PASSIVE DESIGN TECHNIQUES APPLIED TO GREEN BUILDINGS AS AN AESTHETIC AND SPATIAL DESIGN CONCEPT

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1. INTRODUCTION

The emergence of environmental problems as major social issues throughout the world has prompted sustainable development efforts in a wide range of areas, including industry, construction, and transportation, followed by the execution of numerous studies and policies. The concept of sustainable development has been dealt with in earnest in the construction field since the Declaration of Interdependence for a Sustainable Future at the 18th Chicago Convention of UIA in 1993. This Declaration included tasks to be implemented with respect to green buildings, such as the recycling of resources, application of energy-efficient designs, and utilization of natural energy in addition to the application of sustainable designs. As part of green building practices, countries around the world have been implementing various green building certification standards, such as LEED, GBCC, CASBEE, and BREEAM.

These certification standards prescribe the criteria relating to the external environment, energy conservation, materials and resources, and the indoor environment, with energy conservation being the top priority for each of these issues. This is due to energy consumption in building operation accounting for more than half of the building life cycle cost. Accordingly, although many studies are undertaken for the purpose of developing the means for conserving energy in relation to green buildings, the majority of these studies are concentrated on the development of technologies for environmental facilities through the application of active designs.

study the finite nature, propose hypotheses, and gather their evidence. And, to date, there is little to suggest that copying nature purports any advantages to architects, primarily because fully autonomous buildings or towns have yet to be built. According to the described Malthusian-Darwinian dynamic, the two critical questions that we seek to address in this paper are: i) What is the essence of a sustainable dwelling? and ii) What principles should be adhered to in making a dwelling sustainable? In other words, this study aims to elucidate the essence of sustainability in green building design implementation.

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Sustainability, Energy Conservation, Passive Design, Building Use, Climate Zones

2. BACKGROUND

Regarding the issue of building environmental performance, Sandra F. Mendler (2005) expressed her concern that there is excessive concentration on the building technologies in sustainable designs, and noted the need for a more holistic review of land use, planning, and community issues. Norbert Lechner (2014), on the other hand, pointed out that a building's cost and environmental performance is established generally at the schematic design stage. Moreover, Mark DeKay (2014) asserted that architects ascribe the responsibility for a building's energy consumption to energy consultants or engineers. DeKay also stated that advanced, high-performance buildings, for which an applicable passive design was overlooked at the schematic design stage, usually resulted in higher costs, even if they were green buildings. Alison Kwok (2011) mentioned that unless appropriate passive strategies are employed during the schematic design phase, they may never be included in later stages as passive strategies play an important role in form-related decisions. The outcomes of poor decisions related to building orientation, massing, and layout are nearly impossible to rectify in later design phases in an attempt to retrospectively integrate high performance day-lighting, passive heating, or passive cooling systems. However, although many architectural practitioners are aware of the importance of passive design, its application in practice is highly inadequate mainly due to the lack of relevant data and experiences (K.S. Lee *et al.,* 2013). This study showed that although passive design should be introduced at the schematic design phase, in many cases a building may only become a green building at the stage where an environmental engineer is contracted.

From the perspective of energy conservation, there needs to be comprehensive application of both passive and active designs according to the climate conditions, circumstances, and building use as a means to ensure maximum energy efficiency. While there is a need to employ a combination of the passive and active methods to an appropriate extent, the application of passive design techniques is surprisingly limited. This is due to the lack of knowledge, experience, and reference materials for using the methods of expressing esthetic and cultural values of buildings and regarding environmental performance. Therefore, the realization of green buildings is greatly reliant on technological methods, such as active designs. Also, there often are cases in which esthetic and cultural values are overlooked due to the tendency to focus on the numerical analysis and technological applications with increased technological dependence of the green building.

Lance Hosey (2012) emphasized that a building's shape can have an enormous effect on its performance, and it was estimated that up to 90 percent of a building's environmental impact is determined during the early design phases. In addition, Rumi Engineer (2014) noted the problematic tendency of neglecting the aesthetics of green buildings by pointing out that green building design can be based on the idea that form follows function, which is associated with modernist architectural concepts of the 20th century. This, however, should not be mistaken as a compromise in the aesthetic appeal of the design. In the same manner, American architect Samuel Mockbee (2001) defined sustainable architecture as a combination of aesthetic, environmental, social, political, and moral values. Leon van Schaik (2008) stated that sustainability is the acquisition of a new aesthetic dimension in contemporary architecture beyond its pragmatic and ethical relevance.

Green buildings are defined by the US Green Building Council as highly energy efficient buildings. Accordingly, the form of sustainability currently being discussed relates to technology-oriented green buildings built on the basis of engineering capabilities. The future direction of green buildings should involve comprehensive consideration reflecting technological and socio-cultural aspects. In addition, we are at the point of promoting the aesthetic value of sustainable buildings as well as their functional value.

Meanwhile, several studies have been conducted on the correlation between building form and energy efficiency: a study of the solar envelope and zoning concept including the volume to surface ratio, density, and building height for solar access and cross-ventilation through the analysis of the housing project (Ralph L. Knowles, 2003); a study proposing the conformation of the Residential Solar Block (RSB) that reduces the urban heat island phenomenon through the ventilation path and maximizes the potential of passive utilization of solar energy (Ahmad Okeil, 2010); a study of building form optimized by a genetic algorithm using a computer in order to find a compromise between lighting and heating energy (Luisa G. Caldas *et al.,* 2003); and a study suggesting the methods of optimizing energy-efficient floor shape using a genetic algorithm (Weimin Wang *et al.,* 2006). All of these studies have simulated building form models for the purpose of achieving optimal lighting or energy conservation. However, there have been few studies that systematically explore the relationship between passive design techniques and the aesthetic effect of the building form or the spatial composition of green buildings. Moreover, there is lack of references for reviewing the possibility of applying passive designs in architectural design.

There should be studies of techniques through which aesthetic and spatial designs can be expressed, using passive designs for the application of integrated green designs in the early design stage. Passive design is an element of design that should be introduced at the schematic design phase as it frequently determines the aesthetic and spatial characteristics of the building. However, at present, such discussions are not taking place, while there is also a complete lack of relevant studies or references. Therefore, this study aims to analyze the characteristics of passive design techniques introduced as the aesthetic and spatial concept of green buildings by emphasizing the relationship between the environmental aspects for the reduction of energy consumption and the perspective of aesthetic and spatial designs.

3. METHODS

This study was conducted to propose a passive design technique and controllable environmental factors applied as the aesthetic and spatial design concept based on a comprehensive collection of examples of contemporary green buildings. Further, passive design application methods were to be determined for aesthetic and spatial designs. We have identified the application characteristics for each of the relevant building uses and climate conditions by drawing from the preeminent examples of the different passive design techniques.

Generally, passive and active designs are applied in combination in the case of green buildings. However, active design is dependent on technological methods in which there is use of mechanical systems, which include heat recovery, ventilation, and floor heating systems, or adoption of technological systems using natural sources of energy, such as solar and geothermal energy among others. Accordingly, it is viewed that active design is rarely applied as an aesthetic and spatial concept. Therefore, an analysis will be conducted by limiting the subject to passive design techniques applied as an aesthetic and spatial design concept, with the exclusion of active design.

Passive design is a technique that does not make use of facilities and electric power, and refers to the method of directly utilizing natural energy sources, including the sun and wind. In addition, a passive design results from the use of energy-efficient design methods, which involve taking into consideration the building orientation, shape, and envelope and other factors. As such, this study limits itself to green design techniques for the energy conservation purposes by way of design elements applied as an aesthetic and spatial concept. This study excluded green techniques that have no relevance to energy conservation and that are inappropriate for the discussion of environmental performance. For example, these include the recycling of resources, such as waste material from building exteriors as well as ecological and organic designs like the configuration of animals and plants.

In addition, efficient energy control technologies such as methods of avoiding thermal bridge, window systems with highly efficient insulation, and hybrid ventilation systems have been researched and developed with a focus on passive house. These are techniques designed to lower the energy load by relying on technologies contained in the materials, as well as construction and facilities that can be employed at the construction documentation phase as well as the actual construction phase. Therefore, the application of such technologies as the aesthetic and spatial concept of the building is extremely rare and, as such, it was excluded from this study.

Accordingly, the subjects of this study involve instances in which the environmental control technique was applied as an aesthetic and spatial concept including mass design, spatial design, and facade design of green buildings. Samples were selected from published examples of green buildings, including buildings certified by LEED, GBCC, CASBEE and BREEAM. Buildings that acquired green building certifications such as the above were evaluated on the basis of a diverse range of criteria including the use of the land, energy conservation, and recycling of resources. However, these usually focus on active design or energy efficient green buildings by means of technological methods. In addition, buildings that have acquired green building certification demonstrate the tendency to focus merely on the improvement of environmental efficiency without consideration for design and spatiality. Therefore, this study gathered relevant examples by conducting a literature review of papers presented at sustainability-related seminars, academic dissertations, research data, technology development reports and architectural journals, including the examples of certified green buildings, after which an analysis was conducted using the 48 examples chosen from those reviewed.

4. PASSIVE DESIGN AND ENVIRONMENTAL CONTROL AREA

4-1. Classification of passive design techniques

There are diverse classifications of passive design techniques. Norbert Lechner (2014), in Heating, Cooling and Lighting, categorized green techniques into three tiers of basic building design, passive system, and mechanical equipment use according to the design process.

Accordingly, tiers 1 and 2 corresponding to the passive design technique are categorized into heating, cooling, and lighting methods. *Heating* methods include solar radiation penetration or efficient energy control through surface to volume ratio, trombe wall, and sunspace. *Cooling* methods include shading from solar radiation or the introduction of ambient air through shading and ventilation. *Lighting* methods include natural lighting technique using windows, skylights, and light shelves. Similarly, Alison Kwok (2011), in the 'Green Studio Handbook', categorized green strategies into envelope effect, lighting, heating, cooling, energy production, and water and waste. Among these, the category of envelope including double skin and green roof was added to passive design for energy conservation.

Alternatively, Mark DeKay (2014), in 'Sun, Wind and Light', classified green design techniques capable of being applied in the schematic design phase in accordance with their complexity and scale. They are divided into a. building group scale (neighborhoods, urban fabric, urban elements), b. building scale (entire buildings, room organization, individual rooms), and c. building parts (building systems, elements, materials). This is because architects consider the arrangement of architectural elements or designs by priority, rather than designing the structure in the order of day-lighting, shading, ventilation, heating and cooling in the schematic design phase.

