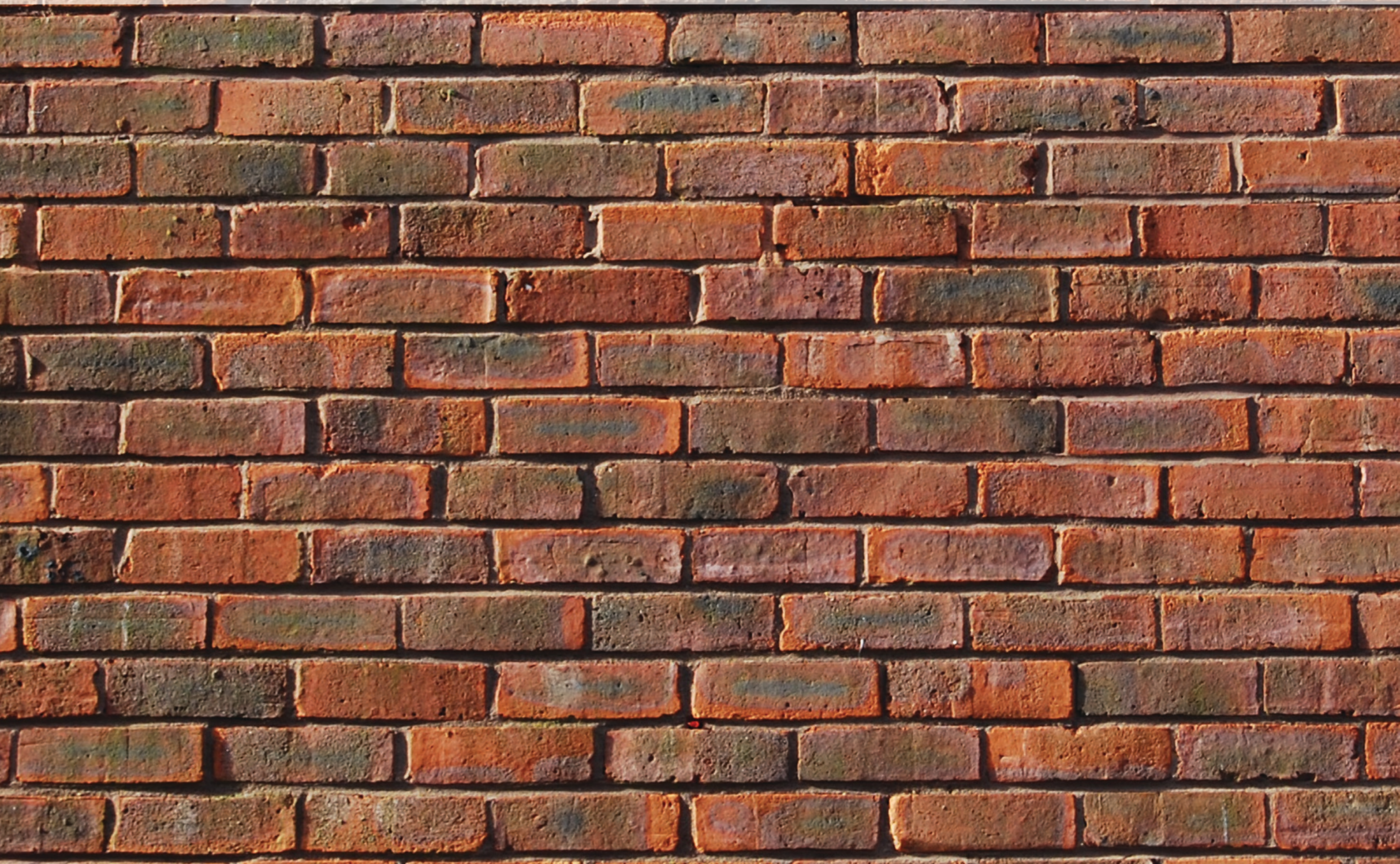
Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)

Co$_2$olBricks

WP5 Education and Economic Promotion

Ventilation system

Educational product: New lecture material for training modules dealing with knowledge and skills how to apply suitable methods of energy efficient refurbishment of historic constructions and how innovation can be combined with cultural heritage



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Ventilation system

Target group: architecture, construction, energy audit students

Educational objectives: To give general understanding of ventilation systems and possibilities to use regulated ventilation in historic buildings.
This measure can help to save up to 8% of total energy used in building

Lecture course: 2 academic hours

References:

Hollowell, Craig D. "Building ventilation and indoor air quality." (2011).

Balta, M. Tolga, Ibrahim Dincer, and Arif Hepbasli. "Performance and sustainability assessment of energy options for building HVAC applications." *Energy and Buildings* 42.8 (2010): 1320-1328.

Meiss, Alberto, and Jesus Feijo. "Effect of openings location on the ventilation efficiency in dwellings." *Informes de la Construcción* 63.522 (2011): 53-60.

Fischer Jr, John C., Michael L. Boles, and Richard K. Mitchell. "Building, ventilation system, and recovery device control." U.S. Patent No. 7,886,986. 15 Feb. 2011.

