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SPATIOTEMPORAL CONTROL OF MECHANICAL EXHAUST AIR VENTILATION

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Synopsis

Centrally controlled mechanical exhaust air ventilation systems in residential buildings can satisfactorily serve only a few of the inhabitants. As the need for ventilation in each apartment varies both temporally and locally, the exhaust air ventilation system should operate accordingly.

On the basis of a new cascade-control method a selfcontained constant flow exhaust air terminal device was constructed. With the device the user can, according to his own needs, increase temporarily his own exhaust air ventilation.

The new terminal devices are suitable for a spatiotemporally controlled mechanical exhaust air ventilation system provided that the ducts are tight, the pressure in the ducts is within the operation range of the terminal devices in all points of operation, and the inside of the building is tight.

1 INTRODUCTION

The mechanical exhaust air ventilation systems in residential buildings in Finland are usually constructed as so called two-speed systems. By changing the speed of rotation of the fan the flow rate of the exhaust air may be reduced to half of its statutory value at hours during which the need for ventilation is considered to be lower. In practise the result is that the higher flow rates are used only when there is considered to be a common demand for increased ventilation. The centralized control systems, however, can satisfactorily serve only a few of the inhabitants. As the need for ventilation in each apartment varies both temporally and locally the exhaust air ventilation systems should operate accordingly.

With the new cascade control system based on exploitation of the flow's own pressure energy it had become possible to build a selfcontained constant flow exhaust air terminal device with which the inhabitant can increase his own exhaust air ventilation rate. Twenty-five constant flow terminal devices were built for the investigations. Their technical properties and suitability for a spatiotemporally controlled exhaust air ventilation system were studied both in the laboratory and in one small residential house that previously had been equipped with centralized control of exhaust air ventilation. No effort was made to construct a terminal device ready for industrial production.

2 CASCADE CONTROL METHOD

Cascade control is a new method /1-11/ for conditioning and/or control of a fluid flow by exploiting the pressure difference created by the flow itself. Cascade control is based on a flow condition according to Figure 1. An intermediate chamber is arranged in the flow duct, which is connected to the inlet space having higher pressure (p_1) with orifice d_1 and with orifice d_2 to the outlet space having lower pressure (p_3). The system is characterized by that

$$\frac{p_2 - p_3}{p_1 - p_3} = \frac{1}{k\left(\frac{d_2}{d_1}\right)^4 + 1} \qquad (1)$$

where

p_1	is	inlet pressure
p_2		intermediate pressure
p_3		outlet pressure
d_1		diameter of the inlet orifice
d_2		diameter of the outlet orifice
k		flow loss factor.

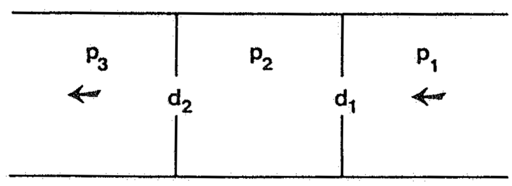


Figure 1. Flow condition in cascade control.

By equipping the intermediate chamber with a flexible wall allowing linear motion, by fastening the other end of the flow duct and by controlling with the aid of a shaped control cone for instance the free space of the outlet orifice ($d_2 = d_{ekv}$) we get a certain position between the opening and the control cone to correspond to each pressure difference ($p_1 - p_3$), Figure 2.

