1 GENERAL INFORMATION

1.1.1 Report date
December 2001 (3rd draft)

1.1.2 Principal researchers
Shinsuke Kato
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
Tel +81 3 5452 6431
Fax +81 3 5452 6432
e-Mail kato@iis.u-tokyo.ac.jp

1.1.3 Other participants
Shigeaki Narita
2025-1 Ono, Atsugi City, 243-0125 Japan
Tel +81 46 250 7095
Fax +81 46 250 7139
e-Mail narita@fujita.co.jp

1.1.4 Project title
A study on features of the hybrid ventilation of Fujita Technology Center.

1.1.5 Principal objectives
The chief purpose of the study is to evaluate effects of Hybrid Ventilation in connection with the energy saving and thermal comfort. Another is to provide experimental information on characteristics of the natural wind and the indoor air flow rate which seems to be useful for Hybrid Ventilation.
1.1.6 Start date / End date
April 2000 to March 2000

1.1.7 Number of man-hours
Man-hours for evaluations and reporting is approx. 800.

1.1.8 Project approach
Nothing in particular.

1.1.9 Building selection
Nothing in particular.

1.1.10 References
Nothing in particular.

1.1.11 Comments
Fujita Technology Center has been so designed and constructed that the effect of the natural ventilation is derived to the maximum. Air flow routes inside the building are comprehensive because the building shape is simple, which is to yield the effective assessment of the theoretical model.

Both inside and outside of the building are regarded as fields for studies and experiments, and hence various sustainable systems including even trials are applied.

2 TEST SITE DESCRIPTION

2.1 Geographic information

2.1.1 Location
Atsugi city, Kanagawa prefecture, Japan, located at Latitude; 35°25’N. Longitude; 139°20’E.

2.1.2 Elevation (height above sea level)
54m.

2.1.3 Terrain; Site plan
The building is located in a suburb of Atsugi city and surrounded by green hills in three directions. The west side is solely open, therefore the prevailing wind direction is west.

2.1.4 Orientation
In order to induce the natural ventilation, the main façade faces the west.

2.1.5 Comments
Nothing in particular.

2.2 Climate information (Summary)
The climate data of the Ebina AMeDAS station is available, which covers the precipitation, the air temperature and the wind speed.

2.2.1 Location of meteorological station
The Ebina station is sited at 35°26’N 139°23’E, and the height of anemometer is 18 m.

2.2.2 % frequency wind speed versus wind direction
The frequency versus wind direction which was measured on the site in 1998 is shown below. The mean wind speed on the site was 2.0 m/s. In addition the data on the Ebina station of 1998 was 2.3 m/s.
2.2.3 Air temperature

The following shows monthly average, and average daily maximum and minimum air temperature from April 2000 to March 2001. The average air temperature was 15.6 °C. Design conditions for summer & winter are 15.9 °C, 32.2 °C, 0.4 °C, respectively.

2.2.4 Degree day information

900 heating degree days (14 °C baseline) and 130 cooling degree days (24 °C baseline) in Tokyo.

2.2.5 Daylight / insolation

The monthly total horizontal solar radiation is shown in the figure of Clause 2.2.3. The total hours of sunlight from April 2000 to March 2001 was 1,905 hours, and the total insolation was 4,566 MJ/m², while the mean annual total hours of sunlight is 1,821 hours, and the mean annual total insolation is 4,200 MJ/m².
2.2.6 **Cloud factor**
Unknown.

2.2.7 **Relative humidity & precipitation**
The design %RH is 50% RH during summer.
The total precipitation was 2,123 mm in 1998, and 1,708 mm in 2000.

2.2.8 **Barometric pressure**
Unknown.

2.2.9 **Soil temperature**
Unknown.

2.2.10 **Other meteorological parameters**
None.

2.2.11 **Comments**
Nothing in particular.

### 3 BUILDING DESCRIPTION

#### 3.1 General description

3.1.1 **Building name**
Fujita Technology Center.

3.1.2 **Building type**
A research institute of a contractor.

3.1.3 **History**
A new construction.

3.1.4 **Design philosophy for IAQ and thermal comfort, energy efficiency and other issues of concern**
The building consists of the office, the atrium and the laboratory as shown in Section 3.2.1. HVAC systems are provided only to the office block and the others are equipped with neither heating nor cooling in principle. Considerations on thermal comfort and energy efficiency etc are performed only for the office block, therefore.

- The Valuable-Air-Volume (VAV) system is applied to reduce the power use of conveyance.
- The night-purge is carried on by the natural ventilation.
- Lightweight construction for the thermal storage.
- Low-emission glass is used.
- Occupants can vote their thermal comfort by means of BEMS (Building Energy Management System), then the operating temperature can alters accordingly. And occupants can also manually operate the natural ventilation system.

