Analysis of various ventilation solutions for residential and non-residential buildings in Latvia and Estonia

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Abstract. As the newly built and renovated buildings consume less energy for heating needs, due to better and thicker insulation, the relative energy consumption for ventilation increases. This leads to necessity for increased effectiveness of ventilation systems, but such systems are more expensive in installation therefore the most economically feasible solution must be found in each case. A specific attention should be paid to such unclassified buildings as dormitories and barracks where occupancy profile and density differs from residential buildings which are already widely analyzed.

This paper presents study results of cost analysis for different ventilation strategies for case study multi-story apartment building in Latvia and Estonia. The compared ventilation strategies include natural ventilation through windows, natural ventilation by having inlet valves with natural exhaust, hybrid ventilation with inlet devices in walls and mechanical exhaust, decentralized mechanical ventilation with room based heat recovery, decentralized mechanical ventilation with apartment based heat recovery and building based centralized ventilation system. For each of these system types installation costs are estimated, based on necessary equipment and actual market prices. Afterwards annual running and maintenance costs are calculated and obtained data compared to select the optimal solution.

The results show that the most cost effective system in longer time period is centralized ventilation system which serves whole staircase. Although the simpler solutions like natural or hybrid ventilation systems with air inlets through walls and mechanical exhausts are initially cheaper the energy costs to heat up the incoming air are high and therefore cost inefficient in longer time period.

Keywords: Ventilation, efficiency, cost analysis.

1 Introduction

One of the most important engineering systems from all is the ventilation. It has always been present in the buildings but the exact solutions have changed during the years. The ventilation system has 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. This makes the choosing 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. In existing researches (1) it is stated that a VHR 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 necessity to carefully choose the appropriate ventilation system type to maximize energy savings while providing good indoor air quality. Investigation (2) have shown that in renovated apartment buildings with natural passive stack ventilation, the indoor air quality is quite bad and has high CO_2 concentration and relative humidity level. Similar data on IAQ problems in multi apartment buildings shows research (3) done in Estonia. Some authors (4) have already performed analysis on how ventilation rates vary depending on chosen system. Others (5, 6) have analyzed the system influence on IAQ.

Although the ventilation solutions for living building sector have been more widely analyzed it is important to provide the solutions also for such unclassified buildings as military barracks, shooting ranges or armories. As there is a strong potential to significantly reduce energy consumption also for them. For example shooting ranges have a need for large amounts of ventilation air and therefore consume a lot of energy however according to some studies (7) state that in case when conventional ventilation methods are used it is not possible to obtain suitably low concentrations of harmful substances in indoor shooting ranges and only a low turbulence displacement ventilation system provides the correct conditions for rapid conveyance of harmful substances to the extraction outlets in the area of the bullet trap. This means that a special attention must be paid in choosing the exact solution.

The paper presents the findings of calculation results of performed cost analysis of different ventilation solutions to determine the most feasible solution for longer running time periods.

2 Methods

A calculation to determine the installation costs of various ventilation systems and their annual running costs is performed in this paper. The comparison is made for typical apartment building located in Latvia and Estonia. The method to achieve this is based on following steps: Determining the necessary ventilation air volumes for each country; Designing various ventilation system types for an apartment; Estimating construction costs of ventilation systems; Performing life cycle costs analysis for each ventilation system including installation costs, annual maintenance and necessary energy for heating and electricity.

2.1 Description of case building

All further calculations are based on a chosen case study building. The building type is a multi-apartment building with 5 stories and 30 flats for each staircase section. The ceiling height is 2.5 m. In building two types of apartments are present. 25 apartments in each staircase are one bedroom (living area 35m^2) while five apartments have two bedrooms (living area 47 m^2). The ventilation volume is calculated for each type of flat and the total ventilation volume necessary for one staircase section.

To determine the design ventilation rate a calculation of both supply and exhaust was performed. Afterwards the largest value was applied as a design value for each flat type. In Estonia multi-apartment building exhaust airflow can be lower if required supply airflow is guaranteed. Knowing the ventilation air volume for the each flat the air for whole staircase section can be calculated. It involves multiplying the calculated ventilation air volume of one apartment with the number of apartments located in one buildings section (staircase) and with the number of stories, in this case five. This is necessary as the centralized AHU unit could serve each staircase separately therefore dividing building into smaller sections.

