

Ventilation of Apartment Buildings and Nursing Homes

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Abstract

The paper presents the results of the investigations into the indoor climate and energy efficiency of ventilation devices in residential buildings and nursing homes. The indoor climate studies discussed in the article were conducted in a nursing home where room ventilation is based on Meltem Air Handling Units (AHU). Similar studies have been carried out in apartment buildings where CO₂ levels in bedrooms were compared before and after renovating the ventilation with Meltem AHU and installing exhaust fans in the bathroom/WC and kitchen. Tenants evaluate the use of Meltem AHU in apartments very positively. The article presents the efficiency results of Meltem AHU with different external air temperatures conducted in apartments in real-life situations. The study shows that skilful renovation of ventilation in old apartment buildings enables to achieve good indoor climate and energy saving at the same time.

Keywords

Indoor Climate, Apartment Buildings, Nursing Home, AHU, Energy Efficiency of AHU

1. Introduction

The paper presents the results of the investigations into indoor climate in nursing homes and residential buildings. In the review of ventilation in European dwellings, it was pointed out that the ventilation of residential spaces in Nordic countries is often poor [1]. As a result of refurbishing, the air tightness of the building envelope increases and as many buildings have natural ventilation, the air change rate is reduced. The performances of the ventilation systems in low-energy residential houses have been presented by Maier *et al.* [2]. The energy performance of heat recovery units has been investigated by Jaber *et al.* [3] and Laverge *et al.* [4]. Ventilation heat recovery in residential buildings has been investigated by Dodoo *et al.* [5]. A number of studies on the ventilation and indoor air quality in apartment buildings have been carried out at Tallinn University of Technology by Mikola and Koiv [6]-[9].

2. Methodology

2.1. Indoor Air Quality

In accordance with the requirements [10] in Estonia, the living area must have natural or mechanical ventilation, which guarantees the air change necessary for human activity. According to the requirements in Estonia [11], air velocity in living spaces, the volume of space per person and the content of harmful substances in the indoor air must not exceed the permitted values.

Values for assessing room temperatures are taken from Estonian standard EVS-EN 15251:2007 [10]. This standard describes indoor environmental input parameters for designing and assessing the energy performance of buildings. The temperature values in case of different classes of thermal comfort are described in **Table 1**. The values to assess the relative humidity of indoor air are taken from Estonian indoor climate standard EVS 839:2003 [12]. The parameters are described in **Table 1**.

On the valid regulative basis, the CO₂ concentration in the indoor air in Estonia is set in the standard of indoor environmental input parameters [10] and designing criteria CR 752 [13]. Danish University of Technology has studied the standard in detail and gives the air flow rate of the classes of indoor climate and the maximum norms of the CO₂ content in the indoor air [14]. These norms also correspond to the values that are given in the designing criteria of indoor climate. Due to that the present study uses the maximum values given in designing criteria CR 752 for accessing the CO₂ content in the indoor air, whereby the CO₂ content in the external air is considered to be 350 ppm. The values to assess the CO₂ concentration of indoor air are described in **Table 2**. The standard for determining the initial parameters of energy efficiency [10] allows short-time deviations from the required parameters of indoor climate. The permitted deviation is up to 5%.

According to the standard for determining the initial parameters of energy efficiency (EVS-EN 15251:2007), it is possible to deduce the airflow according to the measurements of CO₂ concentrations in rooms where the main source of indoor air pollution is people. This method is called the metabolic CO₂ method. To assess the air change of a room by the metabolic CO₂ method it is possible to use Equation (1):

$$C = C_v + \frac{m}{L} - \left(C_v + \frac{m}{L} - C_0 \right) \cdot \left(e^{-\frac{L}{V}\tau} \right) \quad (1)$$

where C is the indoor concentration of CO₂ at time t (g/m³), C_v the concentration of CO₂ in the external air (g/m³), C_0 the concentration of CO₂ in the indoor air at time 0 (g/m³), L the volume flow rate of air entering the space (m³/h), m the volumetric indoor emission rate of CO₂ (g/h), V the volume of the indoor space (m³) and τ is the interval since $t = 0$.

Using literature [15], it is possible to express the relationship between the metabolic heat rate, body surface area and oxygen demand by Equation (2).

