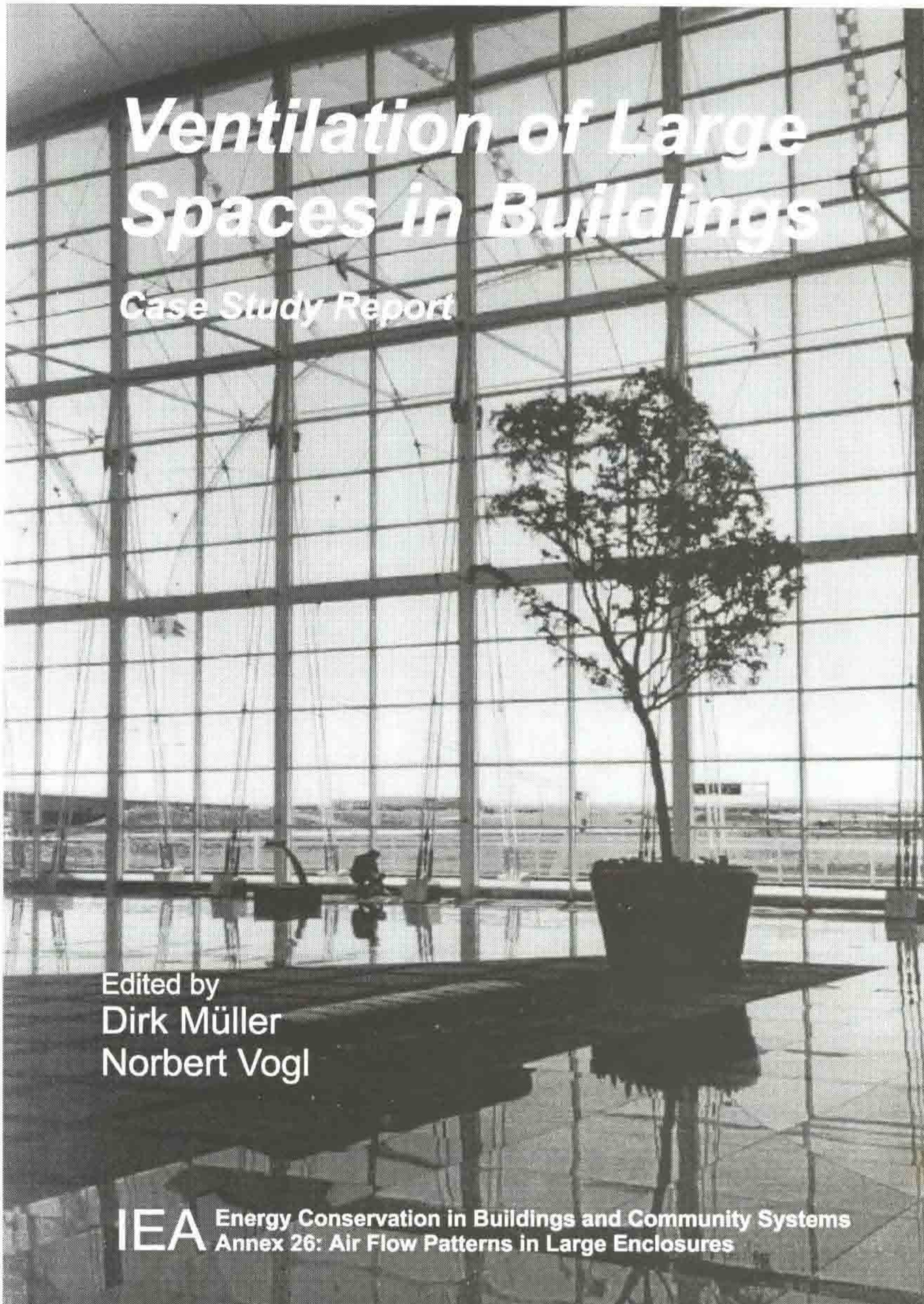


Ventilation of Large Spaces in Buildings

Case Study Report

Edited by
Dirk Müller
Norbert Vogl

IEA Energy Conservation in Buildings and Community Systems
Annex 26: Air Flow Patterns in Large Enclosures

Foreword

During the ANNEX 26 "Energy-Efficient Ventilation of Large Enclosures" many research groups studied the performance of various types of large enclosures. To develop a better understanding of the ventilation situation in large enclosures, many different measurement techniques were applied to case study buildings.

This book is part of the ANNEX 26 publications and it contains brief descriptions of most of the buildings examined by ANNEX 26 participants. The goal of this book is to provide the reader with an overview of the various building types including information about the building performances. For the sake of simplicity, the information about all the buildings have the same form. Unfortunately it was not possible to get all the desired data for each enclosure and therefore only the available data are presented in the following structure:

- Building Description
  - Building type
  - Site and location
  - Building form
  - Building services
- Performance of the Building
  - Energy performance
  - Ventilation performance
- Recommendations
- References

Some of the mentioned enclosures serve as examples in the ANNEX 26 report "Analysis Tools Report-Measurement and Modelling Techniques". That report includes more detailed information on the applied measurement techniques and the performance of the enclosure.

Additionally, the reader is invited to ask the contact person named in the reference section of each building for more information.

Contents

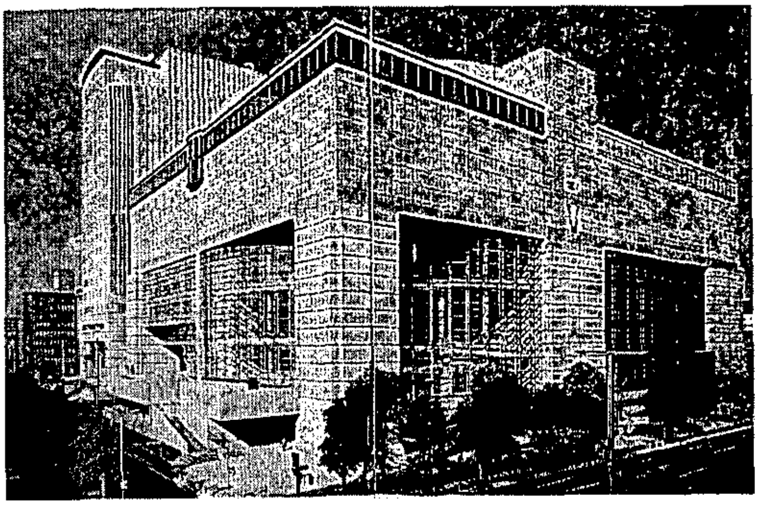
Part I

Atrium

1 Aichi Art Center JP 10

1.1 Building Description

Building type:
Public Hall, Theaters



Owner:
Aichi Prefecture
Nagoya
Japan

Year of completion:
1992

Project Costs:
50 000 000 000 yen

Design Team:
A&T Associates

The government of Aichi prefecture planned to elect a new art center as the base which responds to the trends of artistic culture from now to the 21st century and attemps to improve citizens and cultural affairs through creation, promotion and popularisation of artistic culture. This building is expected to be a response to artistic demands of the people living in Aichi prefecture. And it also aimed to be a place for exchanges among representatives of all fields of arts, for mutual stimualtions and for intercourse among artists and groups from all over the world.

The Aichi Art Center includes opera theater, concert hall, small theater, art museum, cultural information center and international conferece rooms. These facilities are connected to each other by large atrium "Forum". While each facility is hoped to be as fine as possible, the planning of common function is required to unify and efficiently manage each facility, which has each clear functional difference, in order to improve the artistic connection with each other and compose a nwe type of Art Complex up to date.

1.1.1 Site and location

Building Address:
Nagoya
Japan

Latitude:
35 10 N

Description of the surrounding area

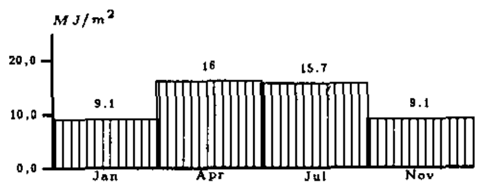


Figure 1.1: Monthly Mean Solar Irradiance

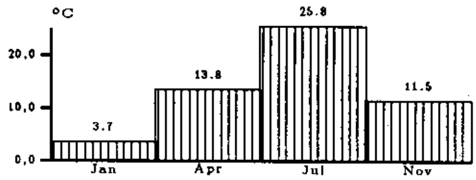
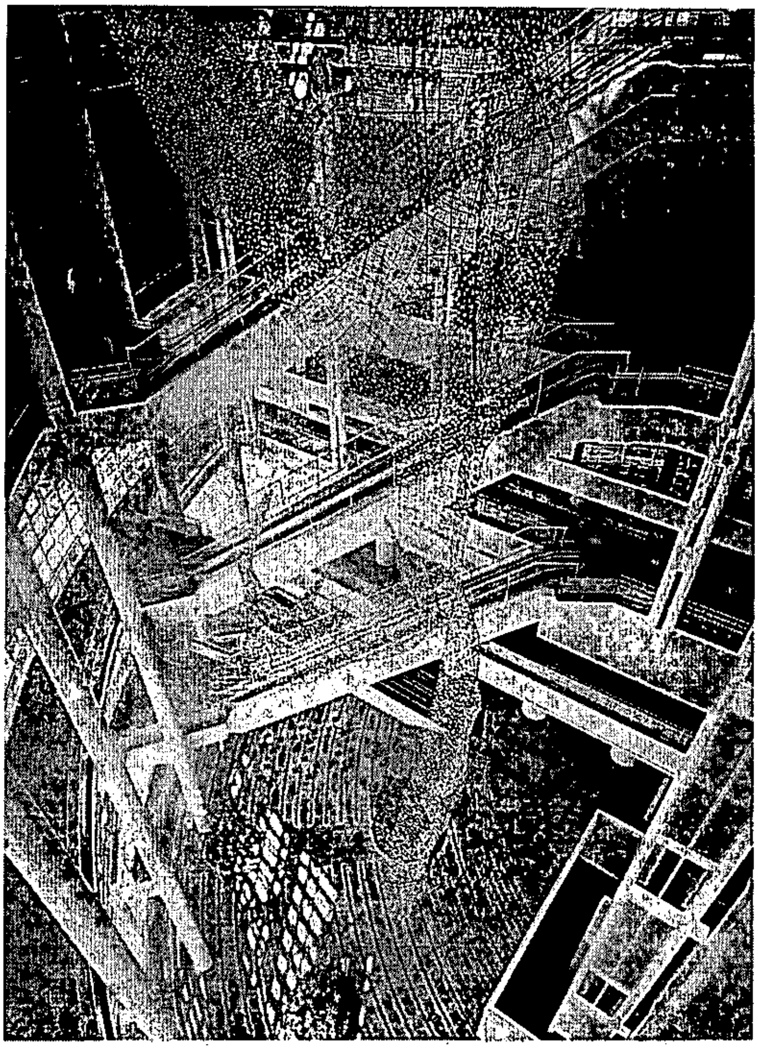


Figure 1.2: Monthly mean air temperature

1.1.2 Building form

Dimensions of the enclosure:
36 m x 36 m
(the shape of the floor
is a quarter circle)
x 50 m
Volume:
50000 m^3

Description of building type



1.1.3 Building services

Internal temperature
Summer:
26 °C
(for occupied zone;
lower part of the space)
Winter:
22 °C

Type of Ventilation Mechanical ventilation

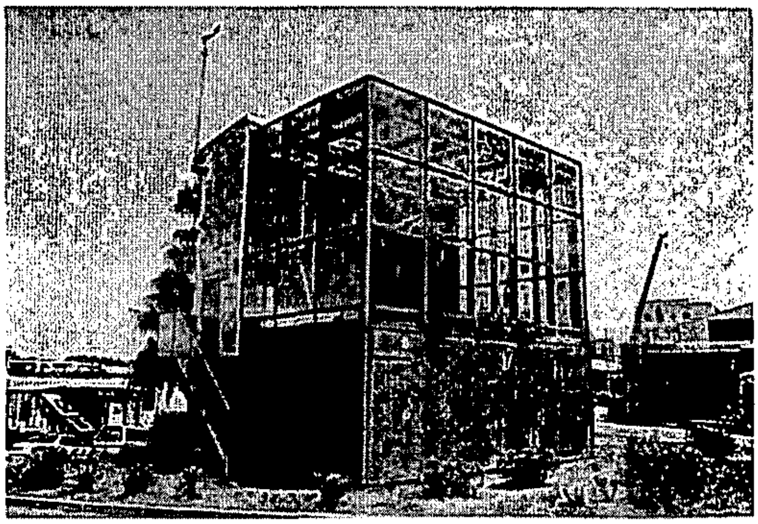
1.2 References

Annex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886
Liaison Engineer Name:	Mr. Mutsumi Yokoi
Institution:	Mechanical & Electrical Engineering 1 Design Division Taisei Corporation

2 Experimental Atrium JP 1

2.1 Building Description

Building type:
Atrium



Owner:
Asahi Glass Co., Ltd., Research Center
Kimihiko Sato, General Manager, Research Center
1150, Hazawa-cho, Kanagawa-ku
Yokohama-shi, KANAGAWA,
Japan
+81 45 334 6111
+81 45 334 6187

Year of completion:
1990

Design Team:
ASAHI GLASS CO. LTD.

The purpose is to study the effect of several factors (envelope materials, air cooling system, natural ventilation and so on) on the thermal environment of the atrium. Then we have carried out the long term and systematic measurement and analysis of thermal environment under various boundary conditions of the experimental atrium. And this atrium was selected as a case-study building for verification of several CFD models, because of its simple shape and clear boundary conditions.

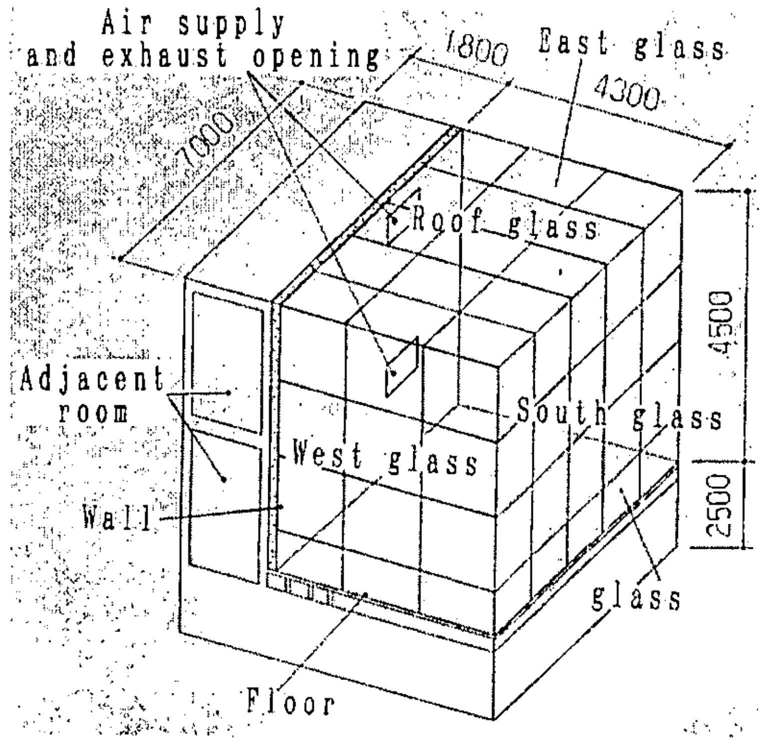
The experimental atrium facing south has three glass walls (south, west and east), a glass roof and two insulated surfaces (north wall and floor). It is easy to change various boundary conditions, because of the simple shape and structure. We have studied the effect of optical properties of envelope materials, thermal insulating layer added on roof glass and so on. And this atrium has cooling system (capacity : 23,600 kcal/h) and several air supply / exhaust openings in order to correspond to measurements of cooling and natural ventilation.

2.1.1 Site and location

Building Address:
1150, Hazawa-cho, Kanagawa-ku,
Yokohama-shi, Kanawaga
Japan

Latitude:
35 20

Description of the surrounding area This atrium lies in the research center (ASAHI GLASS CO. LTD.). There are no obstructions shading solar radiation around the atrium.



2.1.2 Building form

Dimensions of the enclosure:
4.3 m x 7.0 m x 4.5 m
Volume:
135 m^3

2.2 References

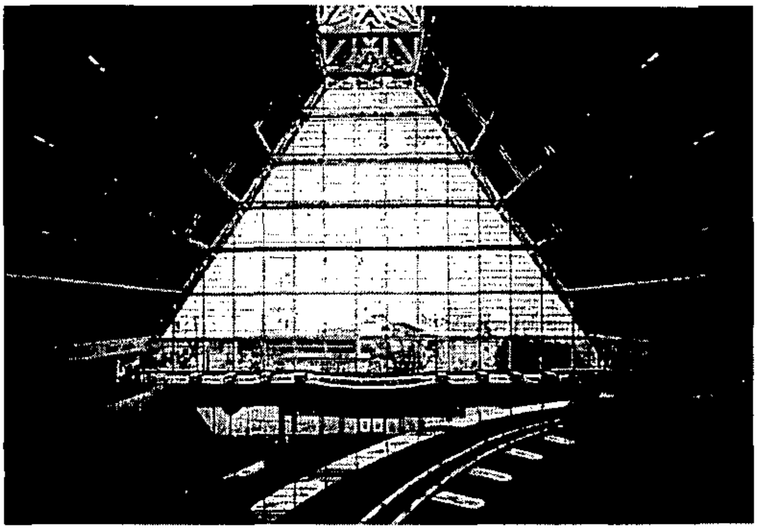
Annex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886

Liaison Engineer Name:	Mr. Takashi Harada
Institution:	ASAHI GLASS Co.,Ltd. Research Center
Investigator:	Toru Hiramatsu Yoshikazu Ozeki Takeshi Harada (Asahi Glass Company) Shuzo Murakami Hiroshi Yoshino Shinsuke Kato

3 Matsushita Electric Industrial Information & Communications Systems Center JP8

3.1 Building Description

Building type:
R & D office



Owner:
Matsushita Electric Industrial Co., Ltd.
1006, Kadoma, Kadoma city
Osaka
Japan
+81 6 3473 1121

Year of completion:
1992

Project Costs:
26 000 000 000 yen

Design Team:
Nikken Sekkei Ltd.

This building was designed to realize thermal comfort and energy saving in the office spaces that have significant increases in cooling load due to the heat generation from office equipment and computers.

This building was designed for R & D office of software as strategical center of information and communication system in the Matsushita group.

This building has open-type atrium. There is no partition between the atrium and the offices. Each office floor is open to the atrium. The office spaces are controlled by both, the underfloor air-conditioning system and personal air-conditioning system.
Natural ventilation and natural lighting system are effective for saving energy.

3.1.1 Site and location

Building Address:
4-5, Higashi-shinagawa, Shinagawa-ku, Tokyo, Japan

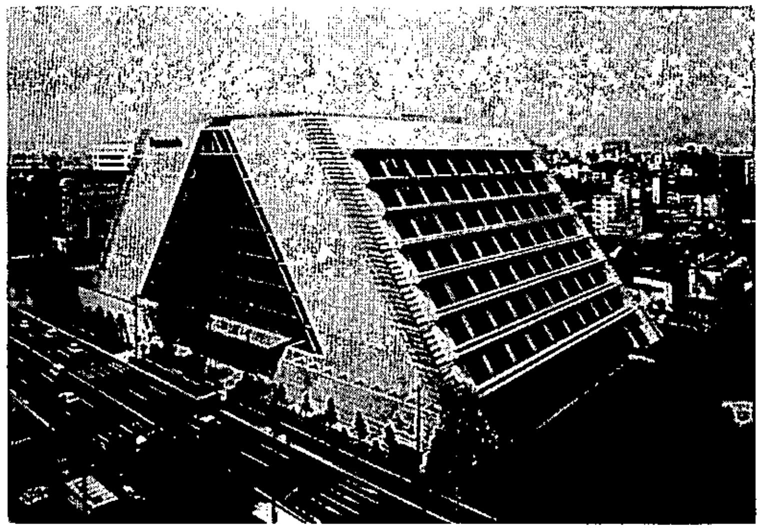
Monthly Mean Wind Velocity:
about 4.0 m/s

Description of the surrounding area It is located in residential and offices area.

3.1.2 Building form

Dimensions of the enclosure:
80 m x 40 m x 40 m
Volume:
60,000 m^3

Description of building type This building has open-type atrium. There is no partition between the atrium and the offices. Each office floor is open to the atrium.
The office space is controlled by both, the underfloor air-conditioning system and personal air-conditioning system.
Natural lighting system is effective for saving energy.



3.1.3 Building services

Degree of Conditioning:
Winter Summer
20 °C 28 °C
Internal temperature:
Winter Summer
22 °C 26 °C
Internal relative humidity:
45%

Type of Ventilation Natural ventilation system was selected for the atrium. The ventilation features are as follows.

1. Outdoor air are provided from the spandrel panels on the exterior walls. At the top of the atrium, an outlet for exhaust air is installed.
2. Outdoor air inlets and outlets are opened on closed by remote control system.

Additional details of ducted system There are some nozzle that provide 70% of supply air, and the line diffusers that provide 30% of supply air, on the wall around the first floor of the atrium. An underfloor air-conditioning system was installed in the second floor.

Fresh air supply ventilation rate:
max. 100% (70 CMH/m^2)

Location of the supply and extract grilles

Control strategy Controlled by the return air temperature

3.2 Performance of the Building

3.2.1 Energy performance

Methods of measurement energy Measuring the temperature difference between cool water supply and cool water of AHU and supply air volume.

Energy consumption of the enclosure
Energy: $7.44 \times 10^8\, J/(a\, m^2)$
Cooling: $2.01 \times 10^8\, J/(a\, m^2)$
Used floor area of the enclosure: $2\,10\, m^2$
Comments:
Peak Cooling Load: 622 100 kcal/h
Peak Heating Load: 168 400kcal/h
Equivalent full load couditioning time: Cooling 600 h/a Heating 600 h/a

3.2.2 Ventilation performance

Methods of measurement ventilation The air change rates were measured by the tracer gas method using SF6. The tracer gas was generated constantly and controlled by a mass flow meter.

