COMPARISON OF DIFFERENT HVAC SYSTEMS IN MULTI-STOREY APARTMENT BUILDINGS IN HELSINKI

Mikko Saari[1], Juhani Laine[1], Sami Karjalainen[1] and Klaus Hamström[2]

[1] Technical Research Centre of Finland (VTT), VTT Building Technology, Finland
[2] Housing Production Bureau of Helsinki (ATT), Finland

ABSTRACT

Good indoor air quality can be ensured most economically with an apartment based supply and exhaust air ventilation system with heat recovery. This paper describes an in-situ comparison study of four different buildings and HVAC systems. The main tasks were to study the energy consumption, indoor environment and operation of the mechanical systems. The air quality was good in all buildings with mechanical supply and exhaust air ventilation systems. Most complaints of inadequate ventilation as well as the highest CO_2 concentration and relative humidity were measured in the building with a centralized exhaust air ventilation system. The measured district heating energy consumption of three of the buildings was 47 - 49 kWh/m³, while the consumption of the building with apartment based mechanical supply and exhaust air ventilation system with heat recovery was only 36 kWh/m³ (30 % lower). The electricity consumption of the fans was twice as high in centralized ventilation units as in apartment based units.

KEYWORDS: air change rate, costs, energy, heating, ventilation system, residential, heat recovery

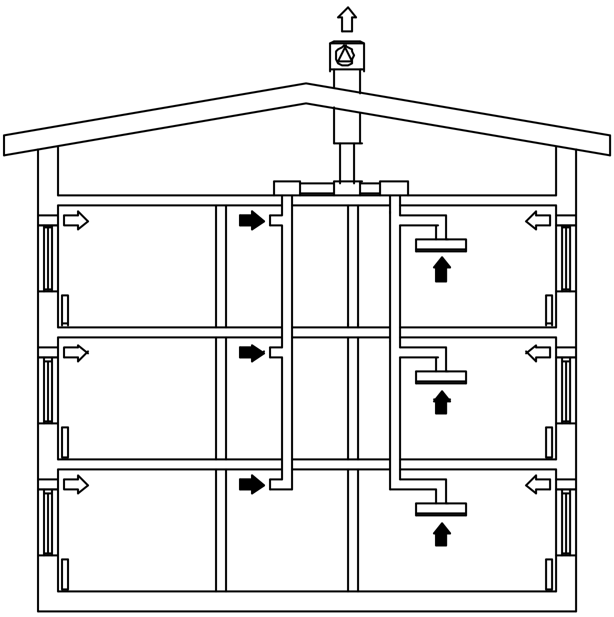
INTRODUCTION

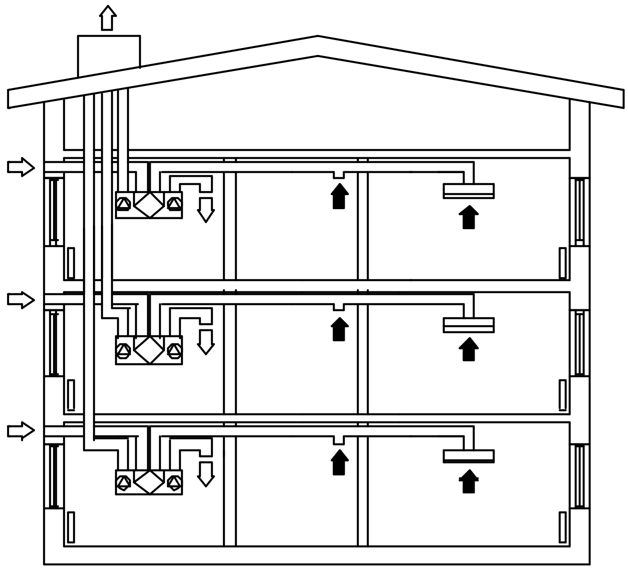
The objective of this study was to compare four different buildings and HVAC systems in practice and to determine the best solutions for the City of Helsinki to utilize when designing new apartment buildings. The main tasks were to study the energy consumption and indoor environment. [1]

METHODS

Four multi-storey apartment buildings (Abraham Wetter Street, Herttoniemi Harbour, Castle Builder's Corner and Ship Bay Arc) built by the Housing Production Bureau of Helsinki were studied for a period of two years in 1995 - 1997. The study focused on the functioning of HVAC-systems, the energy consumption of the buildings, the indoor climate of the apartments, the need of maintenance as well as the opinions of the occupants.

The buildings were located in the Herttoniemi area in Helsinki and had district heating. Three of the buildings used traditional water based radiators for heating and one building used ventilation heating. The oldest building was built in 1989 and had a mechanical exhaust air ventilation system with common ducts. One of the more recently built buildings (1995) had apartment based supply and exhaust air ventilation units with heat recovery. The two other newer buildings had centralized supply and exhaust air ventilation units with heat recovery. The building with ventilation heating had a run-around water-glycol heat exchanger for heat recovery. It also had energy efficient windows to keep the energy consumption low. Figure 1 shows the principle of the heating and ventilation systems in each building.





