Design Principles for Natural and Hybrid Ventilation

Heiselberg, Per

Publication date:
2000

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. (2000). *Design Principles for Natural and Hybrid Ventilation*. Dept. of Building Technology and Structural Engineering, Aalborg University. Indoor Environmental Engineering Vol. R0036 No. 113

Aalborg **UNIVERSITY**

Design P

Design Principles for Natural and Hybrid Ventilation

P. Heiselberg

Paper No 113

Indoor Environmental Engineering

In: Proceedings of Healthy Buildings 2000. 6th International Conference on Healthy Buildings, Helsinki, Finland, August 2000, Vol. 2, pp. 35-46, SIY Indoor Air Information Oy, ISBN 952-5236-06-4

Printed at Aalborg University

Design Principles for Natural and Hybrid Ventilation

P. Heiselberg

DESIGN PRINCIPLES FOR NATURAL AND HYBRID VENTILATION

Per Heiselberg
Associate professor in Indoor Environmental Engineering, Aalborg University
Sohngaardsholmsvej 57, DK-900 Aalborg, Denmark
Tlf.: +45 9635 8541, Fax: +45 9814 8243, E-mail: ph@civil.auc.dk

ABSTRACT

For many years mechanical and natural ventilation systems have developed separately. Naturally, the next step in this development is the development of ventilation concepts that utilize and combine the best features from each system to create a new type of ventilation system – Hybrid Ventilation. The hybrid ventilation concepts, design challenges and principles are discussed and illustrated by four building examples.

Buildings ventilated by hybrid ventilation often include other sustainable technologies and an energy optimization requires an integrated approach in the design of the building and its mechanical systems. Therefore, the hybrid ventilation design procedure differs from the design procedure for conventional HVAC systems. The first ideas to a design procedure for hybrid ventilation are presented and the different types of design methods that are needed in different phases of the design process are discussed.

KEYWORDS: Design, hybrid ventilation, natural ventilation, office building.

INTRODUCTION

Today, in the design of new buildings and retrofit of old buildings an integrated approach is used with focus not only on thermal insulation, airtightness and heat recovery but also on optimal use of sustainable technologies as passive solar gains, passive and natural cooling, daylight and natural ventilation. 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 building design. Under optimum conditions sustainable technologies will be able to fulfil 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.

In well thermally insulated office buildings ventilation and cooling account for more than 50% of the energy requirement, and a well-controlled and energy-efficient ventilation system is a prerequisite of low energy consumption. Natural ventilation and passive cooling are sustainable, energy-efficient and clean technologies as far as they can be controlled, and they are well accepted by occupants and should therefore be encouraged wherever possible. Unfortunately, the design of energy-efficient ventilation systems in office buildings has often become a question of using either natural or mechanical ventilation. This has prevented a widespread use of sustainable technologies because a certain performance cannot be guaranteed under all conditions with natural ventilation. In fact, in the majority of cases a combination of systems would be beneficial depending on outdoor climate, building design, building use and the main purpose of the ventilation system. The development of sustainable ventilation technologies is far behind the development of other sustainable technologies and, certainly, there is a need for development.

For many years mechanical and natural ventilation systems have developed separately. Mechanical ventilation has developed from constant air flow systems through systems with extensive heat recovery and demand-controlled air flows to energy-optimized low pressure ventilation systems. Natural ventilation has in the same period developed from being considered only as air infiltration through cracks and airing through windows to be a demand-controlled ventilation system with cooling capabilities, heat recovery and air cleaning possibilities. The focus in the development has for both systems been to minimize energy consumption while maintaining a comfortable and healthy indoor environment. Naturally, the next step in this development is to develop ventilation concepts that utilise and combine the best features from each system to create a new type of ventilation system – Hybrid Ventilation.

