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Energy efficiency of ventilation systems

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Synopsis

The paper presents a short description of the measurement program and the data collected for the "SynergieHaus"-project initiated by PreussenElektra and partners (now merged to E.ON). Results of airtightness measurements (ACH 50-values) are shown for a total of 320 buildings equipped with ventilation systems. It was found that both for massive (brick) and light (wood frame) buildings a high standard of airtightness can be obtained.

Based on calculations of heat use according to valid German heat conservation regulations „Wärmeschutzverordnung", a comparison between measured heat consumption and calculated heat use is presented. The comparison leads to effective air change rates for different ventilation systems which depend on the flow rates and the efficiency of the heat exchanger.

The energy efficiency of the technical equipment can be expressed by the ratio of measured total energy consumption for space heating, preparation of hot water and ventilation and the calculated heat use. Average values for different ventilation systems are presented.

The different functions and ways of control of ventilation systems lead to different electric power consumption of the fans. For each of the various ventilation systems an average specific power consumption is shown.

List of symbols

N	number of units considered
ACH	air changes per hour
ACH 50	air changes per hour at 50 Pa pressure difference
$U_{m,eq}$	mean equivalent thermal transmittance
A	building envelope area
V_e	volume (external measurements) of the building
$Q_{l,V}$	annual ventilation heat loss
F_{DD}	factor for degree days
$(c_p\ \rho)_{air}$	specific heat and density of air
Vi	internal (air) volume
n_{eff}	effective air change rate

1. Introduction

The investigation of the energy efficiency of ventilation systems was part of a large field study: the "SynergieHaus"-project. This project was initiated by (German electric power utility company) PreussenElektra and partners (25 regional and communal utilities). Its aim was to make a contribution to the development and dissemination of dwellings which need less energy than common ones. Between 1994 and 1999 414 newly built dwelling units in 339 buildings received financial support in the frame of this project. Requirements for eligibility were to remain at least 30% below the annual heating need according to the valid German heat conservation regulations („Wärmeschutzverordnung") [1], the installation of a mechanical ventilation system and an airtight thermal envelope of the building [2, 3].

The individual building projects were intensively assisted in terms of an integrated approach from planning to completion. They were subject to an accompanying scientific program involving monitoring of the buildings. The monitoring program ran until fall 1999. The collected data resulting from the examination of all the objects give an unique survey about concepts of Low-Energy-Buildings which were put into practice in Germany, including installation of technical systems of buildings. From the detailed measurement data of all the objects it will be possible to get an extensive insight into energy consumption of these buildings [4, 5, 6].

2. The measurement program

Depending on the time of completion of each individual building measurements were carried out during a maximum of 3 heating periods. With up to 8 measurement channels per dwelling unit it was possible to collect data of the electric power consumption for the household, ventilation systems, heat pumps and auxiliary units, the consumption of fuel (gas, oil, electricity) and optionally the consumption of hot water or solar heat (Fig. 1) [7]. The data were recorded as 15-min values, saved as daily data sets and transferred via modem to the central data processing and storage at the University of Kassel. The data evaluation enables individual predications for single buildings e.g. in the frame of energy consultations and informations about average consumptions which are presented in this paper.

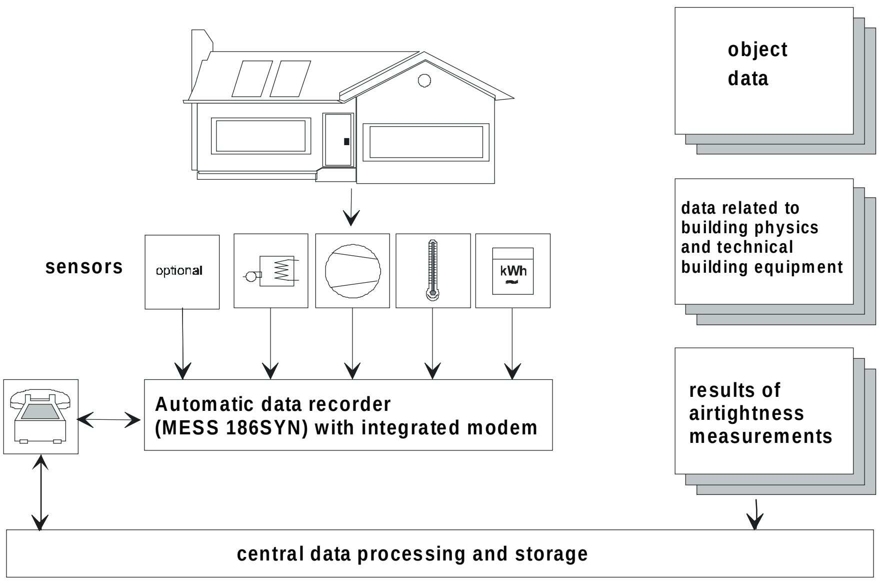

Fig. 1: Schematic illustration of the measurement program.

