ABSTRACT

Because of excessive development of the economy, global industrial pollution, and over exploitation of nature resource, people all around the world begin to promote environmental protection projects and concept, which have been neglected for a long time. Since the concept of sustainable development has become the global consensus in 20th century. It might be the suitable time to introduce a new concept of Sustainable and Ecological Building into architecture in Taiwan. The poor indoor environment in Taiwan is mostly due to crowded living space, highly airtight buildings, poor air circulation, and lack of consensus. Indoor environment is significantly important for human health since people spent most of time indoors. Therefore, utilizing natural and healthy materials for ensuring a healthy and comfortable indoor environment should be the future priority in architectural design.

For the difference of culture and environment, the solutions to future sustainable building need to cater for indigenous living space. Although the solutions are different, the items in evaluating Sustainable and Ecological Building could be standardizing. Therefore, an entire lifecycle assessment (LCA) evaluation system of healthy building has developed in recent years. The system include environmental index of micro-climate in site (PEI), indoor-environment index (IEI), the post-occupancy evaluation method (POEM) and the computer-assistant-design procedure of CFD method. All the system is objective to create a healthy building and ensure a healthy living.

Keywords: Sustainable Building: POEM: CFD: Healthy Building: Microclimate:
Physical Environment Index: Indoor Environment Index

1. INTRODUCTION

What will we face in the coming decade of 21st century? a deep concern coming from my heart when people vigorously celebrated to welcome the millennium year. Excessive development of the economy, global industrial pollution, and over exploitation of nature resource caused a series environmental impacts and human disasters in this decade.[1] All the impacts, global climatic change,
deforest, ecosystem destroys, desertification of land, and global pollution etc, caused by human and also threaten human's life by any kind of disaster. Global environmental issues have become the fateful issues for humanity. When we turn back to look our history and seek for the truth of life, we should find a way to sustainable development in the next century.

2. INTERNATIONAL TREND OF RESEARCH

2.1 Definition of Sustainable Building, Green Building, and Healthy Building

The Conference on the Human Environment held in Stockholm in 1972, made people begin to pay much attention on the issue of global environmental pollution. Serial of conferences about environmental impact, ecological conservation, and sustainable development were held in these decades. A lot of new concepts, items and technology about architecture were therefore created and defined by international consensus in the conference. The Conference of Sustainable Building 2000, which was held in Netherlands in the millennium year also highlighted the importance of sustainable building and demonstrated many paradigm and designing criteria. People were just awakening to environmental consciousness and sustainable development in Taiwan in these couple years. Some concepts and definitions, which were deliberated by most western countries, were not well known in Taiwan. Therefore, it is necessary to introduce these definition and major conclusions that were recognized in serial international conferences.

Sustainable building was concluded as "A sustainable agenda operated on scales of materials, buildings, and urban regions, and must also include consideration of functional, social, economic and ecological factors. Strategies for reaching a sustainable built environment must reflect varied regional conditions and priorities, and different models for implementation: think global, act local “[Sustainable building 2000].

Green Building was stated as "To use the limited resources more efficiently and promote the solutions in economy and environment problems, further more to improve the living environment, is called the Green Building.”[United Nations Commission on Sustainable Development, 1993]

Healthy Building was defined as ”The way in which we experience the indoor environment includes not only physically measurable quantities, such as temperature, draughts, ventilation air flow rates, noise, air quality or light, but also esthetic factors such as layout, light, colors, space, materials and other subjective elements. To these must be added other factors such as job satisfaction and good relationships with superiors and colleagues. A healthy building has all these.”[Healthy building 2000]

According to the above concepts, the relationship of healthy building, green building, ecological building and sustainable building could be summarized in Figure 1. The ultimate goal of these gradational developments, from healthy building to sustainable building, is trying to create a built that could provide a balance of human life, ecological reservation, and nature resources of earth. Therefore, the perspective architecture not only should comprise the basic elements to support healthy human life and also have to take energy-efficient design, regional resources, reuse or renew of nature resources, and the minimum deplete of ecosystem into account.

