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Energy savings and manifold supply ventilation systems

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ABSTRACT

The total energy demand for mechanical ventilation systems depends on the pressure drop. Except for fans, any component in a mechanical ventilation system creates a pressure drop. The fan has to provide a sufficient pressure to compensate for the pressure drop caused by the components.

A reduction of the energy required for ventilation is therefore a question of limiting the pressure drop in the individual components. In this study, a mechanical ventilation system incorporating a manifold with multiple fans was designed aiming at reducing the energy consumption for the main fan by decreasing the pressure drop.

The key advantage of using a manifold is that it is suitable for residential buildings with limited space for air handling unit and duct-work. In this study, the use of a manifold in combination with multiple fans instead of dampers is presented.

The results from the experimental studies supported the conclusion that a ventilation system with manifold and multiple fans required 40% less energy compared with a ventilation system with manifold and dampers.

1. Introduction

Energy savings are important parts of the Danish national energy policy. Ventilation in buildings is energy intensive. In Denmark, the energy consumption of buildings is about 40% of the total energy consumption, of which electricity consumption for the operation of ventilation systems accounts for 30–50% of the energy consumed [1,2].

The energy use for a fan is dependent on the pressure drop, the airflow, the time and the efficiency of the fan. To reduce energy costs one of the challenges is to design air distribution system with a minimum of bends and obstacles in the duct system to have as low a pressure drop as possible. Assuming that the fan in the distribution system has a high efficiency, the energy demand will therefore be as low as possible. According to the fan affinity laws correct dimensioning and design of ventilation systems can reduce the energy used by fans and result in lower operational costs [3–5].

Assuming that a ventilation system is designed with the lowest pressure drop possible and with the most energy efficient components on the market; then the question is: *How can the pressure drop be reduced further without compromising the indoor climate?*

Dampers are usually used to control the airflow in a distribution system. When a damper is used there is always an overpressure across it. This is because the fan is dimensioned to deliver the maximum pressure and airflow to the entire system.

In this paper, a novel design of a mechanical ventilation system with manifold and fans is used to lower the pressure drop in comparison with a mechanical ventilation system with manifold and dampers. By using fans in the manifold, the pressure drop in the ventilation system is lowered by eliminating the pressure drop across the dampers.

One of the advantages of using a manifold for ventilation is that manifold systems are perfectly designed for residential buildings. The ventilation unit is directly connected to the manifold with a duct that fits the size of the ventilation unit. The airflow from the unit goes into the manifold and is managed within and distributed through smaller ducts in the manifold. Because the ducts are connected in parallel, there is no need for additional sound absorbers to eliminate cross talk [6].

A previous study described the balancing method of a mechanical ventilation system with multiple decentralised fans. It was found that it is possible to balance a ventilation system with decentralised fans instead of dampers. Further, it was concluded that energy saving can be obtained. The magnitude of the energy saving is dependent on the pressure difference between the branch with the least pressure and the branch with the highest pressure [7].

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The energy performance of a mechanical ventilation system with multiple decentralised fans implemented in an office building was analysed in a previous paper. The authors conclude that savings of up to 30% on the required energy can be achieved when compared with a conventional mechanical system with flat plate dampers [8].

The objective of this study was to examine the energy saving potential of manifold supply ventilations systems. This paper presents the study of an experimental mock-up in a laboratory environment in order to examine the performance of a ventilation system with manifold and fans compared with a ventilation system with manifold and dampers. The study focused on the energy-saving potential of the proposed ventilation system in a residential building in Copenhagen, Denmark.

2. Method

2.1. Ventilation system with manifold and dampers

In a traditional ventilation system, flat plate dampers are used to regulate airflows, see Fig. 1. This ensures an air distribution in accordance with the desired airflows in different rooms. A ventilation unit is directly connected to the manifold with a diameter of the duct to match the spigot size of the ventilation unit.

For example, a ventilation unit with a given diameter spigot would have the same diameter primary duct connecting the unit to the manifold. The airflow from the ventilation unit is supplied to the manifold. The airflow from the manifold can be controlled by dampers to the various rooms. The balancing dampers set the airflows to meet the design requirements.

