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Combined air heating and ventilation systems in well insulated office buildings

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Abstract

Heating and ventilation systems are most commonly separated because water has far better heat carrying properties than air. In order to fulfill the relatively high needs of heating energy for a poorly insulated building it was more rational to use water as a heat carrier. Nowadays, when the properties of building insulation increased due to material improvements and more strict building standards, it might be more rational to combine the two systems.

The objective of this thesis is to make the necessary theoretical calculations, find out and compare economic and technological benefits and downsides of the traditional systems and this new approach for well insulated buildings. The aim of this study is to find out the reasonability of combining heating and ventilation into one system. The secondary aim is to provide necessary information for designing and simulating this kind of system.

This study examined a single story office building in Finland. Theoretical methods were used to analyse the systems. A number of studies were researched regarding the same subject. Despite of that, there is not enough information on this subject, which creates demand for this research. During this research university professors were interviewed as well as professional designers that had accomplished real projects that involved both types of systems, making the information provided in this research reasonable and reliable. This study examined a theoretical one story office building. Designs and calculations were made using Magicad software and other calculation programs. Information for product lists and prices were taken from existing companies catalogues.

This research found that simplified combined system migh bring both economic and technical benefits. Approximately 25% of total cost for materials would be saved when designing combined system. Furthermore, in combined system the total supply air required to heat the building was only 20% larger than the one designed to be supplied in conventional system. Research on balancing work with respect to heat distribution and air flow patterns is suggested for further analysis of the topic.

Keywords

Air heating, ventilation, combined systems, office building

CONTENTS

APPENDICES

Appendix 1. Building drawing with separate systems (heating system - radiators)

Appendix 2. Building drawing with separate systems (ventilation system)

Appendix 3. Building drawing with combined system (heating with ventilation)

Appendix 4. Analysis of building drawings with separate systems

Appendix 5. Analysis of airflows needed for the building

Appendix 6/1. Page 1 of UAB Leovira commercial offer for ventilation ducts and fittings (separate systems)

Appendix 6/2. Page 2 of UAB Leovira commercial offer for ventilation ducts and fittings (separate systems)

Appendix 7. UAB Leovira commercial offer for air handling unit (separate systems)

Appendix 8/1. Page 1 of UAB Leovira commercial offer for ventilation ducts and fittings (combined system)

Appendix 8/2. Page 2 of UAB Leovira commercial offer for ventilation ducts and fittings (combined system)

Appendix 9. UAB Leovira commercial offer for air handling unit (combined system)

Appendix 10. Specifications of Lesstro R1200VE air handling unit suggested by UAB Leovira for separate system and specifications of Lesstro R1400VE air handling unit suggested by UAB Leovira for combined system

Appendix 11. Bill of materials with prices for hydronic system

1 INTRODUCTION

This thesis researches how heating and ventilation systems can be combined into one. An old approach of separating the two systems was reasonable because of poor building insulation and a relatively high demand of heating energy. The solution to fulfilling this demand was separate heating and ventilation systems. Water for it's good heat carrying properties was chosen to distribute energy and a lot of water to air heat emitters were put in the rooms depending on their heating demand.

Nowadays when the insulation of buildings has increased significantly, the demand of heating energy that a building requires dropped. Now, it might be more reasonable to combine the two systems because of economic and technological benefits. Though this approach is already used in practice, there is not a lot of research done on this topic, which creates a high demand for this type of thesis.

In my thesis I will compare the two systems. I decided to choose a theoretical one story office building, where I designed both type of systems. There were several reasons why I chose an office building. First of all, because of international building standarts, there has to be sufficient ventilation in office buildings. The more fresh air people get the more productive they will be, which is a major economic benefit. Secondly, there has to be acceptable indoor climate in office buildings all the time, which means there has to be air conditioning solution in summer. Air conditioning typically requires higher air flows and thus sets the bar for duct sizes, which the new system might require bigger. Finally, the demand for comfort that heating systems bring, and that would be the main argument for a person to have the traditional system at home (for example underfloor heating in bathrooms) disappear in an office building because of the footwear.

Sudden and significant increase of building insulation requires engineers to rethink the techniques used in ensuring building energy needs and design of systems not only from quantative approach but also from the perspective of how and why the systems were build the way they are now. In my thesis I will discuss the benefits and downsides of conventional and new approach, mentioned earlier, of designing heating and ventilation systems.

2 AIMS

This bachelors thesis consists of one general question and a few additional aims. The main aim is to evaluate if it is reasonable to combine heating and ventilation into one system. The question has to be answered, from different points of view, which means that technological and economic reasons have to be evaluated.

Regarding the economic reasons, I will analyse the cost of materials used for both systems. For this aim to achieve I will compare both designs of systems and calculate how much material was used for the same building to achieve the desired indoor environment. Also I will evaluate how much would the installation cost and how much maintenance work will be required in the future for these systems to ensure the required indoor climate.

Regarding the technical reasons I will research how hard it is to design both systems, and if it is possible to maintain the required heating capacity and indoor climate throughout both approaches. Also such challenging questions as balancing and maintaining required temperatures will be discussed. I will suggest what technical problems might occure during the design and operation stages and how to solve them. Doing this I will also approach the second aim which is to provide basic guidelines for designing the combined centralised air heating and ventilation system. The guidelines will be obtained from numerous researches, interviews with professional designers which have practical expertise in designing these systems and also from existing office building projects that have implemented these systems.

3 HVAC SOLUTIONS WITHIN THE BUILDING

Globally, people tend to spend most of their time in buildings. Americans, for example, on average spend approximately 90 percent of their time indoors /1/.

Although building technologies are not evolving as fast as for example the automotive industry, IT or the financial market. This technological gap is growing every year and the need to address the problems associated with building engineering systems is also increasing. Every day more and more building managers or developers realize what part of their project costs are associated with HVAC systems and turn to those who have mastered this very specific knowledge – building services specialists, to improve and simplify the systems. One of the most recent approaches to simplifying the systems was to combine heating and ventilation systems into one combined holistic system.

3.1 Separate systems – the conventional approach

Heating and ventilation systems are most commonly separated for a number of reasons. First of all, water, as a fluid, has far better heat carrying properties than air. The specific heat capacity of water is very high, reaching approximately 4.2 kJ/(kg·K) at 25 °C, which means that 4.2 kJ of energy is needed to increase the temperature of 1kg of water by 1°C. The specific heat capacity of air though is just around 1.0 kJ/(kg·K) at 25 °C. This means that when we think about distributing energy around the building, we need 4.2 times less kilograms of water to distribute the same amount of heat. Furthermore, when designing the distribution system, the mass is not as important as the volume, because the higher the volume of heat carrier, the bigger ducts / pipes we need which means more materials and higher costs of systems. The density of water is around 1000 kg/m³, while the density of dry air is just around 1.2 kg/m³ at 25 °C and 100 kPa. This means we need approximately 833 times less space to put one unit of mass of water to our distribution system compared to the amount of space that would be needed for the same amount of mass of air. Finally, when looking at heat carrying properties of these two mediums, it’s clear that we need around 3500 times less space to distribute the same amount of energy with water compared to air. In order to fulfill the relatively high demand of heating energy for a poorly insulated building, it was more rational to use water as heat carrier beacause of the quantity of the flow and size of ducts / pipes diameters.

Another major advantage in favor of separating the two systems is the possibility to easily adjust design and balance them. Every room in a building might need different amounts of energy depending on their size, place, orientation and purpose. Also different amounts of fresh air is constantly needed to be supplied to and extracted from the room depending on number of occupants, the purpose of the room and its size. Having these two variables it is usually more convenient to have two separate systems.

3.2 Combined systems – the new alternative

3.2.1 System design affected by the guidelines

Nowadays the level of building insulation has increased significantly as well as the need for sufficient ventilation. According to finnish national standards, the outdoor air flow of the entire building shall be designed to be a minimum of 0.35 $(dm^3/s)/m^2$ of floor surfaceand the outdoor air flow to the occupiable spaces shall be designed to be a minimum of 6 dm^3/s per person. /2, p. 4./ This means that while we need less water in our buildings, to distribute heat, because the demand of energy decreased, we need even more air to reach comfortable and healthy indoor climate. These changes encourages engineers to rethink the way the systems are made.

Finnish guidelines also set permissible tolerances for design values of supplied fresh air that have to be maintained. Permissible tolerances in respect of design values may be as follows:
1) air flow at system and dwelling unit level ± 10%;
2) air flow at room level ± 20%, with, however, the deviation always permitted to be at least 1 dm^3/s;
3) specific fan power of ventilation system + 10%. /2, p. 9./
While the ability to balance the systems might still be a major drawback for combined system, some types of buildings as for example an office building that is researched in this thesis, have most of the rooms designed with similar sizes and serving similar purpose, which might make balancing work much simpler.

The regulations in Finland are set up in a way that ensures energy efficiency and usage of other resources in a way that is least harmfull to the environment. Office buildings as well as health centers by intended use fall under category 3 and have the energy performance reference value limit of 100 $kwh_e/(m^2a)$. /3, p. 3./ In order to maintain the required air flows in office buildings, usually the mechanical ventilation is installed. If building has a mechanical ventilation system, the specific fan power of a mechanical supply and extract ventilation system may be at most 1.8 $kW/(m^3/s)$ and the specific fan power of a mechanical extract ventilation system at most 0.9 $kW/(m^3/s)$. The specific fan power of a ventilation system may exceed the above values if so required by the indoor climate in accordance with the building’s intended use. /3, p. 14./ Throughout all these and numerous other regulations Finland ensures that buildings‘ occupants maintain good health and buildings do as little harm to the environment as possible.

