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Energy-saving potential of a novel ventilation system with decentralised fans in an office building

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ABSTRACT

This study is part of a long-term research work concerning the development of a mechanical ventilation system with low energy demand.

Through use of decentralised fans instead of flat plate dampers pressure drop over dampers can be eliminated. Consequently, the main fan does not need to be dimensioned for the total pressure drop in the entire duct system – but only for the branch with the lowest pressure drop. Hence, the energy demand is reduced.

The methodical procedure for converting a conventional ventilation system with dampers into a system with decentralised fans has been explained in a previous study.

The purpose of the present study was to corroborate experimentally the energy saving potential predicted theoretically. Furthermore, in order to relate to realistic size ventilation systems analyses have been undertaken based on an existing office building intended for 50 occupants.

The findings are that the results of the experimental studies correspond well with the theory for the performance of a ventilation system with decentralised fans and that the expected energy savings are achievable. Analyses of the results of the calculations on the real-size office building show energy savings of about 30% when compared to a conventional ventilation system with dampers.

1. Introduction

Energy savings and energy efficiency are important parts of the Danish national energy policy. Due to further restrictions on the energy demand of office buildings stipulated in the present Danish Building Regulations as well as in the coming regulations expected to be in force from 2015 to 2020, emphasis on reduction of energy used for ventilation is needed [1].

Correct dimensioning and design of ventilation systems can reduce the energy demand of fans and result in lower operational costs [2–4]. Analyses of mechanical ventilation systems in office buildings show a potential for energy savings by using new components [5].

Reduction of energy demand for ventilation has been studied intensively. Many of the studies focus on natural ventilation while others focus on hybrid ventilation, because these technologies eliminate or decrease the energy demand for fans [6,7]. For the mechanical ventilation system in [8], the natural ventilation system in [9] and the hybrid ventilation system in [10] significant reductions in the energy demand were obtained. One drawback for those systems is that they require large structural spaces to be integrated in the building; which are costly due to decreased working or living space. Low energy consuming ventilation system requires large space to obtain low pressure drop and low velocity in the ducts. Apparently there is lack of solutions and knowledge on how to design low energy consuming ventilation systems with limited building space.

One of the major potentials for energy saving is reducing the energy demand for the fan for transport of air in the system. The required energy for the fan depends on the air flow rate, fan efficiency, operating hours and last but not least the total pressure drop in the system [11]. In order to reduce the energy demand for the fan it is essential to improve the integration of ventilation systems in the buildings and reduce pressure drops in diffusers, duct system and air handling unit [1,6,12,13]. Another key aspect for decreasing the energy demand is to customise the flow rate to the actual demand so that the control system has a significant impact on both operating hours and energy demand for the fan [14–17].

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The development of energy-efficient fans opens up for new designs of ventilation systems. A study [18] shows that improved motor technology for small fans provides new opportunities for the design of air distribution systems. In a study [19], integration of decentralised fans in a ventilation system was tested. The integration of decentralised fans in the duct system lowered the dimensioning pressure for the main fan. Due to the lower pressure, the efficiency of the existing main fan decreased from 34% to 15%. Because of the low efficiency of the main fan the results of the experiments could not verify any energy savings.

This paper presents the study of an experimental mock-up in a laboratory environment in order to demonstrate the principal performance of the proposed ventilation system with decentralised fans compared with a traditional system with dampers. In addition, the study focuses on the energy saving potential of the proposed ventilation system in a real office building. A dimensioning method developed in a previous study [20] is here used to demonstrate the magnitude of the energy-saving potential and to demonstrate the use of decentralised fans instead of flat plate dampers in a real office building.

2. Novel ventilation system design

A ventilation system should provide the correct amount of air to comply with ventilation requirements and moreover the airflow should be supplied using a minimal amount of energy. This paper presents a ventilation system developed to lower the total energy requirement for ventilation.

In order to reduce the total energy demand, a system with flat plate dampers was replaced with a system with decentralised fans. For an ordinary ventilation system, the main fan is dimensioned to provide the total airflow and the total pressure to meet the requirement for a nominal airflow and to overcome the largest pressure drop in the system, see branch D in Fig. 1a. For the new system, the main fan was dimensioned to deliver the total airflow and the total pressure to meet the requirement for a nominal airflow and to overcome the pressure in the branch with the lowest pressure drop, see branch A in Fig. 1b. Then, the decentralised fans provided the exact pressure to overcome the related pressure drop [21].

