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Mechanical ventilation with a heat recovery system in renovated apartment buildings

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Abstract. Renovation of existing buildings offers a great opportunity to reduce energy consumption, but often it also reduces indoor air quality, as buildings which were originally designed for natural ventilation are made highly air tight. A solution to the problem would be a mechanical ventilation system, but several problems are experienced when implementing it – no place for installing air ducts, cold air inflow or additional energy needed for incoming air preheating. Ventilation using heat recovery units is the one method out of many other energy saving measures. The advantage of using heat recovery units is energy saving, and as a result, savings on costs of the operation of the ventilation system. This paper describes the renovation carried out in 4-storey apartment buildings. In the course of the study, two buildings were analysed, both belonging to the series buildings of the Soviet Era (103 series), built in 1970 using the same materials, the same construction solutions. The renovation was carried out by one company, using the same materials and the same renovation principles for both buildings. The only difference after the renovation is that a new centralized mechanical ventilation system with a heat recovery unit is installed in one of the buildings, while in the second building the natural ventilation system is preserved. The arrangement of the mechanical ventilation system is rather innovative as the ventilation ducts in the building for fresh air supply are integrated into the facade's insulation layer and enter the living room through the wall directly behind heating radiators. The main questions studied in the course of the research are the efficiency of the mechanical ventilation system heat recovery, the building's air tightness, and the overall system efficiency.

Key words: mechanical ventilation, heat recovery, building renovation, energy efficiency.

INTRODUCTION

The building sector is the largest user of energy and the largest CO_2 emitter in the European Union (EU) and is responsible for about 40% of the EU's total final energy consumption and CO_2 emissions. The EU has established an ambitious target that all new buildings must be nearly zero energy buildings by 31 December, 2020 (Directive 2010/31/EU). However, even if all buildings in the future will be built according to the nearly zero energy building standard, this would still only mean that the increase in energy demand will be reduced, but it would not reduce the exiting demand. Only measures taken in existing buildings will have a significant effect on the total energy demands of building stock.

Since the residential building stock in Baltic countries is very old, mainly built prior to the 1970s or even the 1960s, the current average specific heat consumption in buildings is between 220 and 250 kWh $(m^2)^{-1}$ per year (Cabinet Decree No. 571). Retrofitting of existing buildings offers a great opportunity for reducing energy consumption and greenhouse gas emissions.

The first retrofit alternatives to be considered for existing residential buildings are improvement of the thermal insulation and air tightness. The usual standard renovation of multi-storey apartment buildings includes facade insulation, end wall insulation, thermal insulation of the attic and basement ceiling and replacement of old windows, and heat substation renovation; with this standard renovation, it is possible to reach approximately 50% energy savings (Blumberga, 2008). In absolute terms based on the current Latvian building code, this translates into energy consumption between 75–85 kWh m^{-2} per year. To reduce energy consumption even more and improve the indoor climate, the heat distribution systems and ventilation systems have to be addressed.

In fact, heat losses by ventilation become the main source of heat losses after proper thermal insulation of the building envelope, which can be as high as 30–40% of energy consumption (Klavina, 2012). A study (Orme, 2001) about the energy impact of ventilation and air infiltration in residential buildings in 13 countries shows that the energy losses due to ventilation and air infiltration represent about 48% of the energy delivered for space heating. Tommerup and Svedsen (Tommerup & Svendsen, 2006) reported the ventilation heat losses in typical Danish residential buildings to be 35–40 kWh $(m^2\ a)^{-1}$ per year. As until the 1990s building were designed with natural ventilation, they become airtight buildings after renovation and the air infiltration rate is often not sufficient to maintain acceptable indoor air quality. Shortcuts between different ventilation ducts often become a problem after renovation, resulting in both high discomfort and energy losses.

Indoor air quality is greatly influenced by the amount of fresh air that enters the building. This fresh air replaces the exhausted air, which contains biological pollutants, excess moisture, and volatile organic compounds released from building materials, carpets, furniture, and other household items as a result of aging, decomposition, or curing.

A good solution in such buildings is mechanical ventilation with heat recovery to recover the heat from exhaust air and in such way also reduce the ventilation heat losses. A good strategy for maintaining good indoor climate and reduce energy consumption in a building would be airtight a building with a mechanical ventilation system and heat recovery. This solution may satisfy energy conservation goals in a cost-effective manner without reducing the indoor air quality. Heat recovery systems typically recover about 60–95% of the heat in exhaust air and have significantly improved the energy efficiency of buildings (Mardiana-Idayu & Riffat, 2012).