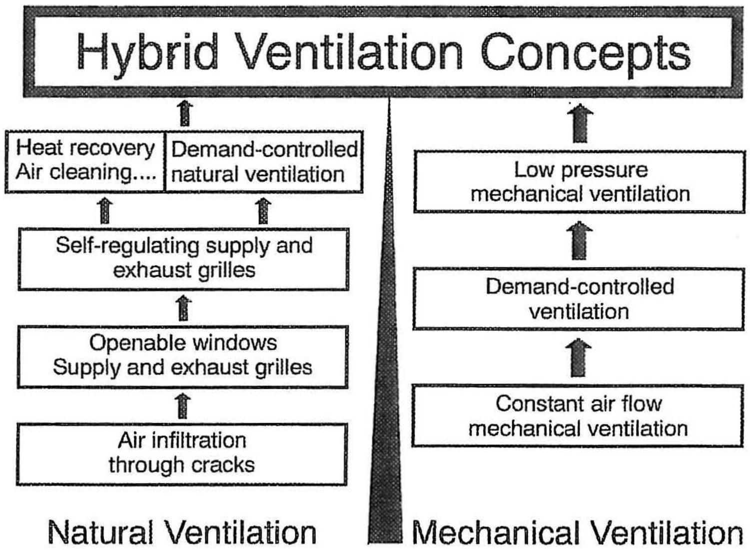

Figure 1. Development of natural and mechanical ventilation systems, [1].

HYBRID VENTILATION CONCEPT

Definition

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 indoor environment by alternating between and combining these two modes to avoid the cost, the energy penalty and the consequentially 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 on 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 the users of the building to exercise direct control of their environment. The control strategies should also establish the desired air flow rates and air flow patterns at the lowest possible energy consumption.

Design challenges

Ventilation of buildings is an important aspect of all building projects. Today, the purpose of the ventilation system is in many projects not only to control indoor air quality but also in summer in an energy-efficient way to achieve thermal comfort through natural cooling. In design of hybrid ventilation systems it is often necessary to separate design of ventilation for indoor air quality control and design of ventilation as a natural cooling strategy in summer. The major reason for this is the fact that devices for indoor air quality control and thermal comfort control in general are quite different, and that the potential barriers and problems to be solved, including the optimization challenge also are fundamentally different.

In optimization of ventilation for indoor air quality control the challenge is during periods of heating and cooling demands to achieve an optimal equilibrium between indoor air quality needs and energy use. This includes first of all a minimization of the necessary fresh air flow rate by reduction of pollution sources, demand control of air flow rates and optimum air supply to occupants. Secondly, it includes reduction of heating and cooling demands by heat recovery, passive cooling and/or passive heating of ventilation air. Finally, it includes reduction of the need for fan energy by low pressure duct work and for other components as well as optimization of natural driving forces from stack effect and wind. During periods without heating and cooling demands there is no need to reduce air flow rates as more fresh air only will improve the indoor air quality and the optimization challenge becomes mainly a question of minimizing the use of fan energy. Besides the above-mentioned challenges the ventilation should of course be provided without creating thermal comfort problems like draught or high temperature gradients.

In optimization of ventilation as a natural cooling strategy the challenge is to achieve an optimal equilibrium between cooling capacity, cooling load and thermal comfort. This includes first of all reduction of internal and external heat loads by application of low energy equipment, by utilization of daylight and by effective solar shading. Secondly, it includes application of the thermal mass of the building as a heat buffer which absorbs and stores heat during occupied hours and returns it to the space during unoccupied hours with night ventilation. Finally, it includes reduction of the need for fan energy by low pressure duct work and other components as well as optimization of natural driving forces from stack effect and wind. The major issues of concern with regard to thermal comfort are avoidance of too low temperatures at the start of the working hours and acceptable temperature increase during working hours. The issues of concern in optimization of hybrid ventilation for indoor air quality control and natural cooling are summarized in table 1.

Table 1. Issues of concern in optimization of hybrid ventilation for indoor air quality control

and natural cooling.

Indoor Air Quality Control	*Natural Cooling*
• Limitation of pollution sources (building materials, equipment, local exhaust, etc.)	• Limitation of heat load (low energy equipment, solar shading, daylight)
• Choice of appropriate indoor air quality targets and related air flow rates	• Choice of appropriate thermal comfort targets (min. and max. values)
• Optimum air supply to occupants and removal of pollutants (ventilation efficiency)	• Optimum air supply to occupants (temperature efficiency)
• Minimize heating and cooling energy (heat recovery, passive heating, passive cooling, etc.)	• Minimize cooling load (thermal mass, night ventilation)
• Minimize fan energy (low pressure duct work and components, natural driving forces, etc.)	• Minimize fan energy (low pressure duct work and components, natural driving forces, etc.)
• Adapting air flow rates to indoor air quality needs (control strategy, demand-controlled ventilation)	•

