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Feasibility of Ventilation Heat Recovery in Retrofitting Multi-Family Buildings

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SYNOPSIS

The work concentrated on estimating the effects of building leakages and terrain parameters on the air infiltration. The analysis was performed mainly using a multi zone airflow model Movecomp with which the building and its ventilation system could be described in detail. The computations were performed for a flat in a 4/8-storey building. The highest infiltration occurred in an untight two-facade flat in open terrain. The calculations gave valuable information on the effect of the location of the leakage. The vertical distribution of the leakage had the most significant effect on infiltration. On the other hand, the tightness of the floor/ceiling and the apartment door did not have significant effect on the whole building infiltration, nor did the number of storeys. The knowledge gained from these simulations will be used in designing sealing techniques for existing multi-family buildings.

The results revealed a significant reduction in the economic feasibility of heat recovery ventilation when the air-tightness of the envelope decreased. It was estimated that, in Finnish climate and energy prices, the air-tightness of the envelope should be in the range of 2-3 air changes at 50 Pa, or better, in order to air to air heat recovery to be economically feasible in existing buildings. This means that the renovation of the ventilation system to include air to air heat recovery should almost always be connected with sealing of the building envelope.

1. INTRODUCTION

The renovation of existing high-rise residential buildings is becoming a major part of the construction work in Finland. At the same time, reduction of energy consumption is required to conserve the global environment. In 1992, the Finnish government decided to reduce the consumption of residential heating energy by 15 % by the year 2005. It has been estimated that 40% of residential heating energy is used for ventilation, which means that the renovation of ventilation systems play a major role in decreasing the overall energy consumption in buildings. The possible improvements to existing systems were described in an earlier paper /1/. Since then the research has focused on the feasibility of air to air heat recovery in residential buildings. Air to air heat recovery has become popular in new single family buildings during the 80's. Many manufacturers provide integrated ventilation units and product development has cut the size and price of the systems. Although many single family buildings are equipped with balanced ventilation including heat recovery, its share in the whole residential building stock remains low. The aim of this research was to study the technical and economical barriers which hinder the use of air to air heat recovery in existing buildings. The research included designing system concepts based on discussions with manufacturers and decision makers in the building process, computer simulations of air flows in buildings and life cycle cost calculations of the feasibility of air to air heat recovery.

2. SYSTEM CONCEPTS FOR AIR TO AIR HEAT RECOVERY

2.1 Typical present system

The majority (ca. 70%) of Finnish apartment buildings is equipped with mechanical exhaust ventilation. Each apartment has typically 2-3 exhaust points, at kitchen and at bathroom. The exhaust valves have a high pressure drop and usually an integrated sound attenuator. Common ductwork connects the apartments in the same vertical shaft. Circular sheet metal duct has been used since 1970's, but older buildings have masonry ducts. Typical pressure loss in the ductwork is 50-100 Pa. The system is usually equipped with a clock-controlled two-speed exhaust fan in the roof. The outdoor air usually enters through cracks in the windows or other components of the envelope. Purpose-built openings for incoming air, or air inlets, were taken into building practice since 1988 when the latest building code came into force. At the same time exhaust hoods in the kitchen became practically mandatory.

2.1 Central ventilation unit with ducted supply

One solution to air to air heat recovery is to install a new supply system and connect the existing, possibly refurbished, exhaust system to it via a heat exchanger. A plan of such solution is presented in Fig. 1. The system needs only one supply fan, which brings benefits in maintenance costs compared to apartment based systems. The installation of supply ductwork in an existing building can, however, cause significant costs. Using the staircase as a supply chamber would reduce the installation costs, but fire safety reasons and fear of contamination have restricted the use of such systems. According to the Finnish Building Code, fire dampers would be required in each apartment and the supply fan should be equipped with a fire emergency circuit breaker. A promising solution for the ducting problem would be placing the ducts outside the building envelope. Architectural reasons can be a major restriction if outside ducting is planned without redesigning the whole facade.

