HI-SMART: HIGHER EDUCATION PACKAGE FOR NEARLY ZERO ENERGY AND SMART BUILDING DESIGN

MODULE #3

CHAPTER 6: HEAT RECOVERY VENTILLATION

Co-funded by the Erasmus+ Programme of the European Union

3.6.1 INTRODUCTION

Buildings built today have to satisfy the demanding energy requirements, that aim at reducing the impact of the building sector on energy use and CO_2 emissions (EPBD – energy performance of buildings directive). Renovation of old buildings are also of concern (EU – Renovation wave or the European Green Deal) as the number of buildings that are to be renovated impose great possibility for energy savings. New, and newly renovated buildings thus are highly insulated and have air-tight openings (windows, doors etc.). The question of ventilation and its energy demand has obtained a more and more significant role in such buildings. At least 50% of heat losses are caused by ventilation in buildings built these days.

Nevertheless, the role of ventilation is not only energy efficiency related. While using less energy, owners and designers have to make sure that sufficient fresh air (minimum hygienic ventilation rate) is available for occupants so that the health and wellbeing, productivity of occupants is maintained. Insufficient ventilation may cause damage to the building or harm the health of occupants (allergies – mould; sick building syndrome: tiredness, respiratory inflammations; productivity).

Another building element that may be affected by ventilation (or the lack of it) is the open combustion gas appliance that is still used in many existing buildings for heating and the production of domestic hot water. This problem is mainly present in the case of renovation projects where the building envelope is renovated, but building service systems remain untouched. Open combustion gas appliances use the air of the room where it is installed to supply the burning process with air. In order to avoid malfunction and accidents, sufficient air has to be provided to the appliance, which may result in the increase of ventilation heat loss in the end.

3.6.2 MEANS OF VENTILATION

There are several ways to provide ventilation to residential buildings:

- The simplest, yet most energy wasting is the manual opening and closing of windows. The correct method of ventilation with manual opening of windows is the following: Ventilation should be short and efficient - with draft across the premises.
- Another possibility is to install air inlets on the windows (or doors). There are several different types of inlet operations: open/close the inlet manually, hygroscopic operation etc.
- The most sophisticated and energy efficient solution for ventilation of residential buildings are mechanical ventilation units with heat recovery. This solution is to be examined in more detail later.

As mentioned above energy demand of ventilation systems may be of concern in the case of buildings that are built according to current energy efficiency regulation. However, there are methods with which the energy demand of the ventilation system can be reduced, namely:

- Adjusting ventilation to actual demands and/or,
- Recovering the energy from ventilation – from the exhaust air

Adjusting ventilation, i.e. demand controlled ventilation is when the ventilation need is detected and operation time is reduced with the time when ventilation is not needed (Figure 3.6.1).

Minimum ventilation rate is still necessary depending on the occupancy and the building needs (insufficient ventilation could cause damage to the building, or harm the health of occupants).

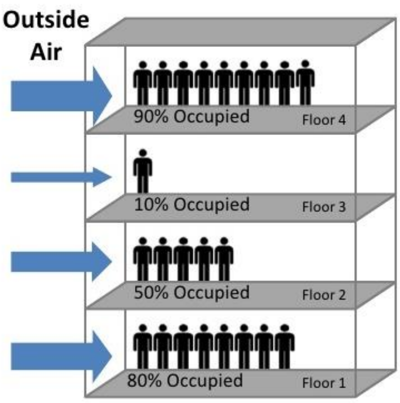

Figure 3.6.1. Demand controlled mechanical ventilation [https://www.horizon-engineering.com]

Note: Demand controlled ventilation was not recommended during the period of Sars-Cov-2 pandemic. Instead, ventilation was recommended to be increased so that the concentration of the virus did not increase in indoor spaces.

3.6.3 THE ROLE OF HEAT RECOVERY IN VENTILATION

Ventilation air is heated in winter and sometimes cooled in summer. By using heat recovery in the ventilation system the thermal energy used for heating can be reduced.

