SYSTEMS**

The method to assess RES in existing green building assessment systems can be divided into two categories: one is to evaluate 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 LEED and GOBAS; the other is to assess by the index of acquiring end-use energy from RES per $m^2$ represented by CASBEE. In the GBTools, the two kinds of index are applied to assess off-site renewable energy usage and on-site renewable energy usage separately. RES evaluation methods for office building of LEED, CASBEE at the execution design stage, GBTools at the design stage and GOBAS at the detail design stage are shown in Table 1. According to detailed comparison, the following conclusions can be obtained:

- The weight of RES in the whole assessment system doesn’t exceed 10%, and CASBEE takes the highest weight. For the other three systems, small difference of weight can be found.
- Large difference exists in the detailed evaluation content of RES. No specific description is provided by LEED, which assess RES efficiency only by the net ratio of the energy from RES to the building’s total energy use. CASBEE differentiate the RES according to the approaches by which renewable energy is applied in the building. Furthermore, direct and conversion usage of renewable energy is emphasized in CASBEE. GBTools assesses the off-site energy that is generated from renewable sources specifically. In GOBAS, RESs are differentiated by the generated end-use energy types, including electricity, heat & hot water, cooling and other extra energy consumption.
- The scoring methods of RES are the same with other items in all of the four systems, and difference between RES and conventional energy system (CES) has not been considered.
- The extra energy consumption of RES is only considered in GOBAS.

<table>
<thead>
<tr>
<th>systems</th>
<th>Index</th>
<th>weight</th>
<th>evaluation details</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEED</td>
<td>SR</td>
<td>4.3%</td>
<td>assess solar, wind, geothermal, biomass, hydro, and bio-gas strategies; SR equals net fraction of the building’s total energy use</td>
</tr>
<tr>
<td>CASBEE</td>
<td>energy usage per $m^2$</td>
<td>10%</td>
<td>assess daylight, natural ventilation, geothermal energy and other RES system; calculate annual direct and converted natural energy usage per $m^2$ [MJ/(m²·yr)]</td>
</tr>
<tr>
<td>GBTools</td>
<td>energy usage per $m^2$ &amp; SR</td>
<td>5.75%</td>
<td>calculate ratio of annual purchased electricity generated from renewable energy to total electricity; calculate the amount of annual energy from on-site RESs per $m^2$</td>
</tr>
<tr>
<td>GOBAS</td>
<td>SR</td>
<td>6%</td>
<td>calculate SR of electricity, heating &amp; hot water energy, cooling energy and other energy; and the extra energy consumption of RES is considered</td>
</tr>
</tbody>
</table>

Although the energy source of RES is natural and can be replenished constantly, the operation of RES
may also consume conventional energy, such as electricity consumption of chiller in ground source heat pump which utilizes geothermal energy to supply cooling and heating. Therefore, extra energy consumption of RES should never be ignored, and only GOBAS takes it into account. However, even for GOBAS, some problems still exist in assessing extra energy consumption. On the other hand, local natural resources and economy level take important influence on RES, which is different from CES and should be reflected in the assessment system. Moreover, no assessment system has focused on the difference between RES and CES. As a result, further research is performed on the base of GOBAS, which aims to improve the evaluation index and scoring method.

**GREEN BUILDING ASSESSMENT SYSTEM (2006)**

GBAS (2006) is the evolution of GOBAS, which has inherited the main theory of GOBAS and developed new contents based on large numbers of case studies. In the assessment of RES utilization, the important improvement includes new effective substitution ratio (ESR) and scoring method.

**ESR**

Assuming the renewable energy earning (REE) reduction according to extra energy consumption is equal to the output of extra energy applied in the normal CES, GOBAS (version 2003) takes the coefficient of performance \(\text{COP} \) as the conversion coefficient between extra energy consumption and reduced REE, which ignores the difference between different CESs. In the new GBAS (2006), ESR is defined as

\[
\text{ESR} = \frac{\text{REE} - Q_{\text{ex}}}{\text{Total energy demand}},
\]

where \(Q_{\text{ex}}\) denotes the loss of REE according to the extra energy consumption, which has the same energy type as REE. \(Q_{\text{ex}}\) is assumed as building’s energy demand generated from main CES with the input of RES’s extra energy consumption. Sometimes, consumed energy type of RES is different from that of CES, and \(Q_{\text{ex}}\) can’t be calculated directly. In this case, Energy Quality Coefficient (EQC) and Energy Conversion Coefficient (ECC) in GOBAS are introduced. EQC is defined as

\[
\lambda = \frac{W}{Q}
\]

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

Based on the exergy principle, exergy included in energy are equivalent to each other and conversion between different types of energy can be realized with EQC.