MATERIALS AND METHODS

There are a number of issues that should be considered during the design phase and before installation of a new ventilation system in existing buildings. Narrow and unsatisfactory functional links between premises, as well as low ceilings, which in most cases do not exceed 2.45 m. These are the usual characteristics of apartments in the multi-storey buildings constructed in series in Latvia. Because of the low ceiling height, it is not convenient to build a centralized system with air ducts going through apartments, besides, the owners of the apartments are against fitting of ventilation channels on the ceiling of rooms. One of the solutions is installation of a decentralized system as has, for example, been implemented in a number of projects in Estonia. However, this solution has shown rather high investment costs and fewer adjustment possibilities as well as problematic maintenance – the need to access all flats or left to the house owner's responsibility (Koiv, 2008; Koiv et al., 2012).

During the design phase, a new solution was found, a centralized ventilation system with air ducts placed outside of the building – in the facade insulation. There are already two examples of public buildings in Latvia (Ventspils City Council and Ergli Vocational School) (Kamenders, 2013) where this solution is used, as well as in Europe (Kalz & Dinkel, 2013). But so far, such solution has not been applied to multi-apartment residential buildings.

Experimental facility

There are two similar renovated residential buildings located at 11 and 17 Zirnu Street, Cesis. Both are 4-storey buildings with a basement and technical floor and belong to the 103 series, built around 1970. Energy audits were carried out in March 2012 before renovation. Renovation works were finished in January 2014.

The situation before renovation was similar. In most of apartments (≈ 53–54%), windows had been replaced by the owners. The attic floor was partially insulated with loose wool (thickness100–200 mm). In the basement, water pipe insulation works had been carried out in a poor quality, certain places were not completely covered. Masonry damages were observed on the external walls. The buildings were equipped with a one-pipe heating system. The radiators were not equipped with special thermostats, even the ones which the owners had replaced; therefore, individual control of room temperature was impossible. Building heating substations were equipped with an automatic control system that provided heat generation according to the outdoor temperature.

According to the information provided by the residents of the buildings, the indoor air temperature in apartments was around 18–21°C. The apartments near the end walls had lower indoor air temperature characteristics. In a part of the apartments, poor circulation in the heating risers was detected.

Originally, the buildings were designed with a natural ventilation system providing air supply through cracks, windows, slots and air extraction through kitchen, toilet and bathroom ventilation shafts. During the visits, mould was detected in most of the apartments.

The renovation carried out in Zirnu street, Cesis, included the following steps:

- Facade and end wall insulation from the outside with 100 mm insulation, window boxes insulation with 30 mm insulation;
- The basement slab insulation (including the walls bordering the apartments) with 100 mm insulation and building plinth insulation with 50 mm extruded polystyrene;
- Staircase roof insulation with 100 mm insulation and attic floor insulation, ensuring a 300 mm layer of insulation all over the floor area;
- Replacement of apartment windows and staircase windows;
- Replacements of attic and entrance doors;

– Renovation of the heating system;
– Renovation of the hot water distribution system.

Table 1 shows the thermal properties of the building components before renovation and the planned ones.

Table 1. Thermal properties (U value (W (m^2 K)$^{-1}$) of the building components before renovation and planned properties

	Basement slab	Facade walls	End walls	Windows	Doors	Attic	Staircase roof
Before	0.56	0.89	0.93	1.8–2.8	3.00	0.28–0.77	1.02
After	0.21	0.28	0.29	1.4	1.6	0.12	0.29

In one of the two buildings (17 Zirnu Street) a new mechanical ventilation system with a heat recovery unit was installed. The main concept of the renovation is to minimize heat losses and maximize heat gains and to ensure high quality indoor climate.

A mechanical ventilation system with three air handling units which are located in the building stairwells at the attic level was installed. Each staircase has its own air-handling unit (Zehnder ComfoAir 550 R Luxe Enthalpie with moisture recovery) designed with a counter flow plate heat exchanger with a highly efficient heat recovery rate and moisture recovery (enthalpy). Preheating of the fresh air is ensured with an electrical coil. The ventilation system corresponds to the 'Passive House' (Passivhaus Institute Dr. Wofgang Feist) requirements. The Latvian Construction Standard LBN 231-03, 'Heating and ventilation of residential and public buildings', requires at least 15 m^3 h^{-1} of fresh air per person if the only indoor air pollution source is the residents. The Construction Standard LBN 211-98, 'Multi-storey residential buildings', states that the air exchange rate per hour in living rooms and bedrooms should be at least 3 m^3 m^{-2} and the indoor air temperature during the heating season should be at least 18°C. The designed air exchange rate is 20–30 m^3 h^{-1} in each room, which corresponds to 1–2 persons per room. During the ventilation design process, the following design parameters were used: minimum outdoor temperature -23.8°C in winter and maximum outdoor temperature +22.3°C in summer; indoor temperature +21°C during the heating season.

