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Survey of Mechanical Ventilation Systems in 30 Low Energy Dwellings in Germany

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1 Synopsis

This paper shows preliminary results of 18 out of 30 inspected ventilation systems in low rise, low energy residential buildings. We propose a method for the assessment of energy efficiency of ventilation systems.

The majority of the inspected exhaust systems fulfills the conditions for the demanded air flow rates and energy efficient operation. However, typically the distribution of airflows to the rooms of the supply zone is rather weather dependent due to insufficient airtightness of the buildings and large stack heights.

2 of 5 exhaust supply systems with heat recovery mismatch energy efficient operation due to high pressure drops. The airtightness of the buildings is insufficient.

Generally, there is a lack of operation and maintenance instructions. By optimized ductwork, fans, motors, and controller the electricity consumption could be reduced by more than 50%.

2. Introduction

In Hesse, a state of the Federal Republik of Germany, since 1987, a increasing number of low energy houses were constructed. This development was mainly due to political measures and sponsoring by the Hessian governement as well as the work of the Institut Wohnen und Umwelt (IWU). One prerequisite for support from the sponsoring program was a mechanical ventilation system, which was demanded mainly by air quality reasons..

In 1993, a program was set up to investigate the performance of the supported ventilation systems. This work was done by the consulting office ebök under contract of the IWU, financed by the "Hessisches Ministerium für Umwelt, Energie und Bundesangelegenheiten". This paper covers preliminary results of 18 of the 30 tested ventilation systems. A final report will be available at the end of 1994.

3. Research Planning

3.1 Types of Buildings and Systems

All systems were installed in 2 to 3 storey 1 or 2 family houses or terraced houses.

The following system types are included in the study

- Exhaust air with manual fan speed control (6 systems) (E_S)
- Exhaust air with humidity control (7 systems) (E_H)
- Exhaust and supply air system with heat recovery by heat exchanger (5 systems) (ESX)

3.2 Measurement Techniques

Since the ductwork contained no designed measurement planes, measurement of air flow rates, pressure drops etc. were often difficult to perform. Therefore a number of different measurement devices and techniques in accordance with /VDI 2079/ and VDI /2080/ were used. Measuring equipment and typical resulting errors are as follows:

- Power demand by digital wattmeter (typical error 5 % of reading).

- Pressure levels by Pitot tube and digital micromanometer (typical error 6%, up to 20% o.r. at very low pressure differences).
- Air flow rate calculated by air velocity measurement by heated wire anemometer (typical error about 14% to 22% o.r.).
- Air flow rate by dynamic air speed indicator (System Halton) (typical error 7% to 12%).
- Air flow rates at air terminals by anemometer-hood (typical error 15% o.r.).
- Relative air flow distribution at terminals by pressure drop factors (typical errors 20% o.r.).

3.3 Design Conditions and Assessment Standards

The design conditions were defined as follows:

- 30 m^3/h outside air flow rate per person, at least 0.3 ac/h, and no more than 0.8 ac/h.
- All rooms with increased humidity or odour emissions are to be equipped with exhaust vents. According to /DIN 1946/ part 6 (draft) minimum air flow rates are established: kitchen 60 m^3/h, bathroom 40 m^3/h, toilet 20 m^3/h, at minimum air exchange rate of 2 ac/h. Minimum air flow rate for integrated cooker hoods 120 m^3/h.
- Living rooms with supply vents (ESX) or outside air supply vents (E) and openable windows.
- Openings in interior walls or doors to allow air flow from supply rooms to exhaust rooms.
- Demand controllable total air flow rates, at least 2 levels, 100% and 50%, of the design condition. An adjustable distribution of supplied air is desirable.
- No disturbing noise levels or draughts produced by the ventilation system.
- Good conditions for inspection and maintenance.
- Energy efficient operation of the ventilation system.

It is assumed that all living rooms and the kitchen have openable windows to allow additional natural ventilation on demand and during summertime. No severe indoor production rates of contaminants, for example radon or formaldehyde, should be present.

