Title: **Report on the Mechanical and Electrical Technology of the Latest Tall Buildings in Japan**

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# Report on the Mechanical and Electrical Technology of the Latest Tall Buildings in Japan

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**Abstract**

The construction rushes of tall buildings have been taken place in the center of Tokyo in Japan. Here, the outline of the latest mechanical and electrical (M&E) technology supporting a tall building and the trend of them are described.

Next, two cases which are the project on the theme of the life prolonging on building and the project on the theme of commissioning process (CxP) are picked up, and the application methods are introduced.

In the former case, the renewal plan with using voids effectively was decided based on life cycle study, and the required techniques were incorporated in the architectural plan. In the latter case, CxP was fixed in project and improvement in building quality was achieved through this process.

**Keywords**: mechanical and electrical technology; life prolonging; commissioning process; Japan

## Introduction

Today, the tall buildings and the large buildings are successively completed in some metropolitan key area (see Fig.1-3). They are observed with their latest building technologies and their charm exceeding the former buildings, although there is an opinion which is anxious about oversupply of office buildings.

In this paper, the feature of the latest M&E technologies adopted to tall office buildings and the feature about some buildings is described concretely.

After height restrictions (31m) of the Building Standard Law were cancelled in 1962, the Kasumigaseki building (147m, 1968) which is the first tall building in Japan was built, and last year tall building rushes were again took place after the former rushes of the 1970s.

In Tokyo, the major redevelopment projects have been progressed in the central area, such as the Marunouchi area, the Shiodome area, the Roppongi area, and so forth. Their characteristics are the same period of completion in 2003. Some factors for this background are supposed to be simultaneous sales of large amount of good land from ’96 to ’97, overlapping of large city redevelopment and considerable deregulation of a floor area ratio by Tokyo Metropolitan Government in 1996.

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**Fig.1** Marunouchi area

**Fig.2** Shiodome area

### 1. The outline of latest M&E technologies in tall buildings in Japan

Many of new tall buildings have realized developed intelligent function, safety, flexibility, telecom infrastructure, comfort/amenity, an environment conscious technology, and etc. with good balance.

The feature of the three major buildings is shown in Table.1.

**Table.1** Mechanical and electrical systems adopted to the latest tall buildings

| | | A Bldg (Marunouchi area) | B Bldg (Shiodome area) | C Bldg (Roppongi aera) |
|---|---|---|---|---|
| Heat Source | | Steam from DHC[*1)], Chiller (using latent heat thermal storage), CGS[*2)] using city gas with usual and emergency use | DHC[*1)] plant and acceptance facilities, CGS[*2)] using city gas | DHC[*1)] plant and acceptance facilities, CGS[*2)] using city gas with usual and emergency use |
| Air Conditioning system | Perimeter system | Simplified air barrier system, 4 direction switching air diffuse system by dedicated AC unit | Air flow window system with ceramic print glass, dedicated AC unit + make-up air unit | VAV system |
| | Interior system | VAV system | VAV system + make-up air unit | VAV system |
| Garbage system | | Garbage compactor, Reuse of a kitchen garbage, the volume reduction machine of firing styrene | Separate collection of garbage | Air shooter (sealed and conveyed automatically to an underground garbage storage room) |
| Energy saving, Resource saving technology | | CGS, Latent heat thermal storage, High efficient equipment, Large temperature-difference water supply, VWV, VAV, Double-glazed glass, Simplified air barrier system, Air flow window system, Free cooling, Cooling by humidification, OA intake control by CO2 concentration, Natural ventilation, Total heat exchanger, Hf type fluorescent light, High luminosity guidance light, Photovoltaics, Reclaimed water system, Rain water use, Water-saved type sanitary fixture, etc. | | |
| Other characteristic equipment | | | Task and ambient lighting, Water-purifying system | The double deck elevator of 2 stories |

### 1.1. Safety

Safe, durable and "tough" building is required for natural disasters (an earthquake, a flood, a typhoon, etc.) and also human disasters (a fire, a terrorism, etc.). The total managed strategy based on calamity scenario is desired with refinement of integrated technology. For safety, the power supply redundancy in an emergency (electrical generator capacity with oil fuel), water reservation (water tank volume, the reclaimed water system, a well for emergency), redundancy of air conditioning (emergency system), etc. were also taken account for many cases. On the other hand perfect safety systems are hard to adopt from the economical efficiency reason.