⇑ 1. Abraham Wetter Street: water based radiators and a mechanical exhaust air ventilation system with common ducts.	⇑ 2. Herttoniemi Harbour: water based radiators and apartment based supply and exhaust air ventilation units with heat recovery.
⇓ 3. Castle Builder's Corner: water based radiators and centralized supply and exhaust air ventilation units with heat recovery.	⇓ 4. Ship Bay Arc: ventilation heating system and centralized supply and exhaust air ventilation units with heat recovery.

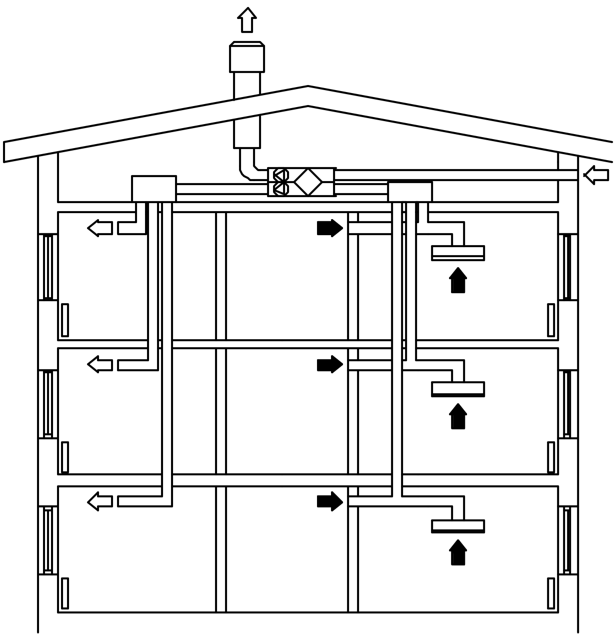


Figure 1. Schematic of the heating and ventilation system in different buildings.

The consumption of heating energy and electricity was monitored monthly during the two year study. The indoor climate was monitored in four randomly selected apartments in each building for a two week intensive period. During the same period, the operation of the heating and ventilation systems were monitored. Average exhaust air flows of the ventilation systems were measured once in 1995. A questionnaire study for opinions of the inhabitants was carried out once in 1997. Maintenance costs were monitored by a service company.

RESULTS

A summary of the results of the buildings is presented in Table 1.

Table 1. Comparison of results of the different buildings.

	Building			
Feature	1 Abraham Wetter Street	2 Herttoniemi Harbour	3 Castle Builder's Corner	4 Ship Bay Arc
Building volume, m³	17 290	25 563	17 110	26 050
Apartment area, m²	4 174	5 262	3 782	5 678
Construction year (construction cost, €/m²)	1989 (n.a.)	1995 (988)	1995 (1 146)	1995 (1 147)
Heating system	Water based radiators	Water based radiators	Water based radiators	Ventilation heating
Ventilation system	Mechanical exhaust	Apartment based supply and exhaust	Centralised supply and exhaust	Centralised supply and exhaust
Temperature efficiency of the heat [illegible]	0	50	35 - 45	40 - 45
Aver[illegible]	[illegible]	2[illegible]	[illegible]	[illegible]
Acce[illegible] answ[illegible]	[illegible]	3[illegible]	[illegible]	[illegible]
Ventilation coefficient, 1/h	0.59	0.70	0.90	0.95
Exhaust air flow, dm³/s/person	10.5	12.0	16.7	18.6
General ventilation insufficient, % of the answers	15	12	12	9
Ventilation insufficient while cooking, % of the answers	61	Occupant control	47	36
Window opening used, % of the answers	86	81	69	80
Average carbon dioxide level, ppm	909	545	521	594
Relative humidity in winter, %	39.6	26.0	25.7	22.8
Absolute humidity difference (indoor-outdoor), g/kg	4.5	1.4	1.8	1.7
District heating energy, kWh/m³/year	49	36	48	47
Electricity of fans, kWh/apartment/year	260	680	1 090	1 360
Specific electricity of fans, kW/(m³/s) *)	1.0	2.2	2.8	3.7
Energy cost, €/m²/month	0.86	0.90	1.10	0.98
Usage and maintenance, €/m²/month	0.048	0.083	0.075	0.053

3. Castle Builder's Corner: water based radiators and centralised supply and exhaust air ventilation units with heat recovery.

4. Ship Bay Arc: ventilation heating system and centralised supply and exhaust air ventilation units with heat recovery.

Cost of changing air filters in ventilation units, €/apartment/change	None	10	7	10
*) Specific electricity of fans is the total electricity effect divided by the total exhaust air volume flow.				

Indoor climate and air quality

The average indoor air temperatures in the buildings were 22.6 - 23.1 °C even though the design temperature was 21 °C. The opinions of the occupants did not vary significantly between the four buildings. Most of the occupants were happy with the indoor temperature, but almost half of them indicated draught from time to time. More than 60 % were satisfied with the indoor air humidity in three of the buildings. Only 47 % were satisfied with the indoor air humidity in the building with ventilation heating (Ship Bay Arc).