3.3.1 Energy Efficiency

Today German building code /WSVO 1993/ is revised for environmental reasons. There is a statement for ventilation systems with recovery by air-to-air-heat-exchanger that the ratio of recovered useful heat to electricity consumption (COP) should exceed a factor 5. This is motivated by different emission levels into the atmosphere by generation of heating energy and electricity.

Using the heating degree day method /HMWT 1990/ specific ventilation energy losses Q_{ex} by 1 m^3/h air flow rate are calculated under typical German weather conditions for low energy houses over one heating period (degree day limits 20°/12°C, heating degree days dd=3400 Kd, specific heat capacity of air $c_{p,air}$=0.34 Wh/(m^3K)). They amount to

$$Q_{ex} = c_{p,air} * dd * 24 = 0.34 * 3400 * 24 = 27744\ [Wh^2/m^3] \quad (1).$$

In order to reach the COP of 5, the maximum allowable air-flow-specific electric power consumption, is calculated by

$P_{spez,max,ESX} = Q_{ex} * eta_x / (t_{op} * COP)$ (2).

Assuming a mean recovery effectiveness eta_X of 70% and an operation period from 1 Sep. to 31 May (operating time t_{op}=6552 h/year), yields the limiting value of air-flow-specific power

$P_{spez,max,ESX} = 0{,}61\ Wh/m^3$.

This number is used as a threshold condition for the energy efficiency of ESX systems.

Assuming an exhaust only system to be one half of an ESX-system the limit for energy efficient exhaust systems amounts to

$P_{spez,max,E} = P_{spez,max,ESX} * 0.5 = 0.3\ Wh/m^3$.

4. Results

4.1 System design

Tab. 1: Basic data of buildings and design values of ventilation systems (E_S: exhaust system fan speed controlled, E_H: exhaust system humidity controlled, ESX exhaust supply system with air to air heat exchanger

system name and type	ventil. volume [m^3]	liv. area [m^2]	actual occup. [person]	design air flow rate [m^3/h]	area spec. rate [$m^3/(hm^2)$]	air exch. rate [ac/h]
FR, E_S	422	179	5	180	1,01	0,43
BU, E_S	300	131	4	160	1,22	0,53
BE, E_S	477	205	3	150	0,73	0,29
HA, E_S	366	140	4	140	1,00	0,38
WH, E_S	513	201	4	180	0,90	0,35
MU, E_S	341	131	5	180	1,37	0,53
WU, E_H	501	188	5	180	0,96	0,36
LA, E_H	476	181	2	180	0,99	0,38
HG, E_H	515	194	3	180	0,93	0,35
HL, E_H	347	118	2	100	0,85	0,29
GS, E_H	359	144	4	140	0,97	0,39
FL, E_H	327	116	3	120	1,03	0,37
KU, E_H	768	307	7	300	0,98	0,39
PR, ESX	427	178	4	180	1,01	0,42
OT, ESX	450	201	5	180	0,90	0,40
RK, ESX	910	441	6	300	0,68	0,33
SC, ESX	389	168	4	160	0,95	0,41
WL, ESX	465	150	3	180	1,20	0,39
mean val.	464	187	4	177	0,98	0,39

Tab. 1 shows the basic data of the systems and buildings. The system name is an internal code.

In most buildings, assignment of rooms to supply or exhaust zones was correct.

4.2 Air Flow and Air Exchange Rates

Of the inspected 18 systems 14 almost met the design values. 3 systems had too low air flow rates. The reason was mainly due to high pressure drops caused by poor design or installation of ductwork. In 1 exhaust system the distribution of exhaust air to the rooms was totally wrong, because some vents were taped or not installed.