When dampers are required, the fan needs to be able to produce the necessary airflow and pressure required for the entire system. This gives an overpressure across all of the dampers.

2.2. Novel design of a manifold with fans instead of dampers

For this novel design, the ventilation system with dampers was converted into a new system with fans instead of dampers, see Fig. 2. When the dampers were replaced with fans, the overpressure in the duct system was eliminated.

In Fig. 3, a simple visualisation of the dimensioning method is shown. The diagram to the left shows a ventilation system with dampers and equal airflow in all branches. In the system with dampers, the fan has to be dimensioned according to the total airflow and the maximum pressure – which corresponds to branch D.

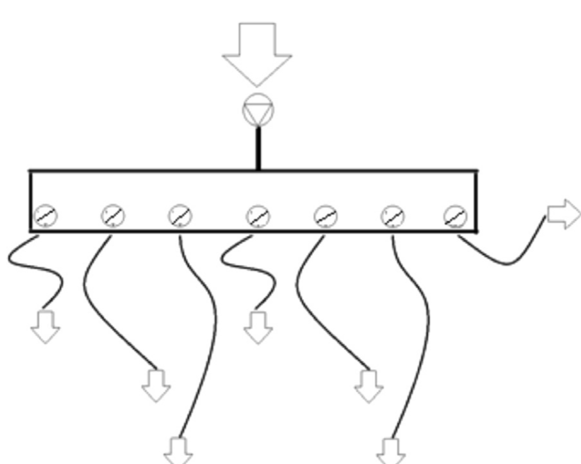

Fig. 1. Sketch of a manifold with 7 dampers and 1 main fan.

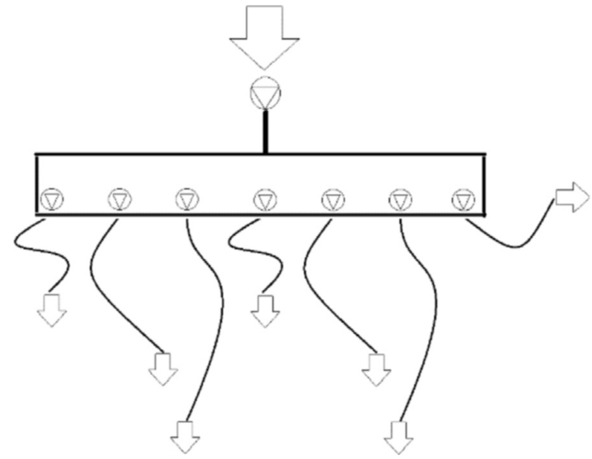

Fig. 2. Sketch of a manifold with 1 main fan and 7 fans instead of 7 dampers.

The diagram on the right shows a ventilation system with fans and equal airflow in all branches. The fans in the branches all have different operating points and thereby they assure that equal airflow is attained. In the system with multiple fans, the main fan only had to be dimensioned for the total flow and the branch with the least pressure – in this case branch A [7].

Fig. 4 shows the system characteristic for the two different ventilation systems. In the figure, it can be seen that there is a potential for energy saving when using fans to balance the air in a ventilation system [8]. The magnitude of the energy saving is dependent on the efficiency of the fans.

2.3. The ventilation system

The calculations and experimental mock-up was based on the layout of the ventilation system in an apartment in a residential building. The ventilation system consisted of 7 inlets, 4 exhausts and 1 kitchen hood. The ventilation system had three different settings for the airflow rate; low, medium or high air change rate. These rates corresponded to inlet volume airflow rates of 55 m^3/h, 185 m^3/h or 370 m^3/h respectively.

Experimental mock-ups of the supply ventilation system with manifold and dampers and the novel supply ventilation system with manifold and fans were carried out in a laboratory environment.

The manifold had an inlet diameter of 315 mm and seven outlets with diameter of 100 mm; see Fig. 5.