The ventilation system is designed so that exhaust air is extracted through the existing ventilation shafts (kitchen and bathroom). Flow regulation is ensured with balancing valves and exhaust grilles with a flow control option. The outputs of all ventilation shafts are collected in a single system with galvanized steel ducts in the building's attic. The ducts are covered with a heat insulation layer (at least 100 mm). Additionally, it is embedded in the attic floor insulation layer.

The air supply system is arranged by flexible plastic air ducts (diameter 75 mm) separately to each living room and bedroom. The air ducts are mounted on the building's facade and enter into living rooms through the wall directly behind the heating radiators (see Fig. 1). The vertical duct parts are built into special wells, which are filled with loose thermal insulation (at least 100 mm). They go down the facade form the attic to the first floor apartments. Fig. 2 shows the air ducts coming from the facade to the attic.

Figure 1. Air ducts are mounted into the facade's insulation layer, enter the living room through the wall directly behind the heating radiators.

Figure 2. Air ducts coming from the facade into the attic (without insulation and already insulated).

The horizontal duct parts are made of flexible plastic duct *Flat 51* 51 × 138 mm. These ducts integrated into the facade insulation so that there is at least 50 mm of thermal insulation between the duct and outdoor air. The supply air stream rate is lower than 1.5 m s^{-1}. The plastic input unit is industrially manufactured with the diameter of 125 mm. The air ducts meet the increased requirements for air density class according to the standard EN 60529, the mechanical perimeter strength of more than 8 kN m^{-2}, and high hygiene requirements. The special constant flow valves installed in the distribution lines placed in the attic control the supply of airflow in each room. Each air duct (Ø75 mm) has its own flow valve.

RESULTS AND DISCUSSIONS

The aim of this study is to compare the energy consumption in the buildings before and after renovation and to compare the indoor climates of 11 Zirnu Street equipped with a natural ventilation system and 17 Zirnu Street, where a new mechanical ventilation system is installed. Monitoring data for this heating season is not yet available.

A study with the energy simulation software TRNSYS for dynamic calculations is performed. The model will be validated with actual measurement data from 17 Zirnu and 11 Zirnu.

To determine the thermal efficiency of the heat recovery unit, heat transfer rate and pressure drop, and indoor climate, the following measurements have been started:

1. Temperature of the fresh and exhaust stream at the inlet and outlet sections of the heat recovery unit.
2. Air flow rates in both circuits.
3. Temperature of the fresh air supply at the attic level and at the first floor level.
4. Pressure between inlet-inlet, outlet-outlet and inlet-outlet sections.

For the temperature and airflow rates in both circuits, the combined airflow and temperature transmitter IVL 10/N is used (see Fig. 3).

To compare indoor air quality, humidity, indoor temperature and CO_2 concentration are measured in two apartments of each building – one with a mechanical ventilation system and one without. For the measurements, the CO_2 sensors *Telaire 7001* equipped with the data loggers *Hobo* (see Fig. 4), which record data about temperature, CO_2 concentration and humidity level with a 5 min interval, are used.

Figure 3. Placement of the combined airflow and temperature transmitter.

Figure 4. CO_2 sensor *Telaire 7001* and data logger *Hobo* placed in a second floor apartment, 11 Zirnu Street.

The standard efficiency of the extracted ventilation air heat recovery will be established. Electricity consumption for whole system and for preheating will be determined.

It is calculated that after renovation, the building's energy consumption for space heating should reduce from 161 kWh $(m^2a)^{-1}$ to 64 kWh $(m^2a)^{-1}$ in 17 Zirnu Street and from 143 kWh $(m^2a)^{-1}$to 74 kWh $(m^2a)^{-1}$ in 11 Zirnu Street. Fig. 5 shows the energy consumption before renovation and the expected consumption after renovation in 17 Zirnu Street (kWh $(m^2a)^{-1}$ (i.e. energy consumption per unit of useful area per year). The biggest savings are given by the buildings' envelopes' insulation (saves 28 kWh $(m^2a)^{-1}$), and old window replacement (saves 22–23 kWh $(m^2a)^{-1}$).