However, such classification excludes aspects of the aesthetic viewpoint in architectural design and describes comprehensive green design techniques including active systems. Therefore, these classifications are different from the perspective of this study. In this study, passive design techniques able to be applied as an aesthetic and spatial concept of the green building were gathered by researching relevant documents and examples. These passive design techniques are categorized into building orientation & shape, open space, opening & device, building skin, and building planting in accordance with the general design processes of mass, space, and envelope design.

4-2. Passive design techniques for each environmental control area

The environmental control area of passive design techniques includes the light environment, air environment, and thermal environment. (Table1)

(1) Light environment

In regard to passive design techniques for controlling the light environment, there exist techniques that utilize south-facing building orientation, the arrangement of the major axis in the east-west direction, stepped or sloped mass facing south, open spaces (atriums and courtyards), the appropriate arrangement of openings (skylights and clerestory), light induction devices (light shelves and daylight ceilings). There also exist techniques for shielding direct sunlight in the case of buildings facing the east and west and producing illumination of an equal intensity indoors in order to create a more pleasant indoor environment on the south side. These include sun shading using a building form technique that adds a translucent skin to the curtain wall, as well as controlling the sunlight using louvers, canopies, and sun screens.

(2) Air environment

Passive design techniques for controlling the air environment originate with considerations of enhancing the effectiveness of natural ventilation. This principle encompasses the Venturi effect, stack effect, cross ventilation, and methods of utilizing topography and geographical features.

The Venturi effect creates natural ventilation by taking advantage of the differences in air velocity. This effect is a prime example of creating a ventilation path by changing the width of spatial gaps between buildings. The stack effect is generated by differences in the pressure caused by differences in height. This method is used to enhance the ventilation effect through the use of a skylight, clerestory, or atrium. In addition, as a method of taking topographical and geographical features, there exist building layout techniques of ventilation paths by taking advantage of the prevailing wind blowing from a particular direction as a result of geographical and environmental features. Also, there are techniques for positioning buffer zones, such as atriums in directions that draw in the prevailing wind, as well as openings, etc.

(3) Thermal environment

From the perspective of energy load, thermal load is the greatest. Therefore, it can be concluded that green techniques for controlling the thermal environment have the greatest effect on energy conservation among the passive design techniques.

The utilization of solar heat is frequently considered, together with the control of the light environment. This is designed to reduce heating load and induce solar radiation along with sunlight by way of the building's orientation and shape, as well as installation of an open space (atrium or courtyard) and openings (skylights, clerestory).

The greenhouse effect that accumulates solar radiation through openings is a phenomenon that produces a positive effect in the winter by lowering heating load, but with an adverse effect in the summer due to increasing the cooling load. In particular, it is the cause of overheating in the atrium. The relative importance of the positive or negative outcome of the greenhouse effect differs in accordance with various factors, such as the region's climate, orientation, location, and size of the openings. Therefore, design must be carried out prudently in consideration of the climatic characteristics along with the controlling of solar heat dealing with seasonal differences.

However, when the cooling load is greater due to the acquisition of solar radiation, it would be advisable to control the thermal environment as well as the light environment simultaneously by shielding or controlling direct solar radiation. This can be achieved by means of the building's orientation and shape. The utilization of translucent skin, louvers, and sun screens is also possible.

In addition, the passive design technique for efficient natural ventilation not only controls the air environment but also controls the thermal environment simultaneously. The design technique includes creating ventilation paths or installing open spaces as well as the appropriate arrangement of openings or ventilation induction devices. These achieve a composite effect for the air environment control utilizing the natural ventilation effect while moderating the overheating phenomenon resulting from the induction of external air. However, utilizing natural ventilation in this instance also causes the indoor space to become exposed to the external air. Therefore, focus should be placed on moderating energy demand through the thermal environment control technique for the intermediate season or concept of establishing thermal buffer zone between the external and internal spaces.

There are also techniques for controlling the thermal environment through more efficient energy control using the insulation effect and preventing heat loss, including minimizing surface area and forming a closed façade, which is particularly effective in cold climates, and a raised roof for hot climates. The double skin method controls the thermal environment in

TABLE 1. Environmental Effect of Passive Design Techniques

Design Area	Passive Design Techniques	Environmental control Area		
		Light Environment	Air Environment	Thermal Environment
Building Orientation & Shape	South orientation	natural lighting	-	solar radiation penetration
	Sun shading form	daylight shading	-	solar radiation shading
	Ventilation path	-	natural ventilation	air intake
	Raised roof	-	-	Efficient control of sunlight
	Volume to surface ratio	-	-	efficient control of sunlight
Open Spaces	Atrium	natural lighting	natural ventilation	solar radiation penetration /air intake
	Court yard, light well	natural lighting	natural ventilation	solar radiation penetration /air intake
Opening & Device	Skylight, monitor roof	natural lighting	natural ventilation	solar radiation penetration /air intake
	Clerestory	natural lighting	natural ventilation	solar radiation penetration /air intake
	Daylight duct	natural lighting	-	-
	Light shelves, daylight ceiling	natural lighting	-	-
	Ventilation duct, ventilation tower	-	natural ventilation	air intake
Building Skin	Double skin	-	-	efficient control of sunlight
	Translucent skin	daylight shading	-	solar radiation shading
	Louver, sun screen	daylight shading	-	solar radiation shading
	Closed facade	-	-	efficient control of sunlight
Building Planting	Green roof, landscaped ramp	-	-	soil insulation
	Green wall	-	-	soil insulation
	Water space	-	-	heat exchange

summer by inducing natural ventilation through convection using the stack effect. By contrast, in winter, a greenhouse effect is produced in the intermediate space. There are also techniques for enhancing thermal efficiency by placing a layer of soil on the building surface for planting and controlling the microclimate by creating a water space inside and outside the building.

5. THE AESTHETIC AND SPATIAL CONCEPT USING PASSIVE DESIGN

In this section, we analyzed the specific application method of passive design techniques that express the aesthetic and spatial concept of green buildings. This involves the consideration of the interconnected relationship between aesthetic and spatial design and passive design techniques. Passive design techniques are classified into the categories of building orientation and shape, open space, opening & device, building skin, and building planting in accordance with the architectural design process.

5-1. Building orientation & shape

In the early design stage, design decisions on the building's orientation and shape are made. These are very important for passive design and have a strong influence on aesthetic and spatial design. Natural elements such as solar radiation or wind are either introduced or shielded in accordance with the building's orientation and shape, and these must be chosen appropriately according to the orientation or function of the building, the climate, and surrounding environments.

(1) South-facing orientation

This is a method of exposing the building to natural lighting and solar radiation in order to gain sufficient daylight. This encompasses methods of orienting a rectangular mass, sloped mass or stepped mass facing toward the south (Fig.1-3). The above are all methods of maximizing the building's south-facing surface and are frequently applied for educational and research facilities for which sufficient solar gains are important because such facilities are spaces within which users are located during the daytime. In addition, the installation of sun shading devices in order to minimize direct daylight during summer is necessary. Greensburg Schools (Fig.1) arranged their plan layout into an H-shaped rectangular mass facing in an east-west direction in order to maximize the south-facing surface. Liceo Scientifico (Fig.2) was able to produce solar heating by way of a greenhouse effect by arranging the sunroom on the southern part of school in a stepped mass. Rooms such as classrooms and library where students spend long periods of time are located on the south side, while large spaces such as the gym and multipurpose hall are located on the north side. SIEEB (Fig.3) emphasizes the sense of rhythm of the stepped mass through the installation of an elongated canopy on the stepped mass.

FIGURE 1: Greensburg Schools (educational facility), Greensburg, USA(continental climate).

FIGURE 2: Liceo Scientifico (educational facility), Roma, Italy (temperate climate).

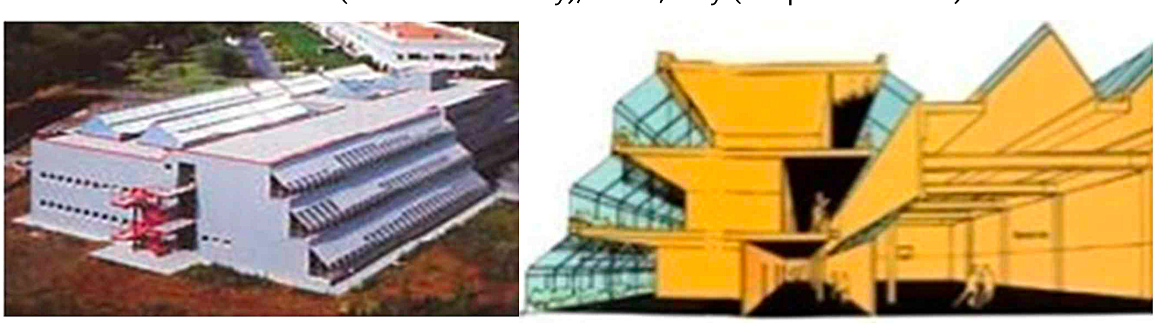


FIGURE 3: SIEEB (educational facility), Beijing, China (continental climate).

(2) Sun shading form

Buildings of this type lean back towards the south where the floors are stepped inwards from top to bottom. This form provides natural shading from the most intense direct daylight in the summer (Fig. 4 & 5). It is an efficient technique for buildings that require equal intensity of indoor illumination, such as offices or buildings located in a hot and dry climate, along with the advantage of the reversely inclined dynamic shape of the building.

FIGURE 4: London City Hall (office building), London, UK (temperate climate).

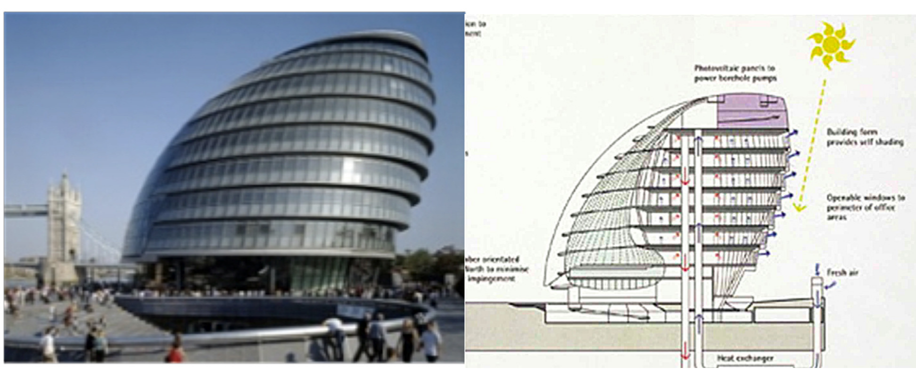


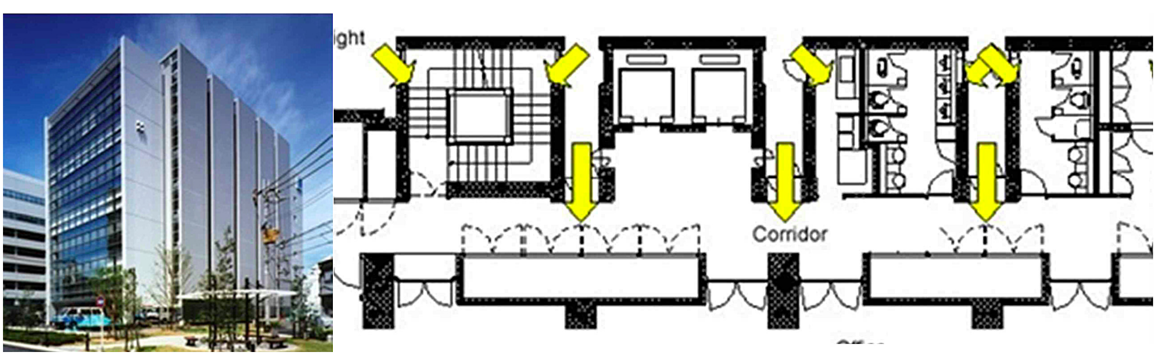
FIGURE 5: Tempe City Hall (office building), Tempe, USA (dry climate).