Static pressure and air velocity in the distribution system was measured for six different set-ups. The measurements were made for three different total airflows for the system with dampers and three different total airflows for the system with fans. The total airflow was distributed as shown in Table 1.

For both distribution systems, the main fan was a centrifugal fan with backward curved blades with a diameter of 190 mm, manufactured by ebmpapst. For the distribution system with dampers, the flat plate dampers were a manually adjusted type DRU from Lindab with a diameter of 125 mm. The tested fans were axial fans also manufactured by ebmpapst. In order to achieve the required airflows, three different fans were chosen. The fan type fixed to the first two inlets was 8412 ($80 \times 80 \times 25$ mm), the fan type fixed to the third and fourth inlets was 3412 ($92 \times 92 \times 25$ mm) and the fan type fixed to the last two inlets was 5214 ($127 \times 127 \times 38$ mm).

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

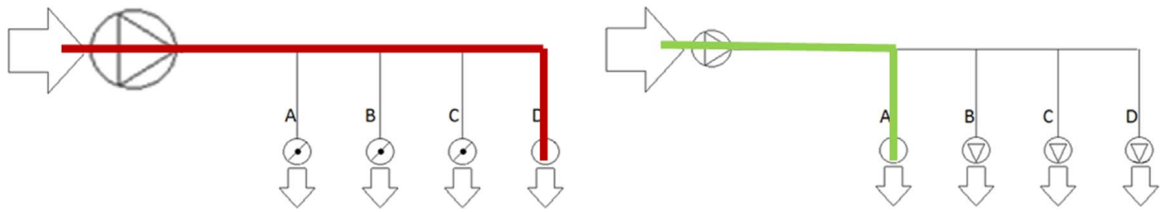

Fig. 3. Simple visualisation of the dimensioning method. To the left is a supply duct system with dampers. To the right is a supply duct system with fans.

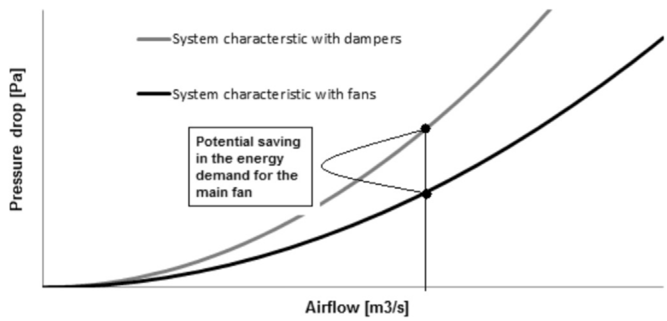

Fig. 4. System characteristic for a ventilation system with dampers (grey) and a ventilation system with fans (black). The black dots show the operating points for the two systems with the same supply airflow. The difference in pressure is the potential saving in the energy demand for the main fan.

645. According to the manufacturer, the accuracy of the Testo device is ± 0.03 m/s for the air velocity and $\pm 0.5\%$ for the pressure.

The static pressure and the velocity were measured in the duct after the main fan and in the seven ducts from the manifold, see Fig. 6. Measurement points were placed at a minimum of five times the hydraulic diameter downstream of an obstacle [9].

All measurements were made at 1-s intervals and calculated as an average of 3 min. In all measurement points, the velocity measurements were conducted at three levels. The static pressure measurements were conducted with a tube in the top part of the ducts. The measurement method had an accuracy of $\pm 3\%$.

Table 1
Dimensioned airflow in the distribution system.

	q_{total} m^3/h	q1 m^3/h	q2 m^3/h	q3 m^3/h	q4 m^3/h	q5 m^3/h	q6 m^3/h	q7 m^3/h
Low	55	7	6	6	9	9	9	9
Medium	185	25	20	20	30	30	30	30
High	370	50	40	40	60	60	60	60