Ventilation Data
Supplied air: $0.172\, dm^3/(s\, m^2)$
Supplied air per person: $3.493\, dm^3/(s\, person)$

3.3 References

Annex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886
Liaison Engineer Name:	Mr. Shinji Yamamura
Institution:	Nikken Sekkei Ltd.
Investigator:	Assoc. Prof. Yasushi Kondo Musashi Institute of Technology, Japan
Liaison Engineer Name:	*Mr. Shinji Yamamura*
Institution:	Nikken Sekkei LTD.

4 Olivetti R&D Center JP 16

4.1 Building Description

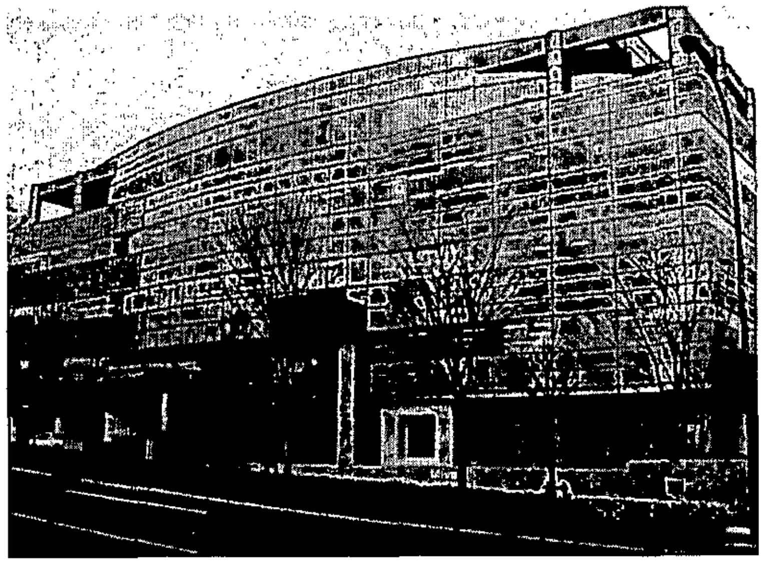
Building type:
Research Center, Office

Owner:
Olivetti Corp. of Japan
13-20, Shin-ei-cho, kohoku-ku
Yokohama
Japan
+81 45 593 7015

Year of completion:
1992

Design Team:
Fujita Corp.

This atrium is designed for regional dwellers to enter easily and



enjoy.

This is a research center of Olivetti Japan for research and development in Japan

This is the four-stories atrium with low ceiling. Mechanical exhaust ventilation from the top of the atrium, prevents the thermal influence on the adjacent spaces in the upper part of the atrium. The sun screen made of cloth is installed.

4.1.1 Site and location

Building Address:
13-20, Shin-ei-cho, Kohoku-ku
Yokohama
Japan

Latitude:
35 26
Altitude:
139 39

Monthly total of Degree Days:
Heating: 122 days 912 °C
Cooling: 58 days 96 °C

Description of the surrounding area This area is easily influenced from the land and sea breeze. The surrounding area is rather opened, and multifamily house with the same size is situated near by. In front of the entrance, there is an asphalt road for the traffic.

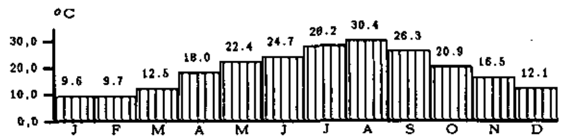
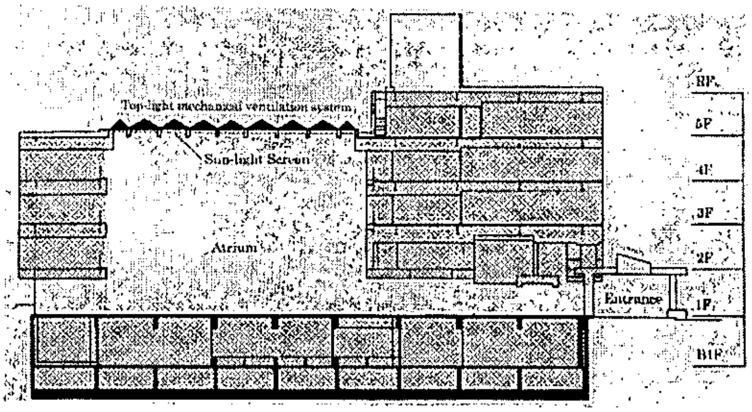


Figure 4.1: Monthly mean air temperature

4.1.2 Building form

Dimensions of the enclosure:
21.8 m x 8.7 m x 14.6 m
Volume:
2,769 m^3



4.1.3 Building services

Degree of Conditioning:
Air conditioning + Floor heating
Total heat load:
Summer:
42,000 kcal/h
Winter:
6,000 kcal/h + 13.35 kW (floor heating)
Internal temperature:
Winter Summer
22 °C 26 °C
Internal relative humidity:
40 to 50%

Type of Ventilation There are supply and extract openings with fans (3,000 m^3/h) at both ends of the roof top.

Location of the supply and extract grilles The line type supply grilles are located on the wall of the ground floor.

Control strategy In summer, air-cooling + roof top ventilation
In winter, air-heating + floor heating

4.2 References

Annex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886
Liaison Engineer Name:	Mr. Shinichiro Nagano Fujita Corporation Building Engineering Research Department
Investigator:	Shinichiro Nagano (Fujita Co.)

5 Sapporo Factory JP 11

5.1 Building Description

Building type:
Shopping Center, Hotel

Owner:
Sapporo Breweries LTD.
Tokyo
Japan

Year of completion:
1993

Project Costs:
whole Project : 40,000,000,000 yen,
Atrium : 2,800,000,000 yen

In this project, a large scale atrium with high energy conservation capability and rich natural lighting environment has been realized efficiently utilizing the local characteristics of a winter city in the complexed commercial facility being redeveloped in Sapporo on the land formerly used for a factory. Despite of disadvantageous conditions in air conditioning and snow accumulation prevention in the winter city, a glass atrium was positively planned. After solving various problems in architectural and building service systems, an atrium space providing bright and comfortable environment through out a year was materialized. The low annual energy consumption verified by the performance test after completion can mitigate the physical regulation of a glass atrium standing on a cold region.

Monitoring Agent:
Taisei Corporation

Design Team:
Taisei Corporation

Complex commercial facility.

5.1.1 Site and location

Building Address:
4 Higashi Kita 2-Jo Chuo-ku Sapporo
Hokkaido, Japan
Sapporo
Japan

Latitude:
43 03 N

Description of the surrounding area

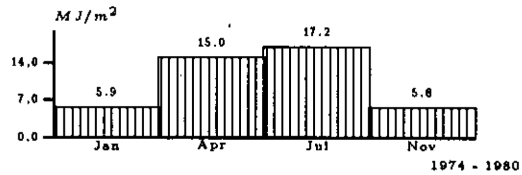


Figure 5.1: Monthly Mean Solar Irradiance

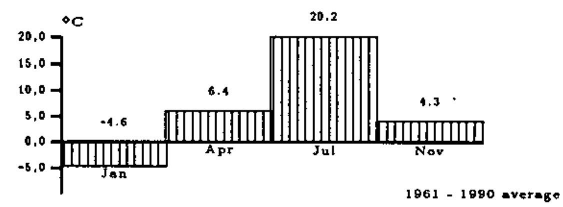


Figure 5.2: Monthly mean air temperature

In Sapporo - city, downtown

5.1.2 Building form

Dimensions of the enclosure:
84 m x 34 m x 39 m
Volume:
100,000 m^3

5.1.3 Building services

Total heat load:
Winter Summer
227 $kcal/hm^2$ 141 $kcal/hm^2$
Heat transfer medium:
2.5 $kcal/m^2h$ K (glass and sash)

Type of Ventilation Natural and mechanical ventilation

Internal temperature:

Winter	Summer
25 °C	26 °C (for occupied zone; lower part of the space)

Internal relative humidity:
40 %

Fresh air supply ventilation rate:
14,000 m^3/h
Total air change ventilation rate:
70,000 m^3/h

Location of the supply and extract grilles Lower part of the atrium; horizontal 3 zones, east, center and west.

Control strategy

summer:	natural ventilation with HVAC
winter:	green house with HVAC

5.2 Performance of the Building

5.2.1 Energy performance

Methods of measurement energy To evaluate the performance of energy conservation, indoor thermal environment is measured for the followings items: temperature and humidity, energy consumption, vertical temperature distribution during winter and summer, radiated temperature distribution.

Energy consumtion of the enclosure
Heating: $1\,181\, MJ(a\, m^2)$
Cooling: $123\, MJ(a\, m^2)$
Used floor area of the enclosure: $3\,000\, m^2$

5.2.2 Ventilation performance

Air supply rates:
71000 m^3/h

Methods of measurement ventilation The ventilation performance was measured with the tracer gas technique.

5.3 References

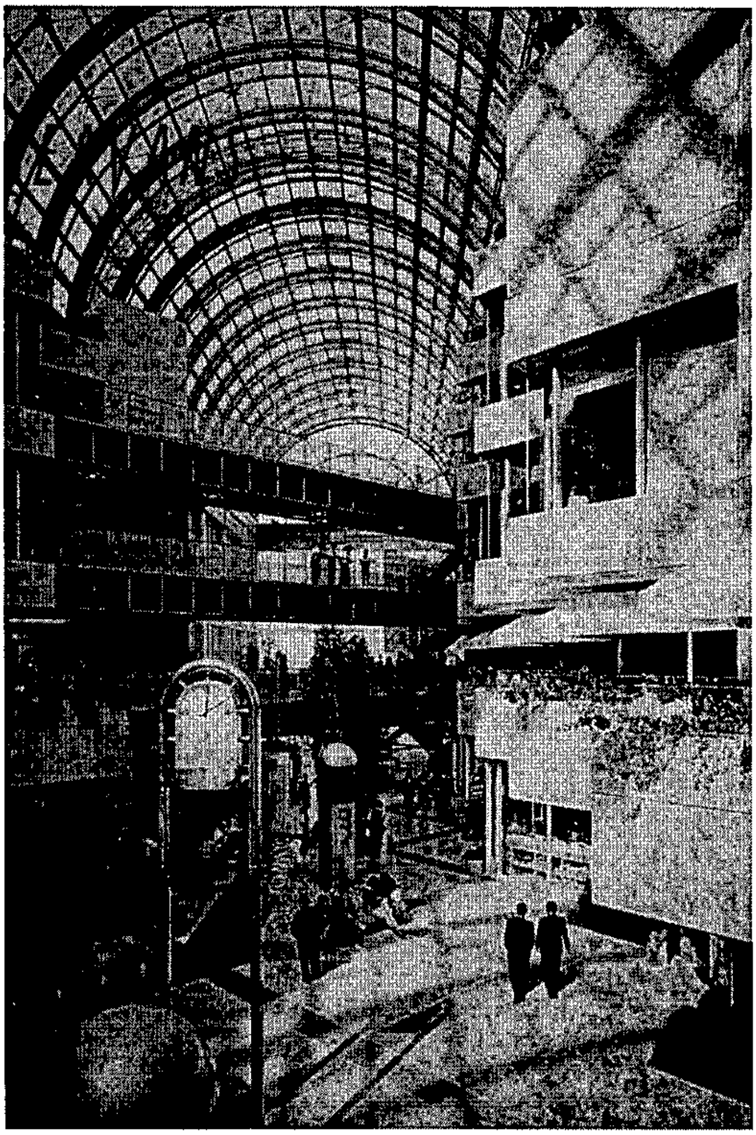
Annex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886
Investigator:	Mutsumi Yokoi (Taisei Co.)

Institution: Mechanical & Electrical Engineering 1
Design Division
Taisei Corporation

6 Seavance Atrium JP 17

6.1 Building Description

Building type:
Atrium



Owner:
NTT Urban Development Corp.,
Shimizu Corp.
Kunio Yazawa
(NTT Urban Development),
Naosuke Imamura
(Shimizu Corp.)
2-2-2 Otemachi, Chiyoda-ku
(NTT Urban)

This project is one of the Tokyo waterfront area redevelopment program. This building is composed of a main glazed atrium and two 24-story rental office building. And under this building there are district heating and cooling plane.

1-2-3 Shibaura, Minato-ku (Shimizu)
Tokyo 100
Japan
+81 3 5441 1111 (Shimizu)
+81 3 5441 0070 (Shimizu)

Year of completion:
1991

Design Team:
Shimizu Corp.

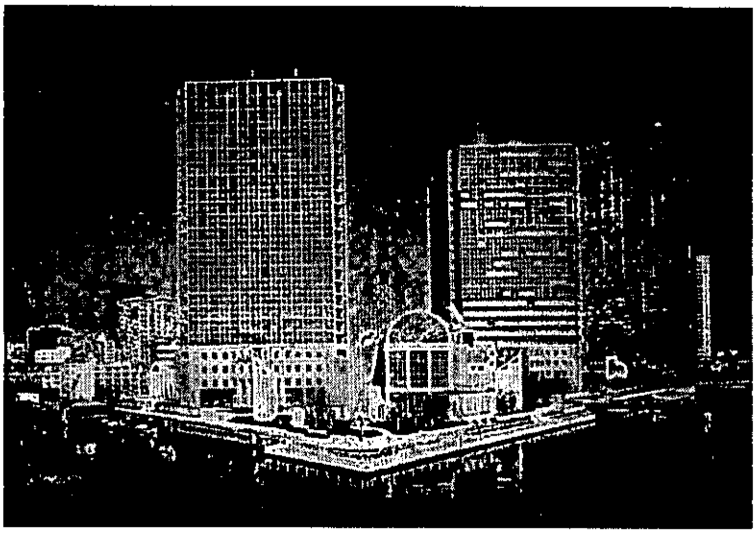
One building is used as the head office of Shimizu Corp. and the other as tenant office. At the atrium some restaurant, bookstore, convenience store etc. are arranged for workers to live conveniently. Special features of this building is the PMV control system of the atrium thermal environment. this system controls the figure of PMV from 1.0 to -1.0 in order to reduce the air conditioning energy.

6.1.1 Site and location

Building Address:
1-2-3, Shibaura, Minato-ku
Tokyo 100
Japan

Monthly Mean Solar Irradiance:
Tokyo data
Monthly Mean Wind Velocity:
Tokyo data
Monthly mean air temperature:
Tokyo data

Description of the surrounding area This area is "water front area" which is located on canal, pier, street and railroad station. And it is in the process of changing to the business area.



6.1.2 Building form

Dimensions of the enclosure:
100 m x 20 m x 30 m

Volume:
60,000 m^3

6.1.3 Building services

Degree of Conditioning:
Air conditioning and
Floor heating and cooling
Total heat load:

Winter	Summer
807 Mcal/h	852 Mcal/h

Internal temperature:

Winter	Summer
20 °C	26 °C

Type of Ventilation This system is based on the natural ventilation in order to reduce the air-conditioning energy. In addition to this fresh air put in the living area.

Fresh air supply ventilation rate:
4,000 CMH
Total air change ventilation rate:
60,000 CMH

Location of the supply and extract grilles
Supply grilles: air supply tower located center line of the atrium
Extract grilles: the leg of the benches arranged at the atrium

Control strategy Zoning system

6.2 Performance of the Building

6.2.1 Energy performance

Energy due to conditioning of air:
2430 GJ/ a

Energy consumption of the enclosure
Heating: 623 $MJ(a\,m^2)$
Cooling: 586 $MJ(a\,m^2)$
Used floor area of the enclosure: 2 000 m^2

6.2.2 Ventilation performance

Ventilation data
Supplied air: 0.0056 $dm^3(s\,m^2)$
Supplied air per person: 0.37 dm^3/s

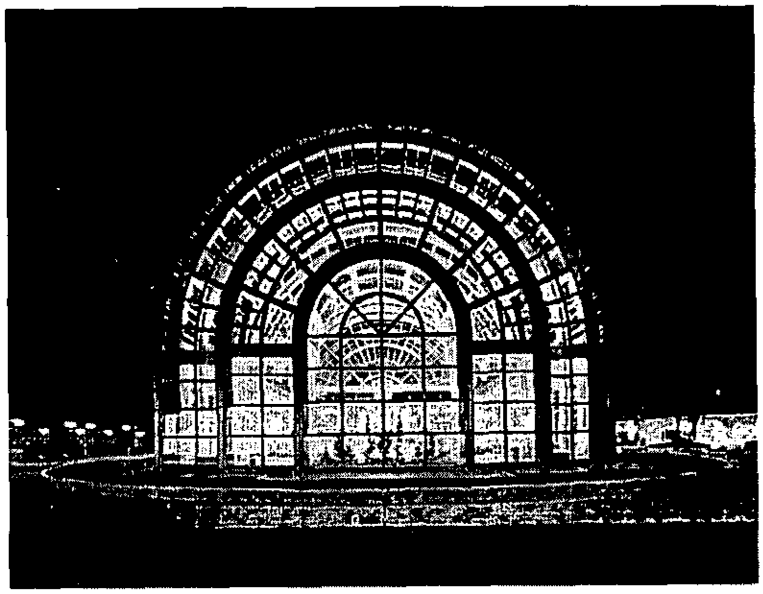
6.3 References

Annex Contact Name:	Kazuki Hibi
Annex Contact Institution:	Institute of Technology, SHIMIZU Corp.
Annex Contact Address:	4-17, Etchujima 3-chome, Koto-ku
Annex Contact City:	Tokyo
Annex Contact Country:	Japan
Annex Contact Tel:	+81 3 3643 4311
Annex Contact Fax:	+81 3 3643 7260
Investigator:	Kazuki Hibi
Institute:	Shimizu Corporation Institute of Technology

7 Sen City (Chiba Sogo) JP 12

7.1 Building Description

Building type:
Department Store



Year of completion:
1993

Design Team:
Takaha UDI

This building is a department store with eleven floors. The three-stories atrium, in the center of the bnilding from the 9th to the 11th floor, is used for a relaxing space with small river, waterfall, trees and sunlight. The floor area of the central occupied zone is 256 m^2 in the 9th floor. The top of the ceiling is 24.4 m high over the 9th floor, and the space above the level, which is 11.1 m high on the 9th floor, is enclosed by glass walls and roof. The external zone of the atrium in the 9th and 10th floor are the corridor to connect with the restaurants, gallery and so on.

7.1.1 Site and location

Building Address:
Chiba
Japan

Latitude:
35 36 N

Description of the surrounding area

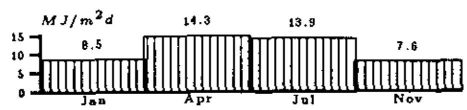


Figure 7.1: Monthly Mean Solar Irradiance

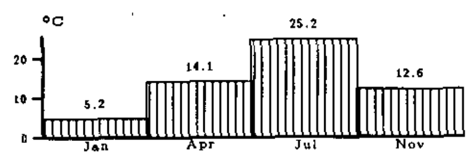
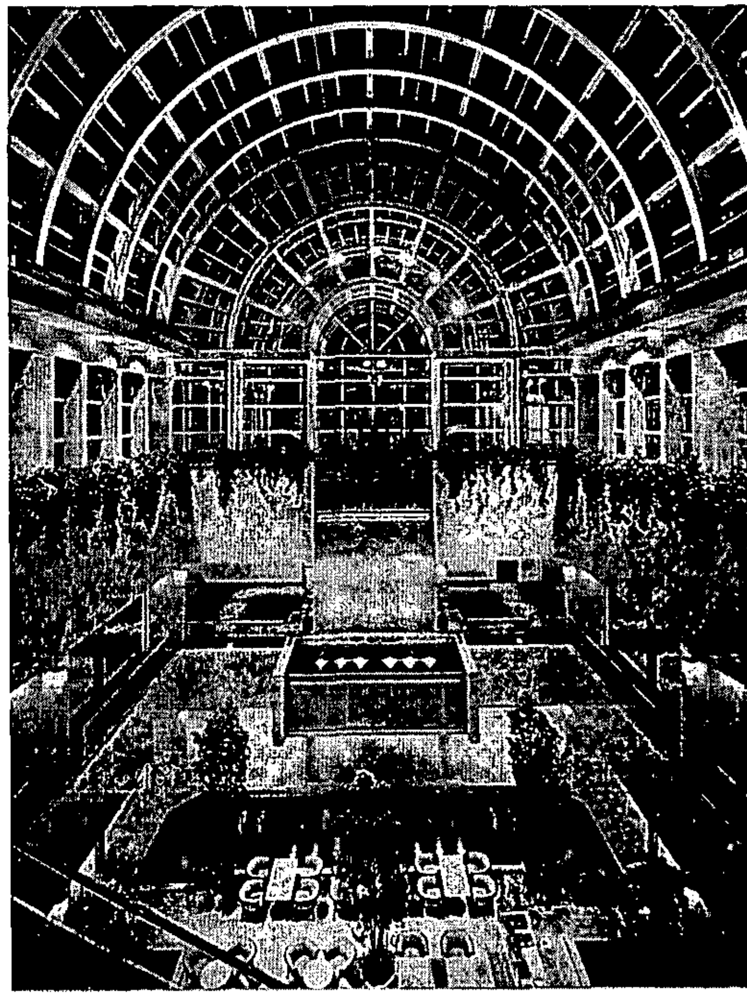


Figure 7.2: Monthly mean air temperature

7.1.2 Building form

Dimensions of the enclosure:
20 m x 16 m x 24.4 m
Volume:
8000 m^3



7.1.3 Building services

Total heat load:

Winter	Summer
130 kcal/h m^2	300 kcal/h m^2

Internal temperature:

Winter	Summer
22 °C	26 °C

Type of Ventilation Mechanical ventilation

Location of the supply and extract grilles
supply : 9 F ceiling for air-conditioning in occupied zone
extract : around the atrium on 9 F and 10 F.

