Heat Recovery Ventilation Systems and their Physical Quantification

Boris Bielek 1, Daniel Szabó 1, Josip Klem 1, Roman Grolmus 2

1 Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Department of Building Structures, Radlinského 11, 810 05 Bratislava, Slovakia
2 Grolmus a spol. s.r.o., Gorkého 226/38A, 971 01 Prievidza, Slovakia
josip.klem@stuba.sk

Abstract. The essence of ventilation is the exchange of air in the room for fresh outside air. At the same time ventilation is a factor that can significantly affect the energy efficiency of a building. Hygienic requirements for ventilation of interiors of buildings in the context of increasing the energy efficiency of buildings lead to the transformation of unregulated ventilation by infiltration to regulated ventilation systems with heat recovery. The regulated ventilation system makes it possible to optimize the ventilation intensity on the basis of a stimulus from the room user or automatically on the basis of sensors monitoring the quality of the indoor climate (temperature and relative humidity, CO2 concentration in the air, etc.). In addition, if we use a ventilation system with heat recovery from the exhaust air to preheat the fresh supply air to the room, we can achieve high energy efficiency of the building by meeting the hygienic criteria of the indoor climate. The article describes heat recovery ventilation systems and their basic conceptual solutions applied in the modern architecture. The heat exchange between the hot exhaust air and the cold supply air in the winter takes place in heat recovery ventilation units in the heat exchanger. The efficiency of heat recovery defines how much heat we can transfer from the exhaust air to the fresh air in the heat recovery exchanger. The efficiency of heat recovery defines how much heat we can transfer from the exhaust air to the fresh air in the heat recovery exchanger. The article analyses individual factors influencing the efficiency of heat recovery. Due to the fact that the manufacturers of heat recovery ventilation units declare in their brochures or websites the values of the maximum efficiencies of their products, we were interested in their real efficiencies under normal operating conditions. Therefore, we subjected to experimental research in a large climate chamber a product from the German manufacturer Lunos, namely a specific type of decentralized heat recovery unit Lunos Next E. The article describes the methodology of laboratory experiment, used experimental basis, brings and analyses measurement results and calculates real efficiency of the subject heat recovery in accordance with STN EN 13 141. In the end it compares measured values with the values from the manufacturer.

1. Introduction
The essence of ventilation is the exchange of air in the room for fresh outside air. This movement of air occurs as a result of compensating for the pressure difference, which can be caused in two ways: by the action of natural forces, when we speak of natural ventilation, or by fans, when it is forced ventilation. The goal of ventilation is to ensure the optimal quality of the environment, i.e., meet hygienic and thermal requirements guaranteeing user comfort. Emphasis is placed on ventilation of all areas with minimal energy consumption and air exchange intensity. Insufficient ventilation can be the...
cause of various skin diseases, respiratory diseases, allergies, oncological diseases and others. From a quantitative point of view, concentrations of pollutants in the air are expressed in units of mass (mg/m³), volume (vol.%, Ppm = parts per million; ppm = 1 cm³/m³), number of particles per unit volume (dust). Insufficient ventilation increases the relative humidity, CO2 concentration, the occurrence of allergens, odor and the concentration of pollutants. In order to meet the increasingly stringent standard requirements for energy performance and thus reduce the operating costs of buildings, it is necessary to use energy-saving elements of technical equipment and eliminate heat losses by building envelope structures. The largest losses are caused by heat transfer and unregulated ventilation in the form of air infiltration through the building envelope. Their elimination can be achieved by increasing the thermal quantification of the envelope of building and increasing its airtightness. Air permeability as a measure of the quality of the building envelope can be quantified using measuring devices using the Blower-Door test method. Possible defects can be detected using detection tools, then a suitable way to eliminate defects should be chosen and thus prevent unwanted unregulated infiltration of air into the interior.

On the other hand, that is opposite of the hygienic requirements for the required air exchange in the room, which is an essential reason for the transformation of the unregulated method of ventilation by air infiltration into regulate ventilation systems.

With regulated ventilation system it is possible to regulate the air supply and exhaust mechanically according to user desires. On the other hand, the entire ventilation system can be regulated automatically by sensors of temperature, humidity, CO2, chemical properties of the air or detectors of the presence and movement of persons. This control system is more effective in achieving a balance between hygiene requirements and the energy performance of buildings. Simply told, by automatically regulated system, it is ventilated to achieve the minimum requirements. By properly designing the regulated ventilation system, we can ensure the hygienically required intensity of air exchange and at the same time prevent excessive ventilation, which would lead to unnecessary heat loss. In an effort to eliminate heat loss from ventilation, ventilation systems with heat recovery are becoming more popular. With the forced ventilation, the heat from interior air is led to exterior without further use. This heat is possible to recover from interior air by means of heat recovery systems. This heat is transferred to the fresh supply air, thus reducing heat loss through ventilation, which is essential from an economic point of view, as it makes ventilation significantly more economical.