(3) Ventilation path

This is a technique for creating a ventilation path by dividing the mass or repetitively arranging multiple masses with open spaces between them in order to improve the micro-climate or temperature control by inducing breezes and ventilation in interior spaces. This technique must be focused on ventilation. The ventilation path must be arranged taking into consideration the prevailing wind during the summer. The Miami Museum of Science (Fig.6) is located in a tropical climate and controls its indoor temperature by inducing the breezes originating from the ocean through the ventilation path. The Sakai Gas Building (Fig.7) utilizes a ventilation path with open spaces placed between divided masses which represent a repetitive rhythm. This building is an excellent case that could be applied to office buildings in urban centers.

FIGURE 6: Miami Museum of Science (exhibition hall), Miami, USA (tropical climate).

FIGURE 7: Sakai Gas Building (office building), Sakai, Japan (temperate climate).



(4) Raised roof

A roof canopy independent from the building reduces conductive solar heat acquired through the roof slab by shielding direct sunlight, and emphasizes the horizontal element of the building shape through the roof canopy. This is a particularly effective technique in hot and dry climates, such as the Masdar Headquarters (Fig. 8). At the Chicago Art Institute, a louver-type independent roof canopy is installed covering the entire building. It converts direct sunlight to diffused light for the exhibition room (Fig.9. Chicago Art Institute).

FIGURE 8: Masdar Headquarters (office building), Masdar City, UAE(dry climate).

(5) Volume to surface ratio

This is a method of reducing heat loss and energy load by organizing spaces in a concentrated arrangement to minimize surface area. In this case, form of the mass is normally either a cubic (Fig. 10. Musasino Sengawa Elementary School) or a cylindricality (Fig. 4.London City Hall).

FIGURE 9: Chicago Art Institute–The Modern Wing (Exhibition), Chicago, USA (Continental-).

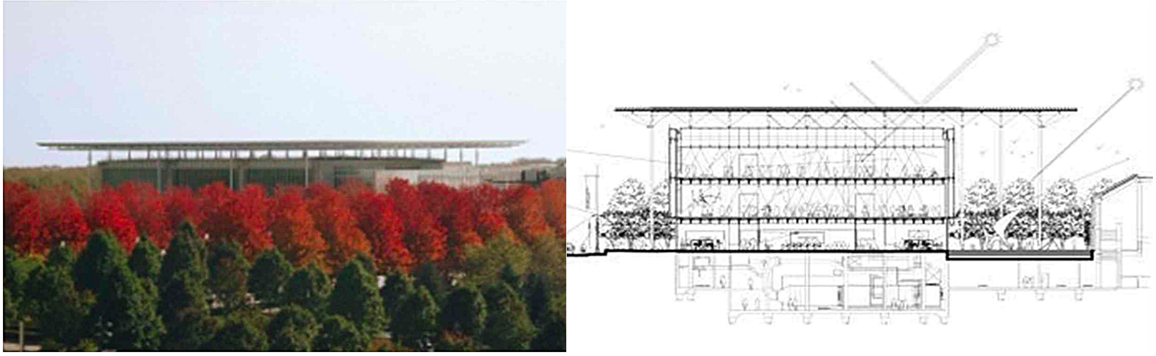
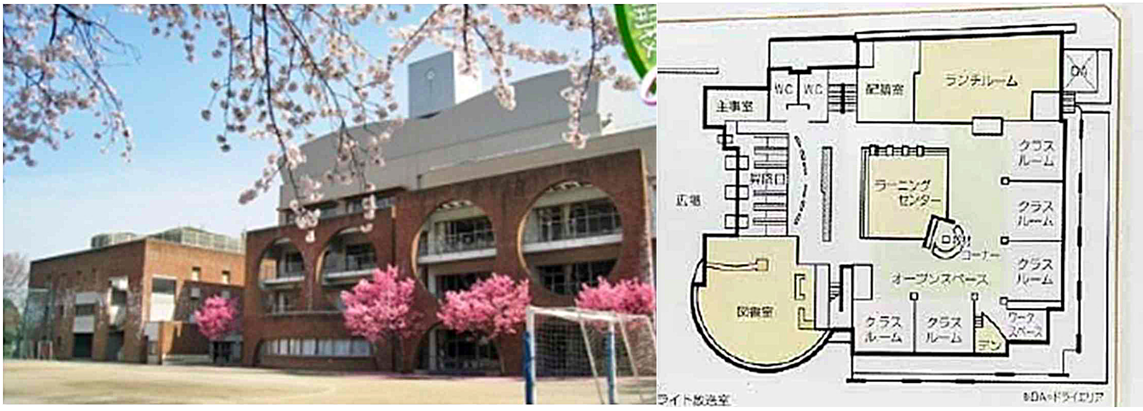


FIGURE 10: Musasino Sengawa Elementary School (education facility), Tokyo, Japan (temperate climate).



5-2. Open space

(1) Atrium

Atriums enable natural lighting and ventilation even in deep spaces that do not have direct contact with fresh air. This type of atrium is located in the central section of the building similar to a courtyard, with a horizontally expanded deep planned building (Fig.11, 12) and a vertically expanded tower type building (Fig.13 & 14).

At the Willis Faber & Dumas Headquarters, a sloped atrium is located in the center of the deep floor areas. Escalators connect the 4 floors directly, and the top floor is connected to a rooftop garden (Fig.11). This case takes both day-lighting and natural ventilation into consideration, as well as link between interior spaces and the roof garden by means of combining the circulation in the central atrium. At the Masdar Headquarters, an example can be found of the maximization of natural ventilation through the stack and Venturi effects through the installation of a cone shaped atrium (Fig.12). In the Commerz bank Headquarters, an atrium is located in the center of the tower with a triangular plan. Sky gardens which rise to the every 4th floor are arranged in a helical format. Skylights are installed at the every 12th floor of the central part of the atrium, creating a structure composed of independent units in order to induce natural ventilation and day-light (Fig.13).

Differing from the courtyard type, the Tokyo Gas Earth Port's atrium is located on the external parts of the building, which functions as a semi-external buffer zone playing the role of entrance hall or indoor garden. In addition, there is a focus on controlling the environment within the atrium itself rather than inducing day-light and natural ventilation into interior spaces in the same way as the courtyard type atrium. The type of atrium exposed to outside air with glass on three sides has a serious problem with cooling load due to direct solar radiation during the summer in temperate climates. However, the Tokyo Gas Earth Port solved such a problem by placing the atrium on the northern side of the building (Fig.14).

FIGURE 11: Willis Faber & Dumas Headquarters (office building), Ipswich, UK (temperate climate).

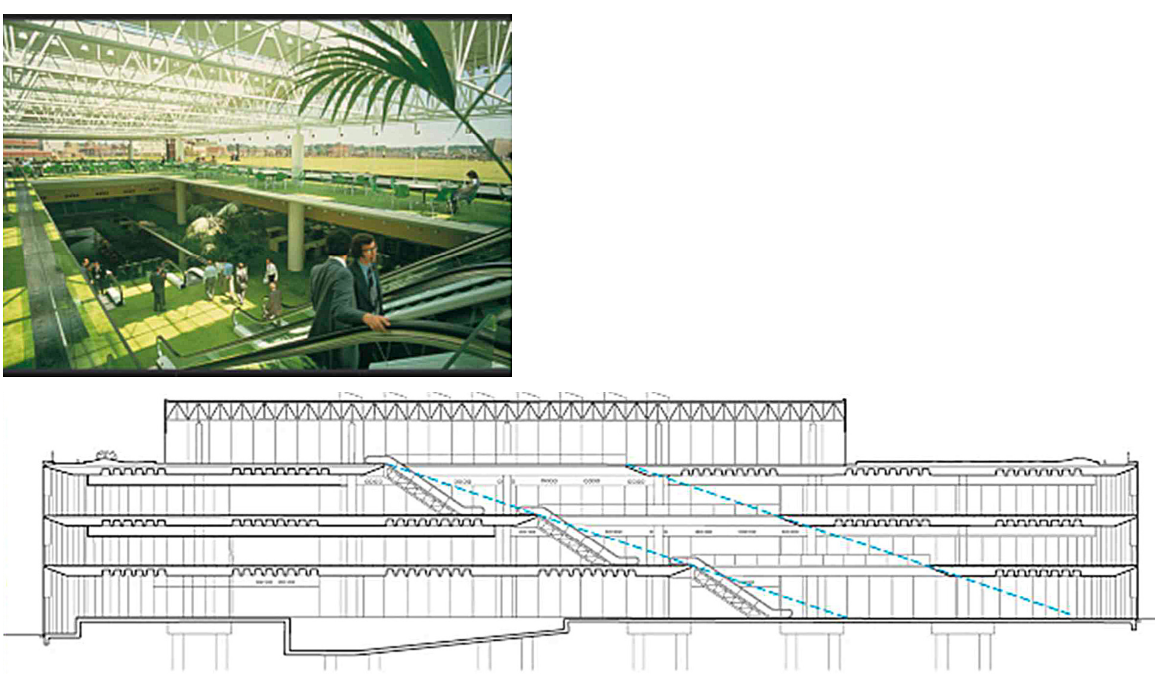


FIGURE 12: Masdar Headquarters (office building), Masdar City, UAE (dry climate).