3. Measurement results

3.1 Airtighness of the building envelope

The use of ventilation systems in low energy buildings requires a sufficiently airtight building envelope. This is necessary to ensure a defined air change rate and air flow in the building. Furthermore, it has to be guaranteed that in case of using a heat recovery system (heat exchanger, air/air heat pump or a combined system) that the air exchange will completely take place over the ventilation unit.
In the frame of the project the requirements concerning the airtightness of the building envelope were defined depending on the installed ventilation system:

- extract ventilation systems (with or without heat recovery): ACH 50≤2.5 h^{-1}
- supply/extract ventilation systems: ACH 50≤1.5 h^{-1}

Results of airtightness measurements are shown in Fig. 2. Here it is differentiated between light (wood frame) and massive (brick) buildings. The measured data are represented by the lowest, the highest and the mean values for a total number of 320 buildings. The mean ACH 50 values of 1.35 h^{-1} (light buildings: N=138) and 1.23 h^{-1} (massive buildings: N=108) are calculated for those buildings only that reached the required values within the first blower door measurement. The numbers in brackets are the mean ACH 50 values for the total number of buildings (light buildings: N=182; massive buildings: N=138) including the ones that needed follow up treatment.
The results show, that under the precondition of good planning and careful manufacturing a high standard of building air tightness can be obtained [8].

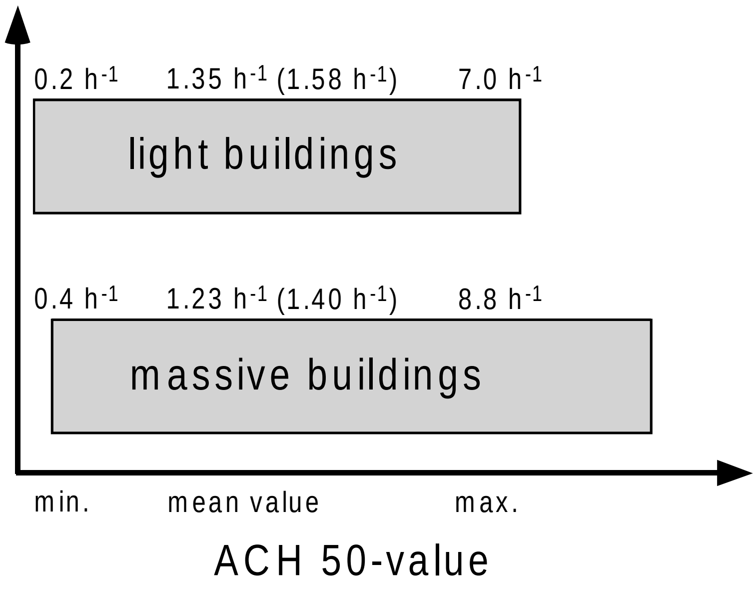

Fig. 2: ACH 50-values for different building types (no. of buildings light: 182; massive: 138).

3.2 Heat use and heat consumption

Requirements in regard to the thermal insulation of the buildings were to remain at least 30 % below the annual heat use according to the current German heat conservation regulations (Wärmeschutzverordnung). In the frame of these regulations the heat use is calculated considering transmission and ventilation heat losses and internal and solar gains. If a ventilation system is installed the ventilation heat loss (based on the air change rate $n=0.8\ h^{-1}$) can be reduced by 5 % for extract ventilation systems and by 20 % for supply/extract systems. The measurement of the heat consumption is carried out at the outlet of the heat generating system. In order to be able to compare calculated and measured data it was therefore necessary to define a "modified heat use" that considers the heat losses due to the heat distribution system and additional heat losses due to non-uniform temperature distribution and non-ideal distribution system control. Furthermore, the modified heat use considers the climate in terms of magnitude of local degree days.