The role of heat recovery is to contribute to energy savings and in many European countries it is a must if the required target values set by the EPB Directive are to be met, mainly due to climatic reasons. It is also necessary to maintain the required indoor air quality and thermal comfort of occupants. [1]

Operation of heat recovery ventilation

In winter: By recovering the residual heat in the extract air, the incoming fresh air is pre-heated, and the supply air enthalpy is increased before it enters the rooms. Ventilation units with heat recovery typically recover about 75–95% of the heat from the exhaust air.

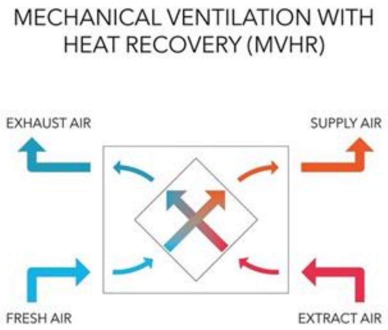

Figure 3.6.2. Operation of MVHR in winter [source: passivehouseschool]

In summer: Hot fresh air enters the unit, cools down in the heat exchanger and a fan moves the air to the room. From the wet rooms of the flat, the humid exhaust air is removed. This removed air cools down the incoming air in the heat exchanger. If weather is cooler outside (night time, ground heat exchanger) a bypass is used and no heat exchange occurs between supply and exhaust. The operation of bypass is shown on the Figure 3.6.3.

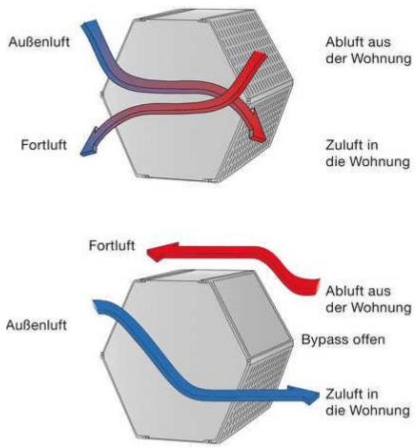

Figure 3.6.3. Operation of MVHR in summer - by-pass

source: Zehnder [https://www.international.zehnder-systems.com/]

Enthalpy heat recovery or EHR

In this case not only the heat, but the humidity from the exhaust air is also recovered. E.g. in winter the dry fresh air can be humidified by the humidity content of the exhaust. There is a prerequisite for this to operate, namely, an internal moisture emission is needed. In summer, it operates similarly but in the opposite direction; The drier exhaust can reduce the moisture content of incoming fresh air.

3.6.4 HEAT RECOVERY VENTILATION SYSTEM DESIGNS

The most common system in residential buildings is when the air is supplied via ducts and by fans to bedrooms and living rooms, and is exhausted from kitchens, bath rooms and toilets via ducts after heat recovery. Often kitchen hoods also remove exhaust air, in this case without heat recovery (see Figure 3.6.4.)

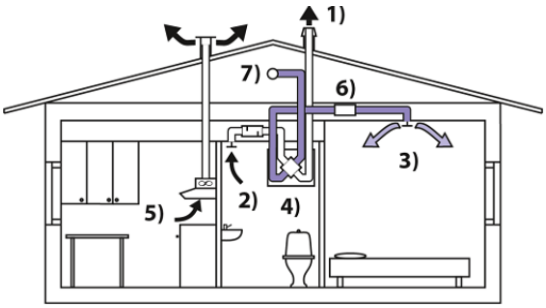

Figure 3.6.4. Operation of mechanical ventilation in residential buildings [1]

(Explanation to Figure 3.6.4: 1 – exhaust air; 2 – extract air; 3 - supply air to the bedroom; 4 – ventilation unit with heat recovery; 5 – kitchen exhaust; 6 – sound attenuator; 7 – outdoor air intake)

Outdoor air is drawn from the outside (7) and it passes to the ventilation unit (4). Here, the supply air is warmed by the exhaust air in a heat exchanger, i.e. heat is recovered. After this, air passes through ducts again to the points of supply (3). If needed sound attenuators (6) are used to reduce noise from the ventilation system. Exhaust air is drawn from spaces like bathrooms/toilets (2) and air passes through the heat exchanger/heat recovery unit to warm the incoming fresh air.