Figure 1. The gradational development of healthy building, green building, ecological building, and sustainable building.
2.2 Evolution of sustainable development

Global industrialization accompanies with fast economic development and modern civilization but also bring massive impacts on environment. In 1960s, people begin to face the shortage of nature resources and the deterioration of environment. The consensus arises out of the growing concerns on ecological conservation and the crisis of energy in 1970s. The Congress of Union International Architect (UIA) held in Warsaw, 1982, declare the importance of building environment affects on human health. Integrating environmental quality and concept of conserving energy and nature resources into architecture have become a new challenge at that time. The World Commission on Environment and Development, which was established by Union Nations, published its proceedings entitled Our Common Future in 1987. The document is also known as the Brundtland Report. Central to the Brundtland Report was the concept of sustainability, which was defined as the principle that economic growth can and should be managed so that natural resources be used in such a way that the “quality of life” of future generations is ensured. The Earth Summit held at Serrado Mar, Brazil in late spring was the extension of the work of the Brundtland Report also sponsored by UN Commission on Environment and Development. The publication of its proceedings, Agenda 21, named after the century has provide a much more comprehensive outline of the possible scope of sustainable development. This report enforced to appeal the consensus of the concepts in the quality of life, efficient use of the earth’s materials, the protection of our global commons, the management of human settlements, chemicals and the management of waste, and sustainable economic growth. In 2000, humanity stands at a defining moment in history. We are confronted by a worsening of ill health, poverty, and hunger and the continuing deterioration of the ecosystems on which we depend for our well-being. Retrospecting to the lesson of our history, it therefore demands immediate attention to find a sustainable way for our future.

2.3 Development of assessment systems in sustainable buildings

A comprehensive assessment system to provide the key environmental performance criteria of sustainable building to facilitate international comparison is needed in promoting sustainable development. Since Our Common Future, published by UN Commission on Environment and Development in 1987, defining the importance of sustainability. Countries around the world began to set the assessment system in respond to the declaration, such as BREEAM conducted by United Kinden, BEPAC by Canada, BEE by USA etc. In general, the internal parts of these assessment system could be define into three categories: (1) conserving energy and environmental protection, (2) ecological conservation and planting (3) comfortable and healthy. These three dimensions should be integrated into assessment system to achieve the ideal sustainable architecture.

![Figure 2. The development of assessment systems in Sustainable building](image-url)
2.4 Indicators of Life-Cycle Assessment

Life-Cycle Assessment (LCA) is an international recognized method of examining the total environmental burden associated with product and its use. It could provide a quantitative assessment of environmental inputs and outputs in any construction process when utilizing in architecture. All stages should be included in LCA system, in which including design, material choose and transportation, construction, use and maintenance, waste management, and energy and materials renew or recycle. All the indicators that are set by countries are summarized in the Table 2.

Summary of indicators in assessment system could been observed that most system contain environmental impacts assessment, surface environment of building, energy-efficient and reuse, water re-cycle, materials selection, efficient use of nature resources, indoor environment and healthy indicators etc. This summary could be the reference provides Taiwan for promoting environmental sustainable indicators of architecture in the future.

Most of sustainable assessment systems were developed in Europe, Northern America, and Japan, all these countries are in high latitude region of earth. Taiwan is located in subtropical and topical region; the climate and regional characteristics are totally different from these countries. Therefore, it is important to develop a sustainable assessment system adopting the characteristics of our region. Taiwan have promoted a Green Building Labeling system, in which also take some indicators into account. But these indicators are not sufficient to integrate all process of building lifecycle. Future enforcement should develop and promote a Life-Cycle assessment system with suitable sustainable building indicators in respond to the sustainable way of humanity.

3. DESIGN A HEALTHY BUILDING IN TAIWAN – THE METHODS AND RESULTS

3.1 Evaluating Method with regional Characteristics—PEI Indicators

The subtropical region is located adjacent to the equators. The main climatic characteristic of this region is 'hot in summer and warm in winter'. Taiwan is surrounding with oceans and its landforms change variously. So, the local climatic features are highly changeful in different time periods and locations in Taiwan. Those features have great influence on the physical environment for cities and built-environment, for example: air quality, thermal comfort...etc. This study takes four large cities (Taipei, Taichung, Tainan, and Kaohsiung cities) as our examination objects and drafts the necessary indicators of physical environment for each city. The first step of the methodology is to review and collect the indicators shown on related research literatures. The referenced material in this study is derived mainly from 'Indicators of Sustainable Development for the United Kingdom' (HMSO, UK, 1996), 'Environmental Indicators; OECD Core Set' (OECD, 1994), 'Development of Indicators for Sustainable Taiwan' (Executive Yuan, Taiwan, 1997)...etc.