2.2 Apartment based ventilation units

Installing apartment based ventilation units is another possibility for air to air heat recovery. A system with both supply and exhaust fans, heat exchanger, filter and preheater can be installed in a top part of a standard cupboard. Only short ductwork is needed, see Fig. 2. The exhaust air can be discharged on the wall, or the existing ductwork can be used to lead the exhaust air to the roof. Unfortunately, neither alternative is accepted in the present Finnish Building Code as overpressurized ducts from bathrooms are not allowed. Experimental buildings and research projects have, however, removed some resistance against wall exhaust discharges /6/. The ease of installation is the major advantage of apartment based systems. The maintenance costs of apartment based systems are expected to be higher than in central systems due to a greater number of components and the difficulties of having to visit homes in order to carry out the maintenance. Another drawback of installing the system in the apartments is the fact that the cost of the preheating electricity is transferred from the building owner to the apartment owner/lodger. This can be prevented by installing a separate electricity network for the ventilation units or by using a hot water preheting coil connected to the central heating network.

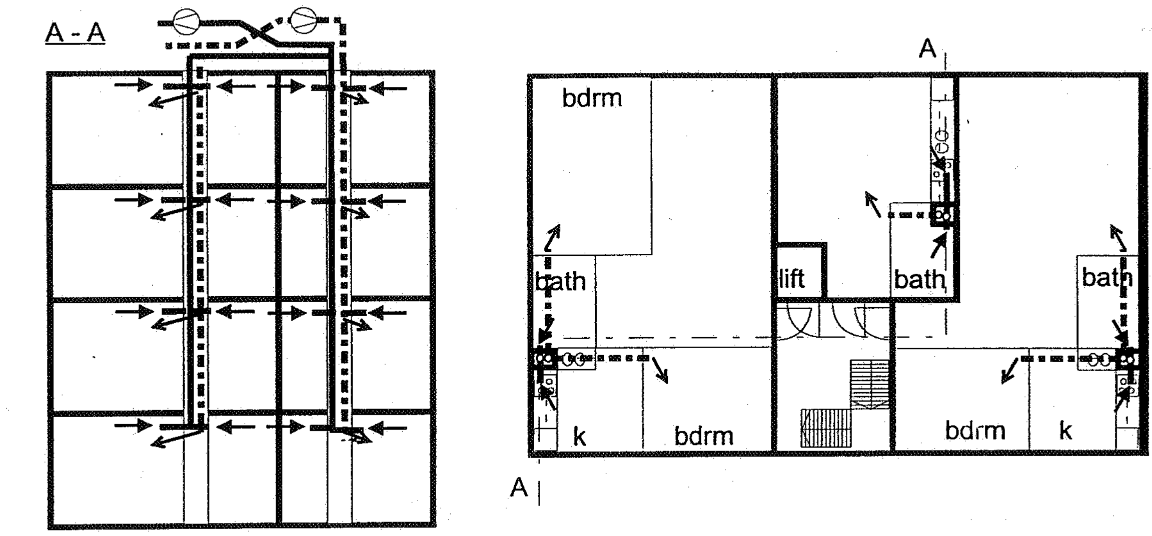

Fig. 1. Plan and section of a typical Finnish apartment block with a central ventilation unit with ducted supply.

