Energy-efficient ventilation systems: Mechanical ventilation for apartment buildings in Sweden

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1. SYNOPSIS

This paper includes a survey of the energy efficiency in 110 ventilation systems in apartment buildings in Stockholm. A report of the evaluation and inspections are included.

2. ABSTRACT

Mechanical ventilation has been the most favoured system in Swedish apartment buildings since the early 1960's. What is there to be learned from the Swedish results? Energy audits in apartment buildings have pointed out the ventilation system as a main consumer of electrical energy. The Swedish Council of Building Research conducted a vast empirical study of 110 fan systems. The objects were chosen within 12 residential districts with different characteristics (system for ventilation, age, size, type of building etc). The ventilation systems showed to be of a very low efficiency, on the average 20 per cent. The electricity demands were high, especially for the systems with heat recovery. As a consequence, the regulations for heat recovery in buildings have been proposed to be withdrawn. The measured area-specific air-flow showed to vary a lot between different buildings and between different apartments. Economizing possibilities in the 110 ventilation systems were studied. At the time for reinvestment, or when changes are motivated for other reasons, components and system designs which reduce the electrical demand up to 60 per cent, are economically motivated.

3. INTRODUCTION

For the last three decades, mechanical ventilation has been the most favoured system in Swedish apartment buildings. For energy conservation purposes heat recovery from exhaust air was included in the building regulations of 1980. This resulted in more electricity demand for driving the fans, a consequence which has not been noticed until recent years. Electrical energy is comparatively cheap in Sweden, a fact that quickly could change in times of European integration including electrical supply. The mandatory targets for low energy consumption in buildings have applied to heating, but have not included electrical power for running the installations. There has now been an increasing interest in knowledge about energy efficient ventilation constructions.

This is the background for this study of electrical energy consumption in 110 ventilation systems in apartment buildings. It is financed by the Swedish Council for Building Research. The purpose of the study is to give an account of the actual electrical consumption in the apartment buildings and to provide a basis for recommendations for a more efficient ventilation solution. In a report (Sandberg 1992) the buildings and the ventilation systems are described in more detail and all measurement data are published.

4. PLANNING THE RESEARCH

Measurements of power demand, air-flow (tracer gas) and pressure drops were taken on different types of ventilation systems divided into 12 separate residential areas of varying age in Stockholm. Measurements were carried out partly at the fan and partly of the air-flow in the apartments that were chosen at random. The following fan driven systems are included in the study:

- Exhaust air (E)

- Exhaust air with recovered heat from exhaust air by means of heat pump (EX)
- Exhaust- and supply air system (ES)
- Exhaust and supply air system with heat recovery(ESX)

Furthermore there are variations regarding ducting, fan types, control systems, forced ventilation in kitchen etc.

5. RESEARCH RESULTS

5.1. Electrical energy consumption for ventilation.

The level of the average energy consumption in the surveyed residential areas is shown in Figure 1. In the figure, the areas are classified by age, the oldest areas on the left. In one of the areas a heat recovery system with heat pump has later been installed.

