Electricity savings from the retrofitting of ventilation systems in three commercial buildings

Per Wickman and Herman Hallstedt, AIB Installationskonsult AB

1. SYNOPSIS

This paper describes the effects of and possibilities for retrofitting ventilation systems in commercial buildings.

2. ABSTRACT

The background of this project is the interest displayed by the City of Stockholm in retrofitting its premises. The objective of this project is to test different steps that will reduce the amount of electricity required to transport air and to describe the methods required to achieve the improvements.

Electricity requirements, pressure settings and airflows have been extensively measured in three different buildings. The results of the measurements show considerable variations in the energy used to transport air in the buildings. The results also show that the potential for reducing energy without deterioration of the indoor climate is considerable.

This paper also takes into account the design of systems and the dimensioning of electric motors and fans. The efficiency of various ventilation systems has been tested and evaluated before and after the implementation of measures. The reduction in energy consumption is in the range of 10-40 percent. The paper also studies the effect on the total costs for operation. A method to attain these substantial improvements is also described.

3. INTRODUCTION

The measured results from previous studies have revealed major deficiencies in the ventilation systems of residential properties. Knowledge about the function of ventilation systems in commercial premises is more limited. Accordingly, the interest in increasing knowledge of and finding solutions that also enhance the efficiency in the ventilation systems of this sector, is considerable.

The aim of this project has been to undertake measurements that establish the functional capabilities of a number of typical ventilation systems in the commercial properties sector and to identify ways of increasing the efficiency of such systems. An additional aim has been to provide a handbook for evaluating the function of such systems and assessing the value of suggested corrective measures.

The measures sought are primarily those that are cost effective by themselves; that is, those measures whose profitability is not dependent on retrofitting measures motivated by other reasons.

It is particularly important that a method of evaluating the profitability of various measures is found in the commercial premises sector, since compared with the residential sector -- in which there are large areas in which similar system solutions are used -- each system in this sector is special. Section five of this paper includes a general outline of such an evaluation system. The procedure described can be beneficially combined with the compulsory ventilation controls recently introduced in Sweden.

The main purpose of this study has been to produce a partial basis for the formulation of an energy program for the City of Stockholm, in connection with the retrofitting of its own buildings. The documentation provided must include a program for improving the energy-efficiency of the ventilation systems. The program must include a description of the measurement and evaluation systems used as a basis for the handbook for the auditing and evaluation of proposed measures.

The efficiency-improvement opportunities have been assessed by implementing concrete measures, such as the replacement of fans and fan motors. The documentation and results constitute the basis for future measures, in the form of a handbook, which has been formulated as simple guidelines, including practical advice.

It shall be possible in a simple manner to connect the efficiency-improvement instructions with future function controls, whose current main purpose is to establish the status of the systems in relation to hygienic requirements.

4. METHODOLOGY

Project work has consisted of three parts-- the collection of measurements and data, the implementation of measures and method development. As such, method development consists of both a purely mathematical portion and a portion that involves the handling and analysis of measurement data -- for example, how measurement data is used as input data for cost calculations.

The study has mainly focused on the technical performance of the systems, such as pressure conditions, airflows and specific power requirements. Naturally, a decisive factor is whether the ventilation air is needed exclusively to satisfy hygienic requirements, or whether it is also used to heat and/or cool the building. The hygienic aspect has been studied specifically, in a library where levels of carbon dioxide have been measured at different loads and flow conditions.

4.1. Case study buildings

Buildings with relatively densely installed ventilation systems have been selected, partly to more easily identify the results the measures may provide and partly to financially motivate the implementation of any measures that may be required. The buildings also represent diffe rent historical eras in terms of installation technology and operating strategies.

The following suitable cases, managed by the City of Stockholm, satisfy both criteria:

Block	Year of Installation	Building Usage	Ventilation system	Measure
Spelbomskan	1981	Library	ES-CAV	Operation
Klamparen	1972	Office	ES-CAV	Motors
Stigbygeln	1983	Office	ES-CAV	Fans
Longholmen	1989	Hotel	ES-VAV	-

4.2. Measurements

In total, 31 measurements have been implemented on 18 air handlers. The measurement process has been divided into momentary and long-term measurements. Momentary measurements of airflow and static pressure along with active and apparent power of the fan motor have been carried out. Long-term measurements of airflow, static pressure and carbon dioxide concentration have been undertaken during periods of one to four days in the library.