Ventilation strategies

There is a whole range of hybrid ventilation principles and strategies and it is impossible to make a complete catalogue. Therefore, the following section focuses on the main principles and illustrates by building examples typical hybrid ventilation principles and strategies and demonstrates how design challenges mentioned in the previous section are solved. The criterion for selection of the building examples has been the innovative ideas with respect to ventilation for indoor air quality and natural cooling used in the buildings and not necessarily because the examples are excellent buildings with respect to indoor climate and energy efficiency. The buildings are IEA ECB& CS Annex 35 pilot studies. They will be monitored during the project and their performance will be reported at the end of the project.

The main hybrid ventilation principles are:

- **Alternating natural and mechanical ventilation**
  This principle is based on a combination of two fully autonomous systems where the control strategy consists of switching between both systems. It covers for example systems with natural ventilation in intermediate seasons and mechanical ventilation during midsummer and/or midwinter. It can also be systems with mechanical ventilation during occupied hours and natural ventilation for night cooling.
- **Fan assisted natural ventilation**
  This principle is based on a natural ventilation system combined with an extract or supply fan. It covers natural ventilation systems which during periods of weak natural driving forces or periods of increased demands can enhance pressure differences by mechanical fan assistance.
- **Stack and wind supported mechanical ventilation**
  This principle is based on a mechanical ventilation system which makes optimal use of natural driving forces. It covers mechanical ventilation systems with very small pressure losses where natural driving forces can account for a considerable part of the necessary pressure.

Example 1: Liberty Tower, Meiji, Japan. (Architects and engineers Nikken Sekkei Ltd.)

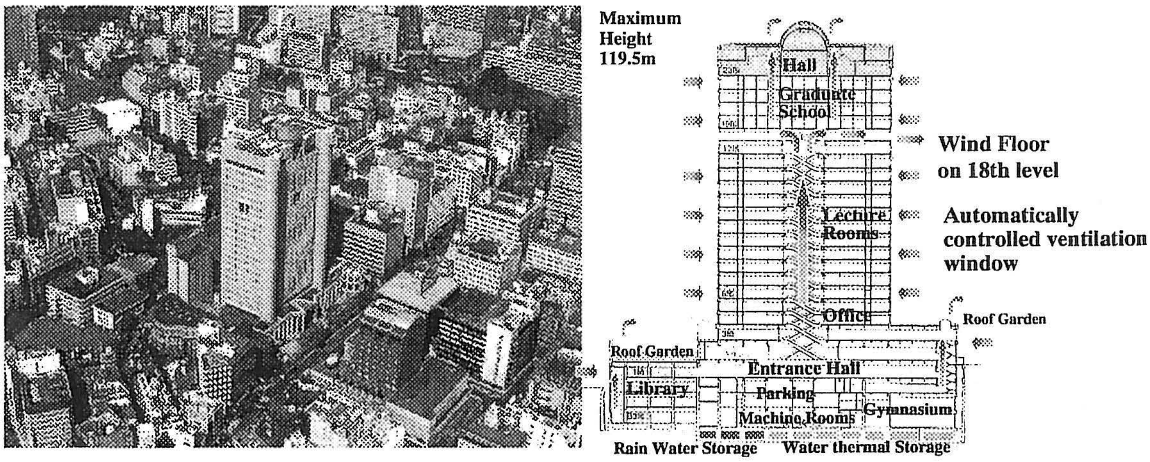

Figure 2. The Liberty Tower of Meiji University. Right: The natural ventilation principle with the central core and the wind floor to enhance natural driving forces.

The Liberty Tower of Meiji University is a high rise building at the centre of Tokyo Metropolitan area, [2]. The hybrid ventilation principle is based on natural ventilation for controlling the indoor climate in spring and fall seasons and a mechanical air-conditioning system in the rest of the year, when the outdoor air is not comfortable.

To enhance natural ventilation driving forces a "wind-floor" concept has been used. A central core is designed for utilization of the stack effect at each floor and above the centre core a wind floor is designed to enhance driving forces from the wind. On every floor there is 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. The system includes automatically controlled natural ventilation windows at night time, an automatic intake of outdoor air and wind floor outlets. Outdoor air intake control is based on CO_2 and temperature sensors and is controlled via BEMS.