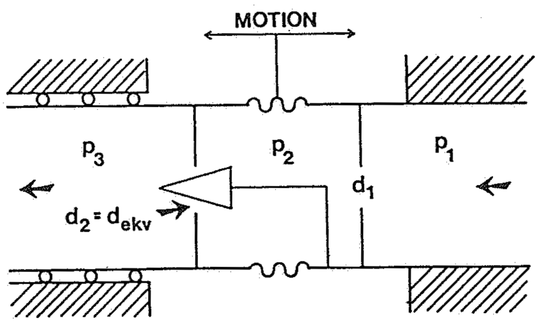


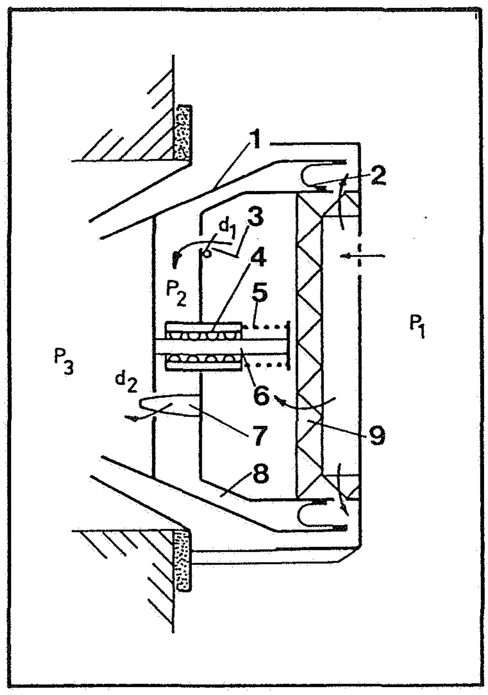
Figure 2. Cascade where the wall in the intermediate chamber is flexible and the area of outlet orifice d_2 is controlled with the aid of a control cone.

In the application the sign of the exponent on the right side of equation 1 is minus (-). In other applications the sign is according to each case either plus (+) or minus (-).

The structural principle of the selfcontained cascade controlled constant flow exhaust air terminal devices used in this investigation is shown in Figure 3. The intermediate chamber of the cascade consists of a main valve cone moving on a linear bearing. The movable valve cone is by a rolling membrane joined to the unmovable part of the intermediate chamber. The control cone has been shaped so that such a position of the movable main valve cone corresponds to each pressure difference value $p_1 - p_3$ that the main air flow of the exhaust air terminal device is constant.

A system has been connected to the constant flow terminal devices with which the control air inlet orifice d_1 can be closed. Then the main valve cone opens to a fixed open position and the main flow is increased. In this position the device is not a constant flow terminal device.

To prevent dirt from accumulating in the linear bearing and control air orifices the control air directed to the intermediate chamber is filtered.



1 Movable main valve cone
2 Rolling membrane
3 Shutter of control air inlet orifice d_1 controlled by a timer
4 Linear bearing
5 Spring
6 Shaft
7 Control cone
8 Intermediate chamber
9 Air filter

p_1 Room pressure
p_2 Intermediate chamber pressure
p_3 Duct pressure
d_1 Control air inlet orifice
d_2 Control air outlet orifice

Figure 3. Structural principle of a cascade controlled selfcontained constant flow exhaust air terminal device.

3 PRINCIPLES OF CONSTANT FLOW TERMINAL DEVICE DESIGN

The constant flow terminal devices were designed on the basis of the centrally controlled exhaust air ventilation system used in the test building, the air flow rates, the coupling sizes of the original exhaust air terminal devices, and the evaluated pressures of the exhaust air fan.

The air flows of the constant flow terminal devices were determined on the basis of the device based exhaust air flows expressed in m^3/h and presented in the Compiled Finnish Building Regulations as follows:

	Constant flow m^3/h	dm^3/s	Increased flow m^3/s	dm^3/s	Coupling size, mm
In kitchen	40	11,1	$\geq$ 80	$\geq$ 22,2	125
In bathroom	30	8,3	$\geq$ 60	$\geq$ 16,7	100

The constant flow terminal devices had to operate within the pressure difference range 100 - 200 Pa, of which the actual working range was evaluated to be 125 - 175 Pa.

Different models were made of each constant flow terminal device type both for wall and ceiling installation. Basically the different models were similar, but those of smaller air flow had been throttled more. The time for increased air flow had been limited to about 50 minutes with a timer. Different technical solutions (so called cord, mechanical, and air control) were used to set the terminal devices on increased flow, Figure 4.