3.2.2 Combined systems and indoor climate

While researching already existing studies on heating through ventiation I found that recommended maximum supply air temperature is limited to 55°C. In this case at the supply air terminal device, the air supplied to the rooms is approximately 40°C. An expert from company “MB intelektuali inžinerija” that has designed these kind of systems, confirmed these findings and recommended me to use a maximum of 36°C at supply air terminal devices. At this temperature building occupants should not feel thermal discomfort. Rather, one of the most common complaint arising from local thermal discomforts, draft, should even suppress, when the air heating is used. The sensation of draught depends on the air temperature. Figure 1 shows that when temperature of air, interacting with body, is higher, people will less likely feel discomfort.

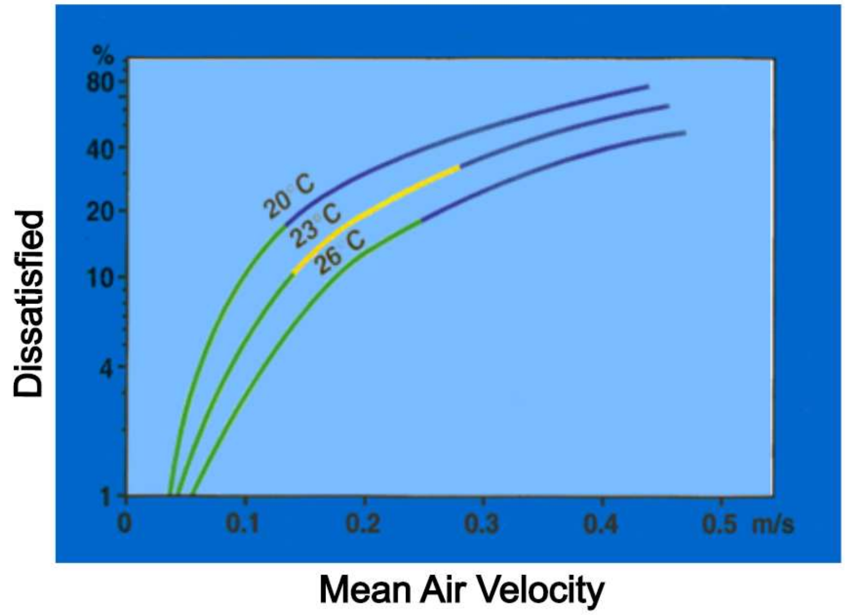

Figure 1. Sensation of draught /4, p. 12/

This means that the increased air supply temperature also gives us possibility to use higher air velocities without people feeling discomfort. This possibility gives us more flexibility when designing the air heating system and considering placements of air terminal devices. Contrary to that, another factor contributing to thermal discomfort – radiation asymmetry, causes risk, when hot air distribution system has to work at maximum heating load. Radiant temperature asymmetry is perceived uncomfortable. Warm ceilings causes greatest discomfort (Figure 2).

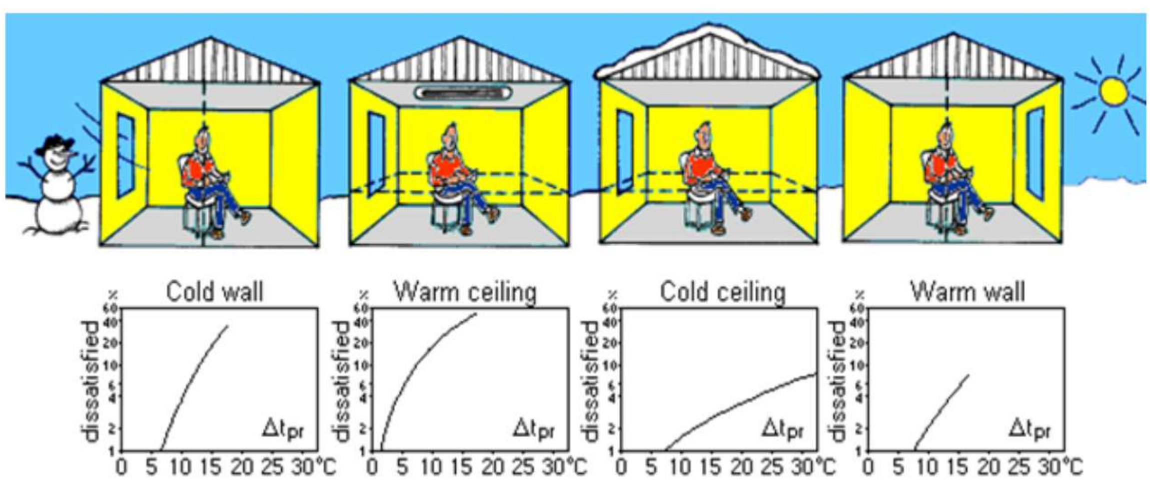

Figure 2. Radiation asymmetry /4, p. 13/

If at maximum heating load the air supplied near the ceiling will cause radiation asymmetry with warm ceiling, there is high probability that people will feel thermal discomfort. This means the system must be designed in a way to ensure good air circulation and even thermal distribution inside the room.

3.3 Earlier Studies on the same subject

3.3.1 Conversion of electric heating in buildings: An unconventional alternative

While searching for information on this topic I came across an interesting research article that inspected an unconventional alternative to avoid installing an expensive hydronic heating system. The research suggested that by using air (instead of water) as heat carrier to distribute heat around the building, the special properties of gravity currents and thermal forces can be an advantage. The research was written as early as 2008 which was staggering, considering that 11 years later we still have so little information about this topic. The experimental study includes a variety of full-scale tests that were taken in a laboratory in Sweden which showed promising results in converting the heating system.

The distribution of air is very important in the princples of heating through ventilation. Warm air is less dense than cold and thus goes up once mixes with ambient air in the apartment. If we increase the temperature of supply air to satisfy building energy needs, there is high potency for the warm air to accumulate near the ceiling and decrease the efficiency of heating the occupied zone. The study in Sweden informs us that Ertheridge and Sandberg have carried out a number of studies and determined that air distribution through horizontal openings using thermal forces is substantialy less effective than through vertical openings due to more complex flow patterns. /5/ Knowing this we can better the design guidelines of heating through ventilation.

An important property of gravity current is that it passes an obstacle in it’s way with ease. This means that for example in air cooling through displacement ventilation, a flux of cool air is supplied into the room with low momentum and spreds across the room floor evenly. Then the heat sources direct the flow up to the occupied zone and further to the extract devices usualy installed in ceilings. While there may be a lot of heat sources in the office building like people and computers, there are not so much heat sinks that would be beneficial in the heating case. Contrary to cooling, the warm gravity wave spreds acroos the ceiling and only interacts with windows and external walls which serve as heat sinks. This increases risk of high vertical temperature gradients in the room. The aim of the study taken in Sweden was to explore the possibilities of using thermal forces and positive gravity currents to distribute warm air around the building. The prerequisite for this approach was that the building would have a room adjacent to all other rooms. This room is called neutral space. The study suggested that most buildings have a hall that can serve as neutral space. The warm air should be supplied to adjacent rooms from neutral space through a vertical opening near the ceiling and leave the room through a vertical opening at floor level (Figure 3).

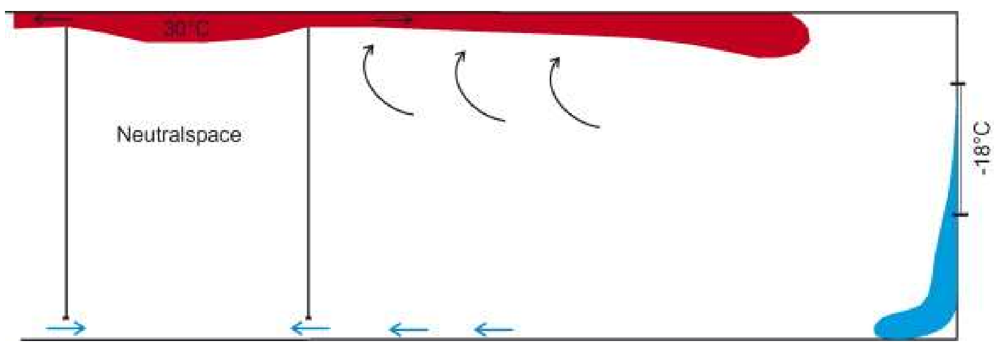

Figure 3. The principle of warm air distribution (Sweden, 2008) /6/

From my perspective this principle is very promising because otherwise, if warm air would be supplied at floor level it would go straight up and be extracted at the ceiling level probably not reaching far enough into the occupied zone and wouldn’t work in rooms with longer lengths. Also the part of room, near the window would be much colder due to cold air currents produced by exterior windows. Another approach would be to place extract air device on opposite side of the room, but then the system in general would usually require more ducts to distribute heat.

The first measurement they carried out was to figure out the temperature profile in a room. To simulate air heating they put convector of 150 - 300W near the ceiling and cooled down exterior window using cooling chamber to -20°C - +5°C. Then thermocouples were placed in the middle of the room at 14 different heights to measure the temperature gradient in the room. Measurements were taken at different heating power and outside temperatures. The results showed that air velocity of the cold draught from the window does not exceed 0.1m/s. Also there is a thin layer of 10 - 15cm of warm air close to the ceiling (Figure 2). Interestingely enough the diagram shows that temperature differences are independent to the heating power and outdoor temperatures. Vertical temperature gradient in the occupied zone, which is defined as 0.1 - 1.8m above floor level, is approximately 1°C (Figure 4 and Figure 5).

