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Exhaust air heat recovery in buildings

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Abstract

The technique of heat recovery from ventilation air in dwellings started in Sweden in late 1979. This was due to an energy crisis and new building codes. The competing heat recovery system, air to air heat exchangers, had a firm grip on the market. Today the situation is on the contrary. Almost all new single family houses are equipped with exhaust air heat pumps. This paper describes the development of the market in Sweden and Germany and also the different techniques of supplementary heating due to national differences in electricity prices. Germany has a situation very similar to Sweden concerning new building codes concerning the allowable energy use for space heating. Starting in 1976 and continued from 1982 to 1995, the building code has prescribed tighter and more insulated houses. The new building code for the year 2000 contains requirements for well insulated and tight buildings so the energy demand for heating from ventilation air tends to reach about 60% of the total annual energy demand for the building. Under these circumstances new buildings must have ventilation systems with heat recovery. Different means of heat recovery from the ventilation system, and the benefit for the environment, by using heat pumps are described. The German market for heat recovery systems is approx. 5–10.000 units/year. Most important for the efficiency of a ventilation system is to maintain the quality criterias concerning:

- equipment
- planning, installation, taking into operation
- operation.

VEW ENERGIE AG has accomplished a field survey of 60 units from 1994 to 1996. As the result was not statistically sufficient, the field survey is followed by an investigation into air quality and reliability.

Keywords: Air conditioning; Heat recovery; Heat pump; Design

Récupération de la chaleur de l'air extrait pour chauffer des habitations

Résumé

La technologie permettant de récupérer la chaleur de l'air utilisé pour ventiler des logements a été inauguré en Suède en 1979 ; elle a été développé dans un contexte de crise d'énergie et de nouvelles normes dans le secteur du bâtiment. Les échangeurs de chaleur air/air étaient solidement implantés sur ce marché mais de nos jours la récupération de l'air de ventilation a pris le dessus. Quasiment toutes les maisons individuelles neuves sont maintenant équipées de pompes à chaleur utilisant de l'air extrait. Cette communication décrit le développement des marchés suédois et allemands ainsi que des

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différentes technologies utilisées pour le chauffage complémentaire et selon les différences nationales des tarifs électriques. L'Allemagne connaît une situation proche de celle rencontrée en Suède en matière de normes du bâtiment récentes. A partir de 1976, puis en 1982 et en 1995, les normes de plus en plus strictes sur l'isolation des logements ont été appliquées. Le code du bâtiment de 2000 comporte des exigences si strictes, en termes d'isolation et d'étanchéité des logements, que les besoins énergétiques annuels du chauffage et de la ventilation ne sont plus que de 60% de la demande totale des constructions en question. Dans ces conditions, des logements neufs doivent être équipés en systèmes de ventilation avec récupération de chaleur. Cette communication décrit les moyens de récupération de chaleur à partir de l'air extrait et les avantages sur le plan environnemental des pompes à chaleur. Le marché allemand des systèmes à récupération de chaleur représente 5000 à 10 000 unités par an. Les critères clés qui gouvernent la performance d'un système de ventilation concernent : les équipements, la conception, l'installation et la mise en service et le fonctionnement.

VEW Energie a effectué une enquête sur 60 installations entre 1994 et 1996. Les résultats n'étant pas statistiquement significatifs, une deuxième enquête est en cours afin d'examiner la qualité de l'air et la fiabilité de ces systèmes.

Mots clés : Conditionnement d'air ; Récupération de chaleur ; Pompe à chaleur ; Conception

1. Market development in Sweden and Germany

1.1. Swedish market development

The birth of the exhaust air heat pump (EAHP) in Sweden happened in the late seventies. Due to new building codes, energy crisis and an interest in new technics for energy conservation the Swedish manufacturers of single family dwellings welcomed the EAHP for heating domestic hot water (DHW). Also the Swedish authorities meant that this was a good step on the road to close down Swedish nuclear power. Thus the installation of energy efficient equipment was subsidised.

As mechanical ventilation was rather new, the EAHPs were primarily installed in new houses.

The energy needed for DHW is about 500 W and the exhaust air energy content is three to four times more. This pushed the EAHP manufacturers to develop systems for partial space heating. In the beginning of the eighties direct electric heating was almost forbidden in the new houses in Sweden. The reason was of course an aim to come to more flexible heating systems — hydronic systems — which allows different kind of heat sources as wood, solar, heat pumps and district heating. So the next step was to create the complete heating machine. Including the three basic functions — heating, domestic hot water, ventilation and heat recovery and all necessary controls in one package. The house builders now had got everything on only 0.36 m^2 of the living area. In Fig. 1 is shown the development from DHW only to total heating.