Installation of the ventilation system with a heat recovery unit in 17 Zirnu Street gives additional savings of 16 kWh $(m^2a)^{-1}$). These results were obtained assuming that the heat recovery unit works with 85% efficiency; the infiltration rate is 0.2 1 h^{-1}; the air exchange rate of mechanical ventilation is 0.5 1 h^{-1} with the total building volume of 4,421 m^3.

If the building at 11 Zirnu Street would have the same ventilation system with a heat recovery unit, the energy consumption after renovation would be 57.7 kWh $(m^2a)^{-1}$), because additional energy savings for heating (16.3 kWh $(m^2a)^{-1}$) due to heat recovery would be obtained.

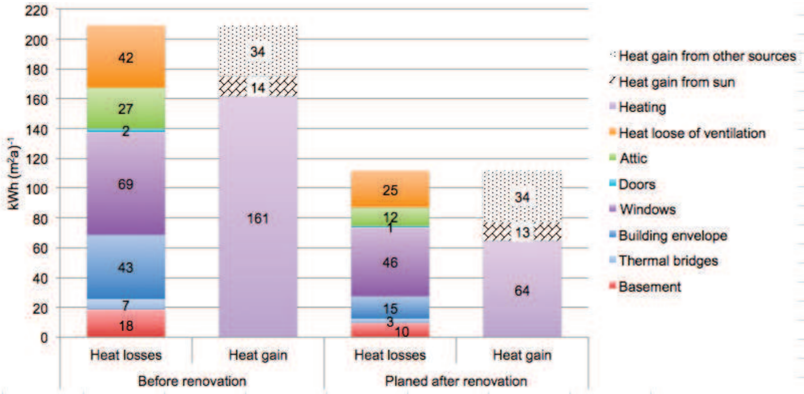

Figure 5. Calculated heat losses and heat gains at 17 Zirnu Street, Cesis, before and after renovation.

Fig. 6 shows the difference in energy consumption for heating in case of a standard renovation that fulfils the normative requirements and in the current case with a new ventilation system installed. The savings compered to the *before* situation range from 44% to 60%, respectively.

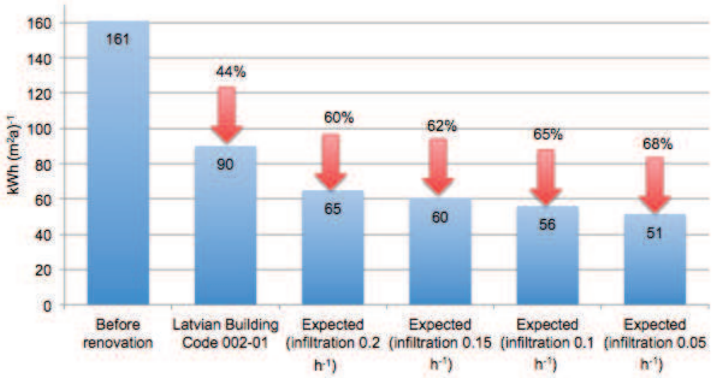

Figure 6. Energy consumption for heating in 17 Zirnu Street, Cesis.

Also Fig. 6 shows how infiltration rate can influence total heat demand. With the infiltration rate 0.05 1 h^{-1} (the same efficiency of the heat recovery unit: 85%) the energy consumption for heating goes to 51 kWh $(m^2a)^{-1}$. It shows that in order to get more from renovation, passive house standards should be strived towards and infiltration rate should be reduced.

The leakage factor of the renovated building was not measured before the beginning of the experiment.

CONCLUSIONS

Calculations of the energy consumption of buildings with and without a mechanical ventilation system were made. The results obtained show how big thermal energy savings are achieved with mechanical ventilation with a heat recovery unit – up to 16 kWh $(m^2a)^{-1}$. In addition, the impact of infiltration on the buildings' energy consumption was evaluated. It shows that in order to achieve bigger thermal energy savings, passive house standards should be used to reduce the infiltration rate as much as possible.

For now, there are two main aspects to think about – the infiltration rate and the efficiency of the heat recovery unit. The infiltration rate has a significant effect on the total energy consumption. It is essential to build highly airtight buildings and strive towards passive house standards. The efficiency of the heat recovery unit is responsible for the recovered amount of heat.

In the end of the heating season, monitoring data will be available and it will be possible to compare the calculated and expected results with the actual situation.

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