Action for Sustainability
The 2005 World Sustainable Building
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SB05 Tokyo

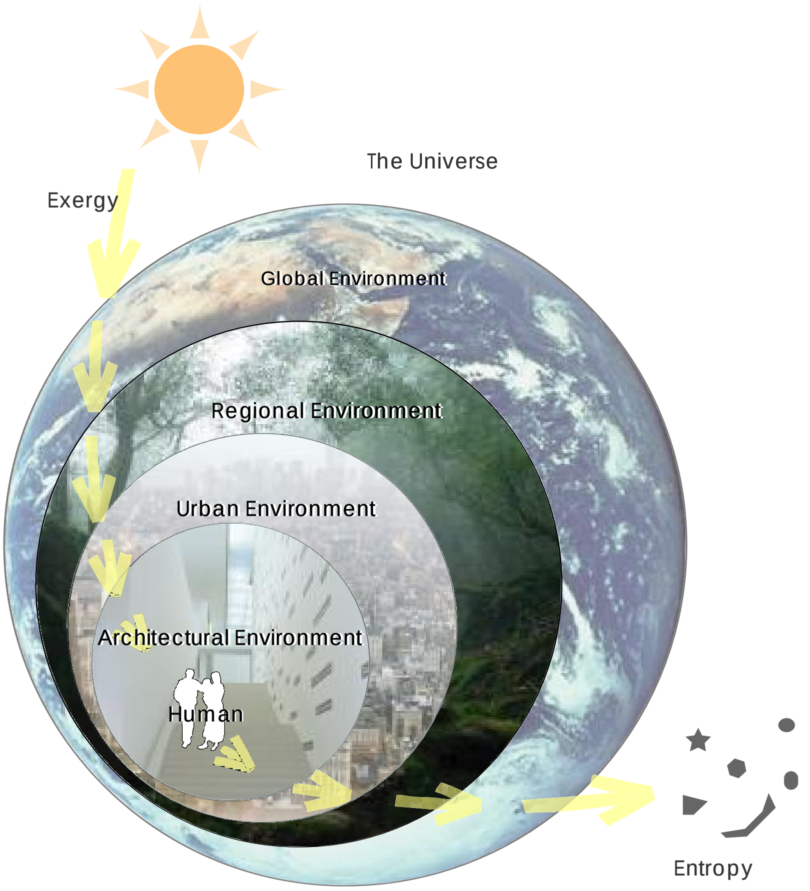
Towards Sustainable Architecture

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.

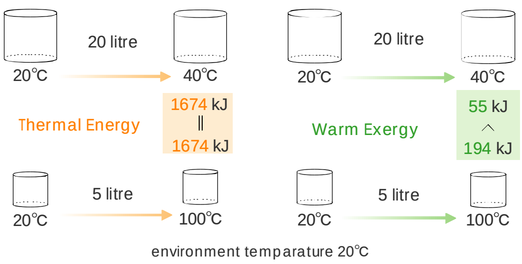
Global Environmental System

The simplest model representing the global environmental system is a closed plastic container with a peace bird representing meteorological and biological activities and a glass of water as the ocean.

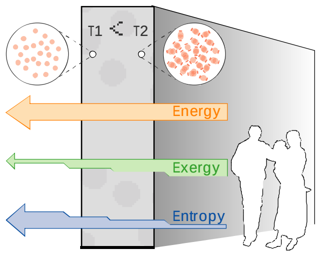
A desktop lamp represents the sun, a covered plastic container represents Atmospheric space on the earth. The peace bird inside represents the whole life system consisting of plants, animals, and microorganisms on the earth. A glass of water represents the ocean, and a plastic bag storing a cooling gel represents the Universe. The peace bird repeats bobbing up and down as long as it is irradiated by the lamp, while at the same time the evaporation of water takes place over the peace bird's head.

Comparison of Energy concept and Exergy concept

The amount of energy contained by water of 20litre at 40℃ is the same as that of 5litre at 100℃,but exergy is different; the latter is three-and-a-half times larger than the former.