Table 1. Thermal classes of indoor climate based on Estonian standards EVS-EN 15251:2007 and EVS 839:2003.

Class of thermal comfort	Summer		Winter	
	Relative humidity, %	Room temperature, °C	Relative humidity, %	Room temperature, °C
I		23.5 - 25.5		21 - 25
II	30 - 70	23.0 - 26.0	25 - 45	20 - 25
III		22.0 - 27.0		18 - 25

Table 2. Class of the indoor climate for rooms with human activity (CR 1752) [13].

Category	Expected percentage dissatisfied, %	CO ₂ concentration at outdoor air level 350 ppm, ppm	Indoor air CO ₂ concentration, ppm
I (A)	15	460	810
II (B)	20	660	1010
III (C)	30	1190	1540

$$Q_{\text{CO}_2} = \frac{0.727 \cdot M \cdot RQ \cdot m^{0.425} \cdot l^{0.725}}{4.83 \cdot RQ + 16.17} \quad (2)$$

where Q_{CO_2} is the human indoor emission rate of CO_2 (l/h), RQ the ratio of M O_2 and exhaled CO_2 , Q_{O_2} human oxygen demand (l/h), m the weight of person (kg), l the height of person (m), M the metabolic heat rate (W/m^2).

Human CO_2 emission rates are mainly related to the surface area of the body and the metabolic heat rate. The ratio of inhaled O_2 and exhaled CO_2 is taken as a constant value in the present study (0.7 to 1.2 met). If the value of RQ is not exactly determined, it can be considered 0.83 [15]. In this case the accuracy of CO_2 emissions is approximately 3%, which is a sufficient result.

The metabolic CO_2 emissions are often observed as the average value of a 24 h period. In this case the average metabolic CO_2 emission is calculated using the weighted average method. In some studies the metabolic CO_2 emissions are shown during the sleeping period. As the CO_2 emissions vary in a wide range in the day time, it would often be much more punctual to use the night time CO_2 emissions in the calculations [10]. In the present study night time CO_2 emissions are used in the case of apartment buildings. In this study adult CO_2 emission is 13 l/h and children's CO_2 emission is 6.5 l/h during the night time. Metabolic CO_2 emissions in different studies are shown in Table 3.

2.2. Ventilation Heat Recovery

Member States of the European Union are required to implement energy efficiency measures for buildings under the Energy Performance of Building Directive [16]. With new building codes, EU member states intend to reduce the total energy consumption in buildings by making the buildings well-insulated and tighter. Due to the tighter and well-insulated constructions, the ventilation loads constitute a growing part of the heating demand between 30% - 60% for new and retrofitted buildings [17]. As the ventilation heating demand plays an important role in the building's total heating demand, the heat exhaust air heat recovery is inevitable.

From the exhaust air it is possible to recover only sensible heat or both sensible and latent heat [18] [19]. Energy is used to cover the heat losses due to ventilation air and to move the ventilation air for mechanical ventilation. The ventilation system also influences the air infiltration through the building envelope.

The temperature efficiency, which does not include latent heat transfer, was used to quantify the effect of heat recovery. The temperature ratio (efficiency) η_{temp} is defined as [18] [20]:

$$\eta_{\text{temp}} = \frac{\dot{m}_{\text{in}} \cdot (t_{\text{supply}} - t_{\text{outdoor}})}{\dot{m}_{\text{min}} \cdot (t_{\text{exhaust}} - t_{\text{outdoor}})} \quad (3)$$

t_{outdoor} is the outside air temperature, t_{exhaust} is the temperature of the extract air, \dot{m}_{in} is the inlet mass flow rate and \dot{m}_{min} is the minimum of inlet and outlet mass flows. In the case of the regenerator, a time-averaged value of the supply air temperature t_{supply} has to be used which is given by [20]:

$$t_{\text{supply}} = \frac{1}{\tau} \int_{t=0}^{t=\tau} t_{\text{supply}}(t) \cdot dt \quad (4)$$

Table 3. Metabolic CO_2 emissions in different studies [21]-[26].

