OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

17th AIVC Conference, Gothenburg, Sweden,
17-20 September, 1996

(Title)

Residential Mechanical Ventilation Systems: Performance Criteria and Evaluations

(Authors)

Viktor Dorer and Dieter Breer

(Affiliation)

EMPA
Swiss Federal Laboratories for Materials Testing and Research
Section 175 Building Equipment
CH- 8600 Duebendorf, Switzerland

Residential Mechanical Ventilation Systems: Performance Criteria and Evaluations

V. Dorer and D. Breer

EMPA, Swiss Federal Laboratories for Materials Testing and Research
Section 175 Building Equipment
CH- 8600 Duebendorf, Switzerland

Synopsis

The performance of mechanical ventilation systems has been checked in several innovative residential houses in the frame of Swiss research as well as pilot and demonstration projects. This paper gives a list of performance criteria for the ongoing comparison and evaluation of these mechanical ventilation systems. For some criteria, target values are proposed.
In the second part, this paper shortly describes four residential buildings with mechanical ventilation systems where such evaluations were performed and highlights interesting design features and results from the measurements. It then focuses on discrepancies between the design goals and what has been encountered in reality during the evaluation campaign. Problem items were, among others, commissioning, occupant acceptance and window opening behaviour as well as sealing of ducts and heat exchangers.

1 Introduction

At present, the benefits and the market chances of mechanical residential ventilation systems are again passionately discussed in Switzerland . The performance of mechanical ventilation systems has been checked in several innovative residential houses in the frame of Swiss research as well as pilot and demonstration (P+D) programmes. Extended commissioning was performed, energy figures were determined, air flows and the air distribution patterns as well as noise levels were measured and inhabitants were interviewed. The results are presently analysed and documented.

In order to have a better basis for the overall discussion of the evaluation and comparison of the systems, the working group on residential mechanical ventilation systems of the VSHL (Swiss association of HVAC manufacturers) has produced among other documents a working paper on performance evaluation criteria and parameters for residential mechanical ventilation systems with heat recovery and is presently establishing recommended target values for a selected number of these parameter [1]. A summary list of these parameters and the respective target values is given in the following section 2. The list will be reviewed considering the outcome of IEA-ECB Annex 27 [2].

In section 4, four research and P+D houses, three apartment houses and one single family house, are shortly described. All these buildings are very airtight and equipped with balanced ventilation systems with heat recovery and with earth coupling for the air intake. Interesting design features of the mechanical ventilation systems and specific results from the evaluations are highlighted. Experiences gained concerning the earth coupling are summarized in section 3.

2 Performance criteria and target values

Performance criteria to be applied to the demonstration buildings mentioned above are listed below. It is obvious that some of these criteria need further explanations for a proper application. In addition is has to be noted that both criteria and target values have to defined separately for different building and systems categories.

2.1 Building and systems categories

- Single family house, multifamily house
- New building/retrofit
- Type of heat recovery (air/air plate , a/a heat pump, air/water heat pump)
- Ventilation only / additional warm air heating or hot water production
- Research or pilot & demonstration building/ other

2.2 Performance evaluation criteria and parameters

Costs
- Investment costs
- Operating costs
- Life cycle costs

Effects on construction and space requirements
- Room needed for system and ducting
- Additional elements such as earth coupling systems or outside air terminals

Power ratings and energies

The general criteria are rational use of energy and use of renewable energy. Specific emphasis is given to the use of electricity and the amount of electrical energy used to gain or recover heat. Energy flows are analysed on the basis of energy flow diagrams, as given in Figure 11. These diagrams are helpful to understand especially more complex systems with heating and domestic hot water supply functions. A second class of criteria applies to the individual components.

System criteria:
- Proportion of renewable energy used
- Proportion of heat recovery compared to ventilation losses
- Seasonal or yearly electrical energy consumption of the system
  1) Total 2) Specific per floor area
- Factor heat gain/electric input
  1) As a performance related figure for design conditions
  2) As an energy related figure for the heating/operation period
     Values ranging from 5 up to 11 have been measured in the evaluation cases.
     A target value of 7 is proposed.
     Critical for the application of this criteria is the definition of the heating period. Any operation of the system in the transient saison jeopardizes of course this value.