In the case of **apartment buildings**, different systems are available for ventilation of spaces:

- centralized
- decentralized

- individual room ventilation

Centralized systems

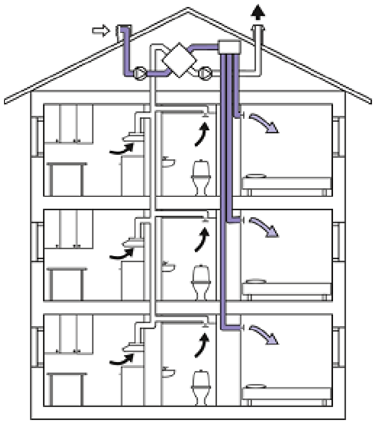

Figure 3.6.5. Centralized mechanical ventilation in an apartment building [1]

The concept is similar to what was introduced earlier for residential buildings. One central ventilation unit supplies the flats in the building via ducts to bedrooms, living rooms. Air is extracted from kitchens, bathrooms and toilets, separately from each flat. Exhaust ducts enter a collector box and afterwards stale, but warm air enters the ventilation unit's heat exchanger. Afterwards exhaust air is removed from the building. Control of this centralized system is somewhat more complex compared to the decentralized solution. But maintenance of the system is easier.

Note to Figure 3.6.5.

The schematic drawing from the REHVA guidebook imposes some practical questions that should be noted. The Figure is useful as it is very easy to follow and understand the operation of the system with it. Nevertheless, in reality, placement of the heat recovery unit in an attic requires lot of attention. There might be a risk that the attic does not have proper insulation, hence, the heat recovery equipment will not be able to fulfil its role. The unit itself has to be covered with insulation if installed in the attic. Another issue to what attention has to be paid is the intake of fresh air from the roof as in most climates in Europe snow may cause a problem for the air intake. In addition, in summer, the heat of the roof may cause malfunction or excess cooling demand if air is taken from there.

Decentralized systems

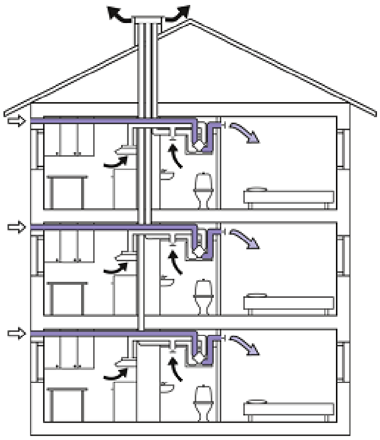

Figure 3.6.6. Decentralized mechanical ventilation in an apartment building [1]

In this case, individual flats have separate, smaller ventilation heat recovery units, installed in a secondary space (e.g. toilet). Fresh air is drawn from the outside and heated by the exhaust in the ventilation unit of the flat. Heated air is supplied to the bedrooms, living rooms. Afterwards, air is extracted from bathrooms, toilets or kitchens and led to the heat exchanger. From the ventilation unit air is exhausted through separate ducts (each flat has its own) to outdoors.

Individual room ventilation

In the case of renovation of buildings, often it is not possible to install duct systems and central units for ventilation in buildings. A possible ventilation/heat recovery solution is the application of room ventilation units.