The Swedish market for new built single family houses, sfh, showed a very big decrease from the late seventies to the mid eighties. After that period we had a rather good increase up to the beginning of the nineties when the building of new houses almost stopped. In Fig. 2 is shown the number of new built single family houses and the installation of EAHṔs. The diagram clearly reflects the impact from the market for new houses in Sweden on the sales of EAHṔs. From the beginning of the mid nineties the Swedish market for sfh

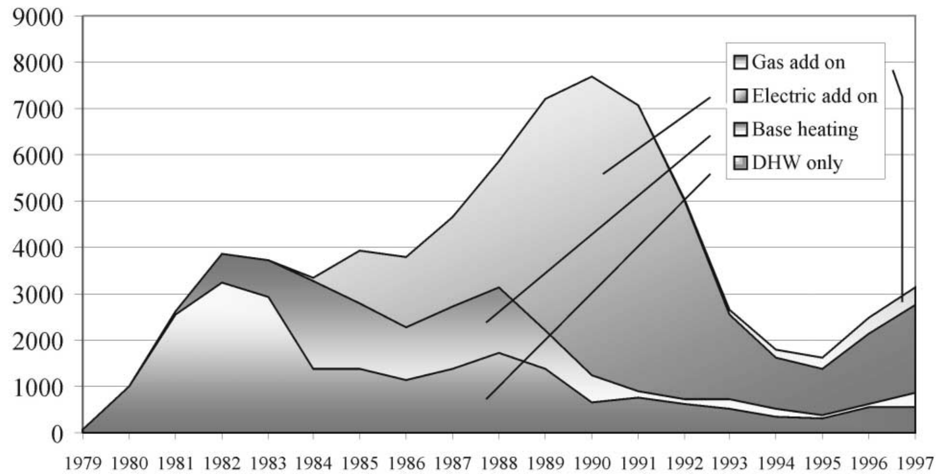

Fig. 1. Diagram describing the development of different types of EAHPs in Sweden from the start 1979.

Fig. 1. Courbe illustrant le développement de différents types de pompe à chaleur utilisant l'air extrait (EAHP) en Suède à partir de début 1979.

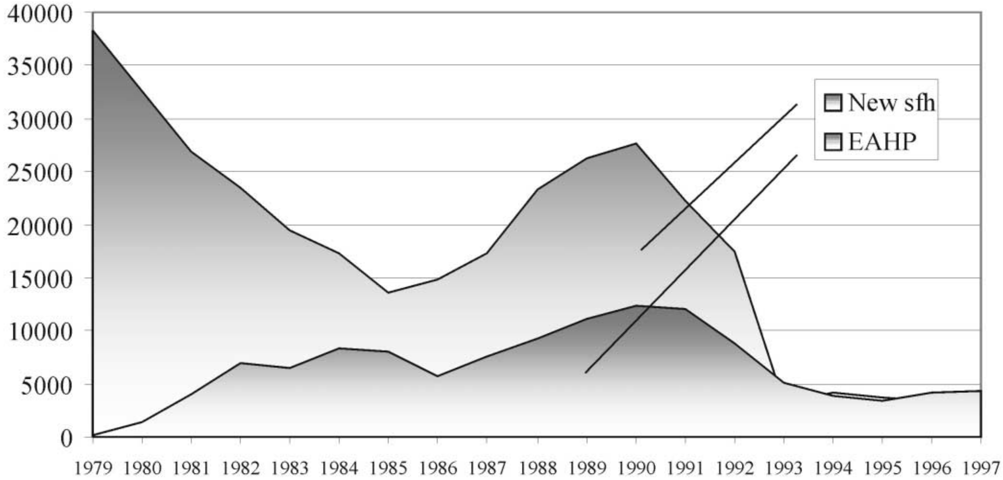

Fig. 2. Diagram describing the number of new built single family houses in Sweden and the total number of installed EAHPs from 1979 to 1997. Source "The National Association of Swedish Wooden House Manufacturers" and SVEP (The Swedish Association of Heat Pump Manufacturers).

Fig. 2. Courbe montrant le nombre de nouvelles maisons individuelles en Suède ainsi que le nombre d'EAHP installées entre 1979 et 1997. Source : « The National Association of Swedish Wooden House Manufacturers » et SVEP (l'Association suédoise des fabricants de pompes à chaleur).