2. Conceptual solutions of recovery ventilation systems

There are 3 basic conceptual solutions of heat recovery ventilation systems applied in the modern architecture:

1. The simplest systems are small local heat recovery ventilation units situated on the perimeter cladding in individual rooms of the building. Through these units the supply of fresh and at the same time exhaust of used air is realized. The unit contains of an exchanger, which takes heat from the used air exhaust from the room and transfers it to the fresh supplied air – figure 1.

2. The second system is decentralized equal pressure heat recovery ventilation of the housing unit. A "small" ventilation unit is used for ventilation, which is equipped with air filtration, fans and a heat recovery exchanger. Air extraction can be realized by a common pipe or separately from the facade of each housing unit. By common pipe, air extraction can be realized through the facade or above the roof of the building – figure 2. The disadvantages of the decentralized system are lower fan efficiency, increased space requirements for the location of the air handling unit and air ducts inside the living space and the noise level of the ventilation unit located directly in the living space. The advantage is to ensure permanent indoor air quality with minimal consumption of thermal energy for heating the supply air. The user has absolute control over the ventilation system, including costs associated with the operation and maintenance of equipment.
3. The third system is centralized equal pressure heat recovery ventilation, where the core of the system is a central air handling unit, which ensures the transport of outside and degraded air, including air treatment (filtration and preheating in a heat exchanger) – figure 3. A minimum distance must be maintained between the position of the air intake and exhaust. The air supply and exhaust is realized by a pair of air ducts, through which the air is distributed to individual housing units and from where the air is distributed to the appropriate rooms. Distribution elements with a sufficient current range serve to disperse the supply air in the living rooms so that the room is evenly ventilated. If equal pressure ventilation, realized by a central ventilation unit for several flats, is forced, the device must automatically balance the pressure conditions in the supply and exhaust air ducts with the intervention of individual users. Variable speed fans are used for this. The disadvantage of the central equal pressure ventilation system is also the increased space requirements for the location of the air handling unit and air ducts. Fans must be equipped with mufflers so as not to disturb the occupants of
housing units or to spread the noise to the outside environment. Unwanted noise propagation can also occur between residential units. The air ducts can be equipped with pipe mufflers, or the end elements are supplied via flexible hoses with noise attenuation. The costs of operating the central facility are calculated between the individual housing units on a flat-rate basis, regardless of the use of the ventilation system.

3. Efficiency of heat recovery units
The heat exchange between the hot exhaust and the cold supply air takes place in heat recovery ventilation units in the heat exchanger. The efficiency of heat recovery defines how much heat we can transfer from the exhaust air to the fresh air in the heat exchanger.

Heat transfer is a complex process that affects many parameters. In general, the amount of heat that the exhaust air transfers to the supply air depends on the size of the area that separates the two air streams and the speed at which they flow through the exchanger. This speed must not be too high so that the air in the heat exchanger has enough time to transfer energy, but also not too low, because the heat transfer coefficient directly depends on it. This means that the efficiency of the heat exchanger can be significantly affected by its oversizing and operation. Simply put, if a large heat exchanger is installed for a small air flow, the heat recovery efficiency increases and vice versa.

The ratio of the amount of supplied and discharged air also has an effect on the efficiency - if we extract more air than we supply, the efficiency of heat recovery increases. It is also affected by the humidity of the exhaust air - the higher it is, the more likely it is that the water vapor contained in it will condense. When moisture from the exhaust air condenses, the bound evaporating heat (latent heat) is also transferred to the supply air and the heat transfer coefficient on the exchanger wall also increases. If all the favourable factors are combined, the so-called the maximum efficiency of the heat exchanger that manufacturers sometimes state in product brochures can be achieved. However, such efficiency is achieved only under extremely favourable conditions (high humidity of the exhaust air, more exhaust air than supply air, low air flow through the exchanger), and not during normal operation.

There are several types of heat recovery exchangers with different efficiencies, the basic ones include cross and countercurrent plate heat exchangers, rotary heat exchangers and enthalpy heat exchangers.