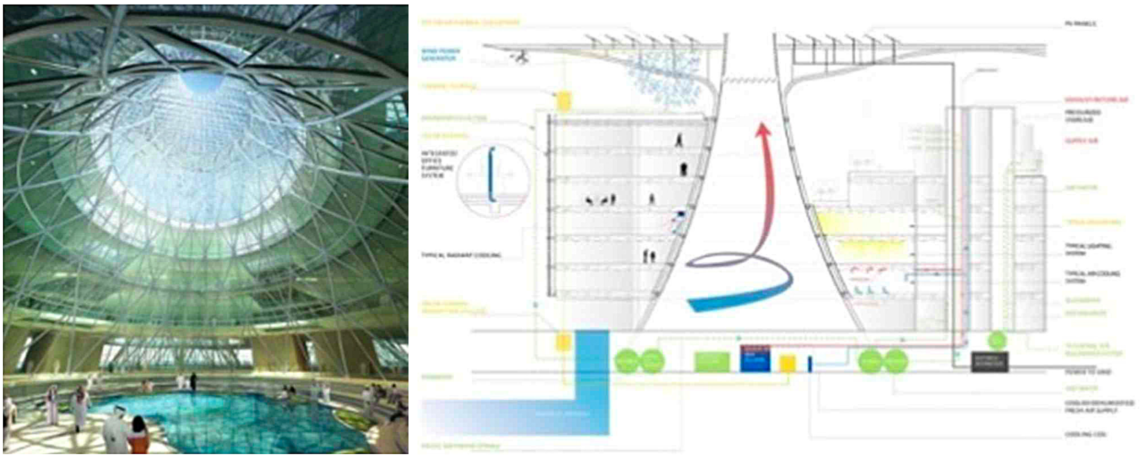


FIGURE 13: Commerz bank Headquarters (office building), Frankfurt, Germany (temperate climate).

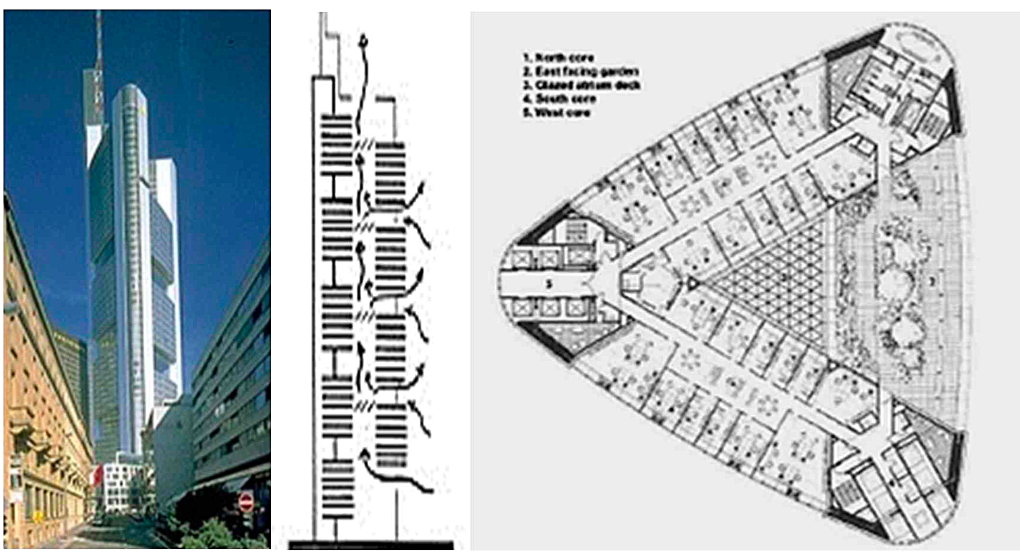
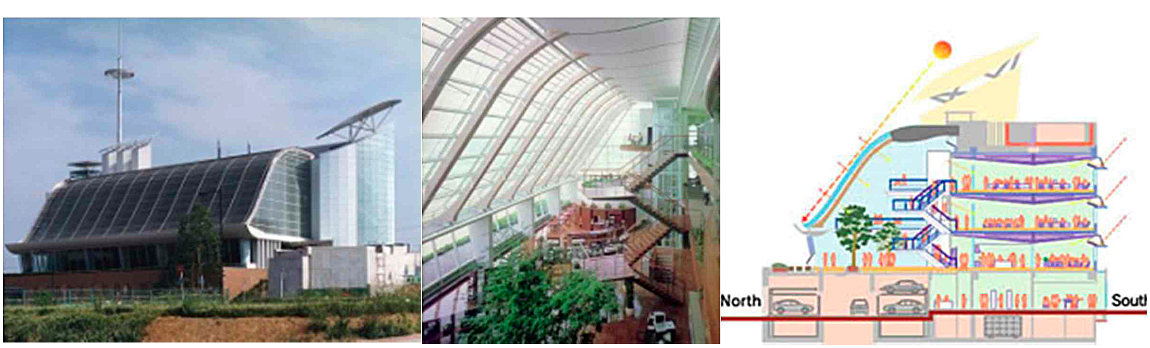


FIGURE 14: Tokyo Gas Earth Port(office building), Yokohama, Japan(temperate climate).



(2) Courtyard and light wells

The courtyard in the deep floor plan enables day-lighting and natural ventilation by introducing exterior space into the central section of the building. The Gotz Headquarters has a glass roof with operable windows enabling day-lighting and cross ventilation in open plan office spaces. It is a flexible space that functions as an atrium or courtyard according to the level of openness (Fig.15). The Aron R&D Center with a wide plan has 27 hexagonal light wells and three triangular courtyards. It incorporates the exterior environment into the building's interior, turning the entire building into a porous space (Fig.16). The Siemens Headquarters is equipped with light wells penetrating from the piloti underneath the building to the roof, which helps to maximize daylight and natural ventilation (Fig.17).

FIGURE 15: Gotz Headquarters (office building), Wurzburg, Germany (temperate climate).

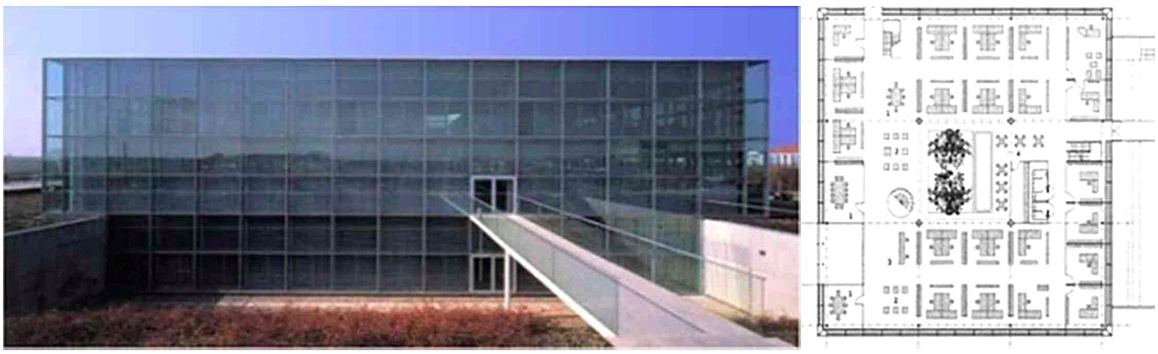


FIGURE 16: Aron R&D Center (office building), Toukai, Japan (temperate climate)

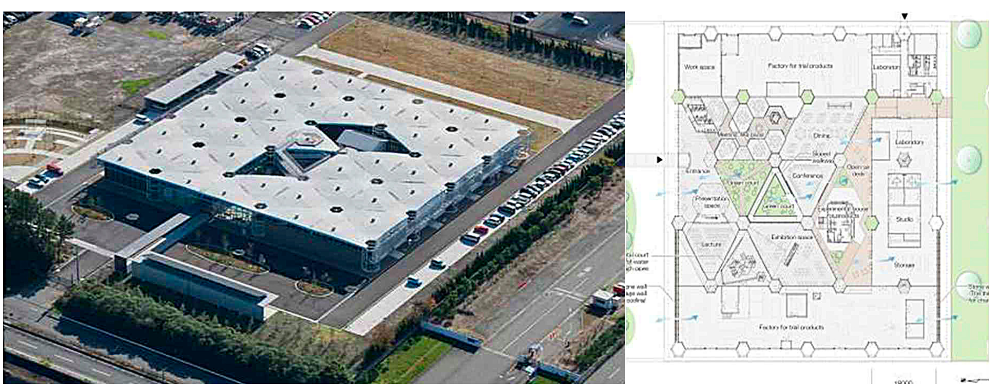
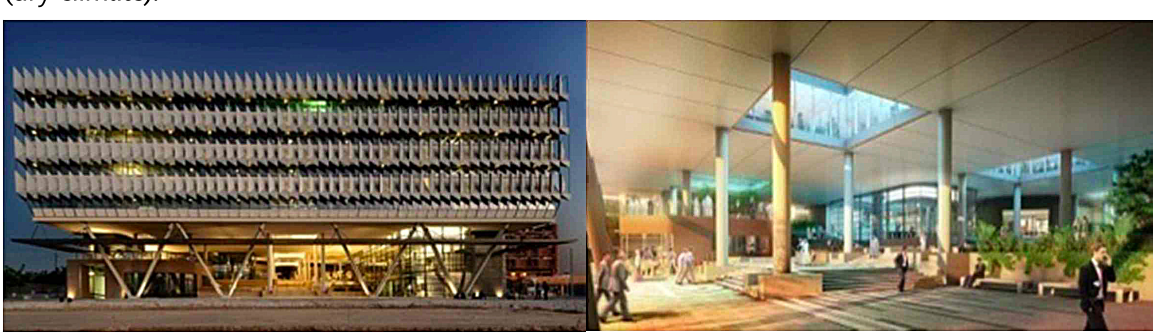


FIGURE 17: Siemens Headquarters, Masdar City (office building), UAE, Masdar City, UAE (dry climate).



5-3. Opening & device

This passive design technique involves openings and devices designed to maximize day-light and natural ventilation. These are used as elements of the building's envelope design, and include openings such as skylights and clerestory, light-inducing devices such as light shelves, and ventilation-inducing devices such as ventilation towers.

(1) Skylight and monitor roof

The Hearst Tower is a renovation project to be constructed with an atrium while preserving the skin of the existing building. Skylights designed to optimize the amount of day-light can be installed between the new high rise office building and existing historic building (Fig.18). This is a technique that introduces green design elements when two different masses are combined. The Sports Centre Pajol induces day-light and natural ventilation by bending and lifting the central parts of the monitor roof on the top of the gymnasium. Although from the exterior it is recognized as a simple cubic building rather than a monitor roof, in the

FIGURE 18: Hearst Tower (office building), NY, USA (temperate climate).