### 1.2. Flexibility

Technical innovation is getting to speed up and the work style in office also changes corresponding to it. An office as a support system for workers should be flexible to meet their new requirement and arouse an office worker's creativity more positively.

The ease of changing tenant partitions and various additional services of a water supply, a power supply and a chilled water supply is required. Recently, there is also a case which appealing for an additional stairs in a tenant area. An advanced and stable telecom infrastructure and related specification (a space, power and cooling capacity, etc.) are thought as important. Stable correspondence for a multi-career and redundancy of a telecom infrastructure, the tenant service through the computer network, IPv6 (Internet ProtocolVer.6) and the power supply supporting telecom infrastructures, cooling, etc. are required. Moreover, a BACnet (Building Automation and Control Networks) protocol etc. is being introduced as open and multi-vendor system to a building control and monitoring system.

**Fig.3** Roppongi area

### 1.3. Comfort/Amenity

The Indoor environmental quality such as temperature, humidity, illumination, noise and etc. is controlled appropriately, and higher office productivity is required. There are also many cases of the glass building which have higher ceiling, large glass window (2.7-2.8mH), a full of open-feeling, good air conditioning system around the window and elaborate lighting system. And coexistence with comfort and energy saving are aimed at. Furthermore, the communication space, such as a short-break space is being improved, and thought as an important factor of high indoor environment quality. An exclusive exhaust preparation for separated smoking area is also required in the trend of smoking control.

**1.4. Environment conscious technology**

The larger a building scale is, the larger its influence is on an environment. So the way of activity on environmental problem to life prolonging building, zero emission, energy saving, garbage saving, recycling and the measure in global views is desired.

Next we actually see the latest technology in two buildings. One is an environment conscious technology, another is a technology for performing project.

## 2. Case study 1 : Life prolonging technology on building[1)]

Long-life is one of the big themes as a concrete countermeasure to the global environment problems in the building field in Japan .

We introduce outline of the building(Nissei Shin-Osaka Building, see Fig.4,Table.2) where long-life was one of three basic policies in design, and got the Award of Technology 2003 of SHASE( The Society of Heating, Air-conditioning and Sanitary Engineers of Japan )

One of the representative features of the building is two external spaces penetrating the building from the rooftop to the bottom which are called “multi-functional voids” and located at the center of office floors(see Fig.5). Multi-functional voids are utilized for diversified applications including natural light well, piping and ducting space, route for carrying in/out facility equipment installed on the rooftop, space for air intake/exhaust for air conditioning, additional piping/ducting space for dedicated air conditioning/ventilation system for special tenants and outside air cooling.

In design stage, renewal work items in 100 years after completion were picked up , and renewal cycle were examined. As a result, it was founded that the works reach peaks at the 30th, 60th and 90th years after completion, and that the air-conditioning, hygiene and electrical facility sections occupy considerable rate, 60% of the total renewal cost of the building in the life cycle (Fig. 6).

Accordingly, the following long life supporting technologies were planned which are based on the characteristics of each work to perform the works as smoothly as possible without stopping the daily functions of the building while restraining pertaining works as much as possible.

**2.1.Multi-functional voids** (Fig.5)

The multi-functional voids were planned to have the function of the replacement space for extending, inspecting and renewing the piping and ducts and of the route for carrying in/out major equipment installed on the rooftop.