Control strategy supply air temperature control with PMV control sensor.

7.2 Performance of the Building

7.2.1 Energy performance

Methods of measurement energy To evaluate the performance of energy conservation, indoor thermal environment is measured for the following items: temperature and humidity, energy consumption, vertical temperature distribution during winter and summer.

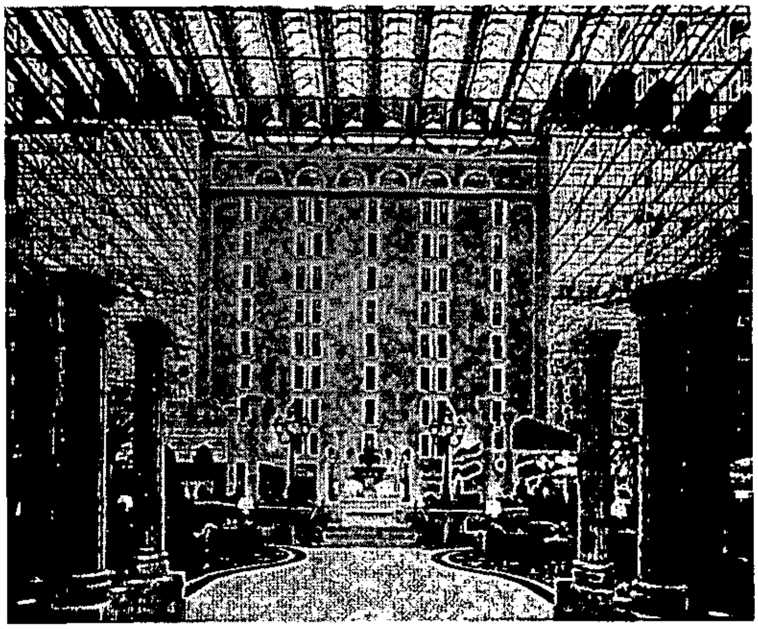
7.3 References

Annex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886
Investigator:	Mutsumi Yokoi (Taisei Co.)
Institution:	Mechanical & Electrical Engineering 1 Design Devision Taisei Corporation

8 Tokyo Bay Hotel Tokyu JP 14

8.1 Building Description

Building type:
Atrium in center of Hotel



Owner:
Sun Plaza
Hirosi Morita, Nihon Sekkei, Inc.
1-7 Maihana, Urayasu
Chiba
Japan

Year of completion:
1990

Design Team:
Nihon Sekkei, Inc.

The site of this building is adjacent to the Tokyo Disney Land and faces to the sea on two directions. This place is easily accessible by public transport from the center of Tokyo, Narita or Haneda airport, within 30 minutes. This location realizes the new type hotel of "city resort hotel" combining the function of the city hotel with the character of the resort hotel.

This area is a new town developed around the Tokyo Disney Land and accommodates hotels, auditoriums, convention facilities, residential buildings and so on. This building, which provides with lodging facilities for visitors of the Tokyo Disney Land, wedding ceremony hall, convention hall, shopping center and so on, is the new type resort hotel.

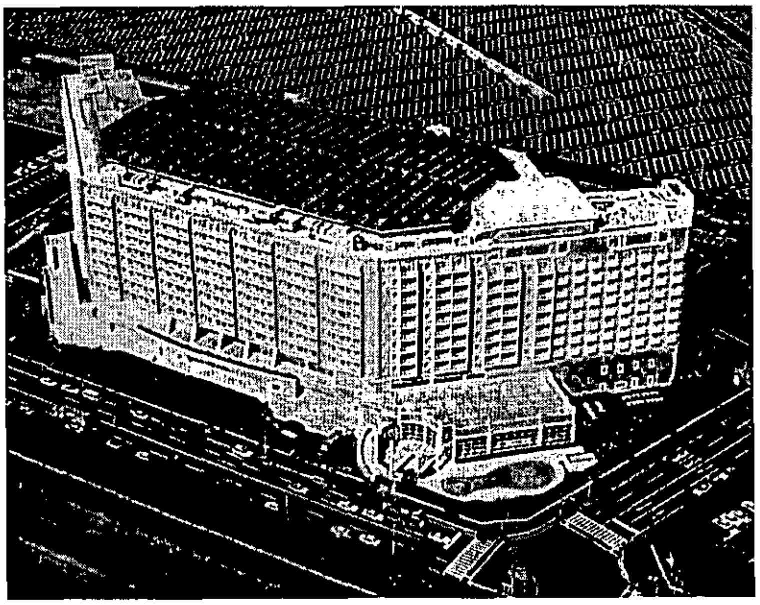
This place, on the one direction, faces to the sea and on another direction, faces to the large parking area of the Tokyo Disney Land. Therefore, outdoor environment is'nt so favorable due to the strong wind.

8.1.1 Site and location

Building Address:
1-7 Maihama, Urayasu
Chiba, Tokyo
Japan

Latitude:
35 37 N

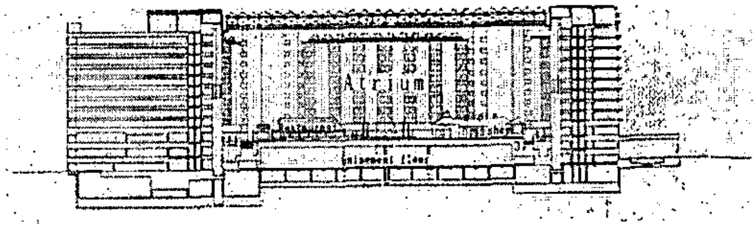
Monthly Mean Wind Velocity:
1.6 m/sec
Monthly mean air temperature:
14.8 °C



8.1.2 Building form

Dimensions of the enclosure:
90 m x 50 m x 37 m
Volume:
155,400 m^3

Description of building type This atrium is encircled by guest rooms and has the large glass roof to utilize sunlight. So, the main consideration in designing was to minimize the influence of solar radiation from the glass roof, on the cooling load.



8.1.3 Building services

Degree of Conditioning:
24 °C - 26 °C
Total heat load:

Winter	Summer
536,000 kcal/h	408,000 kcal/h
(Atrium only)	(Atrium only)

Internal temperature:

Winter	Summer
24 °C	25 °C

Internal relative humidity:
40 %

Type of Ventilation

In this atrium, the occupied zone control system (the occupied zone near the floor is only air-conditioned and ventilated) is installed. In the glass roof, the dampers for discharging hot air automatically due to the stack effect of the temperature difference between indoor and outdoor, and the induction effect of outdoor wind when air temperature in the upper part of the atrium extremely rises, is installed.

Fresh air supply ventilation rate:
7 060 m^3/h
Total air change ventilation rate:
120 000 m^3/h

Location of the supply and extract grilles For the occupied zone control, supply grilles are located on walls around the atrium (about 3 to 4 m high from the floor level). Extract grilles are located near the floor.

Control strategy Automatic control of the temperature and humidity by means of the temperature and humidity sensor located 1.5 m high from the floor level.

Specific features The atrium is surrounded by guest rooms and has the large glass roof (4,200 m^2). In this atrium, there are restaurants, shopping mall, ponds and so on. The water temperature of these ponds is kept 15 °C in summer for the effect of the radiant cooling.

8.2 Performance of the Building

8.2.1 Energy performance

Site deliverd energy:
Electric power and city gas
Energy consumed by subsystems:
5,000 Gcal/month : monthly average of the primary energy consumption (electric power and city gas)
Energy due to conditioning of air:
About 50% (maximum month in cooling)

Methods of measurement energy It is possible to measure the ratio of the energy consumption by means of the ratio of the electric power and city gas consumption.

Energy consumption of the enclosure
Heating: 523 250 $J/(a\,m^2)$
Cooling: 397 670 $J/(a\,m^2)$
Used floor area of the enclosure: 4 300 m^2

8.2.2 Ventilation performance

Air supply rates:
1.3 1/h (155,400 m^3 / 120,000 m^3/h)

Ventilation data
Supplied air: 0.0078 $dm^3/(s\,m^2)$
Supplied air per person: 0.0069 dm^3/s

8.3 References

Annex Contact Name: Prof. Dr. Hiroshi Yoshino

Annex Contact Institution: Department of Architecture, Faculty of Engineering, Tohoku University

Annex Contact Address: Aramaki Aza Aoba, Aoba-ku

Annex Contact City: Sendai 980-77

Annex Contact Country: Japan

Annex Contact Tel: +81 22 217 7883

Annex Contact Fax: +81 22 217 7886

Investigator: Masayoshi Funazu
(Nihon Sekkei, INC.)

9 Yasuda School Business Masters "AKADEMEIA" JP 13

9.1 Building Description

Building type:
Training facilities and sleeping accommodates

Owner:
Yasuda Mutual Life Insurance Company
Nshi Shinjyuku 1-9-1, Shinjyuku-ku, Tokyo, 169-92
Tokyo
Japan
+81 3 3342 7111

Year of completion:
1994

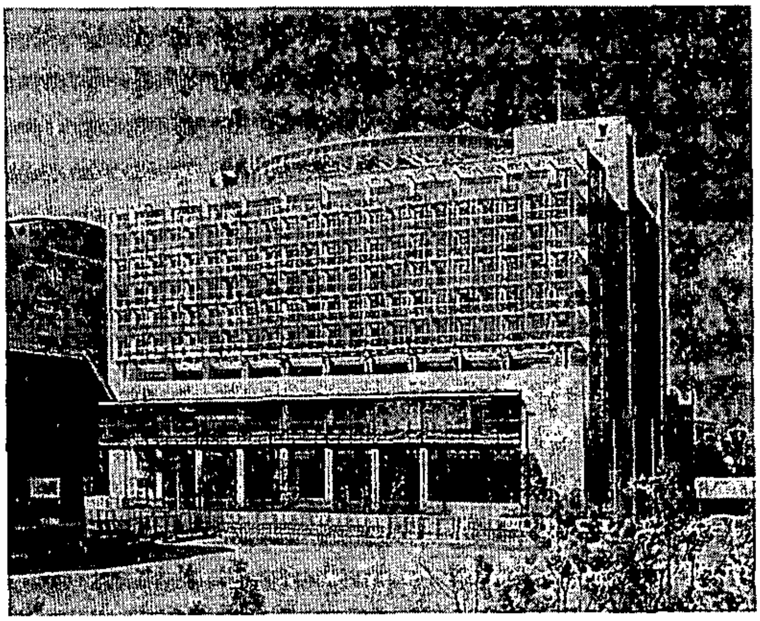
Project Costs:
18,500,000,000 yen

Design Team:
Nihon Sekkei

The outside view of the building looks very simple, but the building gives people the deep impression due to various grids, effective design of the balcony for refuge, waving design of the porch ceiling, the dry-area with a waterfall and so on.

This enclosure is designed as the communication space for members of the company.

This atrium has an elliptic floor. The glass roof is openable. Under the glass roof, the movable solar shading screen is installed.



9.1.1 Site and location

Building Address:
1 Nikko-cho, Fuchu-shi
Tokyo
Japan

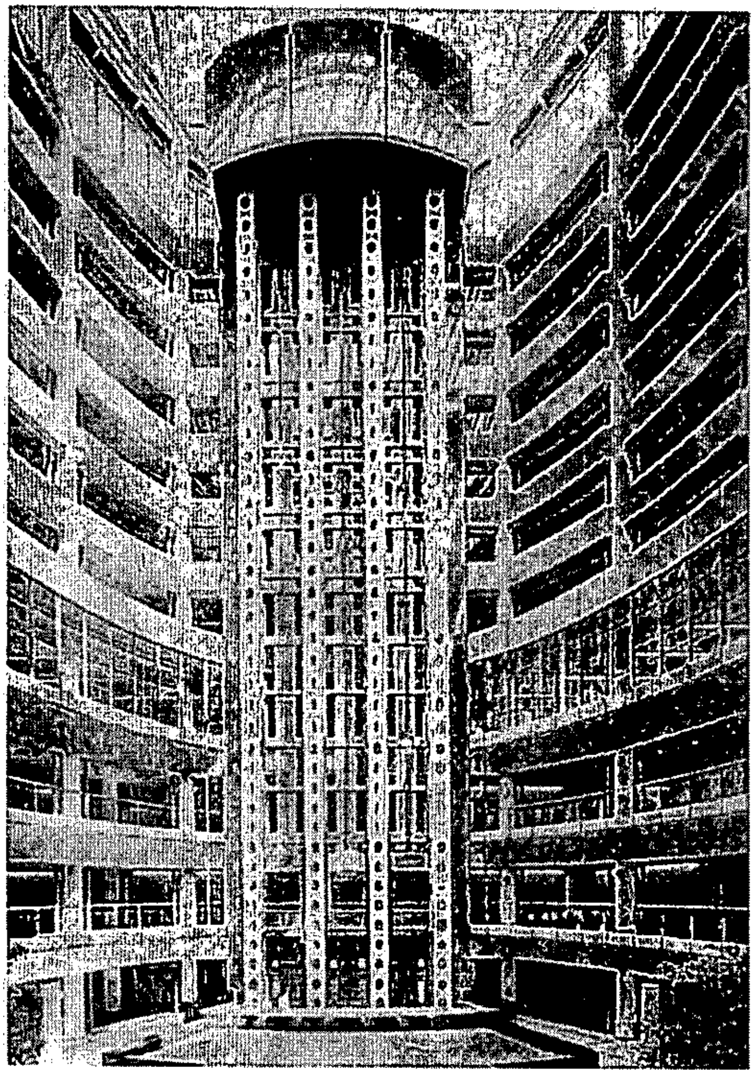
Latitude:
35 7 N

Description of the surrounding area There is little obstacle around the building, and comparatively little traffic on the front street.

9.1.2 Building form

Dimensions of the enclosure:
72 m x 47 m x 47.15 m

Volume:
52,000 m^3



9.1.3 Building services

Total heat load:

Winter	Summer
81 MW	110 MW

Internal temperature:

Winter	Summer
22.0 °C	26.5 °C

Type of Ventilation Individual air-conditioning system

Internal relative humidity:
50 %

Additional details of ducted system Single duct system
Cold and hot water is provided from the district heating and cooling system.

Location of the supply and extract grilles Six towers with supply grilles are installed for the occupied zone on the ground floor. There are two extract grilles on the side of the elevator shaft.

Control strategy Air-conditioning system is operated in summer and winter. In intermediate season (spring and fall), space is naturally ventilated.

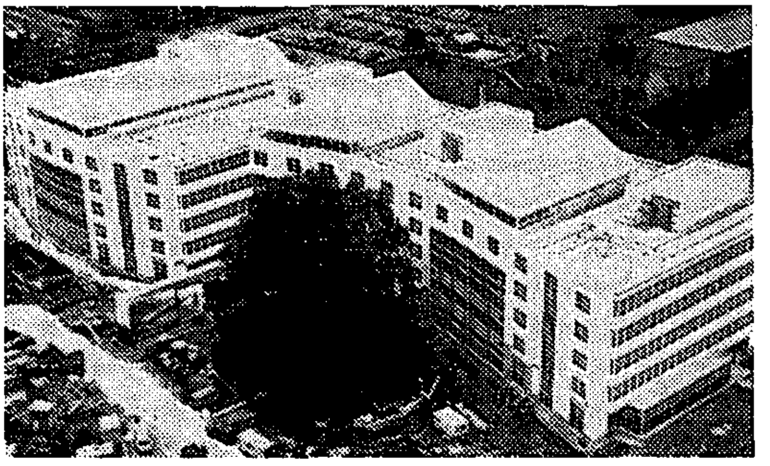
9.2 References

Anuex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+8I 22 217 7886
Liaison Engineer:	Mr Shin-ichiro Nagano
Institute:	Fujita Corporation Building Engineering Research Department

10 Grafenau Zug

10.1 Building Description

Building type:
Office Building



Owner:
Landis & Gyr Immobilien
Bullens
Landis & Gyr AG
Zug
Switzerland
41 42 24 24 60
41 42 24 52 70

Year of completion:
1993

Design Team:
Architekturbuero Bosshard + Sutter, Zug

The building "Grafenau" is a new office building, finished in the present state 1993. The first of two planned expansions by an additional wing on the west side started in October 1994 and will be completed by November 1995. It contains three atria with 320, 320 and 640 m^2 floor area respectively, 26 m high each, facing south; one is subject to detailed measurements (atrium "East", 320 m^2).

It is an office building in the centre of the town of Zug. The atria contain the main entrances to the building and are used mainly as a walk-through space. In the large atrium, an interior one–storey building with a presentation room and in the East atrinm, a cafeteria room are embedded.

The building incorporates a number of new technological features: The building is not air-conditioned but is equipped only with 'gentle' cooling (adiabatic, evaporative cooling). The supply air is blown into the room via a source air system. The air which is preheated in the atria by the sun is drawn off at the top and supplied to the offices via the ventilation system. A stat-of-the-art control system with automatic energy accounting is installed.

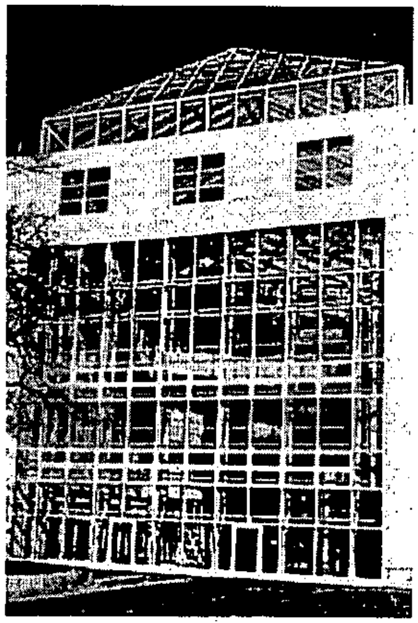
10.1.1 Site and location

Building Address:
Gubelstrasse 22
6301 Zug
Switzerland

Latitude:
47 n.L.
Altitude:
425

Monthly Mean Wind Velocity:
2.8 knots Mean per Year

Description of the surrounding area



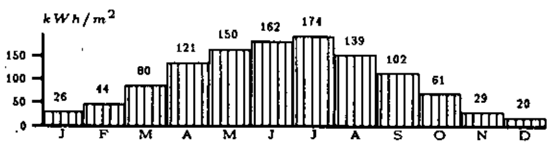


Figure 10.1: Monthly Mean Solar Irradiance

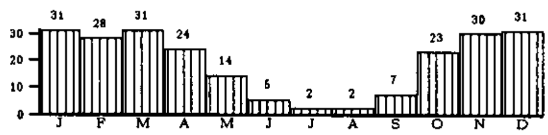


Figure 10.2: Monthly total of Degree Days: (Luzern) d/year (20/12)

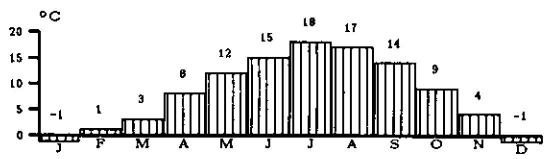


Figure 10.3: Monthly mean air temperature

The building is situated in the centre of the small town Zug (30000 inhabitants), next to the railway station and about 150 m from the shore of the Lake of Zug.

10.1.2 Building form

Dimensions of the enclosure:
18 m small atria, 42 m large atrium
x 16 m for all atria
x 26 m for all atria
Volume:
7 500 m^3 for small atria,
15 000 m^3 for large atrium

Description of building type

10.1.3 Building services

Degree of Conditioning:
Evap. cooling for offices, if too warm in summer
Heat transfer medium:
Water (Radiat) at temp. < 10 °C
Internal temperature:

Winter	Summer
5 - 12 °C	27 - 32 °C

Total air change ventilation rate:
5 ach, when preheated air is extracted (Atria)

Type of Ventilation The atrium ist usually naturally ventilated. In the intermediate season, warm atrium air is used as preheated air for the office ventilation

Location of the supply and extract grilles There are windows to be opened in the south facade, on the roof (at a height of 21 m), and additional openings in the north facade. Air extract for the preheating time is at the very top of the atrium

Control strategy DDC

Specific features The atrium has only natural ventilation (controlled by means of shutters).

10.2 Performance of the Building

10.2.1 Energy performance

Methods of measurement energy All measurement data are determined and stored via the central control system.

Energy consumption of the enclosure There is a facade heating system (air convectors), but it is always never used, as the atrium air temperature hardly drops below 10 °C.

10.2.2 Ventilation performance

Ventilation data Naturally ventilated. In the intermediate season, preheated air from the atrium roof is taken at a rate of 5 ach.

Comfort data Air temperature and draft are o.k. all the year around on the ground floor of the atrium (which is the only zone of occupancy in this atrium).

10.2.3 Performance of the applied design or analysis tools

Performance of applied tools compared to the results of measurements Performance of applied design tools:

1. overheating model D. Aiulfi: overheating of 8 °C in summer well predicted based on estimates of solar and internal heat loads and stack ventilation through open apertures.
2. cold downdraft along vertical walls:
   - maximum velocity from P. Heiselbergs model along floor underestimates measurement value (0.3 m/s).
   - CFD predictions give measured values

10.3 Recommendations

Experiences with the building The attained results (for heat consumption) were in accordance with expectations. The electricity consumption is higher than expected since the utilisation differs from that which was planned. However, a great deal of work was needed for adjustments to achieve optimum operation.