In the mechanical air-conditioning system the supplied air flow rate is controlled by a VAV system where the fresh air flow rate is automatically controlled based on indoor CO_2 concentration.

The use of the natural ventilation system reduces the cooling energy of the building considerably, ranging from 90% in April (Spring) to a minimum of 6% in July (Summer), and continues to reduce cooling to about 62% in November (Autumn). The wind floor design on the 18^{th} floor, incorporating the automatically controlled ventilation windows on each of the other lower floors, increases the ventilation rate by 30%.

Example 2: PROBE Building, Limelette, Belgium. (Architect Y. Wauthy, Engineers BBRI)

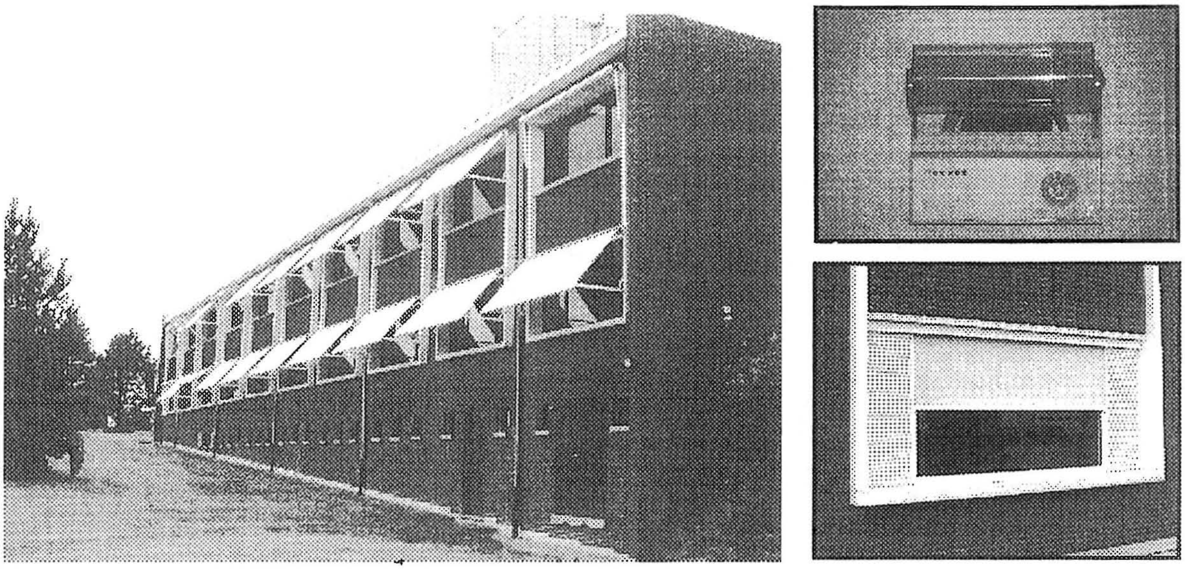

Figure 3. The PROBE building. Top right: Supply grille with presence detection. Bottom right: Louver's for intensive ventilation.

The PROBE building is a renovated office building located on the test site of the Belgian Building Research Institute (BBRI) at Limelette in a rural and very quiet environment, [1]. The hybrid ventilation principle is based on natural ventilation for achieving thermal comfort in summer and mechanical ventilation for indoor air quality control in the heating season. Currently, there is no interaction between the two systems. Each of the systems has their own goals.

Air quality in the heating season is maintained using an infrared-controlled mechanical ventilation system. Fresh air is supplied into each office at 25 m^3 per hour per person and is extracted from the lavatories. Every office has its own infrared presence sensor which restricts supply ventilation to periods in which the office is occupied. This leads to a reduction of ventilation losses of 35%. Airtight duct work and a well-regulated fan are important conditions for the proper operation of this system.

The major problem of the existing building was overheating in summer. An overall solution strategy is chosen that includes passive measures (solar shading, roof insulation, intelligent lighting) and intensive night ventilation with the objective to cool down the internal mass of the building with cold external air for improved daytime thermal comfort. For night cooling the necessary high rates of natural ventilation (14 volumes per hour on average) are provided by means of large grilles located on both sides of the building. Monitoring activities in the summer of 1997 and 1998 have shown significant improvement in thermal comfort. Measurements showed that the indoor temperature remained below 27°C even when the outdoor temperature was above 31°C.

