Design strategies for responsive building elements and integrated building concepts

“What design strategies should be followed for an integrated building design with responsive building elements?”

“What tools are available?”

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• This presentation is not only for the responsive building element, but also for broader energy-saving building elements, which are to be called as “energy-saving technological elements”, here.

• The “energy-saving technological element” is defined as a cluster of techniques, which constitute a single common function to save the energy in the buildings.

• The list of the energy-saving technological elements is as follows. It is easier to see the list to understand the definition.
Energy-saving buildings

Energy-saving TE for natural energy utilization
1. Natural ventilation (for space cooling)
2. Day lighting
3. Photovoltaic cells
4. Passive solar (for space heating)
5. Solar hot water system

Energy-saving TE for heat control by the envelope
6. Insulated envelope
7. Solar shading

Energy-saving TE for building equipment
8. Heating and/or cooling
9. Ventilation
10. Domestic hot water
11. Artificial lighting
12. Equipment for conveyance (Elevator, etc.)
13. Electric appliances and others
14. Cogeneration

RBE
Advanced Energy-saving TE
- Earth Coupling
- Thermal Mass Activation
- Phase Change Material
- Dynamic Insulation
- Advance Integrated Facade
Competition among elements toward real energy-saving buildings

• For the experts developing/promoting each element, the element is everything.

• But, designers, etc. would like to pick up cost-effective elements from alternatives.

• Fare evaluation and validation is needed for designers etc. They are sensitive and clever.

• It is also for the earth.
Stage 1
Grasp design conditions & residents' request
- Check the potential of natural energy utilization of site
- Grasp lifestyle of residents

Stage 2
Decide on design target and course
- Choose a type of house according to the design target
  → Priority of technological elements

Stage 3 & 4
Basic Design
- Site plan & plan
- Section and façade
- Envelope specification
- Building services

Stage 5
Analysis of basic design & checking the effectiveness
- Basic items for LEHVE
- Natural energy utilization
- Envelope insulation and solar shading
- Energy efficient equipment

End of design

Identify design conditions related to energy performance of buildings

Energy-saving technological elements, which fit to design conditions, are to be identified, to be determined of their specifications, etc.

“LEHVE” is abbreviation of “Low Energy Housing with Validated Effectiveness”. The term is used in a Japanese design guideline of energy-saving residential buildings for architects and builders (non-experts on energy-related engineering.)
Design

• Sometimes, “design” for the architecture tends to be respected as highly sophisticated and noble activity, but the design for low energy architecture has to be much more simplified and accessible.

• “Design” is just “to show how they make the building” referring to the dictionary.

• For the low energy architecture, they should take into consideration the design conditions such as climate, building use, occupants behavior, economical conditions, etc. That is the starting point, and the most important key step in the design activity of the buildings.
Key steps in the evaluation (for residential building case)

• To determine the **design condition** and the **reference condition**, which is the basis to be compared when evaluating the improvement by his/her own design.
  – N. of family member
  – Heating & cooling condition (time, temp., etc.)
  – Configuration of the house (area, layout, etc.)
  – Internal heat gain and electric consumption
  – Envelope (business as usual)
  – Equipment (business as usual)

• To determine the **energy consumption ratio** (=own design/reference) on the basis of experimental results, laboratory tests and simulations.
Basic family

Housewife 44
First child 16 (high school girl)
Householder 46 (businessman)
Second child 14 (junior high school boy)

Family structure assumption

4 member family including a elder member
Double income young couple
Elder couple retired
## Time table for week-days of the basic family

<table>
<thead>
<tr>
<th>Time</th>
<th>Householder (46) businessman</th>
<th>Housewife (44)</th>
<th>First child (16) High school girl</th>
<th>Second child (14) Junior high school boy</th>
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</tbody>
</table>
Table-8 Total daily hot water usage for different uses in the basic family (Mae et al., 2008)