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Introduction

Various studies have shown that in the case of historic buildings, the main energy saving potential lies in the air-tightness of the building. However, reducing the fresh air inflow leads us immediately to the question of the ventilation systems and the necessity of ensuring a comfortable indoor climate for the users of a building and for the preservation of the building.

In order to ensure the above mentioned comfortable indoor climate in dwellings, the recommended air change per hour (ACH) should be 0.5 l/h. It means that all the air in the room should be completely changed in two hours. In case of buildings that were built before 1990s this requirement has been taken into account and the buildings are designed so that the necessary air flow is provided by natural ventilation. A common solution for that was to build exhaust air shafts from the sanitary rooms and fresh air was taken from kitchen, the windows and air leakages in the building envelope. This system contributes to a large portion of the annual energy loss of the building and it is no longer a viable option due to continually increasing energy prices.

Importance of fresh air and ventilation

Indoor air quality

The most common concept for an indoor air quality is used is an equivalent to the cleanliness of indoor air. There is a variety of different air pollutants with different potential effects on comfort and health that should be taken into account while designing building services systems.

Some examples of sources of indoor air pollution:

- Inside of the building:
    - People
    - Building materials
    - Technical equipment
    - Furniture
    - Microbial growth
    - Pets
    - Tobacco smoke
- Outside of the building:
    - Traffic
    - Industries
    - Plants (pollen)

During the past few decades the health considerations have become increasingly important in conjuction with comfort. Due to the growing price of energy, people have renovated many buildings, unfortunately without paying enough attention to the indoor climate. There are many factors in indoor climate that may cause health problems , e.g. noise, thermal climate, light, but poor indoor air quality is often the most critical one.

A short overview of the results of the research made in Finland to analyze estimate cost effectiveness of the indoor environment improvements is given below.

The cost effects of a deteriorated indoor environment in Finland (million €/year):

• *Allergies and illnesses due to mould (30%)*	*1,117.7*
• *Cancers caused by radon (450/a)*	*100.9*
• *Sick leaves (15%)*	*504.6*
• *Reduced work performance*	*454.1*
• *Tobacco smoke (heart and circulat.)*	*764.2*
• *Hospital infections (10 %)*	*84.1*
Total cost	***3,025.6***
Total cost per person	***approx. 580 €/year***

(Source: various researches by Olli Seppänen, 2003)

Humidity problems

In the renovated buildings, where there have not ensured normal air change in the rooms, there are often problems with too high relative humidity level in the room air. With colder outdoor conditions the humid starts to condense on the thermal bridges of the envelope of the building. Condensation is a major threat to the structure of the building, and high relative humidity in longer period will create a very favorable environment for various microbes, mold and bacteria spread.

Influence of indoor air relative humidity on indoor air quality is illustrated by the figure below.

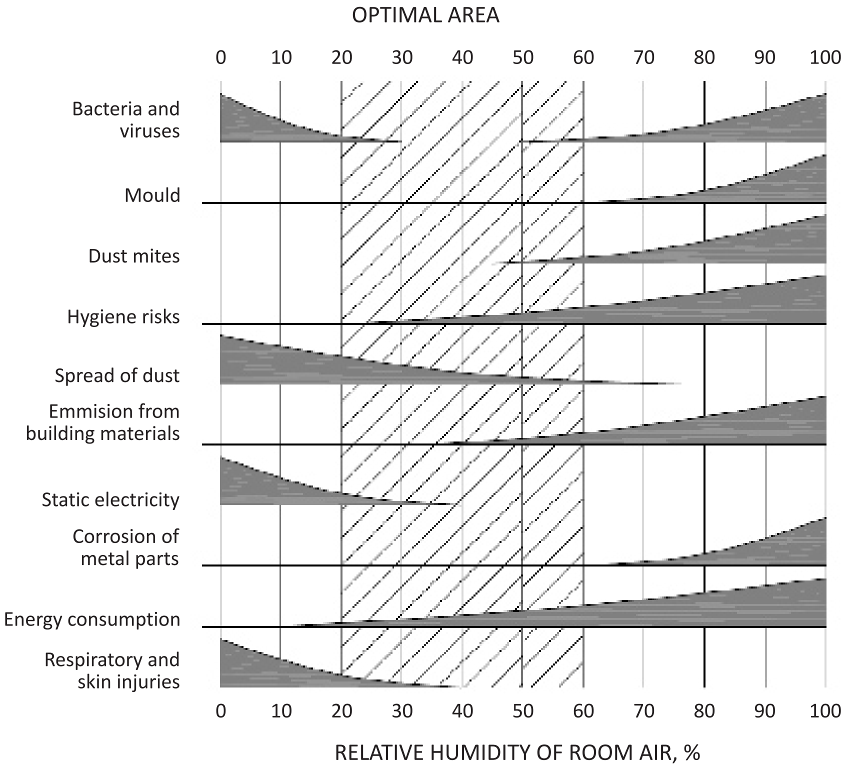

Figure 1. Relative humidity of the room air and the risk factors of consequences. The weight of the line determines the proportional risk. Reccomendation according to the EVS-EN 15251:2007 Class III (renovated buildings)

The latest results of the reasearches by WHO (World Health Organization) says that it is not possible to give exact limits to the relative humidity in the point of human health. Therefore it is agreed, that the lowest value of 20% is not dangerous to the human health and is regarded as the lowest limit to the engineers to design buildings.