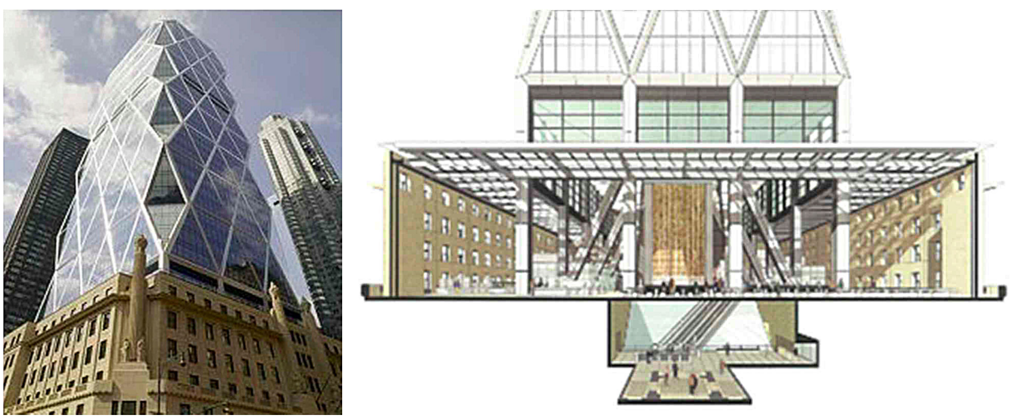
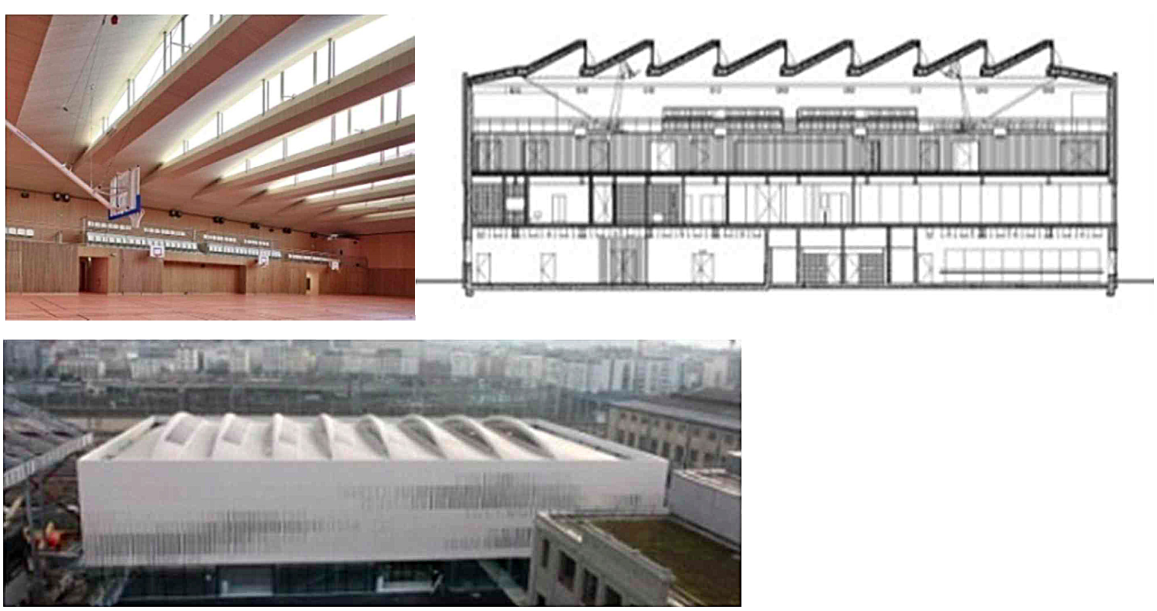


FIGURE 19: Sports Centre Pajol (sports facility), Paris, France (temperate climate).



interior it represents the aesthetic effect of a curved ceiling (Fig.19). This effect is possible in spaces with a long span such as gymnasiums as live loads are not stacked on the roof, allowing the shape of the roof to be relatively unburdened.

(2) Clerestory

IGES enables natural ventilation in the entire building by bringing the prevailing wind into the interior spaces and deliberating them through the atrium's clerestory (Fig. 20). The Pocono Environmental Education Center controls sunlight using its tilted main roof to eliminate the opening on the north side and installing a curtain wall on the south side (Fig. 21). In both cases, hot air gathers in the higher levels through the stack effect induced by installing a sloped shed roof on one side, while ventilation is facilitated by way of an opening in the clerestory.

FIGURE 20: IGES (office building), Kanagawa, Japan (temperate climate).

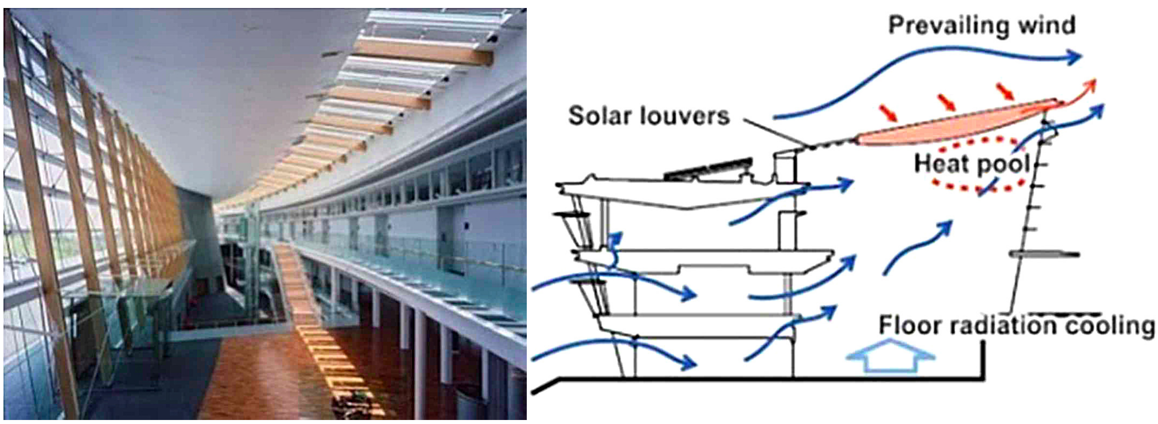


FIGURE 21: Pocono Environmental Education Center (education facility), Dingmans Ferry, USA (continental climate).

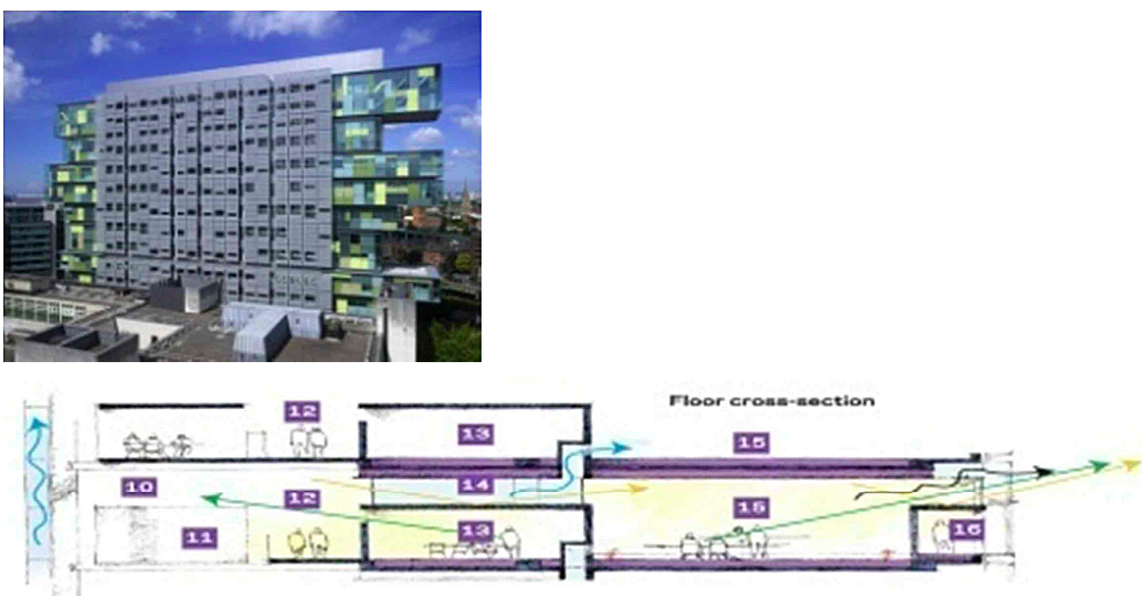
(3) Daylight duct

This light induction device is used to artificially draw sunlight into spaces that do not face to the south or into deep floor areas. The daylight duct of the Solaris building allows daylight to penetrate into the building's interior. Although it is not represented on the façade, it creates a passage of daylight in a diagonal direction within the internal spaces

(Fig.22). The Manchester Civil Justice Centre employed a method for drawing sunlight into internal spaces through the atrium, although such spaces are not directly facing the atrium. This is an example of the use of the adjacent room's ceiling situated between the atrium as the daylight duct, which also creates ceiling height variation (Fig. 23).

FIGURE 22: Solaris (office building), Singapore (tropical climate).

FIGURE 23: Manchester Civil Justice Centre (office building), Manchester, UK (temperate climate).

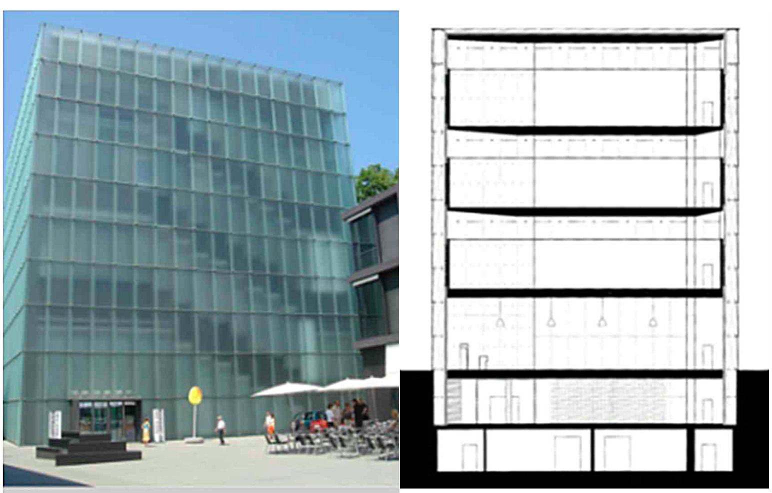


(4) Light shelves and daylight ceiling

These are devices used to draw direct sunlight into the interior of the building or maintain equal intensity of indoor illumination within the deep floor by converting it into reflected light. In many cases, light shelves are a design element that is simply installed on the façade. IGES has produced a three-dimensional façade by protruding the light shelves from the façade and the sloped ceiling (Fig.24). Kunsthaus Bregenz is an example of drawing diffused light into the exhibition hall through the use of a daylight ceiling. The concrete box-like gallery space is wrapped around by curtain walls, and the external wall and ceiling are both made of translucent glass that converts direct daylight into diffused light (Fig.25). Although Kunsthaus Bregenz is a simple rectangular building, it's revealing how the silhouette of the concrete box through the curtain wall of the translucent glass is an example of expression with the pattern of an overlapping façade fitted with a green lighting system.