4. Experimental research of physical parameters of selected heat recovery units
Due to the fact that the manufacturers of heat recovery ventilation units declare in their brochures or websites the values of the maximum efficiencies of their products, we were interested in their real efficiencies under normal operating conditions. Therefore, we subjected to experimental research a product from the German manufacturer Lunos, namely type of Lunos Ne×t E.

Lunos Ne×t E is a decentralized facade heat recovery ventilation unit that combines the advantages of decentralized and centralized ventilation – figure 4. The heat exchange takes place in an enthalpy cross heat exchanger made of aluminium. The unit is controlled by humidity and temperature sensors as standard. Using filters min. M5 (possibility to choose filters up to M9) the maximum air filtration and thus quality hygienic conditions are achieved.

The parameters of the Lunos Ne×t E heat recovery ventilation unit specified by the manufacturer:
- air flow 15 – 110 m³/h
- voltage 230 V / 50 Hz
- input power 22 W
- degree of thermal efficiency 73 %
- max. degree of thermal efficiency 83 %
- sound power level 40 dB(A).
Figure 4. Lunos Ne\textsuperscript{xt} E heat recovery ventilation unit and its basic components [10]

Experimental research was carried out on the large climate chamber of the Laboratory of Physics of Buildings and Structures of the Faculty of Civil Engineering STU in Bratislava – figure 5. It consists of a fixed climatic chamber with programming of modelled conditions of outdoor climate (cold chamber), of mobile climatic chamber with programming of modelled conditions of indoor climate (warm chamber), of mobile intermediate chamber without technology, expanding interior space of climatic chambers, smaller mobile climate chamber called HOT-BOX, for accurate measurement of basic thermal characteristics of building envelope structures with programming of modelled indoor climate conditions. The device works autonomously, according to the program stored in the memory of the microcomputer and under the simulation of dynamic conditions of the outdoor climate. The device is used to determine the thermal properties of building structures in the range of -35 to +60 °C. It contains technological circuits of heat, cold, air humidity, simulation of solar radiation, pressure and speed of air flow, control and regulation part, measurement and recording of all regulated and sensed quantities.

For specific measurements of physical parameters of heat recovery ventilation units, we used the chamber climate set according to figure 6. We inserted a high-efficiency thermal insulator made of extruded polystyrene (XPS) with thickness of 80 mm into the opening of the masking panel separating the cold and hot chamber spaces. We installed a heat recovery ventilation unit on the inside of the thermal insulator (from the side of the hot chamber) – figure 7. We connected the pipes for the supply of fresh outdoor air and the exhaust of used indoor air through a high-efficiency thermal insulator to the cold chamber, where we installed devices for measuring the air flow on them – figure 8.
Figure 5. A view of the large climate chamber for experimental research of synergistic phenomena of heat transfer, water vapor diffusion and air filtration.

Figure 6. Large climate chamber assembly for experimental research of a façade heat recovery unit, consisting of a cold chamber (A), a warm chamber (B), between which there is a masking panel of known physical parameters with a specific hole into which the tested element is fitted.

Figure 7. View of the warm chamber with the installed heat recovery unit.

Figure 8. View of the cold chamber with installed devices for measuring of the air flow through the heat recovery unit at the inlet and outlet of the heat recovery unit.

Cold chamber specification:
- cold and heat circuit: -35 °C to +60 °C
- overpressure and underpressure circuit: -1500 Pa to +1500 Pa
- humidity circuit: 20 % to 90 % r.h.
- air speed circuit: 0.5 m/s to 10 m/s
- solar radiation circuit: 100 W/m² to 1000 W/m²

Hot chamber specification:
- cold and heat circuit: -35 °C to +60 °C
- overpressure and underpressure circuit: -1500 Pa to +1500 Pa
- humidity circuit: 20% to 90% r.h.
- air speed circuit: 0.5 m/s to 10 m/s

For the measurements in question, we maintained a constant temperature $\theta_{ui} = +20$ °C in the warm chamber and in the cold chamber we changed the temperature in the range $\theta_{ae} = -10$ °C, -5 °C, 0 °C, +5 °C, +10 °C, +25 °C and +30 °C. At each set outdoor climate temperature in the cold chamber, we changed the levels of air flow in the analysed heat recovery unit from the minimum flow to the maximum flow. There were 8 different levels of the average airflows measured during the experiment – table 1.

