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Heiselberg, Per Kvols

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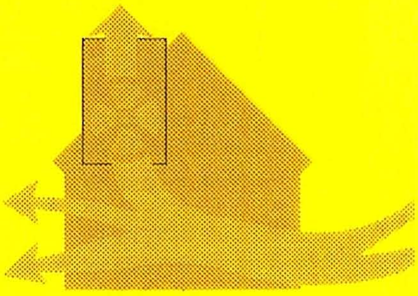

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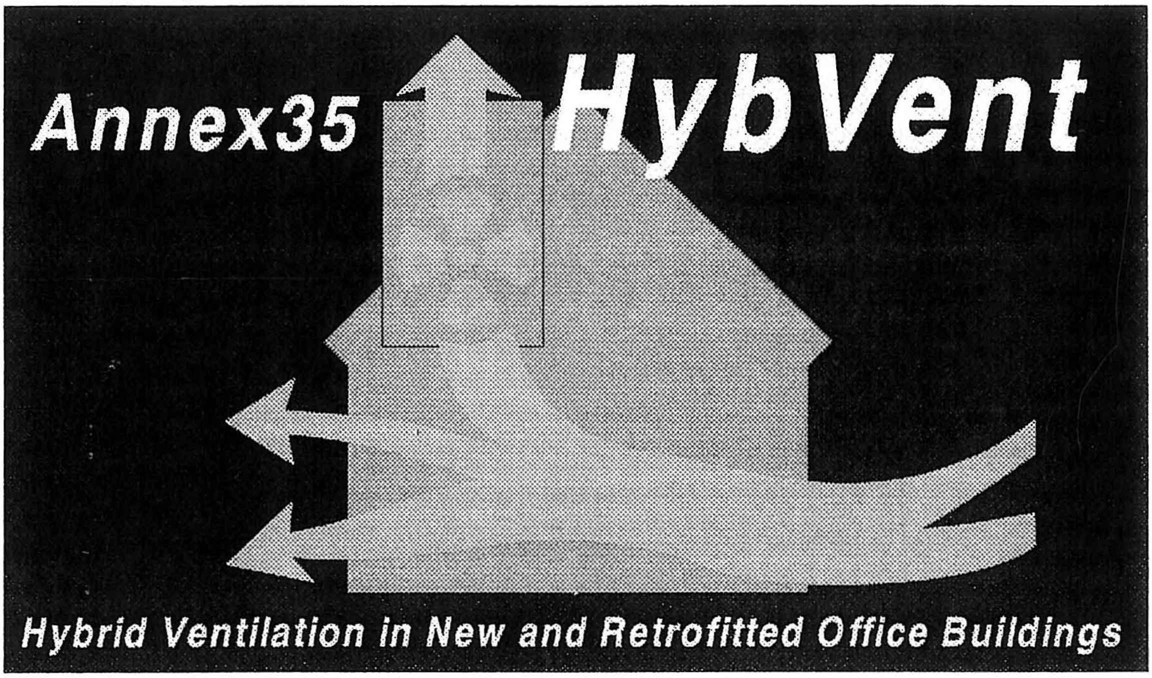

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OPERATING AGENT
PER HEISELBERG
AALBORG UNIVERSITY
Dep. of Building Technology and Structural Engineering
Sohngaardsholmsvej 57
DK-9000 Aalborg
Denmark
Phone: +45 9635 8541
Fax: +45 9814 8243
Email: ph@civil.auc.dk
Homepage: http://hybvent.civil.auc.dk

HYBRID VENTILATION AIR FLOW PROCESS

by

Per Heiselberg, Aalborg University, Aalborg, Denmark

BACKGROUND

Today, energy-efficient buildings are designed to interact with the outdoor environment and they are utilizing the outdoor environment to create an acceptable indoor environment whenever it is beneficial.

The extent to which sustainable technologies can be utilized depends on outdoor climate, building use, building location and design. Under optimum conditions sustainable technologies will be able to satisfy the demands for heat, light and fresh air. In some cases supplementary mechanical systems will be needed and in other cases it will not be possible to use sustainable technologies at all.