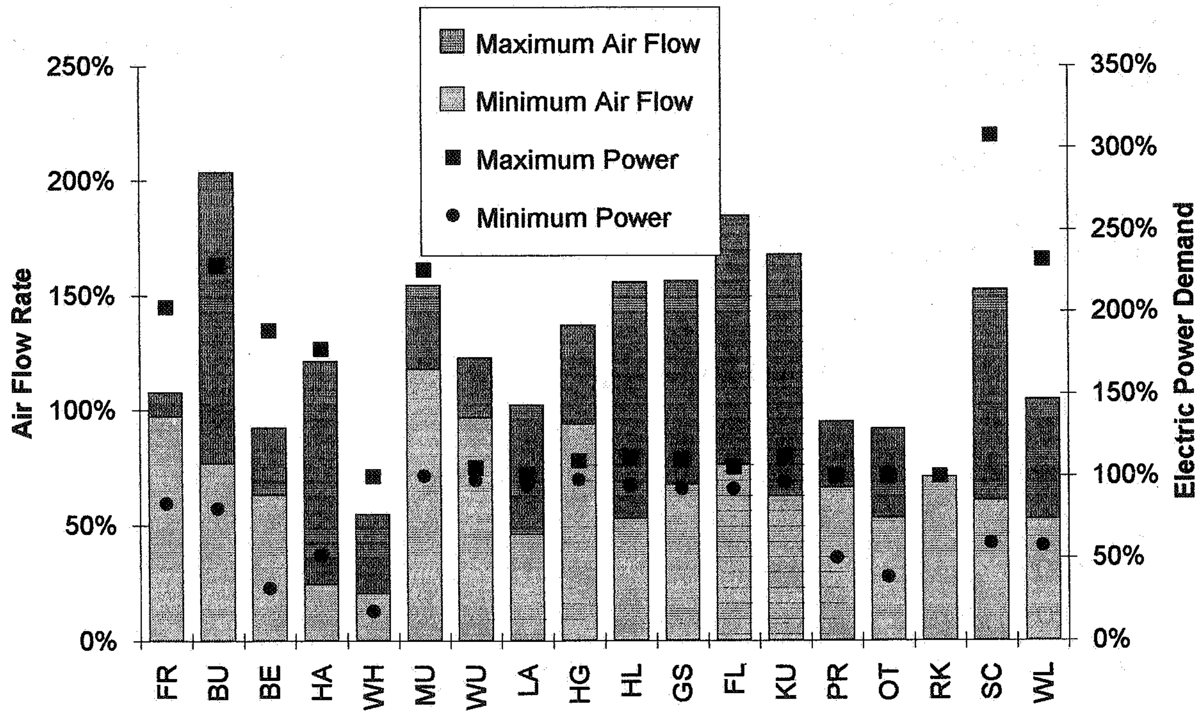

Fig. 1: Control range of air flow rates and electric power demand applied to values at design condition level

Moreover, most systems exhibited more or less severe weaknesses:

- In 9 out of 13 buildings with exhaust systems airtightness was insufficient or the stack hight to large, so the ventilation rate and especially the ventilation of rooms with outside air supply vents was strongly influenced by stack and wind generated forces. Visible indicator for stack driven exfiltration in some buildings was the dust deposition on the filters of the outside air supply vents: at the ground floor the filter was dirty on the outside, at the middle floor dirt settled on both sides, at the upper floor mainly the inside of the filter was dirty. In some rooms of these houses regularly additional ventilation by windows will be necessary.
- The airtightness in all buildings with ESX systems was insufficient compared to recommendations /SIA 180/. This will result in considerable additional in- and

exfiltration. The ventilation losses of the buildings will be considerable higher than predicted by calculations, assuming an airtight envelope /Werner 1993/.

- Air flow rate of integrated cooker hoods were not sufficient for a high capture capacity.
- For some systems sound pressure levels were to high in the design level position, in some cases this was caused by missing sound attenuators, in some cases by sound generation in ductwork.
- In some systems draughts were found due to wrong placement or wrong type of supply vents.