Other design concepts were as follows:

- No partition is installed between the working space and the atrium so as to give a sense of the spacious, and air curtain systems is applied at boundaries.

3.1.5 **Comments**
Nothing in particular.
3.2 Building geometry & materials

3.2.1 Plan

The building consists of 3 wings, i.e. the office, the atrium and the laboratory:

The office wing has 3 stories where researchers and administrators are usually working. The atrium combines the other 2 wings and yields a spacious sense. The laboratory has many rooms of various sizes and the central area is the large void area for huge experimental equipment.

FLOOR PLAN (FIRST TO THIRD FLOOR)

3.2.2 Elevation

WEST ELEVATION

SOUTH ELEVATION
3.2.3 Building form
12.9m (RF Level), 18.7m (PHF Level), 19.8 m (top of the atrium)
3 floors and 1 basement floor.

3.2.4 Volume
Approx. $170 \times 10^3$ m$^3$.

3.2.5 Floor area & materials
GFA 24,148 m$^2$; office 6,742 m$^2$, atrium 1,173 m$^2$ and laboratory 16,228 m$^2$.
NFA Aprox. 21,400 m$^2$

The floor slab is made of reinforced concrete in 150 mm thickness. In the office area the surface is covered with carpets, and in the laboratory covered with vinyl sheets or coated with ethoxyline resin paint. U-value is 3.1 W/(m$^2$°C).

Insulation layers of the top slab and crawlspace (this is for earthquake isolation devices) are 80 mm and 30 mm in thickness, and U-values are 0.4 and 0.7 W/(m$^2$°C), respectively.

3.2.6 Ceiling height
The ceiling height is 2.7 m in general. In almost laboratories no ceiling provided. The floor heights are 4.5 m for the 1st floor and 4.2 m for the 2nd and the 3rd floor. The height of top of the atrium and the large equipment laboratory are 19.8 m and 18.9 m, respectively.

3.2.7 Facades (external walls)
The external wall consists of aluminium curtain wall layer, 30 mm thickness insuration layer, void layer and 35 mm excelsior-board layer. The U-value is estimated 0.8 W/(m$^2$°C).

3.2.8 Windows
- The total area of windows of office block: north 62 m$^2$, south 62 m$^2$, west 354 m$^2$.
- The total area of windows of the atrium: north 356 m$^2$, south 356 m$^2$, east 81 m$^2$, west 81 m$^2$, ceiling 1,173 m$^2$.
- External shading: None
- Shading control: Internal blinds are controled by intencity of direct soler radiation on vertical plane (the west wall of the office block).

3.2.9 External doors or hatches
North 23 m$^2$, south 30 m$^2$, west 22 m$^2$, east 143 m$^2$.

3.2.10 Number, volume and layout of rooms

3.2.11 Attic, basement, crawlspace

3.2.12 Interior walls, including moveable partitions

3.2.13 Interior doors and devices

3.2.14 Stairwells
Number of stairwells: 6
Size of stairwells: each 18m$^2$

3.2.15 Service risers
Number of elevator shafts: 3
Size of elevetor shafts: 9m$^2$
Rubbish chutes: None

3.2.16 Comments
Nothing in particular.
3.3 **Air leakage data** (type, location and crack length for each component)

The air leakage test is scarcely applicable because of the building size.

3.4 **Wind pressure coefficients**

3.5 **Space heating**

Only the office block is provided with heating and cooling.

The single duct VAV system is applied for the office space and 18 air handling units are installed in total. The conference rooms and private rooms are equipped with fan coil units or heat pump air conditioners. The main heating/cooling plant is two natural gas direct fired double-effect absorption water chiller boiler and each capacity is 703 kW. The supply/return temperature is 60/53 °C for heating and 7/14 °C for cooling. The natural ventilation mode is not active for heating duration.

3.6 **Ventilation**

3.6.1 **Ventilation principle**

The ventilation system of the office block is mentioned hereinafter.

The ventilation principle is a cross ventilation that utilizes wind driven forces in combination with stuck driven forces. The air flow is so designated that outdoor air enters from the inlets utilizing smoke exhaust windows of each floor, goes through over the working area and goes out from the top level openings of the atrium which adjoins the office area. The natural ventilation is selected when the outdoor condition accords with a guideline. Windows can automatically open in midsummer, accordingly.

3.6.2 **Components**

![EXPECTED AIR FLOW OF NATURAL VENTILATION](image-url)
3.6.2.1 Fresh air inlets

The total area of inlets is 170 m², i.e. 0.025 m² per 1 m² of floor area of the office block.
3.6.2.2 Fans
3.6.2.3 Heat recovery
3.6.2.4 Filtration
3.6.2.5 Ducts
3.6.2.6 Room supply & extract devices
3.6.2.7 Air exhaust outlets

The total area of outlets of both west and east side of the atrium is 132 m^2. 