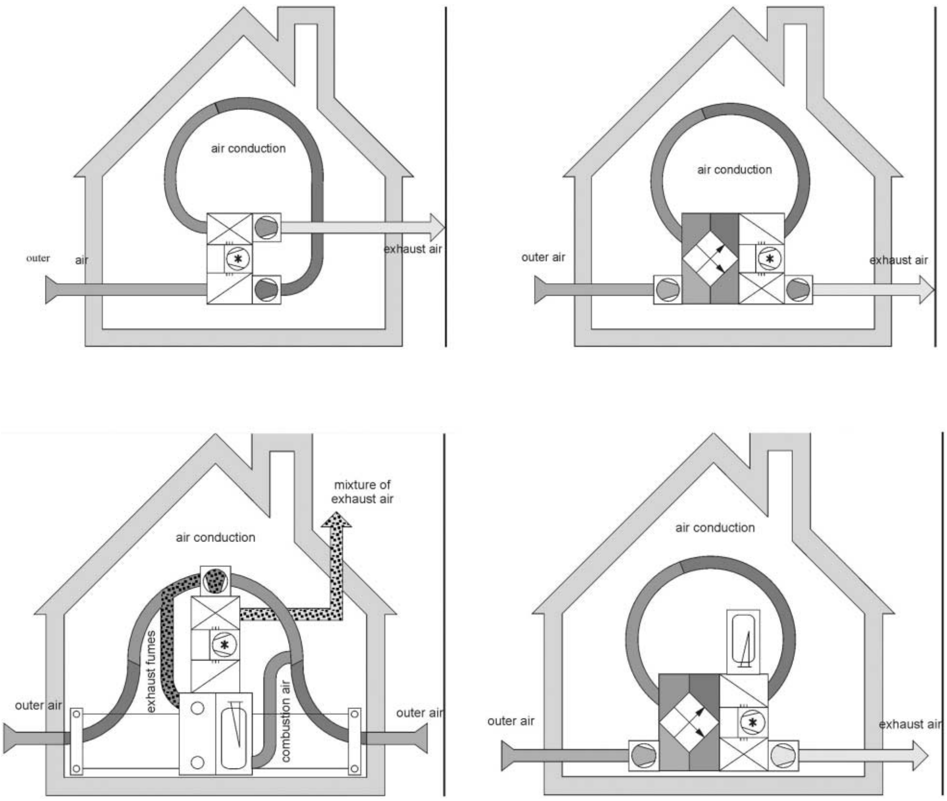

Fig. 3. Commercial forced ventilation systems featuring heat pumps for heat recovery. Source: RWE PLUS AG.

Fig. 3. Systèmes de ventilation commerciaux utilisant des pompes à chaleur pour la récupération de chaleur. Source : RWE PLUS AG.

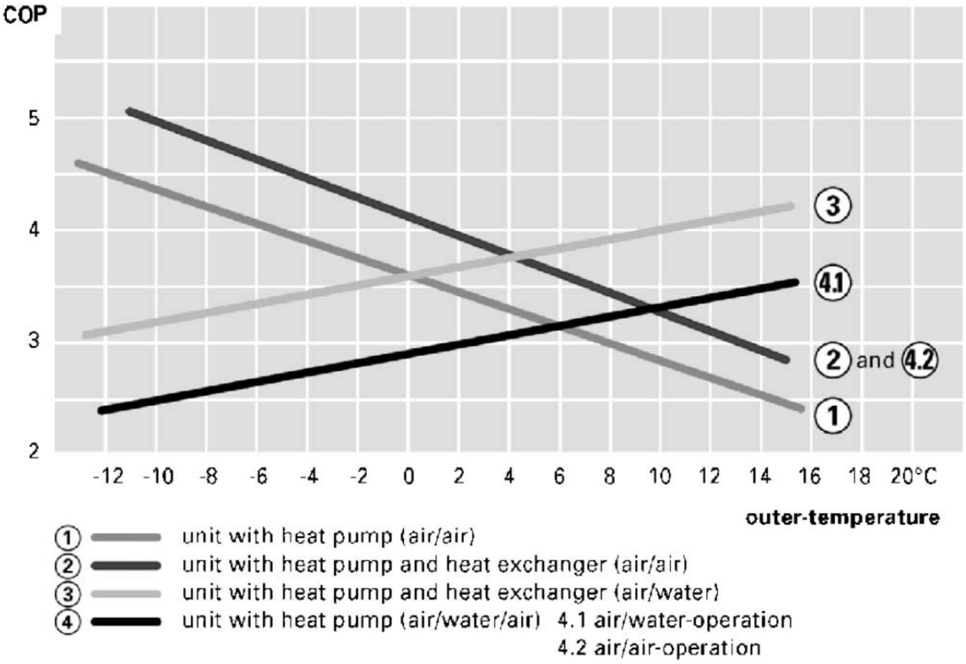

Fig. 4. Typical coefficients of performance of four forced ventilation systems featuring heat pumps for heat recovery. Source: RWE PLUS AG.

Fig. 4. Coefficients de performance typiques de quatre systèmes de ventilation à air forcé munis de pompes à chaleur utilisées pour récupérer de la chaleur. Source : RWE PLUS AG.

has, from a very low level, started a slight increase. Now we also are going towards a mature market concerning EAHṔs. The exchange of earlier installed EAHṔs has begun. This explains why in Fig. 2 the number of sold EAHṔs appears to be larger than the number of new houses in the last years.

1.2. German market development

Forced ventilation systems featuring heat pumps for heat recovery offered on the German market can be grouped by four different processes. A system and manufacturer survey published by RWE PLUS AG [2] reviews forced ventilation systems marketed in Germany.

Exhaust air is the source of heat for the appliances shown in Fig. 3. The heat recovered is transferred to the fresh air (air-to-air systems) or the domestic hot water or the space heating water (air-to-water or air-to-water-or-air systems). Some heat pumps feature an upstream recuperator (crossflow or countercurrent flow type or heat pipe). In air-to-water-or-air systems, the heat recovered is transferred to the fresh air or the hot water by a temperature control system.

The four forced ventilation systems featuring heat pumps for heat recovery differ not only by the fluid to which the heat is transferred (air and/or water), but also by their coefficients of performance as a function of operating conditions and control setpoints. Fig. 4 shows typical coefficients of performance for the four systems.