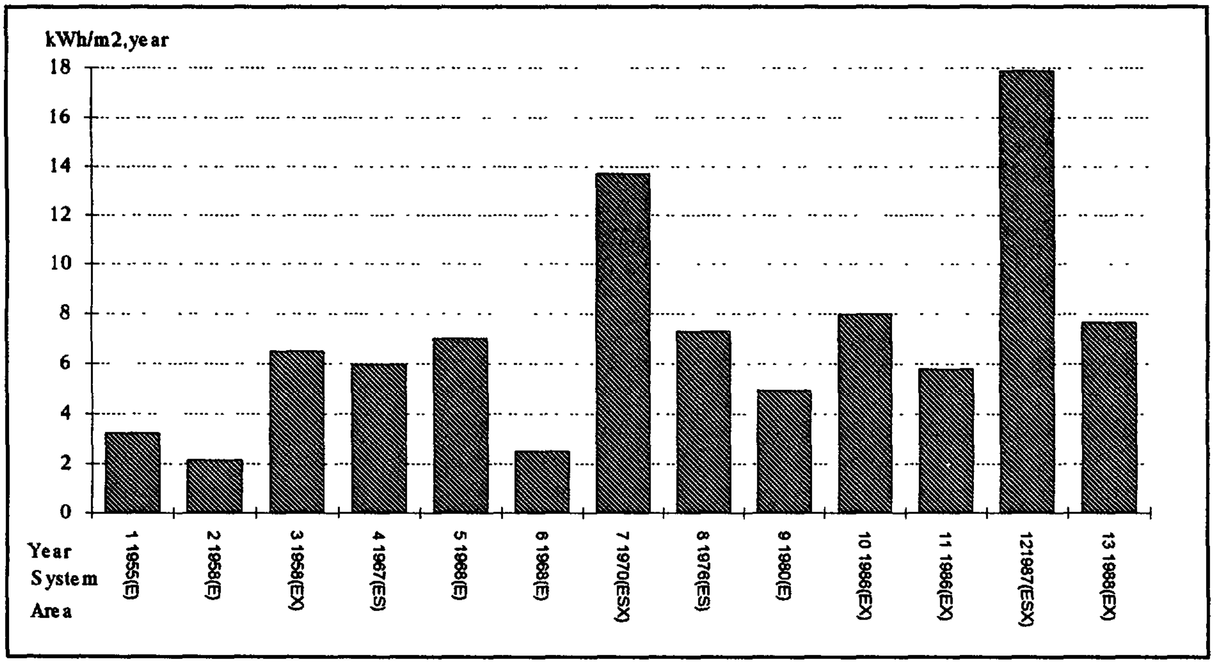

Figure 1. *Fan energy consumption*

The results of the measurements show that electricity consumption for fan driven systems in buildings is considerable, especially for systems with supply air and heat recovery (ESX). Results from the study show that the consumption for fan driven systems must be considered when calculating the energy balance of a building. The energy consumption for heat recovery systems (ESX) is in fact so high that the recovered heat in most cases does not exceed 2-3 times the extra electrical input as compared to a system using only exhaust air. From exhaust air in multifamily buildings about 20 kWh/m2 is recovered (ESX system with 50% recovery) and the difference in fan power demand between ESX system and E system differ more than 10 kWh/m2 in present multifamily buildings. These results have influenced an investigation (Sandberg 1991) questioning the present building regulations' demand for heat recovery. The investigation proposes that the demand for heat recovery is limited only to electrically heated houses and that the energy consumption for running the installations must be included in the total heating calculation.

The bad performance of domestic ESX-systems are by no means necessary. Scaling up the heat exchanger will give more energy recovered and lower preassure drops. Calculations show that 7-8 times the extra

