DEVELOPMENT AND MEASUREMENTS OF COMPACT HEATING AND VENTILATION DEVICES WITH INTEGRATED EXHAUST AIR HEAT PUMP FOR HIGH PERFORMANCE HOUSES

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ABSTRACT

Recently, new integrated heat pump systems for High Performance Houses were developed by the Fraunhofer ISE in Freiburg-Germany. These buildings are constructed with a very thick thermal insulation, three glazing windows and are equipped with a ventilation system with air-to-air heat recovery. They feature an annual heating demand as little as 15 kWh/m² and a thermal peak load of 10 W/m². Thousands of these new buildings have been erected in central Europe so far .

The Compact Ventilation and Heating Device with Integrated Exhaust Air Heat Pump (CVHD) is simultaneously used for space heating, domestic water heating and ventilation. The comparatively low heating load of 1500 W is big enough capacity to fulfil all heating requirements.

The institute monitored and assessed these new systems in more than 30 single family houses. The annual electricity demand for all services in these buildings equals on an average less than 17 kWh/m². For Passive Houses, this new kind of heating has reached a market share of 30% to 50% and can be called a new „standard“. Some industrial companies are developing new units, often in co-operation with Fraunhofer ISE.

Key Words: ***Passive Houses, Ventilation Device, Exhaust Air Heat Pump***

1 INTRODUCTION

Passive houses specifications for room heating set a ceiling at 15 kWh/(m²a) under central European climate conditions. This can be achieved in making use of passive gains caused by occupants or solar irradiation through windows. The heating peak load remains below 10 W/m². Heat distribution occurs by means of hot fresh air, that is anyway needed for hygienic reasons (Werner et al. 1998) . The air change rate is adjusted to 0.4 volume changes per hour. Recirculated air is not necessary. This combination of air heating and ventilation systems leads to cost-cuttings since a conventional heating system, based on hot water, can be saved. By this mean, some of the additional cost for the improved insulation may be compensated.

These buildings have a thermal insulation thickness of 25 to 40 cm and thermal bridges are largely avoided. The ventilation device includes a highly efficient heat exchanger for heat recovery (dry efficiency above 75%). A ground-to-air heat exchanger reduces the ventilation heat losses, helps to avoid draughts caused by cold air and prevents the heat exchanger from freezing in. Thermal comfort is guaranteed by passive construction design measures alone. An active heating system is not nec-

essary, hence the name “Passive Houses“. The heat demand for domestic hot water is the same as in normal buildings and therefore higher than the heating demand in passive houses. The heat demand for domestic hot water is the decisive heat load in the dwelling.

Figure 1: Example of a Solar Passive House. This multiple family dwelling has been erected in the new Freiburg area Vauban. The heating demand meets 10 kWh/(m²a). The apartment in the foreground (author’s flat) is supplied by a newly developed Compact Heating and Ventilation Device with Integrated Exhaust Air Heat Pump.

The system for supplying the remaining heating must be efficient and low-priced. The total electrical energy consumption for ventilation, domestic hot water and heating, including all auxiliary equipment (pumps, fans, control units...) should remain below 20 kWh/(m²a). The heat-providing system should be integrated in one device. The exhaust air from the room ventilation provides an adequate and low-cost heat source for a heat pump. Its practicably usable sensible and latent heat is almost enough to meet the total heat demand of the dwelling. The available supply power is low and therefore heat storage is indispensable. This storage provides ideal conditions for a link to thermal solar equipment. This equipment should be sized to fully cover the domestic hot water demand during the summer period. Such solar collectors can cover up to 40 or 50% of the total annual heat load of Passive Houses.

Many ideas for the inexpensive design and supply of zero-emission houses were developed in the project “Freiburg Energy-Autarkic Solar House” (Voss 1996), including the provision of the residual heat requirement. The concept of integrating an electric-powered heat pump into the ventilation device in the shape of an exhaust air heat pump, storing the heat into a storage tank, and using it to operate a water-to-air heat exchanger in the intake air when heating is needed, was formulated simultaneously by W. Feist (Feist 1996).