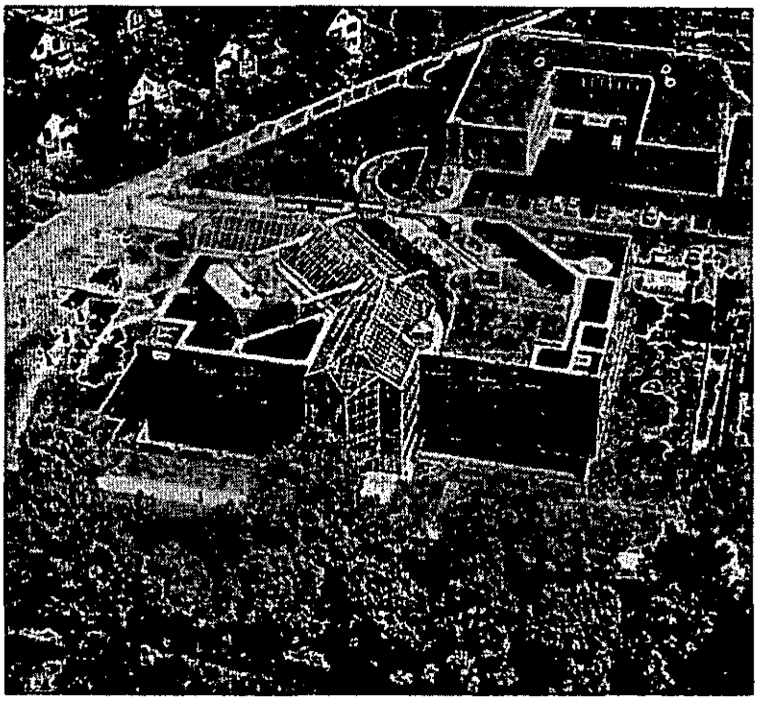
10.4 References

Reference to detailed Annex reports:	*Analysis Tools Rept. Ch. 4.6* *'Annex 26 Reference Case Atrium Grafenau Zug'.* Internal Report, LES/ETHZ, 1996 RoomVent 96 paper
Annex Contact Name:	Alois Schälin
Annex Contact Institution:	ETH Zuerich
Annex Contact Address:	LOW-C4
Annex Contact City:	Zuerich
Annex Contact Tel:	+41-1-632-5446
Annex Contact Fax:	+41-1-632-10 23
Investigator:	Alois Schälin
Engineering:	Roger Ruch Eicher & Pauli AG CH–4410 Liestal Tel.: +41 619219991

11 GVB Office Building

11.1 Building Description

Building type:
Office Building with large atrium



Owner:
Gebäudeversicherung des Kantons Bern
Papiermühlestrasse 130
CH-3063 Ittigen-Bern
Switzerland
++41 31 925 11 11
++41 31 925 12 22

Year of completion:
1992

Design Team:
Meister Architekten, SEC Bern

The GVB office building was finished in June 1992 (GVB = building insurance company of the Kanton Bern). The GVB aimed for a building able to house all offices for their growing business. A heat recovery system and a night cooling system for the offices in the building reduce the total energy consumption. The air in the atrium serves as energy storage. During the heating period warm from the atrium is extracted for the ventilation of the offices The atrium is destined to be a communication area for people working there and customers. The atrium houses a small restaurant, galleries on all floors, bridges which connect the both building parts on the level of the upper floors and several small conference rooms.

The atrium is in the center of the building. It connects the larger part of the building with its smaller part. The offices of the GVB are located in the larger part of the building whereas the other part serves as long-term reserve for office rooms necessary in the future. In the moment these offices are rented to another company.

Atrium is used as heat storage. Heat recovery systems; passive night cooling system for the offices.

11.1.1 Site and location

Building Address:
Gebaeudeversicherung des Kantons Bern
Papiermühlestrasse 130
Postfach
CH-3063 Ittigen-Bern
Ittigen (Bern)
Switzerland

Latitude:
46 57'
Altitude:
550 m

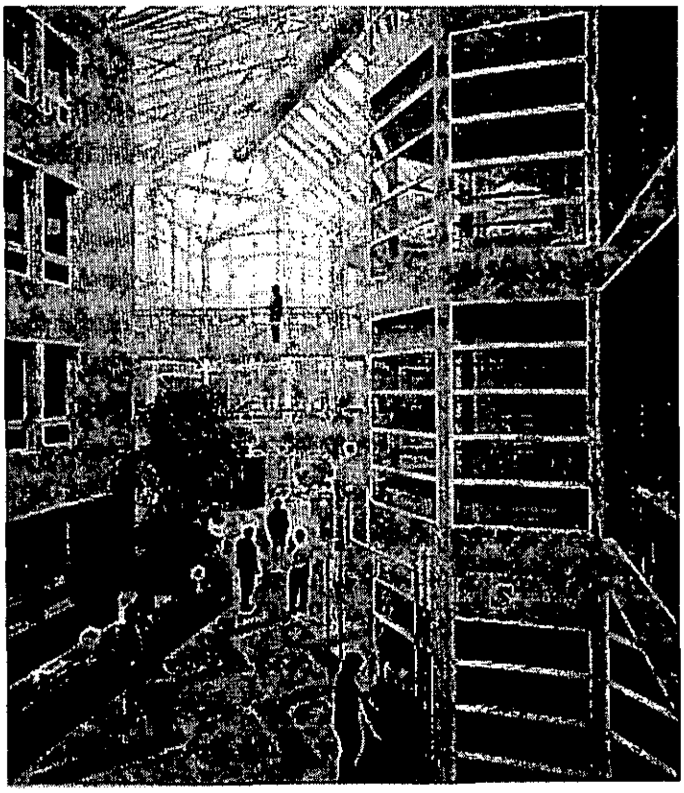
Monthly Mean Solar Irradiance:
Jan.: $28\,kWh/m^2$, $July: 183\,kWh/m^2$
Monthly mean air temperature:
Jan. t=0 °C , July t=18 °C

Description of the surrounding area The building is situated in a suburb of Bern, the capital of Switzerland. The building is surrounded by smaller houses. The distances to the next house is more than 40 m.

11.1.2 Building form

Dimensions of the enclosure:
61 m x 12 m x 16 m
Volume:
8400 m^3

Description of building type The Office building is divided into two parts by an atrium. The atrium situated between the building parts has two glazed vertical facades, one facing west and the other towards the north. At these sides the revolving doors are situated through which all people have to enter the building.



11.1.3 Building services

Internal temperature
Summer:
t = 18 - 25 °C at ground level;
t > 39 °C on the 3rd floor
Winter:
t > 16 °C

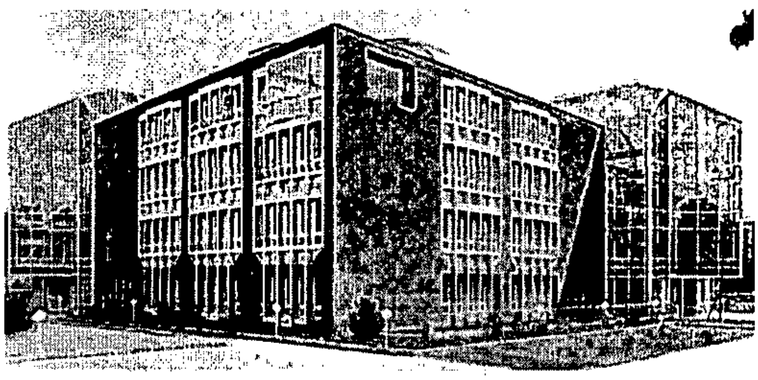
Total air change ventilation rate:
1 - 3 h^{-1}

Type of Ventilation Atrium: Mainly natural ventilated and additional air coming from the offices. In heating period warm air from the atrium is used as preheated air for the offices. When temperature fall below 16 °C in atrium additional energy is supplied by radiators at the windows of the atrium.

Location of the supply and extract grilles Due to a small overpressure in the offices air from the offices penetrates through doors and windows into the atrium (air change rate = 0.5 $1/h$). The preheated air from the atrium is extract through ducts just under the roof. Fresh air form outside is supplied by flaps over the revolving doors (h=2.5 m). Overheating is prevented by flaps in the roof (h=16 m).

Control strategy Depending on the mean of the temperatures at 15 positions in the atrium and the outdoor temperature groups of flaps are opened. At a temperature inside >22 °C and a temperature outside >14 °C the flaps over the revolving doors are opened. Flaps at the roof are opened at inside temperatures >24 °C.

Specific features The glass at the roof has a heat transfer coeff. h= 1.7 W/m^2K with a light transmissivity of 52%. Glass at the fassade has a heat transfer coeff. h= 1.3 W/m^2K with a light transmissivity of 52%.



11.2 Performance of the Building

11.2.1 Energy performance

Site deliverd energy:
Whole building: 4.7E6 MJ/a
Energy consumed by subsystems:
Electricity: 2.5E6 MJ/a; Fuel&Gas: 2.2E6 MJ/a

Methods of measurement energy Central energy management system

11.2.2 Ventilation performance

Temperatures in the supply and exhaust ducts:
Supply from offices: 21 °C;
Natural ventilation: outside temperature

Methods of measurement ventilation Passive Tracer Gas Technique

11.2.3 Performance of the applied design or analysis tools

Performance of applied tools compared to the results of measurements
CFD-simulation of the intermediate season: mean velocity between 0 - 2 m height v=0.12 m/s; mean velocity in the atrium v=0.06 m/s. Temperature-gradient: 0.2 °C/m
Passive Tracer Gas Measurement: leakage air change rate of the atrium = 0.1 h^{-1}. Temperature gradient without ventilation (only leakage air flow) =0.4 °C/m

11.3 References

Reference to detailed Annex reports:

O. Boeck, J. Borth, H. Stymne, *Einsatz eines Passiv Tracing Verfahrens zur Ermittlung eines Luftwechsels eines Atriums*, 8. Schweizerisches Status-Seminar Energieforschung im Hochbau, Zuerich 1994

J. Borth, *Simulation of Air Velocity and Temperature Distribution in the GVB-Atrium*, Internal Sulzer-Report, May 1996

Annex Contact Name: Joachim Borth
Annex Contact Institution: Sulzer Innotec Ltd.
Annex Contact Address: P.O. Box
Annex Contact City: CH-8401 Winterthur
Annex Contact Country: Switzerland
Annex Contact Tel: 052-262 42 51
Annex Contact Fax: 052-262 01 54

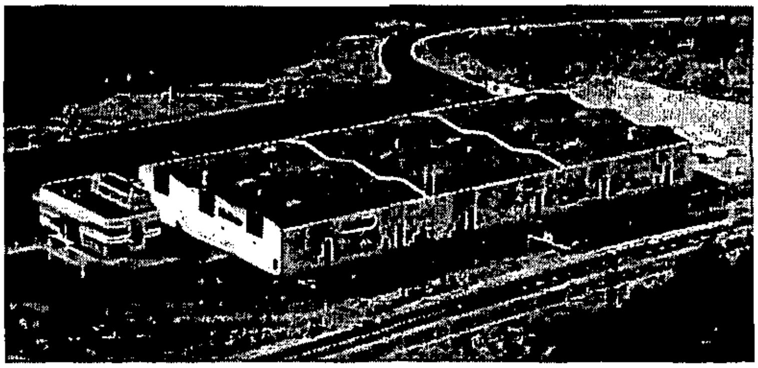
Part II

Industrial

12 Halton Lahti Works

12.1 Building Description

Building type:
Industrial



Owner:
Halton Oy
Kakkonen Kari
Halton Oy, Pulttikatu 2
FIN-15700 Lahti
Finland
+358 3 583 411
+358 3 583 4200

Year of completion:
1989

Project Costs:
The cost of air ductwork including ducts, dampers, air terminals and installation was 32 000 ECUs for the mixing system and 65 000 ECUs for the displacement system (the cost level in 1989).

Monitoring Agent:
Finnish Institute of Occupational Health

Design Team:
Building: Architects office Jorma Salmenkivi Oy Ventilation: Engineering office Erkki Lahtinen Oy

The project is a part of national industrial ventilation research program (INVENT) where this particular building represents modern production and ventilation technology in light engineering industry. The purpose is to show that using advanced ventilation technology, good indoor environment as well as good energy economy can be achieved. A specific objective is to compare the performances of displacement and mixing ventilation in heating conditions. The long-term monitoring of temperatures, air flow rates and energy consumption were done using the permanent building automation system. Detailed measurements of thermal environment, indoor air quality and ventilation parameters were conducted during two winter days using both mixing and displacement air distribution. The performance of displacement ventilation system in heating conditions was also predicted using computational fluid dynamics.

The building is used for production of ventilation system components as kitchen hoods, local ventilation units and dampers. There are about 45 people working in the production hall. They perform mainly machining operations on metal sheets, as cutting, drilling, bending, forming and rolling. These operations generate small amounts of airborne particles. Point welding is intermittently done to some extend in the open area. Stamping and gas gluing are performed in front of local exhaust units. The installed heat load of the production machines is 150 kW.

Two air distribution systems were constructed in the building in order to compare their performances in an industrial hall. The air can be distributed either by displacement or by mixing system. The supply air is used for heating as well as for cooling of the hall. The displacement ventilation is known to perform well in cooling situations whereas mixing may be preferable during heating conditions. The heating of the building is usually necessary in the morning only. During the rest of the day the internal loads are enough to cover the heat losses except on very cold days.

12.1.1 Site and location

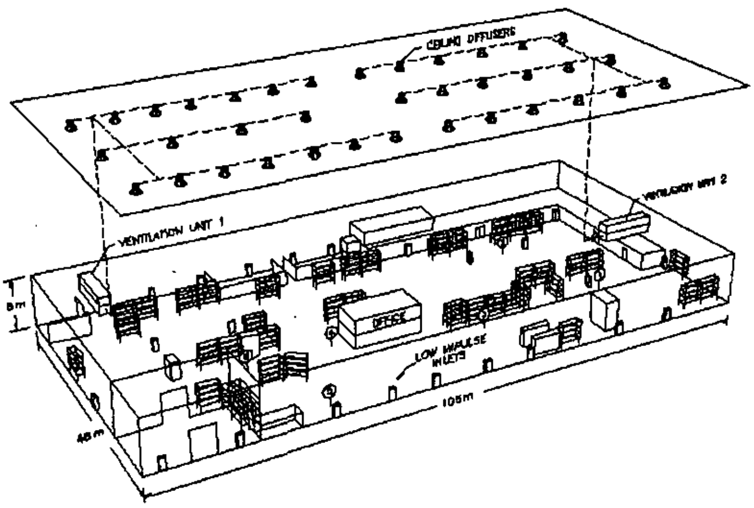
Building Address:
Pulttikatu 2, FIN-15700 Lahti, Finland
Lahti
Finland

Latitude:
60 degr 56 min

Altitude:
90 m

Monthly total of Degree Days:
The specified winter month (Jan. 1990):
693 Kd (base 17 °C)
The whole year 1994:
4594 Kd (base 17 °C)
Monthly mean air temperature:
The specified winter month (Jan. 1990): -5.6 °C
The whole year 1994: 4.3 °C

Description of the surrounding area The building is located next to a highway crossing about 5 kilometers south from the city of Lahti. There is a forest and a hill on the other side of the building which protect the building from direct wind.



12.1.2 Building form

Dimensions of the enclosure:
104.4 m x 47.7 m x 9.4 m
Dimensions Case Space Volume:
42 000 m^3

Description of building type The factory consists of a separate small office and a production hall which is the subject of this study. The hall has a rectangular shape except the folds of the roof. The building is constructed from prefabricated concrete elements which are insulated according to finnish building regulations: U- values are 0.45 W/m^2K and 0.36 W/m^2K respectively. The window area is small.

12.1.3 Building services

Degree of Conditioning:
Heating only.
Total heat load:
Winter:
465 kW
Heat transfer medium:
Air
Internal temperature
Winter:
18.5 °C

Type of Ventilation The building has balanced mechanical ventilation. Two identical ventilation units serving the production hall have heat recovery exchangers and recircula- tion parts. The capacity of each unit is 8.3 m^3/s of which at least 60% is fresh outdoor air. There are also some local exhaust units but their influence on the air flow balance is small.

Additional details of ducted system Two air distribution systems were constructed in the building in order to compare their performances. The air can be distributed either by displace- ment or by mixing system. The diameter of the supply and extract air ducts is 1.0 m.

Fresh air supply ventilation rate:
10 m^3/s minimum, 16.6 m^3/s maximum

Total air change ventilation rate:
16.6 m^3/s 1.4 air changes per hour 3.3 l/sm^2

Location of the supply and extract grilles There are two air extracts at a height of 7 meters from the floor. The 42 supply air terminals of the mixing system (type Halton TRS 400) are located at a height of 7 m whereas the 32 low impulse air terminals (type Halton LVA 400) are installed just above the floor.

Control strategy Room air temperature in the occupied zone is regulated by changing the supply air temperature. To heat up the supply air the first option is to utilize heat recovery, the second stage is recirculation and finally the third stage is to use the heating coil.

12.2 Performance of the Building

12.2.1 Energy performance

Site deliverd energy:
Annually (1994):
Natural gas 434 000 kWh
Electricity 620 000 kWh
During the specified winter month (Jan 1990):
Natural gas 81 000 kWh
Electricity 50 000 kWh

Energy consumed by subsystems:
Electricity consumption during the specified winter month (Jan 1990):
Lights 10 000 kWh
Fans 18 000 kWh
Process equipment 22 000 kWh

Energy due to conditioning of air:
The supply air heating covers not only ventilation loss but also the other heat losses which are for the specified winter month (Jan 1990):
Transmission 70 000 kWh
Ventilation 29 000 kWh
Infiltration 20 000 kWh
Internal loads -40 000 kWh
Total 79 000 kWh

Methods of measurement energy The monthly energy consumptions referred here correspond to a winter month (January 1990) when detailed energy balance for the factory hall was constructed. The electricity and natural gas consumptions for the hall were estimated from total building energy consumptions by subtracting the shares of the small office building and tap water heating (about 15%).

Energy consumption of the enclosure
Heating: $310\, MJ/(a\, m^2)$
Used area of the enclosure: $4\,980\, m^2$
This was calculated from natural gas consumption in year 1994. Note that the electricity supplied for lights, fans and process equipment (620 000 kWh) is bigger than the heating energy.

12.2.2 Ventilation performance

Air supply rates:
Fresh air: 16 m^3/s
Total air: 16 m^3/s
Temperatures in the supply and exhaust ducts:
Low impulse system:
Supply 15 – 27 °C,
exhaust 19 – 21 °C,
outdoor -12 – -6 °C
Mixing system:
Supply 14 – 26 °C,
exhaust 19 – 22 °C,
outdoor -2 – -3 °C

Methods of measurement ventilation The mechanical ventilation air flow rates are continuously monitored using permanent air flow meters in the ductwork. Total ventilation parameters were calculated from tracer gas decay curves.

Ventilation data
Supplied air: $3.2\,dm^3/(s\,m^2)$
Supplied air per person: $360\,dm^3/s$

12.2.3 Performance of the applied design or analysis tools

Performance of applied tools compared to the results of measurements The supply air flow rate was selected in discussions between the designer and the building owner. The designer used the manufacturers catalog data to select the air supply terminals. During the design stage (1988) there were no reliable knowledge available to analyze the performances of air distribu- tion systems in the whole enclosure. Therefore it was decided to construct the two air distribution systems in order to find out their performances in practice.

The CFD computations done in this project showed that vertical temperature gradients will remain small in displacement ventilation in the heating mode because the supply air jet and natural convection flows will effectively mix the air in the enclosure. The temperature gradients were also small in long- term measurements as well as during the detailed measurement campaign.

12.3 Recommendations

Experiences with the building The concentrations of particulate contaminants as well as toxic metals in the factory air were small due to sufficient ventilation and also due to low source strength. The appropriate use of local exhausts in the activities as gasket gluing helped to reduce contaminant sources.

There was not much difference in the performance of displacement ventilation and mixing ventilation in winter situation. Vertical temperature gradients were low with both air distribution methods because of natural convection flows and the supply air flow. The air velocity in the occupied zone was higher with the mixing system and therefore the displacement system is preferred all the year round. Also the differences in indoor air quality and energy consumption between the two air distribution systems were small.

Experiences summary Displacement ventilation system was in this building suitable also for heating.

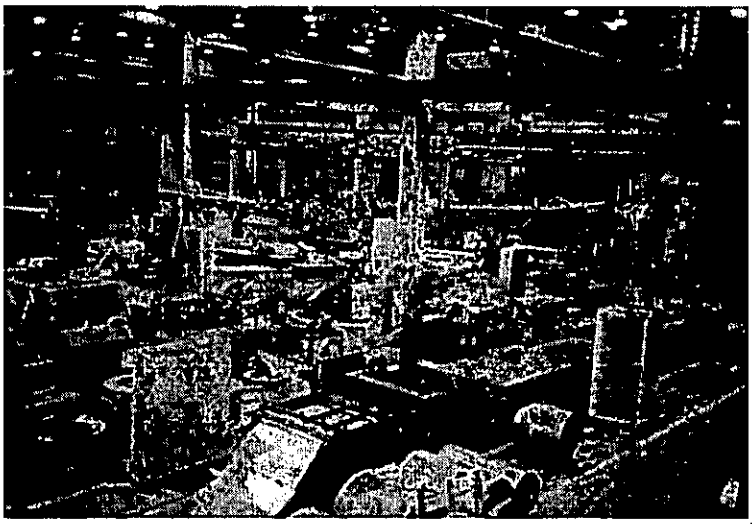
12.4 References

Reference to detailed Annex reports:	**Niemelâ R.,Koskela H, Hautalampi T.** *Ventilation and Indoor Climate in a Manufacturing Plant.* Federation of Finnish Metal, Engineering and Electrotechnical Industries, INVENT Report 42, Helsinki, 1995. **Heikkinen J.** *Temperature stratification in an industrial hall using displacement ventilation in heating mode* (to appear).
Annex Contact Name:	Heikkinen Jorma
Annex Contact Institution:	Technical Research Centre of Finland (VTT), VTT Building Technology
Annex Contact Address:	Lampomiehenkuja 3
Annex Contact City:	FIN-02150 Espoo
Annex Contact Country:	Finland
Annex Contact Tel:	+358 9 4561
Annex Contact Fax:	+358 9 455 2408
Investigators:	Koskela Hannu Niemelâ Raimo Heikkinen Jorma
Other references to publications:	**Hakkola, O.** *Performance of displacement ventilation in heating conditions* (in finnish). Lappeenranta University of Technology, Master thesis, 1990.