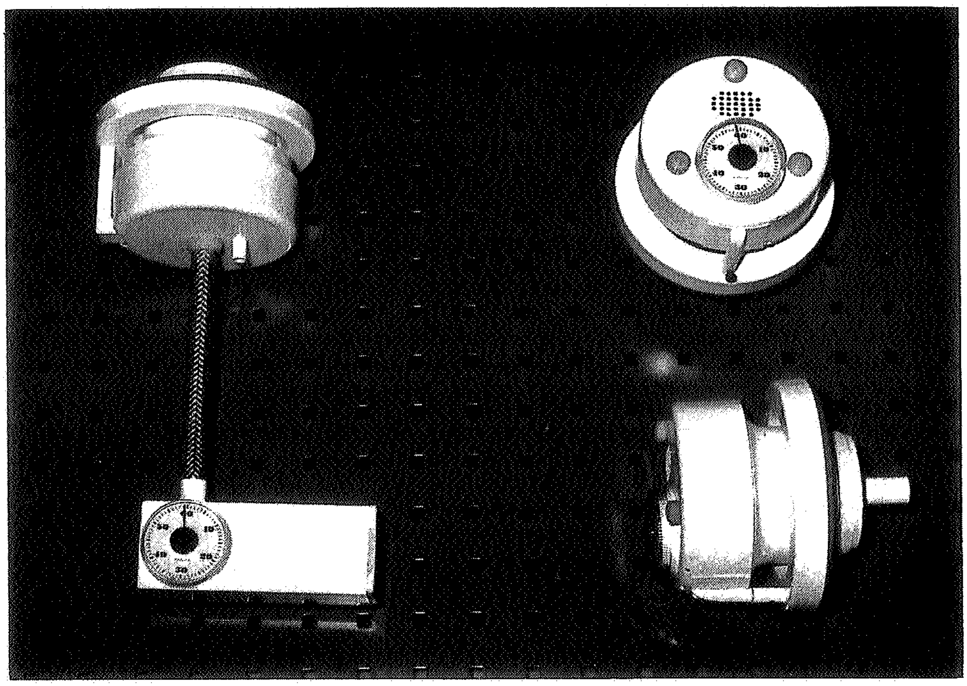


Figure 4. Two models of constant flow exhaust air terminal devices. To the left is the air operated model. The timer and the control air orifice d_1 are in a separate unit. To the right is the cord operated model. The cord to the timer is not installed.

4 PERFORMANCE OF CONSTANT FLOW TERMINAL DEVICES

4.1 Air flow

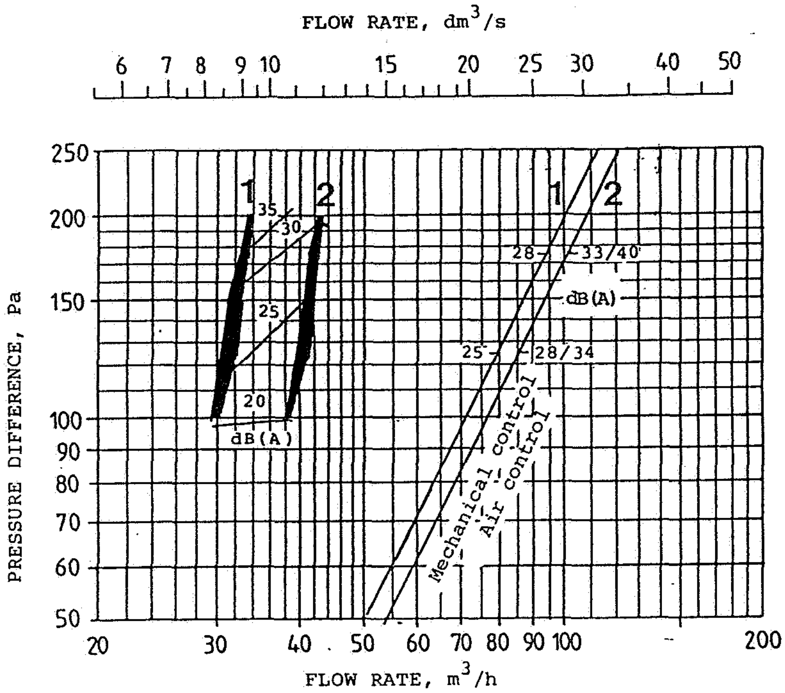
The aim was to build the constant flow terminal devices to within ± 5% air flow accuracy. As it was not possible during construction, due to production technical reasons, to realize all the known operation sensitivity affecting details (for instance mass centre of moving parts and rolling membrane dimensions) of the prototype terminal devices, the ± 10% accuracy sufficient for the air flows of ventilation installation was deemed satisfactory.

Within the pressure difference range 100 - 200 Pa the accuracy of the air flow of the constant flow terminal devices was generally better than ± 10 %, Figure 5. Within the pressure difference range 125 - 175 Pa, the accuracy of the air flow of the constant flow terminal devices installed vertically in the ceiling was better than ± 5 %. Of the constant flow terminal devices installed horizontally on the wall only one half reached this accuracy. The operation sensitivity of the constant flow terminal devices installed on the wall could be improved if the centre of the mass of the movable parts is shifted to the midpoint of the linear bearing.

The planned increased air flows were reached in bathroom terminal devices with pressure difference 70 - 80 Pa and in kitchen terminal devices with an about 110 Pa pressure difference.