Country, study	Object of the study	Adult CO_2 emission, l/h	Infant CO_2 emission, l/h
USA, Dietz & Goodrich 1995	Schools, residential buildings	19	12
Thailand, Leephakpreeda <i>et al.</i> 2000	Schools	16.2	16.2
Ireland, Guo and ja Lewis 2007	Residential buildings	18	18
Sweden, Pavlovas 2003	Apartment buildings	12*	12*
Czech, Jokl 2000	Schools, office buildings, residential buildings	19 (1 - 1.2 met)	18 (3 - 6 yrs and 2.7 met); 19 (14 - 16 yrs and 1 - 1.2 met)
Estonia, Kalamees <i>et al.</i> 2012	Apartment buildings	13*	6.5* (until 14 yrs)

*-night-time.

t denotes the time and τ is the semi-period, which means the duration of a supply or extract process. In the case of the recuperator, the process is in a steady state [20]:

$$t_{supply}(t) = \text{constant} \quad (5)$$

2.3. Studied Buildings

Studies have been carried out for the nursing home at Alutaguse, **Figure 1**. This nursing home has 39 rooms for 1 - 2 persons, the ventilation of which is solved with Meltem AHU.

The nursing home has hotel type rooms, the area is 25 m². The rooms are designed for 2 people (**Figures 2-4**) but in reality 1 or 2 people live in a room. Meltem Komfort AHU with network control has been installed in the rooms. **Figure 3** also shows that with the Meltem AHU polluted air is extracted from the bathroom and the supply air is given to the living room.

Meltem AHU can be installed in the wall construction, **Figure 5** or on the wall.



Figure 1. Outside view of the nursing home.



Figure 2. A two-person room.

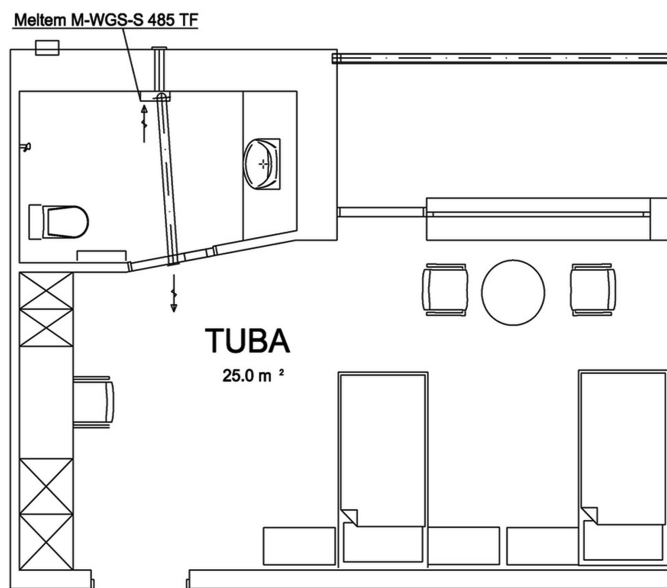


Figure 3. 2-person room solution with Meltem AHU.

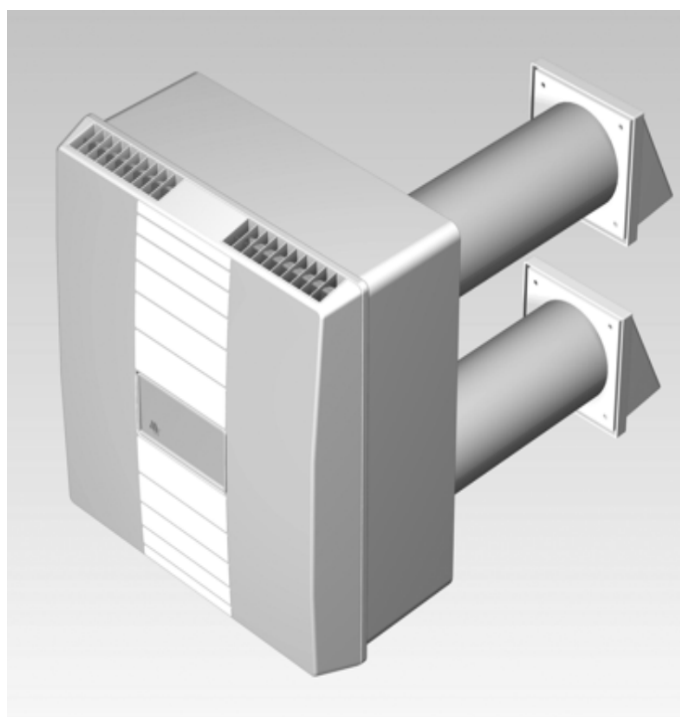


Figure 4. Meltem AHU is installed at the height of 2 m.