Building Envelope System



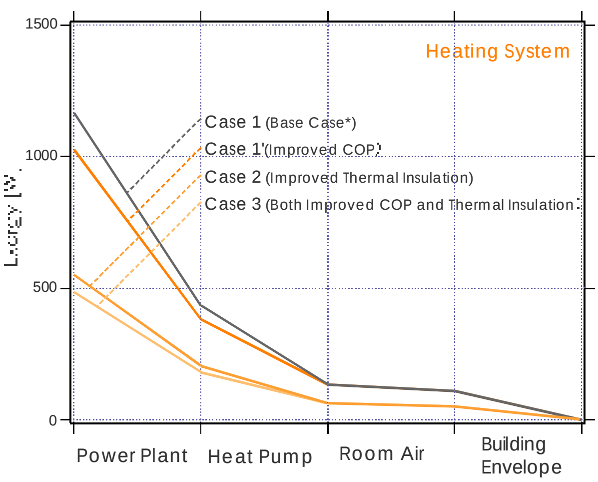
Energy, exergy, and entropy flow in and out building envelope systems. The amounts of energy flowing in and out are the same under thermally steady-state condition; this is according to the law of energy conservation. On the other hand, the amount of entropy flowing out is necessarily larger than that flowing in; this is according to the law of entropy generation. The amount of exergy flowing out is smaller than that flowing in, since exergy is inevitably consumed within the system to produce entropy.

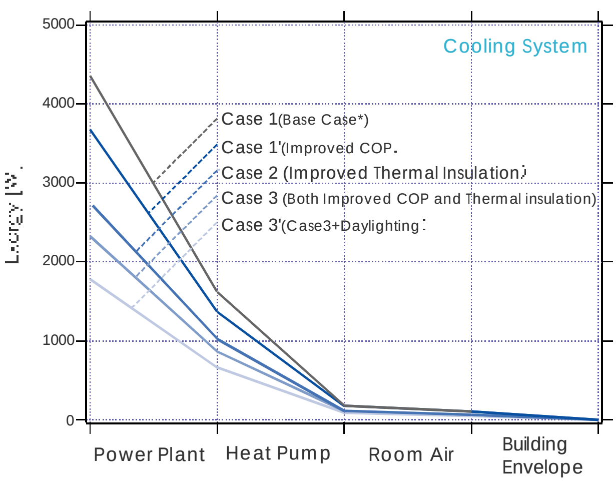
3. EXERGETIC VIEW OF SPACE HEATING AND COOLING

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.

Comparison of Exergy Consumption Patterns



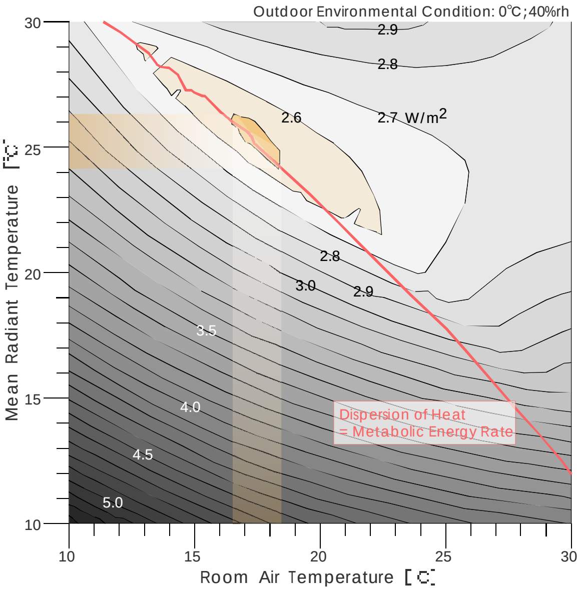


*Base Case = Poor + Thermal insulation of Building Envelope and internal shading

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℃ 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.