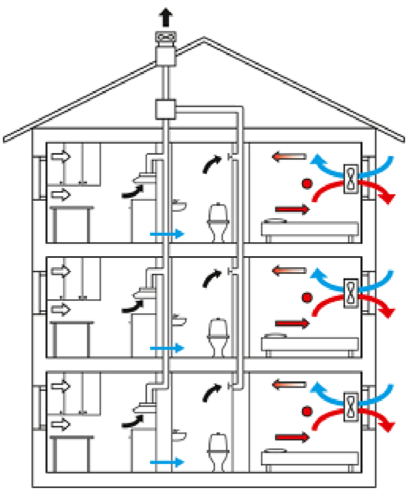

Figure 3.6.7. Individual room ventilation with heat recovery [1]

Ventilation units are installed in bedrooms and/or living rooms. If there is an old mechanical exhaust system it may have significant effect on the efficiency of these units because when exhaust air is removed from bathrooms or toilets, the supply air flow through the unit will increase, resulting in an unbalanced condition when supply flow is higher than the extract air flow through the unit.

Sound attenuation is not possible for this type of solution and a defrost strategy is needed in cold climate countries.

3.6.5 DESIGN PARAMETERS

There are several parameters that have to be considered when designing a heat recovery ventilation unit:

- Air flow rates
    - for indoor air quality in homes,
    - for removal of humidity and pollutants,
- Energy consumption (electric)
- Noise and draught

Required air flow rates in homes

EN 16789-1 specifies the required amount of air per person according to categories:

- Category I: 10 l/s
- Category II: 7 l/s
- Category III: 4 l/s

Given values and the air change rate that is 0.5 1/h for residential buildings give the bases for the design of ventilation systems.

The following table (Table 3.6.1.) contains the minimum air flow rates that are necessary in residential buildings.

Table 3.6.1. Minimum required air flow rates in residential buildings [1]

	Supply (l/s)	Extract (l/s)	Air velocity (m/s)
Living rooms >15m^2	8+0.27		0.1

	l/s,m2		
Bedrooms >15m²	14		0.1
Living- and bedrooms 11-15m²	12		0.1
Bedrooms <11m²	8		0.1
WC		10	
Bathroom		15	
Kitchen/with cooker hood		8 / 25	

Supply air flow rates should equal to the exhaust in order to have a balanced ventilation. When working from the table it is possible that total supply and total exhaust air flow rates are not equal. In such cases, the lower value should be increased to meet the higher. For apartment flats, usually the extract air flow rate determines the design air flow rate and supply has to be increased in order to have a balanced system.

Question of kitchen cooker hoods

In new and air-tight buildings cooker hoods cannot draw air from outside to indoors in order to remove pollution, thus the airflow has to be compensated. Cooker hoods are significant devices that extract approximately 25 l/s when operating. If this air flow is not compensated, negative pressure may develop indoors. Negative pressure may result in e.g. children cannot open doors. If cooker hoods are not compensated, care must be taken that excessive negative pressure is not greater than 30 Pa – which is the limit value for the opening of doors.

Draught

The sensation of draught depends on the air velocity, air temperature and turbulence intensity. Draught rating (DR) is one of the discomfort parameters that should be avoided, thus the maximum mean air velocity of 0.1 m/s is recommended as a design value. In this case, the value of DR is 10%, meaning the percentage of dissatisfied due to draught is 10%. EN 16798:1 [5] incorporates this local discomfort parameter. (Origin: ISO 7730)

It has to be noted that there are cases when draught can increase the comfort sensation of occupants. This is true in summer for example, when draught can be pleasing and higher air velocities may be allowed.

Noise

Noise is an issue in residential buildings as people are more sensitive to noise in a more quite environment. The following table (Table 3.6.2) contains the sound pressure levels that are maximum allowed in different spaces in a residential environment.

Table 3.6.2. Design equivalent continuous sound level [1]

Design equivalent continuous sound level, LAeq,nT	**dB (A)**
Bedroom	25
Living room	30
Wet room	35

It has to be noted that noise is not only an issue indoors, but the noise level caused by the ventilation cannot exceed 45 dB(A) at the balcony of the building or at the neighbour's window.

