Energy saving potential of ventilation systems with exhaust air heat recovery

J Zemitis¹ and A Borodinecs¹

¹ Riga Technical University; Heat, Gas and Water technology institute; Riga, Latvia, Kipsalas street 6A

E-mail: Jurgis.Zemitis@rtu.lv

Abstract. The paper presents the results of data gathering regarding the heat recovery efficiencies of different heat recovery types at various air flows supplied by some of the most common manufacturers. The study showed that the average heat recovery efficiency of modern, commonly used rotary heat exchangers is around 83% while for counter-flow exchangers around 86%. Also, in the paper, the simulation results of heat energy consumption and recovered heat potential for the single-family house are presented. The simulations are performed in IDA-ICE software and show that for the specific building it is possible to reduce the heating energy up to 84% if ventilation with heat recovery is used. The results also showed that in case the internal heat loads decrease, then it slightly affects the heat recovery potential. In the case of no internal gains, this value decreases by 4%.

1. Introduction

Modern, newly built buildings, as well as renovated ones, are quite often equipped with some sort of mechanical ventilation system, whether it would be hybrid type, full supply/exhaust system or local, personalized ventilation system [1],[2]. This is done to increase indoor air quality (IAQ) and, at the same time, to maximally reduce the heat losses that occur through the natural ventilation system. In existing researches [3] it is stated that ventilation heat recovery systems can give substantial final energy reduction, but the primary energy benefit depends strongly on the type of heat supply system. However, for renovated buildings or some lower priced newly built buildings, it could either not be possible or feasible to install such and simpler solutions could be chosen. This leads to the necessity to carefully choose the appropriate ventilation system type to maximize energy savings while providing good indoor air quality.

The adapted European norms require that all new buildings starting from the year 2021 must be meet the requirements to be considered nearly zero energy buildings (nZEB). The definition of nZEB as stated in Latvian Regulations for Energy Certification of Buildings Nr. 383 (Ministru kabineta noteikumi Nr.383 “Noteikumi par ēku energosertifikāciju”) [4], regulates that the building can be classified as an almost zero energy building if it meets all the following requirements: the energy performance of the building for heating corresponds to Class A (residential buildings < 40 kWh/m²/year; non-residential < 45 kWh/m²/year), at the same time, providing indoor microclimate in accordance with the construction, hygiene, and labor protection requirements; total primary energy consumption for heating, hot water supply, mechanical ventilation, cooling, and lighting is not more than 95 kWh/m²/year; high-efficiency systems are used in the building. These systems must include heat recovery from ventilation with...
efficiency at least 75%; some usage of renewable energy sources; no installation of low-efficiency fossil fuel heating equipment in the building.

One of the most important engineering systems to achieve before mentioned parameters is to recover the heat from ventilation systems. As of now the combination of infiltration and ventilation is responsible for approximately 50% of the total heat losses in well-insulated buildings for a moderate Europe climate [5]. To reduce this, mechanical ventilation with heat recovery is used. Such systems can also help to significantly save primary energy, at the same time ensuring good indoor air quality while the airtightness of new and renovated buildings is increasing [3],[6],[7]. The ventilation systems have always been present in the buildings, but the exact solutions have changed during the years. The ventilation systems have evolved starting from simple natural ventilation with supply through construction cracks or windows to fully mechanical ducted supply/exhaust ventilation system with various in-between solutions. For example, integration of ventilation system in ventilated facades show promising results [8]. This makes the choice of the optimal ventilation solution difficult in each specific situation as each type ensures different comfort and control level but also varies in installation and running costs [9]. To select the optimal solution projected payback period for investments in energy saving must be calculated, taking into account the size of the investment, the estimated or actual value of the achieved energy saving effect, the dynamics of energy carriers tariff growth, the discounting of future cash flows, and also a value and a period of loan repayment [10].