Meltem device has an aluminium recuperative heat exchanger, two ventilators, two filter cassettes and a control device.

Meltem room AHU has the same working principles as a standard air handling unit.

A specific feature is that the device serves up to 2 rooms, so the necessary length of the duct is minimal, typically up to 2 m, and the service is located in the AHU room. Thanks to short ducts and EC motors the electrical power of the devices is up to 15 W maximum, and hence the electric energy consumption is about 120 kWh per year, which is significantly lower than with the central balancing system.

The height of the device is 409 mm, the width is 388 mm and the depth is 196 mm. It is possible to use: stan-

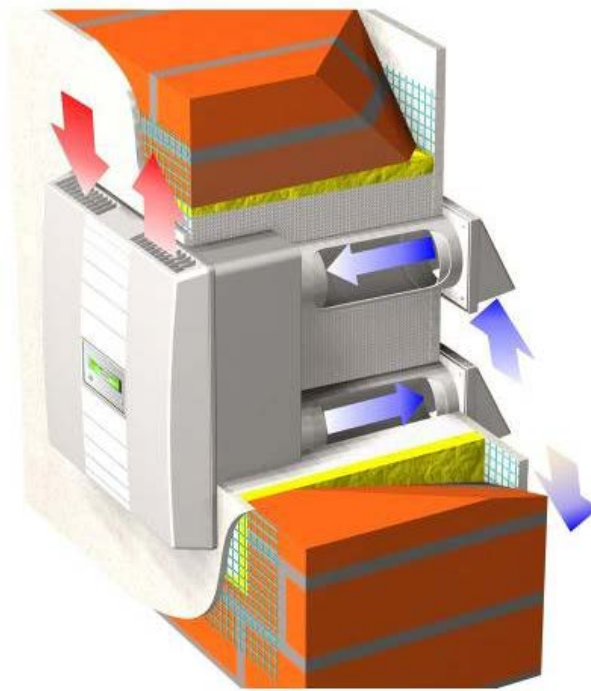


Figure 5. The operation principle of the unit Meltem.

dard filter G4, allergy F7 or absorbent carbon filter F6.

Meltem AHU is available in three modifications: Standart, Standart with network control and Komfort.

According to technical documentation Standart AHU enables three flow rates: 15/30/60 m³/h, power consumption from 3.8 to 12.5 W and noise level from 15.5 to 36 dB(A).

Research of Meltem AHU in apartment buildings (**Figure 6**) was mostly carried out in a 2-room apartment, **Figure 7** and in 3-room apartments. The apartments were fitted with Komfort devices.

As the HVAC requirements of a nursing home and residential building are close, we can also apply the studies of Meltem AHU conducted in apartments to a nursing home.

Figure 6 shows that one Meltem AHU is used in a 2-room apartment. In addition to AHU, an exhaust ventilator has been installed in the toilet/bathroom, which works when the lighting is switched on, and in the kitchen when required. The fans have been programmed to run up to 10 minutes after the light is turned off. After that the ventilation works as natural. The exhaust air ventilator is shown in **Figure 8**.

As the ventilator capacity is 64 m³/h, this ensures good indoor climate in the room while being used. If the ventilator is not in use, the necessary air change is ensured by natural ventilation.

3. Results

3.1. Measurements of Indoor Climate

3.1.1. The Nursing Home

Indoor climate studies in the nursing home were carried out in 4 rooms, 2 of them were single rooms and 2 double rooms. The recording results of CO₂ concentration and relative humidity in different rooms of the nursing home are presented in **Figures 9-11**.

Figure 9 shows that the relative humidity does not exceed the permissible limits of residential premises.

Economic calculations indicate that the construction costs of the ventilation on the bases of Meltem AHU and a centralised system in the nursing home are almost equal. At the same time the power consumption is lower and Meltem device allows flexible use, so the maintenance costs are significantly lower. Due to the lack of metallic ducts the number of light negative ions in the room air is also higher.