Component criteria:
- Proportion of embodied energy contained in the components and its pay-back time
- Specific electric power consumption of fans. A target value of 0.35 W per m3/h of supplied air is proposed.
- Specific heat exchanger efficiency (related to flow resistance).

Air quality

Air quality is primarily evaluated on the basis of delivered outdoor air flow rates and the reliability for the supply. Extensive auditing as e.g. in the European IAQ-Audit project was generally not performed. Also indoor air pollution sources are not characterized in detail. Two to three system operation modes are generally available with different air flow rates: Basic supply ($n_L \approx 0.3$), normal supply ($n_L \approx 0.5$), enhanced supply ($n_L > 0.5$). Additional criteria considered are:
- Handling of extract air in the kitchen (recirculating system, separate exhaust, ducting through the heat recovery system).
- Proportion of recirculation from the heat exchanger.
- Hygienic performance of earth coupling systems.
  This aspects is investigated further in a specific research project conducted at the ETH-IHA in Zurich [3]. Microbiological long term and interval measurements are made in 13 earth coupling systems. Results are expected by the end of this year.

Ventilation efficiency
Ventilation efficiencies are not measured in all cases, but room air distribution patterns and related efficiency values have been measured in the Hausäcker house using tracer gas techniques. For smaller room sizes, air change efficiencies tend to be around 0.5 (fully mixed condition), regardless where inlet and outlet positions are. For larger room sizes and in case of additional warm air heating, efficiency values may vary more.

Thermal comfort
All houses are very well insulated. Therefore, the main concern for thermal comfort is draft. Thus, parameters to be considered are supply air temperature and velocities.

Acoustics and Noise
From the inhabitants perspective, noise produced by the ventilation system is one of the major sources for complaints. This has to be seen under the fact that in Switzerland most dwellings are naturally ventilated and thus any sound from a ventilation system may be judged as annoying. From the evaluations performed so far, it can be concluded that sound generation levels must be evaluated mainly against the background noise and not according to fixed values. Nevertheless, sound levels according to the Swiss standards for system generated noise (30 to 35 dBA) are too high. Acceptable system designs must have significantly lower levels (20 to 25 dBA)

Control, operation, maintenance and reliability
Emphasis is put on criteria like:
- Possibilities for occupants to control flow rates and temperature settings
- Accessibility for cleaning
- Documentation and training of people which are in charge of maintenance

Occupant's perception, acceptability and influence
The occupant's perception of the air quality and the acceptability levels have been determined in many cases using specifically set up questionnaires, prepared by the ETH [4]. A wide spread of different behaviours have been observed, from good acceptance to a total objection including taping of air in- and outlets. Large effects on the system performance have been observed mainly from window opening, because this changes pressures and reduces the amount of available heat for recovery (see Fig. 7).

Design, manufacturing, installation and commissioning of ventilation system
- Manufacturing of components (e.g. leakage of plate heat exchanger)
- Selection and installation of components
- System balancing and commissioning

3 Earth coupling

A respectable amount of buildings are realized in Switzerland with earth coupling for the air intake. This systems normally show factors heat gain/ electric input in the range of 40 to 100. During summer, this system may also provide cooling. Experiences with earth coupling systems can be summarized as follows [5]:

Conditions for profitability:
- Air flow rates according to hygienic requirements
- Requirement for preheating
- No or little additional excavation for the installation of the pipes necessary

Recommendations for the design:
- Airtight, smooth pipes must be used (prevention of radon ingress, low flow resistance)
- Accessibility for inspection and cleaning must be provided
- A bypass is necessary for optimum operation
- Pipe length of approx. 20m is sufficient , air velocity in the pipe < 3m/sec

4 Evaluation cases

4.1 Apartment houses 'Hausäcker'

Figure 1: Apartment houses 'Hausäcker'

Building description

The two residential buildings 'Hausäcker' are located in a town 20 km north of Zurich, each three-storey house has 12 apartments with a heated floor area of approximate 1400m^2. The heating energy consumption per annum and heated floor area is 200 MJ/m^2-a [6]. Both houses use district heat which is delivered in the rooms by floor radiators.