3.6.6 SYSTEM ELEMENTS OF HEAT RECOVERY VENTILATION UNITS

Heat recovery unit

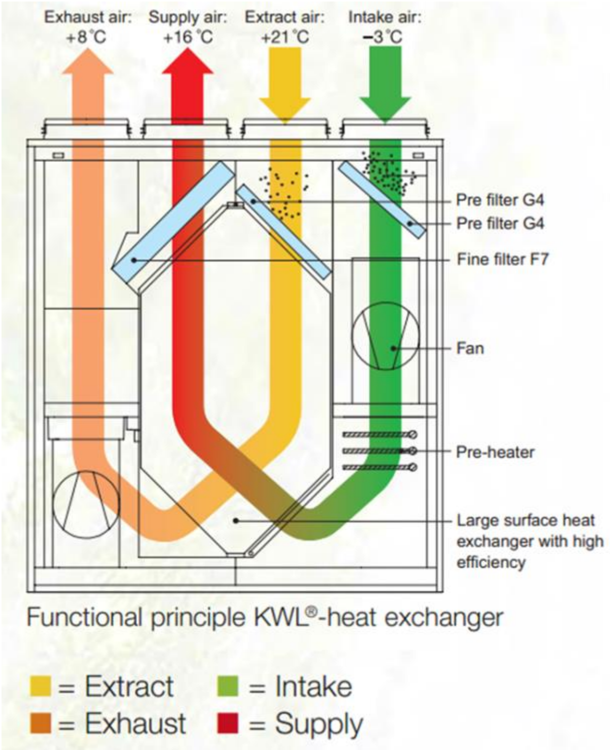

Figure 3.6.8. Structure of a MVHR unit [source: www.heliosventilatoren.de] [2]

The most essential part of the heat recovery unit is the heat exchanger itself.

Heat exchangers can be recuperative, like plate heat exchangers, or regenerative like rotary heat exchangers.

Plate heat exchangers are used counterflow as this solution is more efficient for such heat recovery tasks. Plate heat exchangers consist of thin metal layers (aluminium or steel) that are arranged so that from one side extract air enters the unit and exchanges heat with the incoming fresh air, entering the unit from opposite direction and flowing into different layers of the unit. Thus, the two flows are sealed from each other, only the temperature is transferred through the metal fins. [3]

Figure 3.6.9. Operation of a plate heat exchanger
[source: https://ericorporation.com/products/aluminum-plate-counterflow-heat-exchanger/]

Note: With regards to the Sars-Cov-2 pandemic, the operation of plate heat exchangers is safe; it holds no risks (no contamination of incoming air), rotary heat exchangers have to be investigated for air leaks – leaking cannot be more than 5 % so that they can be operated.

The **advantages** of counterflow heat exchangers used in the ventilation system:

- High sensible heat recovery
- Total separation of fresh and exhaust air streams – no odour or moisture transfer
- Heat recovery efficiency up to 93%
- Aluminium is corrosion resistant

The **disadvantages** of counterflow heat exchangers used in the ventilation system:

- Attention has to be paid to that under certain conditions condensation may occur in the heat exchanger. In this case condensed water has to be safely removed.
- Heat exchangers are sensitive to frosting.

Rotary heat exchangers

Figure 3.6.10. Rotary heat exchanger [source: https://ericorporation.com/products/rotary-heat-exchanger/]

Operation of rotary heat exchangers [3]:

In winter, the rotary heat exchanger is heated from the extract air from the inside, meanwhile the outside air is heated from the heat exchanger.

In summer, the rotary heat exchanger foils are cooled by the extract air and heat is transferred to the incoming air.

In rotary heat exchangers humidity is also transferred as the foils of the wheel are coated with materials that can absorb humidity and release humidity (hygroscopic treatment).