Hybrid ventilation systems can be described as systems providing a comfortable internal environment using both natural ventilation and mechanical systems, but using different features of the systems at different times of the day or season of the year. It is a ventilation system where mechanical and natural forces are combined in a two mode system.

The basic philosophy is to maintain a satisfactory internal environment by alternating between these two modes to avoid the cost, energy penalty and consequential environmental effects of full year round air conditioning. The operating mode varies according to the season and within individual days, thus the current mode reflects the external environment and takes maximum advantage of ambient conditions at any point in time. The main difference between conventional ventilation systems and hybrid systems is the fact that the latter are intelligent with control systems that automatically can switch between natural and mechanical mode in order to minimize the energy consumption.

Hybrid ventilation should dependent on building design, internal loads, natural driving forces, outdoor conditions and season fulfil the immediate demands to the indoor environment in the most energy-efficient manner. The control strategies for hybrid ventilation systems in office buildings should maximize the use of ambient energy with an effective balance between the use of advanced automatic control of passive devices and the opportunity for users of the building to exercise direct control of their environment. The control strategies should also establish the desired air low rates and air flow patterns at the lowest energy consumption possible.

The scope of this annex is therefore to obtain better knowledge of the use of hybrid ventilation technologies. The annex focus on development of control strategies for hybrid ventilation, on development of methods to predict hybrid ventilation performance in office buildings and on implementation and demonstration of hybrid ventilation in real buildings.

Thorough understanding of the hybrid ventilation process is a prerequisite for a successful application of hybrid ventilation, for development of optimum control strategies and for development of analysis methods for hybrid ventilation design. The annex is therefore by theoretical and experimental studies investigating the different elements of the air flow process in hybrid ventilation from air flow around buildings, air flow through openings, air flow in rooms to air flow between rooms in a building. The hybrid ventilation process is very dependent on the outdoor climate as well as the thermal behavior of the building and therefore, it is essential to take all these factors into consideration as well as the air flow process of whole systems.

HYBRID VENTILATION AIR FLOW PROCESS

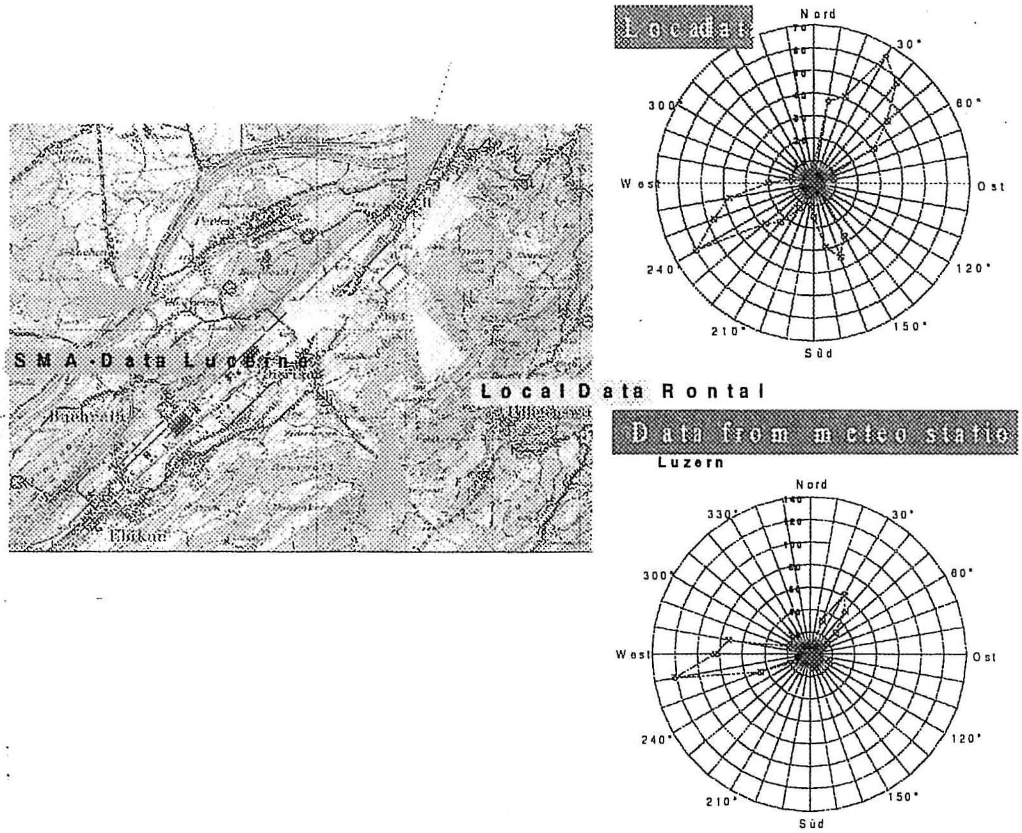
The key difference between natural and mechanical ventilation air flow processes lies in the fact that neither volume flow rate nor flow direction at the ventilation openings are predetermined in the former system. Natural forces drive natural ventilation. The stack pressure is determined by the temperature difference between the indoor and outdoor air, which is, in turn, affected by ventilation flow rates. The wind pressure is strongly affected by the microclimate around the buildings, which is again affected by landforms, vegetation and other surrounding buildings. Human behaviour strongly influences the ventilation. Therefore, natural ventilation is highly unsteady and both volume flow rate and air flow directions can vary considerably during the running period and not necessarily in phase with the occupants needs.