Ventilation is provided by a central balanced system, located in the basement of the building. The intake air is preheated in an earth coupling system and then led through a cross flow plate heat exchanger, resulting in an average supply air temperature of 19°C. No additional supply air heating unit is installed.

In the rooms, the supply air is delivered through specifically designed air terminals, placed in the lower part of the door case. The aged air passes through a gap under the door and an overflow terminal in the upper part of the door case and is extracted in the wet rooms and in the kitchen. Due to fire safety and hygiene requirements, the extract air from the kitchen is directly exhausted without passing the heat exchanger.

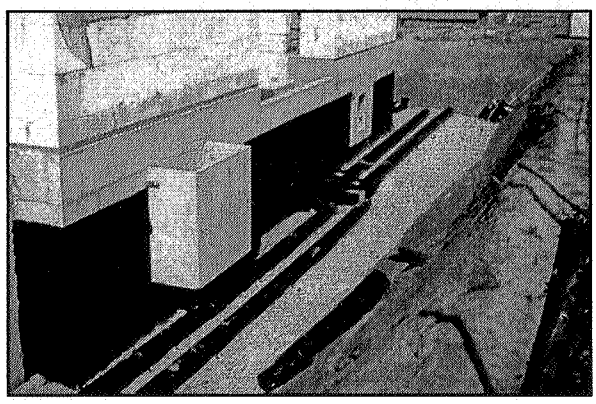

Figure 2: The earth coupling system. The pipes are placed in the regular excavation around the building.

The performance evaluation

The 'Hausäcker' apartment houses were evaluated according to the following performance criteria:

- Detailed determination of temperatures and energy consumption for the whole heating season
- Heat recovery efficiency
- Ventilation efficiency in a typical room
- Inlet/outlet acoustics
- Interviewing of all occupants according a questionnaire developed by the ETH [3]

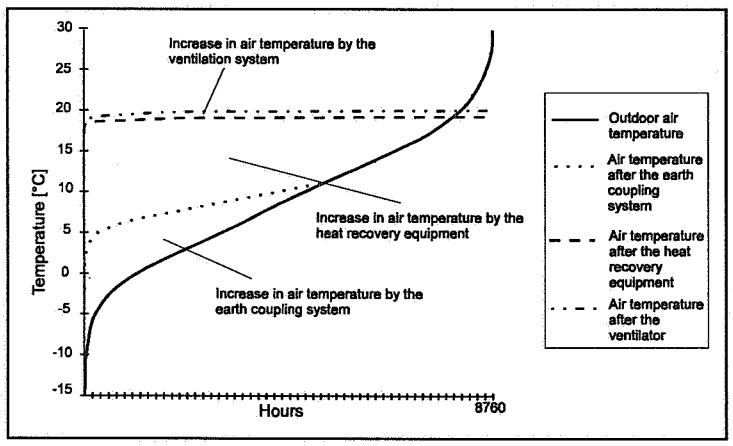

Figure 3: Temperature histograms for outdoor air, air after earth coupling, heat recovery and ventilators respectively.

Results

Visualisation of the air distribution patterns with a smoke generator and tracer gas measurements show a good air distribution in the individual rooms, even in the case of supply air temperature being higher than room air temperature. Although the gap under the door is located just besides the air outlet, no short-circuiting could be observed.