Thus, both sensible heat exchange (due to temperature difference) and latent heat exchange (due to condensation-evaporation) appear in such a heat exchanger.

The wheel is rotated between the two air currents, e.g. once it is heated on one side it is rotated to the other to warm the cold current.

Efficiency of such rotary heat exchanger is up to 85% and frosting is rarely an issue, thus, it can be used in cold climates. The transfer of humidity can be also an advantage in cold climates because low relative humidity indoors can be avoided with it.

Attention has to be paid that rotary heat exchangers may not be applicable in the case of small apartments with high occupant density.

Selection of heat recovery units [1]**:**

In order to be able to select the heat recovery unit:

- the design air flow rate has to be known (sum of room airflow rates)
- the ductwork pressure drop must be assumed (actual pressure drop is to be calculated later):
    - For smaller apartments initial value of pressure drop can be 100 Pa
    - For apartment buildings initial value of pressure drop can be 200 Pa
    - 50 Pa should be added to take into account pressure drops caused by e.g. filters during operation

Based on this data a unit can be selected from manufacturers catalogues.

Once the unit is selected the specific fan power is available.

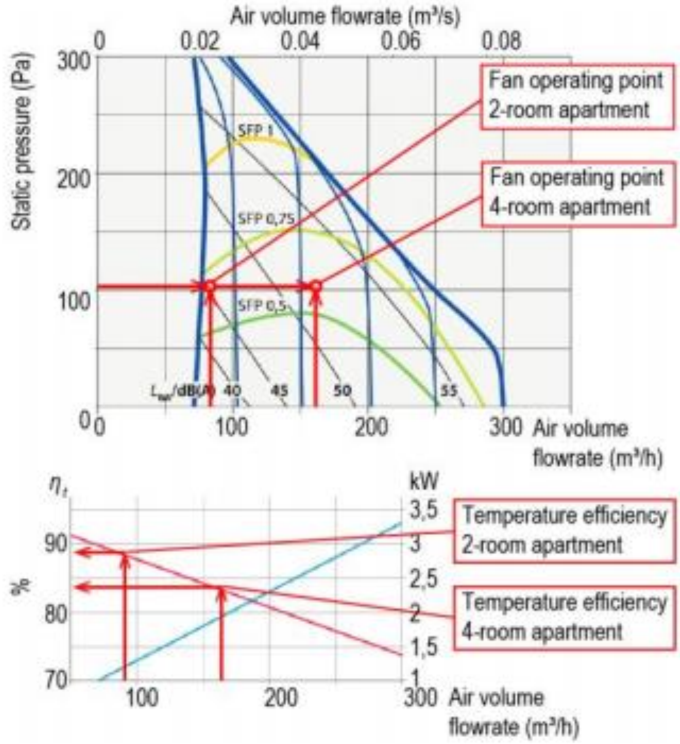

Figure 3.6.11 Example for determining specific fan power [1]

In Figure 3.6.11, an example of an air handling unit diagram can be seen that is taken from a catalogue for determining specific fan power that is needed to provide the needed air flow rate. Two cases are indicated on the diagram: a fan operating point for a 2-room and a 4-room apartment. Fan operating point should be in the middle of the operating area with clean filters so that when pressure drop is increased because of a dirty filter the flow rate could be maintained.

Air terminal units

There are quite a few requirements that air terminal devices have to meet [1]:

- The device has to be such that the supply air reaches the occupied zone.
- Diffusers and exhaust grilles should have pressure drop adjusting possibilities in order to set the required flow rates.
- The pressure drop of diffusers and grilles must not be too high, because that results in higher fan power and increased use of energy.
- The diffusers and grilles must not cause noise.