Example 3: B&O Headquarters, Struer, Denmark. (Architect KHR A/S, Engineers Birch & Krogboe A/S)

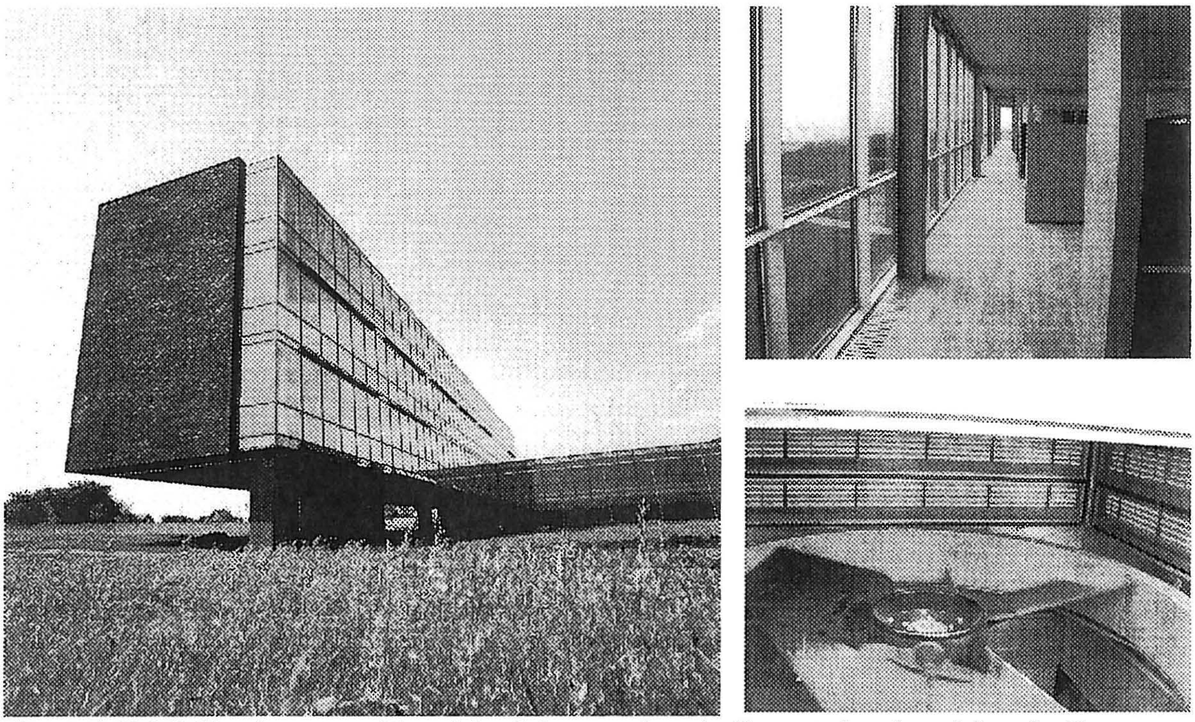

Figure 4. B&O Headquarters. Top right: Inlet openings in floor at the glazed facade. Bottom right: Axial fan at the top of the stairwell.

The B&O headquarters is a three-storeyed open plan office building. The hybrid ventilation principle is stack and wind driven natural ventilation with fan assistance. The north facade, which is shown in figure 4, is fully glazed. Outdoor air is supplied and preheated through low-positioned ventilation windows placed in a narrow band in the glazed north facade at each floor. Ribbed heat pipes, with inlet temperature sensors, are used to preheat the supply air in the heating season. The south facade has a moderate window area for daylighting and has user-controlled windows which are automatically controlled at night to cool the building. Air is extracted through the top of two stairwells which are open to the office floors. Two frequency-controlled axial fans that assist the natural driving forces are located at the top of the stairwells. The fans are controlled by CO_2 sensors in the rooms or air velocity sensors in the extracts. Baffles of sound-absorbent material are placed at the top of the stairwells to reduce the noise level of the fans to a specified low level.