The idea of supplying the complete residual heating requirements of Solar Passive Houses with a CVHD has been studied extensively at the institute (Bühring 2001). The Fraunhofer ISE assists the industry in designing these devices.

2 SYSTEM CONCEPT

The CVHD is simultaneously used for space heating, domestic water heating and ventilation. The heat pump is using the energy of exhaust air after the air-to-air heat recovery as heat source and is often using the supply air as space heat distribution system. The thermal output power of the heat pump varies between 1000 and 1500 W because of the little heat storing ability of the exhaust air.

Such a device consists of a ventilation section, with fans and exhaust air/intake-air heat exchanger, of an exhaust air heat pump, and of a storage tank (see figure 2). The heat pump utilises the sensible and latent residual heat of the exhaust air only after the air-to-air heat exchanger. A condenser of the heat pump heats up the storage tank to warm up the drinking water. This storage tank forms the interface with a solar thermal system. If neither the solar heating unit nor the heat pump provide sufficient heat, supplementary heating of the storage tank is provided by an electrical resistance heating element. If the intake air needs to be further heated, this can be done with a second condenser in the intake air line, which is run alternatively to or in series with the condenser in the service-water storage tank.

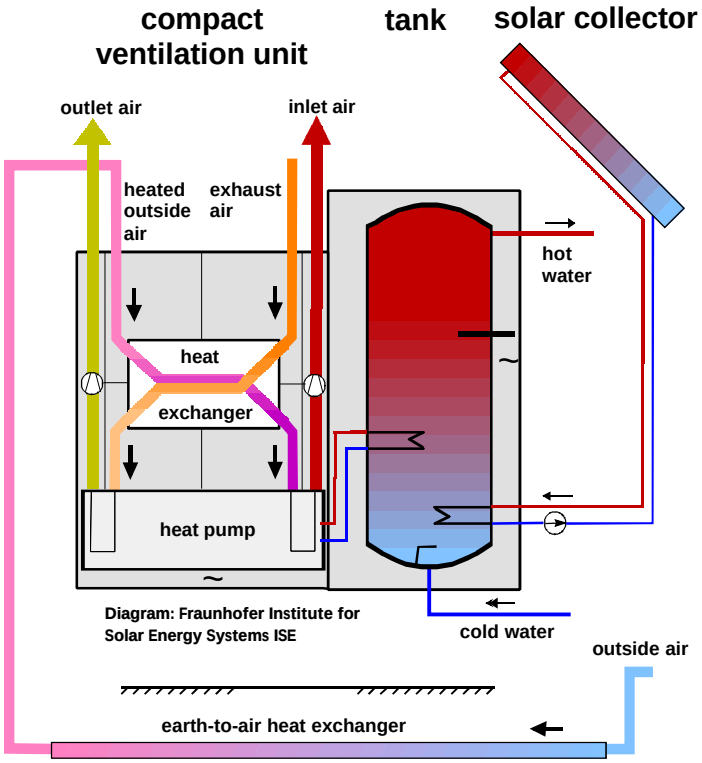

Figure 2: System concept of a Compact Ventilation and Heating Device with Integrated Exhaust Air Heat Pump to supply Passive Houses with space heat, domestic hot water and fresh air.

The use of an underground earth-to-air heat exchanger reduces the heating requirement, and raises significantly the temperature of the heat pump's heat source. Thus the heat pump's COP is increased for the heating of service water.

3 TEST FACILITY

In the Freiburg Solar House, a test facility for integrated ventilation modules with exhaust air heat pump and the functions of ventilation, service-water heating, and space heating has been set up. It has enough room for two units , which can be connected alternately to the house's ventilation system and hot and cold water pipes (see figure 3)., Coolers, heaters, and humidifiers are installed in the fresh-air and exhaust air flows for steady state measurement. The storage temperature can be kept constant by means of a secondary loop with heat dissipation.