One of the challenges of designing an air distribution system with decentralised fans was the efficiency of the decentralised fans. In order to lower the energy demand the decentralised fans had to be selected with the exact operating points for the related pressure drop and airflow, hence the highest fan efficiency available.

The total energy demand of the decentralised fans must be less than the difference between the energy demand of the main fan in a conventional ventilation system and the energy demand of the main fan in the ventilation system with decentralised fans, see Eq. (1).

$$\sum P_{\text{decentralised fans}} < P_{\text{CAV}} - P_{\text{main fan dec fan system}} \quad (1)$$

where $P_{\text{decentralised fans}}$ is the energy demand of each of the decentralised fans [W], P_{CAV} is the energy demand of the main fan in a system with dampers [W], $P_{\text{main fan\_dec fan system}}$ is the energy demand of the main fan in a system with decentralised fans [W].

3. Method

The purpose of the present study was to corroborate experimentally the energy saving potential predicted theoretically. First a mock-up of a ventilation system was tested in a laboratory environment. Then, a real size ventilation system was used to calculate the potential for energy saving when changing a traditional ventilation system with dampers to the new system with decentralised fans.

Table 1
Airflow in the distribution system.

	q_{total} (m^3/s)	q_A (m^3/s)	q_B (m^3/s)	q_C (m^3/s)	q_D (m^3/s)
1	0.060	0.015	0.015	0.015	0.015
2	0.080	0.020	0.020	0.020	0.020
3	0.100	0.025	0.025	0.025	0.025
4	0.140	0.035	0.035	0.035	0.035

3.1. Experimental mock-up

The principal performance of the proposed ventilation system with decentralised fans compared with a traditional system with dampers was demonstrated with a mock-up of the two ventilation systems in a laboratory environment. In Fig. 2 the dimensions of the distribution system can be seen. The black dots show where static pressure and air velocity was measured.

To see the difference in pressure between a traditional ventilation system and a ventilation system with decentralised fans two mock-ups of a ventilation system was tested – one with dampers and one with decentralised fans.

Static pressure and air velocity in the distribution system was measured for eight different set-ups. The measurements were for four different total air flows for the system with dampers and four different total airflows for the system with decentralised fans. The total airflow was distributed to the ducts with equal airflow in all four ducts.

Table 1 Airflow in the distribution system The main fan for both distribution systems was a centrifugal fan with backward curved blades from ebmpapst with a diameter of 190 mm. From the manufacturer the specified maximum efficiency of the fan is 49%. For the conventional distribution system the dampers were a manually adjusted type DRU from Lindab with a diameter of 125 mm. The tested decentralised fans were axial fans also from ebmpapst with a fan diameter of 127 mm. According to the manufacturer the maximum efficiency of the decentralised fans is approximately 25%.

The mock-up was built in a laboratory environment with an average temperature of 20 °C and a relative humidity of 45%.

Measurement device accuracy – Pressure and air velocities were measured by means of a handheld Testo measurement instrument 645. According to the manufacturer the accuracy of the Testo device is ±0.03 m/s for the air velocity and ±0.5% for the pressure. The measurement points are marked with black dots in Fig. 2.

The measurements of pressure and velocity were done to map the pressure levels and air flows in the duct system. Measurement points were placed with a minimum of five times the hydraulic diameter downstream of an obstacle [22].

All measurements were made with an interval of 1 second and calculated as an average of 3 min. At all measurement points the velocity measurements were conducted in three levels. The static pressure measurements were conducted with a pitot tube in the top part of the ducts.

3.2. Office building as a test case

The experiment led to results that support the technology of using decentralised fans to lower the total pressure drop in a ventilation system. On basis of the experiments calculations were carried out for a ventilation system in an office building to demonstrate the magnitude of potential for energy saving.

This part of the study was based on calculations of a two-storey office building intended for 50 occupants with floor plan dimensions of 35 × 15 m and total air flow of 0.108 m^3/s. The two floor plans of the office building consisted of twelve single offices with one ventilation inlet in each room, three medium-sized office rooms with two inlets and one large office space with four inlets, see Fig. 3.