The hybrid ventilation system is automatically controlled by CO_2 level, room temperature or occupancy. The hybrid ventilation system is active according to a certain time schedule or when the building is occupied. The BEMS system has three control modes: Constant mode based on time schedule or occupancy, CO_2 mode based on time schedule and occupancy or a night cooling mode with fan support based on room temperature.

Preheating of supply air reduces the risk of draught in cold periods and will therefore lead to improved thermal comfort. Displacement ventilation with supply openings in the floor is used as air distribution principle to increase ventilation efficiency. Occupants can increase the air change rate by opening supplementary windows and the risk of overheating is reduced by use of night time ventilation.

RECENT PAPERS ON INDOOR ENVIRONMENTAL ENGINEERING

PAPER NO. 109: E. Bjørn: *Simulation of Human Respiration with Breathing Thermal Manikin*. ISSN 1395-7953 R9944.

PAPER NO. 110: P. Heiselberg: *Hybrid Ventilation and the Consequences on the Development of the Facade*. ISSN 1395-7953 R0033.

PAPER NO. 111: P. Heiselberg, M. Pedersen, T. Plath: *Local Exhaust Optimization and Worker Exposure*. ISSN 1395-7953 R0034.

PAPER NO. 112: K. Svidt, P. Heiselberg: *Push-Pull Ventilation in a Painting Shop for Large Steel Constructions*. ISSN 1395-7953 R0035.

PAPER NO. 113: P. Heiselberg: *Design Principles for Natural and Hybrid Ventilation*. ISSN 1395-7953 R0036

PAPER NO. 114: A. Andersen, M. Bjerre, Z.D. Chen, P. Heiselberg, Y. Li: *Experimental Study of Wind-Opposed Buoyancy-Driven Natural Ventilation*. ISSN 1395-7953 R0037

PAPER NO. 115: P. Heiselberg, K. Svidt, P.V. Nielsen: *Windows - Measurements of Air Flow Capacity*. ISSN 1395-7953 R0040

PAPER NO. 116: K. Svidt. P. Heiselberg, P.V. Nielsen: *Characterization of the Airflow from a Bottom Hung Window under Natural Ventilation*. ISSN 1395-7953 R0041

PAPER NO. 117: Z. Yue, P.V. Nielsen: *Flow Pattern in Ventilated Rooms with Large Depth and Width*. ISSN 1395-7953 R0042.

PAPER NO. 118: P.V. Nielsen, H. Dam, L.C. Sørensen, K. Svidt, P. Heiselberg: *Characteristics of Buoyant Flow from Open windows in Naturally Ventilated Rooms*. ISSN 1395-7953 R0043.

PAPER NO. 119: P.V. Nielsen, C. Filholm, C. Topp, L. Davidson: *Model Experiments with Low Reynolds Number Effects in a Ventilated Room*. ISSN 1395-7953 R0044.

PAPER NO. 120: P. Lengweiler, P.V. Nielsen, A. Moser, P. Heiselberg, H. Takai: *Experimental Method for Measuring Dust Load on Surfaces in Rooms*. ISSN 1395-7953 R0045.

PAPER NO. 121: L. Davidson, P.V. Nielsen, C. Topp: *Low-Reynolds Number Effects in Ventilated Rooms: A Numerical Study*. 1395-7953 R0046.

PAPER NO. 122: F. Haghighat, H. Brohus, C. Frier, P. Heiselberg: *Stochastic Prediction of Ventilation System Performance*. ISSN 1395-7953 R0047.

PAPER NO. 123: H. Brohus, F. Haghighat C. Frier, P. Heiselberg: *Quantification of Uncertainty in Thermal Building Simulation. Part 1: Stochastic Building Model*. ISSN 1395-7953 R0048.

PAPER NO. 124: H. Brohus, F. Haghighat C. Frier, P. Heiselberg: *Quantification of Uncertainty in Thermal Building Simulation. Part 2: Stochastic Loads*. ISSN 1395-7953 R0049.

Complete list of papers: http://iee.civil.auc.dk/i6/publ/iee.html

ISSN 1395-7953 R0036

Dept. of Building Technology and Structural Engineering
Aalborg University, December 2000
Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark
Phone: +45 9635 8080 Fax: +45 9814 8243
http://iee.civil.auc.dk