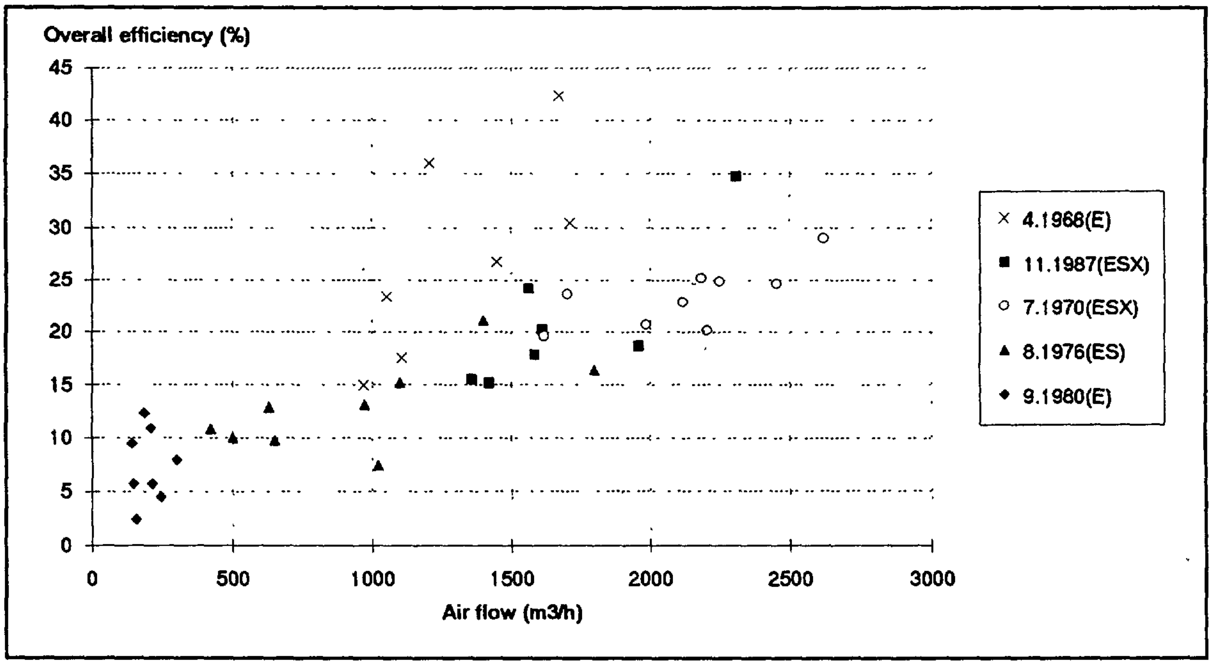

Figure 2. *Results for all fans*

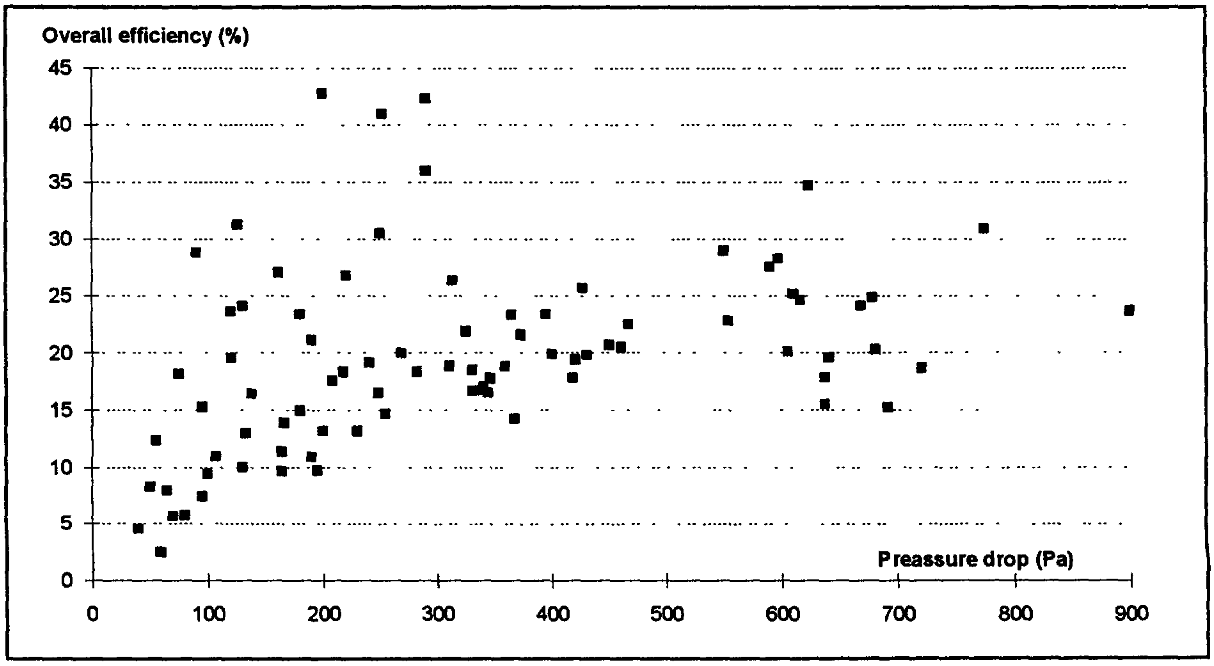

Figure 3.

electrical energy might be recovered (Johnsson 1991).

The average energy consumption for apartment buildings with mechanical ventilation in Stockholm has been calculated at 5.1 kWh/m2 per year.

5.2. Efficiency

Measurements of the total air-flow after the fan, the total static pressure before and after the fan, and energy consumption of the motor, have been used to calculate the system's overall efficiency. The average

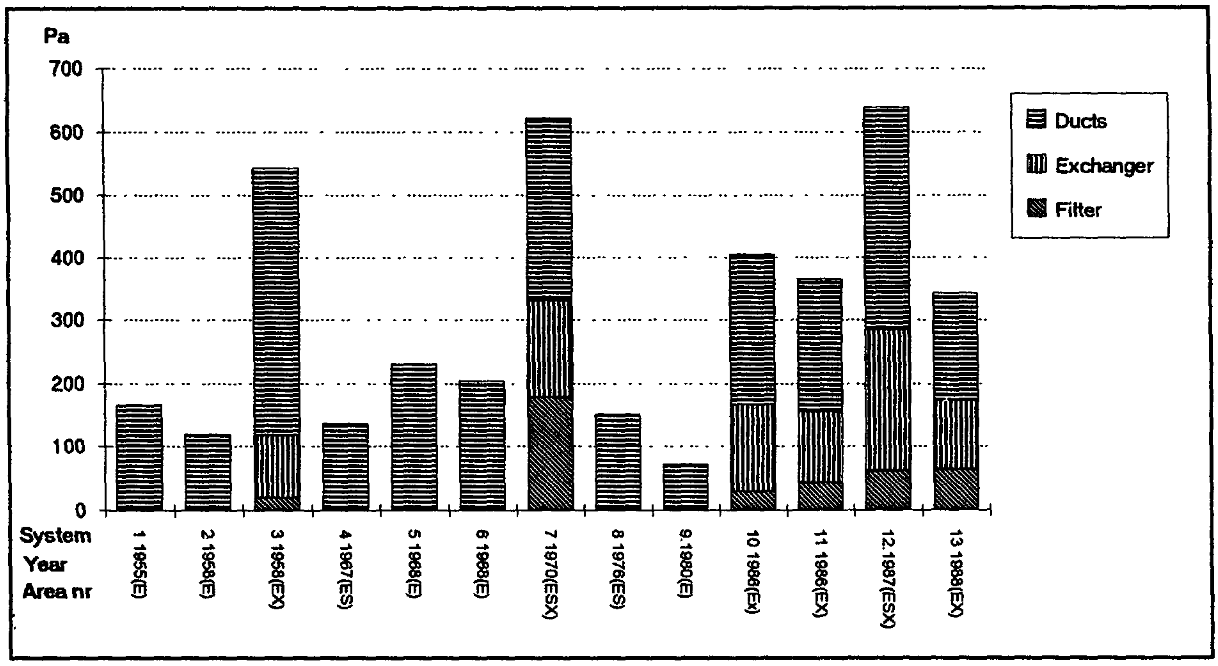

Figure 4. ***Pressure drop***

overall efficiency for the various systems is low throughout. It varies between 7 to 36 per cent from the smallest apartment fans to the largest ventilation systems of tower blocks. The overall efficiency for the total 110 fans only averaged 20 per cent.