**2.2. Securing replacement space and spare space**

The multi-functional voids were also planned to secure the replacement space at renewal for the heat source machines on the 3rd floor, the high voltage

**Fig. 4** Photograph of appearance

Table.2 Outline of building

| |
|---|
| [Outline of building] |
| Building name: Nissei Shin-Osaka Building |
| Address: Osaka City, Japan |
| Owner: Nippon Life Insurance Company |
| Design and supervision: Nikken Sekkei Ltd. |
| Major applications: Offices, restaurants and shops |
| Total floor area: 97,970.73m$^2$ |
| Structure: RC, SRC, S |
| [Outline of air-conditioning facilities**]** |
| Heat source: Gas absorption chiller/heater: 600 RT x 3unit, |
| Ice heat storage by centrifugal chiller:2780 RTh, |
| Centrifugal chiller:600 RT x 1 unit, 300 RT x 1 unit |
| Air-cooled heat pump chiller:100 RT x 2 units |
| Air-conditioning (typical floor): CAV & VAV |

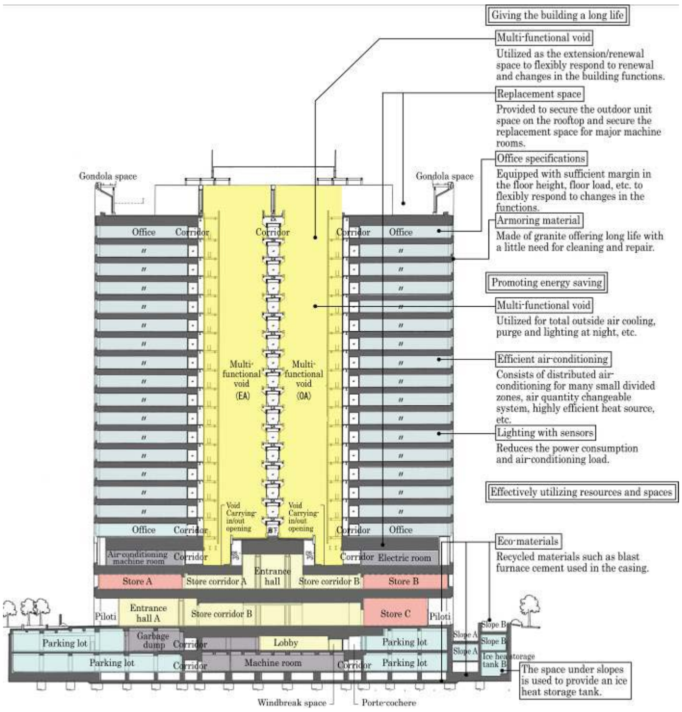


**Fig. 5** Cross section plan

electrical transformers on the 3rd floor, the outdoor machines on the rooftop and the main rigid piping space for air-conditioning inside multi-functional voids.

For the main machine room on the 3rd floor, an adjacent warehouse which have the similar area to the main machine room are prepared for the replacement.

Inside multi-functional voids, the replacement space for main rigid piping was planned to secure replacement works. For the machine area on the rooftop, major machines would be carried in/out through the multi-functional voids.

### 2-3 Load Reduction Effect by Long Life Supporting Technologies

As described so far, various long life supporting technologies were adopted in this building.