For all ventilation design cases the general rule was to supply the air in the bedrooms and living rooms while there are two spate exhaust systems- in bathroom and kitchen. The entrance area will be ventilated with the transfer air.

Table 1. Calculated ventilation air volumes for Latvian and Estonian case study building

Room Nr.	**Room type**	**Latvia**		**Estonia**	
		Supply air m^3/h	**Exhaust air m^3/h**	**Supply air m^3/h**	**Exhaust air m^3/h**
1	Bedroom	55 (90 for 2-room apartment)	-	50	-
2	Kitchen	-	90	-	22 (30 for 2-room apartment)
3	Bathroom	-	50	-	54
4	Storage	-	-	-	10
Total for an apartment (m^3/h)		55 (90)	140	50	86
Total for whole staircase section (m^3/h)		$6 \cdot 5 \cdot 140 = 4200$		$(5 \cdot 86 + 119) \cdot 5 = 2745$	

2.2 Design examples of ventilation systems

To prepare the cost analysis between the most common ventilation system types they all were fully designed for an apartment. The analyzed ventilation types included: natural ventilation by openable windows and natural exhaust (see Fig. 1), natural ventilation by having inlet valves and natural exhaust (see Fig. 1), hybrid type ventilation by having inlet devices in walls and mechanical exhaust (see Fig. 2), decentralized mechanical supply and exhaust with heat recovery (room based heat recovery) (see Fig. 2), decentralized mechanical supply and exhaust with heat recovery (apartment based heat recovery) (see Fig. 3), centralized mechanical supply and exhaust with heat recovery (see Fig. 3). The shown air volumes in all figures are for case of Latvia as it had the higher necessary ventilation volumes according to regulations.

In Fig. 1 two natural ventilation solutions are showed. They are still very common for existing, non-renovated buildings in Latvia and Estonia. The air supply through openable windows or building cracks is the supply type that was foreseen in Soviet time buildings while air supply through special air inlets is usually designed for renovation projects of such buildings.

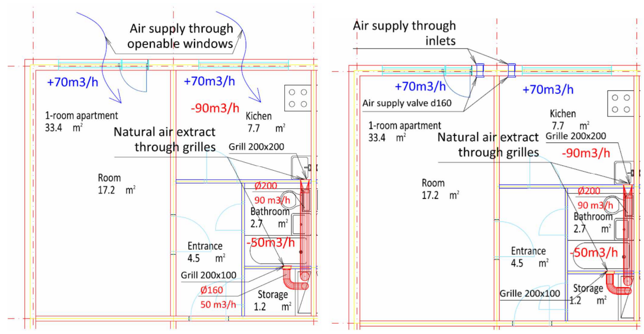

Fig. 1. Natural ventilation system through openable windows and exhaust (left); Natural ventilation system through air inlets and exhaust (right)

For each ventilation type, a specification is provided to show the necessary elements and prices of them. The specification does not include fittings, mounting elements or work price. To compensate this, final cost of the system is assumed to be higher by 10 to 30% depending on the predicted extra elements. These values are later used to compare the overall installation and running costs between various solutions.

Table 2. Specification of ventilation system through openable windows and natural exhaust

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Extract grille	200x100 mm	Pcs.	1	17.00
Extract grille	200x200 mm	Pcs.	1	20.00
Duct	Ø200 mm	m	2	1.90
Duct	Ø160 mm	m	3	1.50
Total cost with 30 % added				**60.00**

Table 3. Specification of ventilation system through air inlets and natural exhaust

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Supply vents	Ø160 mm	Pcs.	2	120.00
Extract grille	200x100 mm	Pcs.	1	17.00
Extract grille	200x200 mm	Pcs.	1	20.00
Duct	Ø200 mm	m	2	1.90
Duct	Ø160 mm	m	3	1.50
Total cost with 30 % added				**370.00**