The efficiency increased considerably with the size of the air- flow. Figure 2 shows the results for all fans in a number of areas. This connection between size and air - flow should be considered when demand for system efficiency is made.

For fan systems with a total pressure drop less than 300 Pascal, there is a tendency of connection between efficiency and pressure drop (figure 3). All the fans in the study were of the radial type with forward-leaning fan blades (F-blades).

Variations in efficiency between different fans of the same type (the same residential area) are surprisingly large, +/- 33 per cent. An explanation for this cannot be given, except that differences in total pressure drop are of the some significance.

Losses in belt drive systems can be considerable for small fan units (Jagemar 1991). One possible solution for an efficient fan would therefore be direct drive. However, direct driven motors often are of the external rotor motor type. Such motors are of lower efficiency. This motor design is used for voltage regulation and has such windings that give larger power losses.

5.3. Pressure drop

There is an obvious connection between an increase in pressure drop and an increase in energy consumption both in theory and in practice. In a system with heat recovery, the pressure drop caused by the filter and heat exchanger is approximately the double. See Figure 4.

The heat exchanger dominates in causing pressure drop. This can easily be rectified by scaling up the heat exchanger unit. Other studies (Johnsson 1991) have shown that up-scaling the unit is economically motivated.

The pressure drop from the roof space down to the apartment is between 100-150 Pa in the areas in the stu-

Table 1. ***Mean values of air flow specific power (ASP), overall efficiency, total pressure drop and air-folw for each residential district***

Area/ Year/system	ASP (Watt/m³/s)	Efficiency percent	Tot.pressure drop Pascal	Air flow m³/h
1. 1955 (E)	449	36	167	8760
2.1958 (E)	534	16	91	2819
3.1958(EX)	2123	25	594	4274
4.1967(ES)	703	21	137	2012
5.1968(E)	898	27	231	1309
6.1968(E)	1431	15	204	1552
7.1970(ESX)	2691	23	623	2126
8.1976(ES)	1246	13	141	944
9.1980(E)	1148	7	72	201
10.1986(EX)	1848	20	365	1605
11.1986(EX)	1786	23	408	2215
12.1987(ESX)	3257	21	780	1687
13.1988(EX)	2084	16	343	2382

dy. Only in the areas where apartments had individual fans, the pressure drop was smaller. This is also the reason why this system has a moderate low power demand in spite of a low efficiency fan.

5.4 Air-flow specific power

At the time of building, the contractor can stipulate the efficiency of the ventilation system by giving a suitable performance figure. Most simply this can be expressed as a demand for air-flow specific power (ASP). ASP is here defined as the ratio between the power the fan demands and the air-flow that is generated. ASP for the different areas in the study appears in Table 1. The mean value for ASP corresponding to ventilation system type appears in Figure 5.

In this diagram the ASP for supply air-flow has been added to the corresponding figure for exhaust air-flow, disregarding different air-flows. The increased energy consumption for systems with heat recovery is obvious in the diagram and as expected two air-flows, supply and exhaust, demand more power than exhaust alone.

5.5. Air-flow in housing

The purpose of installing a fan in a residence is to provide satisfactory air-flow. The building regulations stipulate the minimum acceptable level of ventilation. The regulations have been somewhat differently formed with regard to detail. For the average-sized apartment, the minimum demand has been lowered from