By making a renewal work plan actually, it was

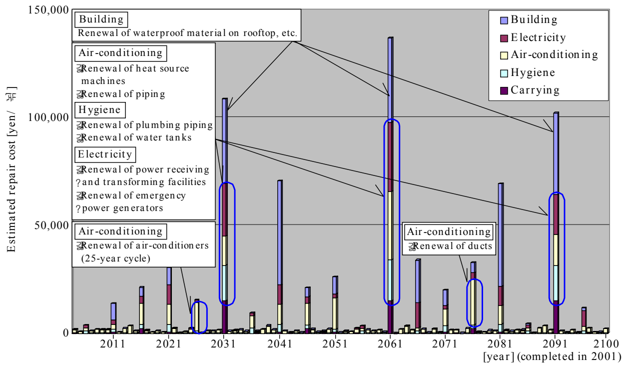


**Fig.6** Estimated long-term repair in life cycle

| Contents of renewal | Air-conditioning main rigid piping renewal work | |
|---|---|---|
| Renewal target or equipment affected when waterproof material is renewed | ?Renewal of main rigid piping inside multi-functional voids Height from 3rd floor to 20th floor: 74 m<br>?Cooling water: 200 A x 2 pipes, 300 A x 2 pipes, 450 A x 2 pipes Cold water: 200 A x 4 pipes<br>?Cold/hot water: 200 A x 4 pipes, 150 A x 2 pipes?Steam: 125 A x 2 pipes?Expansion pipe: 80 A x 2 pipes<br>?(Total weight: Approximately 49.7 t, number of pieces: Approximately 490) | |
| Compared case | Case in which multi-functional voids are utilized | Reference case<br>(in which elevators for people and cargo are |
| Carrying-in/out method or work procedure for waterproof material renewal | ?Carries out and in equipment and materials<br>? from doors on external walls on 3rd floor<br>?(using wreckers for lifting heavy objects).<br>?Carries equipment and materials laterally<br>?up to bottom of multi-functional voids on<br>?3rd floor.<br>?Installs heavy object lifting facilities at top<br>?of multi-functional voids.<br>?Installs rigid piping from rooftop using<br>?heavy object lifting facilities. | ?Unloads equipment and materials at<br>?underground parking lot, and carries them<br>? laterally to elevators for people and cargo.<br>?Unloads equipment and materials on each<br>?floor, and carries them laterally to pipe space.<br>?Installs rigid piping in turn from lowest<br>?floor. |
| Work days | ?Heavy object lifting facilities on rooftop ? 1<br>?dayfor assembly and 1 day for disassembly<br>?Taking equipment and materials into 3rd<br>?floor (spare space) ? 3 days<br>?Installing rigid piping from 3rd floor to<br>?rooftop ? 17 days<br>?Removing piping, and carrying it out to 3rd<br>?floor ? 20 days<br>?Carrying removed piping from 3rd floor to<br>?outside ? 3 days<br>?Total: 43 days | ?Taking equipment and materials into pipe<br>?space on each floor ? 19 days<br>?Installing rigid piping on each floor (from<br>?lowest floor) ? 34 days<br>?Removing piping ? 37 days<br>?Carrying removed piping from each floor to<br>?first basement, and carrying it to outside<br>? 갱 19 days<br>?Total: 43 days |
| Work man-days | ?Preparing heavy object lifting facilities,<br>?taking equipment and materials into 3rd<br>?floor, removing piping and carrying out<br>?removed piping ? 262 people in total | ?Taking equipment and materials into each<br>?floor, removing piping and carrying out<br>?removed piping ? 654 people in total |
| Used energy quantity | Light oil: 1,161 L, electric energy: 2,650 kWh | Light oil: 2,986 L, electric energy: 1,090 kWh |
| Estimated cost [yen/total area (뷖)] | 143 yen/뷖 | 296 yen/뷖 |
| CO2 generated by work | 5,223 kg-CO2 | 8,234 kg-CO2 |

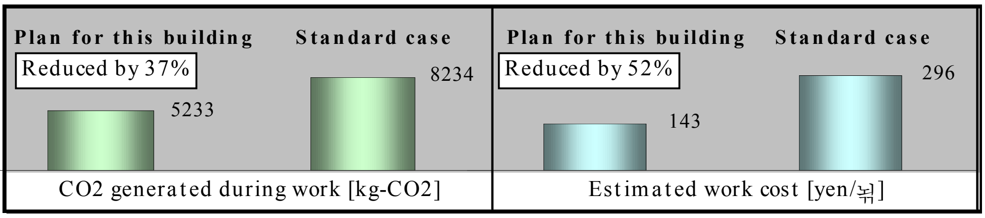


**Fig. 7** Load reduction effect achieved by long life supporting technologies

found that the load on the environment can be reduced considerably compared with a conventional general renewal work technique. As a major case, Fig. 6 shows the load reduction effect in the air-conditioning main rigid piping renewal work.

In concrete, the renewal work can be performed without stopping air-conditioning by utilizing the replacement space for piping inside multi-functional voids. In the renewal plan, piping pieces are stored in the warehouse for replacement on the 3rd floor, and then lifted by a hoist crane through multi-functional voids.

On the other hand, in the standard case, piping pieces are carried into the pipe space on each floor by elevators, and then the renewal work is performed on all floors in turn from the lowest floor.

In the plan with multi-functional voids, the work man-days are reduced by 60% by improving the work efficiency. The work cost is reduced by 52%. The CO2 amount generated by the energy used in the work is reduced by 37% (Fig.7).