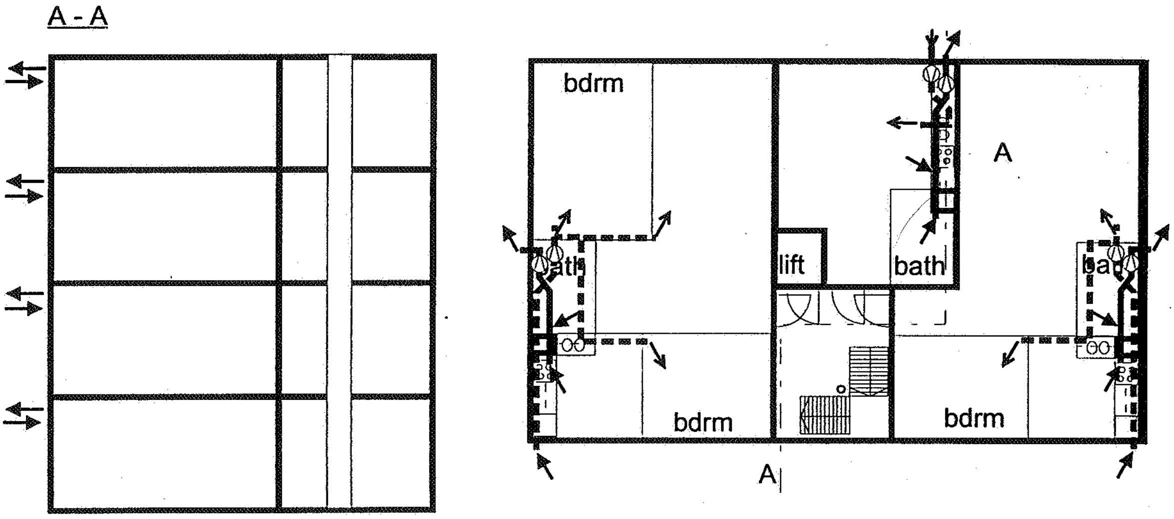

Fig. 2. Plan and section of a typical Finnish apartment block with apartment based ventilation units.

3. COMPUTER SIMULATIONS

3.1 The simulation model

The air flow analysis was performed using a multi zone airflow model Movecomp /2/, with which the building and the ventilation system could be described in detail. The building has a basement and 3 or 7 inhabited floors. The length, width and height of the building are 75 m, 12 m and 14 m respectively. Most of the flats have only two walls facing the outside. Therefore, it was considered reasonable to compute only one 63 m^2 flat on each floor. The air leakages are set to measured values in the actual building, see /1/. The pressure coefficients for the 12 wind directions were taken from reference /5/.

The simulations were performed for a total of 182 weather conditions. The annual results were obtained using the probability of each weather condition at Helsinki-Vantaa and at Rovaniemi airport, Finland, over 30 years.

3.2 Studied parameters

In order to be able to estimate the economic feasibility of heat recovery it is essential to know how much air is exfiltrated from the building. The effects of the following parameters were studied:

- terrain shielding
- tightness of the envelope
- tightness of the intermediate floor
- tightness of the apartment door
- weather data (Helsinki vs. Rovaniemi)
- supply/exhaust air flow difference
- the height of the building
- location of the outdoor air leakage

The terrain shielding was estimated based on the method described in AIVC's Numerical Database /4/. The following equation was used to estimate the wind speed (v_h) at height (h): $v_h = v_m K h^a$, coefficients K and a are given in table 1.

Table 1. Air leakages of the investigated building /4/.

Terrain type	K	a
Open flat country	0.68	0.17
Urban	0.35	0.25
City	0.21	0.33

3.3 Results

The main results of the air flow calculations are shown in figures 3 and 4. It can be seen that the air tightness of the envelope and the terrain shielding are the dominating factors in air infiltration. The effects of supply/exhaust air flow difference and the height of the building are negligible compared to these. The vertical distribution of the leakage had a significant effect on infiltration. In tightening the building it is essential to concentrate on the leakages on the outside wall near the floor and the ceiling. On the other hand, the tightness of the floor/ceiling and the tightness of the apartment door did not have any notable effect on the whole building infiltration. However, their role may be important in the transport of contaminants between apartments.

