Ecology and economy when retrofitting apartment buildings

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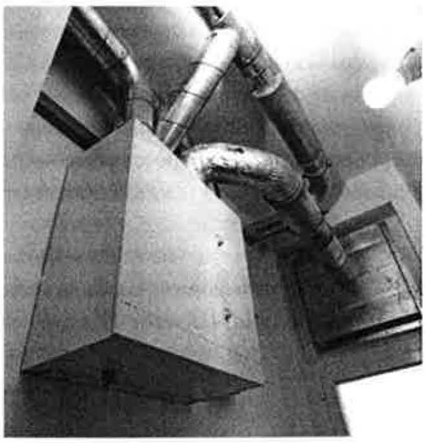
This article describes the retrofitting of a five-family apartment building, implemented as a pilot and demonstration project for the Swiss Federal Office of Energy. The fact that this building on Mutschellenstrasse in Zurich is a listed building, imposes restrictions to the retrofitting process. However, the cellar ceiling, the roof and part of the building facade have been insulated, new windows have been installed and three apartments have been fitted with a mechanical ventilation system with heat recovery. Heating is provided by heat pumps. In the retrofitting process, materials and components have been selected according to housing comfort and environmental criteria. The heating energy requirement has been reduced by 50%.

The builders were only permitted to make minor adaptations to the roof and changes to the facade were out of the question, because the Art Nouveau style of the building facade, dating from 1913, should be preserved, according to the Zurich Historic Buildings and Monuments Department. The main aims for the architects were to increase the comfort level with a better energy efficiency, maintain the property value, and create a marketable cost/benefit ratio which includes environmentally orientated planning and maintenance.

The building has an extension on one side and covers a total of six storeys. The measures taken to improve the energy characteristics of the building, are described as follows.

▼ *Photograph:*
View of a storage room with a ventilation unit. The external wall opening and the external air duct can be clearly seen.



Insulation measures

As a first step, the roof, cellar ceiling and external walls on the third floor were insulated using cellulose fibres, so that heat transmission values considerably improved. Approximately 34% of the outer layer was not insulated. In fact, additional insulation of this 220 m^2 clay brick wall would only result in a reduction in the heating energy requirement (SIA 380/1) of 40 MJ/m^2 per annum. In practice, the heating energy requirement was reduced by 42 MJ/m^2 per annum by installing a mechanical ventilation system with heat recycling. This was considerably less expensive than reinsulation.

Mechanical ventilation

Mechanical ventilation has been installed in the lower three apartments. The decentralised ventilation units have been placed in small storage rooms which are positioned directly underneath each other. These rooms are ideal, enabling short circuits to be used since they are adjacent to the kitchens, bathrooms and the external wall facing the road.

Each of the compact units is fitted with two cross-flow heat exchangers connected in series, two fans (90 W each) and four connection brackets (125 mm wide). According to the manufacturer the heat recovery rate is 70%. Outside air passes through the external wall to the ventilation unit, through the heat exchanger, and from there - as supply air - through conduits and mufflers into the four rooms. Supply and exhaust air conduits have been installed in the suspended ceiling along the corridor. The exhaust air is extracted from the kitchen, bathroom and separate toilet, and led via heat exchangers across the roof, with a separate system for each apartment. The volume of exhaust air and consequently the rate of air change can be selected manually. In the event of frost, the unit is automatically switched off, a disadvantage at low outside temperatures because of the considerable heat recovery potential.

Heating

For heating, two brine-to-water heat pumps are installed in the cellar. On the heat source side they are connected to two vertical borehole heat exchangers, each 150 m deep. At 5°C source and 50°C supply temperature the heat output per unit is 9.9 kW and the coefficient of performance (COP) is 3.8, according to measurements from the Heat Pump Test and Training Centre in Winterthur Töss. Under typical conditions on Mutschellenstrasse, the brine temperature is around 3°C and the supply temperature around 48°C. Output and COP therefore only differ slightly from the aforementioned test values during operation. The seasonal performance factor (SPF) is estimated at

3.2. Supply temperatures up to 55°C instead of 35°C cause a decrease in the SPF of 10-20%. Unfortunately, the higher supply temperatures are necessary because the old heaters, with insufficient capacity, have not been replaced.