4.2 Noise generation

The noise generation of the kitchen constant flow terminal devices remained below 30 dB(A) during constant flow within the whole planned pressure difference range 100 - 200 Pa. Starting from pressure difference 170 - 180 Pa a whistling sound was heard in the bathroom constant flow terminal devices. During increased flow the kitchen constant flow terminal devices were noisier than those of the bathroom, Figure 5.



1 Terminal device for 8,3/16,7 dm^3/s flow
2 Terminal device for 11,1/22,2 dm^3/s flow.

Figure 5. Average flow- and noisetechnical (10 m^2 sound absorption) properties of the constant flow exhaust air terminal devices. The values are presented at constant flow and increased flow.

4.3 Noise attenuation

The measured noise attenuation properties of one bathroom constant flow terminal device met the noise attenuation requirements presented in the Compiled Finnish Building Regulations part C6 with the exception of high frequencies, Table 1. However, at high frequencies additional attenuation of the constant flow terminal devices is easy.

Table 1. Noise attenuation of a 8,3/16,6 dm^3/s constant flow terminal device, dB.

Direction of noise attenuation	Position of adjustment	Octave band center frequency, Hz 63	125	250	500	1000	2000	4000	8000
From duct to room	100 Pa 1)	0	2	6	13	15	11	5	2
	Open 2)	0	1	4	9	11	8	5	6
From room to duct	100 Pa	1	0	4	14	16	13	5	8
	open	1	0	3	8	12	9	5	5
Calculated attenuation room→duct→room	100 Pa	1	2	10	27	31	24	10	10
	open	1	1	7	17	23	17	10	11
Requirement		-	0	4	12	14	16	16	-

1) Constant flow at 100 Pa pressure difference
2) Terminal device completely open (increased flow).

4.4 Duct pressure

In a spatiotemporally controlled exhaust air ventilation system the constant flow terminal devices operate as planned if the planned 100 - 200 Pa underpressure can be maintained in the ducts. Pressure stability in the ducts when the terminal devices are set on increased flow depends on the shape of the specific curves of the fan and ducts. The pressure in the ducts shall be separately adjusted when needed. If several constant flow terminal devices have to operate at the same time with various pressure differences due to for instance thermal forces, a considerably smaller variation can be allowed in duct pressure adjustment than in a situation when all the constant flow terminal devices operate almost with the same pressure difference.

4.5 Control air

The volume flow of the air used to control the constant flow terminal devices was smaller than 0,5 % of the exhaust air flow during constant flow. The control air was dimensioned to be taken from a space where the prevailing pressure was the same as that upstream of the constant flow terminal device.

If the pressure of the control air to the terminal devices differs from the pressure prevailing immediately upstream of the device, the flow will be affected. When the control air is taken from a space which has a higher pressure than that upstream of the terminal device, then the air flow decreases and when the pressure is lower, then the air flow increases, Figure 6.

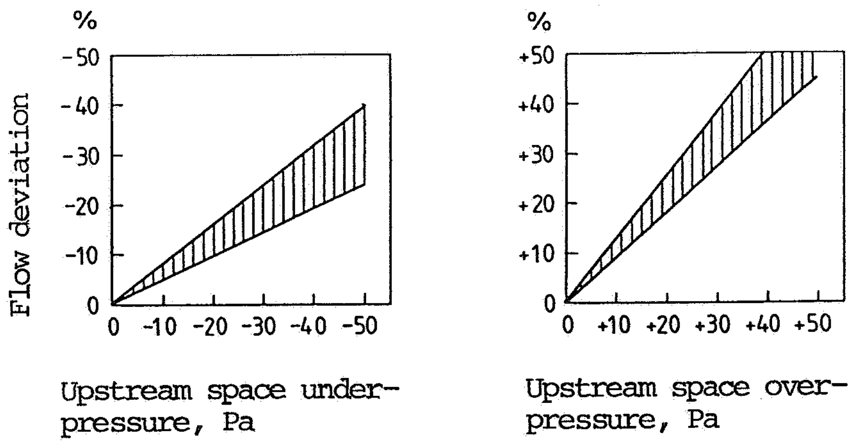


Figure 6. Flow deviation of a constant flow exhaust air terminal device at different pressure differences between upstream space of the device and the control air intake.

When the pressure difference between the control air intake and upstream of the terminal device was kept constant, the terminal device operated as a constant flow device but on a new nominal flow.