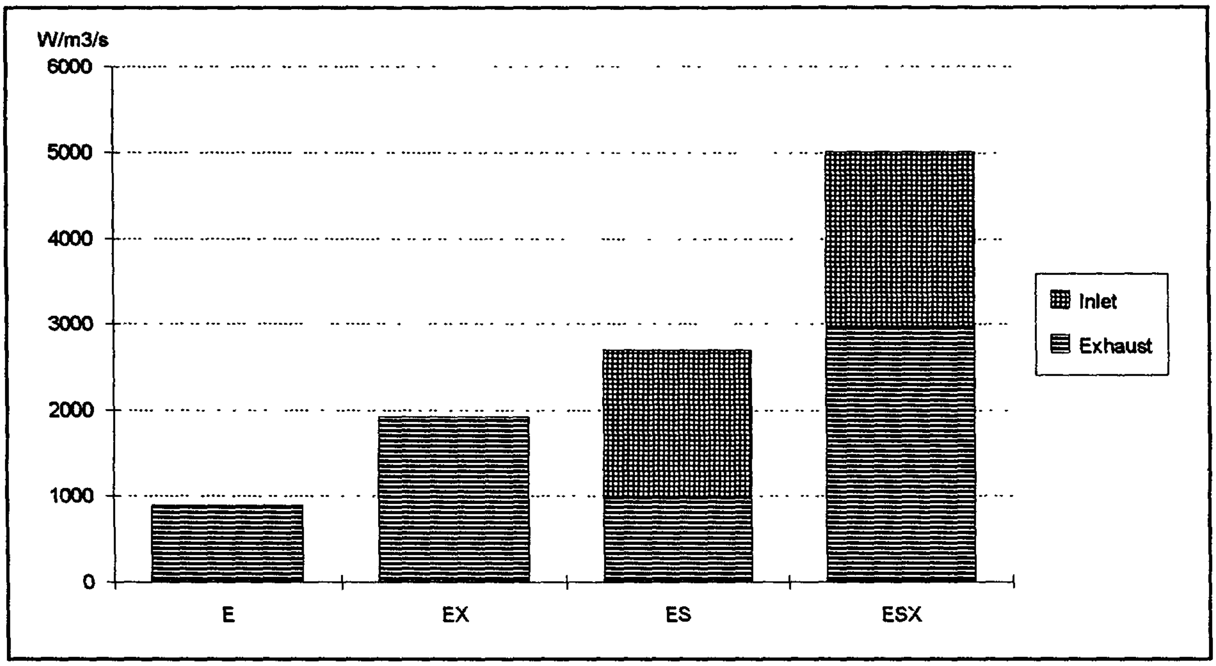

Figure 5. *Air-flow specific power*

0.53 l/s.m2 in the 60's to 0.35 l/s.m2 today. The compiled air-flow of the houses, divided by apartment area, show relatively large discrepancies (Figure 6). Even within the same residential complex, the rate of ventilation varies to the same proportion. This would indicate that the inspections of the fan systems have been carried out unsatisfactory. It also indicates difficulties in measuring and adjusting the systems. In the study we used tracer gas for measuring the air-flow at the fan. In several cases it would not be possible to measure without tracer gas. No wonder the systems are bad adjusted.

5.6. Distribution of air-flow in the house

It is not the average volume of air-flow of the apartment building that is of interest to the tenant, but his actual share. Measurements of air-flow in 110 apartments chosen at random in the studied areas are shown in Figure 7.

The figure reveals that even in apartments built in the last 10 years, the uneven distribution of air-flow is considerable. This is in spite of the fact that these buildings have separate ducts between each apartment and roof space as well as adjustable vents in the apartments. This, however, shows to be less successful than expected.

With an adjustable vent inside the apartment, the tenant is able to alter the setting. In some apartments, the vent was found to be dismantled. In one example the tenant had connected a clothes' drying cabinet to it. Problems with noise and dust may also be reasons why the tenant messes about the setting of the exhaust air vent. As such vent adjustments inside apartments connected to central ventilation systems also affect the air-flows of the neighbours, this should not be possible.

The bad accessibility for adjustments at the time of installation as well as at subsequent adjustments could also be an explanation. When the air-flow in one apartment is adjusted, the air-flow in other apartments will be affected.

The air-flow between different buildings and the air-flow in apartments within the same residential area vary so much that it clearly shows the need for recurrent ventilation inspections. Such inspections have now become mandatory in Sweden.

5.7. Kitchen ventilation

To be able to cope with fume absorption with a minimum of 75-80 per cent efficiency, modern cooker hoods demand an air-flow of approximately 150 m3/h. With a larger hood 90 - 100 m3/h may me satisfactory.

Of the 12 areas studied, only one area had kitchen air-flow over 150 m3/h. Two areas with larger hoods had 80-90 m3/h. The other apartments had lower or even much lower air-flows. Examples of air-flow in kitchens in three different areas can be seen in Figure 8.

Area 2 was a 12-storey tower block built in 1958 with constant air-flow ventilation.

Area 9 was built in 1980 and comprises two-storey dwellings, with a separate fan to each apartment. The fan speed is variable and the main extraction can be chosen for either kitchen or bathroom. This is a typical small building application.

Area 11 was built in 1986 an has heat recovery with a central heat pump.

From these figures appears a wide variety of the air-flows (basic mechanic ventilation as well as extra forced ventilation). This in spite of the similar conditions prevailed within the same residential area. The present building norm stipulates a minimum basic air-flow of 36 m3/h. If this can be considered the lowest hygienic level of kitchen ventilation required, more than half of the apartments were of a lower value.