The comparison between the modified heat use and the heat consumption is given in Fig. 3. It can be shown that there is a good agreement between calculations and measurements for the supply/extract ventilation systems (with different heat recovery systems). For the case of extract systems without heat recovery the measured heat consumption is lower than the heat use. For those extract ventilation systems with air/water heat pumps the measured values are higher than the calculated ones.

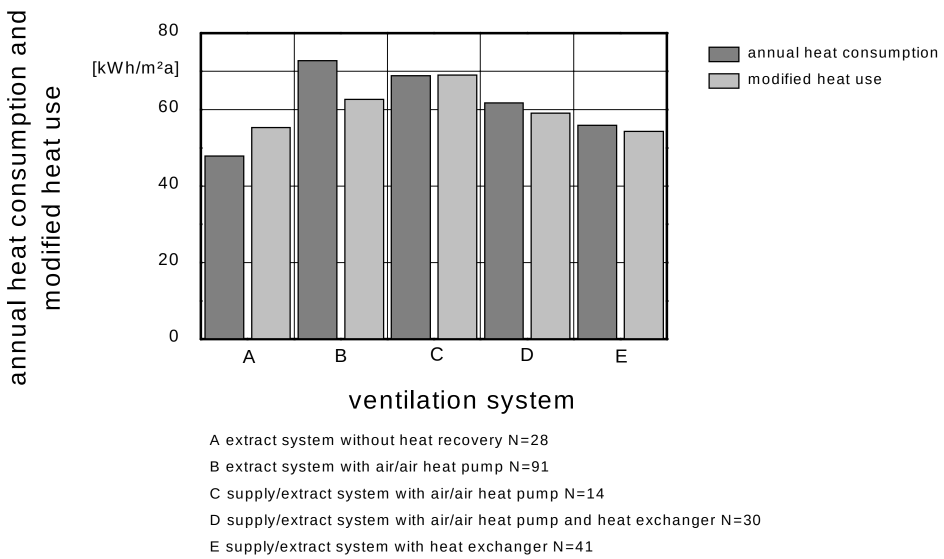

Fig. 3: Comparison of average modified heat use and average heat consumption for various ventilation systems (number of objects 204, measurement period: 6/1/98-5/31/99).

From Fig. 3 it can be also found that the lowest average heat consumption is reported in buildings equipped with extract ventilation systems. This is to be expected because these buildings have a higher insulation standard than the other ones. The explanation is given in Fig. 4, where the characteristic value for the building construction ($U_{m,eq}$ *A/V_e) is plotted for the different ventilation systems considered. $U_{m,eq}$ is the mean equivalent thermal transmittance (equivalent means that the solar gains are already considered in the U-value)

and A/V_e is the ratio between the building envelope area and the volume (external measurements) of the building.
Assuming that all terms of the heat balance with the exception of ventilation heat losses can be described sufficiently one can attribute the difference between measurements and calculations to ventilation.

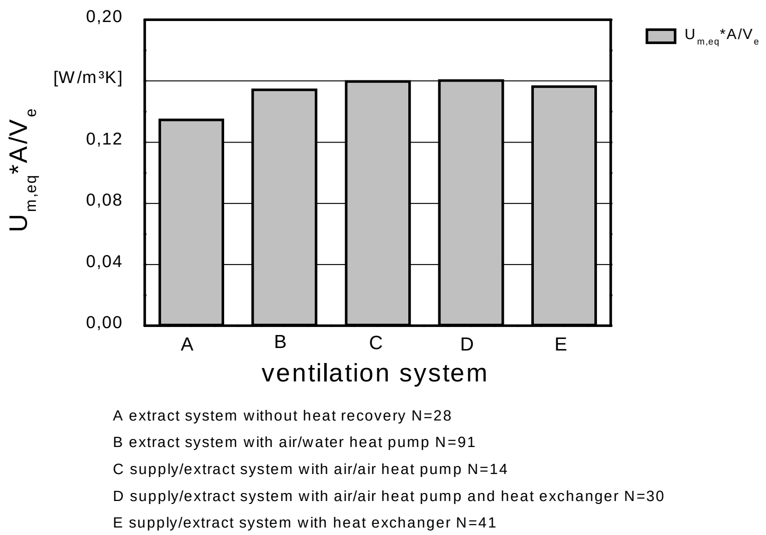

Fig. 4: Mean equivalent thermal transmittance $*A/V_e$ for various ventilation systems (total number of objects 204).