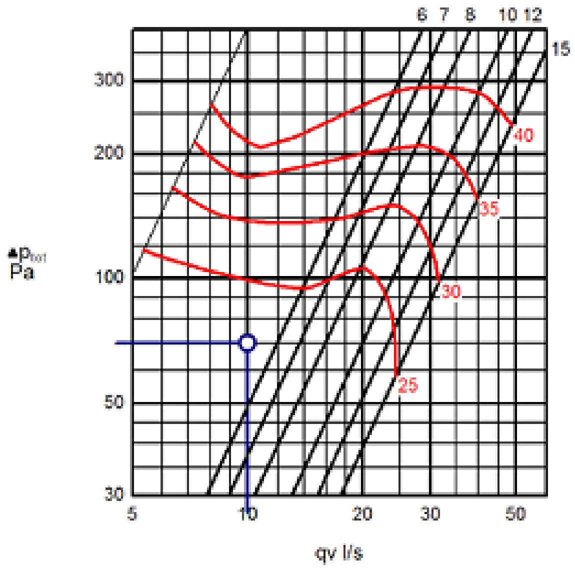

Figure 3.6.12. Selection diagram for a supply diffuser [1]

In Figure 3.6.12. an example can be seen for a selection diagram for supply diffusers. Red lines are sound pressure levels. Blue lines mark the case when air flow rate is 10 l/s and sound pressure level is lower than 25dB. X axes represents the air flow rates (l/s), while Y axes stands for sound pressure levels (Pa)

Positioning of system components

Care has to be taken so that the air handling unit is placed so that it will be convenient to connect it with ducts, electricity and the condensate drain and with enough space and access for future maintenance. Units should be placed indoors (e.g. kitchen, corridor, bathroom).

Air terminal devices (supply & exhaust) should be placed in rooms with effective air exchange.

Ductwork

Ducts should be large enough to ensure air velocities that are within allowed limits regarding noise and energy. Special polymer ducts provide extra sound attenuation, low resistance and hygienic air transport.

3.6.7 PRESSURE DROP CALCULATIONS

Pressure drop calculation:

- Pressure drop due to friction
- Pressure drop of ductwork elements such as bends, branches, air terminals, dampers

Pressure drop due to friction (reaching back to fundamentals of fluid dynamics) :

- Depends on duct dimensions and air velocity
- Ducts should be dimensioned so that friction pressure drop does not exceed 0.6 to 1 Pa/m,
- Air velocities must be checked for noise.

Pressure drop from duct elements depends on:

- air velocity,
- pressure loss coefficients of ductwork elements.

$$\Delta p = \xi \cdot p_d$$

where,

Δp – pressure drop (Pa);

ξ – pressure loss coefficient,

p_d – dynamic pressure

Filters

There are numerous guidelines (national, EU level etc.) that can be followed when selecting filters for the ventilation unit. Here two is mentioned:

a) Aim according to EU Directive 2008/50
    a. the annual average of PM10 should be < 40 μg/m³ and for PM2.5 it should be <25 μg/m³
b) WHO guideline
    a. target for the annual mean value for PM10 is <20 μg/m³ and for PM2.5 is <10 μg/m³.

It can be said that by applying current available filtration technology it is feasible to meet the stricter WHO target.

Local outdoor PMx values can be found in WHO's ambient air pollution database. It is recommended to change filters when the initial pressure drop is doubled or at least once a year.

3.6.8 SPECIFIC FAN POWER (SFP) AND FAN ELECTRICIY USE

Pressure drop calculation of the desired/designed system enable accurate specific fan power calculations.

