Technical article

THE MODEL-BASED AIR FLOW MANAGEMENT SYSTEM

Risto Kosonen and Ismo Grönvall

Oy Halton Group Ltd, Finland

ABSTRACT

Traditionally the variable-air volume (VAV) system is used for demand-based ventilation. With VAV the air flow rates are controlled based on actual demand but at the same time the static pressure of the system has to be adjusted to a relatively high and constant value. The modern approach utilizes the model-based method, which offers a comprehensive system and controllability of the airflow distribution within ductworks. The intelligence of the model-based system is achieved by a computer model of the air flow dynamics within the entire ductwork. The system can therefore balance the air flow throughout the building whilst maintaining the duct pressure at an optimum low level, thus minimizing the fan power requirement and reducing the noise emission. During operating conditions, it is possible to maintain the pressure at as a low level as possible. This means energy saving in electricity consumption. Based on simulation, the electric energy consumption of the fans can be reduced by 25 – 55 % compared to the typical VAV system.

KEY WORDS: Airflow Management, Model-based Control Strategy, Energy Saving

INTRODUCTION

The quality of the indoor climate in commercial and public buildings has been found to be poor in a number of surveys. Poor indoor air causes an increase in symptoms and illness, and it shortens the attention span. Overall, the productivity of the worker will decrease if the indoor air quality is poor.

The way to reduce the indoor air problems is to increase ventilation in different spaces when it is requested. On the other hand, from the energy economy viewpoint, it is worthwhile adjusting the ventilation on a demand basis.

Demand-based ventilation is a way to regulate spaces in various capacity situations. There is an ever-growing need for this e.g. in offices and schools. In upper secondary schools, there is increasingly more classroom-based teaching whereas in lower secondary schools, work is divided between various goup-work rooms in addition to traditional classes, and therefore the number of pupils in the classroom can vary considerably.

A logical point of departure would be to regulate the ventilation in the space according to the activity that is taking place, and to configure an adequate fresh airflow to ensure good conditions in all capacity situations.

On the practical level, large variations in demand will require a ventilation system which enables demand-based control. In conference rooms and classrooms, airflow control should be possible within very wide parameters, such as from 5 to 43 people, so that the variation in energy demand according to the differences in the group size can be managed economically.

In a standard class of 36 people, it must be possible to allow for increased airflow of 20% cater for larger teaching groups. Increasing the dimensioning of central units does not necessarily have the desired effect; the same airflow is distributed in different ways to accommodate different space capacity situations.

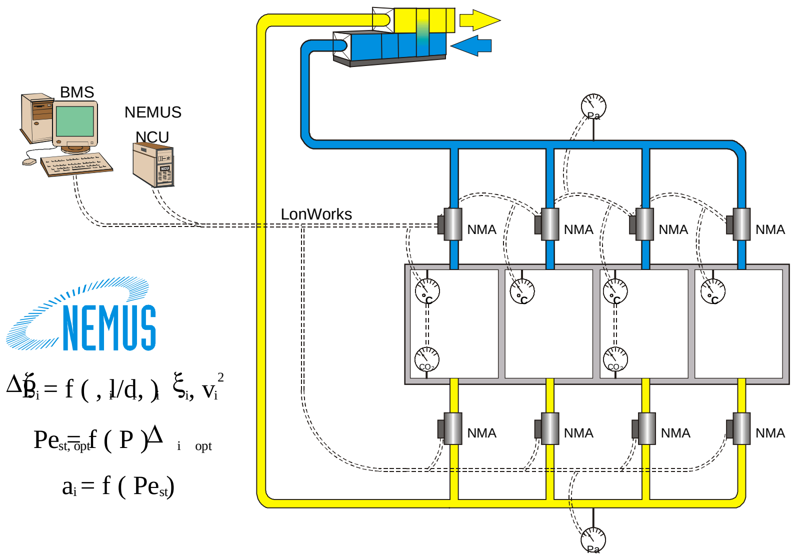
To achieve good condition, the ventilation system should provide (1) the right amount, (2) at the right time, and (3) in the right place. This is not possible with an inflexible system. Future systems should regulate ventilation to meet human needs – not, as now, to simple ventilate large areas of space.

IDEA OF MODEL-BASED CONTROL

Good indoor air quality and the efficient use of energy can be implemented simultaneously with demand-controlled ventilation. The most efficient way of managing the use of electricity is to adjust room-specific airflow values, while maintaining as low a pressure as possible in the ventilation ductwork.

