Integration of Design and Technologies for Responsive Buildings

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1. INTRODUCTION
Buildings are a man-made environment built in nature. The relation between the indoor environment and outdoor nature has become strained since much energy was consumed in order to create a comfortable and safe indoor climate in the 20th century.
It seems that as the indoor climate becomes safer and more comfortable, the more polluted the outdoor environment becomes, resulting in a kind of structural dilemma in our society. In other words, the separation of indoor and outdoor space was expedited as air conditioning technology became prevalent. The energy-saving pressure is accelerating this tendency and is helping destroy the responsive relation between man and nature.
It is necessary for building design to be aimed at a sustainable society to solve this dilemma and to recover the responsive contacts between man and nature. Natural energy resources such as the sun and wind are well-known as clean and renewable energy sources and can be expected to replace conventional fossil energy resources in the future.

2. ENVIRONMENTAL IMPACT OF BUILDINGS
Per-capita, CO2 emissions in Japan were 2.72 tons-C per year (1995) with approximately one third of them emitted from the building sector. The results of the life cycle analysis of buildings show that 8% of total CO2 emissions are related to construction, including CO2 emissions from manufacturing building materials and transporting them as well as emissions at construction site. 23% of total CO2 emissions are related to the operation of buildings such as air conditioning, lighting, hot water supply and etc. A few percent are related to the maintenance and demolishment of buildings. It is found that approximately two third of damaging environmental building impact comes from the building operation; therefore, energy saving during operation is critical in reducing the environmental impact of buildings.
The factors that determine the amount of energy consumption in building operation can be classified into the following two groups:
1) Factors related to the building itself such as shape of the building, layout of rooms, materials and structures of the building envelope.
2) Factors related to the building equipment system and energy management system.
The above classification is also effective in considering the energy saving strategies in buildings. Another possibility in reducing detrimental environmental impacts of buildings is the utilization of renewable energy resources instead of conventional fossil resources. The highlights of the strategy are summarized into the following three aspects;

1) Low energy building design
2) Highly efficient equipment system and management
3) Use of renewable energy

These aspects depend on each other meaning the concept of integration is vital. (Fig.1)
The relation between the energy consumption and the evolution of buildings is shown in Fig.2.
is to convert conventional energy source into a renewable energy source. In the third step, the building itself comes to be a target of design and the concept of low energy design is introduced. Other commonly used terms for low energy design include: passive design, bioclimatic design, etc. These designs have the same features as those of vernacular buildings that depend little on energy to control indoor climate. Incidentally, the low energy design of today is based on much advanced scientific knowledge and technologies and is supported by sophisticated design tools based on various computer simulation techniques. The advanced low energy design should be collaborated with new advanced building service technologies and advanced utilization system of renewable energy. Therefore, this is a new step in the next stage of integration concept toward responsive buildings in the future.

3. Annex 44 Integrated Design Process and Methods

There are various levels of integration; integration of architects and engineers, architecture and HVAC system, architectural designs and service technologies, passive design and active engineering, etc. There exists another idea of integration; namely integration of responsive building elements (RBE) that are defined as building component/subsystems which are actively used for transfer and storage of heat, light, water and air, and rationally combined and integrated with building service functions such as heating, cooling, ventilation and lighting. (Fig.3)

In Annex 44 investigation will be deepened on five specific responsive building elements, whose perspective of improvement and widespread implementation in the building sector to be much more promising:

Advanced Integrated Façade (AIF)
Thermal Mass Activation (TMA)
Earth Coupling (EC)
Dynamic Insulation Systems (DIS)
Phase Change Material (PCM)
However, integration is obviously not limited to RBEs. RBEs are constantly being developed and their variations are widely increasing. The meaning of “responsive” can be two-fold as following:

1) Responsive to dynamic environmental change or fluctuation in order to minimize energy consumption for indoor climate control by HVAC and lighting systems.
2) Responsive to dynamic environmental change or fluctuation in order to maximize human coexistence with nature, contact considered to create more productive and refreshing space for the inhabitants and occupants, especially knowledge workers in offices.