## 3. Case study2 : Adoption of commissioning process[2)]

Efforts to do proper commission of M&E system functions, thereby contributing to energy saving and reduction of environmental load throughout the lifecycle of the building, are being made today in Japan. In this project（see Fig.8,Table.3）, a commissioning process was used from the building planning and design stages, in order to achieve the owner's requirements of increasing property value and achieving energy-saving performance. The commissioning process described here is characterized by verifying the performance of M&E system prior to handover and after the completion of construction, as well as embodying the various quality requirements of the owner for the building, from the planning and design stage onward, and coordinating appropriately.

### 3.1. Creation of commissioning process

The most important theme in this project was to reflect the owner's requirements in the actual plan to achieve "Prime Grade A Office", although it was somehow ambiguous concept.

For this purpose, an organization to conduct the commissioning process was set up and the conference committee, notification documents, product and the like were defined. In addition, the following nine themes relating to M&E system were established (Table.4).

### 3.2. Improvement of property value through commissioning process

The following themes relating to improving the property value of the building were studied and put into concrete form:

(1) Reliability as a 24-hour service building
(2) Securing building functions in the event of a disaster

**Fig. 8** Photograph of appearance

Table.3 Outline of the building

| |
|---|
| [Outline of building] |
| Building name: Pacific Century Place Marunouchi Building |
| Address: Tokyo City, Japan |
| Major Owner: Pacific Century Group, Hong Kong |
| Design: Nikken Sekkei Ltd., Takenaka Corp. |
| Supervision: Nikken Sekkei Ltd. |
| Major applications: Offices, restaurants and shops, hotel |
| Total floor area: 81,693m$^2$ |
| No. of floors: B4F, 32F, P1F |
| Structure: RC, SRC, S |
| Completion of construction: Nov., 2001 |
| [Outline of air-conditioning system] |
| Heat source: Gas absorption chiller/heater, Ice thermal storage with brine chillers and centrifugal chillers: 11,285kW(total cooling capacity), 5,177kW(total heating capacity) |
| Air-conditioning (typical floor): VAV system and simplified air flow system with the seasonal changeover function with air-tight blinds |

(3) Durability performance aimed at achieving long service life
(4) Ensuring low noise level in office spaces
(5) Improving the tenant rentable ratio
(6) Security performance

### 3.3. Ensuring the perimeter environment performance of the glass building through the commissioning process

To achieve a "timeless design," which was one of the owner's requirements for the building, the building was designed as a "glass building" with an exterior consisting entirely of glass from floor to ceiling. For this reason, ensuring indoor environmental performance such as the thermal environment in perimeter areas was an important theme. Numerical requirements for thermal performance were prescribed and the design process was conducted so as to achieve these requirements. In the commissioning process, there were changes to the system, at last stage actual size model test was done for various window systems, and a summer/winter switching airflow system with airtight blinds was adopted (Fig.9). After building construction was completed, verification measurements were conducted for the actual building, and these measurements confirmed the performance that was equal to or higher than the actual size model tests.

At the operational stage, operation methods were readjusted in an effort to strike a balance between tenant services and energy saving and to improve both of them.

### 3.4 Ensuring various types of energy saving performance through the commissioning process

In this project, an effort was made to reduce building energy consumption same as other buildings. But the focus of this project was on the themes specific to tall buildings and the themes that have been recognized as problems but have not been quantified and have tended to be overlooked. One of the themes specific to tall buildings is the "stack effect." To prevent the increased outside air load resulting from the "stack effect," an air balance control system was adopted. Other techniques were also adopted: a large temperature differential transfer system to reduce pumps and fans power energy, variable air volume (VAV) control for offices, inverter control and replacement

ventilation systems for parking areas and machine rooms. Furthermore, the cooling tower fan power was reduced and the cooling water temperature was lowered in an effort to improve the overall heat source coefficient of performance (COP). Illumination dimming control through the use of automatic blinds control and the use of daylight were adopted to lessen the air conditioning load. A simple reclaimed water (recycle water) system aiming at easy maintainance and useing air conditioning drain water and the like was adopted to save water.

Some of these measures are described in greater detail in the following sections.