<table>
<thead>
<tr>
<th>L/day (42°C)</th>
<th>kitchen</th>
<th>bathtub</th>
<th>shower</th>
<th>wash up</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week days (large)</td>
<td>120</td>
<td>150</td>
<td>140</td>
<td>60</td>
<td>470</td>
</tr>
<tr>
<td>Week days (small)</td>
<td>100</td>
<td>150</td>
<td>80</td>
<td>50</td>
<td>380</td>
</tr>
<tr>
<td>Weekend, stay at home (large)</td>
<td>200</td>
<td>150</td>
<td>200</td>
<td>100</td>
<td>650</td>
</tr>
<tr>
<td>Weekend, stay at home (small)</td>
<td>160</td>
<td>150</td>
<td>140</td>
<td>100</td>
<td>550</td>
</tr>
<tr>
<td>Weekend, outgo (large)</td>
<td>10</td>
<td>150</td>
<td>200</td>
<td>20</td>
<td>380</td>
</tr>
<tr>
<td>Weekend, outgo (small)</td>
<td>10</td>
<td>0</td>
<td>200</td>
<td>30</td>
<td>240</td>
</tr>
</tbody>
</table>
Energy saving by choosing efficient lighting fittings, electric appliances and water heaters

40% reduction is possible.
Energy consumption of reference dwelling unit

Reference Dwelling Unit

Primary Energy Consumption (GJ/a)

0.0  5.0  10.0  15.0  20.0  25.0

Ventilation
Lighting
TV
Laundry machine
Cleaner
TV game & CD radio
PC & iron
MD radio & task lighting
Dryer
Refrigerator
Warm toilet bench
Air-conditioner
Cooking range
Electricity for hot water gas
Gas for hot water gas heater

Total 78.1 GJ/a

note: 1 kWh=9.83 GJ in primary energy for this analysis
Energy consumption of a target dwelling unit

Primary Energy Consumption (GJ/a)

- Ventilation
- Lighting
- TV
- Laundry machine
- Cleaner
- TV game & CD radio
- PC & iron
- MD radio & task
- Dryer
- Refrigerator
- Warm toilet bench
- Air-conditioner
- Cooking range
- Electricity for hot water
- Solar hot water system B
- Gas for hot water gas

Total 47.6 GJ/a

42.6 GJ/a → 26.2 GJ/a  -21%

26.8 GJ/a → 12.7 GJ/a  -18%

note: 1 kWh=9.83 GJ in primary energy for this analysis
Framework of newly proposed design method

- For the identification of appropriate energy-saving technological elements or RBE at early design stage, the following items are to be described.
  - **Factors having influences on energy saving (design cond.)**
    - Climate, energy such as solar heat, day light and wind)
    - Site (availability of natural Pre-determined building characteristics such as form, structure, design concept, etc)
    - Building use such as purpose, duration, internal heat gain, etc.
  - **Method to estimate the effectiveness on energy saving**
    - Standardized format of the information including “energy consumption ratio”, which can be defined as a ratio between expected energy consumption and reference (average) energy consumption for corresponding energy use.
    - Procedure to estimate the expected and reference energy consumption by using simulations and results of experiments and monitoring.
    - The estimation shall be done for plural levels of the design for each technological element, and requirements on the specification for those levels shall be described.
An example of design flow

Stage 1
Grasp design conditions & residents’ request
- Check the potential of natural energy utilization of site
- Grasp lifestyle of residents

Stage 2
Decide on design target and course
- Choose a type of house according to the design target
  → Priority of technological elements

Stage 3&4 Basic Design
- Site plan & plan
- Section and façade
- Envelope specification
- Building services
- Basic items for LEHVE
  - Natural energy utilization
  - Envelope insulation and solar shading
  - Energy efficient equipment

Stage 5
Analysis of basic design & checking the effectiveness
- Reduction of energy consumption & CO₂ emission,
  - Initial & running cost

End of design

Stage for quality control through construction. Quality control of energy-saving technological elements

“LEHVE” is abbreviation of “Low Energy Housing with Validated Effectiveness”. The term is used in a Japanese design guideline of energy-saving residential buildings for architects and builders (non-experts on energy-related engineering.)
An example of the evaluation output (only structure)

<table>
<thead>
<tr>
<th>Evaluation index</th>
<th>Reference value</th>
<th>Specification alternatives of the energy-saving TE or RBE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alternative 1</td>
</tr>
<tr>
<td>Energy consumption per year</td>
<td>250 GJ/a</td>
<td>1.0</td>
</tr>
<tr>
<td>Specifications to be followed</td>
<td></td>
<td>(description)</td>
</tr>
</tbody>
</table>