For about 50% of the systems the range of air flow rate control was not sufficient. For speed controlled systems this was due to wrong balancing between the characteristics of ductwork and fan or oversized fans. For the humidity controlled systems this was due to high pressure losses in the ductwork compared to the pressure drop of the humidity controlled air outlet. One of the systems had only an ON-OFF-switch. Fig. 1 shows the relative variation of air flow rate by control and the electric power demand applied to design condition levels.

4.3 Maintenance and Inspection

Almost no operating and maintenance instructions for the ventilation systems were available, in some cases there were data sheets by component manufacturers.

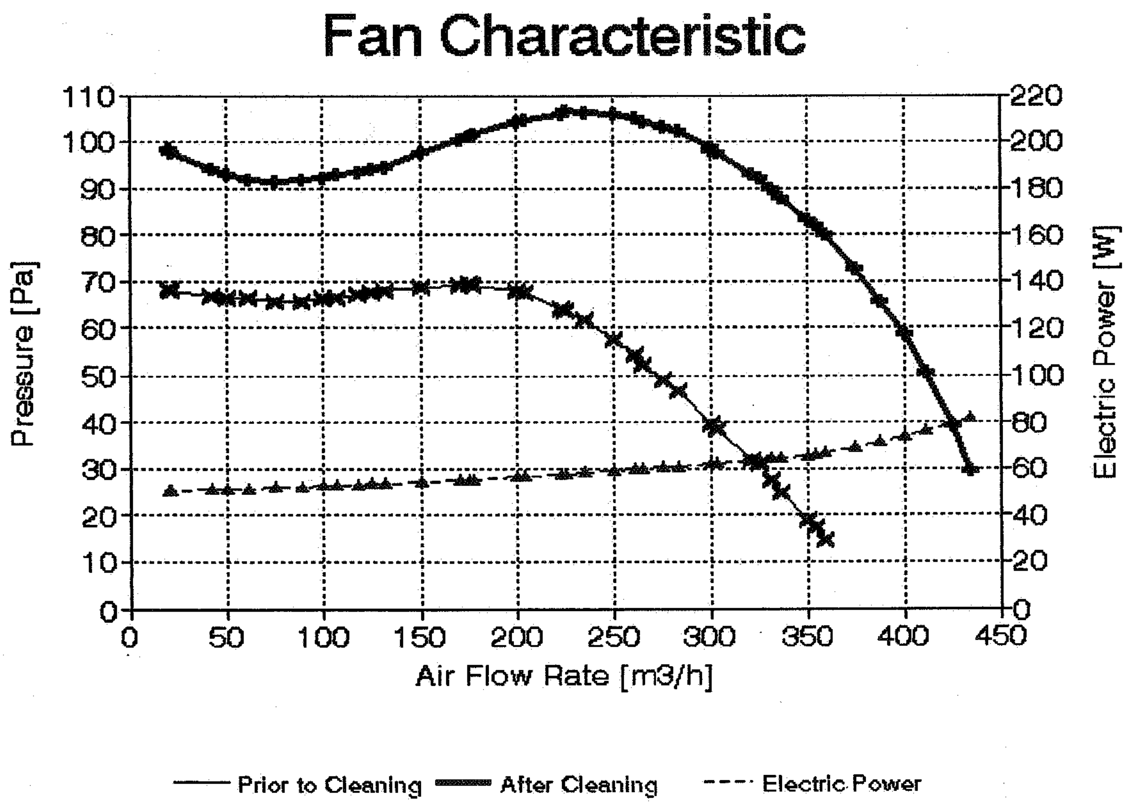

Fig. 2: Characteristic of a fan prior to and after cleaning.

Accessibility of fans and filters for inspection and maintenance purposes was often poor. In many cases this was obviosly due to total lack of planning:

- Turning some fan housings by 180° would improve the accessibility of the maintenance flap and also reduce bends in the ductwork.
- Removal of one filter is impossible because of a lateron installed thermal insulation of a hot water storage tank.