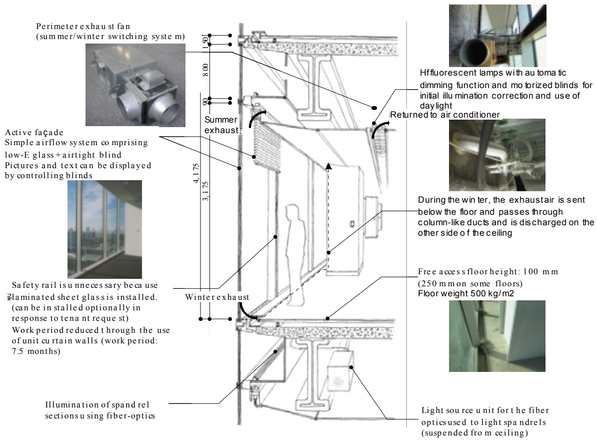


**Fig.9** Section diagram of perimeter areas

#### 3.4.1 Planning and performance verification for the air balance control system designed to prevent the "stack effect"

(1) Requirements

As a measure that could be adopted on the M&E system to prevent the "stack effect," a proposal to control the airflow of outside air (OA) and exhaust air (EA) on standard office floors was submitted. The following items were established as requirements:

• Ensure that the difference between the actually measured air intake/exhaust volume on each floor and the design volume is no more than 10%

• Check the indoor and outdoor air pressure differential at the first floor entrance lobby

(2) Overview of planning

Air velocity sensors and inverters were used to control airflow continuously for three systems on each floor (outside air supply, general exhaust and toilet exhaust). So these systems would not be affected by the outside air pressure or the air pressure differential between the inside and the outside. The set airflow

**Table. 4** The nine themes relating to M&E system through CxP

| | |
|---|---|
| 1. Securing performance in perimeter environments | Perimeter air conditioning, mixing loss with the interior, lighting distribution, daylight control |
| 2. Improving reliability as a 24-hour service building | Power supply backup, air conditioning backup |
| 3. Improving building performance in the event of an emergency | Measures for use in the event of an infrastructure failure, earthquake-resistant performance, disaster prevention performance |
| 4. Securing functions as a building with a long service life | Increasing equipment service life, planning for the future, flexibility |
| 5. Ensuring “quiet” office spaces | External noise ("bullet train") soundproofing, soundproofing/silencing of internally generated noise |
| 6. Improving the tenant rentable ratio and ensuring maintainability | Maximizing the area for exclusive tenant use, securing maintainability |
| 7. Securing security performance | Zoning, coordination with equipment functions |
| 8. Securing energy-saving performance | Prevention of "stack effect," streamlining of wastewater reuse systems, daylight control, streamlining of ventilation, variable air volume (VAV), variable water volume (VWV) |
| 9. Construction of a Building Energy Management System (BEMS) suited for management and operation | BEMS taking into consideration failure and fault predictions |

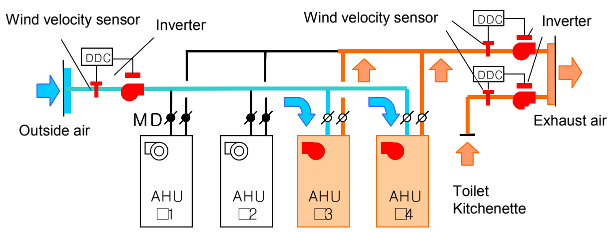


**Fig. 10** Air balance control system on standard floors

was calculated from the number of air conditioners to be operated to ensure that the airflow was controlled to an appropriate volume (Fig.10).

(3) Verification process and results

In the three airflow checks, the actual airflow was finally met to the requirement (Fig.11). The airflow was measured at doors between corridors and stairways on each floor, and the results showed that the maximum airflow for each location was about 400 m3/h. Considering that there are two stairways, it was approximately 10% of the outside air intake for each floor and it was confirmed that the level has been kept low (Fig.12).

With regard to the internal and external air pressure differential at the entrance lobby, the indoor value with the door closed was 1.0 Pa, with positive pressure maintained and it was confirmed that the "stack effect" was being controlled.