The results of the measurements conducted in different rooms show us that room air handling unit Meltem with heat recovery ensures good indoor climate in the nursing home. At the same time rational organization of



Figure 6. Facade of the house.

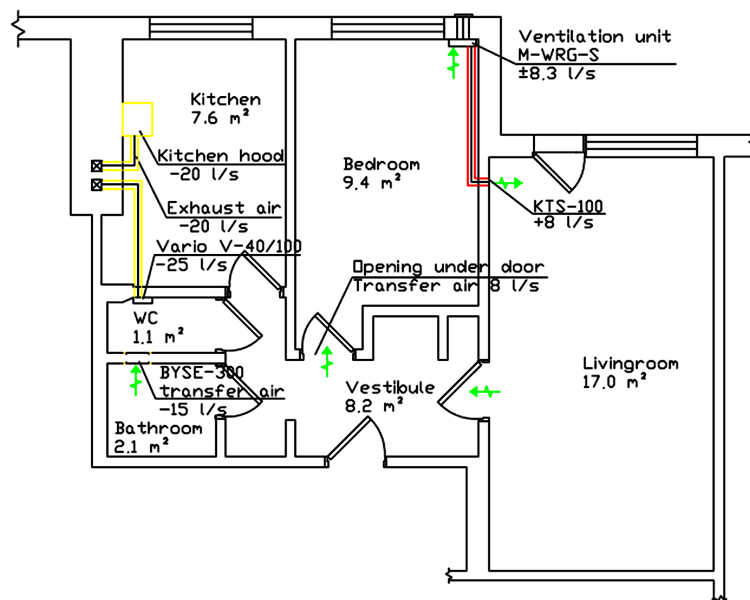


Figure 7. Meltem AHU in a 2-room apartment.



Figure 8. Ventilator in the WC/bathroom, Vario V-40/60.

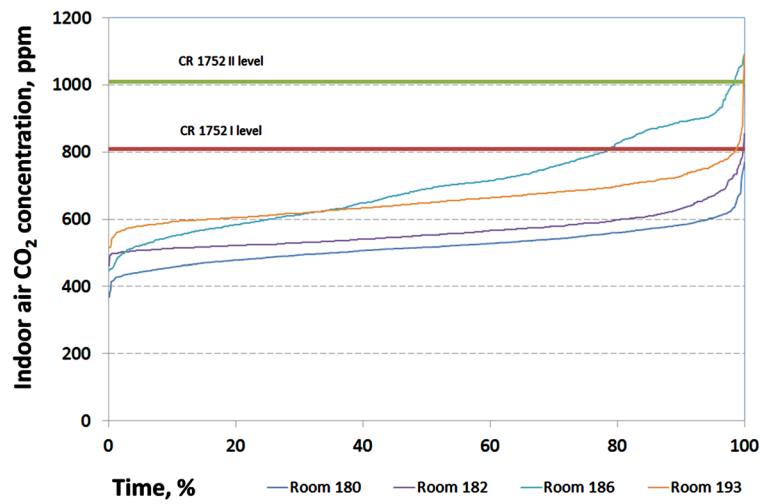


Figure 9. Cumulative distribution of CO₂ concentration in different rooms of the nursing home.

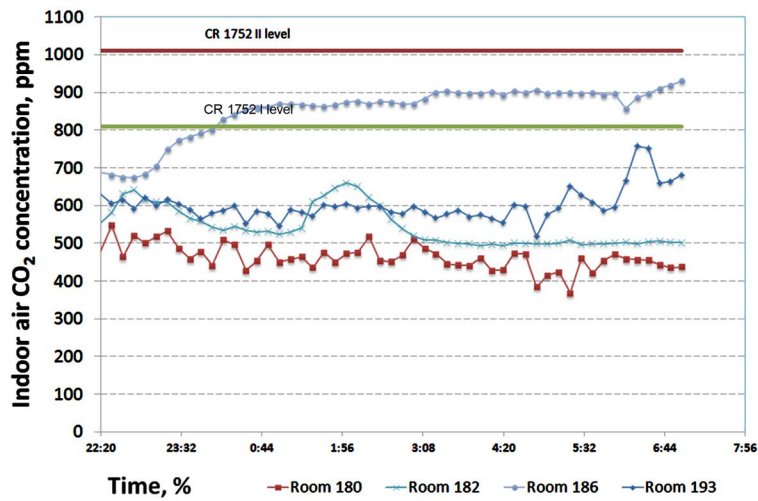


Figure 10. CO₂ concentration in different rooms, air flow rate 25 m³/h.