### Table 1. Average airflow (m³/h) for different levels of airflow.

| Airflow level | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---------------|---|---|---|---|---|---|---|---|
| Average airflow (m³/h) | 12 | 24 | 35 | 46 | 57 | 63 | 80 | 91 |

At each setting of temperatures in the cold chamber and flow on the analysed heat recovery unit, we recorded the temperature and relative humidity in the cold and warm chamber, temperature at the air inlet to the heat recovery unit from the interior, temperature at the air outlet from the heat recovery unit to the interior, air inlet temperature to the heat recovery unit from the exterior, temperature at the air outlet from the heat recovery unit to the exterior – figure 9, air flow on the inlet pipe to the heat recovery unit and air flow on the outlet pipe from the heat recovery unit (in the cold chamber) – figure 8.

![Figure 9](image_url)

**Figure 9.** A view of the installed Pt 100 temperature sensors in the individual zones of the heat recovery ventilation unit

### 5. Results of experimental measurements of the Lunox Neo™t E heat recovery ventilation unit

The results of experimental measurements of the Lunos Neo™t E heat recovery ventilation unit were processed in tabular and graphical form. The results clearly showed a decrease in the efficiency of heat recovery with increasing of the air flow through the heat recovery unit – figure 10., figure 11.
Figure 10. Dependence of the temperature of fresh air leaving the heat recovery unit into the interior (Int-out) and the temperature of exhaust air leaving the heat recovery unit into the exterior (Ext-out) from the fan power level for outdoor air temperature of $\theta_{ae} = -5^\circ C$ and indoor air temperature $\theta_{ai} = +20^\circ C$.

Figure 11. Dependence of the outlet air temperature from the heat recovery unit to the interior on the outdoor climate temperature for different levels of air flow.
To quantify the thermal efficiency of the ventilation unit, the equations were used in accordance with STN EN 13 141:

\[
\eta_{\theta,\text{su}} = \frac{\theta_{22} - \theta_{21}}{\theta_{11} - \theta_{21}} \frac{q_{m22}}{q_{m11}} \quad \text{(mandatory measurement)} \\
\eta_{\theta,\text{ex}} = \frac{\theta_{11} - \theta_{12}}{\theta_{11} - \theta_{21}} \frac{q_{m12}}{q_{m21}} \quad \text{(optional measurement)}
\]

where:
- \(\eta_{\theta,\text{su}}\) – temperature ratio of the unit on supply air side (-)
- \(\eta_{\theta,\text{ex}}\) – temperature ratio of the unit on exhaust side (-)
- \(\theta_{11}\) – air temperature for extract air (°C)
- \(\theta_{12}\) – air temperature for exhaust air (°C)
- \(\theta_{21}\) – air temperature for outdoor air (°C)
- \(\theta_{22}\) – air temperature for supply air (°C)
- \(q_{m11}\) – mass extract air flow rate (kg/s)
- \(q_{m12}\) – mass exhaust air flow rate (kg/s)
- \(q_{m21}\) – mass outdoor air flow rate (kg/s)
- \(q_{m22}\) – mass supply air flow rate (kg/s)

according to the figure 12.

**Figure 12.** Scheme of air inlets and outlets of the heat recovery ventilation unit for quantification of its temperature ratio to STN EN 13 141

**Figure 13.** Dependence of the thermal efficiency to the outside temperature for different levels of air flow according to STN EN 13 141
Results of calculation showed that thermal efficiency is dependent on a level of airflow and on an outdoor temperature – figure 13. With raising the airflow, thermal efficiency decreases because the higher the airflow, there is less time for exhaust air for transferring heat to the fresh air in the heat exchanger. Calculation showed that thermal efficiency was between 0.88 (for level 1 of airflow and temperature of -5 °C and +5 °C) and 0.54 (for level 8 of airflow and temperature of +25 °C). The results of the measurements showed us that the measured air volume flows through the heat recovery unit are lower values (12 to 91 m³/h) than declared by the manufacturer (15 to 110 m³/h). Then, logically and from the measurements, the calculated maximum degree of thermal efficiency in the value (0.88) is higher than declared by the manufacturer (0.83). Average thermal efficiency in the experimental research was 0.70-0.75 which corresponds with degree of thermal efficiency given by manufacturer (0.73) of Lunox Ne×t E heat recovery unit.

6. Conclusions
The trend of construction of low-energy buildings and stricter standard regulations for thermal protection of buildings lead to regulated ventilation systems with the application of heat recovery from exhaust air. This significantly reduces the amount of heat needed to heat the building. This development trend in ventilation systems is fully in line with the structure of the project strategy for the creation of a green or sustainable building.

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