4.2 Housing development 'Hünenberg Eichrüti'

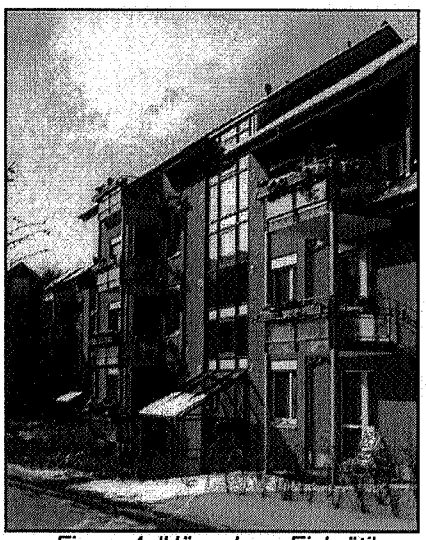

Figure 4: 'Hünenberg Eichrüti'

Building description

The housing development 'Hünenberg Eichrüti' consists of 6 four-storey multifamily houses with total 47 apartments. Three buildings are built together and have one central balanced ventilation system. The energy consumption for heating and domestic hot water is 205 MJ/m^2-a.

In contradiction to the apartment houses 'Hausäcker', the earth coupling system in 'Hünenberg Eichrüti' is located under the garage. Also, heat is recovered by a thermal wheel and not by the more common plate heat exchangers used in the other three buildings described in this paper.

A further measure for energy consumption reduction is the air/water heat pump, which is used for the preheating of the domestic hot water.

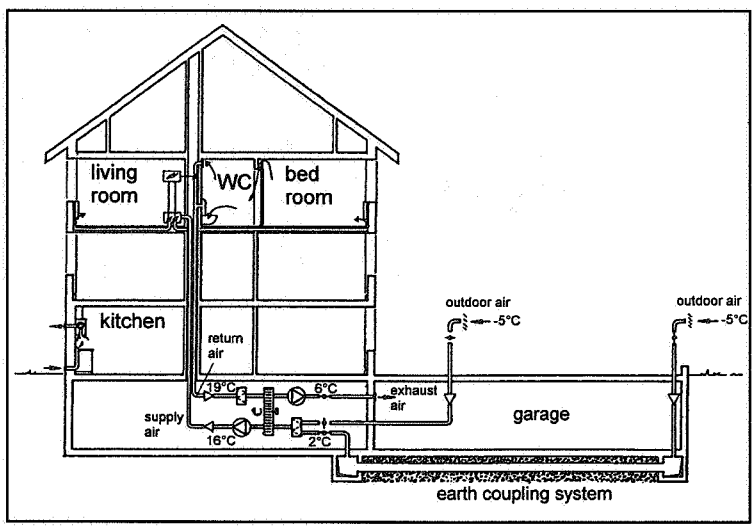

Figure 5: The mechanical ventilation system of 'Hünenberg Eichrüti'

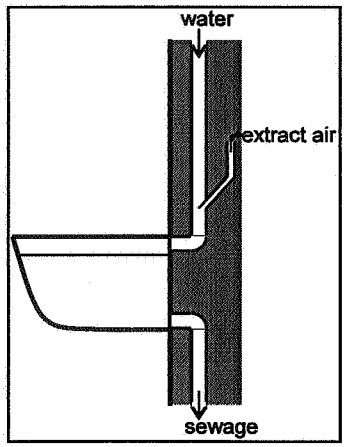

Figure 6: For better source control, the local exhaust system in the toilet is combined with the flushing pipe.

Results of the performance evaluation

Measurements with tracer gas revealed that the natural flow due to airing is much higher than expected (approximately half of the mechanical supply air flow rate, see Figure 7).

Neither could odour transmissions due to leakage in the thermal wheel be detected nor were there any complaints from the occupants in this respect.