13 Ventilation Duct Hall

13.1 Building Description

Building type:
Industrial



Owner:
ABB Flåkt Oy
Rolin Ingmar
P.O. Box 20
FIN-00601 Helsinki
Finland
+358 0 5641
+358 0 5648150

Year of completion:
1975

Monitoring Agent:
Finnish Institute of Occupational Health

The project is a part of national industrial ventilation research program (INVENT) where the building represents modern ventilation technology in light engineering industry. Detailed measurements of thermal environment, indoor air quality and ventilation parameters were conducted during three summer days with both mixing and displacement air distribution. Temperature measurement data was also available for other summer periods. The mixing ventilation used air jets in supply air distribution. In the displacement system the supply air was distributed partly by low impulse units and partly by perforated duct units. The purpose was to study the performance of the different ventilation systems in terms of air quality, thermal environment and supply air distribution. The measurements aimed to produce information detailed enough for the comparisons with calculation models. Furthermore, an additional objective was to develop measurement techniques suitable for large enclosures.

The building is a production hall of ventilation ducts and other components of ventilation units. There are about 50 people working in the production hall. They perform mainly machining operations on metal sheets, as cuttiug, drilliug, beuding, forming and rolling. These operations generate small amounts of airborne particles. Point welding is intermittently done to some extend in the open area.

The building is a production hall of a ventilation company. The hall has two separate ventilation systems. In the older mixing system the supply air distribution is based on air jets located near the ceiling. The displacement system was built in 1990. There are four air handling units equipped with three different indirect evaporative cooliug systems. The performance of the cooling system was studied in another research project. The displacement air distribution was done partly by low impulse units and partly by perforated duct units. The mixing system is normally used in winter and the displacement system in summer.

13.1.1 Site and location

Building Address:
Kalevantie 39,
SF-20500 Turku,
Finland

Latitude:
60 degr 26 min
Altitude:
10 m

Description of the surrounding area

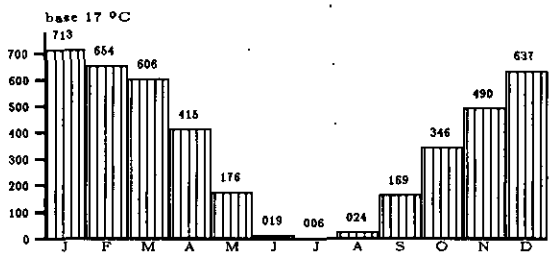


Figure 13.1: Monthly total of Degree Days (Average 1961-1990, base 17 °C)

The building is located in an industrial area 3 kilometres east from the centre of Turku.

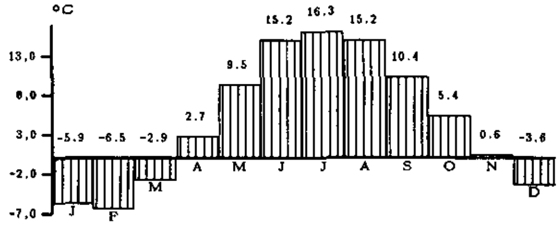


Figure 13.2: Monthly mean air temperature (Average 1961-1980)

13.1.2 Building form

Dimensions of the enclosure:
100 m x 60 m x 9 m
Volume:
54 000 m^3

Description of building type The factory hall is constructed of prefabricated concrete elements with U-value approximately 0.5 W/m^2K. The ceiling has 10 cm mineral wool insulation. The dimensions are 100 by 60 by 9 m. One short wall is common with the neighbouring hall. Two of the walls have 1.5 m high two–glass windows in the lower part. There are six slide doors for material transport in the hall.

13.1.3 Building services

Degree of Conditioning:
Heating and cooling
(indirect evaporative cooliug).
Heat transfer medium:
Air
Internal temperature
Summer:
20 – 25 °C

Type of Ventilation The hall has two separate balanced mechanical ventilation systems. Mixing system is normally used in wiuter and displacement system in summer. In the mixing system the supply air distribution is based on air jets located near the ceiling. Also supply air is introduced in the ceiling level. The displacement system has four air handling units equipped with three different indirect evaporative cooling systems. When cooling is needed, the exhaust air is humidified and heat exchangers are utilised to transfer heat from supply air to exhaust air. The air distribution is done partly by low impulse units and partly by perforated duct units.

Fresh air supply ventilation rate:
18 m^3/s minimum,
28 m^3/s maximum
Total air change ventilation rate:
18 m^3/s minimum, 28 m^3/s maximum

Location of the supply and extract grilles In the mixing system supply grilles are located in the ceiling level at the centreline of the hall. The supply air is then transferred and mixed with air jets. Exhaust air is taken from the ceiling level. In the displacement system there are two air distribution systems both covering half of the hall. In one half the low impulse displacement units are located on the floor and in the other half the perforated duct units are located at 3–4 m level. The exhaust air is taken from the corners of the hall near the ceiling.

Control strategy The temperature stratification is eliminated in winter with the mixing air distribution and utilised in summer with the displacement air distribution and cooling system. In summer the ventilation system is running also during nights to cool down the structures.

13.2 Performance of the Building

13.2.1 Energy performance

Energy consumed by subsystems:
machinery, lights, etc. approximately 500 MWh (40 W/m^2)
fans approximately 230 MWh
heating approximately 1 200 MWh
Energy due to conditioning of air:
fans approximately 230 MWh
heating approximately 1 200 MWh

13.2.2 Ventilation performance

Air supply rates:
18 m^3/s minimum,
28 m^3/s maximum
Temperatures in the supply and exhaust ducts:
For warm summer conditions with displacement system and indirect evaporative cooling:
supply air 20 – 23 °C
occupied zone 22 – 25 °C
exhaust air 25 – 27 °C
outdoor 23 – 29 °C

Methods of measurement ventilation Supply air distribution was measured with 2 – 4 tracer gas experiments in each situation applying step-up and step-down procedures. Sulphurhexafluoride (SF6) was released at constant flow rate to each supply air unit. The concentration was monitored by two photo acoustic infrared analysers with twelve sampling points. Four sampling points were located in the hall at 1.5 m level, four at 5 m level and one at each exhaust. The age parameters, air change efficiency and local air change index were calculated from the concentration curves.

13.3 Recommendations

Experiences with the building The idea of the ventilation arrangement is to use two separate air distribution systems in order to create good indoor environment with low energy consumption. Mixing system is used during the heating period to eliminate temperature stratification. Displacement system is used during the cooling period to utilise temperature stratification for better temperature efficiency and higher local ventilation rate in the occupied zone. Best local ventilation index in the occupied zone was measured with low impulse air distribution. The temperature stratification in the hall was around 2 °C. Cooling of supply air is done with indirect evaporative system to lower the temperature in the occupied zone without increasing energy consumption. In warm summer conditions the temperature in the occupied zone was 3 – 4 °C lower than the outdoor temperature whereas with the mixing system without cooling it was 2 – 3 °C higher than the outdoor temperature. The air velocity in the occupied zone was lowest with the perforated duct air distribution. The contaminant concentrations in the hall were very low with both mixing and displacement ventilation systems, which was mainly due to low emissions in the production process. For this reason all the air distribution systems were sufficiently efficient from the viewpoint of contaminant control in the occupied zone.

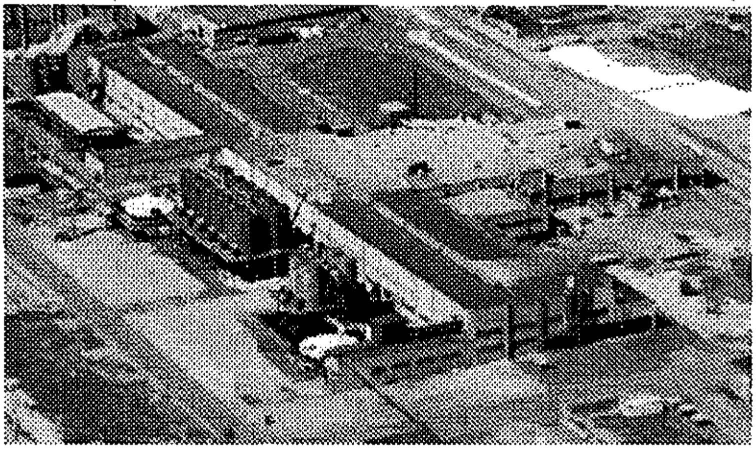
13.4 References

Reference to detailed Annex reports:	**Koskela H., Niemelâ R., Hautalampi T.** *Ventilation Performance and Indoor Climate in a Ventilation Duct Factory.* INVENT Report 43, March 1995.
Annex Contact Name:	Hannu Koskela
Annex Contact Institution:	Finnish Institute of Occupational Health
Annex Contact Address:	Hâmeenkatu 10
Annex Contact City:	FIN-20500 Turku
Annex Contact Country:	Finland
Annex Contact Tel:	+358 21 2736500
Annex Contact Fax:	+358 21 2736556
Investigators:	H. Koskela R. Niemelâ
Other references to publications:	*Industrial Ventilation Programme INVENT - Projects, Companies, Research Institutes 1993.* INVENT Report 33, August 1994. **Ekman C., Rolin I.** *Industrial Ventilation with Indirect Evaporative Cooling* (the report is in Finnish). **Koskela H., Niemelâ R., Hautalampi T.** *Performance of three Air Distribution Systems in a Ventilation Duct Factory.* Proceedings of Ventilation 1994. **Koskela H., et. al.** *The Effect of Indirect Evaporative Cooling on Thermal Environment.* Proceedings of Indoor Air 1993.

14 Outokumpu Zinc Hall

14.1 Building Description

Building type:
Industrial



Owner:
Outokumpu Zinc Oy
Aaro Perkkio
P.O. Box 26
FIN-67101 Kokkola
Finland
+358 6 828 6111
+358 6 828 6605

Year of completion:
1969, ventilation system
was renovated 1992

Project Costs:
The estimated cost for the new air supply system including ducts and supply air terminals was 0.7 million ECU.

Monitoring Agent:
Onlu Institute and School of Technology
(contact Pirjo Kimari)
Ontokumpu company
(contact Juhani Utela)

Design Team:
Outokumpu Engineering
AX Consulting Engineers
(contact Teuvo Aro)

The project is a part of national industrial ventilation research program (INVENT) where this particular building represents heavy metal industry with strong contaminant loading. The areas of usual human occupancy on the two floors are relatively small, as shown in the picture. The ventilation system was renovated in 1992 because the old ducts were corroded. At the same time the air distribution system was changed from mixing type into displacement type because of encouraging results from a preliminary study done by the ventilation designer.

The performance of the new air distribution system was studied during two measurement campaigns in summer and winter conditions. Each campaign took two or three days. The air flow rates, contaminant concentrations, temperatures and air velocities were measured in different locations. About 2600 measurement results were manually recorded by the measurement team. A number of proposals for improvement of ventilation performance were suggested and also tested. The performance of ventilation system was predicted using computational fluid dynamics and also using more simple gravity current and jet equations.

The building is used for production of zinc by an electrolytic process in large pools which are coated with a special foam to prevent the emission of contaminants. In spite of that large amounts of heat and aerosols containing sulfuric acid and zinc sulfate are released to the room air.

The most important thing in this building is to assure the production of zinc without any interruptions. Therefore all the measures to improve ventilation or energy economy should not disturb the process and the free movement of cranes or to cause a safety risk for workers. For these reasons many proposals for ventilation improvement have been rejected, for example local exhaust at the pollution sources, air curtains and the flow obstructions to raise up the clean air layer.

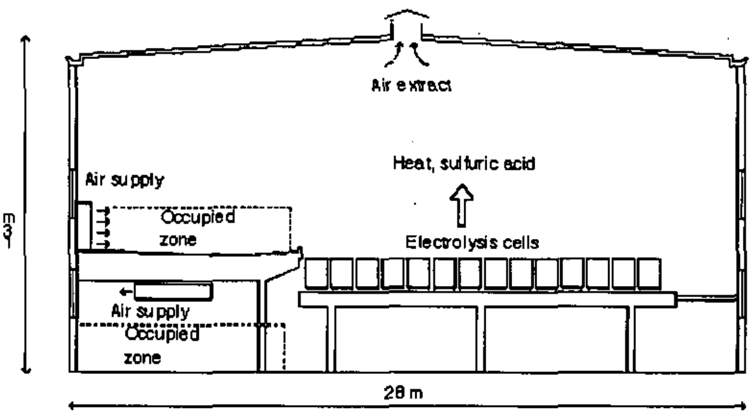
14.1.1 Site and location

Building Address:
P.O. Box 26,
FIN-67101 Kokkola,
Finland

Latitude:
63 degr 50 min
Altitude:
10 m

Monthly Mean Wind Velocity:
Annual average 5 m/s (1994)
Monthly total of Degree Days:
Annually:
average year 4976 Kd,
year 1994 4904 Kd (Base 17 °C)
Monthly mean air temperature:
Annually:
average year 2.8 °C,
year 1994 3.1 °C

Description of the surrounding area The building is located on the seashore in an industrial area about 5 kilometers from the city of Kokkola. There is not much protection from the wind.



14.1.2 Building form

Dimensions of the enclosure:
250 m x 28 m x 13 m
Volume:
88 000 m^3

Description of building type The factory building contains a foundry, an office and the electrolysis hall which is the subject of this study. One of the long walls of the hall is adjacent to the office and the foundry. The other three walls are in contact with the outdoor air. The building is rather leaky.

14.1.3 Building services

Degree of Conditioning:
Heating only.
Heat transfer medium:
Air
Internal temperature:

Winter	Summer
19 °C	20 °C

Type of Ventilation The ventilation air is supplied mechanically at a rate of 6 air changes per hour and is extracted naturally through openings at the top of the building. Most of the air (80%) is supplied to the hall (second floor) and the rest to the first floor.

Additional details of ducted system Before summer 1992, the air was distributed through grilles at a high speed. Almost perfect mixing of contaminants took place. The supply air terminals were then replaced by new displacement type of terminals which were installed at a lower position on the floor.

Fresh air supply ventilation rate:
159 m^3/s
Total air change ventilation rate:
159 m^3/s

Location of the supply and extract grilles The supply air devices are of displacement type and they are installed close to the wall on the floor of the service corridor at distances of 5 m on average. The type of the supply air devices is Halton LVF (height 2.0 m, width 1.9 m and depth 0.6 m) and the air distribution angle is 180 degrees. The air extracts are located at the top of the building.

14.2 Performance of the Building

14.2.1 Energy performance

Site deliverd energy:
Annually for ventilation (supply air heating and electricity for fans):
District heating 22 000 MWh
Electricity 2 000 MWh

Energy consumed by subsystems:
The electricity consumption of the process is 580 000 MWh/year
Energy due to conditioning of air:
Annually 22 000 MWh

Methods of measurement energy The energy needed to heat up the supply air has been computed from the supply air flow rate (159 m^3/s), the supply air temperature (18 °C) and the annual weather data for year 1994 (Degree days 4 904 Kd). The fan energy has been estimated from installed load of the fan motors (350 kW).

Energy consumption of the enclosure
Heating: 11 000 $MJ/(a\,m^2)$
Used area of the enclosure: 7 000 m^2
This is the district heating energy needed for heating of the supply air.

14.2.2 Ventilation performance

Air supply rates:
160 m^3/s
Temperatures in the supply and exhaust ducts:
Supply 18, exhaust 20 – 28 °C

Methods of measurement ventilation The supply air flow rates were measured both from velocities in ducts and in addition from pressure taps of the supply air devices.

Ventilation data
Supplied air: 23 $dm^3/(s\,m^2)$
Supplied air per person: 4 000 dm^3/s

14.2.3 Performance of the applied design or analysis tools

Performance of applied tools compared to the results of measurements The CFD computations showed that the height of the clean air layer will not always be high enough to provide much better indoor air quality in the breathing zone than in the other parts of the hall. It was difficult to set the heat flux boundary conditions for CFD computations and therefore number of simulations were done using different heat fluxes.

A simple formula for the height of the gravity current suggested that the clean air layer is high enough if the temperature difference between the room and the supply air is less than 1.5 degrees. This seems to correspond well the situation in the actual building which means that this simple model is very promising and would have been useful during the design stage. It was not possible to predict the effect of air infiltration on ventilation performance.

14.3 Recommendations

Experiences with the building The performance of the new air distribution system is satisfactory: the experience of the plant engineer is that about 80% of time the concentrations in the occupied zone are clearly lower than in mixing situation. The air quality is however dependent on weather conditions, particulary southern wind will carry polluted air from the pools to the occupied area. Therefore it would be necessary to seal up the building as a first measure to improve the air quality in the occupied zone.

The energy efficient ventilation of this building still remains to be a big challenge to ventilation engineers: at present an air flow rate which is enough for 20 000 people in office environment (8 liters per second per person) is heated up and supplied for ventilation of a hall where only 40 people are working. The present ventilation system has however regarded to be the best available. All further proposals to improve the ventilation system have been rejected because they either disturb the zinc production or does not work properly.

Experiences summary The performance of the new air distribution system is satisfactory.

Recommendations for desing measurement It turned out to be very difficult to make reliable and repeatable measurements in a production hall where the production process is going on and the climate effects ventilation performance. Accurate planning of the necessary measurement parameters as well as the measurement procedure is essential.

Recommendations summary Accurate planning of measurement procedure is essential.

14.4 References

Annex Contact Name:	Heikkinen Jorma
Annex Contact Institution:	Technical Research Centre of Finland (VTT), VTT Building Technology
Annex Contact Address:	Lampomiehenkuja 3
Annex Contact City:	FIN-02150 Espoo
Annex Contact Country:	Finland
Annex Contact Tel:	+358 9 4561
Annex Contact Fax:	+358 9 455 2408
Investigators:	Jukka Alikoski Jorma Heikkinen
Other references to publications:	**Heikkinen, J.** *Outokumpu Zinc Hall, Simplified and CFD Computations. IEA Energy Conservation in Buildings and Community Systems*, 35th Executive Committee meeting, Technical Day Reports, Espoo, Finland 1994. **Miettinen, A.** *Ventilation of Zinc-Electrolyze Hall 1-2.* Federation of Finnish Metal, Engineering and Electrotechnical Industries, INVENT Reports 26 and 27, Helsinki, 1993 (in finnish). **Tahti, E.** *Ventilation of Outokumpu Kokkola Zinc-Electrolyze Plant.* Ventilation 94

15 Polyester Factory

15.1 Building Description

Building type:
Fibreglass Reinforced Plastics Industry

Owner:
Mauves-sur-Huisnes
France

Year of completion:
1993/94

Design Team:
Techniconsult, Brest, France

The same project contains a new fabrication workshop, an old one and the head quarter of the compagny. The study focuses on the new workshop which is equipped with a mixing ventilation system in order to reduced the exposure of workers to styrene. The building has been operating since spring 94. On site measurements were performed in October 94.

In this workshop are made fiber-glass reinforced polyester products: the process involves a manual spreading of a polyester resin containing styrene. During chemical reactions occuring in the process, part of styrene is released in the air. In order to specify the order of magnitude of styrene concentrations, the maximum exposure limit over 8 hours a day is set to 50 ppm in France, whereas it is down to 20 in Finland.

Mixing ventilation was chosen in order to fulfill the two demands already mentionned. One major property of the new workshop is that is overpressured in order to partly ventilated the adjacent older workshop: thus, part of the air pulled in the new workshop goes through two large openings used for carrying materials between the two enclosures.

15.1.1 Site and location

Building Address:
Mauves-sur-Huisnes
France

Latitude:
48 31 N
Altitude:
100 m

Monthly Mean Solar Irradiance:
113,5 in October
(averaged over the past 26 years)
Monthly total of Degree Days:
128.1 degree-days with a 15 °C base
Monthly mean air temperature:
11 °C in October
(averaged over the past 26 years)

Description of the surrounding area Hilly crop fields with bushes

15.1.2 Building form

Dimensions of the enclosure:
42m x 35m x 6m
Volume:
8820 m^3

Description of building type The new workshop contains about 40 working positions limiting by tables on which moulds are mounted and treated. The variety of mould sizes and shapes makes the appearance of the workshop change from one day to another. Working positions are organised in 4 lines; two large alleys are let free of occupancy.

15.1.3 Building services

Degree of Conditioning:
All mechanical ventilation (SA 6)
Heat transfer medium:
All air system
Internal temperature:

Winter	Summer
20 °C	up to 35 °C according to workers

Internal relative humidity:
Not critical; no interna source.

Fresh air supply ventilation rate:
70 000 m^3/h (theoretical);
46 600 m^3/h (measured).
Total air change ventilation rate:
5.3 volume per hour.

Type of Ventilation General mixing ventilation was used in order both to maintain styrene concentration below the exposure limit and to keep a 20 °C mean temperature. The designed total fresh air flow rate was set to get a mean styrene concentration of a fourth of the exposure limit.

Additional details of ducted system Fresh heated air is supplied by two independant duct, fan and heating system. The two make-up systems are monitored independantly by indoor sensors.

Location of the supply and extract grilles Fresh air is supplied throughout 20 inlets (1m diameter circular anemosthats) regularly located 4m above the floor; 24 extraction grilles are located at the floor level.

Control strategy Constant ambiance temperature and flowrates are targeted.

Specific features The already mentionned overpressure of the new workshop corresponds to a 36 100 m^3/h extraction flow rates in comparison with 46 600 m^3/h of supply air flow rate. the other 10 500 m^3/h pour into the older workshop through the two large openings.