If the ventilation heat losses are calculated according to German heat conservation regulations by

$$Q_{l,V} = F_{DD} \, (c_p \, \rho)_{air} \, V_i \, n_{eff} \qquad (1)$$

an effective air change rate for the different ventilation systems can be found as

A	extract system without heat recovery	n_{eff}=0.64 h^{-1}
B	extract system with air/air heat pump	n_{eff}=0.91 h^{-1}
C	supply/extract system with air/air heat pump	n_{eff}=0.75 h^{-1}
D	supply/extract system with air/air heat pump and heat exchanger	n_{eff}=0.67 h^{-1}
E	supply/extract system with heat exchanger	n_{eff}=0.67 h^{-1}

An explanation for the comparatively high heat consumption of buildings equipped with extract ventilation systems with heat pumps (combi-systems) can be found in Fig. 5 where total fan uptimes during the heating period (9 months) for the different ventilation systems are given. The average total fan uptime for the combi-system is about 1200 h longer than for the other ventilation systems. This is due to the fact that the heat pump is used as a generator for heating and hot water preparation.

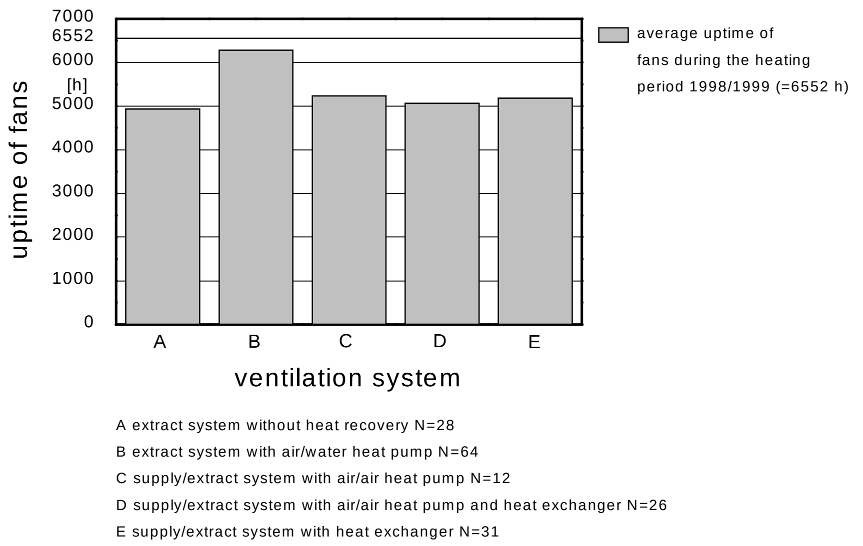

Fig. 5: Mean total uptimes of fans for various ventilation systems in the heating period 98/99 (9/1-5/31; 6552 h; number of objects 161).

3.3 Energy use

The total energy consumption for heating and hot water preparation (fuel for the main heat generator and electric power consumption of heat pumps, ventilators and auxiliary units) is presented only for those buildings which are equipped with gas heating systems (it is not differentiated between low temperature and condensation boilers). Due to this selection it is possible to compare the influence of different ventilation systems.

In Fig. 6 it can be seen that the lowest energy consumption occurs in buildings with extract ventilation systems. It still has to be considered that these buildings have a higher insulation standard than the other ones. This follows also from Fig. 7 where the heat use (including heat use for hot water preparation) – calculated as if there were no ventilation system i.e. the ventilation heat losses are not reduced – is compared with the measured energy consumption. The ratio between the energy consumption and the heat use can be taken to express the energy efficiency of the technical building equipment for heating, preparation of hot water and ventilation. The gas combi system shows the lowest ratio with 1.05 and it goes up to 1.27 for systems with supply /extract ventilation. The findings resulting from Fig. 6 and 7 will change, when the energy is assessed to the primary energy carrier. The conversion factor for gas is assumed as f_{gas}=1.24 and for electricity as $f_{electr.}$=2.97 [9]. The results of the conversion are given in Fig. 8 and 9. Due to the comparatively high share of electricity for systems with heat recovery (heat exchangers/heat pumps) the extract ventilation system takes first place for high energy efficiency.