Some of these problems can be taken care of in the design of the building and the natural ventilation and control system. In hybrid ventilation additional mechanical systems are installed to solve the remaining problems as for example too low volume flow rates and/or unwanted flow directions in occupied hours. However, optimisation of energy consumption (control strategies) requires a detailed knowledge of the air flow process.

In annex 35 individual elements of the air flow process in hybrid ventilation are investigated as well as the air flow process of whole systems.

Air flow around buildings

Climate data is crucial in hybrid ventilation analysis, in particular in natural ventilation mode analysis. Usually climate data is only available from meteorological stations, which is not always representative for the building location and a transformation of meteorological data into local ventilation input data is necessary. However, these local conditions are as mentioned before strongly affected by the microclimate around the buildings, which is again affected by landforms, vegetation and other surrounding buildings. The complex local effects are very difficult to estimate and local climate data measurement is often the only option. Figure 1 shows an example of a commercial building complex in Switzerland in the city of Root with Lucerne as the closest meteorological station. Here both local wind directions and speeds differ considerably from the meteorological data and use of meteorological data would result in misleading conclusions.



Medium & strong winds (>2m/s) **Stronger winds only (>4m/s)**

	Hours with wind speed ≥2m/s			Hours with wind speed ≥4m/s		
	Root	Lucerne	*Factor*	Root	Lucerne	*Factor*
Northeast (0-60°)	235 Hrs.	187 Hrs.	*1.25*	46 Hrs.	32 Hrs.	*1.44*
South (150-180°)	30 Hrs.	74 Hrs.	*0.40*	15 Hrs.	5 Hrs.	*3.00*
Southwest (220–280°)	87 Hrs.	98 Hrs.	*0.89*	36 Hrs.	54 Hrs.	*0.67*

Figure 1. Comparison of local wind data with wind data from nearest meteorological station. /Schälin, 1999/

Pressure distribution on building surfaces

Wind forces appear in natural ventilation calculations in the form of wind pressure coefficients acting over areas of solid models where ventilation openings are intended in building surfaces. The dimensionless pressure coefficient is an empirically derived parameter that accounts for the changes in wind-induced pressure. Its value changes according to the wind direction, the building surface orientation, and the topography and roughness of the terrain in the wind direction. Typical data is given in tabular form in the literature (see for example /Liddament 1986/). However, flows around buildings are very complex and wind pressure coefficients for complex buildings are not readily available.

The use of wind pressure coefficients of solid models is largely a matter of convenience as this data measured for wind loading purposes is readily available. However, several investigations have shown that the pressure difference across buildings varies with the relative size and location of openings. One example is illustrated in figure 2.