15.2 Performance of the Building

15.2.1 Ventilation performance

Air supply rates:
46600 m^3/h (as measured); detailed flow rates per inlet devices were estimated using maximum velocity measured at their vicinity ranging from 930 to 3260 m^3/h for an averaged value of 2330 m^3/h.
Temperatures in the supply and exhaust ducts:
18–20 °C

Methods of measurement ventilation Omnidirectional and directional velocities were measured respectively with thermal and ultrasonic anemometers in three vertical sections of the building; exhaust and supply air flow rates were estimated with a tracer gas equipment based on Helium; air temperature was measured using thermistances. All sensors were monted on a moving mast.

15.2.2 Performance of the applied design or analysis tools

Performance of applied tools compared to the results of measurements The ventilation system seems to comply with the two main objectives given by the building designer. As a matter of fact, temperature gradients stay within a 1 or 2 degree range. Concerning styrene concentrations, they remain mostly in a 20–30 ppm interval, except in some regions where very large moulds were used. As far as velocity fields are concerned, no clear flow pattern can be extracted from the measurements. Air jets resulting from the inlets can interact with each other and seem to have heratic behaviour from one device to another. Moreover, velocity profiles are complex and vary from one device to another. Finally, omnidirectional velocities are generally over 0.2 – 0.3 m/s, which means that the mixing ventilation is acting as designed.

15.3 Recommendations

Experiences with the building Mixing ventilation is not suitable in general when pollutants are involved. In the polyester, factory case, the designer had to face a trade off between indoor air quality and heating aspects. Dilution leads to low exposition levels, but contaminant dispersion is not controled at all.

Recommendations for desing measurement In this case, general ventilation could have been coupled with local capture equipments, in order to minimize the fresh air flow rate (and thus heating cost) and pollutant dispersion. Moreover, supply air diffusion could have been optimized.

15.4 References

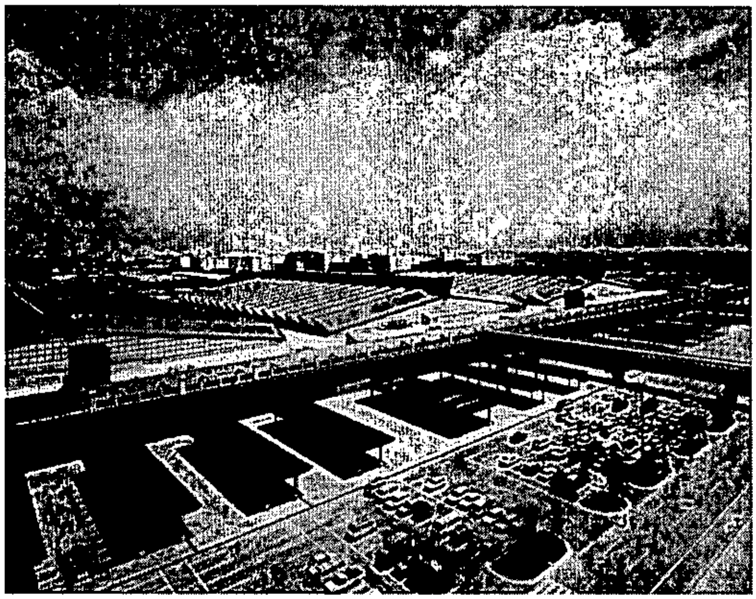
Annex Contact Name: S. Collineau

Investigators: S. Collineau
H. Koskela
R. Niemelâ

16 Tokyo Central Wholesale Market JP6

16.1 Building Description

Building type:
Wholesale Market



Owner:
The City of Tokyo, Dept. of Management
The City of Tokyo
1-1, 5-chome, Tukiji, Chuo-ku
Tokyo
Japan
+81 3 3542 1111
+81 3 3542 0051

Year of completion:
1989

Project Costs:
50 240 000 000 yen

Design Team:
Nikken Sekkei Ltd.

This market building was designed for active use of natural ventilation to save energy and also to be free of maintenance.

This building was designed for wholesale market. It consists of two parts : one comprised by three blocks for fruits and vegetables and other intended for a fish market.

There is no air-conditioning. The internal space is naturally ventilated. The building was designed to be effectively ventilated.

16.1.1 Site and location

Building Address:
2-1, 3-chome,
Tokai, Ota-ku,
Tokyo, Japan

Monthly Mean Wind Velocity:
about 2.6 m/s

Description of the surrounding area It is located in the reclaimed land of Tokyo bay and also sited close to the garden.

16.1.2 Building form

Dimensions of the enclosure:
541 m x 180 m x 28 m
Volume:
1 947 600 m^3

Description of building type This building was designed for wholesale market. It consists of two parts : one comprised by three blocks for fruits and vegetables and the other intended for a fish market.

16.1.3 Building services

Degree of Conditioning:
32 °C (1991, August, 03, 14:00)
Internal temperature
Summer:
26 – 33 °C (1991, August, 3.)
Winter:
7 - 9 °C (1992, March, 3.)

Type of Ventilation This market is naturally ventilated. The ventilation features are as follows.

1) The top of each roof was equipped with the large-scale roof monitor in order to avoid a risk of non-uniform ventilation.
2) Openings for passage of vehicles can be used for ventilation.
3) Maintenance and management are almost unnecessary.

Additional details of ducted system There is no mechanical ventilation system.

Fresh air supply ventilation rate:
100 %
Total air change ventilation rate:
4 – 10 ach. when outdoor wind velocity is 4.0 m/s at monitoring height

Location of the supply and extract grilles

16.2 Performance of the Building

16.2.1 Energy performance

Energy consumption of the enclosure
Used floor area of the enclosure: 86 220 m^2
Comments: This Wholesale Market consists of Agricultural products area and Marine products area.
Agricultural products are: 71 280 m^2
Marine products area: 14 940 m^2

The Natural Ventilation system is only adopted as the air conditioning of this enclosure.

16.2.2 Ventilation performance

Methods of measurement ventilation The air change rates were measured by the tracer gas method using SF6 . The tracer gas was generated constantly and controlled by a mass flow meter.

Ventliation data
Supplied air: $0.059 \sim 0.208\, dm^3/(s\, m^2)$ by Natural ventilation
Supplied air per person: $1.038 \sim 1.053\, dm^3/s$ by Natural ventilation
Comments:

(1) Agricultural products area
Total supplied air: 1 516 000 m^3/h (When outdoor wind Velocity was 3.5 m/s, Measured 1991.8.4)

(2) Marine products area
Total supplied air: 1 121 000 m^3/h (When outdoor wind Velocity was 30 m/s, Measured 1991.8.5)

16.3 References

Annex Contact Name:	Prof. Dr. Hiroshi Yoshino
Annex Contact Institution:	Department of Architecture, Faculty of Engineering, Tohoku University
Annex Contact Address:	Aramaki Aza Aoba, Aoba-ku
Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886
Investigators:	Assoc. Prof. Yasushi Kondo (Musashi Institute of Technology)
Liaison Engineer:	Mr Shinji Mamamura Nikken Sekkei LTD.

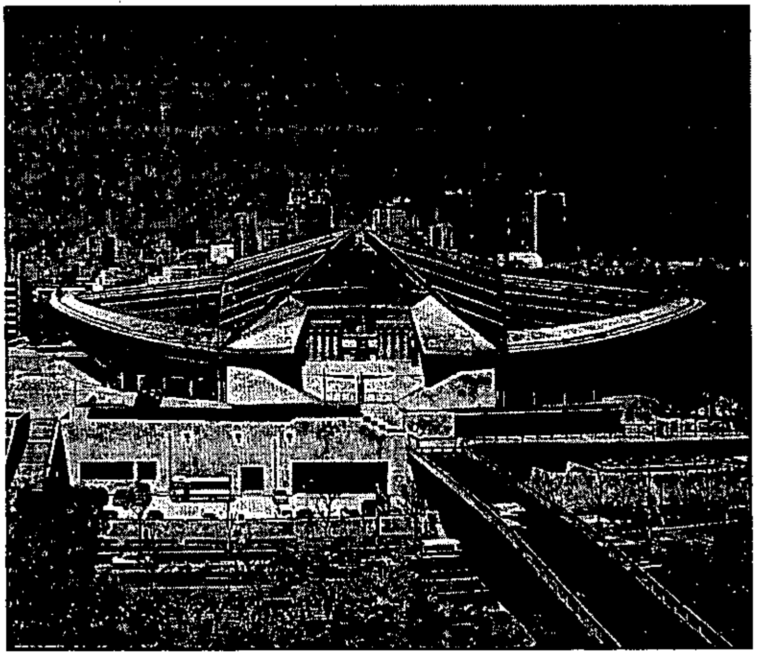
Part III

Sports arena

17 Tokyo Metropolitan Gymnasium JP 9

17.1 Building Description

Building type:
Gymnasium



Owner:
The Metropolis of Tokyo
2-8-1, Nishi-shinjuku-Shinjuku-ku
Tokyo
Japan
+81 3 5321 1111

Year of completion:
1990

Design Team:
Fumihiko Maki

The new Tokyo Metropolitan gymnasium consists of three main athletic facilities (a main arena, sub arena and indoor pool) linked by a deck. Site area: 45 800 m^2, construction area: 24 100 m^2, total floor area: 43 971 m^2.

It is designed to be a gymnasium, which is open to every citizen in Tokyo who might come to exercise his body or to have fun to watch the game etc. It is also designed to serve a space, where can be used for a big game (volleyball, basketball, tennis etc.) with large audience.

Main arena is a large space covered with curved surfaces. From above, the round roof, with a diameter of 120 meters, is seen to consist of two leaf-shaped steel flames balanced against each other. It has a roof finished in thin (0.5 mm) stainless steel.

17.1.1 Site and location

Building Address:
1-17-1, Sendagaya, Shibuya-ku
Tokyo
Japan

Latitude:
35 41' N ; 139 46' E
Altitude:
6 m

Monthly total of Degree Days:
Heating = 900 °C day in a year,
cooling = 130 °C day in a year.

Description of the surrounding area

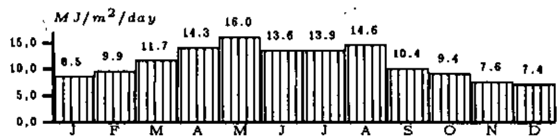


Figure 17.1: Monthly Mean Solar Irradiance

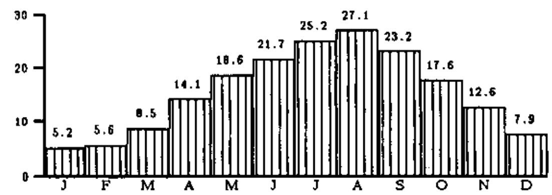


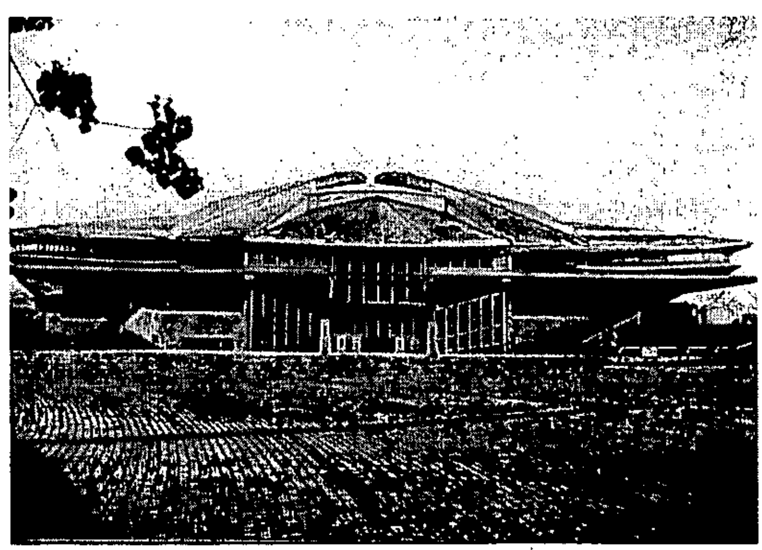
Figure 17.2: Monthly mean air temperature

The site, 4.5 hectares in area, is a part of Meiji park in the center of Tokyo, and the outdoor spaces are always open to people, who might come to relax or to just pass through.

17.1.2 Building form

Dimensions of the enclosure:
Round space with a diameter of 120 m x 27 m (highest part)
Volume:
130 000 m^3

Description of building type Gymnasium, multipurpose space for rock concert, etc.



17.1.3 Building services

Total heat load:
Winter Summer
222 000 kcal/h 942 000 kcal/h
Internal temperature:
Winter Summer
20.0 °C 27.0 °C
Internal relative humidity:
60 %

Fresh air supply ventilation rate:
285,300 m^3/h (max.)

Type of Ventilation Mechanical Ventilation; volume of outer air is controlled according to the use of the gymnasium.

Location of the supply and extract grilles Main supply openings, two-dimensional linear slots around arena, are installed at the tip of the 1 F and 3 F seats zone (2.5 m high and 9 m high). Supply openings are also installed below the seats. Exhaust openings are installed at the wall around the arena (0 m and 7 m high) and at the edge of the floor of arena.

Control strategy Air-conditioning system is controlled according to the use of the gymnasium and it has VAV system.

17.2 Performance of the Building

17.2.1 Energy performance

Energy consumed by subsystems:
It is measured by the data recorded every hour by the main controlling computer.
Energy due to conditioning of air:
It is estimated by the energy consumed by subsystems.

Methods of measurement energy Energy is measured by the data recorded every hour by the main controlling computer.

Energy consumption of the enclosure
Energy: $3.07 \times 10^8\, J/(a\, m^2)$
Cooling: $1.46 \times 10^8\, J/(a\, m^2)$
Used floor area of the enclosure: $14\,000\, m^2$
Comments:
Peak Cooling load: $2\,567\,000\, kcak/h$
Peak Heating load: $1\,224\,500\, kcak/h$
Equivalent Fill load conditioning time:
(Cooling) $400\, h/a$
(Heating) $400\, h/a$

17.2.2 Ventilation performance

Air supply rates:
349 800 m^3/h (max.) They were measured by the anemometer and the data recorded by the main computer.

Temperatures in the supply and exhaust ducts:
Measured by thermocouplers

Ventilation data
Supplied air: $0.0694\, dm^3/(s\, m^2)$
Supplied air per person: $0.0972\, m^3/s$
Comments: Total supplied air: $349\,800\, m^3/h$

17.3 Recommendations

Experiences with the building	
Numerical simulation:	summer and winter flow and temperature distribution in the gymnasium
Model experiment:	summer and winter flow and temperature distribution in the gymnasium
Short term field measurement:	summer and winter flow and temperature distribution in the gymnasium, flow visualization of supplied air
Long term field measurement:	vertical temperature, heat loads, energy consumption

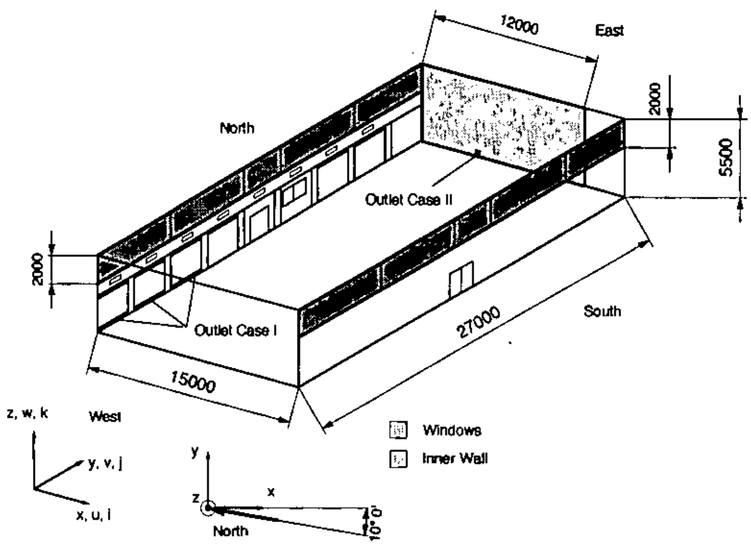
17.4 References

Annex Contact Name:	Shuzo Murakami
Annex Contact Institution:	I.I.S. University of Tokyo
Annex Contact Address:	7-22-1 Roppongi, Minato-ku
Annex Contact City:	Tokyo
Annex Contact Country:	Japan
Annex Contact Tel:	+81 3 3401 7439
Annex Contact Fax:	+81 3 3746 1449
Investigator:	Shuzo Murakami
Liaison Engineer:	Mr Shinji Yamamura Nikken Sekkei LTD.

18 Gymnasium München

18.1 Building Description

Building type:
Sports arena



Owner:
Stadt München
Baudirektor Regnet
Baureferat Abt. 7 Rindermarkt 7
D-80331 München
Germany
+49 89 2332 2109
+49 89 233 7868

Year of completion:
1973

The sports arena of the school called "Karls Gymnasium" in München Pasing was build in the early seventies as a skeleton construction of reinforced concrete. The construction of the walls, ceilings, floors and especially the windows are made according to the standards of this time. This gymnasium belongs to a high school, so thus, during the lessons it is used for school requirements and in the evenings, sport clubs are allowed to use it.

In the year 1990 the heating system was extended in order to save energy, so now the roof of the gymnasium carries a solar collector system. Due to the fact that sports areas require a huge amount of fresh air and thermal energy, it is reasonable to use the solar energy directly for heating the supplied fresh air. The German Federal Ministry for Research and Technology (BMBF 0329160A and 0329016B) financed a research program to show the effectiveness of this solar heating system and to optimize the performance of the system.

This building was selected as a Annex 26 case-study building especially for the use as a CFD test case, because of its simple geometry. This simplifies the boundary conditions of the calculations and the evaluation of all CFD results. Additionally the results of the CFD calculations can be compared with field measurements of temperature, velocity and turbulence values.

18.1.1 Site and location

Building Address:
Gymnasium am Stadtpark 21
81243 München
Germany
Latitude:
48 08'
Altitude:
520 m

Description of the surrounding area This gymnasium lies beside a high school in a suburb of Munich.

18.1.2 Building form

Dimensions of the enclosure:
15 m x 27 m x 5.5 m
Volume:
2230 m^3

Description of building type The gymnasium consists of two halls which can be used separately. The investigations concerning the Annex 26 took place in the larger hall. A big amount of fresh air is needed for ventilation, because of the intermittent human occupancy with high level of human pollutant sources. Building services

18.1.3 Building services

Degree of Conditioning:
No conditioning
Heat transfer medium:
Air
Winter:
17 °C

Fresh air supply ventilation rate:
4100 m^3/h
Total air change ventilation rate:
1.8 l/h

Type of Ventilation

The ventilation system is mechanical. The two halls are heated by air with a separate heating systems. The inlet air is heated by the solar collector system. Additionally an air/water system can be used for heating.

Location of the supply and extract grilles

The room is ventilated by 8 supply openings placed on the south wall. During the measurements the outlet was moved to the east wall and the outlet air was sucked off into the smaller hall in order to ensure that there is no recirculation of outlet air into the ventilation system.

Control strategy Simple single zone control system.

18.2 Performance of the Building

18.2.1 Energy performance

This case study building serves only for the comparison of different CFD-codes. In order to get stationary boundary conditions the solar heating system was not used and thus, the energy performance of the collector system was not measured during the measurement period.

Methods of measurement energy An energy balance of the enclosure was performed by measuring the inlet and outlet temperatures by a known air change ventilation rate.

18.2.2 Ventilation performance

Air supply rates:
1.8 l/h
Temperatures in the supply and exhaust ducts:
Supply: 19.4 °C

Methods of measurement ventilation The ventilation performance was measured with the tracer gas technique.

18.3 References

Reference to detailed Annex reports: A detailed report of the measurements can be found in the Design Tools Report, Chapter 4.5.

19 Gjøvik Fjellhall (Gjøvik Olympic Mountain Hall)

19.1 Building Description

Building type:
Ice Rink, Built in Rock

Owner:
Gjøvik Olympiske Anlegg AS
Arne Blakkisrud
Boks 2802801 Gjøvik Norway
+47 61 13 82 00
61 13 82 10

Year of completion:
1993

Design Team:
Fortifikasjon AS

Since the hall is built in rock it completely relies on the mechanical ventilation for indoor climate and safety in case of fire. When the desition to build the rock cavern was taken, it was argued that the energy consumption should be lower than an above ground building. To document the technical solutions and the performance a research program was initialized.

The mountain hall was constructed in time for the Winter Olympic Games in 1994 to be used as an arena for ice-hockey, but for after Olympic games use it should serve as an general sports arena, exhibition hall and concert hall.

19.1.1 Site and location

Building Address:
Heimdalsgt 2
Fjellhallen 2800 Gjøvik
Norway

Latitude:
61 north
Altitude:
226 m

Monthly total of Degree Days:
4361 degree days per year

Description of the surrounding area

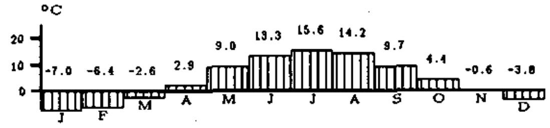


Figure 19.1: Monthly mean air temperature

The entrance to the rock cavern is through a 100 m long tunnel

19.1.2 Building form

Dimensions of the enclosure
91 m x 61 m x 25 m
Dimensions Case Space Volume:
114,000 m^3

Description of building type

Ceiling:
Main ceiling of corrugated galvanised steel fixed along the curved rock ceiling to protect against water dripping from the rock onto the ice rink or the spectators. Some parts of the main steel ceiling are hidden from view by a suspended ceiling. About 60% of the surface area are covered by acoustic absorbing panels.
Suspended ceiling:
A few metres below the main steel ceiling hang a suspended horizontal sheet coated with aluminium at the down-facing side.
Floor:
The ice rink floor from the surface and down:

- Reinforced concrete (15 cm thick) embedded with freezing coils (top layer)
- Styrofoam insulation
- Diffusion barrier

- Levelling with rock material
- Walls

End walls and walls are covered by shotcrete.