AIR OUTLET OF ATRIUM
3.6.3 Frequency of operation, duration of operating cycle
Hybrid ventilation is active during air-conditioning period, 8 am to 9 pm. For the other hours and holidays the natural ventilation mode can be available by manual operations.

3.6.4 Balancing report

3.6.5 Ventilation rate (outdoor airflow supplied by system)

3.6.6 Any recirculation between rooms due to HVAC system

3.6.7 Space cooling
See Clause 3.5.

3.6.8 Comments

3.7 Internal loads

3.7.1 Pattern of occupancy
Hours of occupancy: 10 hours (8:00 to 18:00)
Number of occupants and m²/person: approx. 130 occupants and 16.2 m²/person according to the register, however usual attendance seems around 60%.

3.7.2 Lighting
Lighting gain is approx. 27 w/m².
Lighting is controled by infrared rays sensors which perceive human existance.

3.7.3 Other internal gains
Each person has at least one desktop personal computer.

3.8 Control system and control strategy for ventilation and space conditioning

3.8.1 Type of system
The controle system is BEMS (Building Energy Management System), which is specially developed for the building and named FACMOS (Fujita Active Controle and Health Monitoring System).

3.8.2 Parameters monitored
Energy use (power, gas and water)/performance of zones/equipment as well as dry-bulb temperature, relative humidity, precipitation, solar radiation, wind speed, and wind direction.

3.8.3 Sensors
A mobable wireless dry-bulb temperature sensors is provided for every floor area of 81 m² of the office that is controled by a VAV unit. A humidity sensor is provided for return duct of every air handling unit. The other rooms where fan coil units are installed are equipped with wall mounted thermostats.
A dry-bulb temperature sensor, a relative humidity sensor, an anemometer, a precipitation meter and an pyrheliometer are placed on/above the roof for monitoring the outdoor conditions.

3.8.4 Control strategy & internal design conditions
The above-mentioned FACMOS judges modes of Hybrid Ventilation; whether natural ventilation, outdoor air cooling or HVAC subject to signals of the sensors (wind speed, outdoor air temperature, rainfall) while room conditions are controled by local sub systems in principle. The air inlets/outlets are operated by motor driven devices. All HVAC/mechanical ventilation systems cease during the natural ventilation mode.
The current scheme of applying the natural ventilation is shown bellow, and the final operation scheme will be determined due to this study.
Operating room temperature is 26°C/22°C for cooling/heating and relative humidity is 50%.
3.9 Pollutant sources

3.9.1 Interior sources
None except laboratories, where the pollutants are exhausted by the local ventilation.

3.9.2 Exterior sources
Pollutant sources seem few because of the building locating at a suburb.

3.10 Furniture, interior fittings

3.11 Costs
The cost information is not useful because the building is a laboratory and various experimental systems are provided, which are too complicated for the cost to be divided.
3.11.1 Building
3.11.2 Plant
3.11.3 Control system

3.12 Monitoring programme

3.12.1 Measurement objectives
The measurement performed for the 2nd floor of the office block is mentioned hereinafter.
The comprehensive field measurement and questionnaires were carried out in order to evaluate the effect of the natural ventilation/Hybrid Ventilation. The chief measurement objectives are as follows.

- To observe and record conditions of the air flow and air exchange rates of the cross ventilation over the workplace.
- To study the thermal comfort for the cross ventilation.
- To estimate the energy saving caused by the natural ventilation.

3.12.2 Parameters to be measured, Measured plan
Parameters to be measured are shown in the following tables.
The long term monitoring through the year under the normal operation is being carried on since June 2000.
The short term detailed monitoring and experiments were undertaken May 15 to 30 of 2000.

<table>
<thead>
<tr>
<th>PARAMETERS TO BE MEASURED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITEM</td>
</tr>
<tr>
<td>DRY-BULB TEMPERATURE</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>GLOVE BALB TEMPERATURE</td>
</tr>
<tr>
<td>RELATIVE HUMIDITY</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>AIR FLOW RATE</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>WIND SPEED/DIRECTION</td>
</tr>
<tr>
<td>ENERGY</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

3.12.3 Parameters analysis
The temperature was measured by thermo couples. The indoor air flow rate was measured by hot wire anemometers and 3D ultra-sonic anemometers. The wind speed and direction were measured by an aero-vane. The data was recorded in data logers at intervals of 1 minute in principle.
3.13 Results from monitoring programme

3.13.1 Distributions of air flow rates through air inlets

The distribution of air flow rates of an air inlet were measured as following manner. Two examples of measurement data are shown.

It was seen that fresh air always goes indoors even to the contrary wind direction, and that the faster the wind speed is, the wider the distribution of air flow rates at the inlet is.
3.13.2 Decline of indoor air flow rates

The decline of indoor air flow rate was measured as follows.