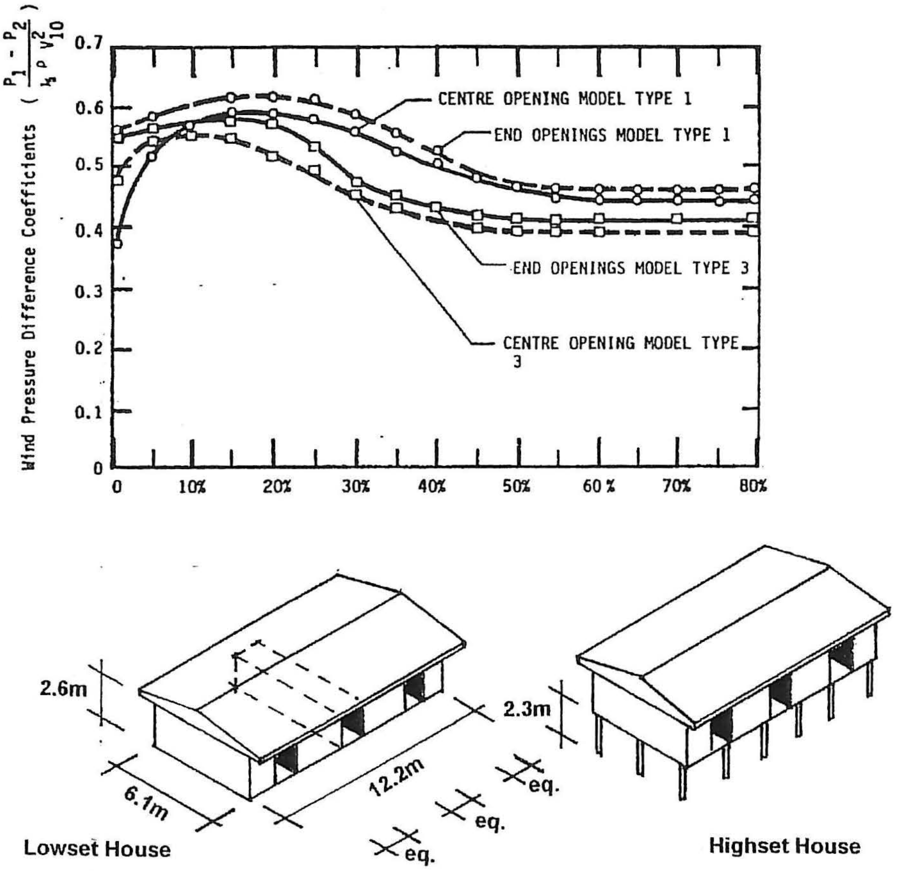


Figure 2. Pressure difference coefficients versus porosity of the building with three equal openings for wind normal to a long wall. Model type 3 refers to a highset house and model type 1 to a lowset house /Aynsley, 1999/.

In annex 35 wind pressures around buildings with openings and the impact on ventilation performance is investigated by experimental studies in wind tunnels and by theoretical CFD studies. The wind pressures around buildings will also be studied on two of the pilot studies. In Belgium wind speeds, -directions and -pressures are measured as well as the ventilation performances in the PROBE building. In Denmark the impact of air flow and local climate around the B&O Headquarters building on the optimum location and control of air inlets and outlets is investigated by CFD-calculations. Preliminary results of the work will be reported in the next annex meeting in April 2000.