The idea of the model-based air flow management system (Nemus) is based on a computer model of the air flow in the ventilation ductwork. The model-based control allows the system to optimize the pressure to as low a level as possible while saving the electricity needed for the fan. The system balances the entire ventilation ductwork to correspond with each of the different usage scenarios of the building. Figure 1 illustrates the concept of the model-based system. The basic components are room sensors and controllers, intelligence dampers, and the calculation unit (NCU; including the ductwork model), which is connected to the building management system (BMS).

Figure 1. The concept of the model-based air flow management system.



Advantages and the unique function of model-based control

The reliable air flow measurement of a room branch demands an air velocity of over 2 m/s in the damper. In practice, this means that the part-load conditions are normally outside reliable measurement range. Only the airflows that are quite near the nominal flows are possible to measure reliably. In addition, the function of the dampers requires sufficient authority (the ratio of the pressure loss in the damper and the total pressure difference). For the dampers to function in VAV system, a minimum pressure of 100 Pa is needed. In VAV, the parallel dampers influence the operation of each other; this means bigger or smaller fluctuations in the air flows.

With the model-based air flow management system, however, there are no such requirements: the pressure difference of the damper is always kept low. The fixed minimum static pressure of the damper is 15 Pa. There are also no requirements for a minimum velocity or authority of the damper because the control is based on the model. Furthermore, there is no disturbance in operation between the parallel dampers because the airflows are changed simultaneously. This guarantees that there will be no fluctuation in the set airflows.

One other significant difference between VAV and the model-based system is the pressure control of the fan. The ordinary VAV system tries to keep the static pressure of the ductwork constant and guarantee enough pressure for each damper. Consequently, there is a group of sensors and the fan is controlled based on the highest demand. Normally the topology of the ductwork is so complex that it is not possible in practice to optimize the system at every operating point. This leads to over sizing of the set point of the static pressure.

With the model-based system though, the pressure of the fan is calculated based on the ductwork model. This means that the pressure is always as low as it could be in each operation point.

The accuracy of the model-based control system has been studied in laboratory conditions by VTT [1]. The study showed that the average accuracy is 7.6 % when the estimated uncertainly of the measurements is 5.4 %. It should be noticed that the ductwork model is created by using only theoretical equations and parameters without any calibration measurements. During a normal installation phase, the ductwork model will be calibrated and fixed according to the installed ductwork. This guarantee that the changes and mistakes during the installation phase do not affect the operation. It should also be noted that the accuracy of the model is reasonable if it compared with the accuracy of the airflow measurements in the building site conditions (typically 15 % accuracy reached).

ENERGY-EFFICIENCY OF THE SYSTEM

The energy-efficiency of the model-based airflow management system was studied by simulations. The systems analyzed were the VAV and the model-based control system. The simulations were carried out for the selected simple zone of the case building. This case zone included six different spaces, whose principle of ductwork is shown in the Figure 2. In this case, there is one air-handling unit (AHU) with a nominal airflow rate of 7,660 l/s. The pressure loss of the AHU is 800 Pa at the nominal airflow rate. The maximum ductwork pressure loss of the model-based system is 168 Pa and 280 Pa for the VAV system. The minimum pressure loss of the VAV damper is 100 Pa and for the model-based system, 15 Pa.

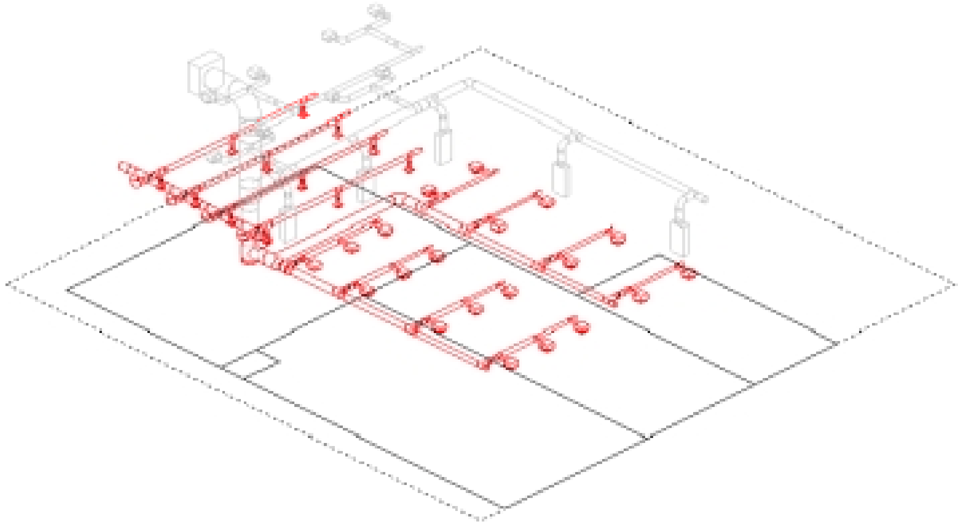


Figure 2. The principle of the ductwork in the case-study building.

