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Technical Synthesis Report **Annex 35**

Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)

Energy Conservation in Buildings and Community Systems

35

Technical Synthesis Report Annex 35

Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)

Edited by Rajinder Jagpal

*Based on contributions from Australia, Belgium, Canada, China, Denmark, Finland, Germany
Greece, Italy, Japan, Norway, Sweden, The Netherlands, United Kingdom and USA*

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation for Building and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation. The objectives of collaborative work within the ECBCS R&D program are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified by (*)):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)
Annex 16:	BEMS 1- User Interfaces and System Integration (*)
Annex 17:	BEMS 2- Evaluation and Emulation Techniques (*)

- Annex 18: Demand Controlled Ventilation Systems (*)
- Annex 19: Low Slope Roof Systems (*)
- Annex 20: Air Flow Patterns within Buildings (*)
- Annex 21: Thermal Modelling (*)
- Annex 22: Energy Efficient Communities (*)
- Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
- Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
- Annex 25: Real time HEVAC Simulation (*)
- Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
- Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
- Annex 28: Low Energy Cooling Systems (*)
- Annex 29: Daylight in Buildings (*)
- Annex 30: Bringing Simulation to Application (*)
- Annex 31: Energy-Related Environmental Impact of Buildings (*)
- Annex 32: Integral Building Envelope Performance Assessment (*)
- Annex 33: Advanced Local Energy Planning (*)
- Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
- Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
- Annex 36: Retrofitting of Educational Buildings (*)
- Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
- Annex 38: Solar Sustainable Housing
- Annex 39: High Performance Insulation Systems (*)
- Annex 40: Building Commissioning to Improve Energy Performance (*)
- Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG)
- Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)
- Annex 43: Testing and Validation of Building Energy Simulation Tools
- Annex 44: Integrating Environmentally Responsive Elements in Buildings
- Annex 45: Energy Efficient Electric Lighting for Buildings
- Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
- Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings
- Annex 48: Heat Pumping and Reversible Air Conditioning
- Annex 49: Low Exergy Systems for High Performance Built Environments and Communities
- Annex 50: Prefabricated Systems for Low Energy / High Comfort Building Renewal
- Working Group - Energy Efficiency in Educational Buildings (*)
- Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
- Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

(*) - Completed

Annex 35: Control strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings.

This report contains a summary of the work of Annex 35, the formal duration of which was from 1998 to 2002. It is based mainly upon the final report of Annex 35, "Principles of Hybrid Ventilation".

Definition of Hybrid Ventilation

Hybrid Ventilation is a two-mode system which is controlled to minimise the energy consumption while maintaining acceptable indoor air quality and thermal comfort. The two modes refer to natural and mechanical driving forces.

Purpose of Ventilation

All hybrid systems have to provide air for indoor air quality purposes, but some in addition also provide air for thermal conditioning and thermal comfort during working hours.

Purpose of the Control System

The purpose of the control system is to establish the desired air flow rate and air flow pattern at the lowest energy consumption possible.

Objectives

The objectives of Annex 35 were:

- to develop control strategies for hybrid ventilation systems for new build and retrofit of office and educational buildings;
- to develop methods to predict hybrid ventilation performance in hybrid ventilated buildings;
- to promote energy and cost-effective hybrid ventilation systems in office and educational buildings;
- to select suitable measurement techniques for diagnostic purposes to be used in buildings with hybrid ventilation systems.

Subtasks

Annex 35 included three subtasks:

- Development of Control Strategies
- Development of Analysis Methods
- Pilot Studies

Participants: Australia, Belgium, Canada, China (Hong Kong), Denmark, Finland, France, Germany, Greece, Italy, Japan, Norway, Sweden, The Netherlands, United Kingdom, U.S.A.

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1 Introduction

Today's buildings should be designed to interact with the outdoor environment. When building design is integrated with the design of building services it may be possible to use the outdoor environment to create a comfortable indoor environment, with minimal energy use for ventilation, space heating or cooling.

More than half the energy used by a well-insulated office building can be spent on ventilation and cooling. This can be reduced drastically by well-controlled, energy efficient ventilation systems.

Using natural ventilation alone can sometimes have limitations and therefore the spread of this ventilation approach has been slow. When combined with mechanical ventilation, however, natural ventilation has enormous potential to provide acceptable internal comfort conditions in an energy efficient manner.

Definition of Hybrid Ventilation

The purpose of ventilation is to provide acceptable indoor air quality and thermal comfort.

Hybrid ventilation systems provide a comfortable internal environment using both natural ventilation and mechanical systems, but using different features of these systems at different times of the day or in different seasons.

Hybrid ventilation combines mechanical and natural forces in a two-mode system. The mode that is active reflects the external environment and takes maximum advantage of ambient conditions at any point in time.

A hybrid system, unlike a conventional system, has an intelligent control system that can switch automatically between natural and mechanical modes in order to minimise energy consumption.

In cold climates, the use of hybrid ventilation can avoid the current trend towards mechanical cooling triggered by factors such as higher occupant expectations, higher internal gains and changes in building design. In warm climates, hybrid ventilation can reduce the reliance on all year round air-conditioning.

As well as reduced energy use, hybrid systems can lead to improved productivity because users will have a greater degree of control over their environment in a building with openable windows and passive cooling.

Estimating the initial cost of hybrid ventilation is often made difficult by the fact that it combines mechanical installations and building elements. In hybrid systems, the balance of investment in these two elements tends to shift towards the building itself. The life cycle costs for buildings with hybrid ventilation tend to be lower than for traditional buildings, but the relationship between the initial, operating and maintenance costs is different.

Reference:

Van der Aa, A. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", Principles of hybrid ventilation CD, Technical Report 11, Aalborg University, Aalborg, Denmark.

1.1 Annex 35 background and objectives

The Annex 35 research programme started in 1998 and was completed in 2002. Sixteen countries contributed to the research – these were Australia, Belgium, Canada, China (Hong Kong), Denmark, Finland, France, Germany, Greece, Italy, Japan, Norway, Sweden, The Netherlands, United Kingdom, and U.S.A.

The objectives of Annex 35 were to:

- Develop control strategies for hybrid ventilation systems for new build and retrofit of office and educational buildings.
- Develop methods to predict ventilation performance in hybrid ventilated buildings.
- Promote energy-efficient and cost-effective hybrid ventilation systems in office and educational buildings.
- Select suitable measurement techniques for diagnostic purposes to be used in buildings with hybrid ventilation systems.

The research led to the following outputs:

- State-of-the-art review of hybrid ventilation technologies and of control strategies and algorithms. Assessment of potential for hybrid ventilation retrofit.
- Principles of Hybrid Ventilation, including solutions for energy-efficient and cost-effective hybrid ventilation.
- Control strategies for hybrid ventilation.
- Analysis tools for performance prediction of hybrid ventilation. Decision tools for hybrid ventilation applications.
- Refinement and recommendations of suitable measurement techniques for diagnostics and commissioning of hybrid ventilation systems.
- Demonstration of the principles through thirteen pilot studies.

2 Principles of hybrid ventilation

Three key approaches to hybrid ventilation approaches have been identified.

Natural and mechanical ventilation

This approach is based on two fully autonomous systems. The control strategy either switches between systems or runs both in parallel but for different tasks. An example is a system that uses natural ventilation in mid-season and mechanical ventilation in summer and/or winter. This approach is also used by a system which provides mechanical ventilation in occupied hours and natural ventilation for night cooling.

Fan-assisted natural ventilation

This approach uses natural ventilation combined with an extract or supply fan. During periods of peak demand or when the natural driving forces are reduced, pressure differences can be enhanced by fan assistance.

Stack and wind-assisted mechanical ventilation

In this approach a mechanical ventilation system optimises use of natural driving forces. It is used in systems with small pressure losses where natural driving forces can contribute significantly to the pressures needed.

2.1 Optimising ventilation

The design of a hybrid system needs to be optimised for indoor air quality (IAQ) and temperature control. In some climates it may be more important to optimise for one aspect over another. For example in warm climates, temperature control is likely to be important all year round. In cold climates the control of indoor air quality without compromising thermal comfort is likely to be important. In temperate climates, however, IAQ and temperature control will generally need to be considered.

Ventilation optimised for natural cooling requires a balance between cooling capacity, cooling load, thermal mass and thermal comfort.