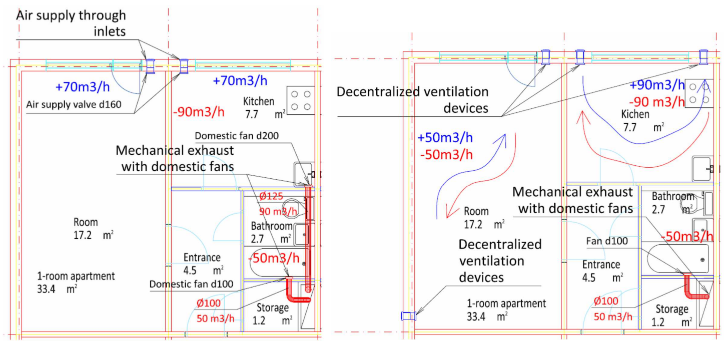

Fig. 2. Hybrid type ventilation system with supply through air inlets and mechanical exhaust (left); Decentralized ventilation system with room based mechanical supply and exhaust with room based heat recovery (right)

The left figure above shows the most commonly used ventilation system in newly built objects in Latvia and Estonia as it is relatively cheap and provides reliable ventilation volume with mechanical extract ventilators. In more advanced cases the extract duct is equipped with roof ventilator and a special extract device that evens the ventilation volume by compensating the natural stack effect.

Table 4. Specification of hybrid type ventilation system with supply through air inlets and mechanical exhaust

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Supply vents	Ø160 mm	Pcs.	2	120.00
Domestic type extract fan	Ø100 mm	Pcs.	1	70.00
Domestic type extract fan	Ø200 mm	Pcs.	1	90.00
Duct	Ø125 mm	m	2	1.20
Duct	Ø100 mm	m	3	0.90
Total cost with 30 % added				**525.00**

Table 5. Specification of decentralized ventilation system with room based mechanical supply and exhaust with room based heat recovery

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
Paired decentralized ventilation devices (50 and 90 m^3/h)	-	Pcs.	4	485.00
Control unit	-	Pcs.	1	320
Domestic type extract fan	Ø100 mm	Pcs.	1	70.00
Duct	Ø100 mm	m	2	0.90
Total cost with 10 % added				**2560.00**

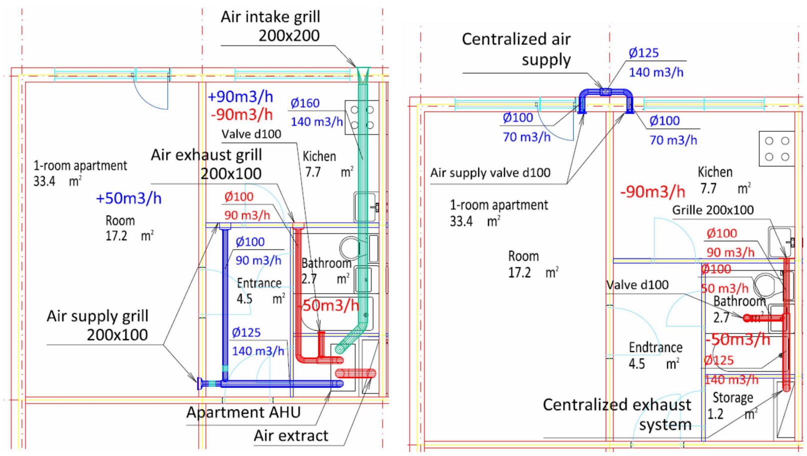

Fig. 3. Decentralized ventilation system with apartment based mechanical supply and exhaust with apartment based heat recovery (left); Centralized ventilation system with building based mechanical supply and exhaust with heat recovery (right)

In Fig. 3 fully mechanical ventilation systems with controlled supply/exhaust ventilation volumes are shown. Such type of system grants the highest precision in setting the necessary ventilation volume as well as provides the possibility to set up daily ventilation schedule which reduces the energy consumption. The mechanical ventilation system can either be located in each apartment or made centralized in AHU located in attic.