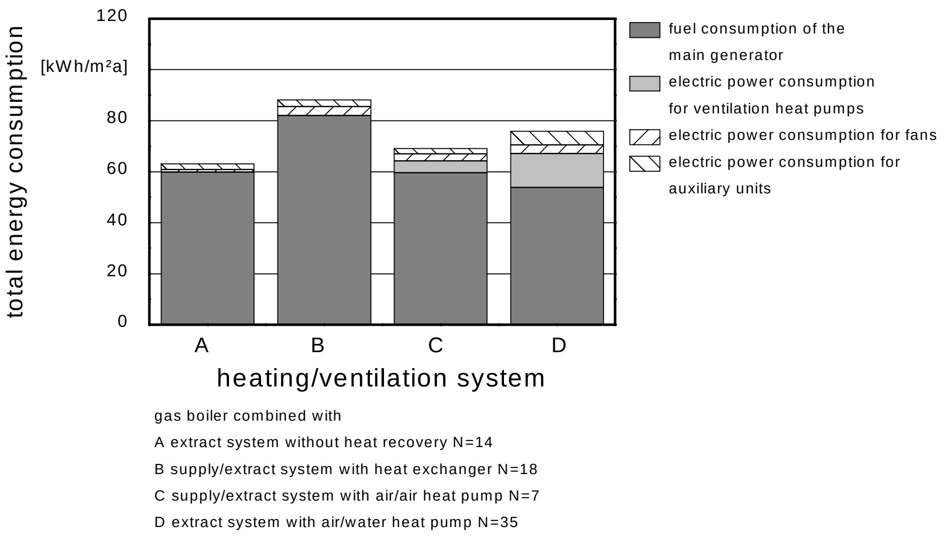

Fig. 6: Average total energy consumption for buildings with gas generators and various ventilation systems (number of objects 74, measurement period: 6/1/98-5/31/99).

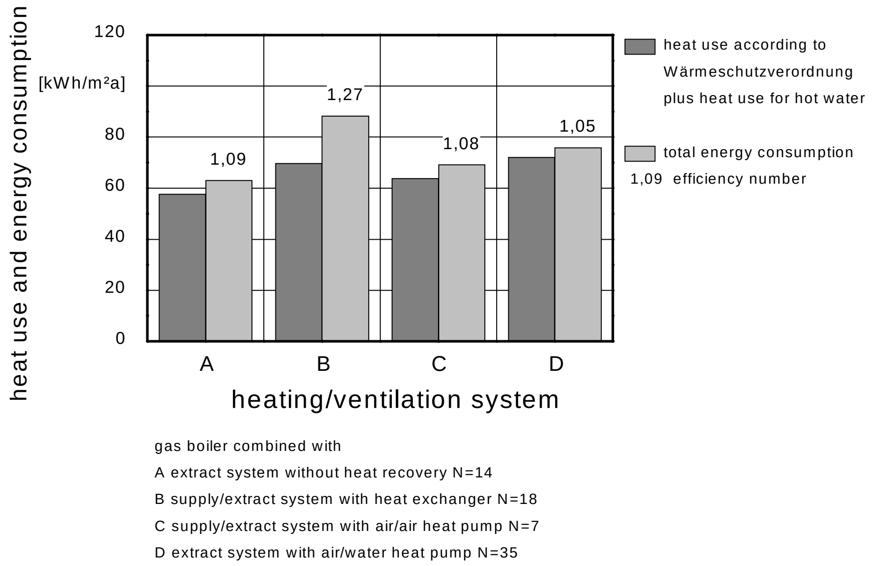

Fig. 7: Calculated heat use for space heating and hot water preparation and average total energy consumption for buildings with gas generators and various ventilation systems (number of objects 74, measurement period: 6/1/98-5/31/99).