Several different heat recovery types can be applied to ventilation systems [11], but especially in cases of nearly zero-energy buildings it is vitally important to take into consideration that the exhaust temperature after heat exchanger for fully mechanical supply/exhaust ventilation systems must be limited to 0° to +5°C, depending on the heat recovery type, as for such buildings more often the aim is to have as high heat recovery efficiency as possible [7]. In general, there are 3 types of ventilation heat recovery systems – rotary, plate heat exchangers (can be divided in cross-flow or counterflow) and run-around coils [12]. The heat recovery units can also be divided whether they are recuperative or regenerative. Recuperative heat exchanger means that the heat exchanger is intended to transfer thermal energy from one air stream to another without moving parts. Examples of these include a plate or tubular heat exchanger with the parallel flow, cross flow or counter flow, or a combination of these, or a plate or tubular heat exchanger with vapor diffusion. Example of the regenerative heat exchanger is a rotary heat exchanger which consist of parts like rotating wheel, a drive mechanism, a casing or frame, and seals to reduce bypassing and leakage of air from one stream or another. Such heat exchangers, if made from a special material which allows latent heat transfer, have varying degrees of moisture recovery capability depending on the material used [13]. For example, some manufacturers have the heat exchanger made with aluminum core with a silica gel-based coating. If such technology is applied then it can increase the IAQ as during the winter it is vitally important to recover as much moisture as possible, especially in the cold climatic conditions of Latvia. The existing studies have proven the benefit of such solutions [14].

Nowadays one of the most used ventilation heat recovery types is rotary. It can be applied both in domestic and commercial air handling units as it can be in various sizes. For large air volumes, a rotary heat exchanger can consist of multiple smaller units, therefore, saving space. Other types of heat recovery who have the risk of freezing consume extra energy for preheating, defrosting or reduce the supply air volume, therefore, compromising the IAQ. At the same time, one of the disadvantages of rotary heat exchangers are the potential of air cross-contamination from exhaust and supply, however, this can be reduced if special purging section is applied. On average the air overflow is in range of 0.04% to 5%. Estimated efficiency can be up to 85%.

Some years ago, the cross-flow plate-type heat exchanger was the most popular type of energy recuperation because of its relatively low cost and that it can be installed in a simple single-component ventilation system. It can be also be used in both domestic and commercial ventilation systems. Cross-flow heat exchangers do not have any modulation possibility, therefore, a risk of overheating or introducing extra heat in cooling period exists if no bypass is installed. In general, this type of recuperator has very high efficiency for extract and supply air separation - up to 99.9%, therefore it can
serve bathrooms and office rooms in one system. As the heat recovery efficiency of such units is only up to 70%, they have lost their market share as they do not comply with the eco-design regulations.

Counter-flow plate type heat exchangers have the highest maximum energy efficiency. They can be installed in both domestic and commercial ventilation systems. The efficiency of such type of heat recovery units can reach up to 95-98% at outside air temperatures around -5° to 0°C. However, a drawback of such devices is their need for preheating and defrosting. At lower outside temperatures the heat exchanger starts to freeze up and to defrost it the fresh air supply is closing and blowing warm air through the heat exchanger in the recirculation mode, at this point the units become louder and no or reduced air exchange is ensured. To avoid this a preheating of the outdoor air to -5° / 0°C must be provided.

In addition to these, it is possible and, in many cases, more appropriate to use smaller decentralized, room-based ventilation systems as they give the possibility to install ventilation system with heat recovery in confined spaces. However, some additional parameters and climatic data must be accounted for. A study analyzing indoor relative humidity in apartments with room-based ventilation system with rotary heat exchanger indicated that it is suitable for single-room ventilation of dry rooms, such as living rooms and bedrooms, while excessive moisture from kitchens and bathrooms provided a mold risk [15]. Other publications indicate that a specific type of decentralized ventilation system with two heat exchangers, which are hydronically connected in parallel, is an appropriate solution for use in hot and humid climates because more cooling and dehumidification capacity is available [16].

A study [17] suggests that in renovated apartment buildings with natural passive stack ventilation, the indoor air quality is quite bad and has high CO2 concentration and relative humidity level. Similar data on IAQ problems in multi-apartment buildings shows research [18] done in Estonia. Some authors [19] have already performed analysis on how ventilation rates vary depending on the chosen system. Others [20] have analyzed the system influence on IAQ. Another aspect to take into consideration is the necessity to ensure the necessary ventilation or VOC control. The existing standards regarding ventilation volume usually do not account for this and that can lead to bad and even harmful IAQ.