In the event of there being different operating levels -- such as full and half speed, variable flows or mixture with supply air and recirculated air -- the measurements of pressure, flows and active effect have been undertaken over longer periods. To facilitate the continuous measurement of flows, a special measurement instrument was designed and calibrated at the National Institute for Materials Testing (Åman 1990). This instrument measures the dynamic pressure of a large portion of the air duct's cross section, which is transformed into an electric signal.

The calculated performance factors include specific power demand and overall efficiency. The specific power demand expresses the electrical demand needed by the fan motor to transport one m^3 of air per second. Overall efficiency shows the relationship between the flow multiplied by total static pressure and electricity to the fan motor.

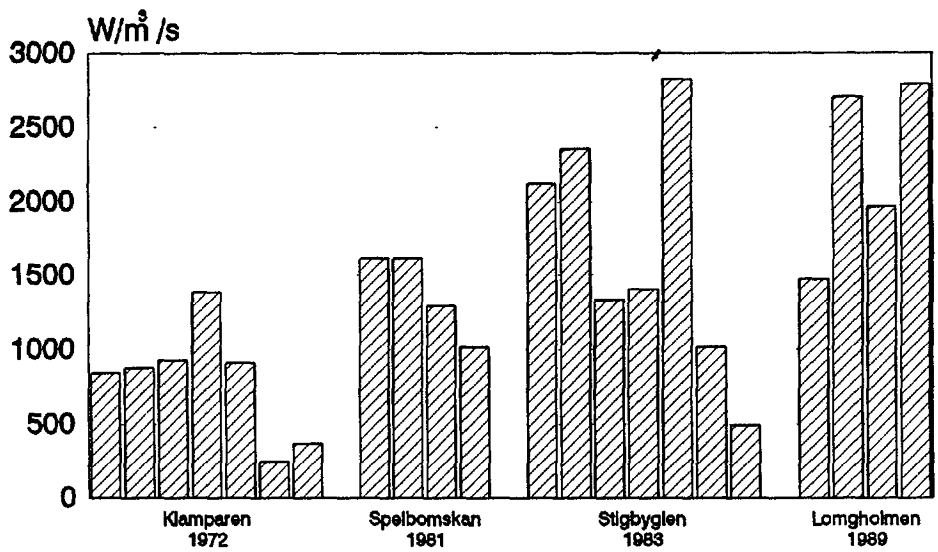

Figure 1. ***Specific power demand before the measures were implemented. The oldest installations have the lowest power demand, mainly due to low static pressure in the duct system.***

5. ENERGY-EFFICIENCY MEASURES AND RESULTS

Since the project relates to existing buildings, the measures focused on fine-tuning existing installations. Three different types of measures were implemented: replacement of motors, replacement of fans and changes in operating strategy.

The Klamparen property, which did not require any corrective measures with respect to the fans or operating strategy, required a replacement motor. In the Stigbygeln property, fans with improved overall efficiency were installed, while the motors were found to be well dimensioned. In the case of the City Library, the operating strategy was changed however, this required new motors with two-speed operation and the installation of a carbon dioxide sensor in order to control the airflow according to the need for dilution of indoor air. In the Longholmen property, no cost effective measures were found.

The following section shows a number of the main results from the various measures implemented to provide technical improvements. The costs are reported as specific investments per saved kWh/year. The method of calculation can then be selected.

5.1. Motors

The results obtained through the replacement of motors during the project suggest that overall efficiency is more sensitive to the load than is indicated in the product data. This may be due in part to the fact that the fixed age-related losses (mainly friction losses) increase more than the rest of the losses in the case of larger motors and fans operating at a low load.

The motors in the Klamparen property were substantially overdimensioned and have been replaced in two phases. During the first phase, standard motors with the right dimensions were installed without changing flows and pressure.

Another effect of the motor replacements was that consumption of current was reduced drastically by 50 to 60 percent. However, there are currently no incentives in Sweden for reducing the consumption of current, since only the active power is used as a basis for demand charges. It is highly likely that this situation will be changed in the near future.