Table 6. Specification of decentralized ventilation system with apartment based mechanical supply and exhaust with apartment based heat recovery

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
AHU (140 m^3/h)	-	Pcs.	1	1800.00
Air intake grill	200x200 mm	Pcs.	1	40.00
Extract air roof hood	Ø160 mm	Pcs.	1	200.00
Air supply grill	200x100 mm	Pcs.	2	17.00
Air exhaust grill	200x100 mm	Pcs.	1	17.00
Air exhaust valve	Ø100	Pcs.	1	5.00
Duct	Ø160 mm	m	10	1.50
Duct	Ø125 mm	m	4	1.20
Duct	Ø100 mm	m	7	0.90
Silencers	Ø100 mm/ L=1000mm	Pcs.	4	75.00
Total cost with 20 % added				**2900.00**

Table 7. Specification of Centralized ventilation system with building based mechanical supply and exhaust with heat recovery

Name	Size	Units	Quantity	Average price in EU for one unit (EUR)
For whole building				
Centralized AHU (4200 m^3/h)	-	Pcs.	1	9500.00
Air intake grill	Ø560 mm	Pcs.	1	100.00
Extract air roof hood	Ø560 mm	Pcs.	1	700.00
Silencers	Ø560 mm/ L=1000mm	Pcs.	4	250.00
Duct	Ø560 mm	m	20	17.30
For apartment				
Air supply valve	Ø100 mm	Pcs.	2	5.00
Air exhaust grill	200x100 mm	Pcs.	1	17.00
Air exhaust valve	Ø100 mm	Pcs.	1	5.00
Duct	Ø160 mm	m	3	1.50
Duct	Ø125 mm	m	4	1.20
Total cost with 30 % added*				**560.00**

*The total cost includes the cost of all units located in the apartment and 1/30 of whole price for whole building units, as there are thirty apartments that would be served by the AHU.

3 Results

The results are based on the comparison of calculation results of economic analysis for designed ventilation systems as cost analysis has a major importance in choosing the appropriate ventilation system. To compare cost efficiency of different ventilation systems the following factors was taken into account: installation costs, maintenance costs, heating costs to heat up the ventilation air during heating period, electricity consumption for powering the ventilation system, assuming that the ventilation system works continuously through whole year. The cost comparison is done for one staircase of previously described case study building and with following assumptions:

1) Cost of installing all necessary equipment;

2) Annual maintenance cost for all necessary equipment for whole staircase section;

3) Cost of heating supply air for one heating season assuming the Heating degree days for base indoor temperature of +21,0°C for Latvia 4263, for Estonia 5656 (8) and assuming that the heating occurs by district heating system with following costs - for Latvia 55.55 EUR/MWh; for Estonia 65 EUR/MWh;

4) Annual cost of all energy necessary to power the ventilation devices for whole staircase apartment assuming that they are powered by electricity with the cost of 0.169 EUR/kWh for Latvia; 0.15 EUR/kWh for Estonia.

Table 8. Comparison of installation and running costs for Latvian / Estonian case study (upper numbers are for Latvia, lower for Estonia)

Type of ventilation system	Installation costs[1)] (EUR)	Maintenance costs[2)] (EUR)	Heating costs[3)] (EUR)	Powering costs[4)] (EUR)	Total Annual costs (EUR)
Natural by opening windows and natural exhaust	1800	- -	8005 8110	- -	8005 8110
Natural by having inlet valves and natural exhaust	11 100	300 450	8005 8110	- -	8305 8560
Hybrid by having inlet devices in walls and mechanical exhaust	15 750	450 600	8005 8110	1155 1025	9610 9465
Decentralized mechanical supply and exhaust with heat recovery (room based system)	76 800	750 750	1600 (eff. 0,80) 1620 (eff. 0,8)	535 580 (0,16 $W/m^3/h$)	2885 2950
Decentralized mechanical supply and exhaust with heat recovery (apartment based system)	87 000	1050 1500	1200 (eff. 0,85) 2030 (eff. 0,75)	3455 (SFP 1.0) 3210 (SFP 1.6)	5705 6740
Centralized mechanical supply and exhaust with heat recovery	16 760	1000 1000	1600 (eff. 0,80) 2030 (eff. 0,75)	2070 (SFP 1.2) 4010 (SFP 2.0)	4670 7040