For a building constructions and thermal bridges in it, the relative humidity should be as low as possible in the cold period in order to avoid the risk of condensation. However, for an old wooden furniture or floors inside the rooms, the relative humidity should not stay below 30% to 35% in longer periods.

Figure 2. Picture of consiquenses of too high relative humid (Source: http://www.kredex.ee/public/Energiatohusus/Seminaride_materjalid/Kredex_sisekliima_ja_ventilatsioon.pdf)

In conclusion to the relative humidity part it is seen, that it is not easy to set very strict limits to the indoor air relative humidity. Specially in old buildings, there are so many criteria that must be taken under consideration and therefore every building should be looked as new case.

Different types of ventilation systems

Ventilation systems can be divided in different ways, but one of the most common and user-friendly way is the following:

- Natural ventilation (without fans)
- Forced ventilation (air moved by fans)

The energy consumptions of both types of ventilation systems can be reduced by more intelligent management.

Natural ventilation

In case of natural ventilation, the air movement is caused by two factors:

- The difference between indoor and outdoor temperature;
- Wind.

The bigger the both factors are the more intensive is the air change in rooms. This means that in colder weather conditions the rooms and the building is often over-ventilated and in warmer and windless weather, there is a lack of fresh air. As both of these factors are directly dependent on the external climate, the system is considered to be a non-controllable system. Users of the building cannot change the air volume rate no more than by switching it ON or OFF; this means by opening and closing the exhaust grilles.

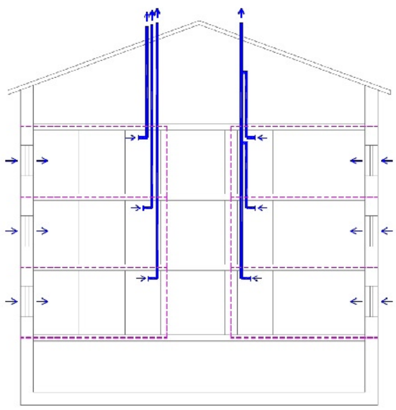

Figure 3. The principle of operation of a natural ventilation

Practice has shown that with such a solution it is not possible to ensure neither the needed air volume flow nor comfortable indoor climate in rooms. Especially critical is the situation in lower buildings (one- and two-stories houses) and at the top floors of a block of flats in warmer ambient temperatures.

Mechanical ventilation

Forced ventilation works on the principle that fresh air flow is provided by mechanical ventilators. Most common solutions are either mechanically forced exhaust or mechanically forced supply and exhaust. In the first case, the exhaust suction is from bathrooms, toilets, kitchens and the intake is from the valves in the walls of living rooms and bedrooms. Installing mechanical exhaust without supplying sufficient amount of fresh air will not provide the necessary airflow and satisfactory interior climate. In case of mechanical intake and exhaust the air is exchanged through ventilation ducts in individual rooms.

The advantage of mechanical ventilation is that the required interior climate can be achieved with changing the settings of the system no matter what the outdoor weather conditions might be.

Ventilation without heat-exchange

The most common solutions of ventilation without heat-exchange can be found on Figure 2. Central ventilation system is described on the left side of the figure and apartment based individual solution can be seen on the right.

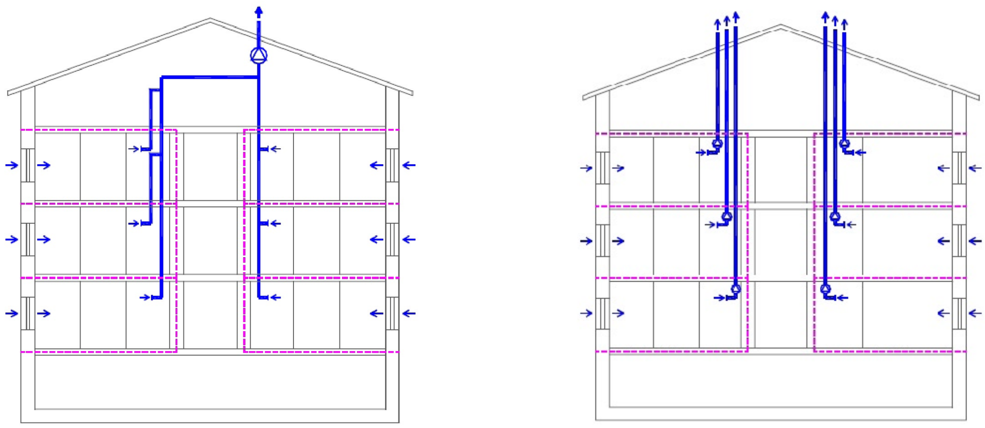

Figure 4. The principle of operation of mechanical ventilation without heat recovery

Mechanical exhaust system is easily controlled with the speed of the ventilators. Based on the system type it can be regulated individually by every flat or by the whole building.

Central systems cost approximately 10…20% less than individual systems although prices may vary great deal depending on the building. On the other hand, yearly heating cost of a building is higher because there is no opportunity to regulate the airflow of individual flats. For example, when only 2 flats out of 6 are occupied all of them are still being ventilated with the central system in the same way. If the building had individual systems, only the occupied 2 flats would be ventilated and therefore less energy would be used.