ECC of CES and RES are defined as

\[
\text{ECC}_{\text{CES}} = \frac{\lambda Q}{\sum (\lambda_{\text{CES}_{\text{used},i}} W_{\text{CES}_{\text{used},i}})}
\]

and

\[
\text{ECC}_{\text{RES}} = \frac{\lambda_{\text{RES}} Q_{\text{RES}}}{\sum (\lambda_{\text{RES}_{\text{used},i}} W_{\text{RES}_{\text{used},i}})},
\]

where

\[
\text{ECC}_{\text{CES}} - \text{ECC of the CES to acquire Q, GJ;}
\]

\[
\text{Q} - \text{the i type end-use energy demand, GJ;}
\]

\[
W_{\text{CES}_{\text{used},i}} - \text{the j type CES consumption to acquire Q, GJ;}
\]

\[
Q_{\text{RES}} - \text{the i type end-use energy demand of a building acquired by RES, GJ;}
\]
W_{RES, used} -- extra energy consumption to obtain \( Q_{RES, I} \), GJ.

Based on EQC and EEC, the exergy included in the energy consumed by RES and CES are equivalent and the following formula can be achieved:

\[
\sum \lambda_{res, used} W_{res, used} = \sum \lambda_{ces, used} W_{ces, used}
\]  

(5)

Combining Eq.(5) and Eq.(3), \( Q_{EC} \) can be calculated by

\[
Q_{EC} = \frac{ECC_{ces} \sum \lambda_{res, used} W_{res, used}}{\lambda_{res}}.
\]

Moreover, introducing Eq.(6) and Eq.(4) into Eq.(1), the following formula to calculate ESR can be obtained.

\[
ESR = \frac{\lambda_{res} Q_{EC} - \lambda_{res} Q_{raw}}{\lambda_{res} Q_{raw}} - \frac{ECC_{ces} \sum \lambda_{res, used} W_{res, used}}{\lambda_{res} Q_{raw}} = \frac{Q_{EC} - ECC_{ces} \left( \frac{1}{\lambda_{res}} \right)}{Q_{raw} \left( 1 - \frac{ECC_{ces}}{ECC_{res}} \right)}
\]

(7)

where energy type of \( Q_{raw} \) and \( Q_{RES} \) are the same, and \( \lambda_{RES} \) is equal to \( \lambda_{raw} \).

As seen in Eq.(7), ESR is different from SR in LEED, which is net ratio of REE to total energy requirement. A correction coefficient, which is decided by efficiency of CES an RES, cannot be ignored. When extra energy consumption of RES is considered, ESR increases with ECCRES with same energy amount generated from RES. Furthermore, if ECCRES is lower than ECCCES, ESR becomes negative. In other words, such RES should not be applied in this building.

In order to illustrate the importance of the new ESR index, a geothermal heat pump hot water system (GHPHWS) is analyzed as a case study. Important parameters of different hot water systems are shown in Table 2, and ECCCES is calculated by Eq. (3). The EQC of hot water (90°C) from a central heating system is lower than that from other systems, so the ECCCES of the central heating system is the highest one. Because the EQC of electricity is 1, the ECCCES of the electric boiler is the lowest one.

<table>
<thead>
<tr>
<th>Boiler</th>
<th>Central Heating</th>
<th>Oil</th>
<th>Gas</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECCCES</td>
<td>0.36</td>
<td>0.17</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1.00</td>
<td>0.90</td>
<td>0.90</td>
<td>1.00</td>
</tr>
<tr>
<td>EQC</td>
<td>0.23</td>
<td>0.44</td>
<td>0.52</td>
<td>1.00</td>
</tr>
</tbody>
</table>

With a given average annual COP of 3-4 for a geothermal heat pump system to supply hot water, the ECCRES is 0.25-0.34. Given that the heat energy supplied by a GHPHWS is 50% of the total heat demand, the ESR5 of the GHPHWS substituting for different types of CESs is determined in Figure 1.
Figure 1. ESR for GHPHWS substituting for different conventional hot water systems

In LEED assessment, the SR is 50%. Actually, the extra energy consumption of GHPHWS cannot be ignored. For a GPHWS with the COP of 3-4 to substitute for different CESs, the following conclusions can be got:

- An obvious diversity of ESR was achieved and ESR increases with COP of GHPWS.
- Because of high EQC of supply hot water (110°C/90°C) in the central heating system (EQC=0.23), the ECCCES of central heating system is very high. When a GPHWS is used to substitute for the city district heating system, the ESR becomes negative due to high ECCCES of the city district heating system is higher than ECC of GPHWS. In this case, it is not an energy conservation approach to apply GPHWS to substitute for central heating system.
- When substitute for the other three systems, ESR is larger than zero.
- The LEED assessment method cannot distinguish the difference between energy system efficiency and energy type; furthermore, the rating result could mislead designers and customers.