2. Exhaust air heat pumps compared to other systems

The ventilation standard of today has developed from natural ventilation via simple mechanical exhaust ventilation via a roof fan or a kitchen hood fan to more complicated mechanical exhaust and supply ventilation systems with heat recovery. The over all trend today is towards simple exhaust ventilation with an exhaust air heat pump for heat recovery and total heating. There are three major reasons for that:

- the exhaust ventilation system only needs one fan and a less complicated duct system.
- the EAHP can heat DHW as well as the space
- the EAHP recovers two to three times more energy than the air to air heat exchanger

Other advantages for the simple exhaust ventilation system is that:

- the building has always a lower pressure than the outside — minimises the risk for vapour condensation in the walls — risk for mould

Table 1
Summary of energy use in single family houses from different Swedish research projects. Explanation: Reference 2:3 is equipped with an air to air heat exchanger. The other houses have exhaust air heat pumps

Tableau 1
Maisons individuelles : résumé de la consommation d'énergie (données obtenues à partir de projets de recherche). Note : la référence 2 :3 est équipée d'un échangeur air à air. Les autres maisons sont équipées de pompes à chaleur

Reference	Building type	Building area, A m^2	Total electricity demand, E_{tot} kWh	Energy saved, E_s kWh	E_{tot}/A	$E_s/E_{tot}+E_s$ %
1	1 1/2 storey	116	12,800	6100	110	32.3
2:1	2 storey	87	9100	–	105	–
2:2	2 storey	125	10,600	–	85	–
2:3	2 storey	125	13,905	–	111	–
3:1	2 storey	108	14,820	4255	137	22.3
3:2	2 storey	129	15,940	6864	124	30.1
3:3	2 storey	161	18,290	8230	114	31.0
3:4	2 storey	141	16,180	7270	115	31.0
3:5	1 1/2 storey	144	15,660	6830	109	30.4
3:6	2 storey	123	11,850	4270	96	26.5
3:7	1 storey	115	13,055	5980	114	31.4

- there is no hygienic need for cleaning the duct system, which must be done in supply duct systems, by specialists, every 10 years in Sweden
- it is easier to keep the noise level down

The inhabitants in a very cold climate, to avoid draught, can close the supply of fresh air through the window or wall vents. This might lead to too low ventilation. By mechanical supply ventilation where the air is heated there is no need for closing the vents.

Some projects have been monitored in Sweden during the last 10 years. For example Höglund [5], Bergström [6] and Harrysson [7]. The results are summarised in Table 1. All houses are built in the eighties.

The results presented in Table 1 indicate an electricity demand more than 100 kWh/ m^2, year. One explanation is that some houses were built according to normal standards at the time being and other houses were built with a higher standard concerning the building envelop. The consumption of electricity for the household is rather high which can be seen in the last column where a total energy conservation ratio is presented.

From another project Harrysson [8] with more than 330 single-family houses is shown that with simple exhaust ventilation and EAHP the total amount of bought electricity varies between 90 and 100 kWh/m^2, year. This includes the house hold electricity. The normal use of house hold electricity in Sweden is 3500–4500 kWh/year.

3. Development of space heating in Germany

As the world climate debate continues, the Federal Republic of Germany has defined the objective of reducing carbon dioxide emissions attributable to the consumption of energy by 25–30% below the 1989 level by the year 2005. This objective requires major energy conservation efforts. German legislation on the efficient use of energy dates back to the seventies when the Energy Conservation Law applicable to energy consumption for space heating was enacted in 1976 in the wake of the first oil crisis. The Law breaks down into the following four sections:

- Thermal Demand Regulation
- Heating System Regulation
- Heating System Operating Regulation
- Space heating cost allocation provisions

Requirements under the different regulations were increased over the years. Fig. 5 illustrates the changes in annual thermal demand requirements.

4. Benefits for energy and the environment

The first two Thermal Demand Regulations published in 1976 and 1984 mainly laid down limits for the overall heat transfer coefficient (η-value). The 1995 Regulation was the first standard which did not specify overall heat transfer coefficients, but limited the annual thermal demand of buildings.

The continuous decrease in annual thermal demand (see Fig. 5) as a result of stricter thermal insulation requirements changed the shares of structure heat loss, internal and solar heat gains and ventilation heat loss in the heat demand equation. While structure heat loss determined thermal demand in the past, ventilation heat loss will become the critical factor in future. The percentage contribution of ventilation heat loss to total thermal demand has risen from 24% in 1976 when the first Thermal Demand

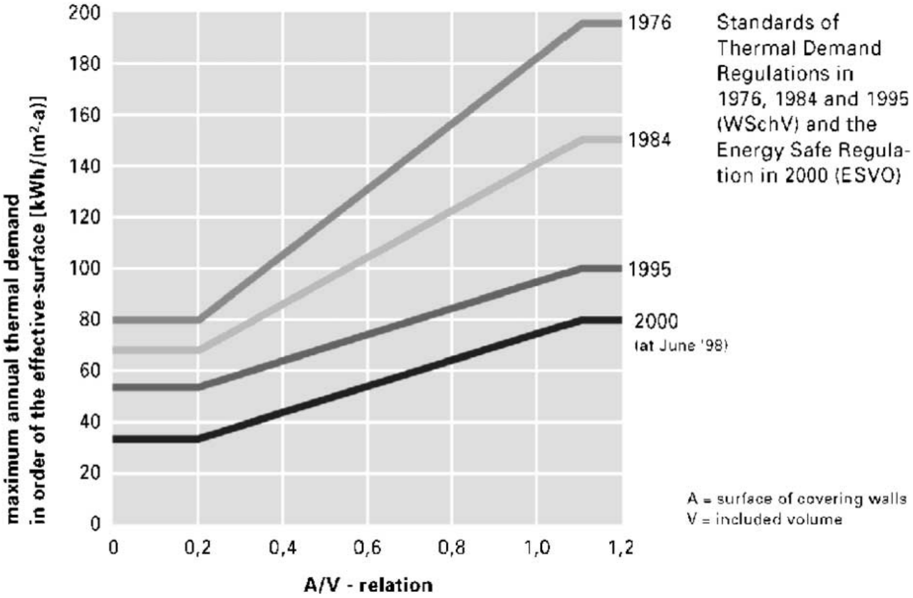

Fig. 5. Changes of annual thermal demand requirements under the Thermal Demand and Energy Conservation Regulations. Source: RWE PLUS AG.