According to the inherent physical characteristics, indicators are then classified into eight categories, including acoustics, lighting, thermal comfort, air quality, water quality, greens, vibration, and electromagnetic fields of physical environment. The analytic hierarchy process (AHP) method, which was developed by Thomas L. Saaty (1971), is carried out to do the weighting among eight categories and those indicators in the same category respectively. Expertise with respect to every professional field was involved in the process of deciding the relevant weight. To begin with, the literature review, group brainstorming and Delphi method were used for selecting the proposed indicators. These indicators, then, were classified into the independent categories to set up the hierarchy. The nominal-ratio scale of pairwise comparison among the indicators represented as the score from 1 to 9 was adopted, which was filled in a positive reciprocal matrix to calculate the eigenvector and maximum eigenvalue. The consistency ratio was obtained to filter out the null questionnaire when the value of the consistency index (C.I.) was greater than 0.1. For each category, the weighting value was obtained by the geometric mean of experts'
questionnaires. The numbers of experts under consultation in four cities are 16 (Taipei), 4(Taichung), 19(Tainan), and 7(Kaohsiung).

The presented results, announced a set of dominant physical indicators, and the weightings of various physical categories, are fitted for the assessment on the physical environment to benefit the occupants' health. The experts' opinions, based on the recent situations and the domestic environmental requirements, were applied. The results show that the “Air Quality” environment and the “Water Quality” environment are the first and second of the physical environment on both city and building scale in Taiwan. They deserve more emphases. We also propose a comprehensive index, Physical Environmental Index for sustainable cities and buildings (PEI-C, PEI-B), to evaluate the physical environment.

3.2 Evaluation method in design procedure—CFD computer simulation

For more detail evaluation of buildings in design process, utilizing Computer assisted design, the effects of different environment can input into the environment setup. By different boundary condition setup, the results can be corresponding to the microclimate and geography. Figure 5 shows the variation for different interior design.

3.3 Building Doctor Diagnosing Method – POEM
The healthy living environment was the basic requirement for old buildings, or new buildings in sustainable building. A S.O.P. diagnose procedure in field study was setup for POEM (Post-Occupancy Evaluating Method) evaluation. The factors adopted in diagnosis including wind velocity, temperature, humidity, noise and illumination, and health factors on radiation, electromagnetic field, dust, chemical factors such as CO, CO₂, O₃, SOx, HOCH₂, TVOC, biological factors such as Bacteria, Fungi, Endotoxin and Allergy. The overall indicators are also involved in the criteria of the mechanical engineering, building owner and the architects.

3.4 Environmental evaluation in existing buildings—Indoor Environment Index (IEI)

In the similar manner of risk assessment, presented by Gadeau et al. (1997), we propose a comprehensive index, indoor environment index \((IEI_{(AHP)})\), to evaluate the indoor environment. It is assumed that there is an integrated effect accumulated from every category of physical-environment impact on occupants’ health. Therefore, the index \(IEI_{(AHP)}\) shown in Equation 1 is based on the summation of \(Sx\), the evaluated score of the physical-environment category \(x\), multiplied by \(Wx\), the weighting of the physical-environment category \(x\).

\[
IEI_{(AHP)} = \sum S_x \cdot W_x 
\]  

In addition, there is not less than one indicator in the physical-environment category. The evaluated score of the \(i\)th indicator in the category \(x\), \(S_{xi}\), is evaluated on a score-grade of 20, 40, 60, 80 and 100, which corresponded to the risk values on the occupants’ health. When the score of \(S_{xi}\) exceeds 60, it means no sanitary risk is incurred. The \(Sx\) is based on the scores consisted of \(S_{xi}\). If there exists \(S_{xi} < 60\), then the score of \(Sx\) is the minimum of \(S_{xi}\) in order to emphasize the worst conditions of indoor environment; if for all \(S_{xi} \geq 60\), it means that no one is reached sanitary risk, we give \(Sx\) the arithmetic mean of \(S_{xi}\), that's:

\[
if, \exists i, S_{xi} < 60, then: S_x = \min(S_{xi}), else, S_x = \frac{1}{n} \sum_{i=1}^{n} S_{xi} 
\]
Figure 8 shows the results of the AHP analysis from the experts’ questionnaires. The original weighting is listed in sequencing: “IAQ” (0.221), “Thermal comfort” (0.159), “Acoustics” (0.155), “Illumination” (0.125), “EMF” (0.103), “Greens” (0.070), “Vibration” (0.054) and “Water quality” (0.051). This occurrence reflects the opinions from the experts on the practical aspects of the recent period and the domestic situation. According to the economic sense, the minor categories whose weighting were less than 0.1 were filtered out. It means that the influence ratio of each minor category is less than 10% of whole benefit for the recent environment. Figure 14 shows the results after the adjustment, there are five categories left, and the adjusted weighting is listed in sequencing: “IAQ” (0.290), “Thermal comfort” (0.208), “Acoustics” (0.203), “Illumination” (0.164) and “EMF” (0.135). Substituting the adjusted weighting into Equation 1, we get:

\[ IEI_{(AHP)} = 0.203 \cdot S_{\text{Acoustics}} + 0.164 \cdot S_{\text{Illumination}} + 0.208 \cdot S_{\text{ThermalComfort}} + 0.290 \cdot S_{\text{IAQ}} + 0.135 \cdot S_{\text{EMF}} \]  

Figure 8 The original weighting from the experts’ questionnaire

Figure 9 The adjusted weighting of the essential categories

The scale being used to transmit the value of the field-measurement to a grade is the score of 20, 40, 60, 80 and 100. Table 2 shows the relationship of the evaluated score corresponded to the field-measurement magnitude. These indicators consisted from the five categories were advised through literature review and experts’ consultation on the practicable and essential aspects. The manner of score-evaluation was represented a five-interval scale, divided from the physical magnitude, and used a set of references as the benchmarks for determining the scores of 20, 40, 60, 80 and 100.

Here, the references corresponded to the score 60 were referred to the criteria of the regulation adopted widely for human-health protection. It means occupants were caused the sanitary risk by the exposure to an indoor environment whose evaluated score of any indicator is less than 60, respectively.

In “Acoustics” category, two indicators, the equalized sound pressure \( L_{\text{eq24H}} \) for dwellings and \( L_{\text{eqD}} \) for offices, were included. In “Illumination” category, four indicators, including the intensity of luminance for the ambiance and the operated face, uniformity ratio and daylight-use ratio, were used for assessment. In “Thermal Comfort” category, there were six indicators for assessment, including indoor temperature in various season, relative humidity, air velocity and PMV. In “IAQ” category, five common indoor air pollutants were appointed as the characteristic compounds. In “EMF” category, the electric-field intensity and the magnetic flux on the extremely low frequency (50/60 Hz) were used.

The presented results, announced a set of physical indicators, the weightings of various physical categories and evaluated scales corresponded to the field-measured values, are fitted for the assessment on the built environment to benefit the tenants’ health. The experts’ opinions, based on the recent situation and the domestic environment, were applied. Figure 10.

<table>
<thead>
<tr>
<th>Advised indicators</th>
<th>Units</th>
<th>Evaluated score corresponded to the field-measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Acoustics” Category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For dwellings, Equalized SPL in 24 hours (( L_{\text{eq24H}} ))</td>
<td>dB(A)</td>
<td>&gt; 55 □ &gt; 50 □ &gt; 45 □ &gt; 40 □</td>
</tr>
</tbody>
</table>

Table 1. Scales of the evaluated score corresponded to field-measured value
### Indoor Air Quality category

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suspended particulate matter (PM₁₀)</td>
<td>mg/m³</td>
<td>25</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>ppm</td>
<td>2</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>ppm</td>
<td>2</td>
</tr>
<tr>
<td>Formaldehyde (HCHO)</td>
<td>ppm</td>
<td>8</td>
</tr>
<tr>
<td>Volatile organic compounds (VOCs)</td>
<td>mg/m³</td>
<td>5</td>
</tr>
</tbody>
</table>

### Electromagnetic Fields category

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric field intensity of extremely low frequency (ELF)</td>
<td>kV/m</td>
<td>5</td>
</tr>
<tr>
<td>Magnetic flux of extremely low frequency (ELF)</td>
<td>tesla</td>
<td>100</td>
</tr>
</tbody>
</table>

### Thermal Comfort category

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor temperature, summer season</td>
<td>°C</td>
<td>26</td>
</tr>
<tr>
<td>Indoor temperature, spring &amp; autumn season</td>
<td>°C</td>
<td>25</td>
</tr>
<tr>
<td>Indoor temperature, winter season</td>
<td>°C</td>
<td>24</td>
</tr>
<tr>
<td>Indoor Relative Humidity</td>
<td>%</td>
<td>60</td>
</tr>
<tr>
<td>Indoor air velocity</td>
<td>m/sec</td>
<td>0.15</td>
</tr>
<tr>
<td>PMV</td>
<td></td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Illumination category

