Towards Sustainable Architecture

Using the concept of exergy, this exhibit shows you first how the whole system consisting of humans, architecture, and the global environment works. This state-of-the-art knowledge is then adopted to help clarify the key aspect of Sustainable Building.

1. NESTED STRUCTURE

We humans spend most of the hours of a day in "architectural environment" space, such as office rooms and others. Urban environmental space is formed as a set of "architectural environment" spaces. The urban environmental space is surrounded by mountains, forests, woods, rural districts, rivers, seas and villages. Let us call such an environment, which surrounds the urban environmental space, as "regional environment". The largest regional environment is the "global environment" surrounded by the Universe.

Each environmental space is surrounded by the next larger one while at the same time surrounds the next smaller. This nested relationship of environmental spaces is the most important characteristics of environmental spaces with various sizes.
2. EXERGY

The view of environmental spaces described above has been developed through a series of exergy researches on the built environment using the concept of exergy.

Each of the architectural and urban environmental spaces works as a system by letting energy and matter to flow in and flow out through its system boundaries.

The incoming energy and matter are of higher quality, while the outgoing ones are of lower quality. Any system is performing its target activities by converting high-quality energy and matter to low-quality ones within the system.

The quality of energy and matter is expressed by the concept of "exergy." It represents the resource-capacity of energy and matter, or their "ability to disperse themselves into their environment." Exergy can explicitly show us the degree of "consumption" quantitatively, which is brought by "dispersion" of energy and matter.

The qualitative degradation of energy and matter by a system to work can be represented in terms of entropy, which indicates the state of "wasted heat" and "wasted matter" or the "degree of diffusion" of energy and matter.

Any system works both by feeding on exergy and by disposing of entropy into its environment to drive its activity.

3. EXERGETIC VIEW OF SPACE HEATING AND COOLING

These two graphs below show examples of exergy consumption patterns during the whole process of space heating and cooling from a power plant, to a boiler or a heat pump, to building envelope.

As can be seen from the difference in the whole exergy consumption profiles between Case 1, 2 and 3 from both graphs, it is more effective to install thermally well-insulated glass windows and exterior walls and thereby reduce the heating or cooling exergy demands than to install a boiler or a heat pump with an extremely-high thermal efficiency.
4. EXERGETIC VIEW OF HUMAN BODY

The figure shows a relationship between the human-body exergy consumption rate, metabolic energy rate, room air temperature, and mean radiant temperature under winter condition (outdoor air temperature of 0°C and relative humidity of 40%; this approximates a typical winter condition in the Tokyo-Yokohama area). There is the optimal combination of room air temperature and mean radiant temperature, which provides us with the lowest exergy consumption rate. This is consistent with the room conditions that most people feel comfortable with well-designed passive solar heating, radiative panel heating and others.

<table>
<thead>
<tr>
<th>Mean Radiant Temperature</th>
<th>Room Air Temperature</th>
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</thead>
<tbody>
<tr>
<td>10°C</td>
<td>20°C</td>
</tr>
<tr>
<td>15°C</td>
<td>25°C</td>
</tr>
<tr>
<td>20°C</td>
<td>30°C</td>
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</tbody>
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5. A CASE STUDY ON "COOL" EXERGY USE IN FUKASAWA

It is very important to make a full use of building envelopes to cultivate and produce the coolness from the immediate outdoor environment. We need both hardware and software. "Hardware" refers to an appropriate combination of thermal mass, insulation of walls, solar control over windows, and natural ventilation. "Software" is the lifestyle of occupants enabling the hardware to work accordingly.

Indoor air inevitably warmed up by various activities of the occupants and also solar heat gain from windows can be replaced by the outdoor air taken in by nocturnal ventilation. This process involves the interior building envelopes being cooled by ventilated air, then turning this coolness into cool exergy to be used on the following day. During daytime the windows may be closed and external shading is fully used to enjoy the cool radiant exergy coming off from the interior wall surfaces.

Dwelling units of Fukasawa Symbiotic Housing Complex have been performing well, using the cool exergy storage and its effective consumption. The eave, balcony, pergola as well as rich plants taken care of by the residents, which create an intermediate buffer zone between indoor and outdoor help reduce thermal impacts, and that the natural ventilation, and also during daytime, windows and curtains are opened for natural ventilation.
Measured Temperatures in Fukasawa

This graph is a comparison of the measured indoor and outdoor temperatures on a fine summer day (August 7th, 1998). The air temperature in the dining room is 1 to 3°C lower than outdoor temperature and the floor surface temperature is 2 to 3°C lower than outdoor temperature during the daytime.

The reason for this is that solar control over the southern balcony having the pergola with plants worked successfully and the outdoor air of 25 to 27°C is taken in effectively by natural ventilation through the balcony space and thereby cool exergy is produced and stored in the building envelopes.

Numerical simulation of the exergy balance of the measured room was made for two cases: one with nocturnal ventilation and the other without nocturnal ventilation.

Case 1 assumed that the room is naturally ventilated during daytime and the windows are kept closed during nighttime (18:00 to 06:00). Case 2 assumed that the room is ventilated all the time. The sunshade is assumed to be fully installed for both cases.

Simulation Case 1

Simulation Case 2

The rate of storing warm exergy has negative values from 1:00 a.m. until the morning. This indicates that warm exergy is released into the room space. During the daytime, a small amount of warm exergy is stored. This results in releasing a large amount of warm exergy during nighttime with the drop of outdoor temperature.

The rate of storing cool exergy has negative values (2.5W at maximum) during the daytime. This indicates that the concrete floor is releasing the cool exergy. This is made possible by nocturnal ventilation.

Positive values in exergy storage rate indicate "storage" and negative values indicate "release" to the room space.

6. CONCLUDING REMARK

The concept of exergy quantifies the ability of energy and matter to "disperse" into their environmental space and also what the "consumption" is. With this in mind we can renew our look at built environment together with us as human-body system and global environmental system. We have so far confirmed through exergy research that design of thermally well-insulated building envelope systems is the first priority to realize well-being in the built environment.

In winter condition, such a building envelope system provides us with the lowest exergy consumption rate inside our body. In summer condition, a combination of solar control with external shading devices and nocturnal ventilation realizes the production of cool exergy by cultivating the immediate outdoor environment. This has been verified by measurement and simulation with respect to Fukasawa Symbiotic Housing Project.

The concept of exergy is useful to review and renew our look at the built environment and thereby helps those concerned about planning, designing, and operating sustainable built environment.

Information

An activity at "Graduate School of Environmental and Information Studies, Musashi Institute of Technology"

Musashi Institute of Technology Graduate School of Environmental and Information Studies http://www.yc.musashi-tech.ac.jp/index.html


Iwamura laboratory http://www.yc.musashi-tech.ac.jp/~iwamura-lab/