Increase of installation cost = pay-back time
Reduction of running cost
An example of the energy use for the domestic hot water

<table>
<thead>
<tr>
<th>Energy use</th>
<th>Reference Energy consumption (primary energy basis, 9.83 MJ/kWh&lt;sub&gt;e&lt;/sub&gt;)</th>
<th>Energy-saving Technological Elements</th>
<th>Specifications (More detailed requirement is to be attached to each of the specifications.)</th>
<th>Energy consumption ratio (the ratio for the reference case [Level 0] is 1.0) and the specifications (or combinations [+]) of specifications expressed by the numbers, from (1)-1 to (2)-3, which are shown in the column of “Specifications”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic hot water</td>
<td>24.5GJ</td>
<td>(1) Solar Hot Water System</td>
<td>(1)-1. Solar hot water tank, which is not connected to any hot water heater (1)-2. Solar heat collector connected to hot water heater</td>
<td>Level 0</td>
</tr>
<tr>
<td>Note: To determine the above reference energy consumption and the energy consumption ratios, clear definition of the design condition is crucial.</td>
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<td>(2) Efficient water heater including pipes and terminal devices</td>
<td>(2)-1. Latent heat recovery gas instant water heater (2)-2. CO&lt;sub&gt;2&lt;/sub&gt; heat pump water heater (2)-3. Utilization of well insulated pipe/bathtub and faucet with thermostat or single lever, etc.</td>
<td>Gas instant water heater (reference)</td>
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</table>
The structure of energy consumption and building energy performance has been studied mainly by four methods:

1. Field surveys
2. Experiments in research houses
3. Computer simulations
4. Laboratory experiments

These methods have advantages and disadvantages.
1. Field surveys

- It reveals real energy consumptions, indoor environment, consciousness of residents, etc.
- By the POE, the interaction between the environment and the residents can be observed.
- But, even the reasons of slight fluctuation of the indoor temperature cannot be interpreted, due to lack of information on related factors.
- Not easy to validate the energy saving by a particular element. Controlling related factors is necessary, but difficult in many cases.
- Even if sex and age of members of two families are equivalent, they usually use energy in quite different ways.
- A large number of samples are needed to exclude the effect of such factors, in order to validate the effectiveness of a particular element.
2. Experiment in research houses, in order to evaluate the energy performance of elements

- Even internal heat gain has not been simulated in many of the research houses. It has large impact on heating & cooling load, etc.

- In mild climate situation, intermittent and partial heating and cooling has to be considered. The equipment should have been operated by assuming the interference by occupants.

- For co-generation, assumptions on the usage of electric appliances are critical. The heat load assumptions are also important.
3. Computer simulations

- Auxiliary components like pumps, fans, heaters, should be taken care into consideration. They should not be neglected in the evaluation.
- Once the accurate model is developed through theoretical studies and experimental validation, the computer simulation is the most powerful tool to do the systematical evaluation.
4. Laboratory experiment

• Wide range of conditions can be simulated by facilities in the laboratory. The artificial climate chambers, supply water temperature control equipment, etc.

• The interaction with the envelope and occupants cannot be simulated easily.
Design guidance

- Simulation or complicated calculation by the designers is future scenario, especially for houses.
- Specification is most important for practitioners.
- How much energy & money can be saved is very important to make a decision on the pay-back time.
- If a customized information on the energy consumption ratio is NOT available, **inductive/analogical decision** from the existing fact on the energy consumption ratio fits to the habit of designers.
- Having customized reference condition is better, and the extent of the inductive/analogical decision should be limited. However, **the inductive/analogical decision is much better than the decision with no basis**.
- Therefore, **any hints, which help the designers to make successful inductive/analogical judgment** should play an important role in the design methods.
Summary

• The core process of the design for the energy-saving buildings is as follows:
  – Grasp the building design condition, related to the energy use.
  – Find the information on the energy consumption ratio (to what extent each element is efficient for energy saving), which is drawn for the closest design condition. Induction is to be activated by practitioners.
  – Tentatively choose elements, get the prediction, and decide whether they fit or not from the viewpoint of energy and economy.
  – If they fit, the process finishes. If not, change the elements, and repeat the above steps until finding the appropriate elements.

• The direct use of the simulation for customized prediction may be another way.

• Other than the simulation, there are some other methods to get the prediction.