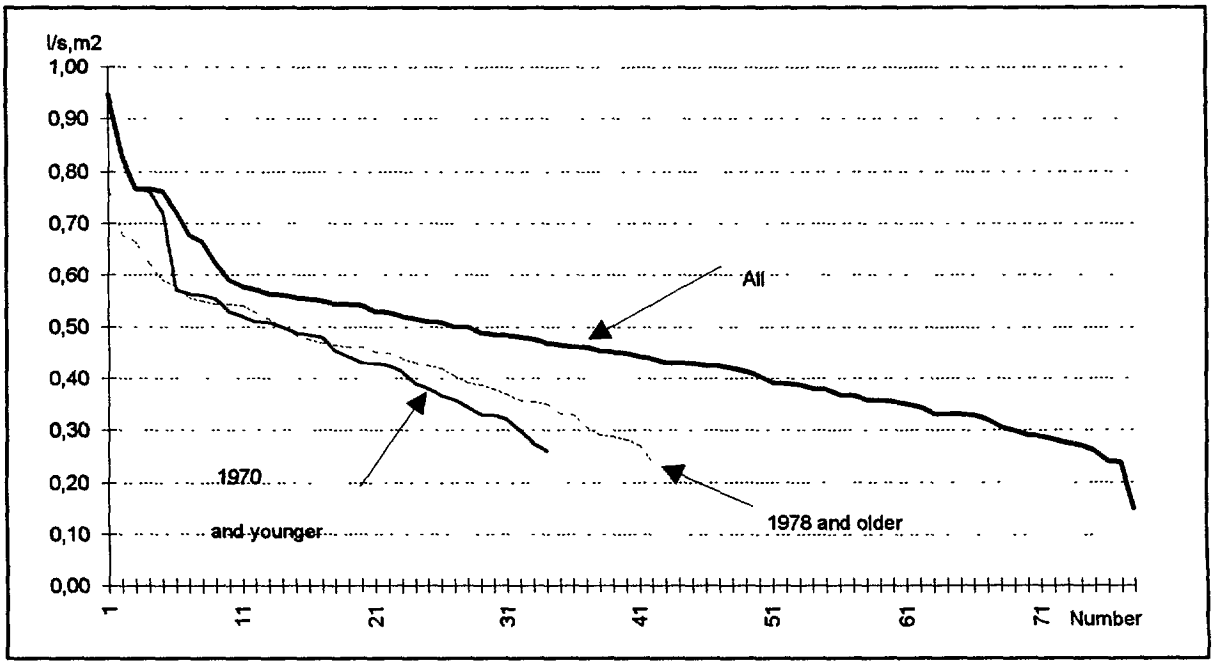

Figure 6. *System air flow*

One area had extra forced ventilation option with an aperture that is opened and closed manually. Many apartments in these houses had the apertures constantly open. This will of course affect the ventilation of the neighbouring apartments. They could hardly achieve the basic evacuation flow. The conclusion can be drawn, that vents with manual closing aperture are completely unsuitable in central ventilation systems.

Three of the apartments had such dirty kitchen evacuation filters, that the air-flow had decreased considerably. The main impression, otherwise, is that most of the tenants clean their filters properly.