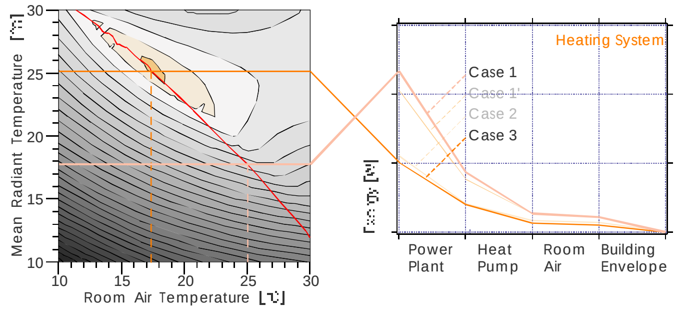
Human-Body Exergy Consumption Rate and Surrounding Temperatures



Thermally Well-Insulated Building Envelopes Provide Us with a Condition of Well Being in Winter

The lowest exergy consumption rate emerges at the point where the room air temperature equals around 18℃ and mean radiant temperature around 25℃ in winter. This suggests that the use of radiant warm exergy is more effective than the use of convective warm exergy for heating purpose to realize both thermal comfort and the lowest exergy consumption rate within the human body.

Such a built environment can be provided by appropriate passive heating strategies, for example good thermal insulation, suitable thermal-exergy storage capacity of building envelopes, and solar thermal-exergy gain through a well-insulated window glazing with a moderate radiant heating system in case necessary.



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 playing important roles including solar control. Basic idea of the floor plan and the layout of window openings are to maximize natural ventilation and day lighting effects.

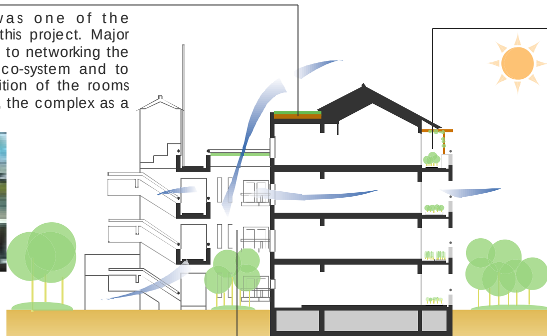
According to our post-occupancy investigations, many of the residents do not use any air-conditioners during the summer time. During night time, windows are opened (window screens and curtains are shut) for nocturnal ventilation, and also during daytime, windows and curtains are opened for natural ventilation.

Setagaya-Ku Fukasawa Symbiotic Housing, Tokyo, Japan

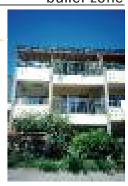
Setagaya-ku Fukasawa Symbiotic Housing is the first case practice of a public housing rebuilding project, completed in 1997, under the banner of "Environmentally Symbiotic Housing", the national policy drive in Japan since 1990. This was designed to holistically integrate a variety of environmentally conscious techniques and devices, including passive design measures, reusing the prior resources such as soil, timbers, wells, trees, etc., rainwater circulation system, greening roofs and walls, recreating biotope and the like. The former residents' participation in the design and construction stages allowed creating a lose-knit community again within the newly rebuilt context also considered for the elderly and the disabled.

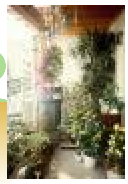
Rooftop greening

Rooftop greening was one of the outstanding characters of this project. Major objectives are to contribute to networking the regional greenery as an eco-system and to improve the thermal condition of the rooms underneath, the apartment, the complex as a whole and its vicinity.

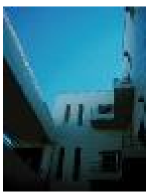


Balcony as an environmental buffer zone





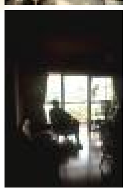
"Void" for day lighting & natural ventilation



Natural Drafting & Ventilation

Passive design methods to improve the living environment require the occupants' understanding of the mechanism and their willingness to apply their lifestyle responding to and enjoying the natural circumstances even in urban areas.