- The flow rate needs to be higher than that for IAQ control.
- Avoid low temperatures at the start of the day. Also an acceptable temperature rise in occupied hours is needed for adequate thermal comfort.
- Reduce heat loads by using energy efficient equipment, daylight and effective solar shading.
- Exploit the thermal mass of the building to absorb and store heat in the day and be cooled during night ventilation.
- Allow window opening for improved occupant comfort and reduced fan energy. As the stack effect is limited during warm periods the system should be optimised for using the wind effect.
- In cold climates the natural mode will dominate for temperature control

Ventilation optimised for indoor air quality control should achieve an optimal balance between IAQ, thermal comfort, energy use and environmental impact during periods of heating and cooling.

- Minimise fresh air flow rates by avoiding internal pollution (i.e. controlling at source).
- Optimise demand control by occupants.
- Use heat recovery and/or passive heating/cooling to reduce heating and cooling demands.
- Reduce the need for fan energy by using low pressure components and optimising wind effect and stack effect driving forces.

Any hybrid system should also reduce the need for fan energy by using low-pressure components and optimising wind effect and stack effect driving forces. Ventilation should also be provided without creating draughts, high temperature gradients and noise.

The control strategy will determine when the mechanical mode is entered and when the system reverts to natural mode.

2.2 Components of hybrid systems

Hybrid systems draw on the components of the natural and mechanical systems of which they are composed. These can include:

- Low-pressure duct work
- Low pressure fans with advanced control mechanisms
- Low pressure static heat exchangers and air filters
- Wind towers, solar chimneys or atria for exhaust
- Underground ducts, culverts or plenums to pre-condition supply air.

Components allowing the control of thermal comfort and indoor air quality can include:

- Manually operated and/or motorised windows, vents or special openings in the façade and internal walls
- Room temperature, CO₂ and/or airflow sensors
- A control system with a weather station

Reference:

IEA ECBCS. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Case Studies, Aalborg University, Aalborg, Denmark.*

3 Design of hybrid systems

3.1 Integrated system and building design

Unlike mechanical ventilation systems, which can be easily retrofitted into buildings, natural ventilation systems need early integration into the building design. Natural ventilation requires openable windows, doors and other openings in the building façade; all of which must be designed into the building envelope. Natural ventilation can also be achieved by a simple ducted system with intakes and exhausts at different heights.

Hybrid ventilation is tailored to each building whereas mechanical ventilation systems can be purchased 'off-the-shelf'. The success of hybrid systems therefore depends on integrating design from the earliest stages of building design; the designer may need to spend more time in the early stages of a hybrid system than for designing conventional mechanical ventilation systems.

Quality control is an important consideration for system design: Section 6 has more information on this.

3.2 The design process

Design of hybrid ventilation systems will be most successful when a logical design process is followed and the design team is comprehensive. Building owners, users, architects, mechanical and electrical engineers, indoor climate and energy consultants will all need to be simultaneously involved.

3.2.1 Initial pre-design considerations

Prior to the ventilation design phase the initial considerations should be collected into a "Building Programme". This will typically include:

- Building functions - functionality, flexibility, PR-value, maintainability, expected lifetime.
- Architectural quality - identity, scale/proportion, integrity/coherence, integration in urban context.
- Economics - initial costs, operating costs, maintenance costs, property value outlook.
- Indoor environment with target values for different zones in the building, visual, thermal, atmospheric, acoustical, mechanical, psychosocial.
- Environmental issues - constructional resources, operational resources, energy use, ecological strain.

The Building Programme should be documented and the measurable target values used as a contract document for design and maintenance of the building.

Assessing the feasibility of hybrid ventilation

An initial assessment of the feasibility of hybrid, natural or mechanical ventilation can be made using Figure 1 below. The designer needs to input the basic conditions for the building in question. Against each condition, the tool indicates whether the possibility for using each mode is High, Medium or Low. The overall possibility of using natural driving forces can be modified by changes to the Building Programme – this may be an iterative process.

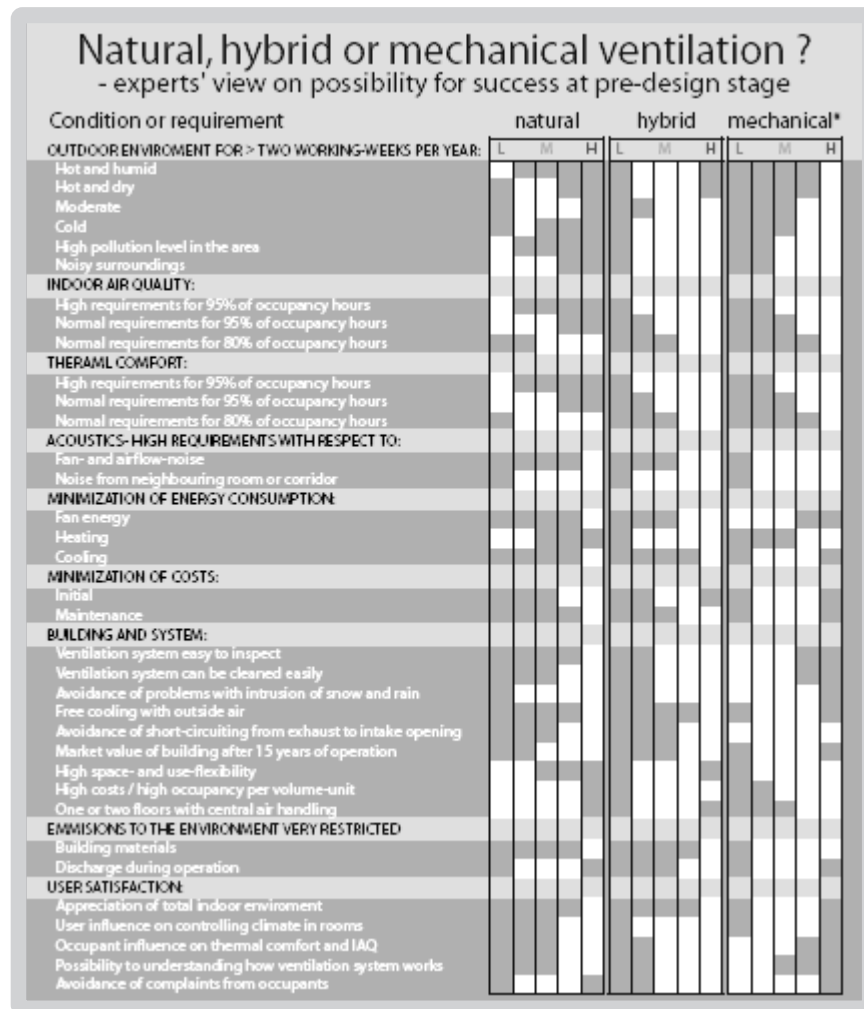


Figure 1: Initial evaluation of options for using pure natural ventilation, hybrid ventilation or balanced mechanical ventilation (with a pressure drop of >500 Pa on intake and exhaust side for the mechanical system)

Reference:

Fracastoro, G.V., Perino M. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", Principles of hybrid ventilation CD, Technical Report 21: A Simple Tool to Assess the Feasibility of Hybrid Ventilation Systems, Aalborg University, Aalborg, Denmark.

3.2.2 The ventilation design procedure:

The ventilation design procedure has four phases:

a) The conceptual design phase – includes decisions about:

- the building form, size, function and location. The ventilation designer will usually have minimal influence over these parameters.
- targets for indoor air quality, thermal comfort, energy use and cost.
- the combination of mechanical ventilation and natural ventilation principles to be used (stack and/or wind driven, single-sided and/or cross ventilation).

b) The basic design phase aims to:

- estimate building heat, solar and contaminant loads
- design hybrid ventilation system layout
- calculate required air flow rates and expected indoor air quality and temperature levels
- estimate annual energy use and peak power demands

This stage can be iterative; if the results do not meet the targets, the building and systems are re-designed before entering the detailed design phase.

c) The detailed design phase in this phase it is necessary to:

- re-evaluate contaminants, thermal loads and optimise source control.
- select types and location of hybrid ventilation components, control strategy and sensor location.
- optimise the system for indoor climate, energy use and cost through hourly calculations based on a design year.

d) The design evaluation phase checks if the design meets the targets by predicting indoor air quality and thermal comfort.

The design procedure for hybrid ventilation is outlined in Figure 2.