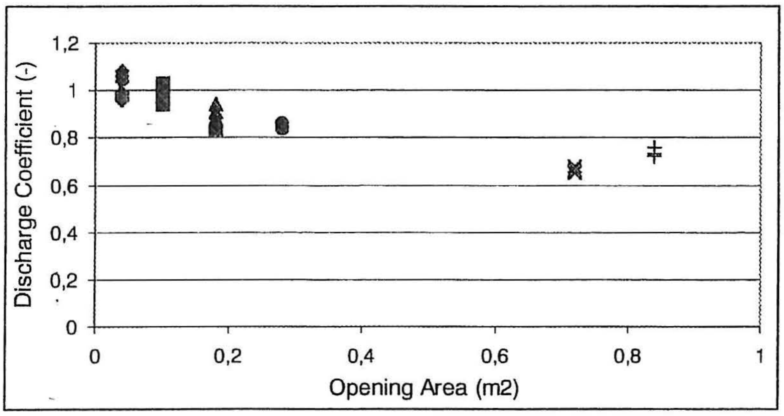
Air flow characteristics of openings

Small Openings

Computation of natural ventilation air flow through small openings is most commonly done using discharge coefficients, which quantify the airflow efficiency of an opening or alternatively the air flow resistance of openings. Many of the discharge coefficient values used are derived from data traditionally used for fluid flow in pipes. Entry conditions such as incidence of openings to the approaching wind, presence of insect screens, adjacent wing walls and eaves, overhangs, inclined window sashes and position of open doors can significantly influence discharge due to momentum effects at windward openings. Also downstream of an opening, surfaces parallel to the flow and close to the edge of the opening can influence the jet issuing from an opening, but are rarely accounted for although they can have significant influences on discharge. Much more work needs to be done regarding these influences to provide reliable design data for computation of natural ventilation.

In the case of discharge coefficients for window or door openings, a value of 0.6 for a sharp-edged rectangular opening is often used. Preliminary results from laboratory experiments show that using a constant value can result in quite large mistakes in volume flow calculations. Figure 3 shows for a side hung window that the discharge coefficient both is a function of opening area, air temperature difference and air flow rate.

A)



B)

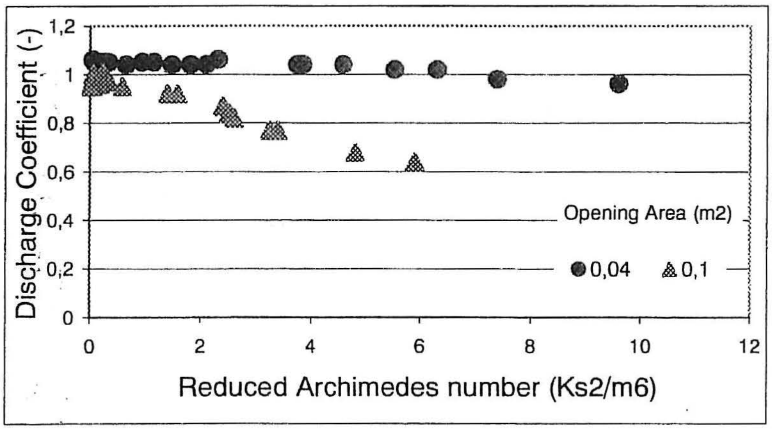


Figure 3. Discharge coefficient for a side hung window. A) as a function of opening area and B) as a function of air flow rate and temperature difference expressed as a reduced Archimedes number. /Heiselberg et al., 1999/.

Large Openings

There is no established theoretical justification for assuming that the wind pressure coefficient approach and the Bernoulli's equation are applicable for calculating flows through large external openings in buildings. Unfortunately this question has significant implications for the methods of calculating wind-induced natural ventilation in multi-zone methods.

It is also difficult to provide component flow characteristics and discharge coefficients for large openings, which are a function of not only the opening geometry, but also the airflow conditions. Etheridge and Sandberg (1996) and van der Maas (1992) has provided a good summary of various empirical discharge coefficient relationships as a function of temperature and opening geometry. The treatment of various openings in analysis methods needs to be based on the physics of the flows through the openings. For flows through horizontal openings, there is still a need for more fundamental research.

Fracastoro and Perinò (1999) have investigated air flow through different large openings and preliminary results have shown that it should be possible to use CFD-calculations to predict air change rates, see figure 4.

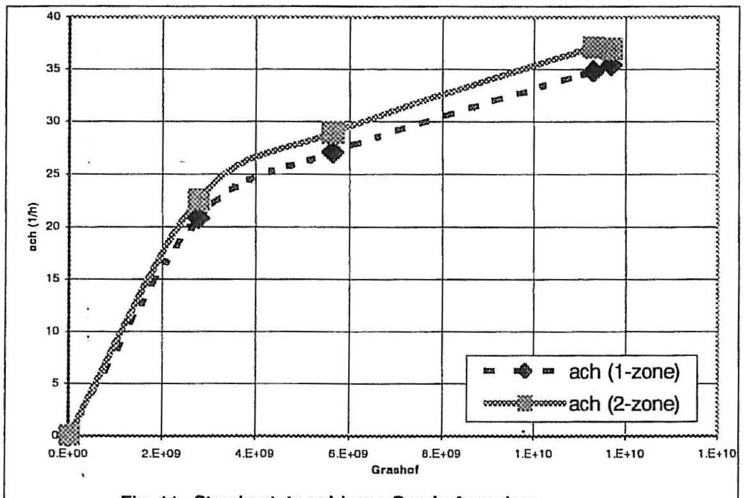


Fig. 11 –Steady-state ach's vs. Grashof number.