3. Energy saving potential

Highly efficient fans are an essential part of a low-energy ventilation system. It is important that the fans are correctly dimensioned and well integrated to obtain appropriate flow conditions and high fan efficiency [10]. The power demand of a fan in a conventional ventilation system was calculated from Eq. (1):

$$P = \frac{\Delta p \cdot q}{\eta} \quad (1)$$

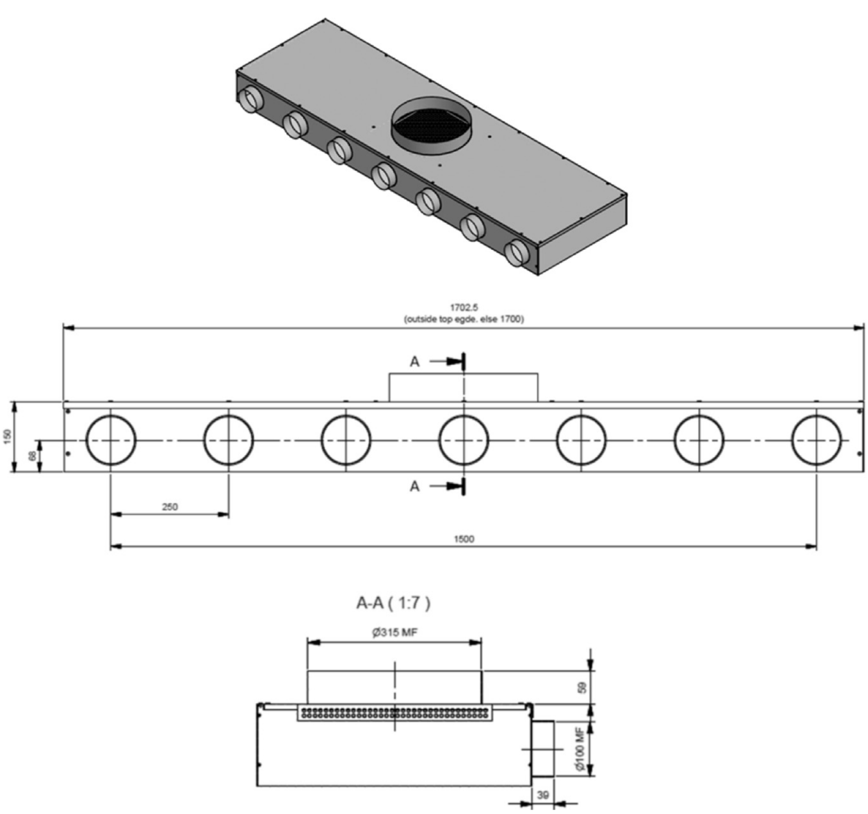

Fig. 5. Dimensions of the manifold with 1 inlet for the main fan and 7 inlets for the balancing fans.

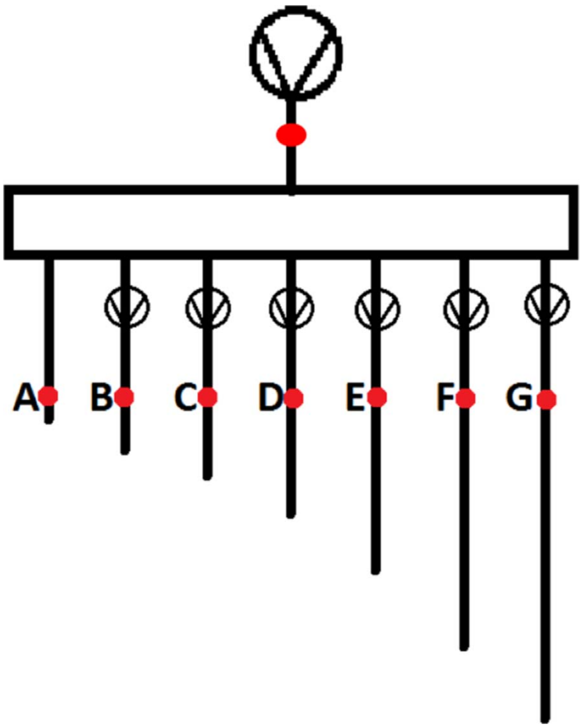

Fig. 6. The red dots indicate the measurement points for the static pressure and velocity. The main duct has a diameter of 160 mm and the 7 ducts from the manifold has a diameter of 63 mm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

where P is the power demand [W]; Δp is the fan pressure [Pa]; q is the airflow rate [m^3/s]; η efficiency [–].