### 3.4.2 Planning and performance verification for simple wastewater reuse system

(1) Requirements

The planning values estimated that the amount of recycled wastewater during a one-year period would be 26,640 $m^3$. In contrast, raw water usage was predicted to be 13,573 $m^3$ per year, a recycling ratio of 57.8% over one year period (raw water / recycled wastewater). As a requirement, the recycling ratio was established as a target value (Fig.13).

(2) Overview of planning

To ensure a comparatively stable raw supply water while reducing the water treatment load, the system was determined to use rainwater as well as air conditioner drain water (cooling tower blow water, condensed drain water and vaporization type humidifier drain water) as raw water. After treatment, this water will be used to flush toilets. The treatment system is a simple one consisting only of sand filtration and a sterilization unit

(3) Verification process and results

The actual water volume for one year period were 38,300 $m^3$/year of recycled wastewater and 29,600 m3/year of raw water. This comes to a reuse ratio of 77.3%, which met the requirements (Fig.14).

### 3.5 Evaluation of actual energy consumption

Primary energy consumption for one year period was 2,780 MJ/$m^2$ per year for the entire building and

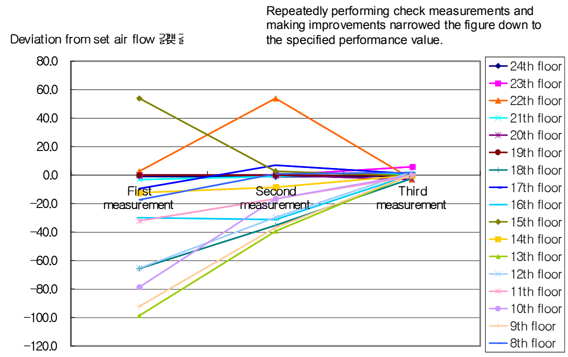


**Fig. 11** Air volume deviation for exhaust airflow

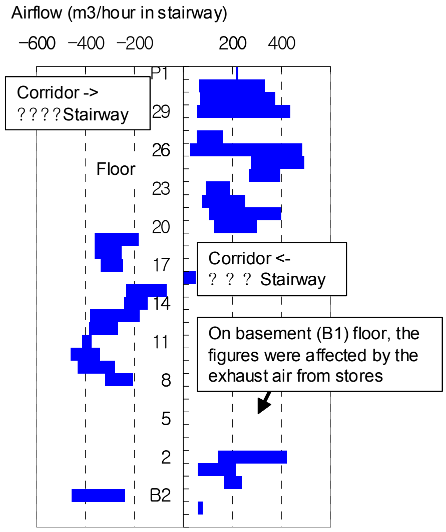


**Fig. 12** Measured air balance (in Feb.)

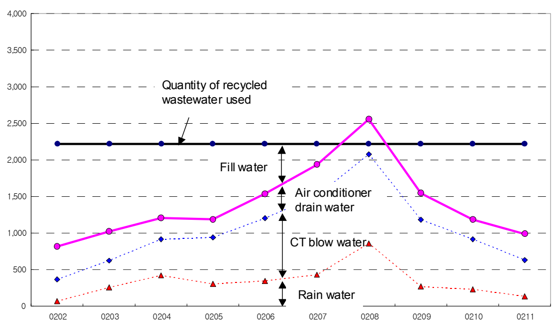


**Fig. 13** Planned quantity of recycled wastewater

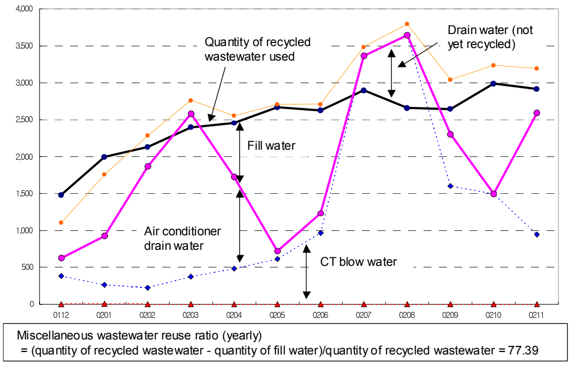


**Fig. 14** Actual quantity of recycled wastewater

2,380 MJ/m$^2$ per year for the office sections (not including the store and hotel sections). At a glance much energy seems to be consumed in this building, but we think it is reduced enough when considering the characteristic of a building and its usage.