4.6 Operation speed

Measurements on the operation speed of the terminal devices showed that after a quick change of the pressure difference of the terminal devices, constant flow was reached within 10 seconds. The terminal devices did not react on quick oscillations of the pressure difference.

5 FIELD MEASUREMENTS

5.1 Follow-up measurements in the test building

The follow-up measurements were made in a small three storey residential building, where the exhaust air ventilation system used, which was equipped with centralized control (two-speed system), was first studied. Then the original exhaust air terminal devices in the existing exhaust air ventilation system were replaced with constant flow terminal devices. The aim of the follow-up measurements was to study the performance of the constant flow terminal devices and to clarify the operational prerequisites of a spatiotemporally controlled exhaust air ventilation system.

In installation and follow-up measurements of the spatiotemporally controlled exhaust air ventilation system in the test building we could not use the results of system tests made in the laboratory with constant flow terminal devices, because the laboratory tests could not be made until the follow-up measurements had started.

In measurements of the centrally controlled exhaust air ventilation system several leaks could be detected in the ducts. When the air flows in the original exhaust air terminal devices had been correctly adjusted, the total air flow of the main ducts was about 50 % larger than the planned air flow.

Reduction of the noise caused by the large leaks in the ducts was possible only by tightening the ducts where possible. The ducts were tightened during installation of the constant flow terminal devices. With tightening the noise level in the apartments could be reduced with 2 - 12 dB(A). The total air flow in the main ducts was, however, still about 12 % higher than the planned air flow.

For noise technical reasons the underpressure of the ducts was lowered during installation of constant flow terminal devices by reducing the fan rotation speed with a transformer and by throttling the suction duct of the fan. These measures decisively reduced the possibilities of increasing the air flow, i.e. keeping the duct underpressure within the planned range.

The three-month follow-up measurements showed that the constant flow terminal devices returned to constant flow after having been set on increased flow. At nights, when the constant flow terminal devices presumably were not set on increased flow, the standard deviation of the air flows was smaller than $\pm$ 4 %, and the variation was $\pm$ 10 % when the extreme values are studied.

Apartment-based measurements showed that the air flows of the bathroom constant flow terminal devices were on average according to the design values during constant flow. The air flows of the kitchen constant flow terminal devices were during constant flow about 14 - 22 % smaller than the design values. The kitchen measurement results could be influenced by the leak air flows observed in the hoods. When the results of measurements made during installation of the constant flow terminal devices were compared with measurement results after four months' use, it was observed that the deviations of single constant flow terminal devices from the design values had increased with time, but the total air flows had remained almost equal. With the constant flow terminal devices set on increased ventilation, the design values of the air flows were not reached mainly due to the poorly realized ducting.

The ventilation of the whole building was increased simultaneously with the previously used centrally controlled exhaust air ventilation system. The underpressures of the apartments with regard to outside air were then clearly larger than with the spatiotemporally controlled exhaust air ventilation system in which usually only a part of the building is in the area of increased ventilation.

5.2 Final inspection of the constant flow terminal devices

The final inspection was made after eight months of use. The constant flow terminal devices had become dirty only on the outside. Filtering of the air used to control the constant flow terminal devices had, according to visual check, kept clean the inside parts critical to terminal device operation.

5.3 Ventilation needs of the inhabitants

The follow-up measurements made in the test building showed that the inhabitants had used temporally increased ventilation rather individually. With spatiotemporally controlled exhaust air ventilation using constant flow terminal devices the ventilation needs of the inhabitants could be satisfied much better than with the centralized control of exhaust air ventilation used previously.

6 OPERATIONAL PREREQUISITES OF A SPATIOTEMPORALLY CONTROLLED EXHAUST AIR VENTILATION SYSTEM

A spatiotemporally controlled exhaust air ventilation system can be realized with cascade-control-based, selfcontained constant flow terminal devices with which the exhaust air flow can be increased. The most important prerequsites of the system are that the ducts are tight, that the dimensioned pressure differences of the constant flow terminal devices can be secured in all points of operation, and that the inside tightness of the building is good, because the supply air must be outside air and not air from a neighbouring apartment.

Acknowledgements

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For a study of controlled intake of fresh supply air also a prototype of a cascade-controlled constant flow supply air device has been constructed. This was dimensioned for a pressure difference of 10 - 70 Pa and an air flow of 5 - 5,5 dm^3/s.

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