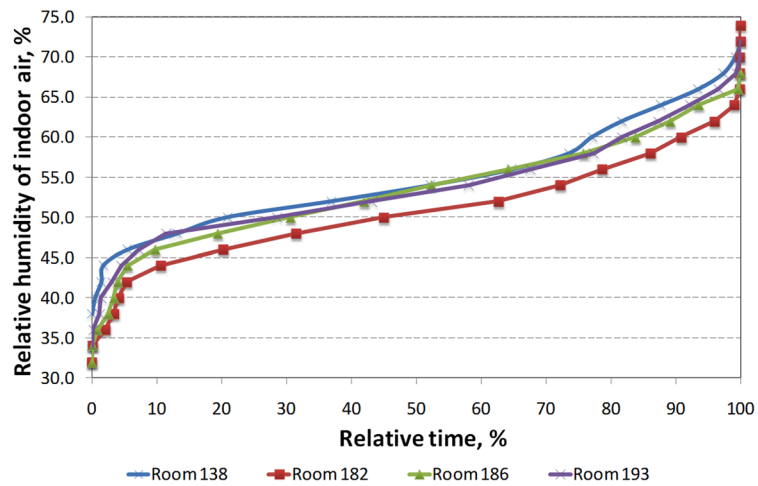


Figure 11. Relative humidity graphs in 4 rooms of the nursing home.

ventilation by Meltem significantly contributes to energy saving compared with balance ventilation.

We see that the carbon dioxide concentration in rooms was less than 1000 ppm, which can be considered a good result, and in the majority of the rooms less than 700 ppm, which can be considered a very good result.

3.1.2. Apartment Buildings

In apartment buildings studies of CO₂ concentration, relative humidity and temperature were carried out after renovating the ventilation. CO₂ level after the installation of Meltem AHU is shown in **Figure 12** and **Figure 13**.

In **Figure 12** we see that the concentration of CO₂ in the bedroom after ventilation renovation was less than 1200 ppm, with 70% of the time less than 1000 ppm, which can be considered a good result. The living room had somewhat higher CO₂ levels but more than 90% of the time the concentration was below 1500 ppm.

Tenants' assessment of the use of Meltem AHU in apartments has been very positive. Carbon dioxide levels in the bedroom have dropped nearly 1000 ppm.

An important study in the meaning of energy consumption was the determination of the temperature ratio of Meltem AHU. The measurement results are shown in **Figures 14-16**.

The temperature ratios for Meltem AHU with a wide range of external temperature are shown in **Figure 14**.

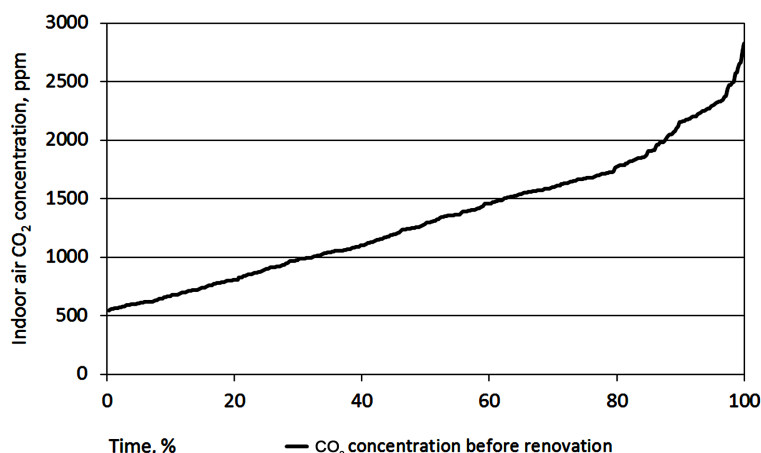


Figure 12. CO₂ concentration in the indoor air before renovating the ventilation (apartment building).