Figure 3: Test facility in the Freiburg Solar House, with room for two compact ventilation devices with an integrated exhaust air heat pump

Thanks to the design of the test facility, it is possible to test, measure, and compare different Compact Ventilation and Heating Devices with Integrated Exhaust Air Heat Pump under constant operating conditions and in long-term tests. In order to draw up external balances of the capacity of the unit, sensors are placed at the intakes and outlets of the air and liquid lines. All temperatures and volume flows, as well as air moistures, are measured. In order to draw up the energy balances for the individual components, sensors are installed at the inlet and outlet of the respective components for temperature, and in some cases volume flows. In the refrigerating loop, the refrigerant pressures ahead of and downstream from the compressor are measured as well. The electrical power input is recorded separately for the compressor, the fans (including rectifiers), the electrical resistance heater, and the overall device.

4 TEST PROCEDURE AS DEFINED IN EN 255-3

One of the most sophisticated test procedures is provided by the European standard EN 255-3 for domestic water heating by exhaust air heat pump. Figure 4 is shown the sequence of operation of the test procedure. At the very beginning the complete system is at 20 °C. Then the heat pump starts its work and heats the water in the storage tank up to 50 °C. When the compressor switches off, elapsed

time and electrical energy requirement for this heating will be determined. Simultaneously when the compressor switches of, half of the tank volume is drawn off. The compressors starts again and when 50 °C is reached, a second time half of the tank volume is taken out while metering the thermal energy contained in the removed water. In the next turn round the electrical energy of the compressor is metered. As a result the COP of water heating can be computed. Next the storage stands a while without drawings. When the lower hysteresis band temperature is reached (i.e. 45 °C, this is the status with the minimum heat capacity in the storage), the compressor runs again. At this moment, the water is withdrawn again, until 40 °C is reached at the storage outlet. The average water temperature while drawing will be calculated. After warming again the storage stands some days without drawings. Due to the transmission losses of the storage to the surroundings the compressor shall warm up the storage from time to time to maintain the specified temperature. The average electrical stand-by consumption is calculated for this stand-by testing period. At the end of the procedure, a great water withdrawing is carried out just after the shut down of the compressor (by this mean, the maximum heat capacity in the storage can be determined). The useful water volume and the average temperature while drawing will be calculated.

Temperatures and electrical power consumption while heat pump measurement corresponding to EN255-3