In order to regulate central ventilation system separately for each individual flat, the system must be fitted with motorized valves, extra mufflers and automated control units. In total, these extras often make the system more expensive than fitting each flat with an individual system.

While regulating ventilation systems it has to be taken into account that the heat energy lost during air exchange is in direct correlation to the ventilated air volume. Therefore, the exchange rate should be kept as low as possible while still maintaining the required interior climate. A good solution when using individual systems is to link the ventilation air rate to security system. Ventilation can be set to automatically switch on lower settings while security is enabled. A simpler and a less costly solution is controlling ventilators with timers.

Ventilation systems with heat recovery

The main working principle of ventilation with heat recovery is that the heat energy of the exhaust air is used to preheat the intake air or utilized in some other parts of the buildings heating system.

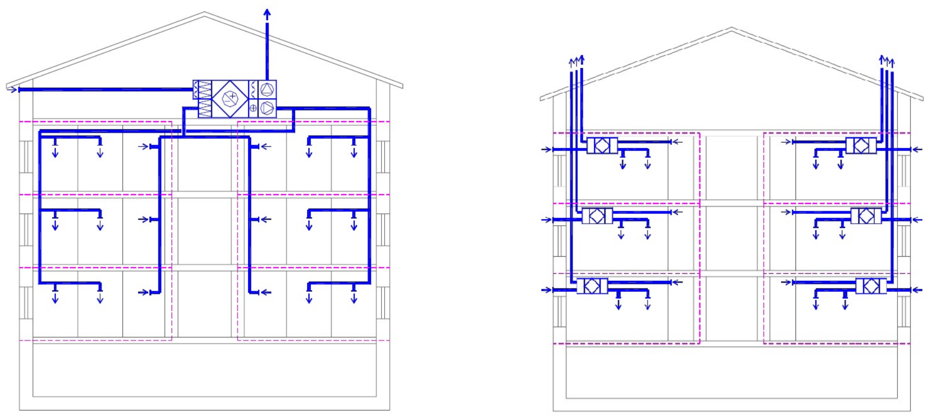

Figure 5. Mechanical ventilation with heat recovery operation principle

Central ventilation with heat recovery

When designed and adjusted correctly, central ventilation system with heat recovery offers most conveniently good indoor climate with the lowest operating costs. European Union standard (Estonian EVS-EN 15251:2007 standard) levels of noise, air quality and air transfer rate for dwellings can be achieved with ventilation systems which use mechanical intake and exhaust.

The thermal efficiency of systems with heat recovery is between 50…90% and annual efficiency between 60…95%

Thermal efficiency describes how much heat is collected from a certain volume of exhaust air. For example, if the coefficient is 80% and outside temperature is -20°C and the required indoor temperature is +20°C. 80% of the temperature difference is 32°C and therefore, fresh intake air is heated from -20°C up to +12°C from exhaust air’s heat.

The annual efficiency of heat-exchanger describes how much of the heat energy, which is needed to heat up the intake air is recovered from exhaust air.

Ventilation systems do not only use energy to heat up the intake air but also use electricity for ventilators. Depending on the type of heat recovery system and ventilators, the annual ventilator energy consumption might be even bigger than the energy amount that is needed to heat up the intake air.

It is possible to save electricity and heat energy by using automated control units and optimizing the airflow settings according to the need.

Local ventilation systems with heat recovery

Local ventilation systems with heat recovery work on the same principle as centralized system – the intake air is preheated with the energy extracted from the exhaust air. The difference is that the units are usually smaller and equipped with local intake and exhaust air distributor as seen on Figure 4.

The advantages of a local system compared to a central system:

+ No need for separate ventilation ducts; therefore, the installation is simpler;
+ Installation cost is lower in case of smaller apartments (up to 2 rooms);
+ Ventilators consume less electricity.

The disadvantages of an individual system compared to a central system:

– While working at full capacity the noise can be above the comfortable noise level;
– While not working at full capacity the heat recovery efficiency rate is significantly lower than described in product technical description sheet;
– The systems work and reliability is highly dependent on characteristics and exterior climate of a building (e.g. building height, wind);
– To maintain good indoor climate in bigger flats (3 rooms or more), it might be more expensive than centralized system.

Local ventilation systems with heat recovery are one of the best solutions for smaller flats for historic buildings and for those protected by heritage. However, before starting with this solution, suitability calculation where different variables are taken into account should be made.

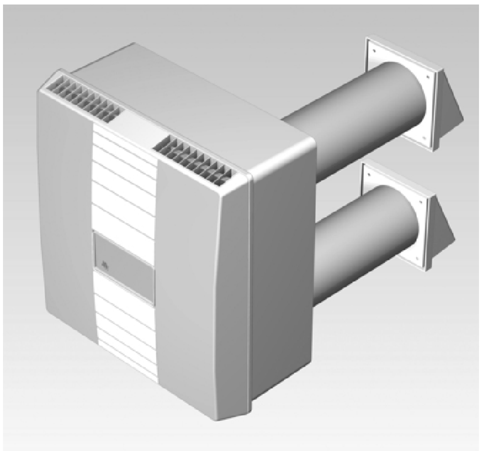

Figure 6. Local air handling units with plate type heat-recovery.
(Source: www.meltem.com)

Local and central ventilation unit with plate heat recovery work on the same principle: intake air is heated through the surface of the plate while the airflows do not mix.