Targets

The challenge for designing a hybrid ventilation system is to find a solution that uses the natural mode as much as possible and uses the mechanical mode when the natural mode is inadequate or less energy efficient. The balance between time spent in each mode will depend on the type of hybrid system and control strategy, the local climate and running and maintenance costs. There will also be a strong dependence on the price and availability of energy and the dimensions of the natural 'components' of the system.

Targets are usually based on maximum threshold limits. If these are expressed too narrowly, mechanical ventilation is likely to be chosen even if natural ventilation could achieve the targets averaged over time. Some research also indicates that occupants appreciate some variation in the indoor climate.

Mechanical systems can provide constant flow in accordance with occupant's needs but a natural system will result in a wider range of air flow rates. The variability of natural driving forces (wind and temperature) may produce excessive air flows and at other times insufficient air flows.

Outside the heating or cooling season excessive flow rates can be exploited to reduce pollutant levels. High flow rates, however, may reduce thermal comfort. When natural flow rates are too low, the mechanical mode can supplement ventilation.

Environmental and cost considerations

The environmental impact of the system should be minimised by considering the energy demand in operation but also through a life cycle assessment of the wider environmental impact of all components. It is also important that the system design allows for possible changes in building use during its lifetime.

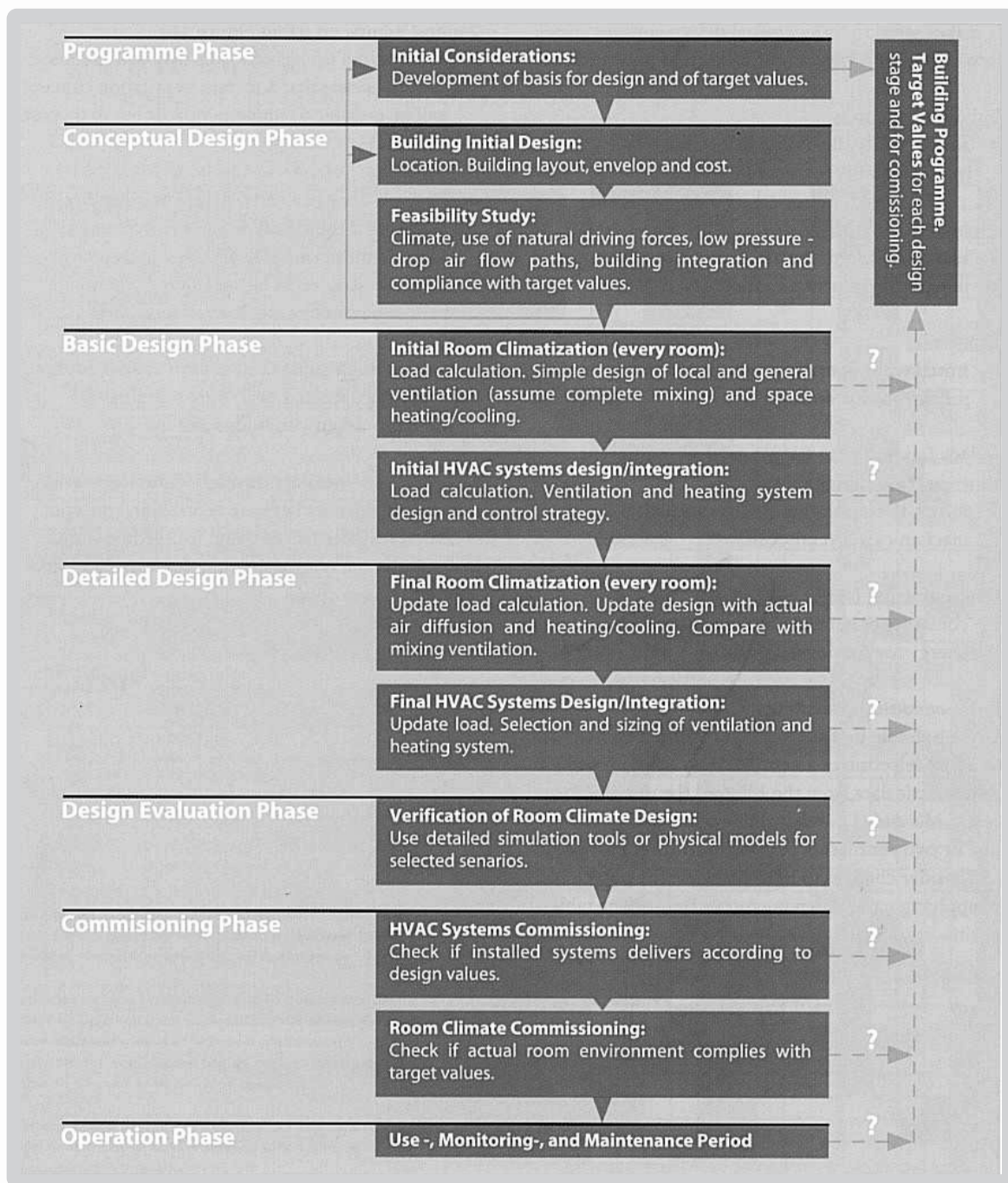


Figure 2: Design procedure for hybrid ventilation

Developing a concept

The integrated design of heating, cooling, lighting and ventilation of buildings can be accomplished in 3 steps:

- 1 Design of the building to minimise heat loss in winter; maximise heat gain in winter; minimise heat gain in summer; and use daylight and fresh air efficiently. At this stage the size of heating, cooling and lighting loads will be decided. The output from this stage is a building orientation, design and internal layout that minimises the thermal load during overheated periods and makes it possible to exploit the dominant driving forces to ventilate the building.
- 2 Climatic design, where decisions are made about the use of passive heating and cooling, natural cooling, day-lighting techniques and natural ventilation. The output from this stage is a design for the natural mode of the hybrid ventilation system including an appropriate control strategy.
- 3 Design of mechanical and electrical systems to handle the loads that /are minimised through the first two steps.

Table 1 can be used as a checklist to avoid some common pitfalls.

Avoid	Look out for
<ul style="list-style-type: none"> • Poor insulation and thermal bridges in building envelope. • Infiltration/exfiltration (Building tightness should be < 1 ach @ 50 Pa with all openings closed). • Pollution from interior building materials, from use of building, activities and from outdoor environment. • Solar heating of intake air when room cooling is needed. • Direct solar heating of occupants. • Noise transfer from outside and from other rooms of building. • Negative effects from wind and buoyancy. • Air velocities > 1 m/s in air flow paths and 1.5 m/s in components at design load. • Inefficient room ventilation. • Excess use of lighting, heating and ventilation. • Condensation or liquid water leading to mould growth in intake air flow paths and in rooms. • Air flow paths which do not allow easy inspection and cleaning. • Shutting down ventilation completely for periods. • Building design with little thermal mass exposed in intake air flow paths and in rooms. • Use of deep spaces and internal rooms. • Recirculation of exhaust air to the intake side. • Need for mechanical cooling/dehumidification below outdoor air level. 	<ul style="list-style-type: none"> • Availability of natural driving forces on construction site. • Minimize airflow rate for building while satisfying indoor target values. • Minimize pressure drops in ventilation air flow paths. • Possibility of using outdoor air without filtering. • Possibility of using direct airflow from/to outside without a noise, control, burglary, insect or rain problem. • Use large room volumes compared to buildings with mechanical ventilation. • Use large floor-to-ceiling height. • Use exposed thermal mass in the building structure. • Minimize need for ducting of ventilation air. • Minimize need for conditioning of ventilation air. • Use heat recovery in cold climates. • Use demand control. • Use air overflow between rooms either for supply or extract side of ventilation system. • Use a large height difference between ventilation intake and exhaust to maximize stack effect. • Install wind towers and vents that utilize wind (but prevent excess ventilation). • Incorporate basement and underground culverts to dampen outdoor temperature swings for natural cooling.

Table 1: Factors to look for and avoid when considering solutions for using natural ventilation.

Reference:

Wouters, P. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", Principles of hybrid ventilation CD, Technical Report 9: Performance assessment of advanced ventilation systems in the framework of energy and IAQ regulations, Aalborg University, Aalborg, Denmark.

4 Control strategies

In hybrid systems a strong interaction exists between the ventilation system and the control strategy. It is essential that design is integrated as many of the hybrid ventilation components are an integral part of the building. Close cooperation between the HVAC engineer and architect will be needed.