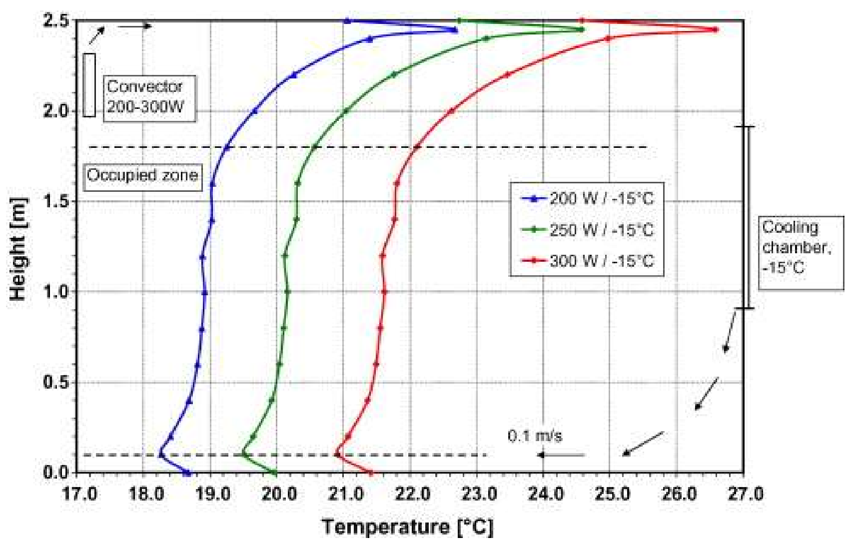

Figure 4. Example of temperature profile in bedroom (no external ventilation) /6/

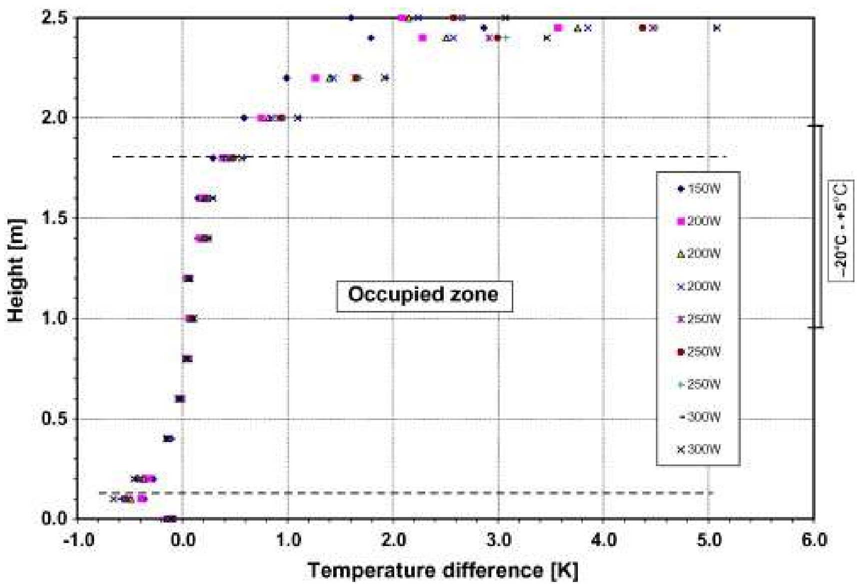

Figure 5. Deviation from average room temperature in various cases /6/

These results indicate that the system, designed this way, should produce sufficient results in providing good indoor thermal environment. The most important fact is that despite of how much heat the room requires, which fluctuates greatly depending on the season, the system should produce stable indoor environment and not exceed an average of 1°C temperature gradient in occupied zone.

Also in this research tracer gas were included to determine how long supplied air stays in the apartment. The results obtained showed that the local mean age of air was 2.5h whereas the nominal time constant was 2.0h. This means that by using this system the apartment was quite well ventilated.

This research suggested to use thermal forces to supply air into the rooms. As a room heat demand increases, the thermal forces would also increase and the system would be self regulating to a certain extent. This research was based on renovating old family houses where the hall is not very long. In my thesis I will be researching office buildings, where hall is usually long and the risk of temperature differences along the hall increases. This way if heat will be delivered only in one end of the hall, the rooms in the other end risk of having not enough heat delivered to them. This problem can be fixed by delivering balanced heat flow along the hall which requires ducts to be installed equal to the length of the hall.

For this reason I find it more rational to deliver heat directly to the rooms as it would require only a fraction of the total duct length to improve the system. This way the system does not necessarily need a neutral space and is more flexible from designing point of view. The study also found that on average the temperature in neutral space is 2 degrees higher than in occupied rooms. This is unnecessary and if heat was delivered directly to the rooms of an office building, the system should save energy because it would not overheat the hall. Finally, using duct system to distribute warm air to rooms also gives possiblility to regulate the flow and minimize nominal time constant.

3.3.2 Re – inventing air heating: Convenient and comfortable within the frame of the Passive House concept

Another research I found was a paper summarizing the work of experts and scientists from Passive house institute in collaboration with EMPA (Swiss Federal Laboratories for Materials Testing and Research). The passive house concept is spreading rapidly around central Europe minimizing the energy consumption in buildings significantly. The paper discusses how improved building envelope allows simplifications in heating systems and presents in detail the characteristics of combined heating and ventilation system that is realized in many passive houses.

The research presents many guidelines to design the air heating system. Many different options occur concerning the air heater. The air heater should be installed downstream the heat recovery unit (Figure 6). Air heater may take energy from heat storage or directly from energy source. Energy sources such as air heat pump condenser, district heating or even direct electric heating can be used. However, as the research states, direct electric heating is usually associated with high primary energy and completely contradicts the basic principles of saving energy, when talking about passive houses. Important principle of air heating, mentioned in this research is that air heater must be designed with higher heating power, p_H, than the need of heat delivery to rooms, p_R, because ventilation losses, p_V, have to also be taken into account. The maximum temperature of supply air is limited to 55°C because at higher temperatures dust carbonization may occur on heated surfaces and odour emissions may appear. Using recirculation air is not recommended because of complexity of system and increased cost due to additional ventilation system parts required. If heating power is not enough at peak demand, the study suggests installing a small radiator instead of designing higher air flow rates for acoustical reasons and economical benefits due to smaller duct sizes. According to research, heat losses from ducts have to also be inspected as they can produce a large share of energy compared to total heat distribution.

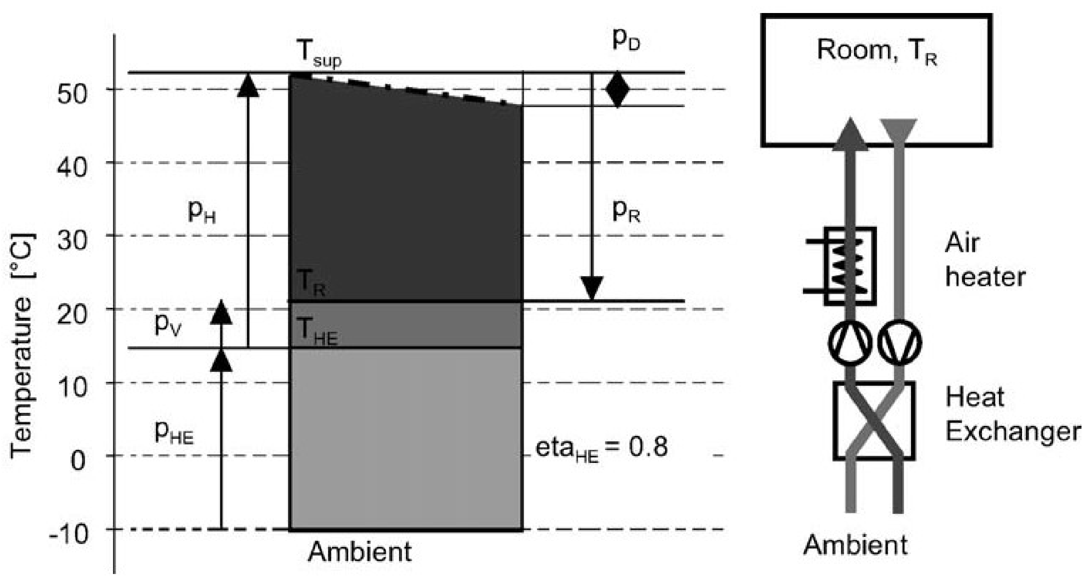

Figure 6. Heat delivered to the room and required heating power /7, p. 10/.

where	p_{HE}	heat transfer from heat exchanger
	p_H	heating power of air heater
	p_V	part of heating power compensating “ventilation losses”
	p_R	heat delivered to room by air
	p_D	heat delivered through duct case (to room)
	T_{HE}	air temperature after heat exchanger
	T_{sup}	supply air temperature
	T_R	room air temperature

Multizone air flow simulations show that heat is well distributed between the rooms by forced ventilation, transmission through internal walls and by convective air currents. Sufficient heat distribution gives us an advantage when designing and considering the placement of air terminal devices. The design can be more flexible because even if only the rooms in the supply zone are actively heated, the surplus heat will transfer to adjacent rooms with ease. However, while distributing air between rooms in a dwelling is no problem, maintaining different temperature settings in rooms is rather difficult. This means that while heat distribution patterns that air heating systems produce might be of help to design a passive house, it can be challenging for the designer, when trying to design a building which for some reason have rooms with different temperature settings. Research states that duct insulation is not obligatory but can be of help when trying to achieve sufficient distribution of heat between rooms with different temperature settings. Alternative duct materials can also be used instead of insulation. Conventional duct and insulation materials have negligible thermal mass, but when the distribution system is partially or completely imbedded in building structures with high thermal mass, the building delays the heat transfer. This can cause irritation of occupants and overall increased discomfort if heating system is expected to react quickly to changed settings. Moreover, combining heating and ventilation systems means that the supply air temperatures will vary greatly during the heating season, depending on the heat energy required by building to ensure thermal comfort for occupants. The research states that temperature differences between the rooms and air terminal devices vary from +20K at maximum heating load, to -8K when heater is off. This leads to air flow patterns varying greatly depending on the temperature difference. Simulating building with transient building simulation TRNSYS showed that there is no dominant temperature difference during the season. Also internal heat gains interact with air flow patterns greatly. Thus, an optimal placement for air terminal device is unknown.