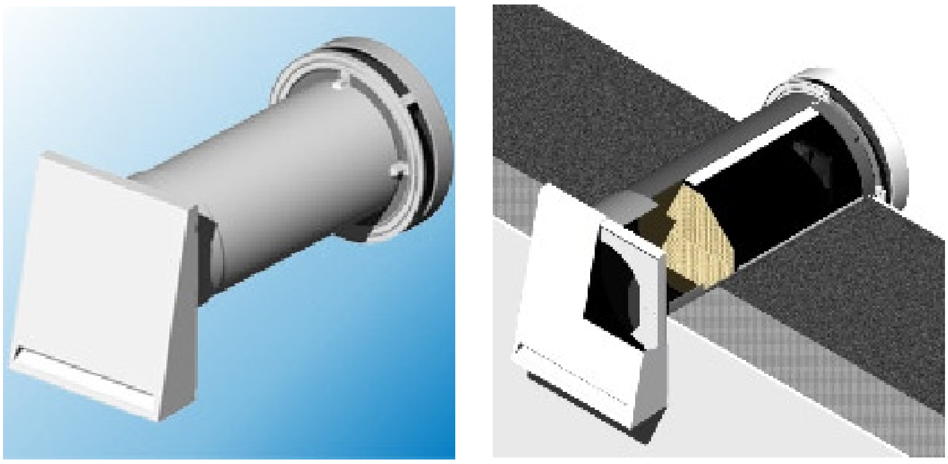

Figure 7. Local air handling units with ceramic accumulator type heat recovery.
(Source: www.intelivent.ee)

The working principle of local air-handling units with accumulator is that two ventilators are always used in parallel operation. One valve operates as an exhaust fan, extracting the air out through the ceramic accumulator, where the heat is stored, while the other valve works as a filter and an intake for fresh air. At intervals the two units change their working direction: the first unit will work now as the intake and the second as the exhaust.

While working at maximum capacity ceramic accumulators' peak efficiency of the ceramic accumulator can be up 90%. At lowers speeds the efficiency drops significantly.

Exhaust Air Heat Pump

Working principal of exhaust air heat pump is that the extracted air is cooled down to below zero temperature and the recovered heat from it is transferred via the heat pump to the water of the heating system of a building (Figure 8).

Figure 8. Working principle of exhaust air heat pump. (Source: www.nibe.com)

The working principle is the same as that of an air-to-water heat pump, the difference is the source of the heat. The air-to-water heat pump uses as its heat source outside air while exhaust air heat pump uses the heat from ventilated air of the building.

Coefficient of performance (COP) of the heat pump of the ventilation system describes the ratio between the recovered energy from ventilation and used electric energy for retrieving it. Exhaust air heat pump with a COP=4 means that for every 12 kW of energy retrieved from exhaust air, the pump itself uses 12/4=3kW of electric energy.

Advantages of ventilation with heat pump compared to centralized ventilation with heat recovery:

- + Possiblity to install into buildings where centralized system would complicated or impossible;
- + Already existing ventilation exhaust channels can be used;
- + Economically reasonable for buildings with above average heat loss and hot water usage;
- + Generally less expensive installation and maintenance.

Disadvantages of ventilation with heat pump compared to the centralized ventilation with heat recovery:

- – Increases heating load of the building due to the fact that intake air not being preheated;
- – Cold intake air might cause thermal discomfort for habitants;
- – Produces energy only when ventilation system is being used;
- – Produced heat is limited to the amount which is recoverable from exhaust air and it's compression;
- – Generally higher annual energy expenses;

Results

Energy consumption

Outdoor temperatures

All the annual energy consumption calculations have been made hourly according to the data of Estonian test reference year for energy calculations.

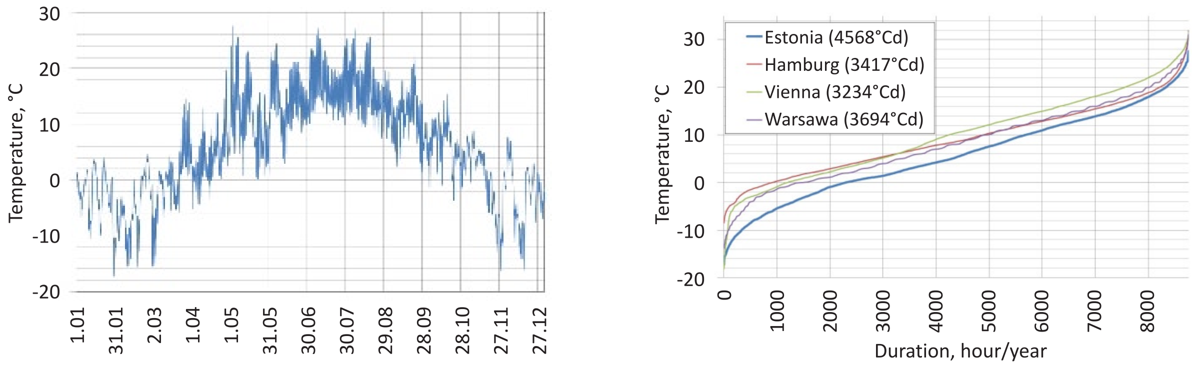

Figure 9. The outdoor temperature according to the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) IWEC Weather Files.