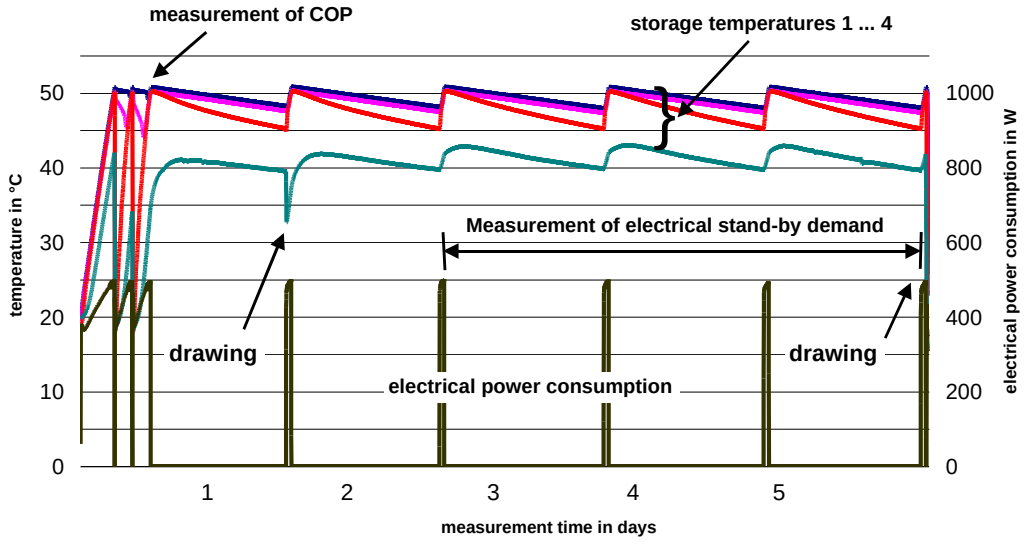

Figure 4: Test procedure as defined in EN 255-3

The measurement provides not only the parameters according to EN 255-3, but also some insight in the function and performance of the units' components. On request, further sensors can be placed in the unit: some temperatures in the air flow after each component, some temperatures in the refrigerant loop, refrigerant pressures and electrical energy demands of each main component. The institute can be commissioned by the manufacturer to assess in details the performance of the components of the whole system and elaborate solution to alleviate the identified problems or weaknesses

5 EXAMPLES OF ANALYSED DEVICES

The Fraunhofer ISE was commissioned to carry out tests on different commercial products. Those with the highest market relevance are shown in the figures 5.

Figure 5a: A-System

Figure 5b: B-System

Figure 5c: C-System

5.1 A-System:

The A-System is the market leader in heating Passive Houses in Germany, Austria and Switzerland. More than thousand units have been installed and run in occupied buildings throughout middle European countries.

The system design is shown in figure 2. It uses only the exhaust air as heat source for the heat pump and features two condensers: one for the storage tank (a coiled mantle condenser around of the storage) and one for the direct heating of the supply air. They are working alternatively with priority for air heating. A resistance heater operates as power reserve in the storage tank. The producing company is still developing the product line in close co-operation with Fraunhofer ISE. The newest generation of products was tested in January 2005.

5.2 B-System:

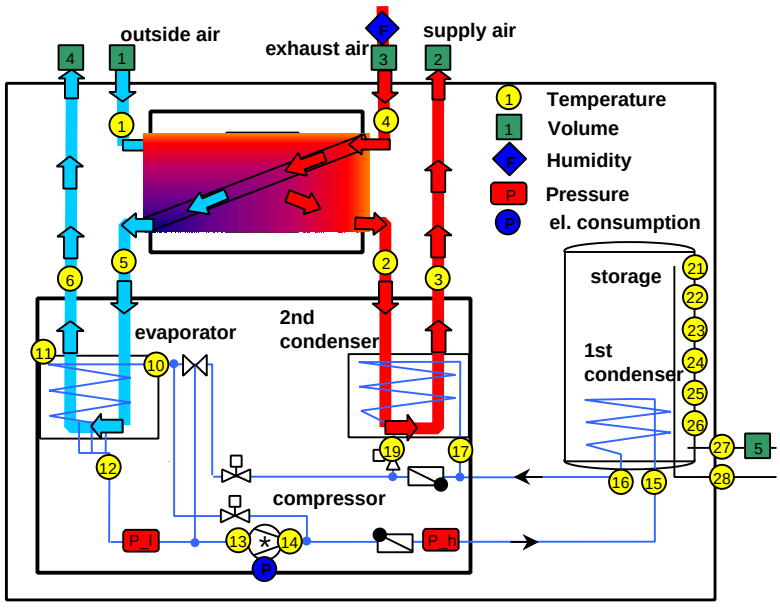

Figure 6: Design and scheme of system B with two condensers in series. All sensors were used for the measurements at the test facility to quantify not only overall system efficiency but also component performance.

The B-System is part of a system family for different kinds of buildings. It is the smallest one, developed especially for apartment buildings and has an integrated storage tank with a volume of 200 litres. The air inlets and outlets are placed left-side and right-side of the air module on the top of the ventilation device.

The heat pump uses only the exhaust air as heat source and has two condensers which are placed in series in the refrigerant loop. So, the high temperature of superheated and compressed refrigerant steam can be used for water heating on the same pressure level as defined by simultaneous air heating. Some measurement results will be shown in the next paragraph and in more details at the conference.