Fig. 5. Variations en termes de demande thermique annuelle selon la réglementation sur la demande thermique et la conservation d'énergie. Source : RWE PLUS AG.

Regulation was published to 55% after the publication of the new Energy Conservation Regulation (see Fig. 6).

Energy demand for space heating will, therefore, in future be controlled by ventilation heat losses. To optimize both energy consumption and hygienic conditions, forced ventilation systems featuring heat recovery equipment are, therefore, ideal for buildings, as they eliminate the influence of accidental window opening times on energy consumption.

Under the 1995 Thermal Demand Regulation, the heat demand allowed to make up for ventilation heat losses was for the first time increased by 20% for forced

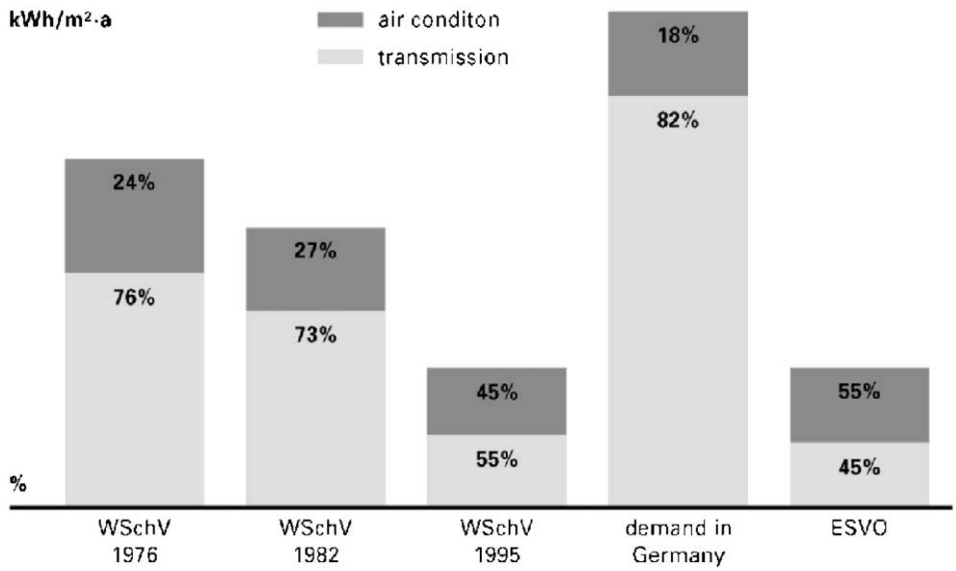

Fig. 6. Changes of ventilation and structure heat losses in residential space heating. Source: RWE PLUS AG.

Fig. 6. Chauffage des habitations : pertes de chaleur liées à la ventilation et à la structure. Source : RWE PLUS AG.

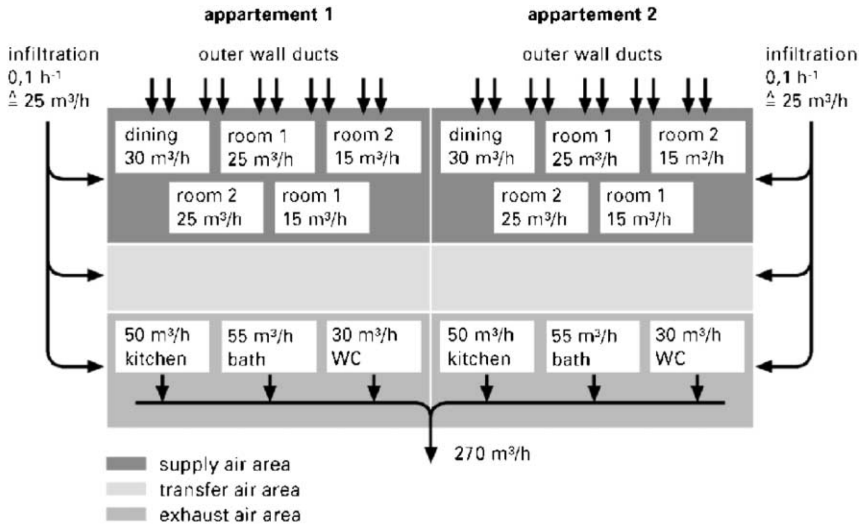

Fig. 7. Air flow rates and air distribution in two semidetached two-storey houses equipped with a common forced ventilation system. Source: RWE PLUS AG.

Fig. 7. Débits d'air et répartition d'air dans deux maisons semi-indépendantes à un étage équipées d'un système commun de ventilation à air forcé. Source : RWE PLUS AG.

ventilation installations featuring heat recovery systems, if the following conditions are satisfied:

- heat recovery efficiency $\geqslant$ 60%
- electricity-to-heat ratio for heat transfer systems $\geqslant$ 1:5
- electricity-to-heat ratio for heat pump systems $\geqslant$ 1:4

Forced ventilation systems must be tested under standard conditions to verify whether the above requirements are met.