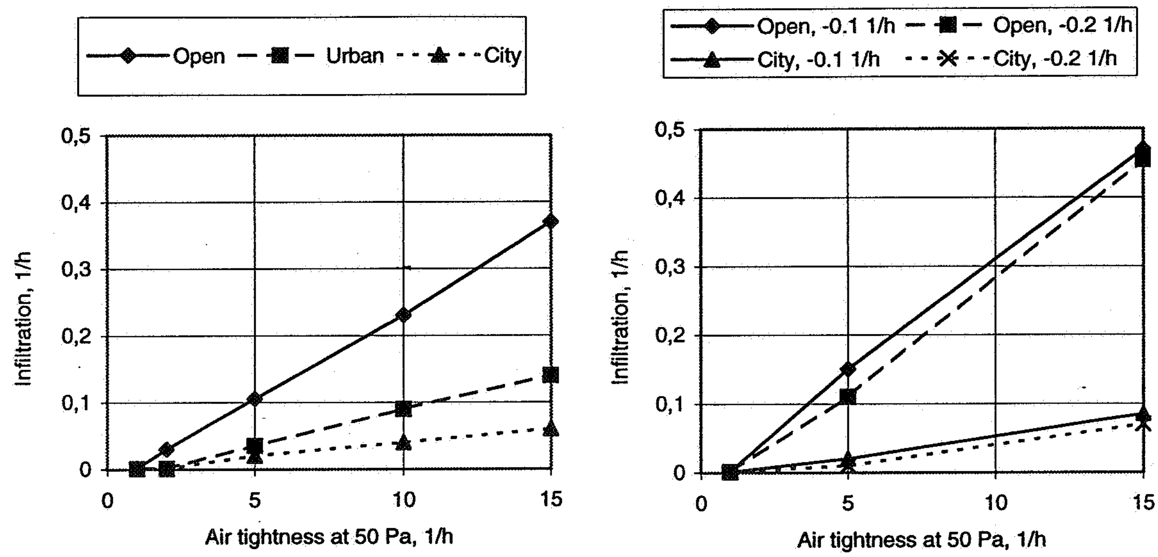

Fig. 3. a. Infiltration at different terrain conditions (Helsinki); b. Infiltration at different supply/exhaust air flow difference (exhaust 0,5 1/h, supply 0,3 1/h or 0,4 1/h) and terrain conditions (Rovaniemi).

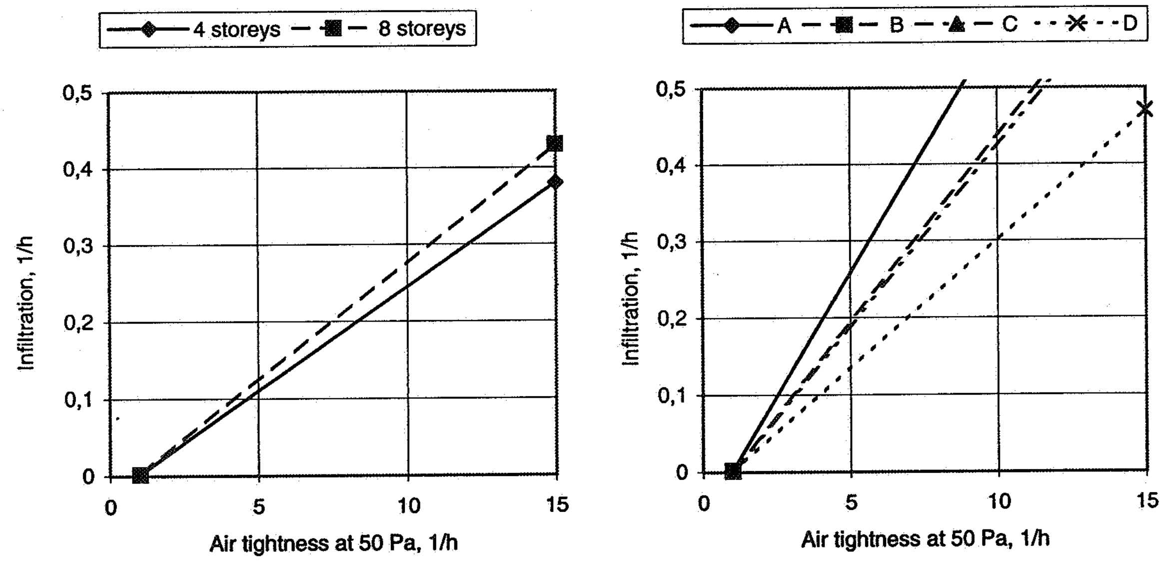

Fig. 4. a. Infiltration at buildings of different height (Helsinki); b. Infiltration depending on the location of the outdoor air leakage (Rovaniemi, A: cracks at 0.0 m and 2.5 m; B: 50% of leakage at 1.25 m, 25 % at 0.0 m and 2.5 m; C: cracks at 1.0 m and 2.0 m; D: one crack at 1.25 m).