Regarding the overall thermal comfort in the supply rooms both researches produced similar results. The test room that was set up by reaserches at EMPA, confirmed the results obtained by the research in Sweden. Measurements at

EMPA show that despite the type of air terminal device, a good thermal climate and air exchange efficiency shoud be produced by heating through ventilation for both largely negative and largely positive temperature differences. The performance of air patterns between these two extreme conditions shoud be even better. A simple grille with a device to regulate the flow shoud work almost as good as far throw nozzle with adjustable flow, which works better only in largely negative temperature differences. Air exchange efficiency is better when air gap is left below the door.

In conclusion, type and position of supply air terminal device do not intervene with thermal comfort greatly. Other aspects, such as accustics, price and ease of installation may have priority when considering type and placement of air terminal devices. Combination with wood stoves was also discussed in the research which is not an option in my case when designing an office building.

4 METHODS

During this research the combined system was designed in a theoretical office building in Finland and was compared to traditional system to better reflect the idea of the thesis and to do the necessary calculations. The main reason for choosing Finland over other countries is because I'm more familiar with it's building codes, regulations and climate overall. Finland's climate requires well insulated office buildings to have both heating at winter season and air conditioning in summer which is perfect for my study. Also the EU regulations set the rhythm for construction industry to improve the insulation and energy efficiency of the buildings significantly over time. To make research more rational and practical I will design systems taking the properties of an ordinary office building using the latest building standarts to ensure sufficient building envelope and to emphasize the reasonability of this new approach. Better insulation in the future would only produce better results, because less energy and thus less hot air would be needed which would simplify the system even more.

4.1 One story office building

The object I chose to analyse is a drawing of theoretical one story office building located in Oulu. The properties of building (Table 1) and it's environment were used from the building standarts, assuming that an ordinary office building is built in Oulu.

Table 1. Building design information

Building location	U - values (W/m^{2}K)						Leakage coeficient (1/h)
	Roof	Floor	Windows	Doors	Exterior walls	Internal Walls	
Oulu	0,08	0,12	0,80	1,00	0,15	3,00	0,16

The building belongs to the third climatic zone where design outdoor air temperature is -32°C (Figure 7 and Table 2).

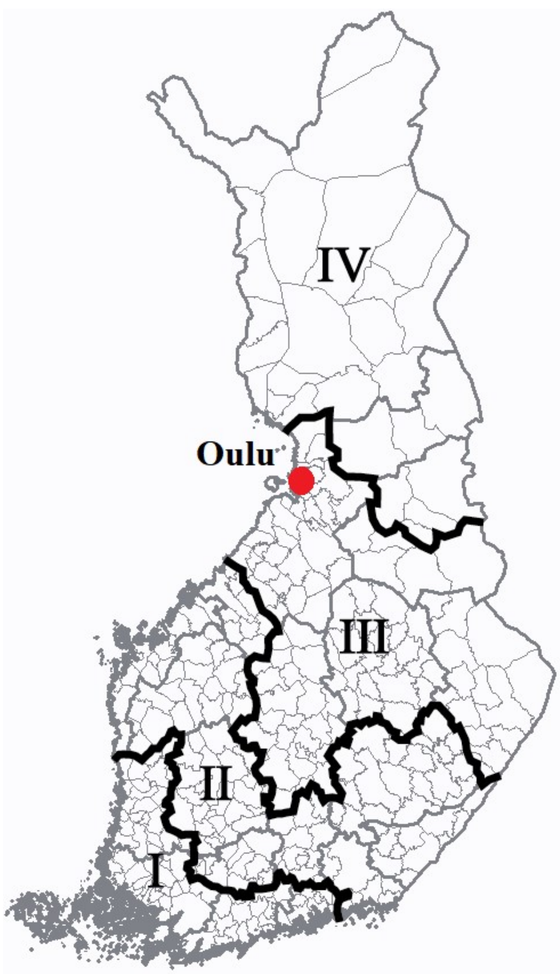

Figure 7. Climatic zones of Finland and destination of Oulu /3, p. 16/

Table 2. Design outdoor air temperatures for various climatic zones

Climatic zone	Design outdoor air temperature, °C
I	-26
II	-29
III	-32
IV	-38

According to monthly weather data for climatic zone III, the average outdoor air temperature of the entire year T_o = 3.43°C /9, p. 19/.

4.2 Software for calculations

The Autocad and MagiCAD softwares were used to design the systems and calculate heat losses. These softwares help aquire data faster and more reliable. Further calculatons like expenses were done with Microsoft Excel for fast data analysis and visualization.

4.3 Formulas used in calculations

To analyse the system, total heat losses of different rooms are calculated according to Equation 1.

$$Qtot = Qstr + Qleak + Qsup \tag{1}$$

where	Q_{tot}	total heat losses of room	[W]
	Q_{str}	structural heat losses	[W]
	Q_{sup}	supply airflow heat loss	[W]
	Q_{leak}	leak heat loss	[W]

After that, airflows needed to heat different rooms are calculated using Equation 2.

$$Qvsuph = \frac{Qtot}{\rho c(Tsup - Td)} \tag{2}$$

where			
	Qv_{suph}	Airflow needed to heat the rooms	[l/s]
	Q_{tot}	total heat losses of room	[W]
	T_{sup}	Recommended maximum supply air temperature	[K]
	T_d	designed room air temperature	[K]
	c	specific heat capacity of air	[kJ/kg·K]
	ρ	fluid density	[kg/m^3]

The difference in energy supply is then calculated according to difference of originally designed and recalculated air flows in air heating case using Equation 3.

$$\Delta W \Delta Qvsup = \Delta Qvsup \cdot \ \rho \cdot c \cdot (Tsup - Td) \tag{3}$$

where			
	$\Delta W_{\Delta Qvsup}$	difference in energy supply according to difference of originally designed and recalculated airflows	[W]
	ΔQ_{vsup}	difference of originally designed and recalculated air flows in air heating case	[l/s]
	T_{sup}	Recommended maximum supply air temperature	[K]
	T_d	designed room air temperature	[K]
	c	specific heat capacity of air	[kJ/kg·K]
	ρ	fluid density	[kg/m^3]

5 RESULTS

5.1 Technical analysis

5.1.1 Separate systems

Analysis of drawings was done to the office building containing separate heating and ventilation systems (see Appendix 1, 2). Energy calculations as well as design information were taken from these drawings and air change rates were calculated in different rooms (see Appendix 4).

Table 3. Building design information and calculated air change rates (extract from appendix 4)

Room name	V, m^3	T_d, °C	T_{sup}, °C	Qv_{sup}, l/s	Qv_{ext}, l/s	n
Office room 1	43	21	18	20	18	1,7
Office room 2	55,6	21	18	26	23	1,7
Office room 3	31,3	21	18	15	13	1,7
Office room 4	55,4	21	18	26	23	1,7
Office room 5	65	21	18	30	27	1,7
Meeting room	43,5	21	18	85	70	7,0
Break room	24,2	21	18	38	38	5,7
Information room	17,9	21	18	8	7	1,6
Storage room 1	16,9	21	18	0	5	1,1
Storage room 2	29,3	21	18	0	5	0,6
Entry room	13,6	21	18	0	5	1,3
Copy room	25,8	21	18	19	32	2,7
Corridor	104,1	21	18	34	0	1,2
WC 1	14,1	21	18	0	20	5,1
WC 2	15,8	21	18	0	20	4,6
Technical room	36	18	18	0	40	4,0
SUM	**591,5**			**301**	**346**	

As we can see from table 3, the highest air change rates are in meeting room and break room. These are the rooms where larger number of people tend to stay for shorter period of times. These are going to be the most problematic rooms when designing heating through ventilation because not only they will have higher internal gains coming from people, but also higher airflows, which mean higher energy supply. This can result in room overheating. There are also rooms like storage room or WC where only extract ventilation is used. Although these rooms don’t need supply ventilation according to the design drawing, they all have heat losses. This means that energy one way or another has to be supplied to the room. To further analyse the system, total heat losses of different rooms were calculated according to Equation 1.

Table 4. Heat losses of different rooms (extract from appendix 4)

Room name	Q_{str}, W	Q_{leak}, W	Q_{sup}, W	Q_{tot}, W
Office room 1	419	121	73	613
Office room 2	554	157	94	805
Office room 3	207	89	53	349
Office room 4	550	157	93	800
Office room 5	521	184	110	815
Meeting room	343	123	306	772
Break room	167	68	136	371
Information room	37	51	30	118
Storage room 1	164	48	0	212
Storage room 2	59	83	0	142
Entry room	242	38	0	280
Copy room	53	73	70	196
Corridor	636	294	122	1052
WC 1	29	40	0	69
WC 2	110	45	0	155
Technical room	121	96	0	217
SUM	**4212**	**1667**	**1087**	**6966**

In table 4 we can see that structural heat losses account for the highest portion of total heat losses. Although as expected, meeting room and break room have a large portion (around 50%) of their total heat losses coming from supplied air. This is because temperature of air supplied to the room is only 18°C while the required air temperature in the room is 21°C. Higher air change rates in these rooms mean that radiators have to heat more air and thus compensate for the 3°C difference.