19.1.3 Building services

Degree of Conditioning:
Some of the air could be cooled/dried
Total heat load:
Summer:
Light 110 kW and 5800 persons
Winter:
Light 110 kW and 5800 persons
Internal temperature:

Winter	Summer
15 °C	15 °C
(Design value was 10 °C)	

Fresh air supply ventilation rate:
Maximum 140.000 m^3/h for areana,
160 000 m^3/h total
Total air change ventilation rate:
Maximum 140.000 m^3/h for arena,
160 000 m^3/h total

Type of Ventilation Mechanical balanced ventilation. In priciple it works like displacement ventilation.

Location of the supply and extract grilles 2/3 of the air is supplied at low velocity beneath the tribunes and flows through entrance openenings into the arena. 1/3 is supplied at low velocity at the top of the tribunes. Exhaust is from top of the ceiling area.

Control strategy Constant supply air temperature

19.2 Performance of the Building

19.2.1 Energy performance

Energy due to conditioning of air:
2040 $MWh/year$

Methods of measurement energy Reading electricity meter.

19.2.2 Ventilation performance

Methods of measurement ventilation Measurements were done both continously for one year and and for shorter periods when the arena was occupied. The long term measurements were mainly to find the energy use for ventilation and transmission heat loss. The short term measurements were done by simple smoke tests and measuring tracer gas and CO_2 concentration in different positions, air velocity and air and surface temperatures together with airflow rates.

19.3 Recommendations

Experiences with the building The the ventilation is operated with a higher supply air temperature compared to design values. This causes the supply air to short-circuit to the exhaust when the internal heat load is low or moderate. Because of this the energy use for heating is increased compared to design values. To reduce the energy use it should be used as a separate heating system.

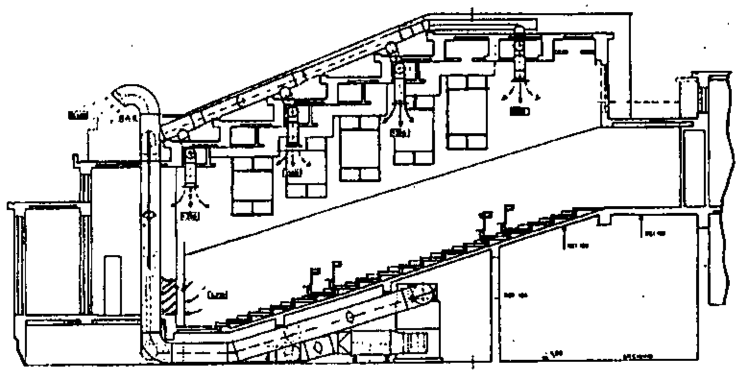
Part IV

Auditoria

20 Torino Polytechnic Auditorium. IT1

20.1 Building Description

Building type:
Auditorium



Owner:
Politecnico di Torino
C.so Duca degli Abruzzi n 24
10129 TORINO
ITALY
+9-11-5646666

Year of completion:
1991

Design Team:
Studio PRODIM
Torino

This enclosure is a university auditorium located in the Politecnico of Torino, one of the largest engineering school in Italy. The room lies in a building structure built in the early fifties, and it has been recently equipped with a CO_2–controlled mechanical ventilation plant (DCV system) in order to provide a satisfactory IAQ.

This auditorium is one of the largest auditoria of the Polytechnic of Torino and it is widely employed during the first two-years classes. Sometimes it is also used as an exhibition hall for little concerts and shows. The enclosure was included in the annex 26 case-study buildings in order to verify analysis tools and measurement techniques.

The auditorium was selected as annex 26 building especially to test CFD-calculations and to point out qualities of different measurement procedures used to evaluate ventilation plant performances. An experimental campaign was developed, mainly using tracer gas techniques. The measured parameters were compared with the predicted ones; the theoretical results were obtained using both commercial CFD codes and simplified engineering models.

20.1.1 Site and location

Building Address:
Polytechnic Auditorium
C.so Duca degli Abruzzi n 24
10129 TORINO
ITALY
+9-11-5646666
Torino
Italy

Latitude:
45 deg 11 min
Altitude:
282 m

20.1.2 Building form

Dimensions of the enclosure:
21.8 m x 16 m x 5.5 m
Volume:
1750 m^3

Description of building type The Auditorium has a capacity of about 350 seats arranged along 17 rows divided in two groups by a longitudinal main passage. The room has a step-wise floor sloping down from the main entry to the teachers desk. All the mural boundary surfaces are made of brick. The ceiling is arranged following large steps and, with a small portion of the two lateral walls, is the only boundary surface that is directly connected to the outdoor. All the other walls divide the auditorium from other confined spaces such as corridors, other auditoria and technical rooms. A total of ten windows, covered by heavy curtains, are placed in the upper part of the two lateral walls.

20.1.3 Building services

Degree of Conditioning:
heat and cool only
Heat transfer medium:
30 kW
Internal temperature:

Winter	**Summer**
20 °C	variable

Internal relative humidity:
not controlled

Type of Ventilation The ventilation system is mechanical and it is a constant air flow rate with a CO_2-controlled recirculation rate (DCV system). During the winter time, when necessary, the supply air is heated by means of hot water (80 °C); an enthalpie heat recovery unit allows some energy savings and also performs a certain degree of humidification of the inlet air. During the summer time the supply air is cooled by means of well-water, and, since its temperature is constant at about 15 °C, the control of the thermo-hygrometric conditions of the air is limited in range. Two series of filters ensure a solid particle uptake.

Additional details of ducted system The ventilation and air conditioning system is placed in a technical room below the auditorium; the air treatment is centralized. There are two fans, one for the supply air and one for the exhaust air, that generates a balanced and constant volume flow rate . A system of conjugate dampers allows the adjustment of the recirculation rate. The recirculation control is based on the occupancy load, i. e. measuring the CO_2 content with a sensor located in the exhaust duct.

External Temperature:

Fresh air supply ventilation rate:
variable depending on CO_2 content (10400 m^3/h maximum nominal, design, value)
Total air change ventilation rate:
about 6 ach.

Location of the supply and extract grilles The supply air is distributed by means of 8 circular inlet grilles located about 1 meter below the ceiling. These diffusers are of the variable geometry type, with 6 helicoidal blades generating a turbulent flow. The jet shape (i.e. penetration length, opening angle, swirl...) is set changing the angle of attack of the blades; its regulation is based on the temperature difference between the supply air and the exhaust air. The polluted air is exhausted by two grilles located in the lower part of the auditorium, sideways the teachers desk.

Control strategy It is a simple single zone control system.

20.2 Performance of the Building

20.2.1 Energy performance

Methods of measurement energy The Energy balance of the enclosure was evaluated measuring inlet and outlet air temperature and flow rate.

Energy consumption of the enclosure
Heating: $1\,170\,MJ/(a\,m^2)$
Used area of the enclosure: $155\,m^2$

20.2.2 Ventilation performance

Air supply rates:
With cleaned and new air filters, an average supply air flow rate of 10700±900 m^3/h was measured without recirculation.
Temperatures in the supply and exhaust ducts:
Variable with occupancy load and meteorological conditions

Methods of measurement ventilation With certain air recirculation, an average value of 9735±800 m^3/h was found. The performances of the system however decrease over the time, and with exhausted air filters the supply air flow rate rednces to 5050±740 m^3/h (without recirculation) and the balance between exhaust and supply air lacks (exhaust air flow rate: 6950±700 m^3/h). Tracer gas techniques (step-down, Step-np, constant emission, pulse)

Ventilation data
Supplied air: $18.6\,dm^3/(s\,m^2)$
Supplied air per person: $8.3\,dm^3/s$

Comfort data
Zones: Single
Draft problems: Sometimes
Draft problems arise when the diffuser blades generate a jet with a small opening angel.

20.2.3 Performance of the applied design or analysis tools

Performance of applied tools compared to the results of measurements Analysis performed with simple lumped parameter model, used to predict the concentration history of CO_2 has shown good performances , but the knowledge of the overall ventilation efficiency is required. Some simulations performed with CFD codes have shown the ability in predicting the fluodynamic and concentrations fields. Some care must be taken in order to achieve reliable results; freqnently concentration of pollutants are underextimated. Prediction of ventilation indices (that are normalize with respect to a reference concentration) shows better results.

20.3 Recommendations

Experiences with the building Simple lumped-parameter models have shown to be easy to use, quick to develop and quite reliable, but the information they give are limited. In the field models a great number of discretization elements is needed, therefore large computational time and memory capacity are required for the simulation. Qualitative predictions are, usually, rather promising, but the reliability of quantitative results, specially for pollutant concentrations, require the accurate optimization of the numerical model. Frequentely predicted pollutant concetrations are under-extimated. For what concerns measurement tools, experimental tracer gas techniques is rather effective in characterising large enclosures. One of the most critical factor is the coarse spatial "definition" of the results. A comparison between the different methods has pointed out that the step-down method seems to show a better reliability.

Recommendations for design measurement Particular care should be taken in implementing and solving the models with CFD techniques; critical points are the near wall regions, the simulation of human occupancy and the complete and correct knowledge of the boundary conditions. Simple lumped-parameter models show quite good performances, but their use, frequentely, require empirical parameters, and hence they should only be applied to first attempt analysis. When only global values of ventilation indices are required, measurements can be easily and quickly performed at the plant site.

20.4 References

Reference to detailed Annex reports:	*"Demonstration of Tools on Case Study Buildings"* - Analysis Tools Report - Annex 26.
Annex Contact Name:	Gian Vincenzo Fracastoro
Investigator:	Marco Perino
Other references to publications:	*"Preliminary Analysis of IAQ in a University Auditorium"* - **G.V. Fracastoro, M. Perino** - forum presentation - Annex 26 expert meeting Poitier - France. *"Analisi teorico-sperimentale della qualita dell aria in un' aula universitaria"* - **G.V. Fracastoro - M. Perino**

21 Queens Building

21.1 Building Description

Building type:
Offices, classrooms, laboratories, lecture theatres

Owner:
De Montfort University
The Gateway, Leicester, LE1 9BH, U.K.
+44-166-2551551

Year of completion:
1993

Project Costs:
8,000,000 pounds (UK)

Monitoring Agent:
De Montfort University

Design Team:
Short Ford Associates; Max Fordham Associates

The Queens Building at De Montfort University, Leicester is a three storey building housing the Department of Mechanical and Manufacturing Engineering and contains lecture theatres, classrooms, laboratories and offices. Almost all of the building is naturally ventilated; this is facilitated by the use of large chimneys or stacks which use the greater buoyancy of the indoor air to "pull" fresh air through openings in the facades into the building. Warmer, "stale" air is then discharged via the chimney exits. Extensive use is made of daylighting using skylights.

The building serves as the Department of Mechanical and Manufacturing Engineering, De Montfort University and is used for the delivery of lectures, and for laboratory instruction. It also houses research teams working in various areas such as image processing and also contains staff accomodation.

Most of the building is naturally ventilated. Tall stacks (up to 23.5 m high) are used to facilitate stack driven ventilation. Laboratories located on either side of the entrance are cross ventilated and can draw air from a cooler shaded courtyard area. The school contains two lecture theatres which have self-contained natural ventilation systems. In spite of very high heat gains (up to 100 W/m^2) comfortable conditions can be maintained in the spaces. Each auditorium is connected to 18.5 m high stacks. Extensive use is made of natural lighting via skylights. A combined heat and power unit is used as a lead "boiler" in the heatingcircuit. Additional heat is provided by two condensing boilers.

21.1.1 Site and location

Building Address:
De Montfort University,
The Gateway, Leicester, LE1 9BH,
UK

Latitude:
52 30'

Monthly total of Degree Days:
approx. 208

Description of the surrounding area The building is located in a city centre site beside a lighly used road.

21.1.2 Building form

Dimensionsof the enclosure:
12.6 m x 20.7 m (max) x 5.9 m (room); 18.5 m (stacks)
Dimensions Case Space Volume:
870 m^3 (room only); 1055 m^3 (room, stacks plus underfloor void)

Description of building type The building contains open plan offices, laboratories and lecture theatres (which have self contained natural ventilation systems).

21.1.3 Building services

Degree of Conditioning:
None.
Total heat load:
Summer:
17.8 kW
Heat transfer medium:
Air, water (heating)
Internal temperature
Summer:
27 °C
Winter:
21 °C

External Temperature:

Winter	Summer
-3 °C	27 °C

Fresh air supply ventilation rate:
Actual: 0.9 to 8.8 m^3/s;
design: 1.5 m^3/s.
Total air change ventilation rate:
Actual: 0.9 to 8.8 m^3/s;
design: 1.5 m^3/s.

Type of Ventilation The lecture theatre is naturally ventilated. A large stack height and the temperature difference between inside and outside is used to generate large enough pressure differences between inlets and outlets to drive air through the space.

Additional details of ducted system Outside air enters adjacent to a lightly used road into three plenums via modulated control dampers. It disperses within voids underneath the seating and enters the room via vertical grilles positioned at ankle height. Air leaves the space via two large openings near the base of two stacks (the height of each stack above ground level is 18.5 m). The effective crossectional area of each stack is 2.4 m^2 (width 3.5 m, breadth 1.5 m).

Location of the supply and extract grilles Supply grilles are positioned under the seats adjacent to heating coils at ankle height. The extracts are located at the top of the stacks.

Control strategy During an occupied period, if the average internal temperature exceeds a set point (i.e. 19 °C) the inlets and outlets will open, if the internal temperature is greater than the outside temperature. Otherwise the openings will close to minimum positions which are determined by the carbon dioxide sensor in the room (located in one of the stacks); i.e. 10% open with a CO_2 concentration of 350 ppm and 100% open when the CO_2 concentration is equal to or greater than 1,000 ppm. A mixing valve plus actuator varies the flowrate to the heating circuit and is controlled using the average room temperature.The fans (one in each theatre) are started if the average internal temperature is 3 °C above the room set point and greater than the external temperature plus 2 °C (provided the inlets/outlets are open and if it is not raining). When the space is unoccupied, in winter the openings close, and in summer they open at night to precool the room to a set temperature (summer is assumed to occur when the minimum outside temperature is greater than 13 °C; based on temperatures recorded for the previous 24 hours). In the event of a fire, the room inlets and stack outlets fully open and the extract fan is switched on. External air (not internal) humidity is monitored and recorded, but is not used by the control system.

Specific features Tall stacks are used to promote natural ventilation. The bnilding is "heavyweight" and has large areas of exposed surfaces (providing significant radiant cooling). Surfaces are precooled at night via night venting. The ventsare opened when the building is unoccupied in summer when the external airtemperature is less than the internal air temperature.

21.2 Performance of the Building

21.2.1 Energy performance

Methods of measurement energy The total building energy demand is monitored; the lecture theatre energy usage can be estimated from these figures.

Energy consumption of the enclosure
Heating and hot water consumption: $143\,kJ/(a\,m^2)$
Used area of the enclosure: $187\,m^2$
Separate areas in the building are not metered individual. The above figure is based on the usage of the entire building (August 1994 to July 1995).

21.2.2 Ventilation performance

Air supply rates:
Actual: 0.9 to 8.8 m^3/s;
design: 1.5 m^3/s.
Temperatures in the supply and exhaust ducts:
Summer:
c. 21 to 34 °C;
c. 23 to 26 °C
Winter:
c. -4 to 5 °C;
c. 21 to 23 °C

Methods of measurement ventilation Tracer gas decay (SF6 gas is used; velocity measurement in the stacks.

Ventilation data
Supplied air: 4.3 *to* 45.5 $dm^3/(s\,m^2)$
Supplied air per person: 5.3 *to* 56.7 dm^3/s (vents full open)

Flowrates are highly variable and depend upon:

I Inside/outside temperature difference

II wind speed and direction

III effective opening area

Comfort data
Zones:
seating position (left hand side/right hand side; facing the front of the theatre)
lecture standing position; high level.

Draft problems: Sometimes.

RHS seating positions: potential draft risk in winter and mid-season (external temperatures less than or equal to about 10 °C) in areas adjacent to external inlet openings.
Lecture position: Cold downdrafts can occur from one stack in winter and mid-season when stack outlets are begining to close.

21.3 Recommendations

Experiences with the building Conditions in the space during "summer" (minimum external temperature greater than 13 °C)

1. Stable room air temperatures (20 to 23 °C) and ceiling slab temperatures (22 to 24 °C).
2. Apparent effectiveness of pre-cooling of exposed brick and concrete surfaces.
3. Low room air velocities.
4. Much higher room air velocities were recorded on the right hand side than on the left hand side.
5. High wind induced ventilation rates.

Conditions found during "winter" runs (average external temperatures less than 5 °C)

1. High temperature differences (i.e. c. (21-6) or 15 °C) produced large flowrates;
2. Very low inlet air temperatures were recorded."Mid-season" conditions (average external temperature equal to c. 10 °C)

Points (1) and (2) above (for winter runs) were also applicable assuming an average internal temperature of about 21 °C and an outside temperature of c. 10 °C. Very good agreement was reached between flowrates measured using stack mounted velocity probes

Experiences summary Ventilation rates were driven by both 'stack' and wind Air speeds in the occupied zone, away from the inlets under the seats, were low. Thermal mass had a dominant effect, with internal temperatures remain stable and invariably cooler than outside in summer. Ventilation distribution was uneven in the occupied space (due to the uueven layout of inlets in the underfloor supply plenum).

Recommendations for desing measurement

1. Ensure that sufficient and appropriate sensing equipment is inserted when the building is being constructed (as part of a building management system).
2. Carry out periodic recalibrations of sensors and associated equipment (hence there should be a routine procedure for gaining access to high-level areas; the methods used may coincide with those used by the building maintenance personnel).
3. Isolate the area(s) under examination so that uncontrollable influences are minimised (i.e. lock access doors) such that ventilation areas are fully under the operators control.

Recommendations summary

1. At the design stage, the effects of both wind and temperature difference should be considered.
2. The inlets and outlets should be positioned symmetrically about the room ceutre line. Alteruatively it should be possible to vary the areas of inlet grilles.

21.4 References

Reference to detailed Annex reports: Chapter 4.2, *Analysis Tools Report.*

Annex Contact Name: Eoin M. Clancy, Andrew Howarth.

Annex Contact Institution:	De Montfort University, Coventry University.
Annex Contact Address:	Institute of Energy and Sustainable Development, De Montfort University, The Gateway, Leicester LE1 9BH, UK; School of the Built Environment, Coventry University, Priory Street, Coventry, CV1 5FB, UK.
Annex Contact City:	Leicester, Coventry
Annex Contact Country:	U.K.
Annex Contact Tel:	+44-116-2577417; +44-1203-838299
Annex Contact Fax:	+44-116-2577449; +44-1203-838485

Other references to publications:

Eppell H, Mardaljevic, J, Lomas, K L, *Computer Simulation for low energy building design*, ECADAP Group, School of the Built Environment, De Montfort University, Leicester, 1993.

Lane-Serff G. F., Linden P F, Parker, D J and Smeed, D A, *Laboratory modelling of natural ventilation via chimneys*, Proceedings of PLEA 91 Conference, Sevilla, 1991.

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Stevens, Bart, *A testing time for natural ventilation*, Building Services (CIBSE Journal), November 1994, pp. 51-52.

Webb, Robert, *Offices that breathe*, New Scientist, 11 June 1994, pp. 38-41.

Architecture Today, no. 41, Sept. 1993.

Clancy, E. M. and Howarth, A. T., *Measurement of Environmental Conditions in a Naturally Ventilated Lecture Theatre*, IEA Annex 26, 5th Expert Meeting, Leamington-Spa, October 1994.

Clancy, E. M. and Howarth, A. T., Walker, R., *Assessing Environmental Conditions in a Naturally Ventilated Lecture Theatre*, European Conference on Energy Performance and Indoor Climate in Buildings, Lyon, France, 24-26 November 1994.

Clancy, E. M. and Howarth, A. T., *Measurement of Environmental Conditions in a Naturally Ventilated Lecture Theatre, Development of Passive Buildings -Future or Folly?*; Seminar at the Institution of Mechanical Engineers , 15 December 1994.

Clancy, E. M. and Howarth, A. T., *Measurement of Environmental Conditions in a Naturally Ventilated Lecture Theatre*, IEA Annex 26, 6th Expert Meeting, Room, Italy, April 1995.