The System Engineering Department of RWE PLUS AG operates an official forced ventilation system test laboratory which allows tests of the tightness and the ventilation and energy efficiency of the equipment. The results of these tests are the basis for the approval of equipment by DIBT, the German Civil Engineering

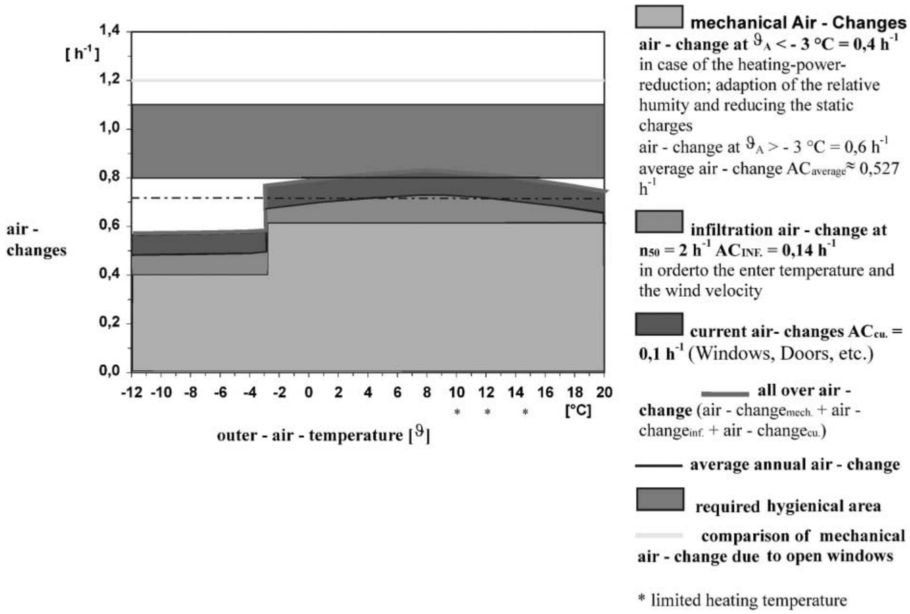

Fig. 8. Air changes and breakdown of air changes in a building equipped with a forced ventilation system.

Fig. 8. Débits d'air et répartition du renouvellement d'air dans une maison équipée d'un systèmes de ventilation à air forcé.

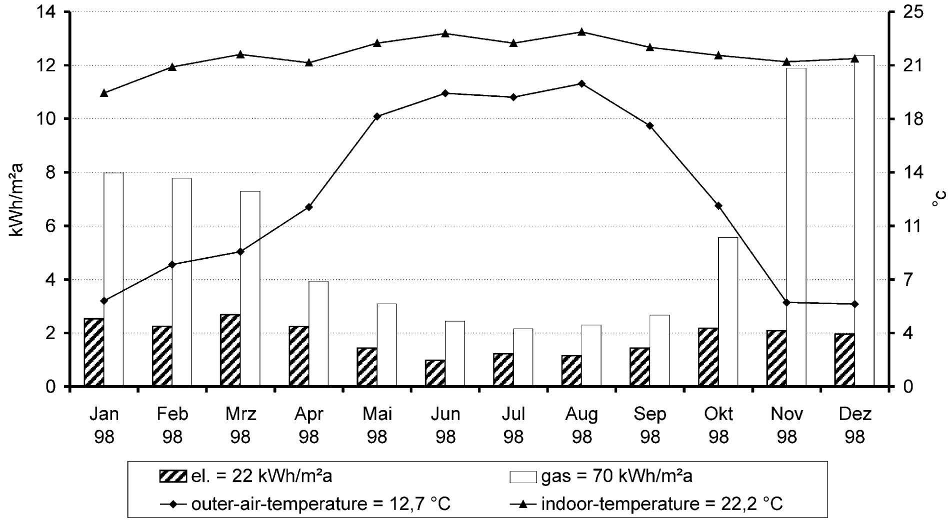

Fig. 9. Final energy consumption of a low-energy building consisting of two semidetached houses. Source: RWE PLUS AG.

Fig. 9. Consommation d'énergie globale d'une maison à basse consommation d'énergie comprenant deux maisons semi-indépendantes. Source : RWE PLUS AG.

Institute, under German building regulations. The key technical data determined in accordance with defined test criteria and the test results are published by RWE PLUS AG in its Bulletin [1] to allow a comparison of systems offered on the market.

The new Energy Conservation Regulation will combine the Thermal Demand Regulation and the Heating System Regulation. The new Regulation will no longer limit heat demand, but primary energy consumption for space heating. According to the present draft Regulation, annual energy consumption for space heating may not exceed 60–100 kWh/m^2. depending on the ratio between the outside surface and the volume of the building.

Annual heat demand for space heating (accounting for heat recovery) must be determined in accordance with EN standard 832 and Part 6 of EN standard 4108 and must reflect losses from the space heating installation itself. As EN standard 832 does not lay down how losses from the space heating system and quantities of heat recovered are determined, these data are calculated in accordance with Part 10 of DIN standard 4701.