Individual control of windows should be maintained, as far as possible, even if it is at the expense of guaranteed indoor thermal comfort or air quality at a specific level. Research suggests that users are more tolerant of deviations in the indoor thermal climate if they are in control of it. Automatic control is needed to support user control to achieve a comfortable indoor environment and to control ventilation (and energy use) during unoccupied periods. Automatic control is particularly important for rooms with many occupants (such as meeting rooms, open plan offices) and pre-conditioning rooms for occupation.

Simplicity of the control strategy and user interface is essential as building users will frequently not be technically literate. Designers should aim for a system that responds rapidly and unobtrusively to the needs of users and is also easily understood by maintenance staff.

As a minimum the control strategy should include:

- A winter control strategy – indoor air quality will be the main parameter to control
- A summer control strategy – maximum room temperature is the main concern

A control strategy for the spring, where there may be occasional demand for heating or cooling, is also needed.

Hybrid ventilation can be used in cold temperate and warm temperate climates; in cold climates the control strategy should minimise the ventilation energy needed to achieve good IAQ and a good indoor climate in summer and spring without mechanical cooling. In warm climates the control strategy should focus on reducing the energy use for mechanical cooling in summer.

4.1 Control tasks

The control strategy should determine the time and rate of control as well as the mode in relation to weather conditions. It should also reflect the needs of the building owner, users and relevant regulation or standards.

- 1 IAQ in occupied hours** – can either be controlled manually, by simple timers, motion detection or direct measurement of IAQ. Perceived IAQ is higher for occupants already in the room than those entering the room. Usually the IAQ level is designed for the perceived level for people entering the room. CO₂ levels are a good indicator of IAQ if people are the only pollutant source. However, in some cases other pollutants from materials and activities will be significant.
- 2 IAQ during non-occupied hours** – will be needed to remove built up pollutants from occupancy, pollution from materials and cleaning and to precondition air for the next period of occupancy. This is particularly important in airtight buildings.
- 3 Room temperature during occupied hours in summer** – can be controlled manually or automatically. On hot summer days, the small difference in inside and outside air temperature may result in inadequate cooling even with high flow rates. Air movement stimulated by open windows can be an important factor in thermal comfort.
- 4 Solar shading** – external solar shading should be centrally controlled with an allowance for override by occupants in individual rooms. The central control will be based on solar radiation on the different building facades. Where the solar intensity varies considerably on the same

façade more than one control per façade will be needed. User controlled internal shading (such as blinds or curtains) may be appropriate to control glare.

- 5 Night ventilation in summer** – controlled night ventilation can improve thermal comfort during the day and reduce energy use from daytime mechanical cooling where this is installed. The building structure should be as cold as possible without causing discomfort to users in the morning. Normally control should be automatic and either central for the building or zoned for each room or areas of the building. Central control is based on the temperature of, carefully selected, representative rooms. Local control is usually used in large rooms with fan assistance.
- 6 Preheating of ventilation air** – may be needed to avoid sensations of draughts. Control of coils or radiators for preheating the supply air should, normally, be based on the temperature of inlet air.
- 7 Severe weather override** – override of normal controls may be needed in severe weather. Windows may need to be closed and solar shading rolled up. In frost, dampers or hatchers in front of preheating devices may need to be closed.
- 8 Room heating** – all rooms should have local control of heating. The control of supply water temperature should be central and weather compensated.
- 9 Room cooling** – in hybrid ventilation systems it is important to have a strategy which controls inlets and mechanical cooling with user-override built in. Users will need careful guidance on how to operate windows when cooling is on.
- 10 Fan assistance** – fans can be controlled by the temperature or IAQ in rooms; by the pressure in the supply or exhaust ducts; or by air flow through the fan. The fan control can be on/off, stepped or continuous. However, continuous control is difficult where the fan is in parallel to the natural ventilation flow path.
- 11 Alternating natural and mechanical cooling** – is controlled usually by external temperature or humidity.

4.2 Sensors

The control strategy will rely on temperature, IAQ and occupancy sensors as well as weather conditions. Tables 2 and 3 show the types of sensors that might be needed in a control strategy.

Table 2: Sensors in the building

Temperature	Ordinary room and duct temperature sensors are reliable and not expensive. Surface temperature sensors exist but is not so much experience with their use in control systems.
CO₂	CO ₂ is an IAQ indicator of body odour but is not harmful to people in the concentrations normally found in buildings. CO ₂ -sensors are quite expensive and need regular calibration, see “TR5 CO ₂ ”
VOC	VOC is an indicator of IAQ. There is little experience with the use of VOC -sensors. It is not clear what they are measuring and how to calibrate them.
PIR	Infrared presence sensors are reliable and not expensive. They are easy to test and can also be used for other purposes e.g. control of artificial light.
Air speed	Air speed sensors can be used to measure the airflow rate in ducts. Airspeed sensors are quite expensive and need regular cleaning and calibration.

External temperature	External temperature sensors are reliable and not expensive. The problem is often to find a position to install them where the temperature is not influenced by the building or solar radiation.
Wind	Traditionally wind speed is measured with a cup anemometer and wind direction is measured with a wind vane. A new type without moving parts is available where both speed and direction is measured by using Doppler effect in two directions.
Solar radiation	Solar radiation sensors do not need to be very accurate for control purposes. It is preferable to have a sensor on the upper part of each main facade.
Precipitation	Precipitation sensors are reliable and not expensive. They normally only need to produce an on/off signal for overrule purposes.

4.3 Developments in controls

There have been a number of advances in control technologies though some may need further refinement:

- **Integration of controls** for ventilation, heating, solar shading and lighting into one Building Management system is beneficial as it allows better coordination, makes operation easier and reduces the number of sensors needed.
- **Use of thermal comfort sensors** to measure operative temperature instead of air temperature. This approach recognises that there can be large temperature differences between the air and surfaces.
- **CO₂ sensors** – CO₂ is a good indicator of indoor air quality. Ideally an IAQ sensor should be located in each building zone. Effective demand control of IAQ can significantly increase the energy efficiency of a hybrid system.
- **Advanced control techniques** – require carefully optimised sensors and actuators and complex controls logic.

References:

Hendriksen, O.J. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 6: A sensor survey for hybrid ventilation control in buildings, Aalborg University, Aalborg, Denmark.*

Aggerholm, S. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 1: Hybrid ventilation and control strategies in the case studies, Aalborg University, Aalborg, Denmark.*

Mayer, E. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 7: Individual thermal comfort controlled by an "artificial skin" sensor, Aalborg University, Aalborg, Denmark.*

Van der Aa, A. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 5: CO₂ sensors for IAQ, Aalborg University, Aalborg, Denmark.*

Michel, P. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 4: Advanced control strategy, Aalborg University, Aalborg, Denmark.*

5 Predicting performance

The HVAC designer needs methods to assist, evaluate and optimise the design of hybrid buildings. For natural ventilation, in contrast to a mechanical system, neither the flow direction or the velocity at the openings is predetermined. The stack pressure is determined by the temperature difference between inside and outside, which in turn is affected by ventilation flow rates. The wind pressure is strongly affected by the building's microclimate.

Analysis methods for hybrid systems can be complex as they must be able to deal with mode switches (natural to mechanical) and model the control strategy.

A number of methods of varying complexity are available for analysing air flows and energy use in mechanical or natural systems. Some of these are outlined below:

Simple analytical and empirical methods

These can be applied to buildings with simple geometry. For example in single sided ventilation and one-zone buildings with two openings

Multi zone or network methods

Network methods can predict the overall ventilation rate for the whole building and individual flow rates through openings. Network methods can't predict detailed flow patterns in each zone of the building.

Zonal methods

The indoor air volume is split into several well-mixed 'macro-volumes' in which temperature and pollutant concentrations are assumed to be uniform. Equations for the driving flow elements (e.g. jets, plumes and boundary layer flows) can be applied to calculate mass flows between zones.

Computational Fluid Dynamics (CFD) methods

CFD methods are most suitable for analysing air movement within and around buildings. They also allow detailed analysis of air flow patterns, pollutant and temperature distributions within a space. However, a CFD simulation for annual performance of a hybrid system is very time consuming and beyond the capacity of most computers.

Each method has different applicability to each of the design stages.