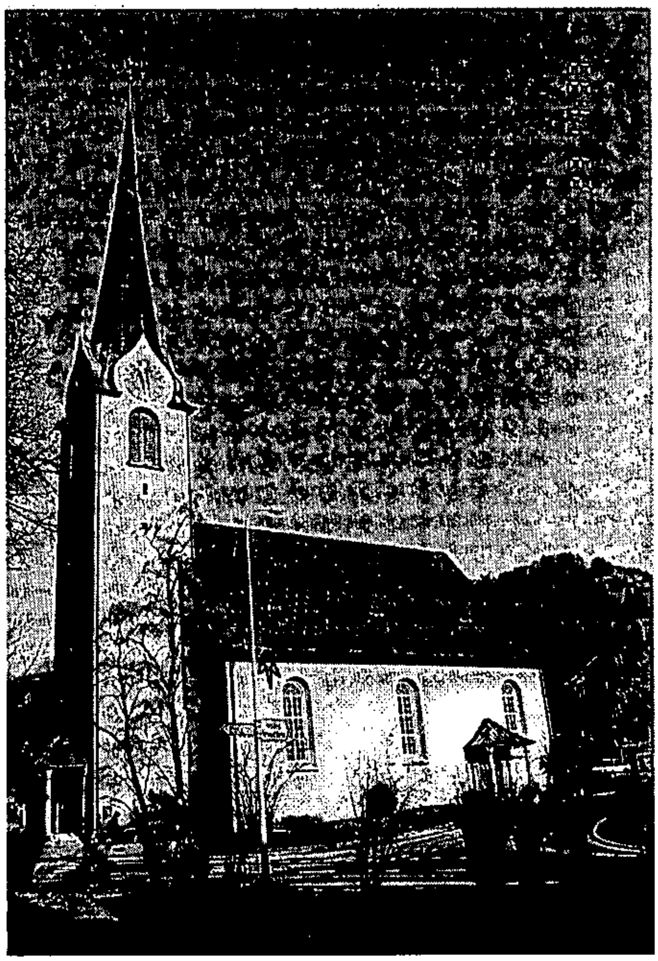
Part V

Others

22 Evangelische Kirche Ebnat

22.1 Building Description

Building type:
Country Church



Owner:
Evang. Kirchgemeinde Ebnat-Kappel
Alfred Moergeli,
President of the Parish Council
Buechel
CH-9642 Ebnat-Kappel
Switzerland
+41 74 31 935

Year of completion:
1762

Design Team:
Hans-Ueli Grubenmann

Because of several building problems like wet walls and a leaky roof, the church of Ebnat had to be renovated. There were also complaints about cold down drafts near walls and about overheating in the benches. Before a new control system for the electrical bench heaters was installed, the energy efficiency and the thermal comfort was therefore investigated.

The church is used for the service every two weeks in alternation with the other church of the town.

Because the building is not used permanently, the heating strategy has to be a compromise between energy saving and preventing humidity damages. Before renovation the air temperature was kept to a base temperature of +10 °C between occupation times, during occupation it was raised very rapidly to a temperature of +16 °C. The bench heating rods warmed up mainly the air causing large air movements, while the walls having a huge thermal mass remained cold.

22.1.1 Site and location

Building Address:
Evang. Kirche,
CH-9642 Ebnat-Kappel
Ebnat-Kappel
Switzerland

Latitude:
47 degree
Altitude:
640 m

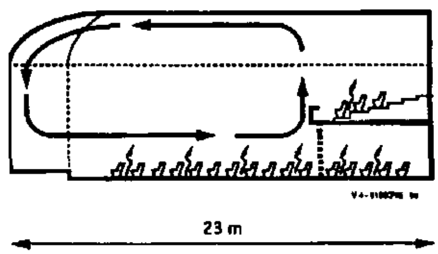
Description of the surrounding area Ebnat is situated in a valley running in east/west direction. The hills forming the valley are rising to an altitude of 1400 m.

22.1.2 Building form

Dimensions of the enclosure:
23 m x 12 m x 9 m
Volume:
2100 m^3

Description of building type The walls having a thickness of

Main air circulation showed in the longitudinal section



1 m, were made of natural stones and mortar without any thermal insulation, there were 9 tall windows. The arched ceiling is carried by a wooden construction. The interior, i.e. walls and ceiling, were covered with a plastering, which had cracks at several parts during the time of our investigation, but still looked reasonably airtight. The church was heated electrically by bench heaters.

22.1.3 Building services

Internal temperature
Winter:
+10 to +16 °C

Type of Ventilation
No ventilation system, i.e. ventilated by infiltration

22.2 Performance of the Building

22.2.1 Energy performance

Site deliverd energy:
319 $MJ/m^2/year$

Methods of measurement energy The heating energy consumption was measured by reading the eletricity meter.

22.2.2 Ventilation performance

Methods of measurement ventilation The air flow pattern was visualized with the help of a fog machine. The natural air change was measured with a tracer gas system using the method of constant concentration with several dosing and sampling points placed in the room according to the air flow pattern.

22.3 Recommendations

Experiences with the building The flow visualization revealed an air circulation covering the whole space between the front wall and the gallery in the back of the church, see figure main air circulation. Accordingly the temperatures measured were homogeneous. Thermal comfort was not so much affected by down streams and radiation of cold walls as expected. The infiltration rate measured in winter time, averaged to 0.04 per hour during a week. This was very low and therefore the energy loss by infiltration was small compared to the transmission loss through the walls.

22.4 References

Other references to publications:	*Air flow and comfort measurements in churches*, **T. Rüegg e.a.**, contribution to the Roomvent 94 conference in Cracow Poland 15.-17. June 1994, conf. proceedings vol. 2, p. 455 - 468
Investigator:	Thomas Rüegg EMPA - 175 CH-8600 Dübendorf Tel.: 01-823-4789

23 Galleria Vittorio Emanuele

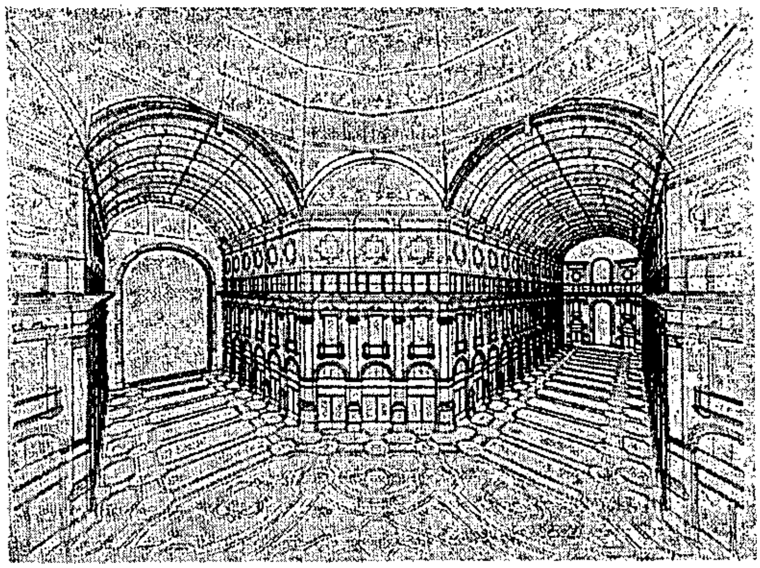
23.1 Building Description

Building type:
Shopping Center, Historical Building

Owner:
Comune di Milano
Ripartizione Demanio e Patrimonio
Comune di Milano
Via Larga 12
I-20122 Milano
Italy
+39 2 6236 .

Year of completion:
19th century

Design Team:
Arch. Mengoni



Galleria Vittorio Emanuele is a covered area in the centre of Milan. In the Galleria there are shops, bars, restaurants, and offices. Its the most popular meeting point of the city.

The building is naturally ventilated.

23.1.1 Site and location

Building Address:
Piazza del Duomo, Milano
Milan
Italy
Latitude:
45 27 '
Altitude:
122 m

Description of the surrounding area

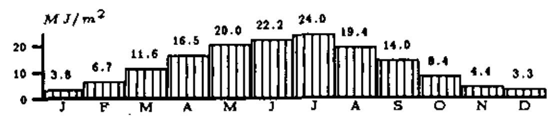


Figure 23.1: Monthly Mean Solar Irradiance

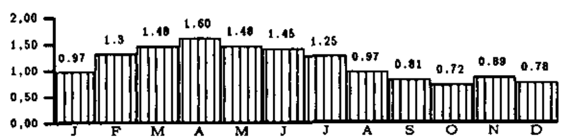


Figure 23.2: Monthly Mean Wind Velocity

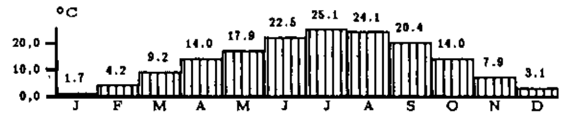


Figure 23.3: Monthly Mean Air Temperature

The Galleria is located in the centre of Milan, the largest city of northern Italy. Private cars are not allowed in the neighbourhood of the building. The Galleria connect Piazza della Scala with Piazza Duomo, and Via S. Pellico with via U. Foscolo. The most important commercial, political, religious and business buildings of Milan are located in proximity of Galleria Vittorio Emanuele.

23.1.2 Building form

Dimensions of the enclosure:
196 m
(Piazza della Scala - Piazza Duomo)
105 m
(Via S. Pellico - Via U. Foscolo)
x 14.4 m (wings) 42.0 m (octagon)
x 30.0 m (wings) 46.0 m (octagon)
Volume:
total 121570.88 m^3

Description of building type Galleria Vittorio Emanuele is a cross plan building: it consist of four orthogonal wings which intersect themselves in a central octagon. The four wings are fully open at their external ends. Building has a ground coverage of 3824 m^2. The structure of buildings faced on the Galleria consists of different thickness bricks walls, covered by plaster or gypsum. Heat plant of these buildings consists of two boilers of 2900 kW.

23.1.3 Building services

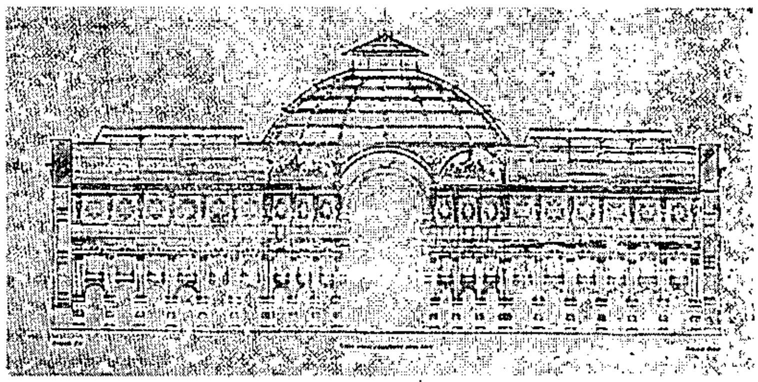
Heat transfer medium:
5.81 w/m^2 °C glasses
Internal temperature:
Winter: **Summer:**
7.5 °C 24.3 °C
Internal relative humidity:
64%

Type of Ventilation Natural Ventilation is performed by openings at the ends and at the top of wings and at the top of cupola wich cover the octagon.

Specific features The roofing of Galleria is made of glasses supported by iron load bearing frames. A truss structure closes the vaults of four wings and of the cupola, leaving leaks along all the wings and at the top of the cupola.

23.1.4 Ventilation performance

Methods of measurement ventilation Hot wire sensors were located at different positions and heights: in centre of the octagon at 11.1, 19.7, 32.0 and 43.2 meters in Foscolo wing (near end) at 15.0, 22.0 and 29.0 meters in Foscolo wing (near wall) at 4.5, 15.0 and 22.0 meters



23.2 Recommendations

Experiences with the building The microclimate of the Galleria Vittorio Emanuele was studied by mean of a fixed monitoring system. The aim of this research was to characterize how the external conditions (air temperature, wind speed, solar radiation) influence the thermal stratification and natural ventilation inside the Galleria. More than one year and a half of data were collected. The influence of wind and solar radiation on thermal stratification was investigated.

Experiences summary No chimney effect was observed. Highest values of air velocity were observed at low levels

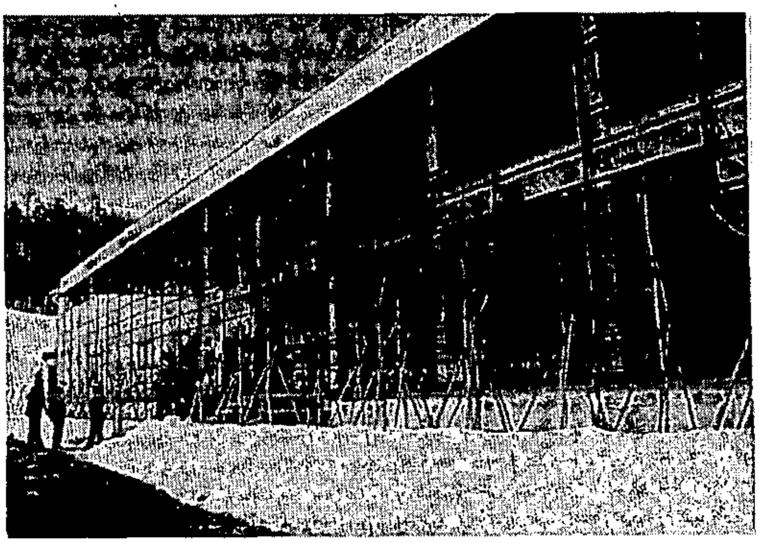
23.3 References

Annex Contact Name:	Marco Citterio
Annex Contact Institution:	ENEA
Annex Contact Address:	Via Anguillarese 301
Annex Contact City:	I-00060 S. Maria di Galeria - Roma
Annex Contact Tel:	+39 6 3048 3703
Annex Contact Fax::	+39 6 3048 6315

24 IDIC Long open Office Building JP 15

24.1 Building Description

Building type:
Two-storied ferro-concrete structure



Owner:
PS Co., Ltd.
Takehisa M. Hirayama,
Marketing Manager
Takaido-nishi 3-5-10 Suginami-ku
Tokyo 168
Japan
+81-3-3335-5154
+81-3-3335-1125

Year of completion:
1992

Monitoring Agent:
Laboratory of Building Environmental Engineering, Department of Architecture, Tohoku University

Design Team:
Andrea Hikone

"Ecologically Aware Construction" has been one of the basic design principles at IDIC. This building is a research center gathering and disseminating information about the climatic control needs in the Honshu island, combined with facilities for production of systems to meet these needs.

IDIC is a center for the promotion of information exchange. It also accommodates an office space, research facility, seminar space, and a production plant for heating radiator units and HOS air duct heating units.

The building is a long office building of east-west orientation and consists of the following features :

- Convectors with water for space heating and cooling
- External insulation
- Double glazing

The ventilation system is a kind of longitudinal displacement ventilation.

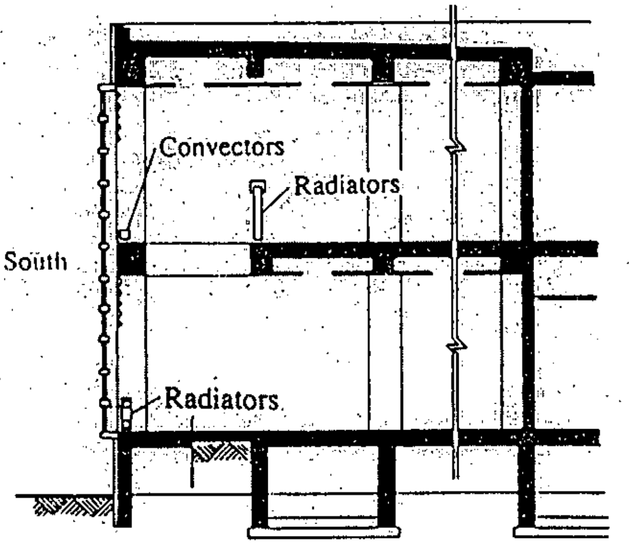
24.1.1 Site and location

Building Address:
Oaza Noda Onishimizu
Matsuo-mura, Iwate Prefecture
Japan

Latitude:
39 57
Altitude:
373 m

Monthly Mean Solar Irradiance:
0.8 kWh/m^2day during June to Sep.93
Monthly mean air temperature:
18 °C during June to Sep. 93, and
0.25 °C during Nov. 93 to Feb. 94

Description of the surrounding area IDIC is located at the foot of the Hachimantai Plateau in the village of Matsuo. The glass facade of a continuous atrium connecting the office and meeting spaces on both the floors provides the view of surrounding forest and sky on the south, and through the trees to the distinctively majestic volcanic cone of Mt. Iwate in the distance.



24.1.2 Building form

Dimensions of the enclosure:
57.6 m x 9.6 m x 6.6 m
Volume:
3700 m^3

Description of building type

This is a two-storied building made of ferro-concrete. It has a ground coverage of 1404 m^2 and total floor area of 1863 m^2, on a land area of 25,000 m^2. The building is a long office building of east-west orientation, dominated by horizontal geometry.

24.1.3 Building services

Degree of Conditioning:
Usually, the dampers in the supply air ducts are kept half open.
Heat transfer medium:
All water system
Internal temperature
Summer:
Around 20 °C, within the range of 18 to 25 °C, during Jun.93 to Sep.93
Winter:
Around 20 °C, within the range of 16 to 24 °C, during Nov.93 to Feb.94
Internal relative humidity:
Around 55%, within the range of 40 to 60%, during Nov.93 to Feb.94

Fresh air supply ventilation rate:
4,837 m^3 in ordinary case (dampers half open)
Total air change ventilation rate:
1.2 times air change per hour in ordinary case (dampers half open)

Type of Ventilation This is a kind of longitudinal displacement ventilation. The design value of outdoor air intake is 6000 m^3/h, which is 1.4 air change per hour.

Location of the supply and extract grilles Supply grills are located on the east, at the working area and hall space. Exhaust grills are located at west wall, dressing room, two lavatories and the kitchen space.

Control strategy Single zone system

Specific features This is a kind of longitudinal displacement ventilation. The design value of outdoor air intake is 6000 m^3/h, which is 1.4 air change per hour. Supply grills are located on the east, at the working area and hall space. Exhaust grills are located at west wall, dressing room, two lavatories and the kitchen space. Outdoor air is taken from the roof through two routes is distributed to the working area from nozzles connected to supply duct, and hall space from punched boards of the supply chamber in the east wall. On the other hand, indoor air is exhausted through five routes from the outlets of west wall, dressing room, two lavatories and the kitchen space.

24.2 Performance of the Building

24.2.1 Energy performance

Site deliverd energy:
Electrical energy delivered to the building is 371.7 MWh in one year.

Methods of measurement energy To evaluate the performance of energy conservation, indoor thermal environment is measured for the following items : Temperature and humidity, Energy consumption, Vertical temperature distribution during heating and cooling season, Air tightness.

Energy consumption of the enclosure
Heating: $160\,MJ/(a\,m^2)$
Cooling: $33\,MJ/(a\,m^2)$
Used floor area of the enclosure: $1\,071\,m^2$
Comment: Energy consumption of the enclosure is estimated from electricity consumption (only energy source).

24.2.2 Ventilation performance

Air supply rates:
4,837 m^3/h
Temperatures in the supply and exhaust ducts:
During the summer, max. 30 °C, min. 15 °C and avg. 23 °C, and During the winter, max. 25 °C, min. 5 °C and avg. 18 °C, in the supply duct.

Methods of measurement ventilation

To evaluate a type of longitudinal displacement ventilation installed in a long office space of east-west orientation, the measurement of airtightness of the building envelop, supply and exhaust airflow volume in the ducts, and age of air at various points are measured.

Ventilation data
Supplied air: $1.75\,dm^3/(s\,m^2)$
Supplied air per person: $8.5\,dm^3/s$
Comments: These values are calculated from measured supply air flow rate (taken under design condition) as follows:

1) Supplied air:

$$6729[m^3/h] \times 1000[dm^3/m^3] \times \frac{1}{3600}[h/s] \times \frac{1}{1071}[1/m^2]$$

2) Supplied air per person:

$$6729[m^3/h] \times 1000[dm^3/m^3] \times \frac{1}{3600}[h/s] \times \frac{1}{220}[1/person]$$

Comfort data
Zones: Office space
Draft problems: Sometimes
Comments: In winter season, cold draft occurs at night time (off hours).

24.3 Recommendations

Experiences summary The measurements provide evidence that the actual ventilation performance of investigated office spaces is almost the same as designed.

24.4 References

Reference to detailed Annex reports:
Conclusions

1. Due to measurement of supply and exhaust air flow volume, the total air flow volume at each air inlet and outlet is found nearly equal to that in the design stage.
2. Due to measurement of airtightness of building envelope, the equivalent leakage area per floor area is 0.9 cm^2/m^2 when the indoor - outdoor pressure difference is 10 Pa. It is found that this office space is extremely airtight.
3. Due to measurement of age of air, the values of age of air increase with the distance from the east wall. This increase reveals that the outdoor air flows from the east to west in the whole open space by means of the ventilation system.
4. In summary, the measurements provide evidence that the actual ventilation performance of investigated office space is almost the same as designed.

Annex Contact Name: Prof. Dr. Hiroshi Yoshino

Annex Contact Institution: Department of Architecture, Faculty of Engineering, Tohoku University

Annex Contact Address: Aramaki Aza Aoba, Aoba-kn

Annex Contact City:	Sendai 980-77
Annex Contact Country:	Japan
Annex Contact Tel:	+81 22 217 7883
Annex Contact Fax:	+81 22 217 7886
Other references to publications:	*Proceedings of Fourt International Conference of Air Distribution in Rooms*, Vol. 2, 6 (1994), 64-75 **Prof. Dr. H. Yoshino** Tohoku University, Sendai, Japan

Kartographie und Druck
Peter List
Viktoriastraße 18 · D-52066 Aachen
Telefon und Telefax 0241/512896

During Annex 26 “Energy-Efficient Ventilation of Large Enclosures” many research groups studied the performance of various types of large enclosures. To develop a better understanding of the ventilation situation in large enclosures, many different measurement techniques were applied to case study buildings. This book is part of the Annex 26 publications and it contains brief descriptions of most of the buildings examined by Annex 26 participants. The goal of this book is to provide the reader with an overview of the various building types including information about the building performances. For the sake of simplicity, the information about all the buildings have the same data structure.

Building Description
- -Building type
- -Site and location
- -Building form
- -Building services

Performance of the Building
- -Energy performance
- -Ventilation performance

Recommendations
References

Some of the mentioned enclosures serve as examples in the Annex 26 report “Analysis and Prediction Techniques”. That report includes more detailed information on the applied measurement techniques and the performance of the enclosure.

Additionally, the reader is invited to ask the contact person named in the reference section of each building for more information.

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Lehrstuhl für Wärmeübertragung und Klimatechnik
RWTH Aachen
Eilfschornsteinstraße 18
D-52056 Aachen
Germany

Tel: +49 241 80 5400
Fax: +49 241 8888 143
E-mail: www@wuek.rwth-aachen.de