A breakdown of the total enrgy consumption reveals that a large portion is accounted for by lighting power (Fig15). This is thought to be due to the bulbs used on standard floors and hotel sections that have much importance as design elements, and to the power required to light up the building. It is thought that an operational effort would be needed in order to reduce the energy consumption.

The amount of power consumption by the air conditioning heat source was a small percentage of the total (28%) and air conditioning pumps and fans was 12%. It is seemed that the energy saving techniques was effective.

Figures 16 and 17 show a portion of the power energy consumption status on office floors. The lighting power consumption was larger than standard offices because of high illumination of 750Lx. In addition, the OA power consumption at night and on non-work days was about 50% of the peak consumption.

## Conclusions

From the latest projects, two cases were picked up mainly, and life prolonging of a building and improvement of a building quality through commissioning process were mentioned. Two cases won the Award of Technology 2003 of SHASEJ (The Society of Heating, Air-conditioning and Sanitary Engineers of Japan) and are therefore thought to show the part of the latest trend in building M&E engineering.

Many Japanese engineers have developed new technology and have applied them to buildings. Many of their efforts were measured and verified in indoor environmental quality or at building performance after building completions. But the results are hardly known to foreign countries.

We will be pleased if they can contribute to introducing Japanese engineering technology and become the references in the case of future project.

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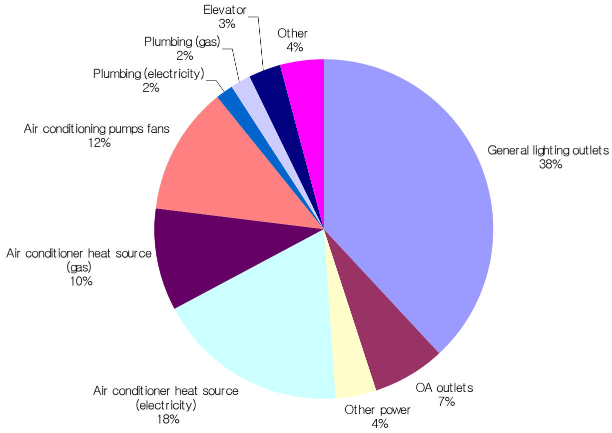


**Fig. 15** Breakdown of prnergy consumption during a one-year period

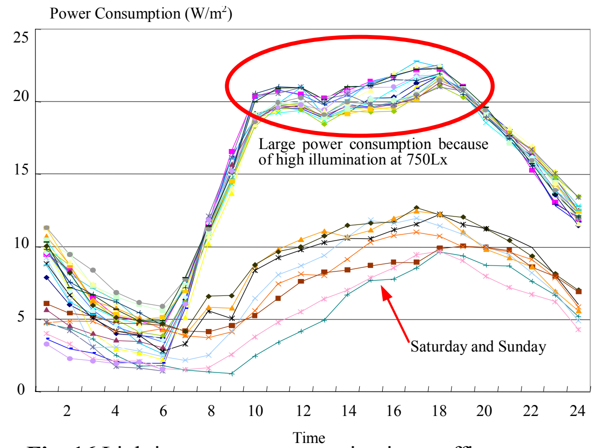


**Fig. 16** Lighting power consumption in an office area

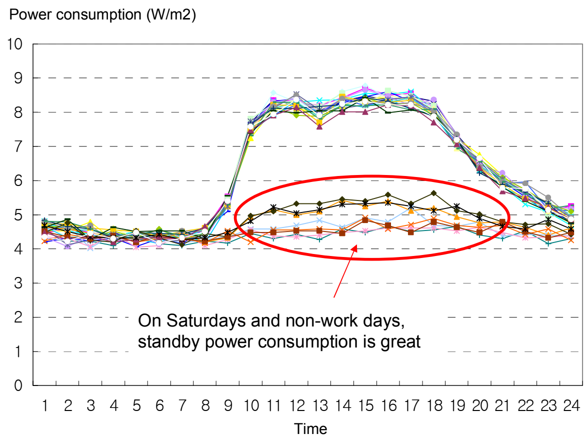


**Fig. 17** OA power consumption in office area