Reference:

Author. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, State of the art of hybrid ventilation – a review of existing analysis tools*, Aalborg University, Aalborg, Denmark.

5.1 Developments in prediction methods

There have been a number of developments in methods for predicting whether natural ventilation will provide adequate ventilation. These range from simple rules of thumb to more complex interactive computer tools¹.

Method	Inputs/Applicability	Outputs
Vent sizing methods	<ul style="list-style-type: none"> • Building typology • Surrounding terrain • Test Reference Year (TRY) of the location 	<ul style="list-style-type: none"> • Permeability of the building envelope in order to satisfy the required air change rate. • Effective pressure difference across the envelope (as a function of outdoor-indoor temperature difference and wind velocity). • The fraction of time that the natural ventilation rate exceeds the required air change rate during the heating season - if the fraction is <1 the designer will need to either increase the envelope permeability using natural devices or calculate the amount of time mechanical ventilation will be needed.
Analytical solutions in simple buildings	<ul style="list-style-type: none"> • Indoor/outdoor air temperatures • Wind pressure • Flow rate from fans • Size of ventilation openings 	Solutions for different single-zone buildings with up to three openings and simple mixed mode ventilation systems (openings or openings and a fan).
Zonal methods, multi-zone methods and CFD	<ul style="list-style-type: none"> • Used to investigate the effect of thermal stratification on airflow 	Proper estimation of the building's neutral level
Combined thermal and airflow methods	<ul style="list-style-type: none"> • To predict annual performance of hybrid systems thermal and airflow modelling are combined. 	<ul style="list-style-type: none"> • Investigation of the system performance with an accuracy that is sufficient for design and optimisation of hybrid ventilation systems.
Probabilistic methods	<ul style="list-style-type: none"> • Lighter constructions which are more sensitive to internal load variations (e.g. wind, outside temperature, solar radiation). Methods allow for the fact that input parameters are not 100% certain. 	<ul style="list-style-type: none"> • These methods enable design for peak load, estimating annual energy use and an estimate of the range of variation and uncertainty. Can be used to evaluate the trade-off between economy (cost, energy and environment) and risk (expectations not met, violation of regulations etc).

Table 4: Outline of developments in prediction methods.

References:

Fracastoro, G.V., Perino M. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 21: A Simple Tool to Assess the Feasibility of Hybrid Ventilation Systems*, Aalborg University, Aalborg, Denmark.

De Gids, W. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report TR13: Methods for vent sizing in the pre-design stage*, Aalborg University, Aalborg, Denmark.

Li, Y. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 12 Analysis of natural ventilation – a summary of existing analytical solutions*, Aalborg University, Aalborg, Denmark.

Author. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Paper 25: Zonal model: a simplified multi-flow element model*, Aalborg University, Aalborg, Denmark

Li Y, (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Paper 15: Integrating thermal stratification in natural and hybrid ventilation analysis*, Aalborg University, Aalborg, Denmark.

Brohus H, Frier C and Heiselberg P. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 19: Stochastic Single and Multizone Models of a Hybrid Ventilated Building – A Monte Carlo Simulation Approach*, Aalborg University, Aalborg, Denmark.

Schild Peter), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 22: Probabilistic Calculations by COMIS Spreadsheet user interface and general*, Aalborg University, Aalborg, Denmark.

Brohus H, Frier C and Heiselberg P. Haghghat F (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 18 Quantification of Uncertainty in Thermal Building Simulation by means of Stochastic Differential Equations*, Aalborg University, Aalborg, Denmark.

Brohus H, Frier C and Heiselberg P. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 17: Stochastic Load Models based on Weather Data*, Aalborg University, Aalborg, Denmark.

Selecting a prediction method

Different predictions methods will need to be drawn upon at different phases in the design of the building and ventilation system. These are summarised in Table 5.

Table 5: Applicability of prediction methods to different design stages

	Simple analytical and empirical models	Zonal models	Multi-zone air flow models	Thermal models	CFD - Models	Combined airflow and thermal models
Design phase	<ul style="list-style-type: none"> • Conceptual • Basic 	<ul style="list-style-type: none"> • Detailed 	<ul style="list-style-type: none"> • Detailed • Evaluation 	<ul style="list-style-type: none"> • Basic • Detailed • Evaluation 	<ul style="list-style-type: none"> • Detailed • Evaluation 	<ul style="list-style-type: none"> • Detailed • Evaluation
Purpose	<ul style="list-style-type: none"> • Analysis of air flow rate, thermal comfort and energy use in discrete time steps or on yearly basis 	<ul style="list-style-type: none"> • Analysis of air flow and temperature distribution in a single room 	<ul style="list-style-type: none"> • Analysis of air flow rate through the envelope on a yearly basis • Analysis of air flow rate between zones on a yearly basis • Analysis of IAQ in buildings 	<ul style="list-style-type: none"> • Analysis of thermal conditions in zones on a yearly basis • Analysis of energy use on a yearly basis 	<ul style="list-style-type: none"> • Analysis of airflow, IAQ and temperature distribution in a single room • Analysis of airflow around building • Analysis of surface pressure on envelope 	<ul style="list-style-type: none"> • Optimization of building and system performance through combined analysis of airflow rates, temperature conditions and energy use
Available models	<ul style="list-style-type: none"> • Flow element models • Spreadsheet programs • Vent sizing programs 	<ul style="list-style-type: none"> • Detailed 	<ul style="list-style-type: none"> • COMIS • CONTAM 	<ul style="list-style-type: none"> • TRNSYS • EnergyPlus • BSIM2000 • CAPSOL • ESP-r • IDA 	<ul style="list-style-type: none"> • Fluent • Flovent • Vortex • CFX • PHOENICS 	<ul style="list-style-type: none"> • TRNSYS + COMIS • Tas-Flows • CHEMIX • IDA-ICE
Outputs	<ul style="list-style-type: none"> • Mean indoor temperature • Peak temperatures • Draught risk • Heating & cooling load • Energy use 	<ul style="list-style-type: none"> • Distribution of airflow • Distribution of pollutant concentration • Distribution of temperature 	<ul style="list-style-type: none"> • Airflow rates through envelope opening • Airflow rates between zones • Average IAQ in each zone 	<ul style="list-style-type: none"> • Hour by hour temperature variation in zones • Hour by hour heating and cooling loads • Hour by hour energy use 	<ul style="list-style-type: none"> • Detailed distribution of airflow and temperature • Study of design problems (troubleshooting) • Mechanism of heat transfer and airflow in enclosures 	<ul style="list-style-type: none"> • Hour by hour variation in temperature, airflow rate, IAQ and energy use • Optimised control strategy

	Simple analytical and empirical models	Zonal models	Multi-zone air flow models	Thermal models	CFD - Models	Combined airflow and thermal models
Necessary equipment/computer	<ul style="list-style-type: none"> • Hand calculator • Personal computer, etc. 	<ul style="list-style-type: none"> • Personal computer 	<ul style="list-style-type: none"> • Personal computer 	<ul style="list-style-type: none"> • Personal computer 	<ul style="list-style-type: none"> • Powerful personal computer • Workstation 	<ul style="list-style-type: none"> • Powerful personal computer • Workstation
User	<ul style="list-style-type: none"> • Practitioner 	<ul style="list-style-type: none"> • Expert 	<ul style="list-style-type: none"> • Expert/researcher 	<ul style="list-style-type: none"> • Expert 	<ul style="list-style-type: none"> • Expert/researcher 	<ul style="list-style-type: none"> • Researcher
Required time for application	<ul style="list-style-type: none"> • About half day per case to input data 	<ul style="list-style-type: none"> • About one day per case to input data 	<ul style="list-style-type: none"> • About two days per case to input data 	<ul style="list-style-type: none"> • About two days per case to input data 	<ul style="list-style-type: none"> • About one week per case to input data 	<ul style="list-style-type: none"> • About one week per case to input data
CPU time	<ul style="list-style-type: none"> • A few minutes 	<ul style="list-style-type: none"> • 1-10 hours 	<ul style="list-style-type: none"> • 1-10 hours 	<ul style="list-style-type: none"> • < 1 hour 	<ul style="list-style-type: none"> • 10-100 hours per case 	<ul style="list-style-type: none"> • 10-100 hours per case

Table 5: Applicability of prediction methods to different design stages

5.2 Design issues

Multiple steady state solutions and dynamical phenomena

Air flow in buildings can behave as a dynamical system¹ displaying non-linear phenomena. This means that a number of stable or 'steady state solutions' are possible satisfying the same energy and momentum balance.