5.1.2 Combined systems

From the total heat losses acquired, and knowing that the maximum air temperature that can be supplied to the room is 36°C, I was able to calculate the airflows (Qv_{suph}) that need to be supplied to the room in order to cover heat losses (Table 5) using Equation 2.

Table 5. Analysis of airflows needed for the building (extract from appendix 5)

Room name	V, m^3	T_d, °C	T_{sup}, °C	Qv_{supv}, l/s	Qv_{suph}, l/s	n_h
Office room 1	43	21	36	20	34	2,9
Office room 2	55,6	21	36	26	45	2,9
Office room 3	31,3	21	36	15	19	2,2
Office room 4	55,4	21	36	26	44	2,9
Office room 5	65	21	36	30	45	2,5
Meeting room	43,5	21	36	85	43	3,5
Break room	24,2	21	36	38	21	3,1
Information room	17,9	21	36	8	7	1,3
Storage room 1	16,9	21	36	0	12	2,5
Storage room 2	29,3	21	36	0	8	1,0
Entry room	13,6	21	36	0	16	4,1
Copy room	25,8	21	36	19	11	1,5
Corridor	104,1	21	36	34	58	2,0
WC 1	14,1	21	36	0	4	1,0
WC 2	15,8	21	36	0	9	2,0
Technical room	36	18	36	0	10	1,0
Sum				**301**	**385**	

After aquiring airflows needed to heat the rooms, the air change rates were recalculated according to these flows (Appendix 5). As we can see from Table 4, the air change rates are much higher than needed in office building according to building standarts. In office rooms air change rates almost doubled compared to the ones designed with separate systems. On the other hand, the air change rates in break room and meeting room decreased by half. This is because airflows that are needed to cover demand of heat loss are different from those that were originally designed in building. In the combined system the difference in airflows also brings difference in energy supply, because the enegy comes together with air supllied to the room. The difference in energy supply was then calculated according to difference of originally designed and recalculated air flows in air heating case using Equation 3.

Table 6. Difference in energy supply (extract from appendix 5)

Room name	T_d, °C	T_{sup}, °C	Qv_{supv}, l/s	Qv_{suph}, l/s	ΔQv_{sup}	$\Delta W_{\Delta Qvsup}$, W
Office room 1	21	36	20	34	-14	-253
Office room 2	21	36	26	45	-19	-337
Office room 3	21	36	15	19	-4	-79
Office room 4	21	36	26	44	-18	-332
Office room 5	21	36	30	45	-15	-275
Meeting room	21	36	85	43	42	758
Break room	21	36	38	21	17	313
Information room	21	36	8	7	1	26
Storage room 1	21	36	0	12	-12	-212
Storage room 2	21	36	0	8	-8	-142
Entry room	21	36	0	16	-16	-280
Copy room	21	36	19	11	8	146
Corridor	21	36	34	58	-24	-440
WC 1	21	36	0	4	-4	-69
WC 2	21	36	0	9	-9	-155
Technical room	18	36	0	10	-10	-217
Sum			**301**	**385**	**-84**	**-1548**

From the results obtained with these calculations it was clear that if airflows were to be left like thay were originally designed, the building would still need extra 1,5kW of energy to cover the demand of heating power (Appendix 5). Also, while some rooms need an increase in airlfows, other rooms need reduced air flows. This means that while majority of rooms would lack energy, there are some rooms like meeting room and break room, that would be overheated significantly. To solve these problems, firstly, the higher airflow was chosen in order to cover heat demand or to provide enough clean air for people. After that, heat balancing work was done. The airflows in rooms, surrounding the overheated rooms were decreased in order to increase heat transfer between rooms and for surplus heat to transfer from overheated rooms (Appendix 5).

Table 7. Heat balancing (extract from appendix 5)

Room name	Qv_{supv}, l/s	Qv_{suph}, l/s	ΔQv_{sup}	$\Delta W_{\Delta Qvsup}$, W	$\Delta W_{balance}$, W	Qv_{supb}, l/s
Office room 1	20	34	-14	-253	-37	32
Office room 2	26	45	-19	-337	5	45
Office room 3	15	19	-4	-79	-7	19
Office room 4	26	44	-18	-332	-80	40
Office room 5	30	45	-15	-275	-5	45
Meeting room	85	43	42	758	758	85
Break room	38	21	17	313	313	38
Information room	8	7	1	26	26	8
Storage room 1	0	12	-12	-212	-212	0
Storage room 2	0	8	-8	-142	-142	0
Entry room	0	16	-16	-280	-280	0
Copy room	19	11	8	146	-196	0
Corridor	34	58	-24	-440	82	63
WC 1	0	4	-4	-69	-69	0
WC 2	0	9	-9	-155	-155	0
Technical room	0	10	-10	-217	-1	10
Sum	**301**	**385**	**-84**	**-1548**	**0**	**385**

With the new airflows obtained after heat balancing, the combined system was designed according to building standarts and using recommendations from other researches discussed in this thesis. The designed parameters of combined system are presented in Table 8.

Extract ventilation was designed in a way for the transfer air to travel from clean rooms, where people work, to rooms like storage room or WC while also taking into account the transfer air flow patterns. To distribute heat evenly in the building the transfer air was designed in a way for the overheated rooms to transfer a portion of it‘s supply air together with surplus energy to rooms that only have extract ventilation and lacks heating energy. This way the rooms that only have extract ventilation should get it‘s heating energy not only by conductive heat through walls, but also with warm transfer air that enters the room from surrounding heated spaces.

Table 8. Designed parameters of combined system

Room name	V, m^3	T_d, °C	T_{sup}, °C	Qv_{supb}, l/s	Qv_{ext}, l/s	n
Office room 1	43	21	36	32	24	2,7
Office room 2	55,6	21	36	45	35	2,9
Office room 3	31,3	21	36	19	15	2,2
Office room 4	55,4	21	36	40	34	2,6
Office room 5	65	21	36	45	33	2,5
Meeting room	43,5	21	36	85	35	7,0
Break room	24,2	21	36	38	24	5,7
Information room	17,9	21	36	8	0	1,6
Storage room 1	16,9	21	36	0	15	3,2
Storage room 2	29,3	21	36	0	50	6,1
Entry room	13,6	21	36	0	20	5,3
Copy room	25,8	21	36	0	0	0,0
Corridor	104,1	21	36	63	45	2,2
WC 1	14,1	21	36	0	25	6,4
WC 2	15,8	21	36	0	20	4,6
Technical room	36	18	36	10	10	1,0
Sum				**385**	**385**	

For the rooms that only have extract ventilation to get the heat required to cover heat losses, door grilles have to be installed in every room. Also some grilles have to be installed in walls to ensure sufficient heat distribution. This is done for example in copy room. The surplus heat carried with transfer air from meeting room reaches copy room, and then travels further to storage room which only has extract ventilation, is in constant underpressure and has a heating demand of 142W.

5.1.3 Heating algorithm

Each room has both supply and extract ventilation branches designed with automatic damper that controls airflow and temperature of air according to temperature setting of the individual room. Temperature sensors should be placed in a room to give information for these dampers. The automatic valve should be programmed so that firstly if heating demand of room decreases, it should react by closing the damper for the air to reach designed air flow needed for sufficient indoor climate. After reaching this limit it should give impulse for the main heating coil to reduce heating power. This way, the rooms should have the minimum designed air flows, needed for people to have clean air, supplied to room all the time. This process is explained in detail below (Figure 8).

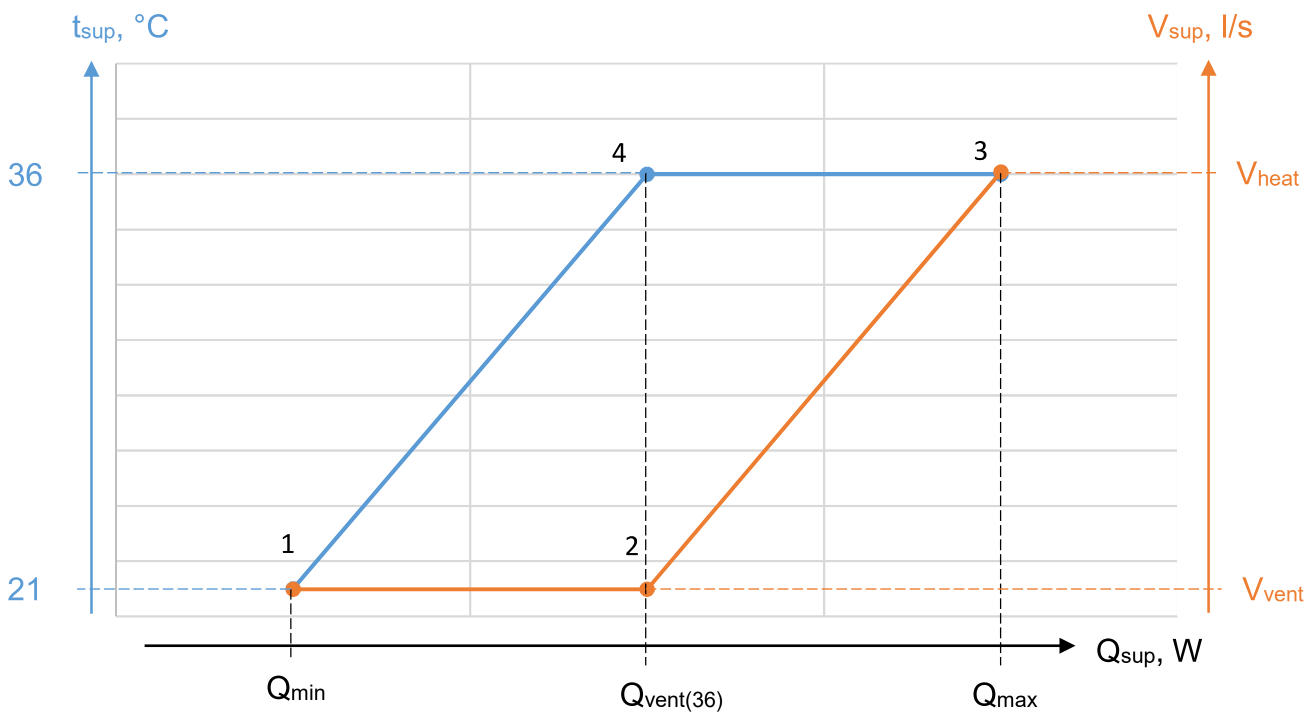

Figure 8. Heating algorithm

Heating algorithm consists of 4 processes:

1-2 temperature increase

2-3 volume increase

3-4 volume decrease

4-1 temperature decrease

Each room has its heat supply controlled by the following algorithm:
At the start of the heating season (Q_{min}), the standard ventilation air volumes are kept constant (V_{vent}) while the supply air temperature is being increased above 21°C to compensate the increasing heat demand of the rooms. When the heat demand further increases ($Q_{vent(36)}$) and the supply air temperature peaks at the maximum designed (36°C), the standard supply air volume for ventilation cannot carry any more heat, therefore it is starting to increase as well. It reaches its peak

(V_{heat}) at the design conditions when there is maximum amount of heat needed (Q_{max}), e.g. in the coldest period of the season.

5.2 Economic evaluation

5.2.1 Cost of materials

To evaluate economic reasons I consulted local manufacturer of ventilation equipment UAB Leovira, located in Vilnius, Lithuania for ease of communication. They made different commercial offers for ventilation pipes, fittings and air handling units for both separate and combined systems (Appendices 6, 7, 8, 9). The commercial offers they provided me with showed that the ventilation ducts and fittings for separate system drawing would cost 4361EUR while the total amount for combined system was 7235EUR. The main difference in the price of these systems was due to expensive gears for flow dampers, that are needed in combined heating and ventilation case, to ensure sufficient control of indoor climate.

An expert in air handling units from UAB Leovira, suggested to use Lesstro R1200VE-DE in separate system. This AHU has nominal air flow of 1200 m^3/h, 0,96 SFP value and annual efficiency of 65,2%. For combined system he suggested Lesstro R1400VE-DE with nominal air flow of 1400 m^3/h, 1,26 SFP value and annual efficiency of 62.3%. The price difference of these two AHUs is only 600EUR and there is not much difference between the parameters of these AHUs (Appendix 10).

To evaluate the costs of the hydronic system I exported bill of materials from the drawing of separate systems using magicad software. Then I evaluated all the products separately, using websites of local resellers such as “Vilpra” /8/ and “Jaukurai” /9/. The total price of hydronic system I calculated was 6585EUR which is almost the same as the price for ventilation system in separate systems case. The total costs and price differences are presented in table 9 below.

Table 9. Economical evaluation of different systems

Product	**Combined system**	**Separate system**		**Price difference**
		hydronic	**ventilation**	
ducts/pipes + fit	7 235 €	6 585 €	4 361 €	2 874 €
AHUs	2 490 €	x	1 871 €	619 €
TOT	9 725 €	6 585 €	6 232 €	
TOT	**9 725 €**	**12 817 €**		**-3 092 €**

From table 9 we can see that when comparing the total costs of materials between two systems, approximately 25% of total cost for materials would be saved when designing combined system.

5.2.2 Installation and maintenance

When visiting local manufacturer UAB Leovira and consulting about the cost of the ventilation systems, their engineer technologist said that there would be not much difference in the price of installation between the two systems. This is because the systems are similar when looking from installation point of view. Their main price difference is due to gears and flow dampers and while there might be more work to adjust the flow dampers, the amount of work needed to install both systems would be almost the same. This means that combined system gives us opportunity to install only one system and reduce the cost of installation by the same amount that would be required to install the hydronic system.

Unfortunately the same priciples as evaluating the cost of installation cannot be applied when talking about the cost of maintenance. The combined sytem design is still a new approach and requires more supervision then conventional systems. During first stages of operation, filters should be checked and duct casings as well as other duct components should be inspected more often for dust carbonization and other pollutants that may occur in higher air temperatures. Thermal distribution should also be inspected during winter and summer seasons and building occupants shoud be surveyed to better understand thermal conditions in the building. Flow dampers should be readjusted or recalibrated if needed to ensure good thermal environment. All these precautionary measures are highly recommended to be done during first years of combined system operation. All these measures also apply to conventional systems, although the probability for something to go wrong is higher for combined system, because of higher temperatures, air flow rates and difficulty in heat balancing. Although there are no exact numbers of how much all these precautions bring the price of maintenance up for combined system, compared to traditional one, maintaining one system is easier, than taking care of two. Hydronic systems, for example, produce higher risk of leakage damage, because leakage water can damage building equipment, while the most harm that leakage air can do is cause imbalance in thermal distribution. In separate system design, both ventilation and hydronic systems should be inspected from time to time, while in combined system all the workload goes to one system.

6 DISCUSSION

This study was designed to evaluate the reasonability of combining heating and ventilation systems into one holistic system. The combined system was researched from both technological and economic perspectives. During this research the combined system was designed in a theoretical office building and was compared to traditional system to better reflect the idea of the thesis and to do the necessary calculations.

From economical point of view the main results showed that the combined system is 65% more expensive when comparing to traditional ventilation system due to expensive gears and flow dampers. However it replaces both conventional hydronic and ventilation systems and when comparing the total cost of materials approximately 25% of total cost for materials would be saved when designing combined system. The findings also suggest that combined system gives us opportunity to install only one system and reduce the cost of installation by the same amount that would be required to install the hydronic system. Furthermore, in separate system design, both ventilation and hydronic systems should be inspected from time to time, while in combined system all the workload goes to one system.

From technological point of view the system is fairly easy to design with respect to the values and desing recommendations that are presented and discussed in earlier researches on the same subject. It is easy to maintain required heating capacity without increasing supply air flow rates to unreasonable amounts. In combined system the total supply air required to heat the building was only 20% larger than the one designed to be supplied in conventional system. During this research basic guidelines were achieved that are needed to design the combined centralised air heating and ventilation system. The hardest thing in designing this type of system, as expected, turned out to be balancing and maintaining required temperatures in rooms where larger number of people tend to stay for shorter period of times. The results showed that meeting room and break room would be overheated significantly if the air that is required by number of occupants would be supplied in combined heating case. The amount of heating energy supplied to these rooms would be two times larger than required to cover total heat losses. The balancing problem was solved by carefully redesigning flow patterns with respect to heat distribution. However many heat calculation iterations would be needed or sophisticated simulation software should be used to precisely calculate heat distribution in rooms and within the building.

In conclusion, combined heating and ventilation system has a lot of potential. While building standarts continue to get stricter with respect to energy savings, they give potential for HVAC systems to be simplified. Simplified combined system migh bring both economical and technical benefits though it still needs further research. Balancing work with respect to heat distribution and air flow patterns would be my suggestion for future studies to further analyse the potential of this system.