5.3 C-System:

The C-System device was newly developed for Passive Houses and also for so called "3-litres-Houses" with a space heating demand of less than 30 kWh/(m²a). In order to meet the higher heating power requirement the heat pump uses not only exhaust air as heat source but also a second outside air flow, that is mixed to the exhaust air just before the evaporator to boost the power of the heat source.

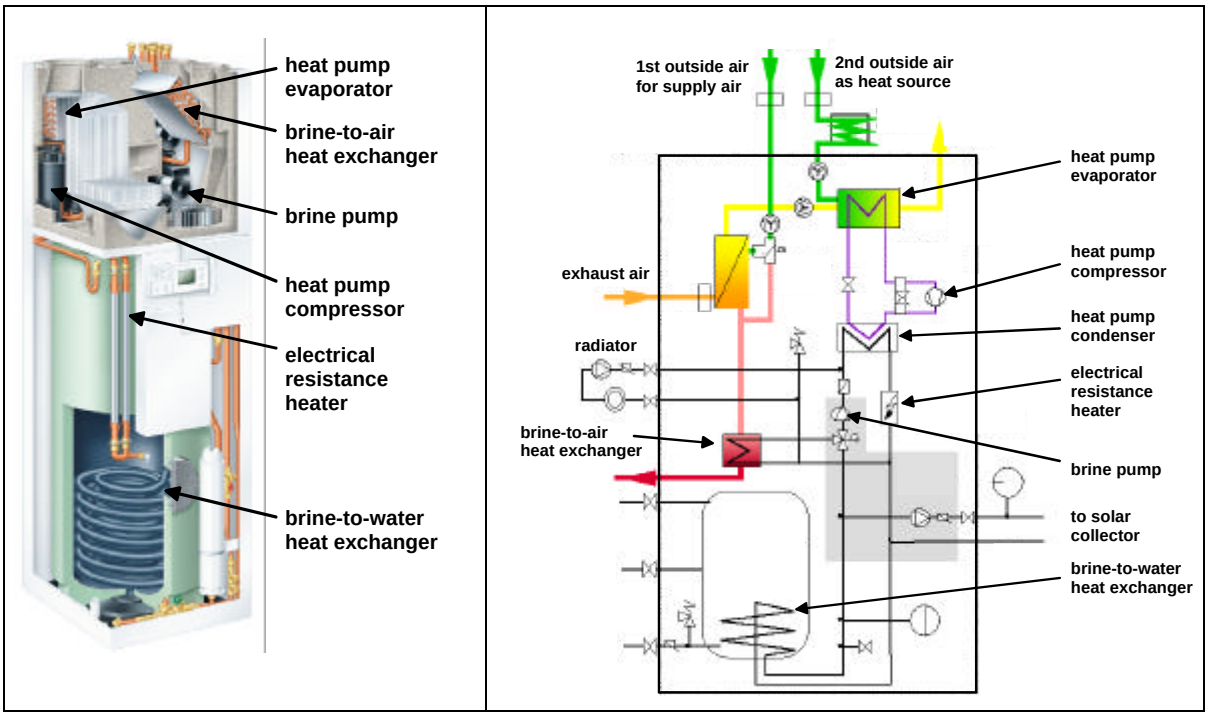

Figure 7: Design and scheme of system C with internal brine loop.

The heat pump has only one condenser, that transfers heat to an internal brine loop. The brine can be heated additionally by a solar thermal collector or with a electrical resistance heater of 6 kW. The internal 250-litres storage tank is heated up by means of the heat released by the brine flow. In the supply air, a brine-air heat exchanger is placed and a radiator for the bathroom also can be connected.