The airflow rate for a flat is taken according to the air change per hour (ACH) 0.5 1/h (Q=75 m^3/h; Q=21 l/s). The temperature of supply air is takent to be +18°C and the extract air temperature has been regarded the same as the indoor air temperature, +21°C.

The ventilation system was assumed to work accordingly:

- Monday to Friday 12 hours
- Saturday and Sunday 24 hours

The working time of natural ventilation system is regarded as always ON (24 hours a day and 7 days a week), because of the system airflow is not controllable.

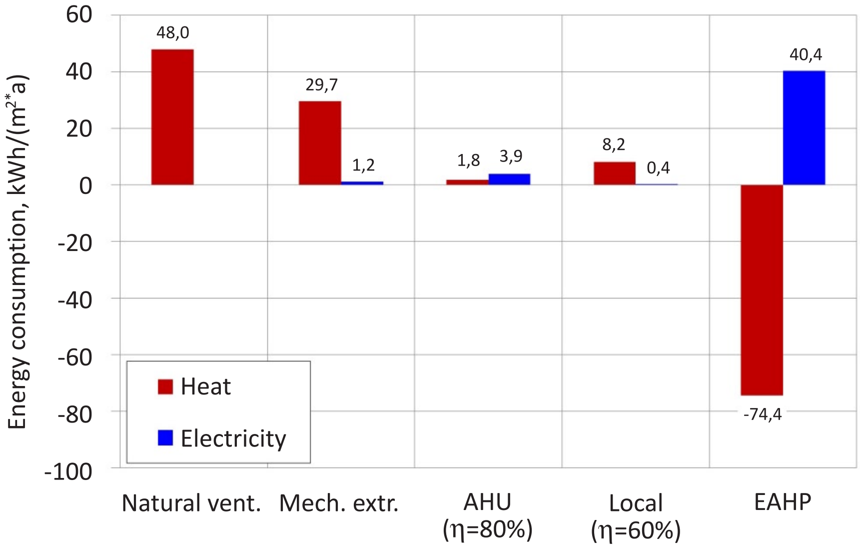

Figure 10. Estimated annual energy consumptions of different ventilation system solutions in a 60m2 flat. (Natural vent.- Natural ventilation; Mech. extr.- Mechanical extraction system; AHU (η=80%)- Central air handling unit system with heat recovery 80%; Local (η=60%)- Local decentralized system with heat recovery 60%; EAHP- Exhaust air heat pump).

Net present value calculations

Calculations for different solutions are based on established prices of Estonian building market.

This paper has analysed different ventilation systems: centralized, individual flat units, local devices. Their design and installing costs may vary greatly depending on the architecture, size, and existing technical solutions of the building. In order to be able to compare their costs, different systems are reduced to a 60m^2 3 room flat (including VAT 20%).

- Natural ventilation 0 €
- Mechanical extraction system 500 €
- Central air handling unit with heat recovery 80% 3100 €
- Local ventilation devices with heat recovery 60% 2800 €
- Exhaust air heat pump 2400 €

The extra costs that may occur from other technical systems of a building have not been taken into account in the calculation *(for example: rebuilding the heating system because of the increased heat loads, increase of electricity consumption etc).* These costs may vary for every building type and heating system too greatly to make generalisations.

For the energy prices, the current price levels were used (including VAT 20%):

- Electricity 135 €/MWh
- District heating 76 €/MWh

In the net present value calculations the following interest rates were used:

- The real interest rate 3%
- The rise of energy prices 2%

Results

All the results of economic calculations are presented in net present value *(NPV is defined as the sum of the present values of the individual cash flows of the same entity)* and include construction costs and discounted energy costs for the analysed period (5; 10; 15 and 20 years).

NB! The estimated annual energy costs of the natural ventilation system are shown on the graphs as well. However, it should be noted that this solution does not guarantee the required indoor climate. The Given energy consumption is theoretically calculated according to the Estonian TRY-mis see on? climate data. According to TRY the natural ventilation does not ensure the required air change volume for more than 3000 hours per year and in colder weather conditions (outdoor temperature below -10°C) the air change per hour is more than 1.5 times greater than required. This means that the energy saving is achieved at the expense of indoor climate.

Exhaust air heat pump (EAHP) solution is calculated for a block of flats the annual heating energy consumption for a space heating of which is 150 kWh/(m^2*a). Calculation have taken into account the extra heat energy needed for heating up the supply air from outside, the electricity used by the heat pump and the heat produced by the heat pump which can be used for heating the domestic hot water and space heating system. The seasonal performance factor (SFP) of heat pump is regarded as 4.0 and since it is economically more beneficial that the working time for a heat pump is regarded as always ON.

In the figures below, the extra heat produced by EAHP is shown as a negative value. It means that for obtaining the real costs of the system over a period, the negative value should be subtracted from the positive values.