4. LIFE CYCLE COST CALCULATIONS

4.1 Calculation method

A simple steady-state energy balance was used to calculate the energy recovered by air to air heat exchanger. The balance consisted of losses due to transmission, ventilation and infiltration, and internal gains including solar radiation. The heating energy was calculated for the whole year at 2°C intervals, the recovered ventilation energy was calculated only when external heating was required and when the outdoor temperature was above the anti-freezing set point of heat recovery air exchange.

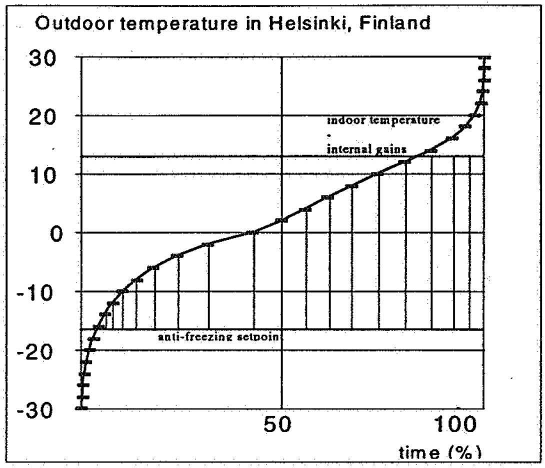

Fig. 5. The calculation of the energy saved by the air to air heat recovery (vertical hatch).

The life-cycle cost calculation is an analysis of the present values of future costs. The economically feasible investment to a given system was calculated based on the estimated maintenance and repair costs. The maintenance costs included: the cost of heating the ventilation air, the reduction in the initiation fee, the regular maintenance costs, and the cost of the electricity used by the fans.

4.2 Studied parameters

The various system solutions to air to air heat recovery were compared to a standard mechanical exhaust system. A similar base level of investment costs was assumed for all systems (even the existing exhaust system needs repairing to meet the present requirements). The total air exchange rate was set at 0.5 1/h. Infiltration was included in the total rate in order to achieve a comparable indoor air quality in all systems. The infiltration was subtracted from the exhaust air flow in the balanced systems to give the appropriate energy penalty. For example, with an infiltration of 0.15 1/h, only 0.35 1/h of exhaust air goes through the heat exchanger.

4.3 Results

The results of the air flow calculations were combined with the life cycle cost calculations and the results were presented in nomograms, see Fig. 6 for an example. At an air tightness of 8 1/h at 50 Pa, the economically feasible investment to air to air heat recovery is 80 FIM/m^2 in urban terrain, but only 30 FIM/m^2 in open terrain. The results depend strongly on the weather data, the costs of heat and electricity, and on the rate of the interest. Therefore, is it difficult to apply the nomograms outside Finland. They will, however, give an indicative picture of the effect of air infiltration on the economic feasibility of air to air heat recovery.