3.1. Power demand

The power demand of the main fan in the conventional system with flat plate dampers was calculated from Eq. (2):

$$P_{CAV} = \frac{\Delta p_{CAV} \cdot q_{CAV}}{\eta_{CAV\ fan}} \tag{2}$$

where P_{CAV} is the power demand of a system with dampers [W]; Δp_{CAV} is the fan pressure for the main fan in the CAV system [Pa]; q_{CAV} is the airflow rate for the CAV system [m^3/s]; $\eta_{CAV\ fan}$ is the efficiency of the fan for the CAV system [–].

The power demand of a system with decentralised fans was from Eq. (3) expressed as Eq. (3):

$$P_{dec\ fan\ system} = \frac{\Delta p_{mainfan} \cdot q_{dec\ system}}{\eta_{mainfan}} + \sum_{i=1}^{n} \frac{\Delta p_{decfan,i} \cdot q_{decfan,i}}{\eta_{decfan,i}} \tag{3}$$

where $P_{dec\ fan\ system}$ is the total power demand of a system with a main fan and decentralised fans [W]; $\Delta p_{main\ fan}$ is the fan pressure for the main fan in the system with decentralised fans [Pa]; $q_{dec\ system}$ is the total airflow rate for the system with decentralised fans [m^3/s]; $\eta_{main\ fan}$ is the efficiency of the main fan for the system with decentralised fans [–]; $\Delta p_{dec\ fan,i}$ is the fan pressure for the decentralised fan,$_i$ [Pa]; $q_{dec\ fan,i}$ is the airflow rate for the decentralised fan,$_i$ [m^3/s]; $\eta_{dec\ fan,i}$ is the efficiency of the decentralised fan,$_i$ [–].

In order not to exceed the power demand of the main fan in the system with dampers, the decentralised fans must have a minimum efficiency compared with the efficiency of the main fan in the system with dampers.

Table 2
Corresponding airflow and pressure for dimensioning of the main fan.

	q_{total} [m^3/h]	Δp [Pa]	Reduced pressure for the main fan [%]
Manifold with dampers	55	1.5	
Manifold with dampers	185	13.5	
Manifold with dampers	370	49	
Manifold with fans	55	0.3	80
Manifold with fans	185	3	80
Manifold with fans	370	11	80

4. Results and discussion

Section 4 focuses on the results of the calculation and the experimental mock-ups to validate the energy saving potential of the novel ventilation system with manifold and multiple fans. Analysis of the calculations showed that there is a potential energy saving of 40%, when installing a manifold with fans compared with a regular manifold with dampers.

The calculations were based on the method described in the previous Section 2.1 and the energy saving potential described in Section 3.1 [7]. Mock-ups of a ventilation system with manifold and fans and a ventilation system with manifold and dampers were tested in a laboratory environment in order to verify the calculations in terms of static pressure and air velocity. Evaluation of performance and applicability was also carried out by means of calculations and experimental mock-ups.

4.1. Calculated dimensioning pressure for the main fan

The difference between the dimensioning pressure for the main fan in the ventilation system with fans and the dimensioning pressure for the main fan in the ventilation system with dampers gives an indication of the potential for energy saving. In Table 2 the dimensioning pressure for the main fan for the two systems are shown. The reduced pressure for the main fan is the difference in percentage between the dimensioning pressure for the main fan in the manifold system with dampers and the dimensioning pressure for the main fan in the manifold system with fans.

4.2. Fans

4.2.1. Efficiency of the fans in the manifold

The efficiency of the multiple fans in the manifold is decisive so that the total energy consumption of the fans does not exceed the energy saved by reducing the dimensioning pressure.