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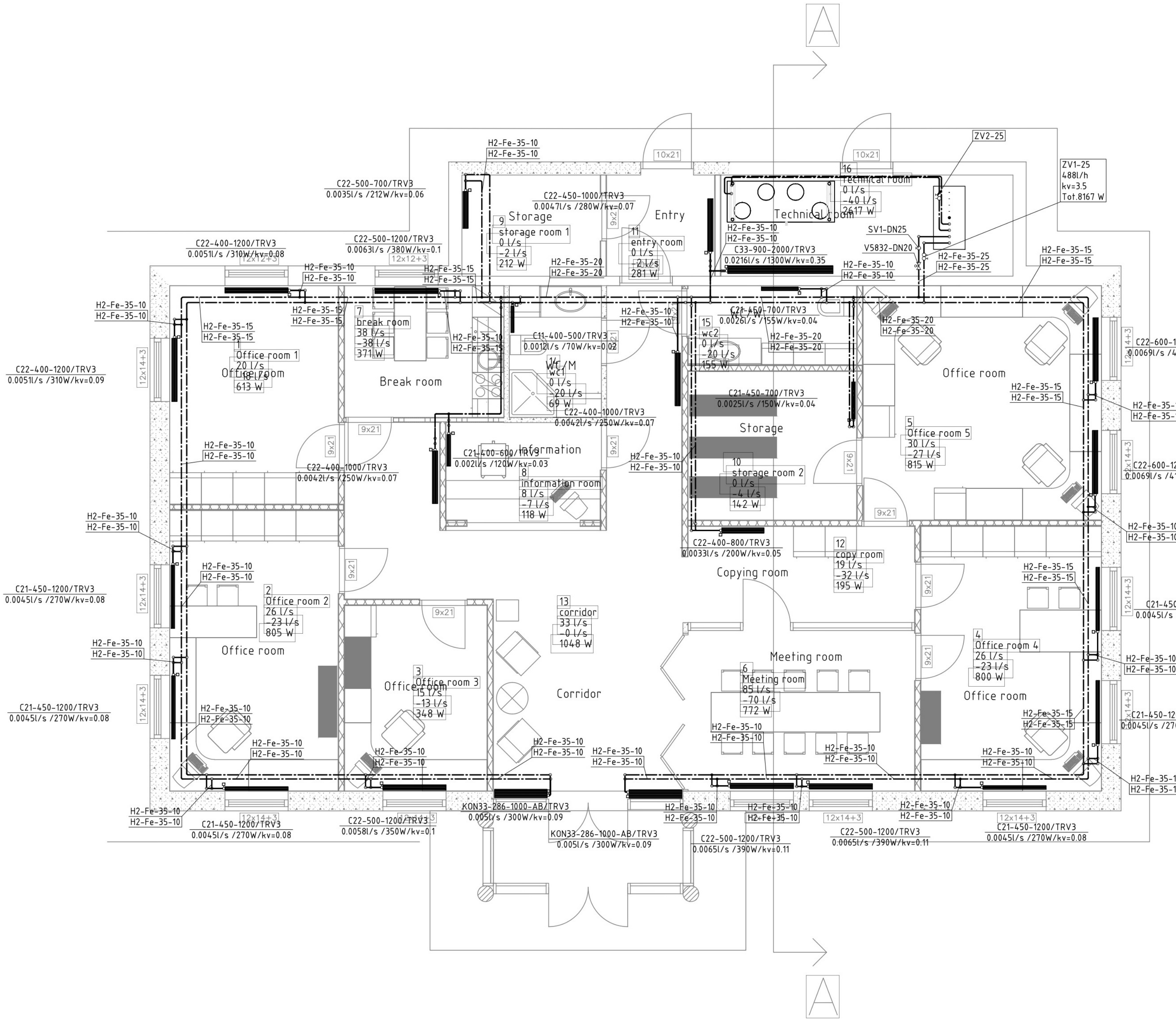
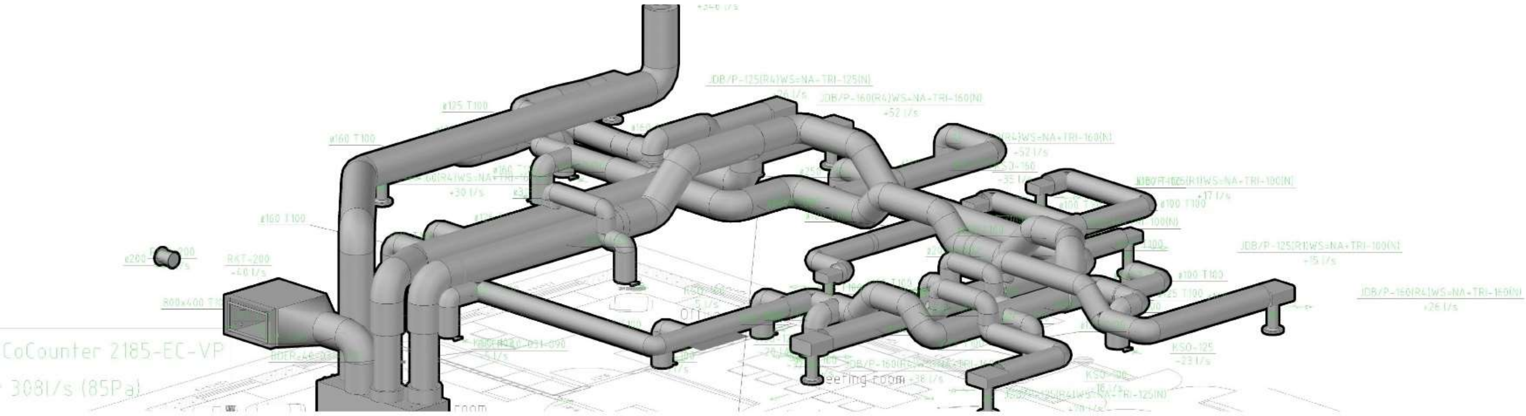
Appendix 1

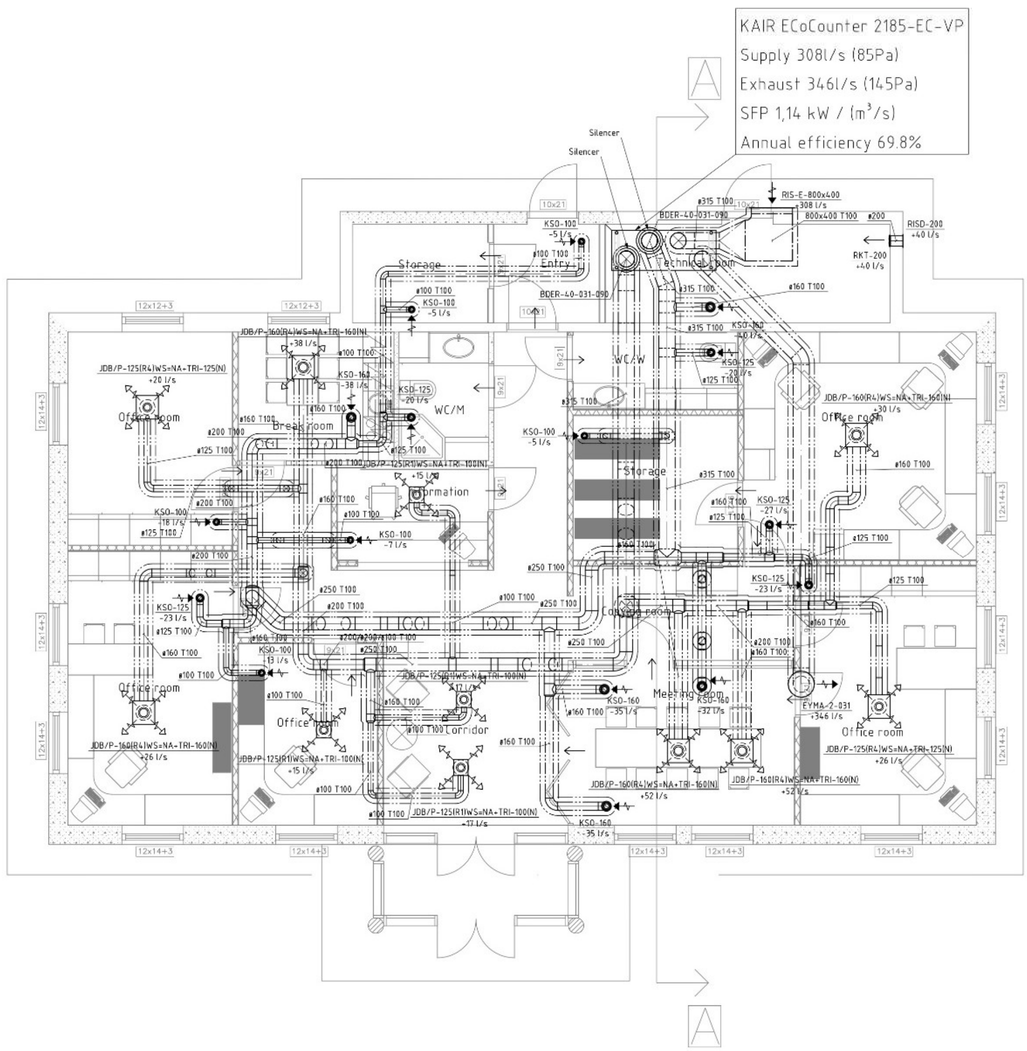
Building drawing with separate systems (heating system - radiators)



Appendix 2

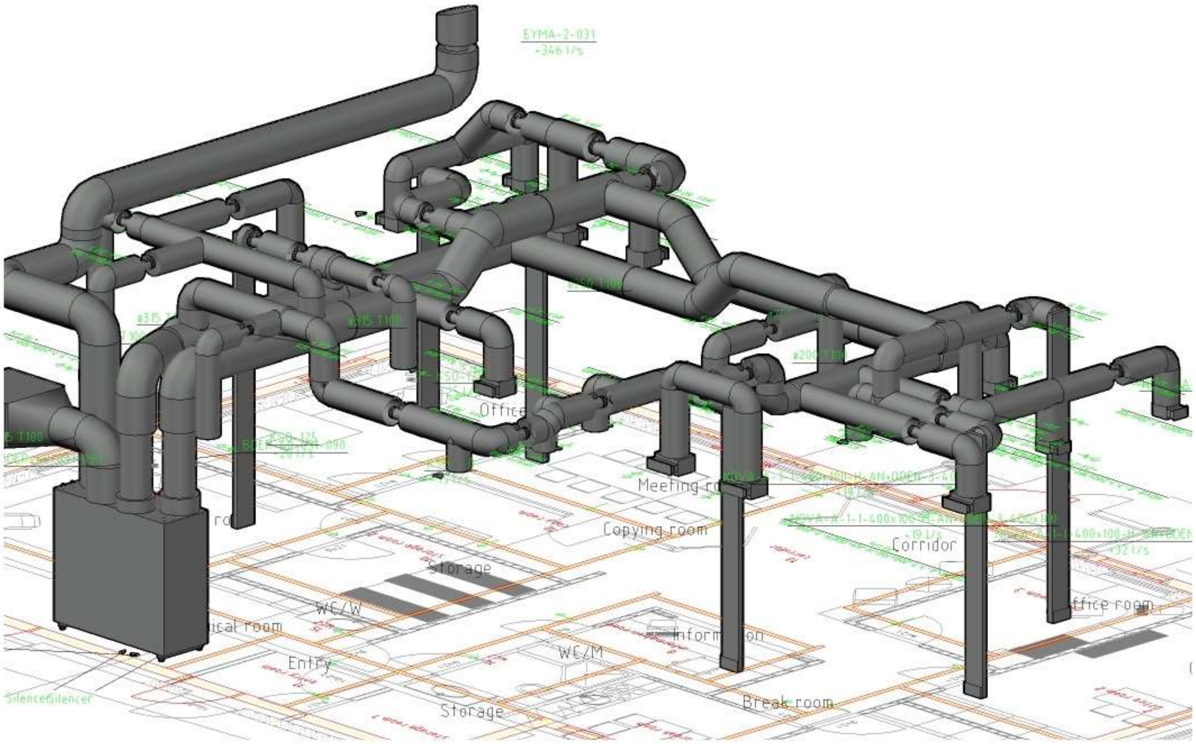
Building drawing with separate systems (ventilation system)