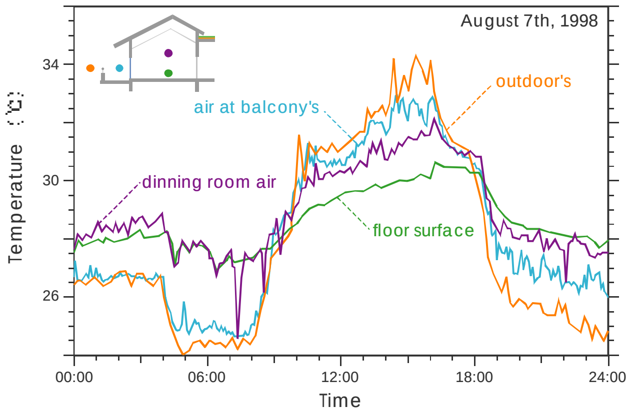
Our post-occupancy investigation shows that 40% of the panelists first open the windows when it is hot in summer, before using any other equipment such as air-conditioner. This reveals that the buffer zones between indoor and outdoor help reduce thermal impacts, and that the natural drafting and ventilation in housing units are quite successful.



Measured Temperarures 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℃ lower than outdoor temperature and the floor surface temperature is 2 to 3℃ lower than outdoor temperature during the daytime.

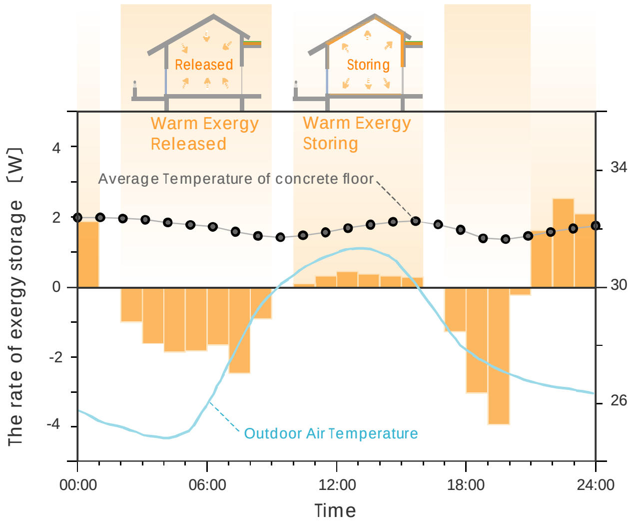
The reason for this is that solar control over the southern balcony having the pergola with plants worked successfully and the outdoor air of 25 to 27 ℃ is taken in effectively by natural ventilation through the balcony space and thereby cool exergy is produced and stored in the building envelopes.



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.

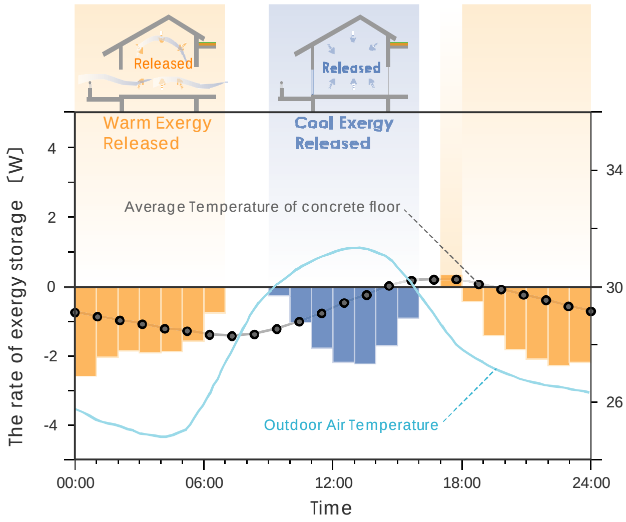
Case 1 assumed that the room is naturally ventilated during daytime and the windows are kept closed during nighttime (18:00 to 06:00). Case 2 assumed that the room is ventilated all the time. The sunshade is assumed to be fully installed for both cases.

Simulation Case 1



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. See from 10:00 to16:00. Storing warm exergy during daytime results in releasing a large amount of warm exergy during nighttime with the drop of outdoor temperature.

Simulation Case 2



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

Shukuya laboratory http://www.yc.musashi-tech.ac.jp/~shukuya/

LowEx.Net http://www.lowex.net

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