6 EXPERIMENTAL RESULTS AT THE TEST FACILITY

6.1 A-System:

The test conditions are given in table 1. The set value for air flows was 175 m³/h:

Table 1: Test conditions for the testing of A-System device

test conditions	exhaust air	outside air
volume flow	146 m³/h	173 m³/h
temperature	19.6 °C	6.8 °C
relative humidity	40%	-

Further to the results as defined in EN 255-3 some more results are shown: the average heat load for heating the storage, the average electrical power demand in this time and the COP for water heating at space heating days. In this value the heat losses of the compressor or other parts of the heat pump, delivered to the supply air, are calculated as additional heat gains because they are used as thermal power for space heating. The results are shown in table 2:

Table 2: Results of the testing of A-System device

test results	value
heating time (without resistance heater used)	7:50 h
electrical energy for first heating	3225 Wh
thermal power for heating after drawing	1142 W
electrical power demand for heating after drawing	399 W
COP for water heating after drawing	3.02
COP for water heating after drawing, space heating days	3.39
average stand-by electrical demand	21 W
average drawing temperature	46.8 °C
maximum drawing of water with 40 °C	348 litres

6.2 B-System:

The test conditions are given in table 3. Set value for air flows was 120 m³/h:

Table 3: Test conditions for the testing of B-System device

test conditions	exhaust air	outside air
volume flow	132 m³/h	131 m³/h
temperature	20.1 °C	9.0 °C
relative humidity	41%	-

The results are shown in table 4:

Table 4: Results of the testing of B-System device

test results	value
heating time (without resistance heater used)	8:36 h
electrical energy for first heating	2400 Wh
thermal power for heating after drawing	783 W
electrical power demand for heating after drawing	296 W
COP for water heating after drawing	2.64
COP for water heating after drawing, space heating days	3.15
average stand-by electrical demand	21 W
average drawing temperature	45.9 °C
maximum drawing of water with 40 °C	290 litres

6.3 C-System:

The test conditions are given in table 5. Set value for air flows was 120 m³/h:

Table 5: Test conditions for the testing of C-System device

test conditions	exhaust air	outside air
volume flow	140 m³/h	144 m³/h
temperature	20.1 °C	9.3 °C
relative humidity	40%	-

In this device the heat losses of the compressor are not used in supply air, because the compressor is placed in the exhaust air before the evaporator. Only heat losses of the device to the surroundings are space heat gains in case of placement of the unit inside the heated space. But they could not be measured in booth testing situations. The results for C-System are shown in table 6:

Table 6: Results of the testing of C-System device

test results	value
heating time (without resistance heater used)	5:30 h
electrical energy for first heating	3012 Wh
thermal power for heating after drawing	1250 W
electrical power demand for heating after drawing	610 W
COP for water heating after drawing	2.26
average stand-by electrical demand	37 W
average drawing temperature	46.0 °C
maximum drawing of water with 40 °C	288 litres

The brine pump has a power demand of 95 W. With a more efficient direct current brine pump with an electrical power demand of only 10 W the COP will rise up to 2.7.

6.4 Discussion of the results:

The different air volume flows were chosen in respect to the design point, which depends on the heated floor area. For an average air change rate of 0.4 changes per hour and a room height of 2.5 m one need 1 m³/h per m². The coiled mantle condenser in A-system causes a high COP because of the excellent stratification in the storage. The use of the two condensers in B-system in series will rise the COP, if heating demand and water warming demand appears on the same time. The use of cold out-

side air, mixed to the exhaust air, as part of the heat source lowers the COP, but rises the heat capacity without using the resistance heater. To prefer one of the systems depends on the heating demand of the building.

7 EXPERIMENTAL RESULTS FROM THE FIELD TEST

Within a monitoring campaign of three years carried out in 50 detached single family Passive Houses with electrically-driven heat pump the Fraunhofer ISE metered and gathered the monthly data from the residents. The programme was sponsored by the utility company Energie Baden-Württemberg EnBW in the context of a market penetration campaign for heat pumps in Passive Houses. The owners of the buildings were awarded a funding of 5000 Euro for installing a heat pump system, combined with thermal solar collectors, and for sending data monthly to Fraunhofer ISE. The participants of the programme get a monitoring report from the institute yearly.