Mechanical forces from mechanical systems tend to suppress these non linear phenomena, however, in naturally ventilated buildings they need to be controlled, particularly in fire situations. For example, lack of control could lead to oscillating flows through a solar chimney, or two possible smoke layers, or a situation where a smoke layer can either exist or not exist.

Multiple solutions to problems with even simple geometry are possible and these multiple steady state solutions are confirmed by small-scale experiments and CFD predictions.

The steady state solution obtained for ventilation air flow rates and temperature conditions depends not only on the present conditions but also on the initial conditions or 'history'. Even tiny uncertainty in the initial conditions can lead to problems with predicting the ventilation state.

References:

Li, Y. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 12 Analysis of natural ventilation – a summary of existing analytical solutions*, Aalborg University, Aalborg, Denmark.

Author. (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Paper 31 Experimental modelling of wind opposed buoyancy-driven building ventilation*, Aalborg University, Aalborg, Denmark

Improved modelling of airflow through openings in the building envelope

Small openings

The discharge coefficient (C_d) is useful for predicting the ventilation flow rate through a small opening. C_d depends on the contraction of the streamlines near the opening and the turbulent pressure losses. The discharge coefficient is not a constant but varies for the typical flow conditions for purpose provided openings in the building envelope as a function of the following parameters:

- Pressure difference across the opening
- Temperature difference
- Opening type, area and local geometrical conditions
- Location of opening in the façade
- Relative size of the opening in relation to the façade area
- Relative size of the inlet and outlet opening and their relative location

The standard model, based on the Bernoulli equation, and assuming uni-directional flow applies.

¹: A dynamical system is a deterministic process in which a function's value changes over time according to a rule that is defined in terms of the function's current value

References:

Sandberg M (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 25, Wind- induced air flows through large openings, Aalborg University, Aalborg, Denmark.*

Heijmans N, Wouters, P (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Report 23, Impact of the uncertainty of wind pressures on the prediction of thermal comfort performances, Aalborg University, Aalborg, Denmark.*

Large openings

These are defined as openings where the standard model can't be applied by using the pressure coefficient from a sealed body. Flow can occur across part or all of the opening in both directions. The applicability of the standard model depends on the size and location of the opening in the façade and the wind direction relative to the opening.

- The model can't be used if the opening is >30% of the façade area, for a wind driven-flow with wind direction close to right angles to the building.
- As the wind-direction becomes more parallel to the opening the discharge coefficient decreases.
- Models have been developed for calculating the correct discharge coefficient and the pressure difference across the opening.

Thermal comfort design in rooms

Thermal comfort is determined by the velocities and temperatures of the air flow at entry into the occupied zone. Fresh air is often supplied through window openings and/or air inlets in the building envelope. It is important to be aware of the ventilation characteristics of different window types.

The application of jet flow models to window openings is complex because jet flow characteristics depend on pressure difference and opening area. The controllability of flow rate and resulting room comfort level from window openings is different to other types of ventilation openings. Natural ventilation systems therefore have a lower maximum (air flow and/or cooling) capacity than mechanical systems.

But research shows that it is possible to develop natural ventilation openings which significantly reduce the maximum velocity in the occupied zone compared to windows

More information:

Author, P (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", *Principles of hybrid ventilation CD, Technical Paper 58, Window openings – air flow and thermal comfort, Aalborg University, Aalborg, Denmark.*

6 Quality control

Quality control should be embedded in a framework for all stages of preliminary design, design and operation of a hybrid ventilation system. Two key aspects of quality are reliability and commissioning:

- Reliability, expressed as a fraction between 0 and 1, represents the probability that the system can fulfil the design requirements between certain time intervals. It is influenced by maintenance, basic air quality and the system load. A reliable system ensures the desired air flow in different climactic circumstances and during the system's lifetime.
- Commissioning ensures that the systems are designed, functionally tested, and capable of being operated and maintained to perform as intended in the design specification.

Model Quality Control (MQC) is a generic framework for quality control of building services processes covering all stages from the programme phase to the operational phase. The quality level must be precisely defined; in the MQC framework 'quality' means that the delivered performance matches the requirements and expectations of the building owner, time plan and budgets and technical aspects. All partners in the building process, including the owner, need to be aware of the MQC model in order to comply. Although implementing the MQC process will need an initial investment of effort and cost it should deliver savings in the long run from a better quality ventilation system.

Reference:

Van der Aa, A., *Op't Veld P (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", Principles of hybrid ventilation CD, Technical Report 10, Quality control for hybrid ventilation, Aalborg University, Aalborg, Denmark.*

ASHRAE publication (1996) 1-1996 *The HVAC Commissioning Process, Atlanta USA*

Model Quality Control (MQC) structure

The MQC model can be applied either to the entire hybrid ventilation system or separate elements.

A quality matrix can be developed building in key decision points, at various stages of the building and system design/operation. This enables assessment of whether the targets and requirements defined in the programme phase are met.

- The matrix (see Figure 3) has 10 different quality aspects on the vertical axis: General, Organisation, Communication, Requirements, Means, Purchase, Time, Finances, Realisation and Experience.
- The phases of the process are on the horizontal axis: Programme, Design, Elaboration, Realisation and Operation.

A reference number is entered in each cell in the MQC matrix; this links it to another matrix which indicates which subjects are covered. These subjects are then covered in more detailed specification sheets. It is not always possible, or necessary, to fill in all cells of the matrix.

MQC MATRIX						CELL CONTENTS			SPECIFICATION SHEET II.3-2	
aspect	project phase					subject	partial subject	specification sheet	characteristic	specification
	I	II	III	IV	V					
0						II.3-1				
1										
2										
3		II.3				II.3-2				
4										
5										
6						II.3-3				
7										
8										
9										

Figure 3: Example MQC matrix and specification sheets

7 Case studies

The thirteen Annex 35 case studies covered a range of building types, ventilation principles, and control strategies. The key characteristics of each case study are summarised in Table 6. Full details of case studies are available on the HYBENT CD-rom.

Reference Brohus IEA ECBCS (2002), "Control Strategies for Hybrid Ventilation in New and Retrofitted Office and Education Buildings (HYBVENT)", Principles of hybrid ventilation CD, Case Studies, Aalborg University, Aalborg, Denmark.

This section focuses on two case studies; Tånga School in Sweden and the IVEG office building in Belgium.

7.1 Tånga School, Sweden

Almost half of all schools in Sweden were built during 1961 and 1975. This group of schools has the highest heating energy use i.e. 170 kWh/m² year.

The Tånga school was built in 1968 and has 20 classrooms, 10 workshops, a dining hall, kitchen, gymnasium and offices with a total floor area of 9350 m². The building and the HVAC technology are somewhat better than typical for the period. Some improvements were carried out in 1989 (new windows) and 1991 (added thermal insulation). The school consists of four, two-storey buildings (A, B, C and D);

- **A** - with auditorium, dining hall, kitchen, offices. The building has two stories, is almost rectangular and has a flat roof. Heated volume is 8628m³
- **B** - with mainly classrooms. The building has two stories, is E-shaped and has a flat roof. Heated volume is 12,031m³
- **C** - with mainly workshops. The building has two stories, is rectangular and has a flat roof. Heated volume is 3,672m³
- **D** - with a gym.

The school needed renovation due to wear and tear and the owners were interested in implementing energy saving features and hybrid ventilation.

The school is located in Falkenburg, on the west coast of Sweden, 100km south of Goteborg. The school is located in a mostly residential area. The immediate surroundings are flat with some scattered trees to the south. At some distance there are some residential buildings.

Summary of climate data

- Average meteorological wind speed 3 m/s.
- The average outdoor temperature for January is 1.6 °C and for July 16.1 °C.
- The annual average temperature is 7.2 °C.
- Yearly heating degree days 3325, based on an indoor temperature of 17 °C i.e. assuming that the difference between the actual indoor temperature and 17 °C is generated by internal gains.
- The global solar radiation on a horizontal plane is 161.2 kWh/m² (July), 11.3 kWh/m² (January) and 957.9 kWh/m² (annual).