In addition to the fact that in relative terms power losses in the motor decrease when it is operated at the right load, resistive losses between the motor and the point of measurement/consumption meter are proportional to the extra consumption of current caused by the reactive power.

In a cable being passed by current, the resistive losses are converted into heat. If, for example, the cable to the motor is 50 meters long and the cross-section of the conductors is 10mm^2, the losses increase by slightly less than 3 percent if the effect factor is reduced from 0.8 to 0.5 at a power demand of 17 kW (Lindahl 1983). During continuous operation, this results in annual resistance losses of approximately 3,700 kWh per year.

Before a power-correcting measure is implemented to reduce the reactive power, knowledge about the

Table 1. ***Rated and measured output and overall efficiency (including fans and transmission) before and after motor replacement. Each line correspond to a given flow rate.***

Existing motor			New motor		
Rated	Measured	Overall	Rated	Measured	Overall
output	output	efficiency	output	output	efficiency
kW	kW	%	kW	kW	%
3.7	0.67	34	1.1	0.59	39
4.0	0.91	38	1.1	0.69	51
5.5	1.24	21	1.1	0.77	34
11.0	1.98	47	3.0	1.80	52

Motors with the correct dimensions increased the overall efficiency of four motors by 5 to 13 percentage points.

operating conditions of the ventilation system is essential.

If the system is corrected centrally, there is a risk that it will be fixed at an unsatisfactory operating level. Instead of power-correction, it would perhaps be preferable to improve the operating point of the fan motor. This would also reduce resistance losses from the internal network.

In the latter case, the investment per saved kWh/year would be approximately ECU 0.2 to 0.3 per kWh. If the motors were to be replaced in any event, the reduced investment in the smaller new motor should be included in the calculation. Moreover, the reduced energy consumption due to the lower resistance losses is not included in the calculation.

The second motor replacement involved the installation of a special high-efficiency motor. According to the product data, the motor's overall efficiency should have been approximately 10 percent better than that of the standard motors.Unfortunately, this motor increased energy consumption by approximately 15 percent. Since only one such motor was installed, no general conclusions can be made, however the result did not inspire the use of this type of motor in additional tests.

5.2. Power transmission

This study has not analyzed any losses from mechanical power transmission. In general, it may be said that with respect to the type of air handler normally used for office and residential ventilation, the losses from belts are probably underestimated.

Since the actual power demand of an electric motor is nearly always lower than the rated output, and since the power required by the belt transmission is not exclusively dependent on the motor effect, it is easy to exaggerate the overall efficiency of belt transmission. It is essential that these conditions are taken into account when the belt transmission is dimensioned.

Approximately 5 of the 18 motors studied operated with loads exceeding 50 percent of full load. Theoretically, if a 1 kW motor is fully loaded, the efficiency of the belt is about 85 percent. If the motor is 50-percent loaded, the efficiency decreases to about 75 percent (Jagemar 1991).

The centring and tension of the transmission belt are important factors for the function of power transmission. Although an excessively loose belt does not increase the required power, it does increase the wear on the belt. Eventually, the belt will also skid. An excessively tight belt substantially increases the required power.

In the Stigbygeln property, the transmission belt was adjusted following the fan replacements. In one instance, the power demand decreased sharply, by about 20 percent, following the adjustment.

5.3. Fans

As a rule, the replacement of a fan is a more extensive measure than the replacement of a motor. At the same time, it provides greater opportunities for optimizing the efficiency of air transportation in the individual objects. However, a correct assessment of the fan's status regarding the load and the operating point is a decisive factor.

In many cases, replacing a fan with forward-curved blades with backward-curved blades provides positive results. However, this is not always the case. In selecting the necessary measures, flow requirements and pressure conditions, as well as practical capabilities, are decisive factors.

One might think that fans with superior technical performance should always be installed, since the difference in cost is marginal, and the improvement in overall efficiency could be essential. One reason why this not always is the case is that normally no detailed knowledge is available about the function of the systems -- particularly of pressure and flow conditions, which could have a negative impact on the operating range of the fan.