The ventilation system heat recovery yearly efficiency is dependent on the specific project and the internal heat gains as well as designed air flows. To study how these parameters affect the energy amount, which is recovered, dynamic simulations must be performed, and the obtained results analyzed.

2. Methods

The study in this paper is divided into two subtasks – data gathering of actual various ventilation system type heat recovery efficiency and dynamic energy consumption simulations of the specific building to analyze the energy saving potential and influence on comfort level.

At first the heat recovery efficiency of existing, in the market available, AHUs with various heat recovery types and air volumes was compared. This was done to gather data about the average heat recovery efficiency to correctly assume what level of heat recovery can be taken into dynamic simulations. In the last few years, more attention has been paid to energy efficiency including the minimal allowed heat recovery efficiency by AHUs. The Commission Regulation (EU) No 1049/2001 Requirement 1253/2014 implements eco-design requirements for ventilation equipment. The eco-design is a requirement that does not permit the design and installation of equipment with lower parameters, which is signed in this regulation. According to these requirements, the minimal heat recovery efficiency starting from the year 2018 is 73% for heat recovery systems without indirect medium while for run-around type systems the lower limit is 68%. This means that it is necessary to check the actual heat recovery efficiency to ensure that the building can be considered an nZEB.

To study how different technical solutions can influence the annual energy consumption for the whole building, various ventilation strategies in accordance with other parameters were tested with dynamic simulation software. The used software for the simulations was IDE-ICE which is widely used by professionals and researchers as the software enables is based on dynamic multi-zone simulations of thermal indoor climate as well as the energy consumption of the entire building. The main advantage of the software package is the possibility to obtain a detailed report for each of the building zones as well
as for the whole building. The results include heat and airflows, maintained temperatures, sources of heat losses and energy costs to maintain a comfortable temperature.

The analyzed building is a two-story-high private residential building with a total heated area of 466.5 m². Both stories have similar planning and area. The ceiling height for premises located on the 1st floor is 2.85 m, while for the 2nd floor the height differs from 2.4 to 3.0 m, as the roof is slightly sloped. For the purpose of analysis, it is assumed that the building is located in Latvia and weather data of the city of Kolka is used. The U-values of the external envelope elements are as follows: External wall - 0.17 W/(m²·K); Windows – 0.82 W/(m²·K) and g-value of 0.5; Floor on slab - 0.12 W/(m²·K); Roof - 0.11 W/(m²·K). All of these correspond to the required values of the Latvian building code. The temperature setpoint for the heating season was set to be +21°C, while for cooling season to be at +25°C.

Figure 1. Floor plans of the analyzed residential building.

For the first simulation scenario, it was assumed that the building is equipped with a constant air volume ventilation system which ensures close to 0.5 air exchange rate for the whole building or in total 640 m³/h. The assumed heat recovery efficiency of AHU is set at 85%, which represents close to the average value according to the previously performed study (Table 1). Also, the internal heat gains from people, lighting, and equipment were simulated. For each of the rooms, a specific occupancy profile was created. For all the living rooms it was assumed that the persons will be present at home from 17:00 in the evening until 8:00 in the next day at weekdays and all the time on holidays. For the bedrooms, the occupancy schedule was set to be occupied from 22:00 in the evening to 6:00. As the building is relatively large the maximal number of occupants reach 16 persons (Figure 2). Although this would most likely not be realistic, such value is left as 30 m² per person is still quite representative.

Figure 2. Weekly overall occupancy schedule for simulated building.

The schedule of equipment used is also adjusted according to occupancy. It is foreseen that equipment is used from 6:00 to 8:00 and from 17:00 to 23:00 on weekdays, while on Saturdays and Sundays it is used all the time. The lighting schedule is a bit more complex and is dependent on the time of the year. For the period from 1st September to 30th April the light is on from 6:00 to 8:00 and from 17:00 to 23:00, while for the rest of the year the light is switched on later – at 20:00.
3. Results and discussion

3.1. Heat recovery efficiency of different heat recovery types
To check how the eco-design regulation has affected the improvement of heat recovery units, data of typically used ventilation units with specified air volumes were gathered. The analyzed manufacturers include Komfovent, Systemair, Flaktwood and IV Produkt. For each of them, a unit ensuring 400, 700, 1000 and 5000 m$^3$/h has been looked at and the specified heat recovery value noted. The parameters to perform the energy efficiency calculations at winter regime for all of the devices were: outdoor temperature -21°C and RH 80%, while indoor temperature +20°C and RH 40%. This represents the data for a cold region like Latvia. The results are shown in Table 1 and Table 2.