For fans to have minimum energy consumption the fans has to operate with the maximum efficiency. For this system all the fans have different operating points and it is therefore essential to carefully select the right fans in order to keep the energy

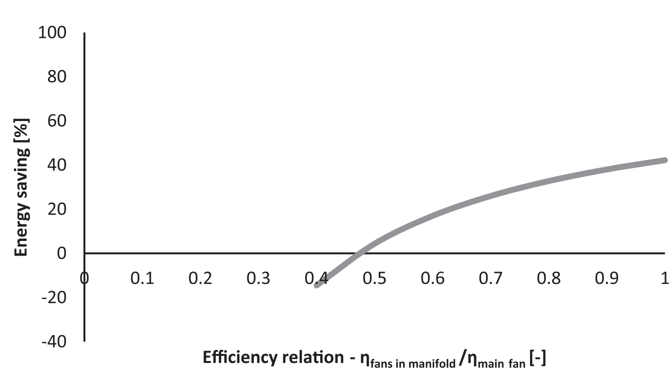

Fig. 7. Relation of the energy saving and the efficiency of the fans in the manifold.

consumption at a minimum.

The energy consumption of the multiple fans depends on their efficiency. Fig. 7 shows the energy saving as a function of the relation between the efficiency of the fans in the manifold and the efficiency of the main fan in a system with dampers.

Fig. 7 shows that when replacing a manifold with flat plate dampers with a manifold with fans, the magnitude of the energy saving depended on the efficiency of the fans in the manifold.

The correlation between the energy saving and the efficiency of the fans in the manifold can be seen from Fig. 7. There was an energy saving of 42% when the fans in the manifold had the same efficiency as the main fan ($\eta_{\text{fans in manifold}}/\eta_{\text{main fan}}=1$). The energy saving decreased to approximately 4%, when the efficiency of the fans in the manifold was half the efficiency of the main fan ($\eta_{\text{fans in manifold}}/\eta_{\text{main fan}}=0.5$).

When the fans in the manifold had an efficiency of less than 48% of the efficiency of the main fan in the system with dampers, a negative energy saving was noticed.

This means that the energy saving potential was determined by the efficiency of the fans.

Example: The main fan in the traditional manifold with dampers has an efficiency of 70%. The fans in the manifold then need a minimum efficiency of 33% ($0.48 \cdot 70$) in order not to exceed the energy consumption of a system with dampers.

4.2.2. Theoretical analysis of manifold with or without main fan

In order to lower the maintenance cost and improve the applicability, it is an option to develop the manifold without a main fan and only have fans in the manifold, see Fig. 8.

When the main fan was removed, the dimensioning pressure for the fans in the manifold changed which means that the fans in the manifold needed to provide a larger pressure, see Fig. 9.

In Fig. 9 the pressure distribution with (to the left) and without (to the right) main fan is presented.

The dark grey columns show the pressure distribution for the manifold with dampers. The light grey columns on the graph to the left show the pressure distribution for a manifold with a main fan and multiple fans. The light grey columns on the graph to the right show the pressure distribution for the manifold only with fans in the manifold.

When the main fan was dimensioned to overcome the pressure for the branch with the least pressure, then the pressure distribution on the remaining branches was lower than when the main fan was eliminated.

This means that when there was no main fan, then the multiple fans in the manifold had to overcome a larger pressure and therefore the performance of the fans had to be higher than for the system with a main fan. In the ventilation system with a main fan, the pressure that the multiple fans needed to overcome was smaller and therefore the performance of the fans did not need to be as high as for the system without a main fan.

In the investigated system, the efficiency required of the multiple fans in the manifold increased from 48–59% in correlation to the efficiency of the main fan in the system with dampers. This means that the energy-saving potential decreased when there was no main fan.

Example: The main fan in a traditional manifold with dampers has an efficiency of 70%. The fans in the manifold then require a minimum efficiency of 33% ($0.48 \cdot 70$) when there is a main fan or 41% ($0.59 \cdot 70$) when there is no main fan.

4.3. Full scale measurements

A mock-up of a ventilation system with manifold was tested in a laboratory environment in order to verify the calculations in terms of static pressure and air velocity. Fig. 10 illustrates the calculations of a system characteristic and the measured results for the ventilation system with manifold and dampers and the results for the system with manifold and fans.