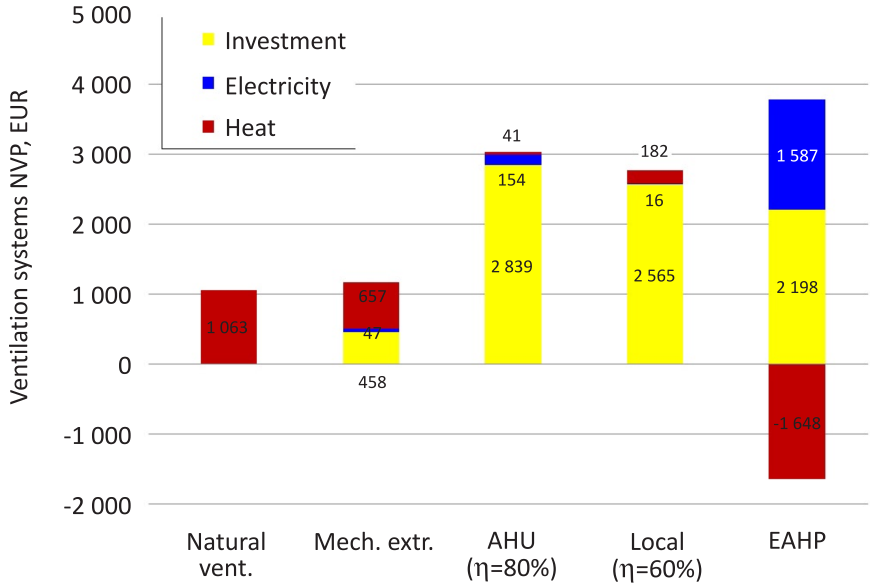

Figure 11. Estimated costs of different ventilation system solutions for a 60 m2 flat with the real interest rate of 3% and the rise of energy prices 2% over a 5-year time period (Natural vent.- Natural ventilation; Mech. extr.- Mechanical extraction system; AHU (η=80%)- Central air handling unit system with heat recovery 80%; Local (η=60%)- Local decentralized system with heat recovery 60%; EAHP- Exhaust air heat pump).

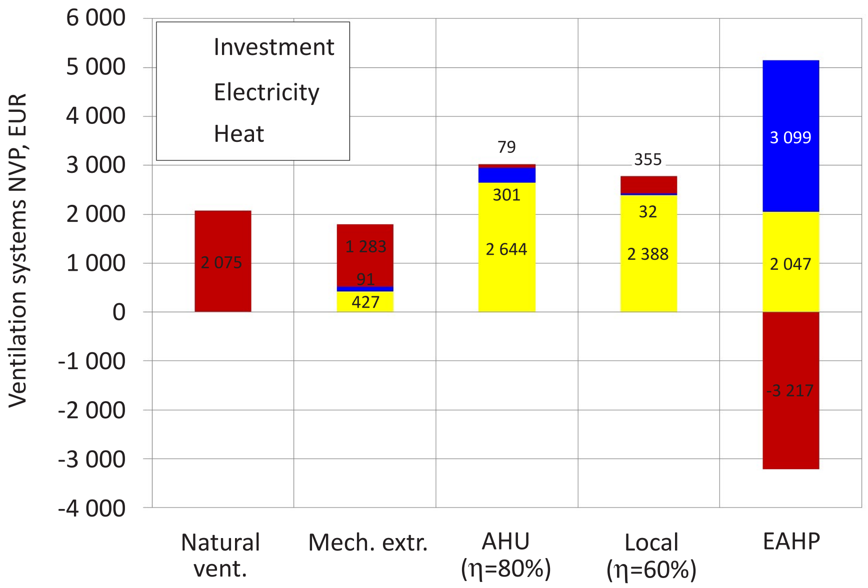

Figure 12. Estimated costs of different ventilation system solutions for a 60 m2 flat with the real interest rate of 3% and the rise of energy prices 2% over 10-year time period (Natural vent.- Natural ventilation; Mech. extr.- Mechanical extraction system; AHU (η=80%)- Central air handling unit system with heat recovery 80%; Local (η=60%)- Local decentralized system with heat recovery 60%; EAHP- Exhaust air heat pump).