The choice of fan is affected by flow requirements, operating costs, controllability, required space and noise levels. It is not always self-evident that priority can be assigned to operating costs. Moreover, since there is a limited range of effective fans to choose from, it may be difficult to combine a good operating range with high efficiency. A prerequisite for good performance is that the fan operates within its best operating range regarding pressure level and airflow.

The actual pressure levels in a system will tend to deviate from those calculated. The data specified for the fan is based on ideal laboratory conditions and the actual system does not normally operate under ideal conditions. Deviations between measured performance and that specified in the fan curves provided by the manufacturer are often due to the losses caused by unsuitable connections to the fan outlet, uneven speed distribution in the fan outlet or rotation in the fan outlet. Such deviations are called system effects.

These difficulties may combine and cause greater deviations in the actual functioning of the system, compared with the expected deviations. It would be beneficial if one could measure the pressure and flow of any major system before selecting the fan.

In existing systems, it is often possible to measure the performance of the air handler and the air duct systems. Accordingly, prior to a renovation project, the potential for selecting the correct fan dimensions is good. The profitability of a possible measure can be calculated carefully and will provide a good basis for an assessment of the measures required.

In the Stigbygeln property, the potential for a fan replacement was good and two of 34 fans have subsequently been replaced. The system, which was constructed at the beginning of the 1980s, serves an office floor. The air handler was specially designed to cope with the narrow space available for the installation. Recirculated air can be utilized during the winter to reduce the heating load, when the heat batteries provide insufficient heat.

The pressure-drop is relatively high. The existing fans had forward-curved blades and a power efficiency of approximately 60 percent at the designed operating range. New fans with backward-curved blades were available with suitable fastening devices and connectors. The new fans have a significantly higher power efficiency, approximately 80 percent.

Due to the narrow spaces available, it was difficult to secure the new fans onto the existing frames. This had a major impact on the installation time required for the replacement. An additional problem that arose during installation was involved the centring of the fans with the outlet. As a result, it was difficult to seal the area between the outlet and the housing. The new airflow levels were approximately the same as the levels before the replacement. On the other hand, an increase in static pressure was registered, which may be due to a change in the velocity profile after the fan.

The replacement of the exhaust air fan yielded power saving of 30 to 40 percent, dependent on the proportion of exhaust air. The reduced power requirement was mainly attributable to an improvement in the efficiency of the backward-curved blades, approximately 25 percent, and also to the fact that the fan now works within a better operating range.

The cost for the fan replacement amounted to about ECU 1 600 to ECU 2 100 corresponding to ECU 0.4 to 0.8 per saved kWh/year with respect to present costs. If the fans are in operation throughout the year rather than 4000 hours/year, the specific investment is reduced to ECU 0.2 to 0.4 per saved kWh/year.

5.4. Change in operation

Since the required flow varies substantially according to the heating, cooling and dilution need in the premises, it should be possible to adapt the flow to these factors. This can be achieved by distributing the air more efficiently and by operating the fans at full and half speed dependent on the load.

The Spelbomskan property includes both office space and areas that are open to the public, such as reference rooms, periodicals room and book-rooms. The various types of premises are subject to different loads. To establish which portion of the building required most air, measurements of carbon dioxide and temperature levels were conducted in the various premises. This made it possible to determine the required level for airflow.

Another conclusion was that the excess air from rooms with low loads could be used to ventilate rooms with higher loads. This enables a reduction in the total flow of air through the building, while still improving the indoor climate.

To achieve the desired function, two-speed motors were installed, although the existing fans were retained. Although the fans have forward-curved blades, it was not considered necessary, in relation to the operating range, to replace them with backward-curved blades. It was not possible to find a fan with backward curved blades with a suitable operating range capable of being integrated with the air handler.

To be able to control airflows during two-speed operation, a carbon dioxide sensor was installed in that part of the premises to determine the flow requirements of the system.

5.5. Handbook

A handbook was developed to audit the function and performance of the system and to assess the profitability of efficiency-enhancing measures

The audit procedure asseses the general status of the system, the age of the building and ventilation system, and the designed airflows and static air pressure. The type and manufacture of the system and data relating to the fans and motors are determined and listed to a pre-designed form. The relevant rpm figures and the operating strategy of the system, in terms of controls, operating periods, defrosting, etc., are studied.