5. Field tests in low-energy-houses

The share of heat recovery systems in the total heating load depends critically on the size of the space-heating appliance installed and the heat demand of the building. If the requirements of the new Energy Conservation Regulation are complied with, it will normally be between 60 and 90%.

In the Low-Energy Program of RWE PLUS AG [3], buildings were equipped with the unit 3 forced ventilation system shown in Fig. 3 featuring an integrated gas-fueled wall-mounted water heater. Data were measured over a test period of 3 years. One of the buildings consisted of two two-storey semidetached houses with identical ground plans. The data of the building are summarized in Table 2.

The exhaust air flow for each house was set to 135 m^3/h to obtain the minimum number of air changes necessary for hygienic reasons. Fig. 7 shows fresh air, cross-room and exhaust air flows including air infiltration rates.

The exhaust air flow was calculated using the fresh air flows across the outer wall valves and the infiltration rates determined by the blower door method.

The total air changes which determine the energy efficiency of the building consist of forced, infiltration and natural air change elements. In spite of the provisions of EN standard 832, all three elements must be compounded to obtain the ventilation heat losses of a building equipped with a forced ventilation system. Fig. 8 compares the total number of air changes of the building and the number of air changes necessary for hygienic reasons [4].

Total energy consumption for space heating, ventilation and domestic hot water production totaled 17,296 kW in 1998 equivalent to 92 kWh/m^2 (see Fig. 9). The heat pump accounted for 22 kWh/m^2 (electricity) and the water heater for 70 kWh/m^2 (natural gas). The thermal demand is 5.5% higher for a normal-temperature year of 3700 degree days.

Table 2
Building data. Source: RWE PLUS AG

Tableau 2
Données obtenues de l'industrie du bâtiment. Source : RWE PLUS AG.

A/V	0.75 m^{-1}
$V_{air\ conditioning}$	482 m^3
$A_{heating}$	188 m^2
$Q''_{H\ admistable}$	83.8 kWh/m^2·a
$Q''_{H\ real}$	53.9 kWh/m^2·a
$Q_{N\ all\ over}$	8.3 kW
$Q_{S\ specific}$	44 W/m^2
$n_{50\ house\ left}$	1.42 h^{-1}
$n_{50\ house\ right}$	1.41 h^{-1}
$AC_{mechanical}$	0.56 h^{-1}
$AC_{infiltration\ (n50)}$	0.1 h^{-1}
$AC_{current}$	0.1 h^{-1}
$AC_{all\ over}$	0.76 h^{-1}
Wooden outer wall	0.27 W/m^2·K
Wall	0.37 W/m^2·K
Surface	0.31 W/m^2·K
Roof	0.17 W/m^2·K
Windows	1.50 W/m^2·K
Heat allocation	55/45°C

6. Advantages for the customer

On the basis of the measured energy consumption for space heating, ventilation and domestic hot water production, a forced ventilation system featuring a heat pump reduces final energy consumption by 20% and primary energy consumption by 20% when compared with a conventional system consisting of a gas-fired boiler and a forced ventilation system to produce the same indoor air quality. The capital expenditure for the installation featuring the heat pump exceeds the cost of the conventional system by 3800 DM, while the annual cost of energy is 280 DM lower.

The measured coefficient of performance of the system installed in the experimental low-energy building for space heating, ventilation and domestic hot water production was 3.9, while simulation runs predicted an annual coefficient of performance of 4.2.

7. Results of VEW field experiments

Against the backdrop of debates on the 1995 Thermal Demand Regulation and the forthcoming Energy Conservation Regulation, RWE PLUS AG decided to field test 60 forced ventilation systems featuring different heat recovery systems [3]. It was the objective of these tests to demonstrate existing final energy and primary energy saving potentials and to identify weaknesses in design, installation and operation (see Figs. 10 and 11).

RWE PLUS AG also intended to determine which factors allow conclusions regarding the efficiency of the different systems and system deficiencies in order to improve the performance of heat recovery systems and to lower energy consumption. The field tests showed that forced ventilation systems featuring heat recovery equipment largely perform as expected. However, performance may be weak if buildings and forced ventilation systems are not designed to high standards,

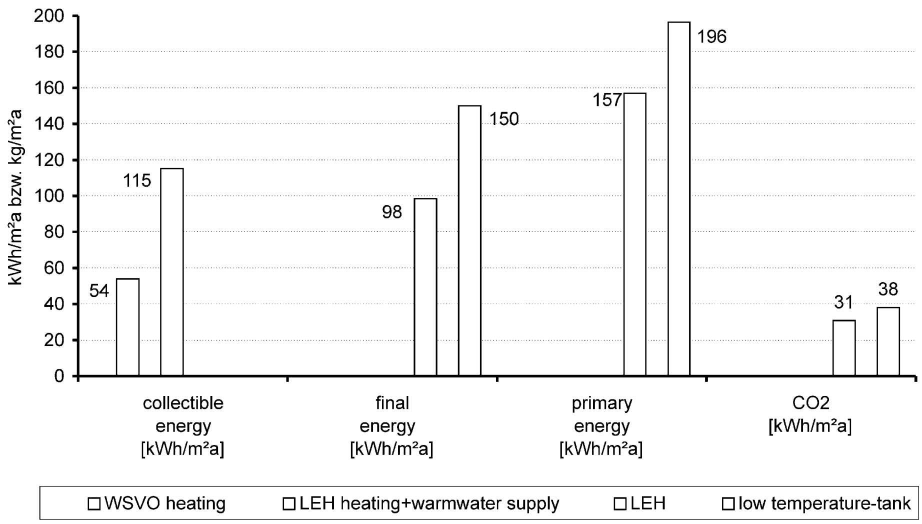

Fig. 10. Reduction in primary energy consumption and CO_2 emissions by the integration of a heat pump for heat recovery. Source: RWE PLUS AG.