Therefore, “responsive building” can consist of three patterns from combinations of 1) and 2) mentioned above. They are; pattern A : 1) only, pattern B : 2) only and pattern C : 1)+2).

In pattern A, the building may be isolated strictly from the exterior environment because its fluctuation often disturbs the stable, comfortable indoor climate thus making it difficult to control the indoor climate. In pattern B, the building may impart a fresh and pleasant feeling on occupants but may increase energy consumption from HVAC and lighting systems. Obviously, pattern C is the most preferable but it is critical to strike a balance between passive- and active approach. The image in Figure 4 represents the best combination of active technologies and passive design, where a building can convert its building mode daily and seasonally, corresponding with the exterior environment.
Design flow of Responsive Building is shown in Figure 5. An Integrated Design Process especially affects the design team as:
- The client takes a more active role than usual,
- The architect becomes a team leader rather than the sole form-giver,
- The mechanical and electrical engineers as well as the energy specialist take on active roles in the early design stages.

4. INTEGRATED DESIGN

Creative integrations of design and advanced technology are required along with flexible and innovative design methodology. New types of low energy architecture are emerging. Representative examples of emerging architecture in Japan are described in the pages that follow. Fig. 6 shows the technologies concerning energy and material integrated into each building design.

Fig. 6. Sustainable Technologies Integrated into Building Design (6 examples of emerging architectures)
Daito Bunka University, Itabashi Campus  
Tokyo, JAPAN  
Architect: Ben Nakamura, Keisuke Yamamoto and Kenji Hori  
floor area: 7,269m2  
structure system: steel frame, RC frame  
completed: 2003

Institute for Global Environmental Strategies  
Kanagawa, JAPAN  
Architect: Nikken Sekkei Ltd  
floor area: 6,991m2  
structure system: steel frame, SRC frame, RC frame  
completed: 2002

Library and Lecture Hall

Main Facade Faces to West for Panoramic Views

Climate Control Concept in Summer at Lecture-Hall No.3

Sun Light Control System at West-facing Façade

PV Installed Building Envelope (Roof and Facade)

Wind Simulations for Passive Cooling System

By the courtesy of the architects

By the courtesy of Nikken Sekkei Ltd
Itoman City Hall  
Okinawa, JAPAN  
Architect: Nihon Sekkei Inc  
floor area: 15,435m²  
structure system: RC frame, PC frame  
completed: 2002

The Egg of the Earth  
Shizuoka, JAPAN  
Architect: Masahito Nagata + OM Institute Inc  
floor area: 2,018m²  
structure system: wooden frame, RC frame  
completed: 2004

Whole Building Covered with Shading Envelope

Head Quarter Office in the Nature

PV Installed Shading Devices

Air Circulating Solar Heating System

Envelope System Correspondent to the Orientation

Wood as Renewable and Ecological Material

By the courtesy of Nihon Sekkei Inc

By the courtesy of OM Institute Inc
Takenaka Corporation Tokyo Main Office
Tokyo, JAPAN
Architect: Takenaka Corporation
floor area: 29,747m²
structure system: steel frame, CFT structure
completed: 2004

Hokkaido Northern Regional Building Research Institute
Hokkaido, JAPAN
Architect: Nakahara, Atelier BNK, Shibataki Inc
floor area: 8,356m²
structure system: steel frame, SRC frame
completed: 2002

Overview from NW. Office in the mid-city area.

Plan & Section Distribution of Illumination During Natural Lighting, June 12:00

Light Court in the Office

By the courtesy of Takenaka Corporation

Office Space Faces to South

Climate Control System in Summer

Left: Atrium between Office and Laboratory.
Right: Light Shelf and Vent-window on South Facade.

By the courtesy of Hokkaido Northern Regional Building Research Institute