50 Pa should be added to take into account the increase of pressure drop of filters during operation. After the SFP is obtained the annual energy use can be estimated:

Annual electricity use of the fan:

$$E_v = SFP \cdot q_v \cdot \tau \qquad \text{(kWh)}$$

Where:

E_v – electricity use (kWh),

SFP – specific fan power (kW/(m^3/s),

q_v – air flow rate (m^3/s),

τ – time (h – 8760h)

Heat recovery efficiency (also known as temperature ratio) and specific fan power describe the thermal and electrical efficiency of ventilation units. SFP describes the air moving efficiency that is based on flow rate and the total power input.

$$SFP = P/q_v \qquad \text{(kW/(m}^3\text{s)}$$

Where:

P - the total power input of the ventilation unit incl. fans, actuators and controls, kW,

q_v – design air flow rate (m^3/s)

Heat recovery efficiency can be calculated according to EN 13141-7 [6] for residential ventilation units. Figure 3.6.13 helps to understand how the temperature ratios and mass flow rate ratios are taken so that the supply and exhaust efficiencies can be calculated.

$$\eta_{t,sup} = \frac{t_{22} - t_{21}}{t_{11} - t_{21}} \cdot \frac{q_{m22}}{q_{m11}}$$

$$\eta_{t,exh} = \frac{t_{12} - t_{11}}{t_{11} - t_{21}} \cdot \frac{q_{m11}}{q_{m22}}$$

Where:

t_{22} is the supply air outlet temperature (supply) (°C)

t_{21} is the supply air inlet temperature (outdoor) (°C)

t_{11} is the extract air inlet temperature (extract) (°C)

t12 is the extract air outlet temperature (exhaust) (°C)

q_{m22} is the supply air mass flow (l/s)

q_{m11} is the extract air mass flow (l/s)

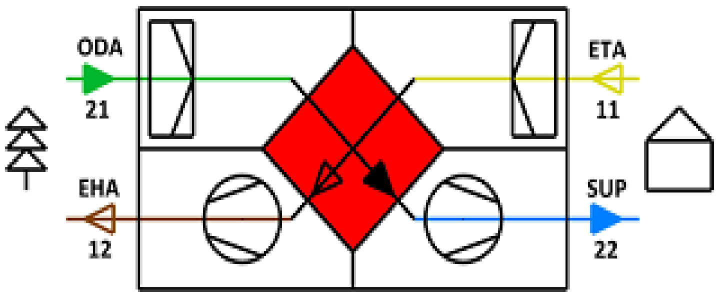

Figure 3.6.13. Schematic drawing for the calculation of heat recovery efficiency [1]

Annual energy efficiency is based on the ratio of recovered energy and heating demand of the ventilation without heat recovery. (EN 16798-3:2017) [4]

$$\varepsilon_{sup}=1-(Q_{coil}/Q_{off}) \qquad (1)$$

ε_{sup} – is the annual efficiency of heat recovery (1)

Q_{coil} – is the annual heating energy of supply air including defrosting (kWh)

Q_{off} – is the annual heating energy of supply air without heat recovery (kWh)

Heating energy for the ventilation supply air is calculated for every operation hour from t_{22} to supply air temperature setpoint (by default 18°C) and summed for all hours.

3.6.9 SUPPLEMENTS FOR HEAT RECOVERY VENTILATION

Heat recovery ventilation units may be supplemented with ground air heat exchangers.

In this case 1-1.5 m below the ground level air pipes are installed. In this region the effect of external weather is not significant.

In winter air can be preheated with the warmth of the soil so that pre-heated air enters the ventilation system and in summer air can be pre-cooled in the ground. These systems might be useful in climates with extreme temperatures.

3.6.10 REFERENCES

[1] REHVA Guidebook No. 25.: Residential heat recovery ventilation

[2] Helios – KWL, and other manufacturer heat recovery products

[3] ASHRAE Handbook: HVAC Systems and Equipment

[4] EN 16798-3: Energy performance of buildings. Ventilation for buildings. Part 3: For non-residential buildings. Performance requirements for ventilation and room-conditioning systems (Modules M5-1, M5-4)

[5] EN 16798-1: Energy performance of buildings. Ventilation for buildings. Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Module M1-6

[6] EN 13141-7:2021: Ventilation for buildings. Performance testing of components/products for residential ventilation. Part 7: Performance testing of ducted mechanical supply and exhaust ventilation units (including heat recovery)

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