Scoring Method

In GOBAS, assessment of renewable energy system includes substitution of electricity, hot water & heating, cooling and other end-use energy demand by RES and the total score of this item is the sum of these four aspects. In other words, RES must substitute for the CES all in electricity system, hot water & heating system as well as cooling system. On the other hand, application of RES depends on the local natural resources, economy level, building type and other conditions. According to large numbers of case studies, it is hard to substitute RES for CES in all systems or the cost will be too high. Actually, it is reasonable to design one or two kinds of RES according to the project's condition. As a result, a new scoring method is proposed in GBAS (2006) and it has higher feasibility in practical application. In the new method, the highest score of each sub-item equals 5, and the total score of LR1.3 equals the sum of four sub-items. When the total score exceeds 5, only 5 scores can be got.

$$LR1.3=\min(LR1.3.1+LR1.3.2+LR1.3.3+LR1.3.4, 5).$$

The score level of four sub-items are shown in Table 3. Considering the difficulty to substitute for different CES, the ESR range to get the same score is different from each other. For substitute for electricity in office building, the total electricity demand is very high, and current techniques to obtain electricity by RES are not widely applied. Therefore, if ESR varies in the range of $[0.5\%, 1\%]$, 3 scores can be got. While to substitute for hot water system, the range of $[40\%, 60\%]$ for ESR can get 3 scores, which results from small amount of hot water required in office building.
Table 3 Score level of GBAS for Office Building

<table>
<thead>
<tr>
<th>Score</th>
<th>LR1.3 Renewable energy utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0%&lt;ESR≤20%</td>
</tr>
<tr>
<td>2</td>
<td>20%&lt;ESR≤40%</td>
</tr>
<tr>
<td>3</td>
<td>40%&lt;ESR≤60%</td>
</tr>
<tr>
<td>4</td>
<td>60%&lt;ESR≤80%</td>
</tr>
<tr>
<td>5</td>
<td>80%&lt;ESR≤100%</td>
</tr>
</tbody>
</table>

LR1.3.1 hot water LR1.3.2 cooling LR1.3.3 cooling LR1.3.4 electricity

Take examples of two typical green buildings in China (Figure 2), which can represent the current green building level in China. Many energy conservation and environment-friendly techniques have been applied in the two buildings, and this paper only focuses on the RES. PV system and solar hot water system are designed in the two building to provide electricity and hot water, and the ESR values are exhibited in Table 4.

Table 4 Score level of GBAS for Office Building

<table>
<thead>
<tr>
<th>Building</th>
<th>ESR</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LR1.3.1 hot water</td>
<td>LR1.3.3 electricity</td>
</tr>
<tr>
<td>A</td>
<td>30%</td>
<td>1.5%</td>
</tr>
<tr>
<td>B</td>
<td>50%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Applying scoring method of GOBAS and GBAS to assess the RES level of the two buildings, the score of item “LR1.3” can be obtained in Table 5. For the GOBAS system, weight of all the four sub-items equal 0.25, and the final score of “LR1.3” equals the weighted average value of four sub-items. For the reason that only hot water and electricity are substituted by RES in the two buildings, the final scores of “LR1.3” are 1.75 and 2 separately. Although, only hot water and electricity have been substituted by RES, a great deal of money has been invested in the RES in the two buildings and the owners have tried their best to apply renewable energy. It is unreasonable to require all the projects to utilize RES to substitute for all the CES, and the investment can hardly be accepted by the owners. As a result, the assessment method of GOBAS is too rigorous to be applied practically. Actually, all the electricity has been substituted by a PV system and partial of hot water has been by solar hot water system. In other words, RES has played an important role and the score can not be low. In the new GBAS, the score of “LR1.3” equals the sum of all the sub-items and 5 are obtained for the two buildings, which can represent the real level of the two buildings’ RES.
Table 5  Score of Renewable Energy Utilization (LR1.3)

<table>
<thead>
<tr>
<th></th>
<th>GOBAS</th>
<th>GBAS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score</td>
<td>Weight</td>
</tr>
<tr>
<td>LR1.3.1 hot water</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>LR1.3.2 heating</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LR1.3.3 cooling</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LR1.3.4 electricity</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>LR1.3 Renewable Energy Utilization</td>
<td>1.75</td>
<td>2</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Based on the former research of GOBAS, this paper developed a new calculation method of ESR and improved scoring method of GOBAS. Applying ESR, the extra energy consumption of RES are considered and efficiency of both RES and CES can not be ignored. If the efficiency of RES is lower than that of CES, the ESR is negative and RES can not be supported in the building. In this case, not only the end-use energy quantity generated from RES should be concerned, but also the efficiency of RES should be taken into account.

Considering the economical level and the condition of practical projects, an improved scoring method is developed in GBAS, in which not all the end-use energy must be substituted by RES. If CES can be substituted by RES in one or two types of end-use energy with high ESR, the final score of “LR1.3” can be high. With the new scoring method, the enthusiasm of owners to apply ESR will be maintained.

As a large and comprehensive system, GBAS has a critical influence on the development of green buildings in China. However, the assessment system should still be improved with the development of green building industry. This paper contributes to the improvement of renewable energy utilization assessment. Further work is still necessary.

REFERENCES