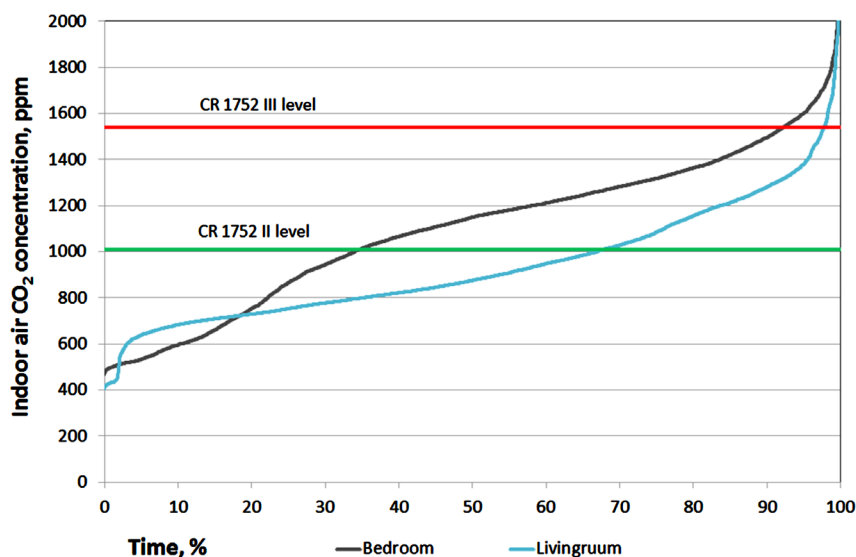


Figure 13. CO₂ concentration after the installation of Meltem AHU.

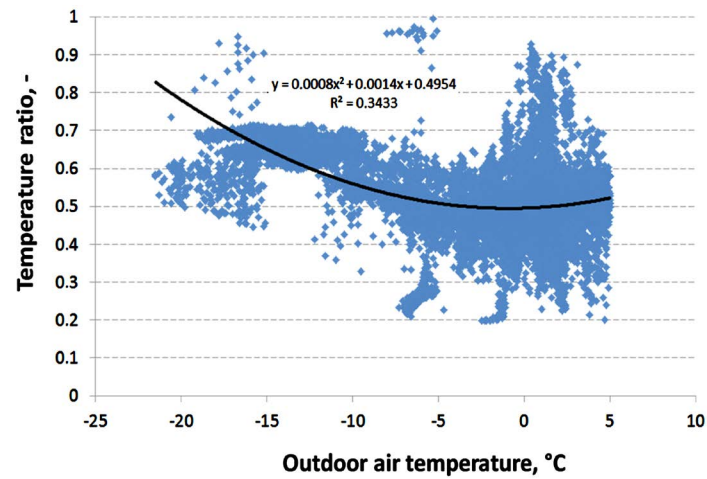


Figure 14. Temperature ratios for Meltem AHU with a wide range of external temperature.

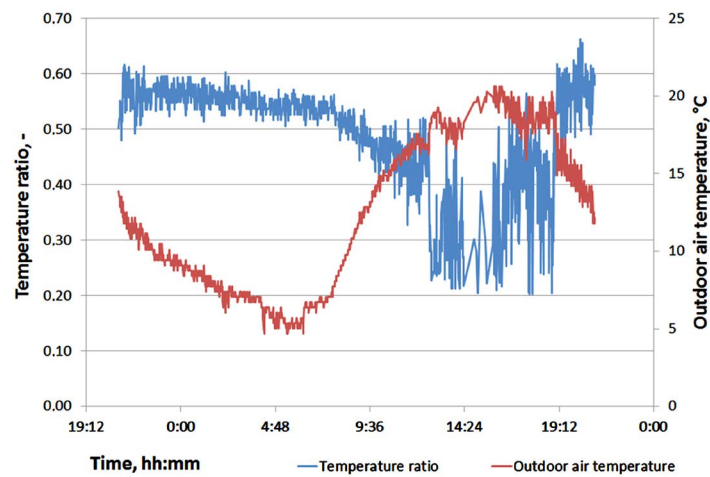


Figure 15. Temperature ratios and outdoor air temperatures for Meltem AHU at the 5th speed.