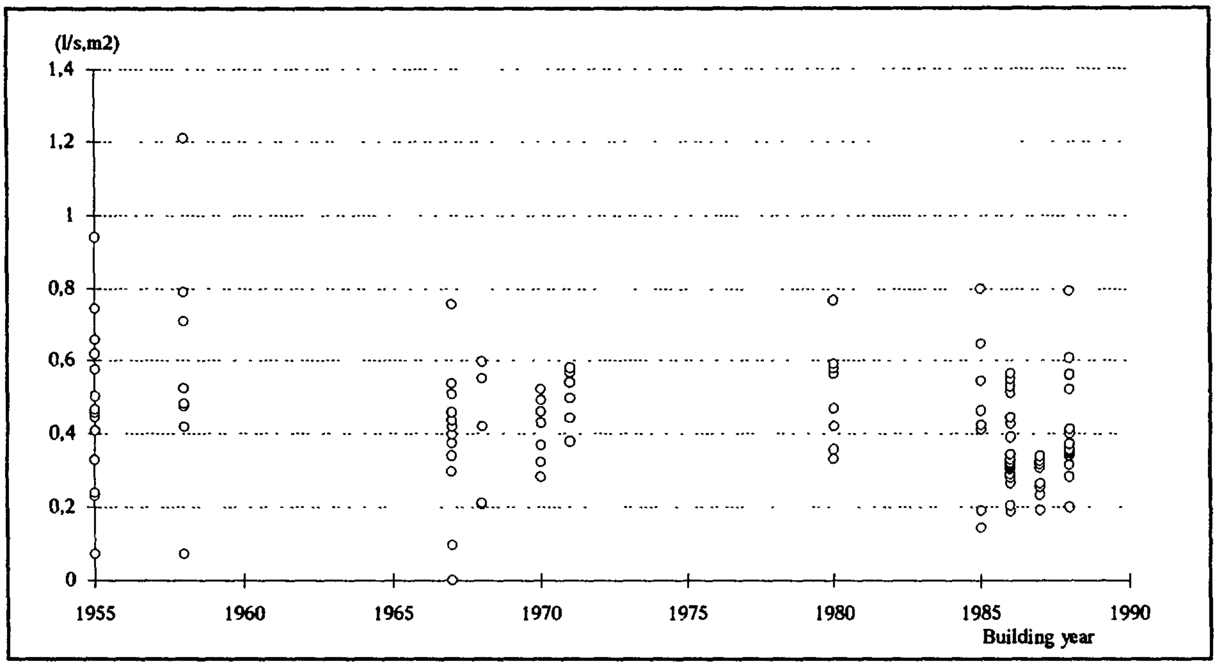

Figure 7. ***Apartment air-flow***

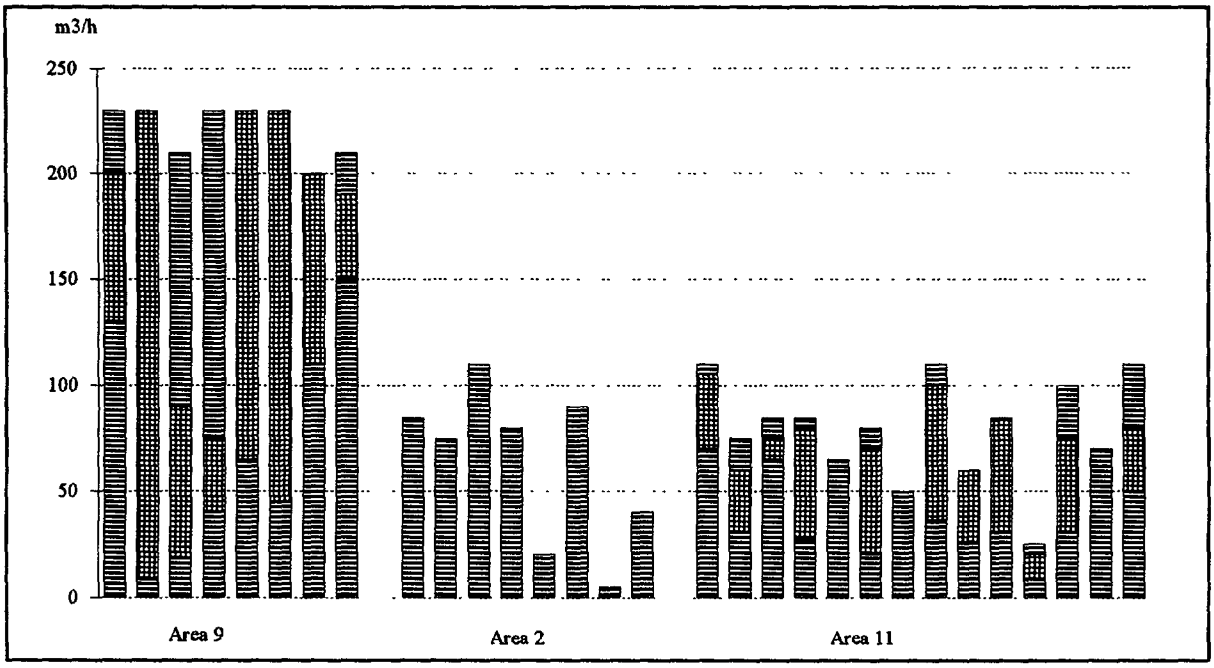

Figure 8. ***Air-flow from cooker hood***

5.8. Fan speed regulated systems

Three ventilation systems with central fans were speed regulated. The purpose of this is to raise the fan's capacity when many of the apartments have open vents in kitchen and in bathroom. The speed regulation was controlled with a signal from a pressure sensor located on the low pressure side of the exhaust fan.

By measuring pressure and air-flow continually for one week in two of these areas, it could be established that the air-flow rate remained at the same level regardless of fan speed regulation. This may be accounted for by the fact that the pressure drop over the evacuation vent aperture is too low in comparison with the total system pressure of the fan. Instead it appears that the extra force flow is achieved at the expense of the other apartments. The air-flow is re-distributed amongst the other apartments connected to the same distribution box. The result being the same as if it was a constant speed fan system.

5.9. Fan units for small houses and apartments

In Sweden alone, 60 000 small fan units for constant running are installed yearly comprising both small houses and apartments. The de-centralized system is simpler in duct design. The total pressure drop is low, often between 50-100 Pa. Unfortunately, the market is totally dominated by fan motors of the external rotor type and F-blade. The total efficiency is very low, usually only 5-10 per cent.

The fan speed can be increased when cooking, but for the basic ventilation they run at the lower speed. The performance of fans on the market vary considerably, a fact exemplified in Figure 9. In the figure fan units for heat recovery in small houses are presented regarding the heat recovered and the electrical energy consumption for driving the fans. All products are approved by Swedish authorities and comply with the