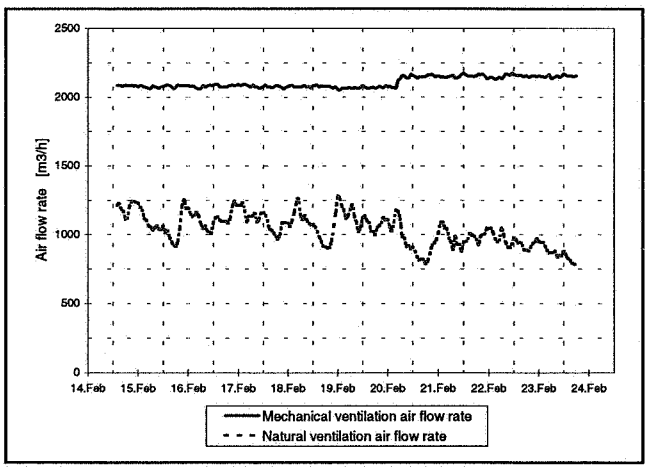

Figure 7: Total outdoor air flow rates in the three-building unit

4.3 Terraced housing development 'Riehen'

Building description

42 apartments and 4 single-family houses form the terraced housing development 'Riehen', located about 5 km north-east of Basel. With a energy consumption for heating and hot water of 200 MJ/m²-a, the development has low energy building qualities [7].

The air passes through the outdoor terminal to the two, 160m long concrete earth tubes and then to the heat recovery unit. Each apartment has its own balanced ventilation system with heat recovery, four of them grouped together in a system room. The four single-family houses have air heating combined with conventional heating, the apartments have just conventional heating. The air outlets are placed at the ceiling, the return air passes via door gaps to the extract air terminals in the wet rooms and in the kitchen. The kitchen hood has a recirculating air system with charcoal filter.

Figure 8: Terraced housing 'Riehen'

Performance evaluation program and results

In the performance evaluation program, estimations of the embodied energy contents of the ventilation systems have been done. The pay-back time of the embodied energy for the heat recovery equipment is approx. 1.5 years, that of the earth coupling system 9 years. (For comparison 'Hausäcker': Average of approx. 6 years).

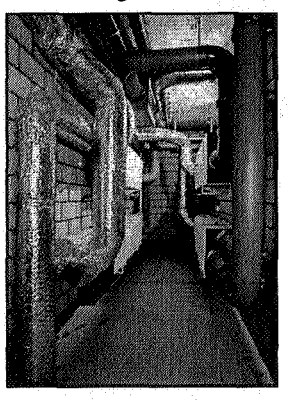

Figure 9: System room with ventilation units for 4 apartments

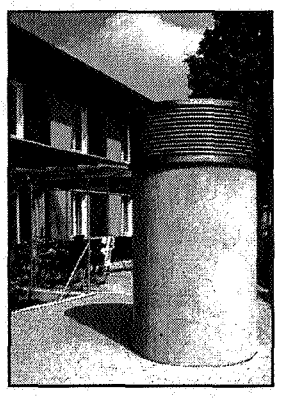

Figure 10: The outdoor air intake terminal

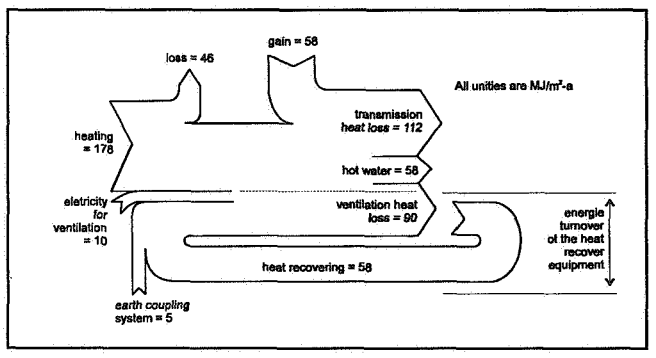

Figure 11: Energy flow diagram of an apartment

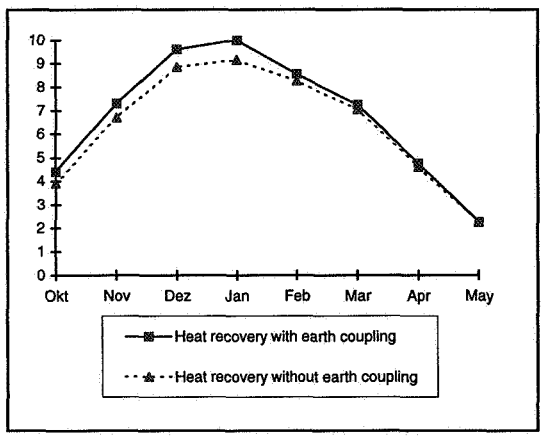

Figure 12: Ratio heat gain / electric input for the ventilation system with heat recovery

The energy flow diagram shows quite distinctively the rather marginal contribution of the earth coupling system. Nevertheless, the real value is higher. Due to the adverse influence of ground pre-heat and heat recovery, only the additional gain is shown.