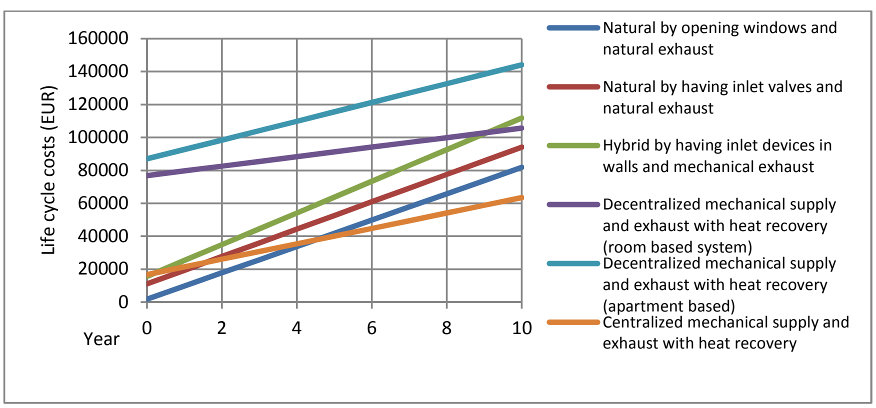

Fig. 4. Life cycle cost comparison of various ventilation solutions for 10 year period for Latvia

The Fig. 4 represents the life cycle cost analysis for 10 year period of different ventilation scenarios in case of Latvian ventilation volumes and climate.

4 Discussion

The results show that different ventilation solutions can very noticeably vary in installation and running costs. In general it can be concluded that the systems can be divided in three price ranges – the simplest one is just having natural exhaust channels and supply through windows (~1800 EUR), the middle price range includes more advanced systems such as natural system with inlet valves, hybrid system with mechanical exhaust and centralized ventilation system (~15 000 EUR), while the most pricy systems are either room based or apartment based decentralized ventilation systems (80 to 90 thousand EUR). However these costs must be looked at in combination with annual running and maintenance costs. For this three different levels also stand out – the most cost efficient is the room based mechanical system, the second are the centralized and apartment based full mechanical ventilation systems as they have high heat recovery, and lastly the most inefficient systems are the ones without heat recovery.

The Figure 4 shows that in general the most economically feasible choice would be to use centralized, building based ventilation system with one AHU for each staircase. In this case the costs of installation and maintenance would be reduced by spreading it evenly through all the occupants. Also the maintenance would be lower as each flat only needs to take care of one unit. The second most economical system is just having natural ventilation through openable windows. Although in such case no heat is recovered but there is no need for electricity or maintenance.

However it must be noted that to make the final decision when choosing ventilation type not only economical factor must be accounted for as the most important task of the ventilation system is to provide good indoor climate even if it means larger investments during construction phase. This means that additional factors like automation level, human comfort, noise generation from ventilation system or outside, possibility to filter incoming air, etc. must be introduced to account for this.

Also the existing experience of Estonia shows that room based ventilation is not recommended as it generates high noise, often not enough space in external wall is present, the wind flows through the device and the actual efficiency is smaller than specified in technical data. This has led to trend to avoid such solution.

5 Conclusions

The results for case study building showed that the design ventilation air volume between Latvia and Estonia for the specific multi apartment building can vary about 1,5 times - 4200 m^3/h in case of Latvia, while for Estonia 2745 m^3/h.

Installation cost for various ventilation system types where calculated and the results showed that the cost can vary from 1800 EUR for simple natural exhaust system up to 87 000 EUR if each flat has a separate full supply/exhaust ventilation system with AHU. The more common solutions as hybrid or centralized mechanical ventilation systems would cost around 15 000 EUR per staircase section.

The ventilation running costs that include maintenance, heating and electricity can vary from 3000 EUR in case of room based decentralized ventilation system up to

9500 EUR in case of hybrid type ventilation system. The running cost between Latvia and Estonia are quite similar as the necessary ventilation volume for Estonia is lower but the price for heating energy is higher. According to cost simulation for 10 year running period for the analyzed ventilation system the results showed that the most cost-effective systems is the centralized full mechanical supply/exhaust system.

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