In many cases dirt was found in fans and ductwork dating from the construction period 2 or 3 years ago, besides dust, also pieces of polystyrene insulation were found, wich was a reason for too low air flow rates and noise nuisance.

Frequently fans, filters, or vents were not clean, especially in the systems with integrated cooker hood. Fig. 2 shows the characteristics of pressure and electric power of a fan prior to and after cleaning /Rochard 1994/. Improper maintenance is the most promiment reason for reduced air flow rates and air quality problems.

None of the systems had inspection protocols or tables with adjustment dimensions for vents or other adjustable parts.

Since the occupants of the inspected single family and terraced houses are not experts in ventilation systems, detailed and comprehensible maintenance, instruction, and operation documents are indispensible.

4.4 Ductwork

In all systems ductwork consisted of circular tubes, normally made by metal sheet coated with zink or corrugated flexible metal tubes, in one case plastic tubes of plumbing system type were used.

Typical pressure drops of the inspected exhaust systems amounted to 75 to 100 Pa, for ESX systems a range from 100 to 300 Pa was found (cumulated of exhaust and supply ducts). Recalculations of the pressure drops of the ductwork typically showed possible improvements: avoidable bendings, too narrow diameters, sharply bended or squashed flexible tubes, wrong air outlets and so on.

Improper fixing or jointing of ducts was frequently found, some ducts were found to be completly disjointed (tape got loose and the wrongly fixed tubes slipped away).

4.5 Efficiency

Measurement of the total air flow, the total static pressure in front of and after the fan, and the energy consumption of the motor were used to calculate the systems' overall efficiency (Fig. 3). The efficiency increased with the size of air flow. Except one, all fans were of radial type with foreward leaning fan blades.

The low efficiency of the systems was due to blade and motor type used in small fans, electronic motor controllers, the position of fan blades in the casing, dirty blades, and working conditions outside the range of optimum fan efficiency.