Item	Characteristics	Comments
Heating system	Conventional radiators with thermostatic radiator valves	
Energy for space and hot water heating	District heating	
Ventilation system	Mechanical exhaust and supply ventilation without heat recovery in building B and C, building A partly installed with heat recovery in 1993	Estimated specific use of electricity of 3kW/m ³ /s Operation controlled by timer set to start at 7:00hrs and stop at 17:00hrs. Classroom ventilation rate is 6l/s/person

Figure 4: Tånga school HVAC system before refurbishment

Design philosophy for IAQ and thermal comfort

Aims were to

- Reduce energy use of building B (mainly classrooms) by replacing the old balanced mechanical system with a demand-controlled hybrid ventilation system using fan-assisted passive stack system with a solar chimney.
- Upgrade existing balanced ventilation systems in buildings A and C with energy efficient versions.
- Achieve a basic ventilation rate during lessons, with purge ventilation through window opening during regular breaks in lessons.
- Control via temperature and CO₂ sensors with an allowance for manual override; this control strategy should enable the ventilation rate to be reduced by 25% during the heating season.
- Pre-heat air using convectors below the windows.
- Provide user-friendly instructions for occupant control of the system.
- Avoid mechanical cooling and instead achieve cooling via windows or night cooling.
- Reduce high indoor temperatures by using solar shading.
- Optimise daylight levels using glare control, day light reflectors and optimised interior surfaces.
- Upgrade lighting with energy efficient fittings and occupancy sensors.
- Reduce the energy use for space heating from 140 kWh/m²/year to 75 kWh/m² year and the use of electricity from 50 kWh/m²/year to 35 kWh/m²/year.

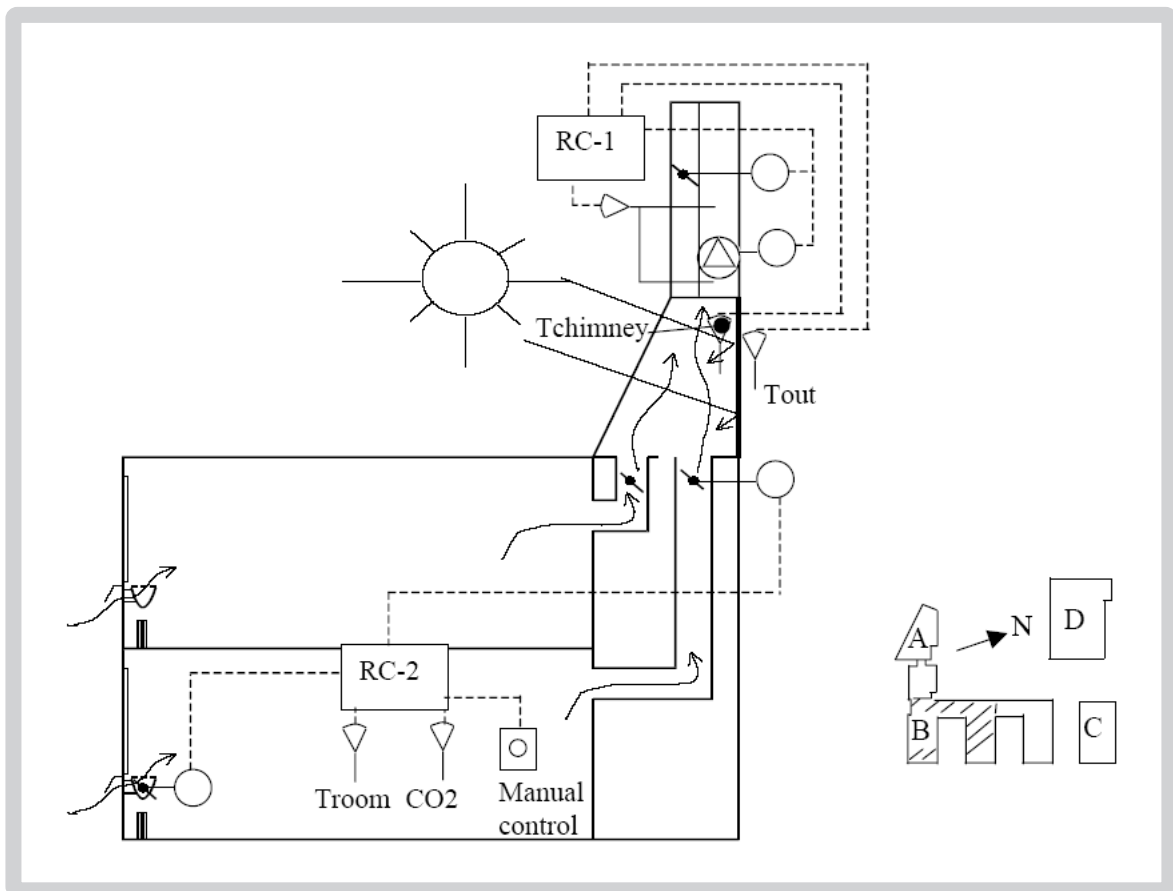
Ventilation principle

The main principle of ventilation of building B school is passive stack ventilation. When stack effects provide insufficient differential pressure, assisting fans supplement the natural driving forces. The outdoor air is distributed to the rooms through several air intakes below the windows in the exterior walls into a stub duct from where it is distributed to the room.

The outdoor air is preheated by convectors under the stub duct. This should bring about mixing ventilation in the classrooms.

The extract air is evacuated through air terminal devices below the ceiling on the opposite side of the room into vertical ventilation ducts. Local dampers are mounted both in the air intakes and in the exhaust duct of each room to allow individual control of the flow rate. To reduce the risk of air from going backward through the duct system all of the classrooms have their air intakes against the predominant wind direction.

To increase the stack effects, 6 m high solar chimneys have been installed on the roof with assisting exhaust fans and central dampers mounted in parallel. In addition to extending the length of the exhaust ducts, the solar chimneys consist of a flat plate solar air collector that heats the air in the chimney and increases the stack effect the last 6 m of the exhaust ducts. There are in total three solar chimneys, each one serving a separate part of the building. It is desirable to get equal stack effects on both floors and when needed having the exhaust fans working simultaneously. To achieve this the design reduced the cross-section area of the exhaust ducts from the first floor.



Control system and strategy for ventilation and space conditioning

A building energy management system (BEMS) controls the HVAC system. This can be operated from external terminals and the sub centrals in addition to the monitoring central. The system monitors the energy use in detail (separately space heating, hot water, electricity for ventilation and lighting for three building zones). Temperature, relative humidity and CO₂ in classrooms is also monitored. The BEMS is designed to ensure good thermal comfort and good indoor air quality with a low use of energy. The system is also designed with a minimum of user control and only the technical manager of the school has access to the automatic control system. The dampers in the inlet and outlets can, however, be adjusted by the teacher to control the air flow in the classrooms.

Sensors

Sensors	Operation
<p>CO₂</p>	<p>At a CO₂ level of 1000 ppm or less the local dampers are set to a minimum open position, controlled by a timer between 6 and 18 o'clock weekdays. A CO₂ sensor in each room controls the local inlet and outlet dampers. The minimum position can be varied as a function of the outdoor air temperature. At low outdoor temperatures and/or high wind velocities the airflow rate is automatically limited to prevent high energy consumption and problems with dry indoor air.</p> <ul style="list-style-type: none"> • At CO₂ levels > 1000 ppm - a signal lamp in the classroom lights up. • At CO₂ levels > 1500 ppm the local dampers open 100 %. The teacher can override the local control system and manually change the position of the local dampers between 50 and 100 %.
<p>Temperature sensors:</p> <ul style="list-style-type: none"> • Indoor air temperature • Outdoor air temperature • Solar chimney air temperature 	<p>In summertime the temperature difference between the outdoor air and the air in the solar chimney, and hence the stack effect, is insufficient to maintain the design airflow rates. The central dampers are closed and the exhaust fan simultaneously started. To avoid a high frequency of starting and stopping of the fan the dampers are opened and the fan is stopped at a somewhat higher temperature difference. When running, the exhaust fan is controlled by the pressure difference over the fan. The exhaust fan increases the pressure difference continuously as the temperature difference decreases. Window airing is possible at any time. In summertime the stack effect can also be used for night cooling of the building. At a centrally located control panel staff can if necessary override both the local and the central control strategy and set a fan controlled design air flow rate of 7 l/s per person in the whole building. The heating system of the school is connected to the district heating system of Falkenberg. The flow temperature to the radiator is controlled by the outdoor temperature. The flow through the radiator or convector is pre-set and each radiator is equipped with a thermostatic valve.</p>

7.2 IVEG Building, Belgium

This new office building, located 30km east of Brussels, was completed in 1999. It is situated in the city centre with the main facades facing northwest and southeast. IVEG is an energy distributor and was keen to reduce energy use in the new design. The building has three floors and has cellular offices

Design philosophy for IAQ and thermal comfort, energy efficiency and other issues

The building has two ventilation systems providing air quality and summer cooling

- A mechanical air supply system with occupancy detectors located in each supply grill and extraction occurs from the toilets.
- Night ventilation based on the stack effect with two large chimneys for extraction. Air is supplied via automatically controlled louvres in the facades. Night cooling is not fan-assisted.