Although the additional gain of the earth coupling system is rather small (see as well Figure 12), the earth coupling system has advantages: On one hand significant gains especially at days with low outdoor temperatures, on the other hand it prevents the heat recovery equipment from freezing, which would lead to an interruption of the ventilation system operation due to the defrosting cicle.

4.4 Zero-heating energy houses 'Wädenswil'

Figure 13: The south façade of the zero-heating houses, in black the transparent insulation of the solar collectors

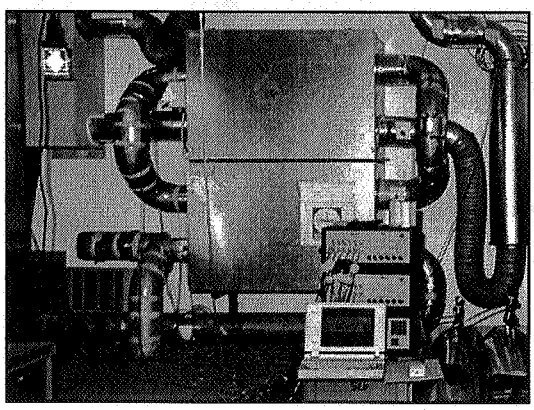

Figure 14: Tracergas measurements at the two cross flow heat exchangers for determination of leakages

Building description

The two zero-heating energy houses constitute together with three low-heating energy houses a housing complex for 10 families, located in Wädenswil, a village at the south border of the lake of Zurich. The three low-heating energy houses have conventional solar collectors of 9 m^2 with a water storage tank of 3 m^3 for hot water. They are heated by a cogeneration plant. The two zero-heating energy houses have large solar collectors of 33 m^2, which are covered with transparent insulation material. The solar energy is used for the floor heating system and for hot water, a large water heating storage tank of 20 m^3 facilitate a seasonal heating storage. Occasional heating with a wood oven in the living room covers the remaining demand in heating energy. The mechanical ventilation system consist of an earth coupling system and two cross-flow heat exchangers.

Measurements and simulations

In order to understand the thermal behaviour of a zero energy house and to work out recommendations for future low energy houses, the Building Equipment Section of the Swiss Federal Laboratories of Material Testing and Research measured most of the energy aspects in one of the two zero-heating energy houses and in the cogeneration plant during 3 years [8,9]. For economical and ecological optimisations, simulation works using the program TRNSYS are in progress.

Results

- Very low energy index, between 17 and 26 MJ/m^2-a, for heating and domestic hot water
- During cooking, odour spreading from the kitchen has been observed in zones with fresh air supply. From that, leakages in the heat exchanger were suspected. This has been confirmed by tracergas measurements (injection and sample points for tracer gas measurement see Figure 15).

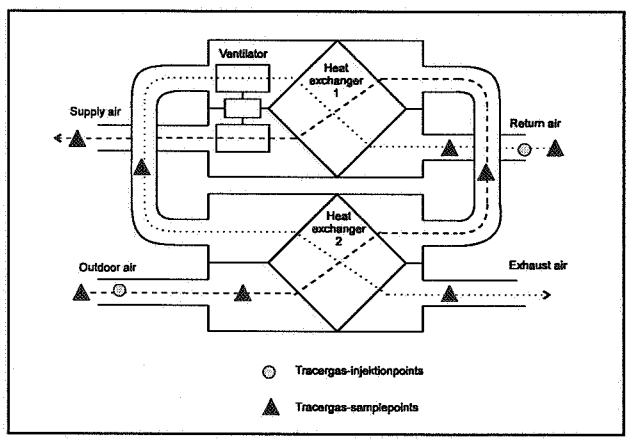

Figure 15: Position of the injection and sample points for the leak detection in the heat exchangers using tracer gas.