Figure 4. CFD- calculations of air change rate through a large opening as a function of Grashof number. /Fracastoro and Perino, 1999/.

Air flow characteristics for other elements

As such, there are no real hybrid ventilation components. A hybrid system in nearly all cases exists of a combination of components, which can be used in purely natural systems or purely mechanical systems. However, in order to allow a correct design and functioning of a hybrid ventilation system, availability of appropriate components is essential and often there is a large potential for performance improvements.

Sandberg 1999 have shown the advantages of using solar chimneys for both cooling of building integrated photovoltaics and as driving force for a hybrid ventilation systems. In both situations a high flow rate with a low temperature is preferable and a design method has been developed and verified by experiments.

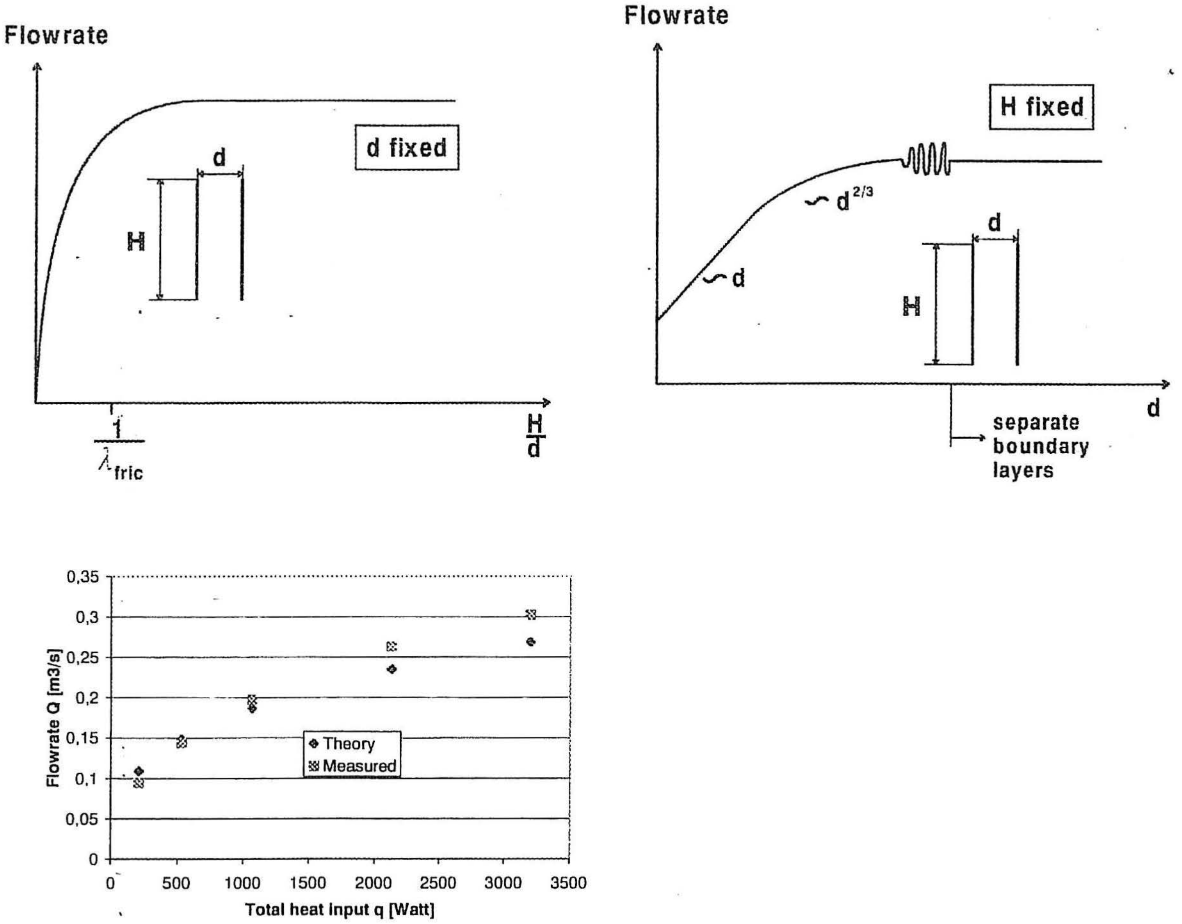


Figure 5. Expected effect of change of geometry on solar chimney flow rate and comparison between measured and theoretical flow rates. /Sandberg, 1999/.

Air flow between rooms in a building

The air flow process between rooms in a building is very important for the performance of hybrid ventilation systems but not very well understood. However, a better understanding is needed before major improvements in design and analysis methods can be achieved. In annex 35 several research groups are studying and developing models for inter-zonal buoyancy driven and forced air flows through both vertical and horizontal openings.

Buoyancy-driven flow occurring in stairwells due to temperature differences between the floors is probably the most common process of vertical air movement in the interior of buildings. Peppes et al (1999) have studied this air flow process both experimentally, analytically and numerically for a two floor stairwell. The volumetric air flow rate through the opening between the two floors was found to be a function of the interzone average temperature difference and the size of the opening. However, further experimental work is needed to discover the general applicability of the found relations.

Air flow process for whole systems

A number of countries use simulation studies with different simulation techniques to study the whole system air flow process and to develop hybrid ventilation concepts for office and educational buildings. An example is the Liberty Tower of Meiji University /Chikamoto et al., 1999/, where the application of a wind floor to induce natural ventilation in a high rise building has been investigated, see figure 6.