It was seen that air flow rates at the distance of 12 m from the inlet were less than 1 m/s.
3.13.3 Air exchange rates

The following drawing shows the relation between the wind speed and the air exchange rate based on the arithmetical average of 1 hour. The monitoring period was May 15 to 30, and September 29 to October 25.

It was seen the air exchange rates were significantly large number and that more than 10 times / hour was gained even at the foul wind direction (i.e. eastward).

3.13.4 Indoor air temperature under natural ventilation

The following drawing shows the difference between the indoor and outdoor air temperature (based on average of 10 min.) under the natural ventilation of 4 days in May.

It was seen the raise of temperature of the indoor air from the outdoor is substantially less than 2 degree.
3.13.5 Marginal conditions for the natural ventilation

In order to find the marginal condition for applying the cross ventilation experiments were carried out, that the natural ventilation is manually operated no matter what the outdoor condition is and occupants vote by means of the intra-net when they feel discomfort. The results of 2 days are shown bellow; the result of May 15 is an example of a cold wether condition. May 29 is one of a hot wether condition. Further studies required, however, it seems that the thermal adaptation can be expected particularly against cold wether.
% OF DISCOMFORT AND INDOOR CLIMATE UNDER NATURAL VENTILATION (EXAMPLE OF COLD WETHER MAY 15, 2000)

(PMV estimated with Clo value 0.9 and relative humidity 60%)
% OF DISCOMFORT AND INDOOR CLIMATE UNDER NATURAL VENTILATION (EXAMPLE OF HOT WETHER MAY 29, 2000)

(PMV estimated with Clo value 0.6 and relative humidity 45%)
3.13.6 Energy conservations caused by Hybrid Ventilation

The following drawing shows the use of natural gas for cooling and daily average air temperature during the detailed monitoring duration. Until May 22 the plant had not been operated, and May 27 and 28, June 3 and 4 are holidays. Colored columns indicate days when the natural ventilation was applied for some hours. For the other days HVAC systems were operated in the whole day.

![Graph showing use of gas and daily average air temperature](image)

It is always difficult to estimate the energy conservation since indoor and outdoor conditions vary from day to day. The following drawing a comparison of hourly gas use and air temperature of June 7 and 8, of which the daily average temperatures are almost same each other. On the former day the whole building was cooled by HVAC systems all day and the natural ventilation was by no means in operation because of wind speed being fast. On the latter day the natural ventilation was in operation between 15 hour and 18 hour. It is seen that the gas use of these hours of June 8 was reduced by less than one third. In addition power of fans lessens as the air handling units of the corresponding area are stopped. The power cut of fans amounts 62 kW.
3.13.7 Annual energy consumption

The following drawing shows result of monthly cooling and heating load of the office wing from April 2000 to March 2001. Total annual cooling load was 217 MJ/m$^2$, which is approximately half of the standard load of modern office buildings in Tokyo. Total hours for the natural ventilation being active was only 89 hours against the total of 975 hours of cooling duration. This is because of an inadequate control. The reason of less cooling load achieved nevertheless, seems the natural ventilation being active during overtimes and holidays. The energy use for these times is not a small portion in an office building of Japan. On the other hand, the heating load was 205 MJ/m$^2$, which is larger by 50% than the standard of modern office buildings. This is because the heat flowing out to the open atrium adjoining the workplace where neither cooling nor cooling provided.

![MONTHLY COOLING AND HEATING LOAD](image)

3.14 Lessons Learned

The most significant problem of the system was that hours in the natural ventilation mode were small as mentioned in the clause 3.13.7. The crucial point seemed to be the enthalpy control that is shown in the clause 3.8.4, i.e., the natural ventilation mode is not active unless the enthalpy of outdoor air is larger than the indoor air. However, the enthalpy of indoor air hardly exceeded the outdoor air in the cooling season once the HVAC mode was active in a day.

This condition has been cancelled in the BEMS since April 2001. The natural ventilation is now controlled by indoor and outdoor air temperatures, wind speed and direction, and rainfall. The following drawing compares monthly hours in the natural ventilation mode during cooling period of the year 2000 and 2001. It is seen that the natural ventilation hours were enlarged significantly. The total hours in the natural ventilation of 2001 was 465 against 89 of 2000.
The energy use was reduced, accordingly. The following drawing also shows the monthly cooling load and average outdoor air temperature of both years. The total cooling load of 2001 was cut down by approximately 20% although the average air temperature of the cooling duration was almost the same (22.7°C in 2000 and 22.5°C in 2001).

The indoor air temperature was frequently up to 28°C in the natural ventilation mode, however, no occupants complained.

MONTHLY COOLING LOAD AND AVERAGE AIR TEMP. (2000 AND 2001)