Table 1. Comparison of heat recovery temperature efficiency for different AHU models with a rotary heat exchanger at various air flow volumes.

| Manufacturer | Model name | 400 m$^3$/h | Model name | 700 m$^3$/h |
|--------------|------------|-------------|------------|-------------|
| Komfovent    | DOMEKT-R-400-H-R1-M5/M5-C6-L/A | 81 | DOMEKT-R-700-V-R1-M5/M5-C6-L/A | 81 |
| Systemair    | SAVE VTR 500 L | 84 | SAVE VTR 700 L | 83 |
| Flaktwoods   | eCO Top 03 | 88.8 | eQ Prime 005 | 91.5 |
| IV Produkt   | ACER-04-AA-N1-01 | 85.3 | ACER-06-AA-N1-01 | 85.1 |
| Average value | 84.8 | | 85.1 | |

| Manufacturer | Model name | 1000 m$^3$/h | Model name | 5000 m$^3$/h |
|--------------|------------|-------------|------------|-------------|
| Komfovent    | VERSO-R-1300-UH-CW-R1-F7/M5-C5.1-L/A | 81.5 | VERSO-R-5000-H-W-R1-F7/M5-C5.1-L/A | 75.2 |
| Systemair    | TOPVEX TR03_HWH-L-CAV M0 | 82.6 | TOPVEX TR12_HWH-L-CAV M0 | 78 |
| Flaktwoods   | eQ Prime 005 | 88.5 | eQ Prime 018 | 85.9 |
| IV Produkt   | ACER-06-AA-N1-01 | 83.4 | EMMT-05-240-50-2-2200 | 79.5 |
| Average value | 84.0 | | 79.4 | |

Table 2. Comparison of heat recovery temperature efficiency for different AHU models with a counter-flow heat exchanger at various air flow volumes.

| Manufacturer | Model name | 400 m$^3$/h | Model name | 700 m$^3$/h |
|--------------|------------|-------------|------------|-------------|
| Komfovent    | DOMEKT-CF-500-F-R2-M5/M5-C6-X | 90 | DOMEKT-CF-700-F-R1-M5/M5-C6-X | 87 |
| Systemair    | SAVE VTC 300 L | 90 | SAVE VTC 700 R | 92 |
| Flaktwoods   | Eco Premium 1 | 84.1 | eQ Prime 005 | 87.9 |
| IV Produkt   | - | - | ATEM-04-AA-EN-Cl-H-00 | 80.5 |
| Average value | 88.0 | | 86.9 | |

| Manufacturer | Model name | 1000 m$^3$/h | Model name | 5000 m$^3$/h |
|--------------|------------|-------------|------------|-------------|
| Komfovent    | VERSO-P-10-C-H-PM/IES/1.4/1.4-F7-M5-X-X-R1-C5.1-X | 73.4 | VERSO-P-50-2-H-PM IES 2 9 2 9-F7-M5-X-X-R1-C5 1-X | 73.5 |
| Systemair    | Topvex SX/C03 EL-R-CAV | 90 | Topvex SC11 HW-L-CAV | 90 |
| Flaktwoods   | eQ Prime 005 | 85.3 | eQ Prime 018 | 83 |
| IV Produkt   | ATEM-06-AA-EN-Cl-H-00 | 80.6 | EMMT-05-240-50-3-3800 | 78.8 |
| Average value | 82.3 | | 81.3 | |

The results of the comparison of heat recovery efficiency show that for both the rotary type and counter flow plate type exchangers the values are very similar (Figure 3). The total average of all models and all air flow volumes showed that in the case of a rotary heat exchanger the temperature efficiency is around 83% while for counter-flow exchangers around 86%. This means that both solutions are a viable option and can be used in cases of new, low energy consuming buildings. The analysis of the
results showed that the models supplied by Komfovent have a bit lower heat recovery efficiency in comparison to others, but this can vary case by case and is strongly depended on the actual airflow volume and how close it is to the next type size for the specific manufacturer.