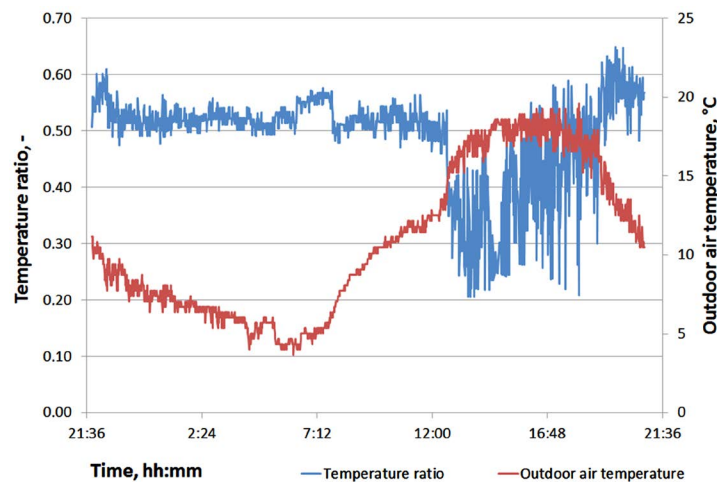


Figure 16. Temperature ratios and outdoor air temperatures for Meltem AHU at the 3rd speed.

Table 4. Noise levels of Meltem AHU-the average of 30 s (Komfort device).

Speed	Air flow rate m ³ /h	Noise level in the centre of living room dB (A)	Noise level in the centre of children room dB (A)	Noise level in the centre of bedroom dB (A)
Background noise	0	22	24.6	23.7
1	15	22.9	25.2	26
2	30	24.1	25.8	26.4
3	60	32.3	34.8	34.8

In testing Meltem AHU in the range of outdoor air temperature from +5°C to −20°C, the average temperature ratio (efficiency) was between 40% to 65%, with a medium size of 60%. In [Figure 15](#) and [Figure 16](#) we can see temperature ratios of Meltem AHU with the 3rd and 5th speed in positive outdoor temperatures. We can see that both temperature ratios are close, with minimum superiority to the fifth speed.

We can see that in real operating conditions the temperature ratio of Meltem AHU is on average close to 0.6, which can be considered a good result.

It should be noted that in old apartment buildings with natural ventilation the use of Meltem AHU in renovating the ventilation is one of the few suitable solutions.

3.2. Control of the Noise Level

Test measurements of the noise level of Meltem AHU have been carried out in 2-room apartments. The measurements were carried out at 5 flow rates next to the device, specifically 0.3 m from the device. Meltem AHU devices were installed in the premises of 10 m², where people sleep.

According to existing normative documents, the noise level should not exceed 30 dB(A) in the bedroom at night and 40 dB(A) in the living room during the day. For measuring the device Delta OHM HD 2010 was used.

The measurement results can be evaluated on the basis of the data given in [Table 4](#). It is seen that Komfort AHU can be used at night at the air flow rate of 15 m³/h, and with certain reservations at the air flow rate of 30 m³/h. If someone sleeps in the next room, the device can be used at the air flow rate of 30 m³/h.

4. Conclusions

The study shows that the new ventilation solution based on Meltem AHU is perfectly suitable for ventilating rooms in nursing homes and apartments. In the nursing home, Meltem AHU could provide good indoor air conditions in the rooms where two persons live and very good results in the rooms with one person. Measuring results conducted in different rooms show that the room air handling unit with heat recovery ensures good indoor climate in the nursing home. In apartment buildings, people's assessment of the use of Meltem AHU in apartments was very positive. The same studies showed that the temperature ratio of AHU was on average 60% over the season and the quality of indoor environment was satisfactory. Investigation proved that with rational and reasonable organization of ventilation we can save energy in renovating the ventilation in old apartment buildings.

Investments on ventilation with room air handling unit Meltem are close to those with the central balanced ventilation system, for example, in the nursing home.

The running costs of ventilation with the room air handling unit are lower than that with the central balanced ventilation system. The study shows that skilful renovation of ventilation in old apartment buildings enables to get satisfactory indoor climate and energy saving at the same time.

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