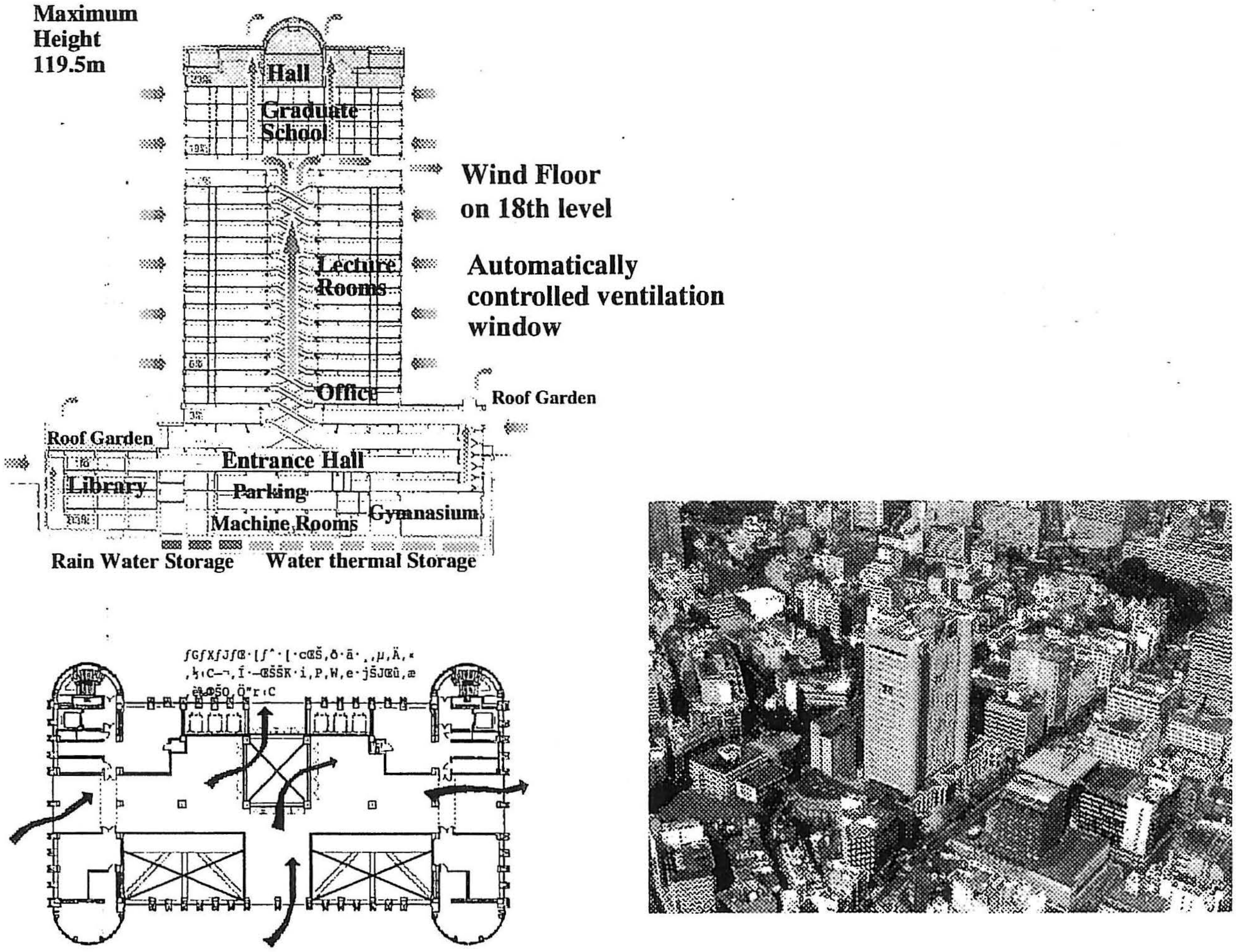
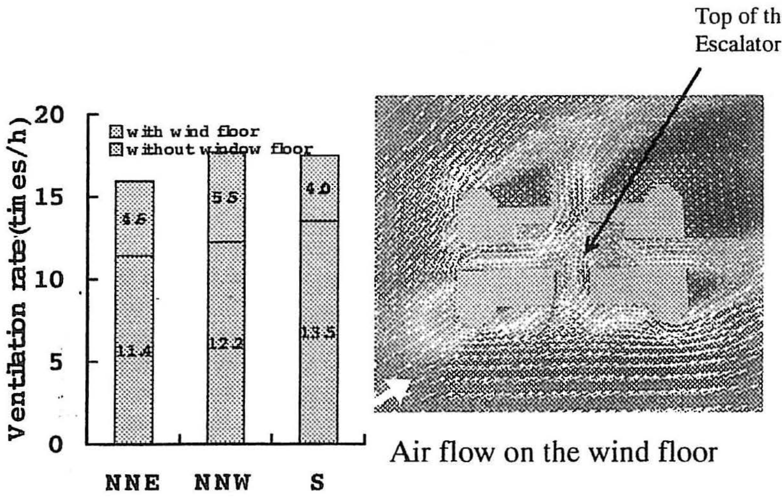


Figure 6: Principle of natural ventilation system and wind floor.

The centre core between 1st and 17th floor formed by escalator space is used as course of air flow for natural ventilation induced by thermal buoyancy. Above the centre core, on 18th floor, the wind floor creates driving force for ventilation on every floor that stimulates air intake via perimeter counter units and exhaust through the opening at the top of the centre core. As the wind floor is open to four directions, the driving force is expected to be stable through the year regardless of wind direction. CFD simulations have shown an expected increase in ventilation rate by 30 % by utilization of the wind floor to increase the driving force by wind. The Liberty Tower is one of the pilot studies in Annex 35 and the monitoring programme will show if expectations can be fulfilled.



Air flow on the wind floor

Results by Simulation

Figure 7. Simulation of ventilation flow rate in Liberty Tower of Meiji University.

ANNEX 35 WEB – SITE

All information about the annex is available on the Annex 35 Web-site (http://hybvent.civil.auc.dk). This web site will gradually grow through the working period of the annex and beside description of the annex, the web–site will include papers and publications, information about pilot studies and monitoring programmes as well as measurement and analysis results.

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Dept. of Building Technology and Structural Engineering
Aalborg University, November 1999
Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark
Phone: +45 9635 8080 Fax: +45 9814 8243
http://iee.civil.auc.dk