The measured data is from the full scale experiment where the total static pressure were measured according to the airflow.

Fig. 10 illustrates that the results of the full-scale experiment shows the same trend as the calculations. The percentage difference between the experimental measurements and the numerical values was in the range from 11 to 25. As the calculations showed there is a potential for energy saving when using fans to balance the air in a ventilation system. According to the accuracy of the measurement devices, the difference between the calculations and the measurements were within a tolerable range.

The magnitude of the energy saving depended on the pressure difference between the branch with the least pressure drop and the branch with the highest pressure drop. The larger the pressure difference between the two branches – the larger potential for energy saving. Further, the saving is dependent on the efficiency of the fans, see Section 4.2.1.

In this experiment the airflow in the branches was varied in three steps; low, medium and high, see Table 2. The variation for all three steps was the same. The percentage of the pressure difference between the system with dampers and the system with fans was therefore the same (80%), see Table 2. This demonstrates that for all three steps the energy saving is the same, see Fig. 11.

The efficiency of the multiple fans has to be at least 48% of the efficiency of the main fan in the system with dampers in all three operating points (low, medium and high volume airflow); see

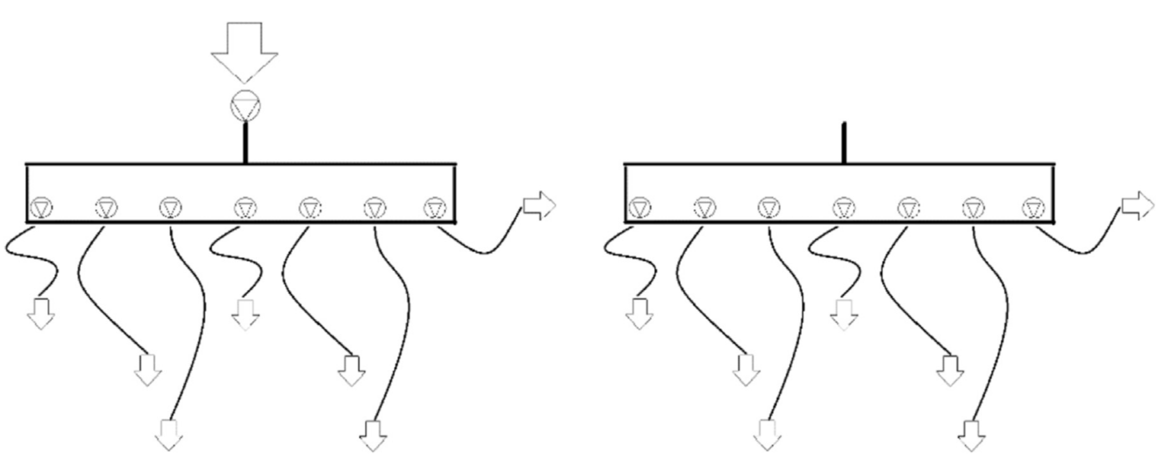

Fig. 8. Illustration of manifold with (to the left) and without main fan (to the right).