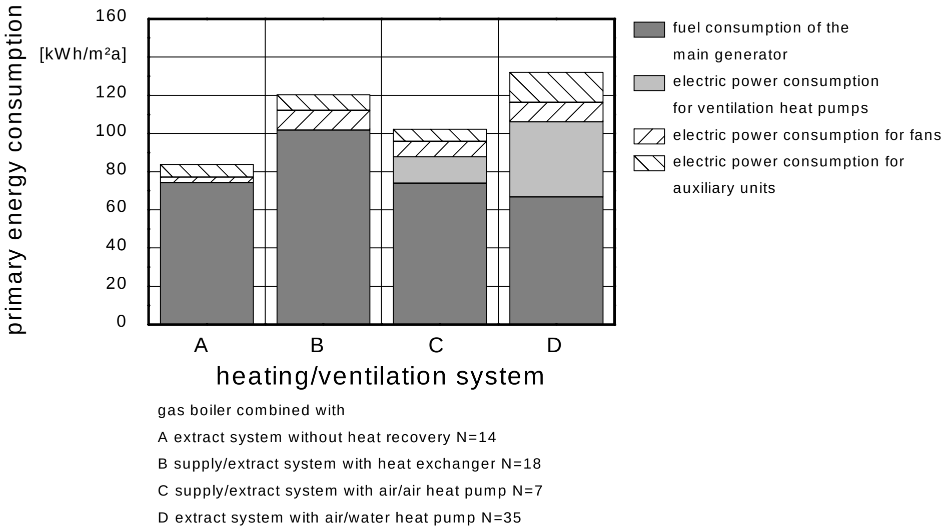

Fig. 8: Average primary energy consumption for buildings with gas generators and various ventilation systems (number of objects 74, measurement period: 6/1/98-5/31/99).

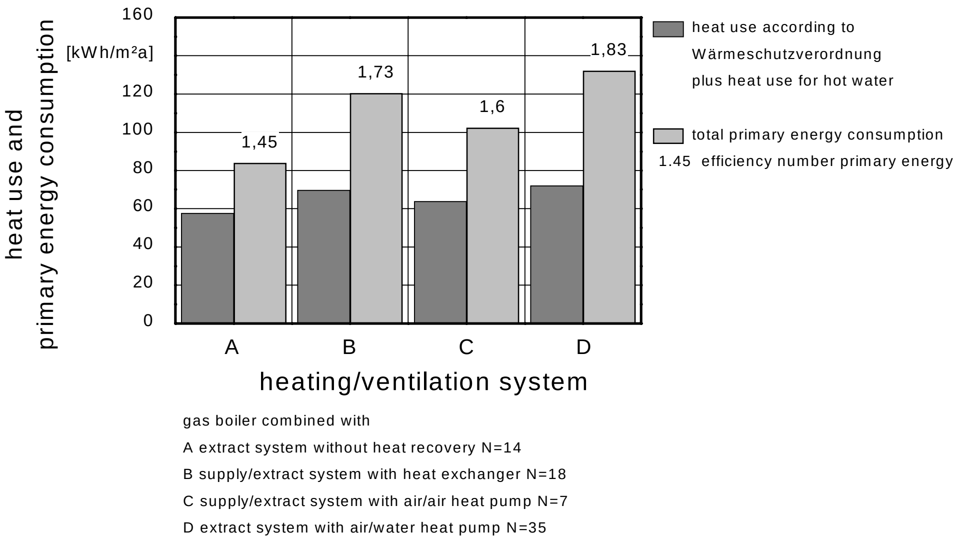

Fig. 9: Calculated heat use for space heating and hot water preparation and average primary energy consumption for buildings with gas generators and various ventilation systems (number of objects 74, measurement period: 6/1/98-5/31/99).

3.4 Electric power consumption of fans

The different functions and possibilities of control of ventilation systems, specifically

- **extract system**: simple ventilation system, controlled by the user depending on individual needs

- **extract system with air/water heat pump**: the ventilation rate is adjusted during the installation procedure, no possibility of operation by the user because a certain air flow is necessary for the heat pump
- **supply/extract systems**: equipped with two fans, used for heat recovery over heat exchangers and /or heat pumps, controlled by the user depending on individual needs

lead to very different electric power consumption of the individual systems. Fig. 10 shows the average specific electric power consumption (referring to the internal (air) volume of the building) for the ventilation systems considered. As expected, the extract systems show the lowest consumption (approx. 0.4 kWh/(m^3a)). Due to the higher pressure losses over heat exchangers and usually higher delivery rates all other systems have a significantly higher electric power consumption (approx. 1.3-1.7 kWh/(m^3a). It is remarkable that the supply/extract systems (2 fans) with air/air heat pump show about the same average electricity consumption as the extract systems (1 fan) with air/water heat pumps.