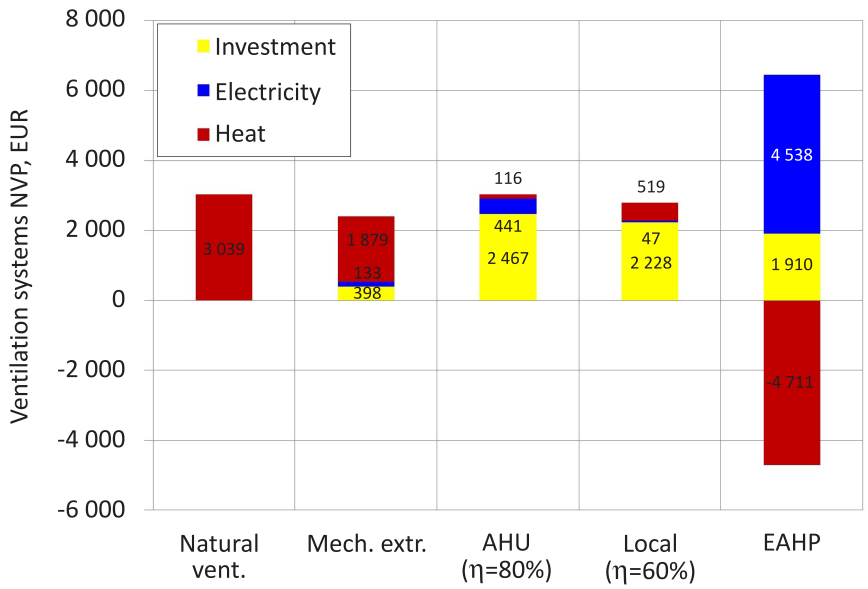

Figure 13. Estimated costs of different ventilation system solutions for a 60 m² flat with the real interest rate of 3% and the rise of energy prices 2% over 15-year time period (Natural vent.- Natural ventilation; Mech. extr.- Mechanical extraction system; AHU (η=80%)- Central air handling unit system with heat recovery 80%; Local (η=60%)- Local decentralized system with heat recovery 60%; EAHP- Exhaust air heat pump).

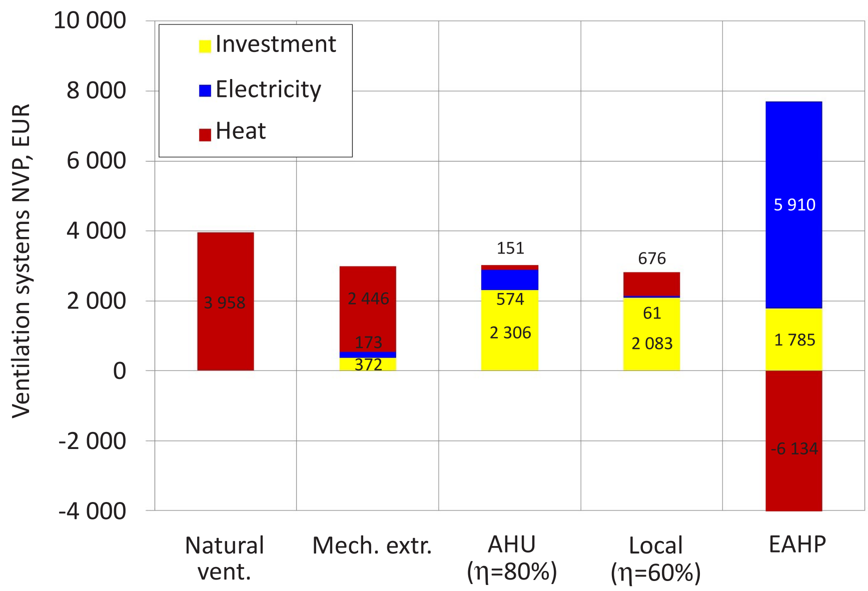

Figure 14. Estimated costs of different ventilation system solutions for a 60 m² flat with the real interest rate of 3% and the rise of energy prices 2% over 20-year time period (Natural vent.- Natural ventilation; Mech. extr.- Mechanical extraction system; AHU (η=80%)- Central air handling unit system with heat recovery 80%; Local (η=60%)- Local decentralized system with heat recovery 60%; EAHP- Exhaust air heat pump).

The results show that the annual operating costs of more energy efficient systems with heat exchangers are more than 5 times smaller than systems without the heat-exchanger. However, if the required initial investment is added to the calculations and the total costs of the systems are compared over different periods, it is seen that the investment evens out its cost after the system has been in use in more than 15 years.

When comparing the results, it should always be considered that the area of the flat observed is 60 m2 which needs relatively small air volume flow to its ensure indoor climate. Therefore, the investments made for installing the air handling unit system with a heat-exchanger does not even out quickly. Systems with greater air volume flow, for example those in bigger flats or in houses, have shorter periods for evening out the costs since the ratio between initial investment and air volume flow is decreasing.

Discussion

This study is aimed primarily to the owners of the culturally valuable old buildings and to the people who are dealing with these (architects, renovators, builders, building managers etc.), in order to explain the importance of ventilation and quality indoor climate. The most commonly used solutions are described and main advantages and disadvantages have been shown.

In the culturally valuable old brick buildings, where there are many limitations for renovation and also some measures to improve energy efficiency are forbidden, all the solutions for renovate the building must be thoroughly analyzed. Must know the goals set and should be careful with potential consequences. Different envelope constructions, different heating and ventilation system solutions and the required indoor climate are closely connected and these should be analyzed always as one big system. For the best result the owner of an estate, architect, energy auditor and engineers must collaborate from the beginning of the project. For example, solutions where the relative humidity conditions for the building envelope should be as low as possible, does not suit for the occupants nor the furniture of the room, which needs a relative humidity above 20%...25%.

The results show that the energy saving potential of ventilation systems with heat exchanger is big, up to 40 kWh/m^2 *a, but without any national subsidies it is still not economically beneficial in first 15 years period. However, taking into account that increasing the thermal resistance of the culturally valuable old buildings may be significally more expensive than in an average building, the energy saving potential from ventilation system should be considered as in top priority. Furthermore, adding the estimated cost of how much money the government spends annually to treat the people poor health, because of the not healthy indoor climate, it would be entirely reasonable for a government to support the renovation in residential buildings.