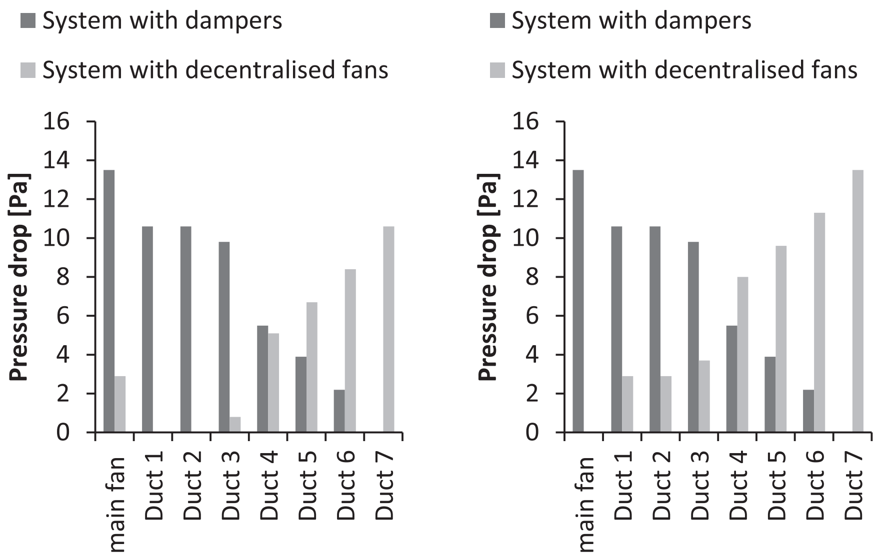

Fig. 9. Pressure distribution in the branches: right, with main fan. Left, without main fan.

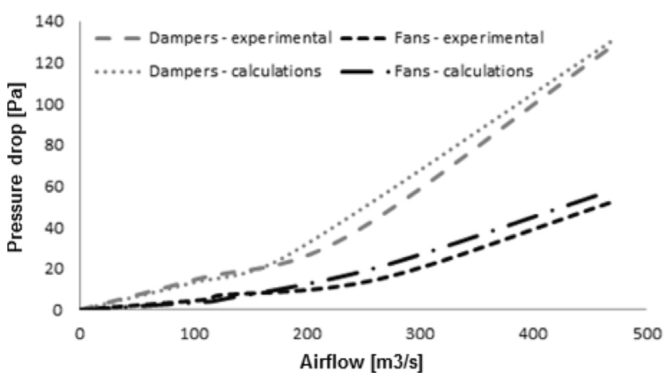

Fig. 10. Results of the corresponding pressure and airflow in the two systems. The figure illustrates the experimental results and the calculated results.

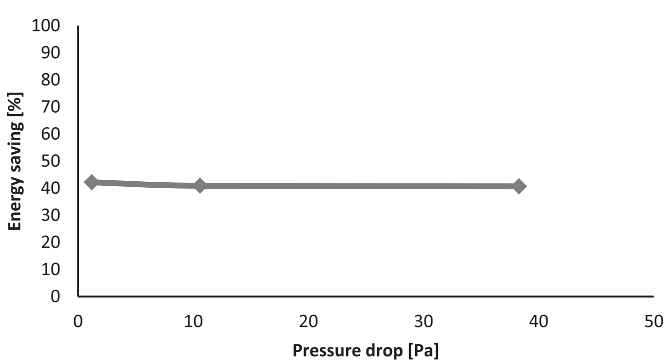

Fig. 11. Energy saving according to the pressure difference between the system with dampers and the system with multiple fans. The energy saving is the same for all three operating points if the efficiency of the multiple fans is constant.

Section 4.2.1.

For an axial fan, it is not possible to have the same efficiency in all three operating points in the preferred operating range. In general, fan efficiency increases with increased blade diameter and speed. Therefore it is essential to choose a fan with a wide operating range. It was significant that the fan had at least the minimum efficiency (in this case 48% of the efficiency of the main fan in the system with dampers) at the lowest operating point.

5. Conclusion

A mechanical ventilation system with manifold and multiple fans has been described in the form of a mock-up in a laboratory environment and a case study of a residential building.

This study confirms that by use of multiple fans instead of balancing flat plate dampers the dimensioning pressure for the main fan can be reduced and a potential for energy saving is achieved.

The degree of energy saving depends on the efficiency of the multiple fans in the manifold. For the studied ventilation system, the required fan efficiency of the multiple fans in the manifold had a minimum of 48% of the efficiency of the main fan. When the multiple fans in the manifold had an efficiency of less than 48% of the efficiency of the main fan, the energy saving was negative. When the efficiency of the multiple fans was the same as the efficiency of the main fan, the energy saving was 42%.

The manifold supply ventilation system with multiple fans is suitable for residential buildings. The manifold requires less installation space because the flexible pipes are usually smaller in diameter than ducts in a traditional ventilation system.

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