Fig. 10. Diminution de la consommation d'énergie primaire et des émissions de CO_2 grâce à l'intégration d'une pompe à chaleur permettant la récupération de chaleur. Source : RWE PLUS AG.

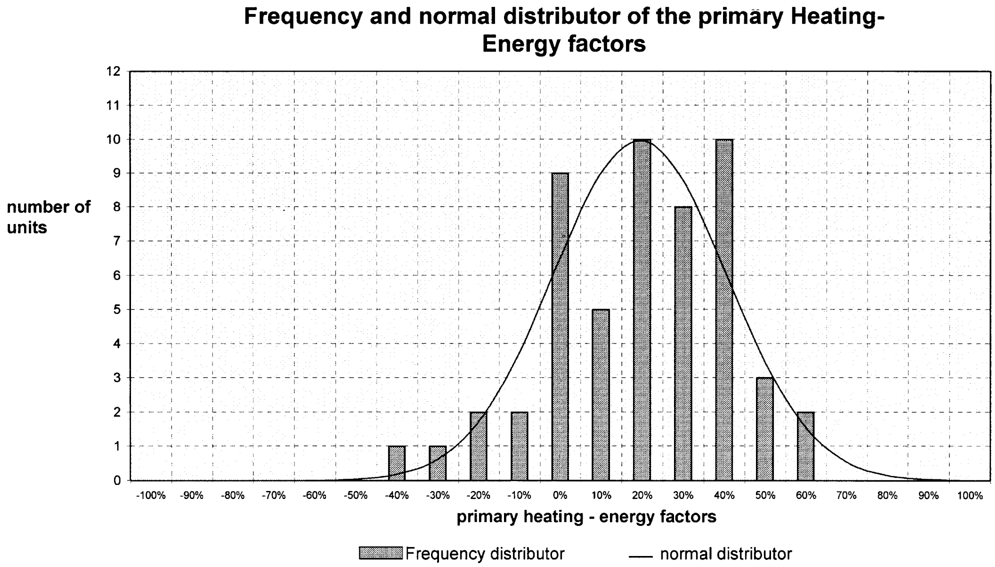

Fig. 11. Measured and predicted coefficients of performance of the experimental system. Source: RWE PLUS AG.

Fig. 11. Coefficients de performance mesurés et prévus du système expérimental. Source : RWE PLUS AG.

installation work is inadequate or the use of heat from the heat recovery system is not given priority. Energy consumption may under these circumstances even be higher than in buildings without a forced ventilation system. On average, the installations tested (partly deficient) lowered primary energy consumption by 19.4% and CO_2 emissions by 18.4% (see Fig. 12). 43% of the installations reduced both primary energy consumption and CO_2 emissions by over 25%.

Discussions with the owners during the field tests showed that they were very satisfied with the technology installed. Owners were particularly pleased with the

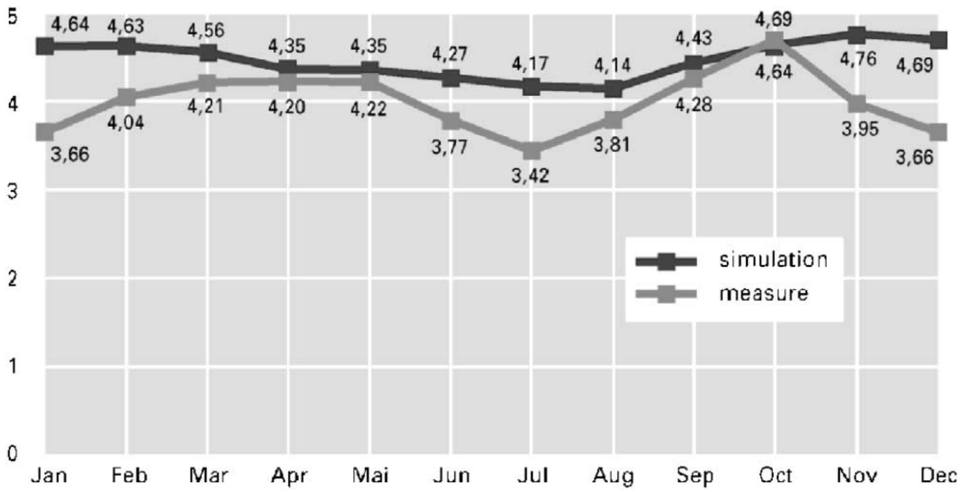

Fig. 12. Normal distribution of the reduction in primary energy consumption. Source: University of Kassel, Professor Dr.-Ing. Hausladen.

Fig. 12. Répartition classique de la diminution de la consommation d'énergie primaire. Source : Université de Kassel, Professor Hausladen.

improvement in indoor air quality and were, therefore, often less concerned by the environmental benefits and by costs.

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