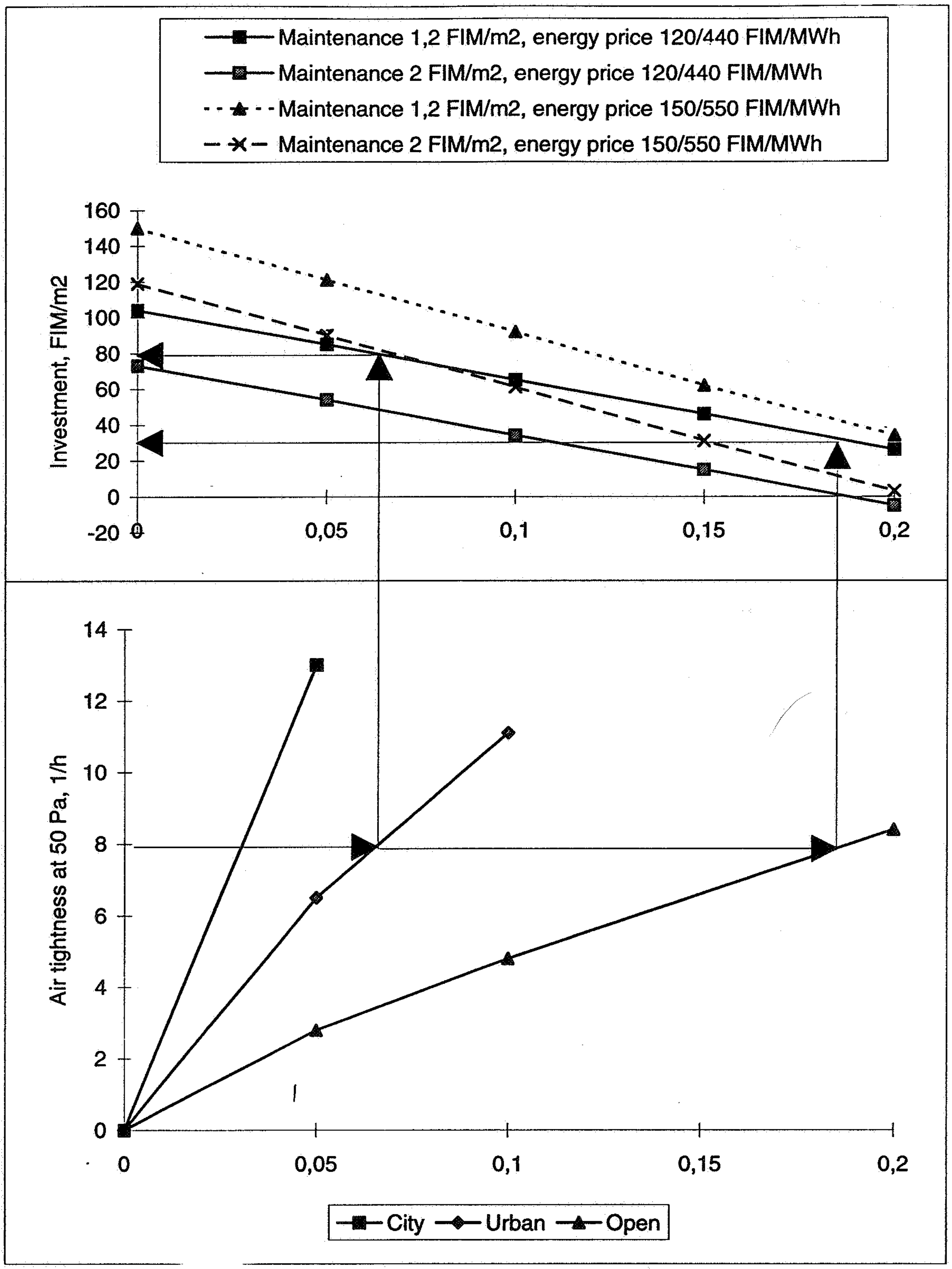

Fig. 6. The economically feasible investment to the air to air heat recovery in Finnish climate. The two levels of energy prices are: heat 120 FIM/MWh, electricity 440 FIM/MWh; and heat 150 FIM/MWh, electricity 550 FIM/MWh. The efficiency of heat recovery is 65 %.

5. CONCLUSIONS

Main part of the work concentrated on estimating the effect of building leakages and terrain parameters on the infiltration. The aim was to be able to give guidance on the feasibility of ventilation heat recovery in the design phase. The computations were performed for a flat in a 4/8-storey building. The highest infiltration occurred in an untight two-facade flat in open terrain. The calculations gave valuable information on the effect of the location of the leakage. The vertical distribution of the leakage had the most significant effect on infiltration. On the other hand, the tightness of the floor/ceiling and the apartment door did not have significant effect on the whole building infiltration, nor did the number of storeys. The knowledge gained from these simulations will be used in designing sealing techniques for existing multi-family buildings.

The results of the simulations were used as a basis for estimating the (uncontrolled) infiltration and its effects on the economic feasibility of air to air heat recovery ventilation. Life-cycle cost calculations were performed for various heat recovery ventilation systems which were compared with a mechanical exhaust system. The result revealed a significant reduction in the economic feasibility of heat recovery ventilation when the air-tightness of the envelope decreased. It was estimated that, in Finnish climate and energy prices, the air-tightness of the envelope should be in the range of 2-3 air changes at 50 Pa, or better, in order to air to air heat recovery to be economically feasible in existing buildings. This means that the renovation of the ventilation system to include air to air heat recovery should almost always be connected with sealing of the building envelope.

ACKNOWLEDGEMENTS

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