FIGURE 24: IGES (office building), Kanagawa, Japan (temperate climate).

FIGURE 25: Kunsthaus (exhibition hall), Bregenz, Austria (temperate climate).



(5) Ventilation duct and ventilation tower

Ventilation induction devices are used to induce natural ventilation through the installation of a vertically extended duct. The ventilation tower vertically protrudes from the façade to represent a repetitive rhythm (Fig.26). The ventilation duct (eco-shaft) of the Swiss Re Headquarters has ventilation duct spaces designed in a helical form on the surface, thereby becoming an element that serves to organize the façade along with the structural system (Fig.27).

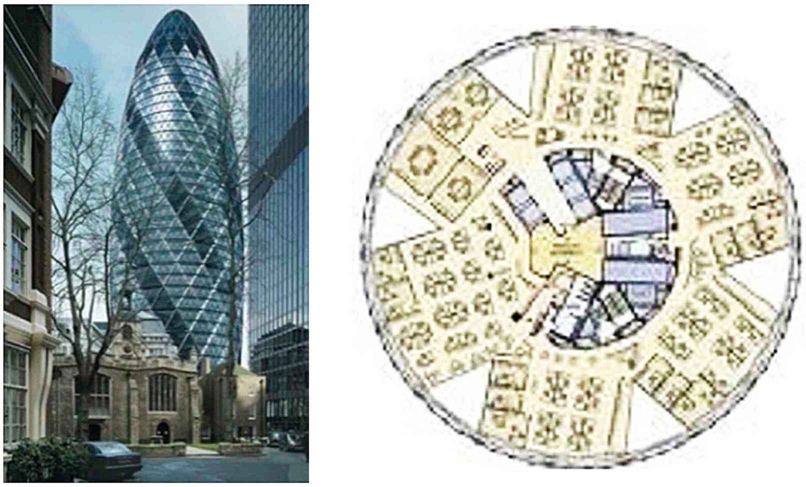
5-4. Building Skin

(1) Double skin

Recently, the curtain-wall system has been frequently incorporated in large scale, green buildings along with the development of high performance materials such as Low-E glass.

FIGURE 26: BRE Office of the Future (office building), Watford, UK (temperate climate).

FIGURE 27: Swiss Re Headquarters (office building), London, UK (temperate climate).



The double skin method is a form of green technology that induces a greenhouse effect in winter while producing natural ventilation in summer, with two skins of separate double glazing.

The Gotz Headquarters emphasizes the transparent and flat façade of glass by utilizing a double skin symbolic of the company as a glass manufacturer (Fig.28). However, the double skin merely emphasizes a monotonous skin design, and is therefore aesthetically featureless. Meanwhile, louvers can be adjusted in wall cavities or the surface of the double skin to allow or shield direct daylight. This is introduced as a façade design element that emphasizes aesthetic features along with a shading effect during the summer. In the GSW Headquarters, ventilation efficiency was maximized using the venturi effect by installing a streamlined wing on the top of the double skin. Moreover, it represents a changing façade design, that is, a kinetic pattern façade and shading effect achieved by installing vertical louvers that move automatically with the hinges on the top and bottom within the double skin (Fig.29). In the Hemiciclo Solar building, a double skin system was incorporated on the balconies of each floor of the housing, along with the installation of a folding-type horizontal louver that can be adjusted to allow or shield direct daylight, thereby configuring a kinetic pattern façade that changes in accordance with the relevant situation (Fig.30).

FIGURE 28: Gotz Headquarters (office building), Wurzburg, Germany (temperate climate).

FIGURE 29: GSW Headquarters (office building), Berlin, Germany (temperate climate).

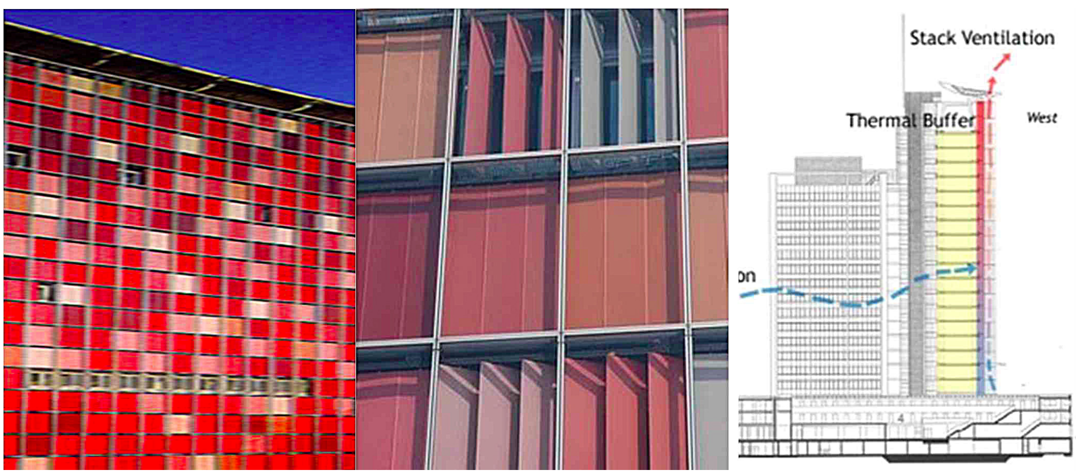


FIGURE 30: Hemiciclo Solar (residence), Madrid, Spain (temperate climate).

(2) Translucent skin

Translucent skin is a sunlight controlling system that works by attaching a perforated plate or translucent wall onto the building skin, producing a design that forms a translucent and uniform skin overlapped with openings on the surface.

The CJ Only One R&D Center emphasized the design element of continuous strips by means of applying light blocking folded panels made of perforated sheets attached to the façade (Fig.31), while the Unilever Headquarters emphasized its translucent skin by means of covering the ETFE membrane (Fig.32).

FIGURE 31: CJ Only One R&D Center (office building), Suwon, Korea (temperate climate).

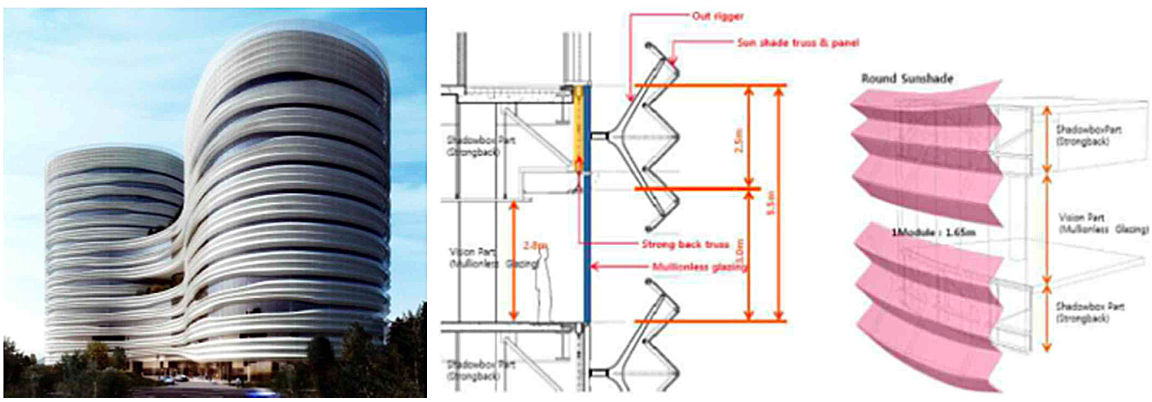


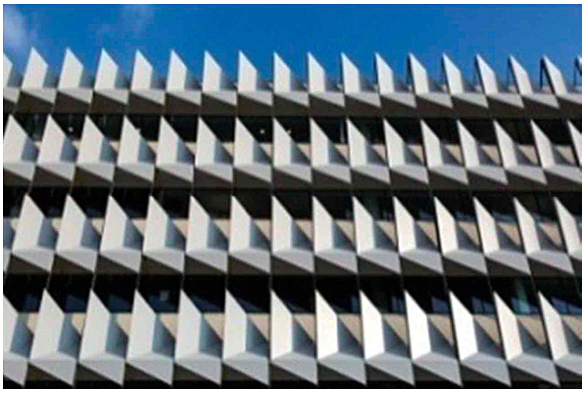
FIGURE 32: Unilever Headquarters (office building), Germany (temperate climate).

(3) Louver and sunscreen

The louver is a sunscreen system that forms a repetitive pattern, creating a unified image of the façade. The façade design differs depending on the form and arrangement of the louver, and has the tendency to emphasize the horizontal element on the south side and vertical element on the east-west side according to the height of the sun. The units of the sunscreen system of Siemens Headquarters in Masdar City are recognized as pixels that represent repetitive patterns on the façade, both horizontally and vertically (Fig.33). The 3M Headquarters Building reveals a strong horizontality through protruded horizontal louvers on the boundary line of the façade along with the canopies on the south side (Fig.34). The

Foshan Pearl Gymnasium is topped with a domed roof that is composed of a multistage overhanging ring truss system with diagonal bracing that functions like three-dimensional louvers (Fig.35). The Education Executive Agency & Tax Offices also produce an efficient shading effect by way of fin-shaped elements along with an emphasis on aerodynamic horizontality through fins that continuously protrude along the mass with a curved surface (Fig.36). In the Kiefer Technical Showroom, sunscreens that can be folded up and down move, making the exterior an ever-changing dynamic sculpture (Fig.37). Although sunscreens are generally installed in the openings of walls, in the Savannah House vertical sunscreens are installed on the skylight, making it a unique case which emphasizes the vertical design element of the façade (Fig.38).

FIGURE 33: Siemens Headquarters (office building), Masdar City, UAE (dry climate).