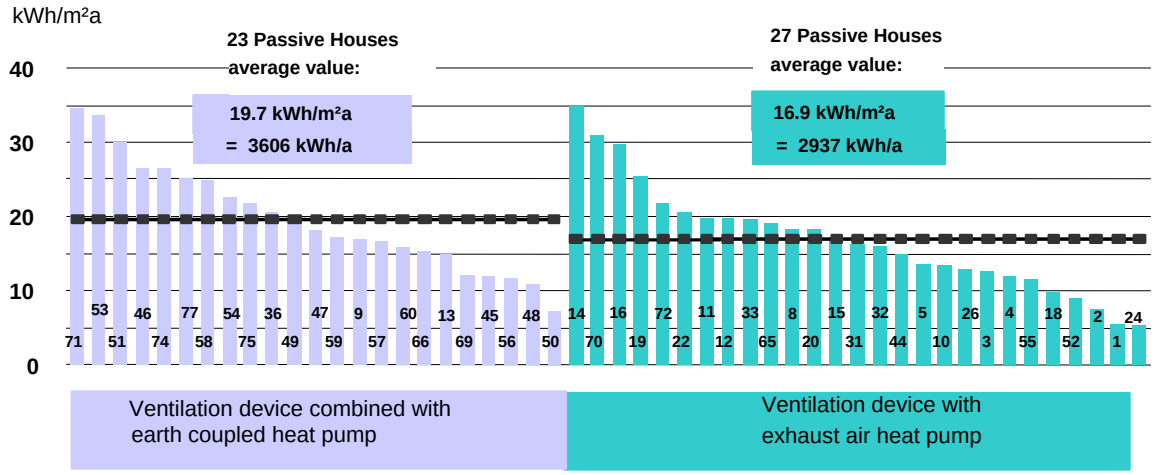

Figure 8: Results of the field test of Passive Houses with electrical driven heat pump and a thermal solar collector. Every bar shows the yearly electrical energy demand of HVAC, related to the heated floor area of the building. The systems with exhaust air heat pump shows in average a higher performance than the earth coupled heat pump systems.

The average electric energy demand for Solar Passive Houses with exhaust air heat pump approaches approximately 3000 kWh/(m²a) for all HVAC functions under middle European weather conditions. In the same programme nearby half of the monitored systems were earth-coupled heat pumps. They had in average an electric energy consumption of 20% more than the exhaust air systems. This is caused by problems of interaction between separated controllers for heat pump, ventilation, solar collector and resistance heater, the energy consumption of the brine pump and not optimised controller parameters for the temperature management in the storage.

The comparatively low energy demand for exhaust air heat pump systems and consequently low operating cost make this technology very cost-attractive. In Germany for example, they took hold of a market share of 30% to 50% in the Passive Houses market segment. Many small and some larger companies are developing and selling CVHD as the ones described in this paper. It is one of the most attractive systems for heating and ventilation in very low energy houses and the most suitable solution for passive houses, a very strong increasing market segment in building construction in Germany and Austria. A market study of the institute, based on interviews with more than 200 German building construction experts, shows an average forecast of approximately 50% of the new buildings in 2010

will be designed as a 3-litre-house or a passive house. Therefore the market for CVHD will rise up to a mass market.

8 SUMMARY

The paper shows the system design of Compact Ventilation and Heating Devices with Integrated Exhaust Air Heat Pump for High Performance Houses CVHD, especially for Passive Houses. Several products of different European companies for this newly HVAC-technology are described. For three of them the testing results according to EN 255-3 are shown. In a monitoring programme with 50 detached single family Passive Houses with electrically-driven heat pumps the CVHD has proved a high efficiency and very low operating cost.

9 ACKNOWLEDGMENTS

The author wish to thank Maico Ventilatoren in Germany, VS-Schwenningen, Energie Baden-Württemberg EnBW in Germany, Karlsruhe and the German Ministry of Economic Affairs for funding the described work.

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