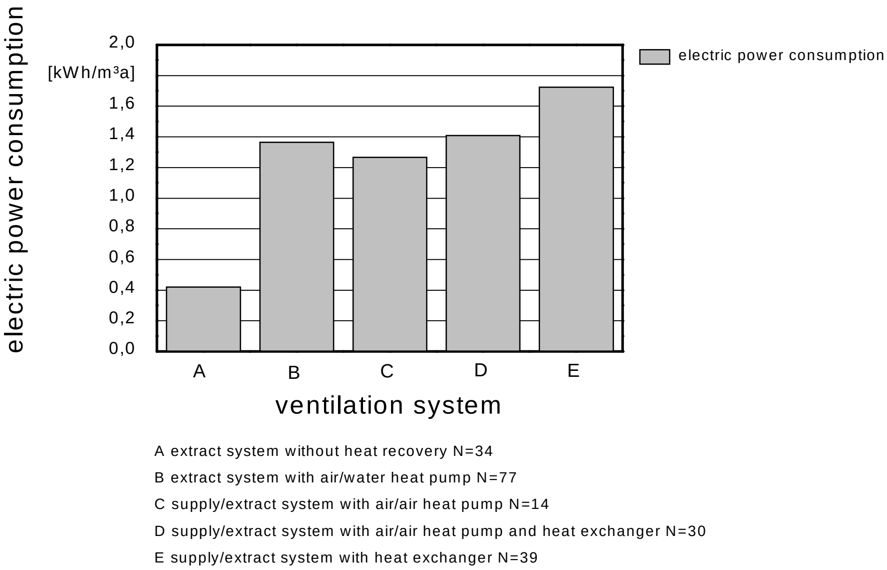

Fig. 10: Average electric power consumption for various ventilation systems (number of objects 194, measurement period: 6/1/98-5/31/99).

4. Conclusions

The measurement program in the frame of the "SynergieHaus"-project gives an extensive insight into energy consumption of low-energy-buildings in Germany. A summary of the results concerning the use and energy efficiency of ventilation systems leads to the following statements

- The average airtightness of the investigated buildings (light and massive) is better than 1.5 h^{-1} (ACH 50) and can be reached with good planning and careful manufacturing. Compliance with this value will be mandatory for future buildings which are equipped with ventilation systems in Germany.
- The average heat consumption of buildings equipped with supply/extract ventilation systems can be predicted very good using the boundary conditions of German heat conservation regulation code "Wärmeschutzverordnung". The application of extract

ventilation systems without heat recovery leads to a lower, the application of extract ventilation systems with heat recovery to a higher heat consumption than those predicted. Effective air change rates (including the effects of heat recovery) can be given as follows

A	extract system without heat recovery	n_{eff}=0.64 h^{-1}
B	extract system with air/air heat pump	n_{eff}=0.91 h^{-1}
C	supply/extract system with air/air heat pump	n_{eff}=0.75 h^{-1}
D	supply/extract system with air/air heat pump and heat exchanger	n_{eff}=0.67 h^{-1}
E	supply/extract system with heat exchanger	n_{eff}=0.67 h^{-1}

- A very good energy efficiency can be obtained for buildings equipped with extract ventilation systems without heat recovery.
- The energy efficiency of extract ventilation systems with air/water heat pumps is comparatively poor. This is mainly caused by
  - a long fan uptime resulting in a higher heat load
  - the dependence of the fan uptime on heat use and not on ventilation needs
  - a relatively high electric power consumption of fans and auxiliary units

  Furthermore, it has to be assured that the heat pump covers most of the heat use. This is especially important if an additional electric heat generator is installed.
- The lowest electric power consumption is ascertained for extract ventilation systems without heat recovery (approx. 0.4 kWh/(m^3a); referring to the internal (air) volume of the building). All other systems show much higher consumption (approx. 1.3-1.7 kWh/(m^3a)). This is due to higher pressure losses and usually higher delivery rates. Using direct current fans is a reasonable way to reduce the electric power consumption.

It has to be pointed out that all measurement and calculation results presented and statements derived therefrom are focussed on energy consumption and energy efficiency only. Obviously, there are other criteria such as comfort aspects, air quality or economy aspects which have to be taken into account when evaluating a ventilation system.

5. References

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