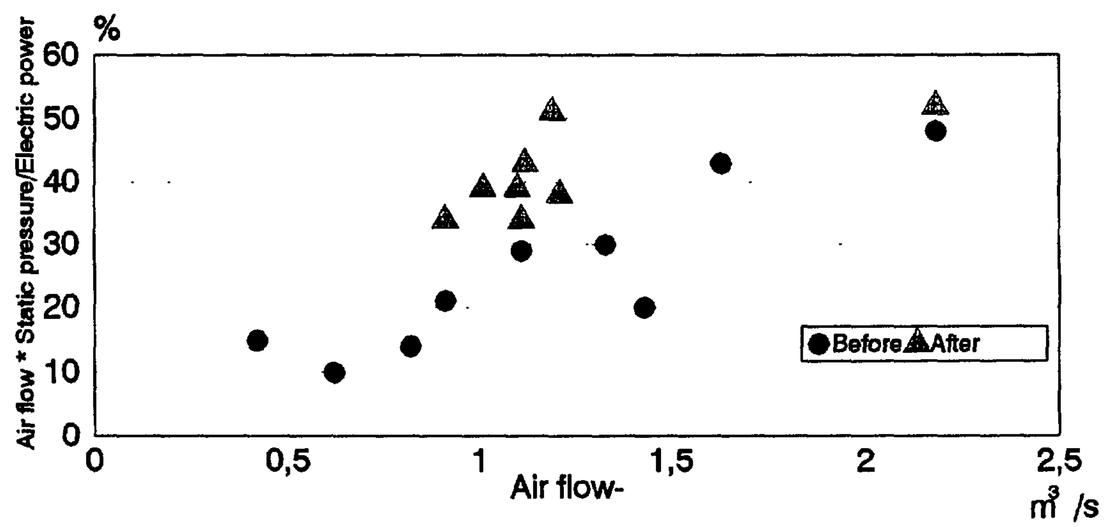

Figure 2. ***Differences in efficiency in relation to the airflow before and after measures. The differences are due to such factors as motor and fan dimension.***

A description of the condition of the system, with respect to care and maintenance, is provided. This covers such features as the replacement of filters and belts and the cleaning of air ducts. Accessibility for operating controls and maintenance is also taken into account.

The building's energy consumption over the past two years is studied from utility bills or specific figures for energy consumption. If no statistics on this item are available, they can be deduced by undertaking two manual read-outs from the consumption meter during a period of operation of at least two weeks.

The correctness of the dimensioning of the fan and motor is determined with the help of measurements, as is the working point on the fan curve and the load. Operating times and needs are studied. to asses the potential for flow control via, for example, CO_2 measurements. Air inlets are studied to estimate the possibility to use variable airflows.

The measured values and the product data for the fans and motors show the losses and their magnitude. Together with knowledge of the specific investment costs, the analysis provides the basis for assessing which investment is economically viable.

6. DISCUSSION

The measurements show a substantial spread in the system's performance, both between the various buildings and the various air handlers. The specific power demand varies from approximately 200 $W/(m^2/s)$ to 3,000 $W/(m^2/s)$. Overall efficiencies vary from about 10 percent to 50 percent, with an average value of approximately 30 percent. The potential to improve the efficiency is considerable.

Not unexpectedly, the analysis of flow requirements and the resulting opportunities to change operating strategy proved to be the most profitable measure. This measure should naturally be combined with more efficient transport of air, where possible.

Since larger fans and motors normally yield better efficiency levels, compared with smaller models, efficiency is influenced by such factors as the size of flow. Dimensioning of the fan and motor is another important factor. This applies particularly to smaller motors, which are adversely affected by low loads, especially when the load is lower than approximately 30 to 40 percent of rated load. This is not an unusual occurrence, having been registered in about 30 percent of the measured air handlers.

The investment required to save one kWh per year varies from ECU 0.2 to ECU 0.8. To ensure the cost of a specific investment remains low, a well-developed method and measurement technique must be applied in order to assess which systems require corrective measures and how such measures should be implemented.

A methodology for assessing the profitability of the various measures is particularly important in the commercial premises sector, in which each system is special, regarding time of operation and need of airflow. Otherwise the costs of feasibility studies will be too high.

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