Of the 9.9 kW heating output, 2.6 kW comes from the compressor and 7.3 kW originates from the borehole heat exchanger, with its specific heat extraction of around 5 kW per 100 m tube length. The brine circulates in the four parallel polyethylene pipes - two each for supply and return - with a diameter of 30 mm. The flow rate is 1.5 m^3/h per tube and the circulation pump (for both tubes) has an electrical power consumption of 60 W, requiring 150 kWh electricity for 2,500 operating hours per year. (Around 500 hours are required for heating water outside the normal heating period.) The hot water container has a capacity of 1,000 litres and is equipped with additional electrical resistance heating to periodically increase the temperature to 60°C, to avoid the development of legionella bacteria.

Swiss standards

The SIA (Swiss Engineers and Architects Association) guidelines indicate that a 37% reduction in the specific energy demand for heating can be achieved for buildings that were constructed between 1901 and 1940 (from 920 to 580 MJ/m^2 per annum). Before retrofitting, the apartment block had an energy characteristic of 690 MJ/m^2 per annum. The insulation and heat recovery using the ventilation system, have reduced the heat requirement for both transmission and ventilation, as shown in **Table 1**. Calculating an energy characteristic for the retrofitted building, assuming that heating is via fossil fuel (for comparison reasons), would result in a value of 334 MJ/m^2 per annum, which is 48% below the "old" energy characteristic.

Using heat pumps results in an even higher energy efficiency within the building. Consequently, the building now also meets the recommendations of Minergie, a joint standard mandated by the cantons of Bern and Zurich for energy-saving methods of construction and operation. Assuming a 50% efficiency for electricity production the electricity demand must be doubled in the calculations to account for the total amount of primary energy used. The recommended maximum energy consumption for heating for retrofitting is 320 MJ/m^2 per annum. It is clear that without the use of heat pumps, this standard would not have been met.

▼ *Table 1: Data for calculation of heat energy requirement*

	Prior to retrofitting	After retrofitting
Heat requirement for transmission	473	216 MJ/m^2 per annum
Heat requirement for ventilation	119	76 MJ/m^2 per annum
Heat gain	114	108 MJ/m^2 per annum
Heat energy demand (SIA 380/1)	478	184 MJ/m^2 per annum
Energy requirement for hot water	108	100 MJ/m^2 per annum
Energy requirement for space heating	**586**	**284 MJ/m^2 per annum**
Energy reference area (ERA)	508 m^2	636 m^2
Efficiency / Seas. Performance Factor	0.85	3.2
Electricity demand		
• Heat pump	–	89 MJ/m^2 per annum
• Mechanical air circulation	–	6 MJ/m^2 per annum
• Photovoltaic system (gain)	–	8 MJ/m^2 per annum
Spec. energy demand for heating	690	87 MJ/m^2 per annum
Spec. energy demand according to definition of Minergie standard (use of electricity doubled)	–	174 MJ/m^2 per annum
Oil consumption (measured)	8,200 kg	–

Note: With the exception of the oil consumption all figures are calculated values. The ventilation heating losses amount to 118 MJ/m^2 per annum excluding, *76 MJ/m^2 per annum* including *heat recovery. Assumptions: room temperature 20°C; temperature to start heating 12°C; change of external air: 0.4/h; energy requirement for hot water 100 MJ/m^2 per annum, prior to the retrofitting 108 MJ/m^2 per annum due to being densely occupied; occupancy per person 30 m^2.*

Ecological aspects

Throughout the project, which was supported by the *Pilot and Demonstration Programme* Energy 2000 of the Swiss Federal Office of Energy and the *Energy Saving Foundation* of the Zurich Electric Power Utility, ecological aspects were considered very important. Not only because a reduction in energy consumption was achieved, but because environmental aspects were taken into account throughout the entire process. This meant that manufacturers, suppliers and tradesmen had to specify all materials and components used. For example mineral-based paints and PVC-free electrical wiring were used, and rainwater was applied for the toilet flush systems and the washing machine. Furthermore, many materials were refitted, such as the old clay roofing tiles (cleaned and then returned to the roof) and doorframes, heaters, blinds and shutters which were sanded down or treated with soda-based paint remover before being repainted.

Conclusions

The project can be seen as a successful example of a retrofit project, achieving considerable energy savings by improving insulation, installing a mechanical ventilation system with heat recovery, and using heat pumps for heating. The fact that environmental aspects were taken into account throughout the entire retrofitting process has contributed to the success and makes it a true demonstration project.

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