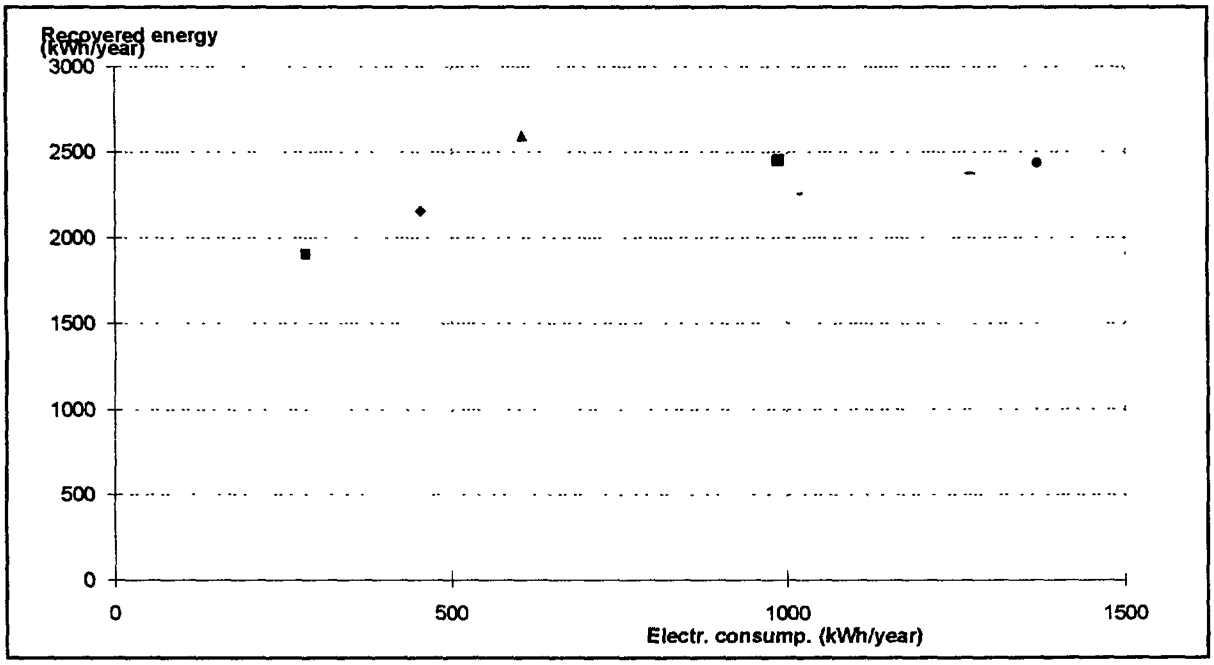

Figure 9. *ESX-units small houses*

regulations for heat recovery.

Choosing the right product on the market is important. But, is it the coming house-owner who makes the choice? Usually not.

In a report, made on behalf of NUTEK, small fans on the market and alternatives for more efficient products and more efficient system designs are discussed (Sandberg 1992).

The main potential for more efficient small fans would be if manufacturers began to install D.C motors in small fan systems. They have higher efficiency even at lower speed. On the market there are only a very few DC fans for sale and to a higher price. In order to make DC motor fans competitive with AC motor fans, a very large production volume is required.

The price is the main obstacle today against small DC fans. A substantial technology procurement is demanded to get DC fans to become the competitive choice. EEC energy standards might be an alternative to technology procurement. Initially DC fan technology might need to be demonstrated for the different applications in question.

6. MEASURES FOR BETTER EFFICIENCY

In the study measures to make the existing ventilation systems more efficient have been calculated.

There were no energy savings in better maintenance. Good maintenance are though necessary for keeping the ventilation system going.

The only investment measure that would pay off in less than five years is changing the fan wheel from F-blade to the more efficient B-blade which was a possibility for two of the 12 systems. For the other systems, a B-blade was not available and a simple change not possible. All the other measures, as changing to a better fitted motor size, a more efficient fan, fan unit, filter size, heat exchanger did not pay off in less than 10 years.

On the other hand there may be other reasons for component changes such as aging systems, high maintenance costs, inadequate air-flows etc. This would provide a good opportunity for changing to more effective components or systems. The extra costs involved for choosing a more efficient alternative pays off best when component replacement becomes necessary. The study shows that the potential for saving in existing buildings is in this case approximately 30 per cent with technology available on the market today. In the individual case, the potential can vary between 0-60 per cent.

Belt drive systems in small fan units are relative inefficient. They also need yearly controls and exchanges of the belt drives and thus a maintenance costs to consider. Unfortunately most direct driven fans in multifamily houses use the less effective external rotor motor. This motor type may be speed regulated with a simpler technic. The more efficient frequency regulating technic is becoming cost effective even for smaller fan systems. Direct drive with frequency regulation and conventional motors will become both an economic and efficient possibility.

The number of efficient fans and systems on the market today is limited. With an increased demand for more efficient equipment, a wider availability would be presented. Normally, neither the consultants nor the contractors have the knowledge or time to seek more effective equipment than the previous conventional choices. Therefore demand to raise the efficiency must come from the property managers or as common energy standards.

7. CONCLUSIONS

- The total efficiency of the present ventilation systems for apartment blocks is only half of what it could have been.
- An energy efficiency classification suitable for domestic ventilation must take into account that the majority of ventilation systems are small and do not have supply air fan systems. Account must also be taken of whether heat is recovered from exhaust air or not due to the higher pressure drop.
- Energy efficiency classifications or common energy standards should be considered to get the property managers rise the efficiency demands on the ventilation systems.
- In small houses and multifamily buildings ESX-systems usually don´t recover more energy than 2 - 4 times the extra input of electrical energy compared with an E-system. This might be improved. Still the economical benefits for choosing an ESX-system is not enough to include demand on heat recovery in building regulations when only the energy aspect is to be considered.

- Installation of speed-regulated systems is one option for more efficient ventilation, but The functional connection between speed control - motor - fan -system is relatively complex. The supplier of the speed-regulated systems has usually not the knowledge of ventilation systems that is needed.

- Small fans (50-100 watt AC) for individual houses and apartments could be considerably more efficient if DC motors were available as standard instead of AC motors. The condition for being commercially viable would be ample production volume. Technology procurement or energy standards for small fans within the EEC would probably be necessary.

ACKNOWLEDGEMENTS

I would like to thank The Swedish Council of Building Research for promoting this paper as well as financing the ventilation study.

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