The buildings with mechanical exhaust air ventilation (Abraham Wetter Street) and the apartment based ventilation (Herttoniemi Harbour) had the largest number of complaints (46 %) of poor indoor air quality. The fewest complaints came from the building with ventilation heating (Ship Bay Arc), which had the highest ventilation rate. The buildings with mechanical exhaust air ventilation and apartment based ventilation had the largest number of occupants detecting odors. The building with ventilation heating had the lowest odor detection, where up to 71 % said that there were no odors at all. In all buildings, regardless of the HVAC-system, window opening was frequently used.

The building with mechanical exhaust air ventilation (Abraham Wetter Street), which represents the current building practice showed the weakest results in ventilation and indoor air quality. Here, the indoor air humidity compared to the outdoor air humidity was approximately three times higher than in the other buildings. At night, the bedrooms had a maximum carbon dioxide concentration of 1400 ppm, which is about twice as high as the concentration in the other buildings. High carbon dioxide concentrations indicates that the concentration of other harmful contaminants may be high as well. High humidity may cause mould problems.

In the building with mechanical exhaust air ventilation the exhaust air flows were typically only half of the recommended values as stated in the Finnish building code, whereas in the buildings with centralized supply and exhaust air ventilation systems the air flows corresponded to the default values in the code. Apartment based supply and exhaust air ventilation showed exhaust air flow rates that were about 20 % lower than the recommended values because the occupants were able to adjust the apartment based ventilation according to their demands. The quality of the indoor air was still as good as that with centralized ventilation systems.

Energy consumption

The building with apartment based ventilation (Herttoniemi Harbour) used the smallest amount of district heating energy. The district heating energy consumption in the building with apartment based ventilation building was 36 kWh/m^3, whereas the annual consumption in the other buildings was 47 - 49 kWh/m^3. If the exhaust air flows in the building with mechanical exhaust air ventilation would continuously have been as required by the building code, the district heating energy consumption would have been about 59 kWh/m^3, which is 10 kWh/m^3 more than the measured consumption. The apartment based ventilation saved district heating energy because the ventilation could be demand controlled, and also because the heat recovery was efficient. The electricity consumption of fans was the smallest in the buildings with mechanical exhaust air ventilation (Abraham Wetter Street) and apartment based ventilation (Herttoniemi Harbour).

Energy and maintenance costs

The building with apartment based ventilation (Herttoniemi Harbour) had the best combination of good indoor climate and low energy costs. Even though the lowest energy bill was reported in the building with mechanical exhaust air ventilation (Abraham Wetter Street) the energy savings were a result of a ventilation rate well below the design value, and thus the indoor air quality was quite poor.

The energy bill was 5 % higher in the building with apartment based ventilation and 10 - 30 % higher in the buildings with centralized supply and exhaust air ventilation. The difference between the lowest and highest energy bill was 0.24 €/m²/month (20 000 € per year).

The total maintenance costs were lowest with exhaust air ventilation (0.048 €/m²/month), whereas with centralized ventilation the costs were 0.053 - 0.075 €/m²/month and with apartment based ventilation the cost were 0.083 €/m²/month.

CONCLUSIONS

The research shows that the inherent problems with mechanical exhaust air ventilation systems have not been solved. The main problem is that the flow of outdoor air into building cannot be controlled in the rooms due to the uncontrollable pressure difference between indoor and outdoor air, which is caused by differences in indoor and outdoor air temperature, the stack effect (especially in multi-storey buildings), wind, external and internal air leaks due to poor construction and open windows. Other problems are draught, dirty outdoor air entering the building and poor sound insulation.

Multi-storey apartment buildings should have a well planned mechanical supply and exhaust air ventilation system with heat recovery in order to guarantee energy efficiency and a good and controllable indoor climate and air quality.

The ventilation systems were left with many faults already during planning and implementation. Most of the faults were due to the malfunctioning of complicated regulators and control devices. The faults were not detected during delivery due to incomplete tests. Simpler systems, fewer mechanical components, avoiding to build parallel systems and cost reduction are central aims in functional housing engineering as well as in achieving a good and controllable indoor climate. The heat recovery from the exhaust air should be more efficient and the energy consumption of fans is too high and needs to be lowered. Without special training and detailed instructions, the maintenance staff is not able to control and maintain modern HVAC-systems and the proper functioning of the system cannot be guaranteed.

According to the research results, ventilation heating is suitable in a modern well thermally insulated multi-storey building. The heat demand per apartment is so low that it is unnecessary to build a separate heat distribution system inside each apartment. Ventilation, however, is always inevitable. The building with ventilation heating was heated with heating coils in the supply air ducts in each apartment. Here, the supply air flows can normally be dimensioned according to the ventilation need because the heat demand is so low.

ACKNOWLEDGEMENTS

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REFERENCE

1. Laine, J., Karjalainen, S. & Saari, M. A comparative HVAC-study of multi-storey apartment buildings by the Housing Production Bureau of Helsinki City (in Finnish), 1998. 60 p. + app. 75 p.