Shading devices, controlled by meteorological stations on the roof, limit solar gains from the south and west facades. Occupancy detectors control the efficient lighting that is installed throughout the building. The false ceilings are open on their border allowing access to the thermal mass. The building and ventilation ducts are airtight by Belgian standards.

Heat recovery is installed in the mechanical system with an efficiency, according to the manufacturer, of 60%.

Control system and strategy

The mechanical (IAQ) and night cooling systems are independently controlled.

Indoor air quality ventilation is controlled by IR occupancy detectors, whereas night cooling is fully automated.

Night cooling control strategy

The building energy manager must choose the following parameters; the usual settings are indicated in brackets:

- Start and finish hours for night cooling (22:01hrs to 07.30hrs)
- Minimum outside day temperature required (22°C)
- Minimum temperature difference required (2°C)
- Minimum indoor temperature (19°C)
- Time step between opening of the different louvres

During the day, the system monitors the outside temperature to determine the maximum temperature. The louvres open if all of the following conditions are met:

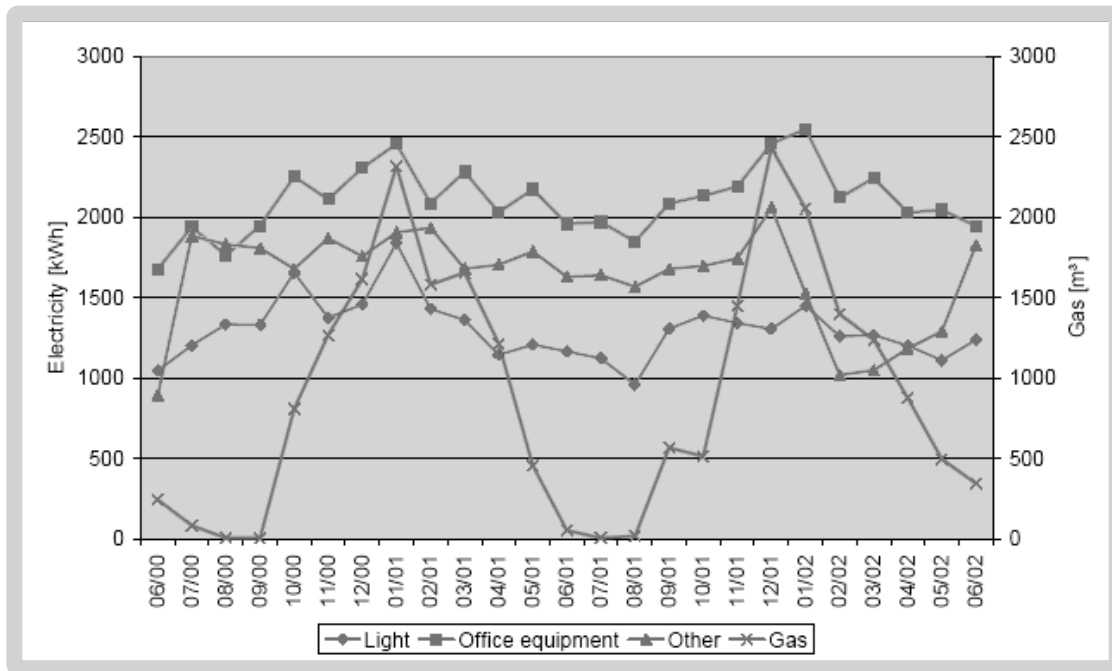
- It is night time
- The maximum outside temperature during the day is higher than required
- The temperature difference between internal and external is higher than required

The louvres are closed if one of the following conditions is met:

- It is day time
- The temperature difference between internal and external is smaller than required
- The indoor temperature falls to less than required

Automatic control of louvres can be manually overridden, for example in the occurrence of a fire. During the day users can open louvres from their personal computers.

Figure 5: Electricity and gas use from June 200 – June 2002



Energy use – the HVAC system uses ~18% of the total building energy use whereas the louvres and solar shading combined use less than 2%.

The occupancy detectors effectively control IAQ; the indoor CO₂ levels fall into the IDA1 and IDA2 IAQ classes defined by prEN 13779. That is CO₂ levels d” 400 ppm above the outdoor level and 400 - 600 ppm above the outdoor level, respectively. This control strategy also reduces airflows and hence the energy used for pre-heating of air.

Overheating was not a problem, except in three offices - investigation suggested this was due to bad sensor location and in one case high solar gains.

Table 6: Summary of Annex 35 case studies

	Wilkinson Building	IVEG building	PROBE building	B&O headquarters	B. Brecht Gymnasium	I Guzzini Illuminazione
Building type	Office	Office	Office	Office	School	Office
Country	Australia	Belgium	Belgium	Denmark	Germany	Italy
Year & New (N) or Refurbished (R)	1997 (R)	1999 (N)	1997 (R)	1998 (N)	1995 (R)	1997 (N)
Volume m³ () effective volume, m³	(1175)	6300	6066	6046	21200	1000
Height - m ()no. of floors)	16 (5)	12 (3)	6 (2)	14 (3)	11 (4)	13 (4)
Ventilation principle	Natural and mechanical	Natural and mechanical	Natural and mechanical	Fan assisted and natural	Natural and mechanical	Natural and mechanical
Control strategy						
IAQ	Manual	PIR	PIR	CO ₂	Manual	Manual
Room temp	Manual	Manual	Manual	Automatic	Manual	Automatic
Night ventilation	–	Automatic	Manual	Automatic	Automatic	Automatic
Building integrated components	–	Chimneys and turrets	–	Stairwells	Atria	Chimneys, turrets and atria

	Liberty Tower of Meiji University	Tokyo Gas Earth Port	Fujita Technology Centre	Media School	Jaer School	Tanga School	Waterland School
Building type	School	Office	Office	School	School	School	School
Country	Japan	Japan	Japan	Norway	Norway	Sweden	Netherlands
Year & New (N) or Refurbished (R)	1998 (N)	1999 (N)	1996 (N)	1998 (N)	1999 (N)	1999 (R)	2001 (N)
Volume m³ () effective volume, m³	256697	170000	–	6000	–	12031	17000
Height - m () no. of floors)	120 (23+3)	18 (3)	27 (4)	5 (1)	12 (2)	7 (2)	3-6 (1-2)
Ventilation principle	Natural and mechanical	Natural and mechanical	Natural and mechanical	Stack and wind assisted mechanical	Fan assisted and natural	Fan assisted and natural	Fan assisted and natural
Control strategy							
IAQ	Constant	Constant	Constant	CO ₂	CO ₂	CO ₂	CO ₂
Room temp	Automatic	Automatic	Automatic	Automatic	Automatic		
Night ventilation	–	–	Automatic	Automatic	Automatic		
Building integrated components	Stairwells and windfloor	Stairwells & turrets & atria & corridors	Atria & underground ducts and culverts	Chimneys & turrets & corridors & underground ducts and culverts	Chimneys & turrets & corridors & underground ducts and culverts	Chimneys & turrets	Chimneys & turrets

The International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS)

The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, with the purpose of strengthening co-operation in the vital area of energy policy. As one element of this programme, member countries take part in various energy research, development and demonstration activities. The Energy Conservation in Buildings and Community Systems Programme has sponsored various research annexes associated with energy prediction, monitoring and energy efficiency measures in both new and existing buildings. The results have provided much valuable information about the state of the art of building analysis and have led to further IEA sponsored research.



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