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average illumination of the ambient</td>
<td>lx</td>
<td>70</td>
</tr>
<tr>
<td>Average illumination at the operated face in offices</td>
<td>lx</td>
<td>500</td>
</tr>
<tr>
<td>Uniformity ratio of illumination at the targeted face</td>
<td>%</td>
<td>0.15</td>
</tr>
<tr>
<td>Ratio of daylight-use</td>
<td>%</td>
<td>2</td>
</tr>
</tbody>
</table>

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**Figure 10.** A completely diagnosing and evaluating procedure in Sustainable and Healthy Building Concept in Taiwan
4. STRIDE FORWARD TO SUSTAINABLE BUILDING – THE FUTURE WAY OF TAIWAN

The beautiful “Formosa” located in subtropical region with unique climatic characteristics and varied landforms. The diversity of regional environment creates varied ecosystems providing ideal diversity of life. Environmental issue has been neglected for many decades in our land. The environmental impacts, over exploitive nature resources, and endanger biodiversity were the alarm in response to our over extension. It is important and also demands immediate attention to promote the concept of sustainability in this fragile island.

As the conclusion of Sustainable Building 2000 have quoted. The spirit of sustainable development is “They can harmonize with troubled waters, and bring it to clearness little by little, they can move with stability, and make life little by little Sustainable”, which is the spirit of Chinese living attitude. Retrospecting to the history and traditional Confucian and Taoism spirit, find a way to sustainable development in Taiwan should be the common consensus for all civilians. Find the way to the sustainable building in Taiwan also should be the future enforcement for human well-being.

ACKNOWLEDGEMENTS

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### Table 2: The Comparison Lists in Evaluation Tools the Entire World

|------------------|-----------------|-----------------|-----------------------|---------|-----------------|--------|-----------------------|---------------------|------------|

* SB2000 International Conference, 2000
* * GBC'98 International Conference, 1998

*: Japan 「環境共生住宅推進協議會」--環境共生住宅 A-Z
*: Taiwan's Seven Indicators
*: Suggestion the New Comprehensive Indicators in Taiwan
Table 2...The comparison lists in evaluation tools all of the world (continued)

<table>
<thead>
<tr>
<th>Evaluation Tool</th>
<th>Country</th>
<th>Year</th>
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<th>Economic performance</th>
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<tbody>
<tr>
<td>BEES</td>
<td>America *</td>
<td>1994</td>
<td>(1) Global warming potential</td>
<td>(1) Solid waste</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(2) Acidification potential</td>
<td>(1) Indoor air quality</td>
</tr>
<tr>
<td>CBE</td>
<td>Sweden *</td>
<td>1998</td>
<td>(1) Global warming</td>
<td>(1) Life circle of materials (Minerals, Metals, Wood...)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(2) Ozone depletion</td>
<td>(2) Thermal environment</td>
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<td></td>
<td>(3) Acidification</td>
<td>(3) Sound environment</td>
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<td>(4) Eutrophication</td>
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<td>(5) Photochemical ozone formation</td>
<td>(5) Electromagnetic field (EMF)</td>
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<td>(6) Piped water quality</td>
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<td>LEED</td>
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<td>(3) Re-Generation Energy</td>
<td>(3) Tests &amp; Characteristics</td>
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<td>(4) Green Power</td>
<td>(4) Low Emission Materials of VOC</td>
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<td>(2) Smoke Hazards</td>
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<td>(4) CO₂ Monitoring</td>
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<td>(5) System Control</td>
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<td>(6) Ventilation Efficiency Improvement</td>
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<td>(7) Thermal comfort</td>
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<td>(8) Planning of Indoor Environment Management</td>
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<td>(9) Sunlight</td>
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<td>1996</td>
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<td>(2) Waste reduction</td>
<td>(2) Water conservation</td>
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<td>(4) Sewer and garbage</td>
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<tr>
<td>Energy star</td>
<td>America **</td>
<td>1998</td>
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<td>(1) Air quality and Ventilation</td>
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<td>(2) Net annual emission of pollutant for building operation</td>
<td>(2) Thermal Comfort</td>
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</tbody>
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※: SB2000 International Conference, 2000  
*: GBC’98 International Conference, 1998  
**: Energy Star International Conference, 2000  
*: GBC’98 International Conference, 1998  
*: Japan 「環境共生住宅推進協議会」--環境共生住宅 A-Z  
*: Taiwan’s Seven Indicators

**: Suggestion the New Comprehensive Indicators in Taiwan
|----------|--------------------------|-------|---------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|-----------------------------|-----------------------------|