![Image of heat recovery efficiency comparison](image)

**Figure 3.** Comparison of average heat recovery temperature efficiencies at various air volumes for counter-flow and rotary heat exchangers.

### 3.2. Simulation results of heat recovery energy potential for single family house

The following simulations can be divided into two separate types. One of them presents the results for the maximal needed heating/cooling power. These are calculated for the most critical day of the year when the temperature is lowest for more days in a row and no heat gains are accounted for or when the temperature is high, and the sun is shining the most in case of a cooling load. The second type of calculations show the results for the whole year simulation. They represent the total amount of consumed and supplied energy as well as energy balance.

The results show that the simulated building in the first scenario would need design heating power of 7.47 kW. This consists of 6.48 kW that are necessary to compensate for transmission heat losses and 0.94 kW that are needed for ventilation air heating. The temperatures in all the premises are close to set point of +21°C, except two rooms that do not have a heating element in them and are heated by the enclosing rooms. As for cooling load, the simulations show that the maximal necessary cooling energy is on 15th September. At this date, the cooling load reaches 11.4 kW.

For the whole year simulation, the results show the energy balance for the situation, which most closely resembles the real-life operation of the building. The total energy for heating, in this case, amounts to 4178 kWh/year or 8.92 kW/h/m²/year. The energy consumption for cooling in the given case is 8465 kW or 18.1 kW/h/m²/year.

![Image of energy balance division](image)

**Figure 4.** Division of energy balance for a year at various months.

The energy balance shows (Figure 4) the division of different internal heat gains and losses. The results show that for given building the internal heat gains from equipment is the major source of heating. Also, the solar gains and energy from lighting are responsible for a large part of passive heating energy. In total the annual heating energy for the building is 32.74 MWh. Of this only 3 MWh are supplied through the heating system while the rest 29.67 MWh or 93.8 % are supplied by solar and internal heat
gains. Also, the recovered energy by the AHU was simulated and the results showed that for the whole year period in total 23328.8 kWh was recovered. The division by the months is shown in Figure 5.

![Figure 5. Recovered energy by the AHU heat recovery for each month.](image)

To see what the results for the building would be if no internal heat sources would be present a comparative simulation was performed. Only in this case the lighting, occupancy, and equipment are take out. The results show that in such a case the total heating energy would amount for 14152.7 kWh/year or 30.25 kWh/m²/year. The cooling energy would be decreased to 1542 kW or 3.3 kWh/m²/year. Also, the annual recovered heating energy by the AHU decreased by 800.4 kWh to 22528.4 kWh.

If a cooling system is added that the AHU can also recover cooling energy. The simulation results showed that in total 0.00368 kWh of cooling energy can be recovered. Therefore, the potential for this is small. If the AHU is equipped with indirect evaporative cooling section than the recovered heating energy is only 14674.8 kWh while recovered cooling energy reaches 44.17 kWh. In case the heat recovery type is changed to rotary type with potential to recover also moisture than the yearly recovered energy amounts to 16471.9 kWh but the necessary energy for heating is 1479.1 kWh while for cooling 1017.3 kWh.

4. Conclusions
The study showed that the average heat recovery efficiency of modern, commonly used rotary heat exchangers is around 83% while for counter-flow exchangers around 86%. Therefore, it can be concluded that they achieve the requirements of eco-design. Also, the results suggest that it could be viable to increase the required minimal heat recovery efficiency to achieve nearly zero energy building status according to Latvian Regulations for Energy Certification of Buildings Nr. 383.

The simulation results for a single-family residential building with a floor area of 467 m² and ventilation air volume of 640 m³/h show the potential of heat recovery from ventilation exhaust air. The total heating energy for a year of the simulated building is 4178.1 kWh, if the AHU is equipped with a heat recovery unit with an efficiency of 85%. For the whole year period in such a case, the 23328.8 kWh was recovered. Therefore, it can be concluded that if no heat recovery would be present than the energy consumption would rise to 26964.8 kWh or 57.8 kWh/m². The results also showed that in case the internal heat loads decrease, then it slightly affects the heat recovery potential. In case no internal gains are present, it decreases by 4%.

In future, it is necessary to perform further simulations regarding heat recovery potential of ventilation systems under various circumstances to find the highest potential work case. Also, it would be necessary to simulate how the variable air volume systems would affect the energy consumption for heating of supply air.