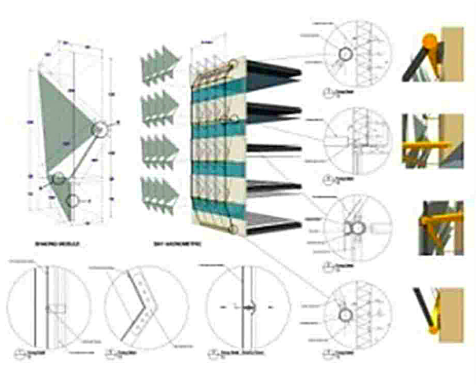


FIGURE 34: 3M Headquarters Building (office building), Milan, Italy (temperate climate).

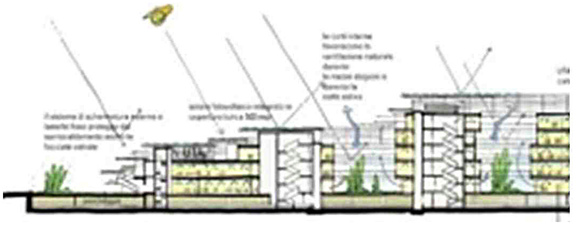


FIGURE 35: Foshan Pearl Gymnasium (sports facility), Foshan, China (temperate climate).

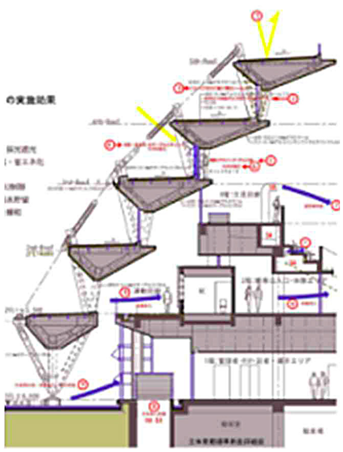
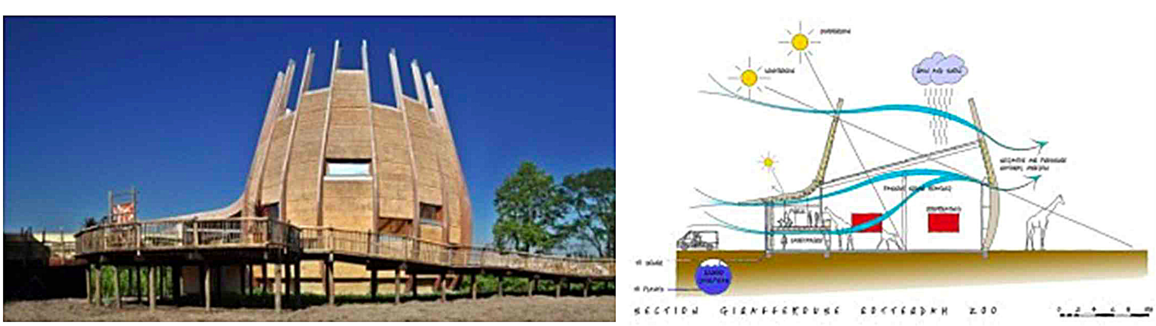


FIGURE 36: Education Executive Agency & Tax Offices (office building), Groningen, the Netherlands (temperate climate).

FIGURE 37: Kiefer Technic Showroom (exhibition hall), Bad Gleichenberg, Austria (temperate climate).

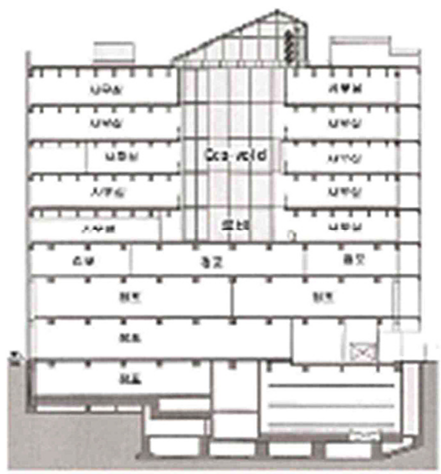
FIGURE 38: Savannah House (zoo), Rotterdam, Netherlands (temperate climate).



(4) Closed facade

The Taisei Sapporo Branch Building has minimized the number of external openings to prevent heat loss in the winter in response to its cold climate, while natural ventilation and day-lighting are induced by placing an atrium in the center section of the building. A closed façade is therefore naturally revealed (Fig.39).

FIGURE 39: Taisei Sapporo Branch Building (office), Sapporo, Japan (continental climate).



5-5. Building Planting

Roof gardens or green roofs are techniques for improving the environmental functionality of a building, acting as a thermal buffer with a soil layer while creating a natural image at the same time.

(1) Green roof and landscaped ramp

Among the green roof techniques, formative differences are largely divided into green roof and landscaped ramp. The California Academy of Sciences is a renovation of the existing building into a museum. The existing façade has been preserved, and aesthetic expression is reflected by way of a domed green roof (Fig.40). Although it is difficult for the greenery on the flat roof to be called an aesthetic concept since it is not easily visible at eye level, in the case of the California Academy of Sciences the outline of the roof was emphasized by forming five mounds on the top of the flat roof. Underneath the dome-shaped green roof, exhibition halls covered with dome-shaped glass were placed in order to induce natural ventilation in the interior spaces by forming an air layer like a double skin between the roof and the domed glass. The TU Delft Library (Fig.41) and the Grand Hall of the CJ Nine Bridges C.C. (Fig.42) illustrate the continuous landscaped ramp that connects the ground with the roof garden using sloping greenery, while the building is harmonized with nature by hiding its shape in the landscape of the green roof. Natural lighting penetrates through the skylight or the courtyard. These techniques are characterized by harmonious visual continuity with the natural surroundings or land.

(2) Green wall

This is a technique of endowing visual identity by giving commercial facilities a green image through the planting of grasses on the walls instead of finishing them with ordinary

FIGURE 40: California Academy of Sciences (exhibition hall), San Francisco, USA (temperateclimate).

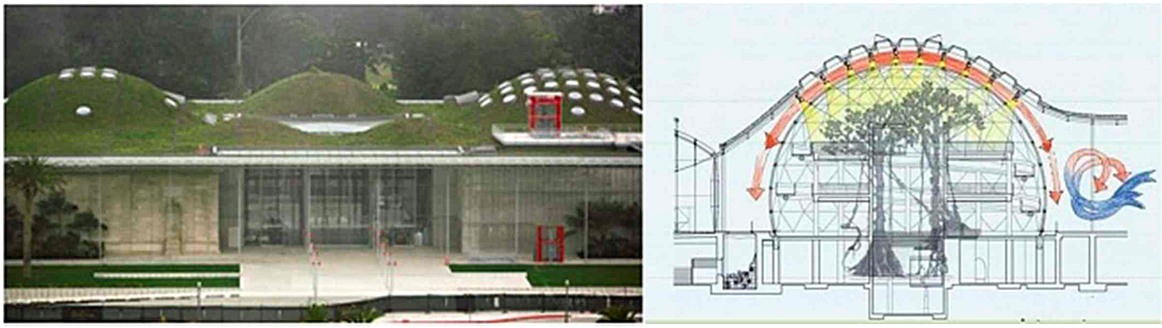


FIGURE 41: TU Delft Library (library), Delft, Netherlands (temperate climate).

FIGURE 42: CJ Nine Bridges C.C. Multipurpose Hall, Seogwipo, Korea (temperate climate).

exterior materials. In the Ann Demeulemeester building, the corner of the building is rounded to express the tender image of green carpet (Fig.43). In the case of the Canal City Hakata, greenery which was planted on the parapet of the terrace in a free-curve form is an attempt to express the fluid design features in visualization of the flow of water (Fig.44). The Seoul City Hall, with the planting of greenery on the main interior wall (Fig.45), and the ACROS Fukuoka Prefectural International Hall, with a green roof of stepped mass (Fig.46), both portray continuous greenery by connecting the greenery of the square or park at the front of the building with green walls.

FIGURE 43: Ann Demeulemeester (commercial building), Seoul, Korea (temperate climate).

FIGURE 44: Canal City Hakata (commercial building), Hukuoka, Japan (temperate climate).

FIGURE 45: Seoul City Hall (office building), Seoul, Korea (temperate climate).

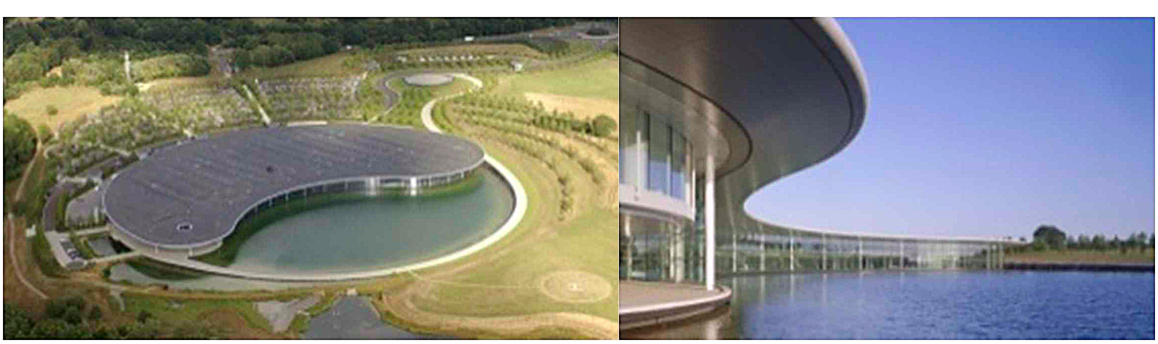
FIGURE 46: ACROS Fukuoka Prefectural International Hall (office building), Fukuoka, Japan (temperate climate).

(3) Water space

Water space is mainly used for environmental control purposes, to produce a cooling effect in the building along with the imparting of a green image. The Jubilee Campus faces a lake on its south side and controls the climate in summer by drawing in the prevailing wind, which is cooled while passing over the lake (Fig.47). The lake at the front of the McLaren Technology Center produces a cooling effect by absorbing the waste heat of the building (Fig.48).

FIGURE 47: Jubilee Campus, University of Nottingham (education facility), Nottingham, UK (continental climate).

FIGURE 48: McLaren Technology Center (office building), Woking, UK (temperate climate).



6. PASSIVE DESIGN FOR BUILDING USES AND CLIMATE ZONES

In this Chapter, the aesthetic and spatial characteristics of the passive design techniques considered above are categorized in accordance with each of the building uses and climate zones. This refers to the consideration of particular techniques in individual examples. Examples include 30 office facilities, 6 educational facilities, and 4 exhibition facilities, etc. These were categorized in accordance with the Köppen climate classification, with 35 examples falling into the temperate climate classification, 6 in continental climate, 5 in dry climate and 2 in tropical climate. The majority of examples were office buildings located in the temperate climate zone (Table 2).