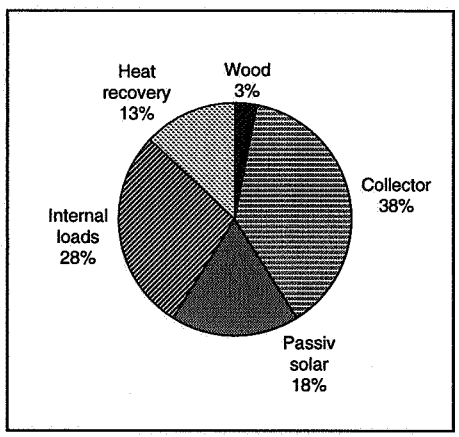

Figure 16: Distribution of heat gains for the 'Wädenswil' house

5 Conclusions

Balanced mechanical ventilation systems with heat recovery are an important element in the design of a low-energy house. Evaluations performed in several in P+D buildings prove the importance of such systems. Nevertheless, many problems, stemming from the design, the installation as well as from occupant acceptability have been encountered. Most of the failures and shortcomings observed can be tracked down to:

- Bad manufacturing of components (e.g. leakage of plate heat exchanger)
- Improper selection and installation of components (e.g. selection of over dimensioned ventilators)
- Bad system flow balancing and inadequate commissioning (resulting in big variations of the flow rates in the individual rooms)
- Too high sound emission at inlet/outlet and sound transmission
- Excessive window airing by and general poor acceptability of occupants

To overcome these problems, the following issues must be carefully considered:

- Careful design, correct manufacturing, proper installation and comprehensive commissioning of the system
- Handout of good and adapted information to the occupants
- Proper and periodically repeated checking and maintenance of the system

6 Acknowledgements

We would like to express our thanks to Peter Hartmann, Thomas Baumgartner and Heinrich Huber who have been responsible for the evaluation campaigns in the 'Hausäcker', the 'Eichrüti' and the 'Riehen' buildings respectively.

This work was financially supported by the Swiss Federal Office of Energy (BEW, project 'IEA-ECB Annex V AIVC'), and the EMPA.

7 References

1 DORER V.: *Evaluation of residential ventilation systems*, working report, residential ventilation group of VSHL (Swiss association of HVAC systems manufacturers), 1996 (in German)

2 IEA-ECB Annex 27: *Evaluation and Demonstration of Domestic Ventilation Systems*. Operating Agent: L.G. Mansson, Sweden

3 FLUECKIGER B.: Project *Microbiological pollution of earth coupled ventilation systems*, Institut für Hygiene and Arbeitsphysiologie, ETH Zürich, Switzerland.

4 WANNER H.U.: *Occupant questionnaire for the evaluation of residential ventilation systems*. Institut für Hygiene und Arbeitsphysiologie, ETH Zürich, (in German)

5 BAUMGARTNER T.: *Principles of earth coupling for ventilation systems* , Presentation at the VSHL Ventilation Seminar 1996, (in German)

6 HARTMANN P.: *Final Report Performance evaluation residential building 'Hausäcker'*, Winterthur, 1996, (in German)

7 HUBER H, Dr.Eicher & Pauli AG: *Housing estates 'Im Niederholzboden, Riehen'. Performance evaluation of the mechanical ventilation system* , Nov. 1995, (in German)

8 ZWEIFEL G., STANGIER R.: *Zero-heat dwellings in Wädenswil, Measurement Report*, EMPA 175, Dübendorf Switzerland, 1995, (in German)

9 STANGIER R., ZWEIFEL G.: *Zero and low energy houses in Wädenswil (Switzerland)*, European Conference on Energy Performance and Indoor Climate in Buildings, Lyon, Nov. 1994