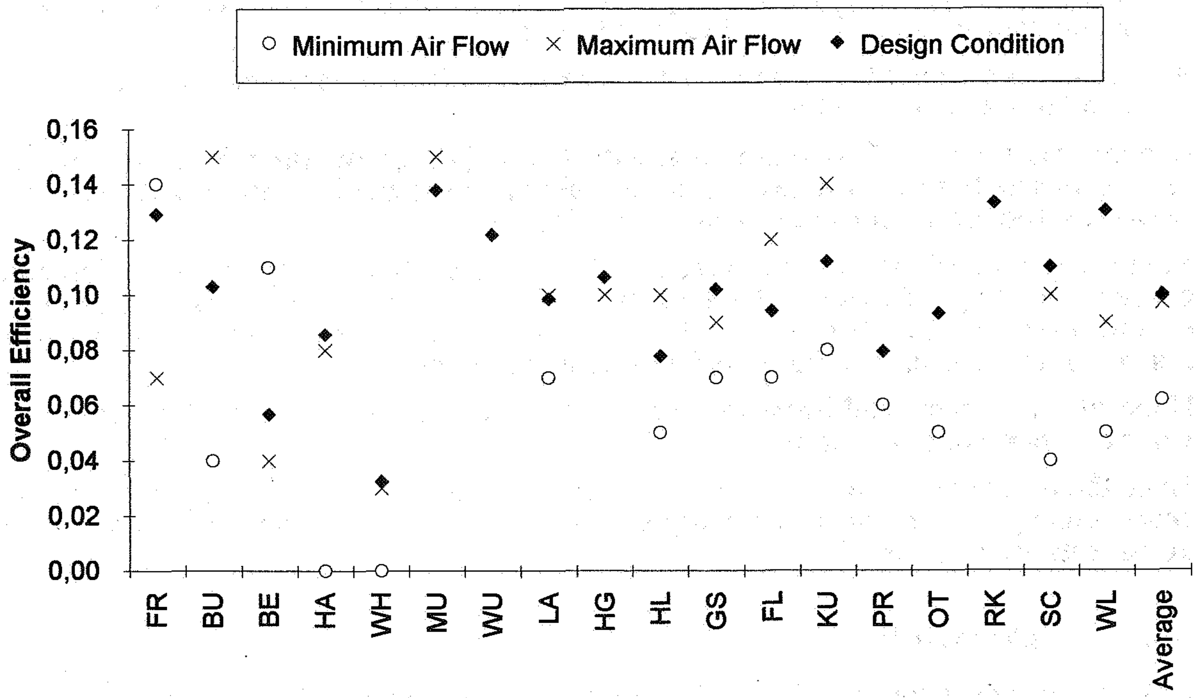

Fig. 3: Measured overall efficiency of ventilation systems

4.6 Electrical energy consumption

4.6.1 Exhaust Systems

The mean electric power of the fans at design conditions ranged from 31 to 76 W, the average air flow specific power amounted to 0,27 Wh/m³, values spread between 0,17 and 0,57 Wh/m³, 3 out of 13 exhaust systems exceeded the limit of 0,3 Wh/m³. Improving the ductwork will lower electricity consumption in speed controlled systems. In some humidity controlled systems the fan capacity was too high for the designed air flow rate.

Under design conditions the electricity consumption was calculated for 6000 operating hours using the measured power demand (Tab. 2).

Tab. 2: Mean, minimum, and maximum values of calculated annual energy consumption per m² of living area of exhaust systems

mean [kWh/(m²a)]	minimum [kWh/(m²a)]	maximum [kWh/(m²a)]
1,49	1,21	1,97

4.6.2 Supply Exhaust Systems with Heat Recovery

The mean electric power accumulated of both fans at design conditions ranged from 39 to 151 W, the average air flow specific power amounted to 0,54 Wh/m^3, values spread between 0,22 and 0,91 Wh/m^3. Two sytems have a very low value < 0.3 Wh/m^3, they were found to possess a very good hydraulic construction of the casing of heat exchanger and fans. Two systems show high values > 0.8 Wh/m^3, they exibited relatively high pressure drops inside the casing due to hydraulic construction and additional heat exchangers for electric heat pumps.

Under design conditions the electricity consumption was calculated for 6000 operating hours using the measured power demand (Tab. 3).

Tab. 3: Mean, minimum, and maximum values of calculated annual energy consumption per m^2 of living area of exhaust supply systems

	mean [kWh/(m^{2}a)]	minimum [kWh/(m^{2}a)]	maximum [kWh/(m^{2}a)]
	2,79	1,32	4,85

5. Measures for Better Efficiency

Possible measures for better efficiency of the systems are:

- Correct design of ductwork.
- Correct choice of fans for operation in the optimum range of fan efficiency.
- Correct adjustment of ductwork.

The average specific consumption of the tested exhaust systems could be improved by the above listed measures to 40%. For ESX systems the possible reduction would lower the the specific consumption by about 50%.

Taking into account newly developed technologies now available also for small ventilation systems (more efficient AC motors, improved speed controllers or DC motors), the specific energy consumption could be lowered from the present mean level by about 3/4 for exhaust systems and about 2/3 for ESX systems. More details are given in /Rochard 1994/. Two prototype systems currently under investigation show promising preliminary results.

6. Conclusions

- In general, the tested ventilation systems fulfill the requirement of energy efficiency. Nevertheless there is still a significant potential for improvement.
- Airtightness of buildings is insufficient. This leads to increased ventilation losses in buildings with ESX systems and to weather dependent ventilation of the supply zone in buildings with exhaust systems.
- Most ductwork and fans are far from the optimum performance. This corresponds to the result of almost total lack of design documents.
- Maintenance of the systems is unsatisfactory. This corresponds to complete lack of maintenance instructions and the poor accessibility to filters and fans, found frequently.

- To improve system performance in the future, better knowledge of architects, engineers and craftsmen is inevitable.
- Developed and available technologies with higher efficiencies should be applied for ventilation systems of small buildings too.

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