Although various passive design techniques are almost evenly present in office buildings, techniques that utilize open spaces and building skin design are distinctive. In the case of office spaces, there are numerous large-scale developments that require natural lighting and natural ventilation in the deep floor areas. Therefore, the utilization of open spaces improves the thermal efficiency of the building by inducing natural light and natural ventilation, and plays a centripetal role in the interior spaces (No.11-17). In addition, the introduction of passive design through skin designs including double skin, translucent skin and louvers reduces the monotonous and tedious appearance of the large scale façade by creating patterns in the façade along with the blocking of the solar radiation or efficient energy control effects (No.28, 29, 31-34, 36, 37). For educational facilities, natural lighting during the daytime is highly important. Consequently, there are many cases in which the natural lighting effect is produced utilizing the building's orientation and shape along the major axis facing the south or the application of stepped mass. Exhibition facilities frequently utilize green building techniques of natural lighting, which maintain illumination at a constant intensity by converting direct sunlight into the diffused light. Case No.9 introduces diffused light via the ceiling through a louver type raised roof canopy, while case No.25 provides natural lighting for exhibition halls by introducing diffused light via the ceiling through the translucent curtain wall. In commercial facilities, it is important to improve identity by emphasizing the uniqueness of the building's appearance. Cases No. 43 & 44 were successful in producing the image of a green building and are endowed with a characteristic facade thanks to green walls. In the case of large-scale indoor sports facilities, ventilation for reducing heat accumulated at the top of the structure is important. Cases No.19 & 35 shield direct sunlight and induce natural ventilation through the use of a monitor roof or louver type skin that covers the entire sports facility. The monitor roof or louver type skin in these cases produces a morphologic character of a large space without columns and with simple openings. In addition, case No.30 utilizes the terraces of apartment housing as spaces similar to the double skin, while the louver type horizontal movable sun screens on the outside are capable of creating an ever-changing kinetic façade.

In terms of climate zones, the majority of the examples belonged to the temperate climate zone. The green buildings in this zone display almost all environment control techniques spread evenly without concentrating on specific techniques. However, the blocking of daylight and natural ventilation are essential in hot climate zones such as the tropical or dry climate zones. Cases No. 5 shields daylight by an inverted pyramid shape, while case No. 6 induces natural ventilation by creating a ventilation path by dividing the masses. Cases No.8 & 12 achieve maximum ventilation efficiency by way of a cone shaped atrium, and control the thermal environment by moderating direct sunshine at the top floor by utilizing an raised roof. Cases No.17 & 33 introduce natural ventilation by way of the

TABLE 2. Characteristics of Passive Design Techniques

Design Area	Passive Design Technique	Environmental Control Area			No.	Building Name	Aesthetic, Spatial Design factor	Building Use						Köppen climate classification			
		Light Environment	Air Environment	Thermal Environment				Office	Education	Exhibition	Commercia	Sports	Others	Tropical	Dry	Temperate	Continental
Building Orientation & Shape	South orientation	natural lighting	-	solar radiation penetration	1	Greensburg School	rectangular mass		○								○
					2	Liceo Scientifico	terraced mass		○							○	
					3	SIEEB			○								○
	Sun shading form	daylight shading	-	solar radiation shading	4	London City Hall	oblique-reverse mass	○								○	
					5	Tempe City Hall		○							○		
	Ventilation path	-	natural ventilation	air intake	6	Miami Museum of science	segmented mass			○				○			
					7	Sakai Gas Building		○								○	
	Raised roof	-	-	efficient energy control	8	Masdar Headquarters (same with No.12)	horizontal element	○							○		
					9	Chicago Art Institute				○							○
	Volume to surface ratio	-	-	efficient energy control	10	Musasino Sengawa Elementary School	square mass		○							○	
Open Space	Atrium	natural lighting	natural ventilation	solar radiation penetration /air intake	11	Willis Faber & Dumas Headquarters	vertical connection of floor	○								○	
					12	Masdar Headquarters (same with No.8)	cone shaped volume	○							○		
					13	Commerz bank Headquarters	spiral arrangement of sky garden	○								○	
					14	Tokyo Gas Earth Port	semi outdoor buffer zone	○								○	
	Court yard, light well	natural lighting	natural ventilation	solar radiation penetration /air intake	15	Gotz Headquarters (same with No.28)	courtyard with sliding roof	○								○	
					16	Aronr&d center	plural small courtyard	○								○	
					17	Siemens Headquarters (same with No.33)	courtyard through the space under piloti	○							○		
Opening & device	Skylight, monitor roof	natural lighting	natural ventilation	solar radiation penetration /air intake	18	Hearst Tower	combination of different masses	○								○	
					19	Sport Center Pajol	free shaped roof					○				○	
	Clerestory	natural lighting	natural ventilation	solar radiation penetration /air intake	20	IGES (same with No.24)	shed roof	○								○	
					21	Pocono Environmental Education Center			○								○
	Daylight duct	natural lighting	-	-	22	Solaris	diagonal path	○						○			
					23	Manchester Civil Justice Centre	ceiling height change	○								○	
	Light shelves, daylight ceiling	natural lighting	-	-	24	IGES (same with No.20)	three-dimensional façade	○								○	
					25	Kunsthaus	overlapped pattern			○						○	
	Ventilation duct, ventilation tower	-	natural ventilation	air intake	26	BRE Office of the Future	repetition of vertical elements	○								○	
					27	Swiss Re Headquarters	spiral pattern	○								○	
Building Skin	Double skin	-	-	efficient energy control	28	Gotz Headquarters (same with No15)	transparent flat skin	○								○	
					29	GSW Headquarters	kinetic pattern	○								○	
					30	Hemiciclo Solar							○			○	
	Translucent skin	daylight shading	-	solar radiation shading	31	CJ Only one R&D Center	repetitive pattern	○								○	
					32	Unilever Headquarter	homogeneous skin	○								○	
	Louver, sun screen	daylight shading	-	solar radiation shading	33	Siemens Headquarters (same with No.17)	repetitive pattern	○							○		
					34	3M Headquarters Building		○								○	
					35	Foshan Pearl Gymnasium						○				○	
					36	Education Executive Agency & Tax offices		○								○	
					37	Kiefer Technical Showroom	kinetic pattern	○								○	
					38	Savannah House	repetitive pattern						○			○	
	Closed facade	-	-	efficient energy control	39	Taisei Sapporo Branch Building	closed façade	○									○
Building Planting	Green roof, landscaped ramp	-	-	soil insulation	40	California Academy of Sciences	landscape façade			○						○	
					41	TU Delft Library							○			○	
					42	Multipurpose Hall							○			○	
	Green wall	-	-	soil insulation	43	Ann Demeulemeester	fluid facade				○					○	
					44	Cannel City Hakata					○					○	
					45	Seoul City Hall	green façade	○								○	
					46	ACROS Fukuoka		○								○	
	Water space	-	-	heat exchange	47	Jubilee Campus	water space		○								○
					48	McLaren Technology Center		○								○	
						Sample No.		30	6	4	2	2	4	2	5	35	6

courtyard that passes through the building vertically from the piloti space to the roof, while installed louvers shield the daylight. In addition, the cold climate zone is characterized by cases of architectural designs with closed façades with minimal openings, in which daylight and natural ventilation penetrate through atrium into the interior spaces (No.39).

7. CONCLUSIONS

This study analyzed the characteristics of passive design techniques introduced as the aesthetic and spatial concept of green building.

Passive design techniques are categorized into building orientation & shape (south orientation, sun shading form, ventilation path, raised roof, and volume to surface ratio), open space (atrium and courtyard), opening & device (skylight, clerestory, daylight duct, light shelves and ventilation duct), building skin (double skin, translucent skin, louver & sun screen, and closed facade), building planting (green roof, green wall, and water space) in accordance with the design process.

A building's orientation and shape are fundamental design elements that need to be taken into consideration in the early stages of the design process. These are methods of allowing or shielding sunlight utilizing the building's shape, or moderating the thermal load using natural ventilation. Solar radiation is introduced for rectangular or stepped buildings, while solar radiation is shielded for buildings that are inversely inclined towards the south. Moreover, natural ventilation is induced by creating ventilation paths through divided masses. The raised roof reduces the conductive heat of sunlight accumulated through the roof slab at the top floor by shielding direct sunlight as well as emphasizing the horizontality in architectural design.

Open spaces in green buildings are ways of emphasizing the spatial relationship by introducing such spaces in the deep area of the building where there is no contact with the exterior in order to create a semi-exterior space. This is also a method of moderating thermal load through natural lighting and natural ventilation. Therefore, such open spaces are frequently incorporated in wide, flat surfaces extending horizontally or in the center section of tower type buildings.

The passive design techniques of openings, light induction installations and ventilation induction installations refer to elements that are not only more efficient in terms of drawing in natural lighting or natural ventilation, but also in terms of the aesthetic function of the façade's design. Openings such as skylights or clerestory are utilized for natural lighting and natural ventilation purposes. They also can be used to express a diverse range of aesthetic and spatial characteristics including the connecting parts of heterogeneous masses, various roof shapes such as sheds and stepped or monitor roofs. Light induction devices such as light shelves and daylight ceilings are installations that introduce daylight into the deeper plan. These techniques allow for various façade designs. Ventilation induction devices are used frequently to generate a repetitive sense of rhythm by revealing the outside of the ventilation tower and maximizing the stack effect.

Skin design realizes efficient energy control or the shielding of sunlight through the utilization of both double skin and louver, or translucent skin and louver. It generates an aesthetic effect of the skin design on buildings with large and simple shape such as office facilities. This is achieved by forming a repetitive pattern with the addition of devices for the shading of sunlight onto the building's skin, and, at times, presents a kinetic façade capable of coping with the external environment.

The passive design technique utilizing building planting improves the thermal function of the building through the insulation effect of the soil layer, while also offering an aesthetic effect produced by the appearance of the greenery. This technique maximizes aesthetic effect through the use of a continuous landscape ramp, green wall, or roof that is connected to the ground rather than a mere roof garden on a flat roof surface.

This study is an attempt to propose techniques for expressing the unique aesthetic and cultural values of buildings using passive design. In addition, this study presents references for decision making for design, by taking into comprehensive consideration the aesthetic and spatial concept and passive design in the early stages of the design process. It is anticipated that interest in the passive design of green buildings will continue to increase in the future. Therefore, further studies are necessary for the purpose of applying effective methods in architectural design by evaluating and predicting the environmental efficiencies of the passive design techniques presented in this study. This will enable the forecasting of environmental efficiencies for reduction of the lifecycle cost in the early design stage. Furthermore, it will establish a background for selection by considering comprehensively the design elements and environmental efficiencies when reviewing multiple examples of passive design techniques simultaneously.

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