The occupation load profile of the different spaces and the nominal air flow rates are presented in Table1.

Table 1. The relative required airflow rates and the nominal air flow rates.

		Relative Airflow Share %					Nominal Air-	
								flow Rates
	Working	Hours	Hours	Hours	Hours	Hours	Hours	(l/s)
Spaces		07-08	08-10	10-12	12-13	13-16	16-20	100 %
Auditorium		20 %	20 %	80 %	20 %	40 %	20 %	1680
Dining Room 1	20 %	20 %	40 %	80 %	40 %	20 %	1200	
Dining Room 2	20 %	20 %	40 %	80 %	40 %	20 %	1500	
Entrance Hall		20 %	20 %	40 %	80 %	80 %	20 %	2000
Classroom 21		20 %	80 %	40 %	40 %	80 %	80 %	320
Classroom 22		20 %	80 %	40 %	40 %	80 %	80 %	320
Classroom 31		20 %	80 %	80 %	40 %	20 %	20 %	320
Classroom 32		20 %	80 %	80 %	40 %	20 %	20 %	320

It is assumed that the minimum air flow rates (20 %) are possible to fulfil with the model-based system. The minimum relative airflow rate of the VAV system is fixed at 30 %. Therefore, during operating conditions, the airflows of the VAV system are slightly bigger than the model-based system.

Figure 3 shows the required static pressure of both systems and Figure 4 the electrical power requirements of the fan.

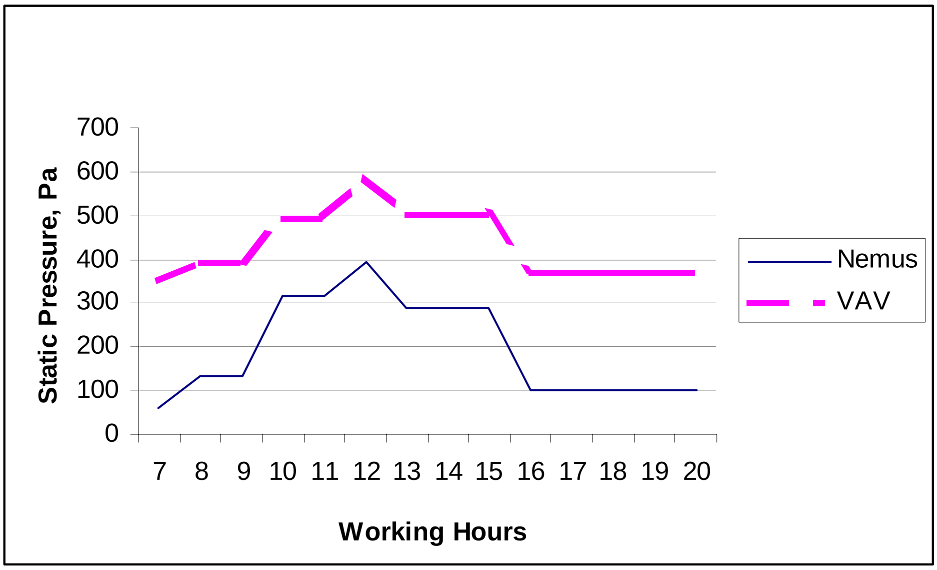


Figure 3. The required of the static pressure for the model-based and VAV systems.