Acknowledgments
This work has been supported by the European Regional Development Fund within the Activity 1.1.1.2 “Post-doctoral Research Aid” of the Specific Aid Objective 1.1.1 “To increase the research and innovative capacity of scientific institutions of Latvia and the ability to attract external financing,
investing in human resources and infrastructure” of the Operational Programme “Growth and Employment” (No. 1.1.1.2/VIAA/1/16/033).

References

[1] Kim M K and Baldini L 2016 Energy analysis of a decentralized ventilation system compared with centralized ventilation systems in European climates: Based on review of analyses Energy Build. 111 424–33

[2] Naumov A L, Tabunshchikov I A, Kapko D V. and Brodach M M 2015 Research of the microclimate formed by the local DCV Energy Build. 90 1–5

[3] Dodoo A, Gustavsson L and Sathre R 2011 Primary energy implications of ventilation heat recovery in residential buildings Energy Build. 43 1566–72

[4] Anon 2013 Ministru kabineta noteikumi Nr.383 Noteikumi par ēku energosertifikāciju

[5] Laverge J and Janssens A 2012 Heat recovery ventilation operation traded off against natural and simple exhaust ventilation in Europe by primary energy factor, carbon dioxide emission, household consumer price and exergy Energy Build. 50 315–23

[6] Silva M F, Maas S, Souza H A de and Gomes A P 2017 Post-occupancy evaluation of residential buildings in Luxembourg with centralized and decentralized ventilation systems, focusing on indoor air quality (IAQ). Assessment by questionnaires and physical measurements Energy Build. 148 119–27

[7] Vinha J, Manelius E, Korpi M, Salminen K, Kurnitski J, Kiviste M and Laukkarinen A 2015 Airtightness of residential buildings in Finland Build. Environ. 93 128–40

[8] Petrichenko M, Nemova D V, Kotov E V, Tarasova D and Sergeev V V 2018 Ventilated facade integrated with the HVAC system for cold climate Mag. Civ. Eng. 77 47–58

[9] Zemitis J, Borodineecs A and Kalamees T 2018 Analysis of Various Ventilation Solutions for Residential and Non-residential Buildings in Latvia and Estonia Springer Proceedings in Energy pp 51–61

[10] Gorshkov A, Vatin N, Rymkevich P P and Kydrevich O O 2018 Payback period of investments in energy saving Mag. Civ. Eng. 78 65–75

[11] Alonso M J, Liu P, Mathisen H M, Ge G and Simonson C 2015 Review of heat/energy recovery exchangers for use in ZEBs in cold climate countries Build. Environ. 84 228–37

[12] CIBSE 2004 CIBSE Guide F: Energy efficiency in buildings

[13] Anon Commission Regulation (EU) No 1049/2001 Requirement 1253/2014

[14] Zhang M, Qin M, Rode C and Chen Z 2017 Moisture buffering phenomenon and its impact on building energy consumption Appl. Therm. Eng.

[15] Smith K M and Svendsen S 2016 The effect of a rotary heat exchanger in room-based ventilation on indoor humidity in existing apartments in temperate climates Energy Build. 116 349–61

[16] Kim M K, Baldini L and Leibundgut H 2013 Advanced Decentralized Ventilation Systems for Cooling and Dehumidification with Compact Heat Exchanger 11th REHVA World Congress CLIMA 2013 (Prague, Czech Republic)

[17] Dindina I, Krumins E and Lesinskis A 2014 Indoor Air Quality in Multi-Apartment Buildings before and after Renovation Constr. Sci. 4–10

[18] Voll H, Kõiv T-A, Kuusk K, Maivel M and Mikola A 2010 Indoor Climate and Energy Consumption in Residential Buildings in Estonian Climatic Condition WSEAS Trans. Environ. Dev. 6 247–56

[19] Santos H R R and Leal V M S 2012 Energy vs. ventilation rate in buildings: A comprehensive scenario-based assessment in the European context Energy Build. 54 111–21

[20] Ben-David T and Waring M S 2016 Impact of natural versus mechanical ventilation on simulated indoor air quality and energy consumption in offices in fourteen U.S. cities Build. Environ. 104 320–36