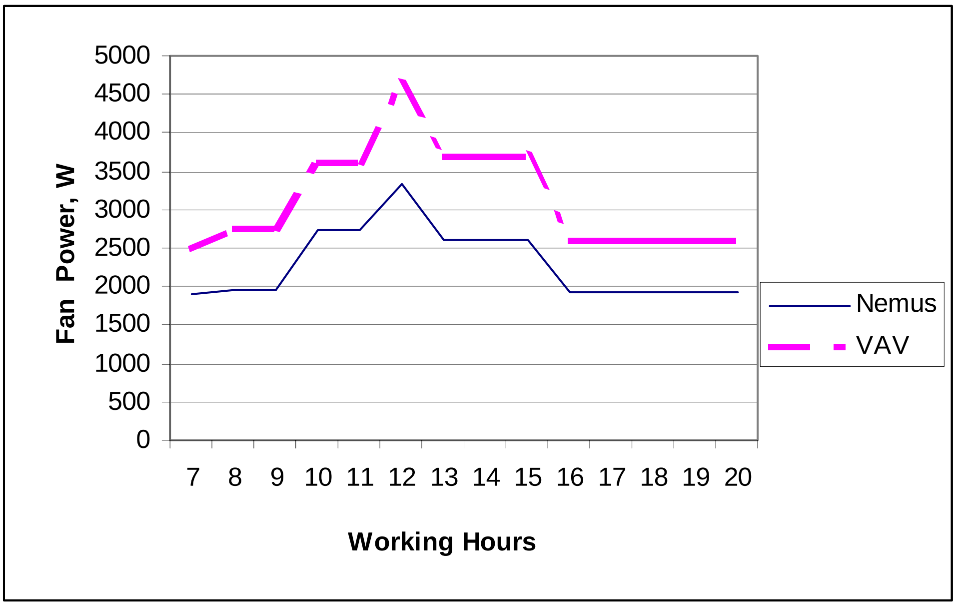


Figure 4. The fan power of the model-based and VAV systems.

The maximum pressure demand of the model-based system is 395 Pa and 588 Pa with the VAV system. Respectively, the fan power requirement of the model-based system is 3,334 W and Power requirement of the VAV is 4,620 W.

The diurnal sum of the hourly fan power requirement gives the energy consumption. In this case, the electrical consumption of the model-based system is 32,000 kWh and 44,000 kWh with the VAV system. The energy consumption is 27 % less with the mode-based system than with the VAV system.

DISCUSSION

The critical element in the reliable function of the model-based system is the model parameters. During the installation phase, the parameters of the ductwork model are accordingly tuned case-by-case. In addition, some sensors are installed in the ductwork, which give feedback from the static pressure. In laboratory conditions, the accuracy of the model-based system is proven reasonable. The average accuracy of the model has been measured as 7.6 %. This could be considered quite good, taking into account the 15 % accuracy of the field measurements.

The simulations carried out show that, with the model-based system, it is possible to reduce the required static pressure, and consequently the power requirement of the fan is lower than that of the typical VAV system. In the case-study, the calculated energy saving is 27 % compared to the VAV system. This saving consists of two elements: firstly, the energy saving arises from the low pressure demand of the dampers, and secondly, by optimization of the requested static pressure of the whole system. It should be noticed that energy saving should be analyzed in each case, e.g. the ductwork size and the occupancy profile widely vary.

The relative payback of the model-based system is the greatest in cases where the airflow demands vary symmetrically, e.g. in offices where the occupation profile of the rooms is the same. In this calculated case, the loads do not vary symmetrically. The same air-handling unit is serving different types of spaces, whose load profiles are quite different. This means that, during the working day, there are high airflow demands in different places of the ductwork: in the morning, first in the classroom and auditorium and after that in the dining rooms. After lunch, people return to the classroom, and so on. This leads to relatively higher pressure than in the case where the occupancy profile of the spaces vary in the same way.

In respect of energy saving, the whole production chain should be analyzed, i.e.the so-called wire-to-air efficiency. One critical element in the chain is the efficiency of the electric motor. Typically the motor efficiency decreases significantly for a part-load condition below 25 %. From the economic point of view, the minimum value of the control range is from 25 to 40 %. With the model-based system the energy-saving effect could be better if the part-load motor efficiency is better. Then the economy in consumption is 55 % compared to typical VAV system.

ACKNOWLEDGEMENTS

This research study is part of the Finnish LON Technology Programme (SAMBA) and the project is financed by TEKES, the National Technology Agency of Finland.

REFERENCES

1. Tuomaala, Pekka; Laine, Juhani; Paananen, Tapio; Hakkola, Olli -1998. Nemus Laboratory Validation Report. VTT Technical Research Centre of Finland, Measurement Report (in Finnish)

For more information, please contact Oy Halton Group Ltd., Risto Kosonen, Tel. +358 9 825 40033