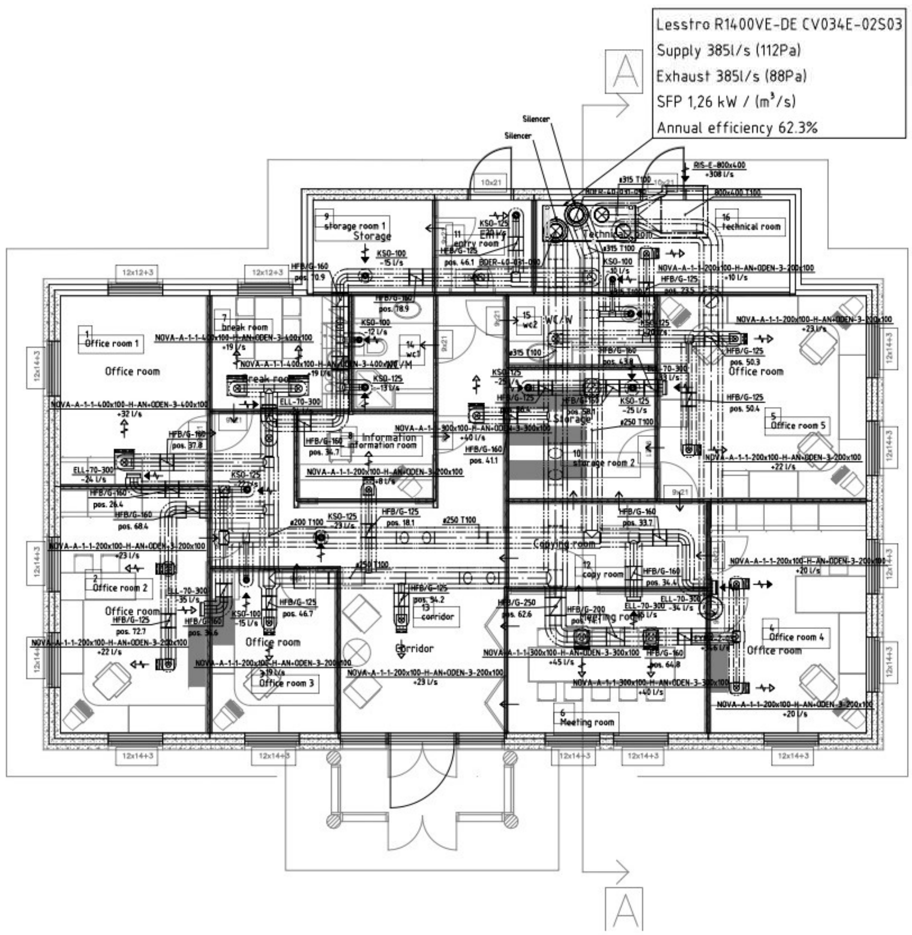




Appendix 3

Building drawing with combined system (heating with ventilation)





Appendix 4

Analysis of building drawings with separate systems

Room name	V, m^3	T_d, °C	T_{sup}, °C	Qv_{sup}, l/s	Qv_{ext}, l/s	n	Q_{str}, W	Q_{leak}, W	Q_{sup}, W	Q_{tot}, W
Office room 1	43	21	18	20	18	1,7	419	121	73	613
Office room 2	55,6	21	18	26	23	1,7	554	157	94	805
Office room 3	31,3	21	18	15	13	1,7	207	89	53	349
Office room 4	55,4	21	18	26	23	1,7	550	157	93	800
Office room 5	65	21	18	30	27	1,7	521	184	110	815
Meeting room	43,5	21	18	85	70	7,0	343	123	306	772
Break room	24,2	21	18	38	38	5,7	167	68	136	371
Information room	17,9	21	18	8	7	1,6	37	51	30	118
Storage room 1	16,9	21	18	0	5	1,1	164	48	0	212
Storage room 2	29,3	21	18	0	5	0,6	59	83	0	142
Entry room	13,6	21	18	0	5	1,3	242	38	0	280
Copy room	25,8	21	18	19	32	2,7	53	73	70	196
Corridor	104,1	21	18	34	0	1,2	636	294	122	1052
WC 1	14,1	21	18	0	20	5,1	29	40	0	69
WC 2	15,8	21	18	0	20	4,6	110	45	0	155
Technical room	36	18	18	0	40	4,0	121	96	0	217
SUM	**591,5**			**301**	**346**		**4212**	**1667**	**1087**	**6966**

Appendix 5

Analysis of airflows needed for the building

Room name	V, m^3	T_d, °C	T_{sup}, °C	Qv_{supv}, l/s	Qv_{suph}, l/s	n_h	ΔQv_{sup}	$\Delta W_{\Delta Qvsup}$, W	$\Delta W_{balance}$, W	Qv_{supb}, l/s
Office room 1	43	21	36	20	34	2,9	-14	-253	-37	32
Office room 2	55,6	21	36	26	45	2,9	-19	-337	5	45
Office room 3	31,3	21	36	15	19	2,2	-4	-79	-7	19
Office room 4	55,4	21	36	26	44	2,9	-18	-332	-80	40
Office room 5	65	21	36	30	45	2,5	-15	-275	-5	45
Meeting room	43,5	21	36	85	43	3,5	42	758	758	85
Break room	24,2	21	36	38	21	3,1	17	313	313	38
Information room	17,9	21	36	8	7	1,3	1	26	26	8
Storage room 1	16,9	21	36	0	12	2,5	-12	-212	-212	0
Storage room 2	29,3	21	36	0	8	1,0	-8	-142	-142	0
Entry room	13,6	21	36	0	16	4,1	-16	-280	-280	0
Copy room	25,8	21	36	19	11	1,5	8	146	-196	0
Corridor	104,1	21	36	34	58	2,0	-24	-440	82	63
WC 1	14,1	21	36	0	4	1,0	-4	-69	-69	0
WC 2	15,8	21	36	0	9	2,0	-9	-155	-155	0
Technical room	36	18	36	0	10	1,0	-10	-217	-1	10
Sum				**301**	**385**		**-84**	**-1548**	**0**	**385**

Appendix 6/1

Page 1 of UAB Leovira commercial offer for ventilation ducts and fittings (separate systems)

COMMERCIAL OFFER

No. 2020-01784
2020-04-27

Terms of payment : 0 d.

Seller :	Buyer :
UAB LEOVIRA, į. k.:124921964	**Kajus Laurynas Motekūnas, 1994-10-03:**
Address : Žarijų str. 4, Vilnius	Adresas :
A./s. : LT227044060000388381, AB SEB bank, Bank code: 70440 LT724010049501382371, Luminor Bank AB, Bank code: 40100	A./s. :

*Price without VAT

Row No.	Name (products, services)	Units	Quantity	Price* EUR	Discount (%)	Discounted price without VAT	Price without VAT EUR
1	Circular duct OSL 100 C-0,4	m	24,00	2,11	25,00	1,58	37,98
2	Circular duct OSL 125 C-0,4	m	12,00	2,67	25,00	2,00	24,03
3	Circular duct OSL 160 C-0,4	m	27,00	3,39	25,00	2,54	68,65
4	Circular duct OSL 200	m	9,00	4,11	25,00	3,08	27,74
5	Circular duct OSL 250	m	12,00	5,27	25,00	3,95	47,43
6	Circular duct OSB 315 C-0,45	m	24,00	7,18	25,00	5,39	129,24
7	Rectangular duct SOP 800x400 L-1250	pcs	1,00	73,00	37,00	45,99	45,99
8	Circular bend BU-45 d-160	pcs	2,00	8,69	45,00	4,78	9,56
9	Circular bend BU-45 d-200	pcs	3,00	11,50	45,00	6,32	18,97
10	Circular bend SAG-45° d-250	pcs	9,00	11,20	42,00	6,50	58,46
11	Circular bend SAG-45° d-315	pcs	3,00	16,00	42,00	9,28	27,84
12	Circular bend BU-90 d-100	pcs	21,00	6,38	45,00	3,51	73,69
13	Circular bend BU-90 d-125	pcs	14,00	7,62	45,00	4,19	58,67
14	Circular bend BU-90 d-160	pcs	15,00	10,87	45,00	5,98	89,68
15	Circular bend SAG-90° d-200	pcs	2,00	12,58	42,00	7,30	14,59
16	Circular bend SAG-90° d-250	pcs	5,00	15,04	42,00	8,72	43,62
17	Circular bend SAG-90° d-315	pcs	5,00	21,10	42,00	12,24	61,19
18	Rectangular bend SAL-90° 800x400	pcs	1,00	124,00	37,00	78,12	78,12
19	T-branch TSHFL 100-100-100	pcs	1,00	6,74	40,00	4,04	4,04
20	T-branch TSHFL 125-125-125	pcs	1,00	7,96	40,00	4,78	4,78
21	T-branch TAG 160-160-100	pcs	2,00	10,07	42,00	5,84	11,68
22	T-branch TAG 160-160-125	pcs	2,00	11,25	42,00	6,53	13,05
23	T-branch TSHFL 160-160-160	pcs	1,00	11,06	40,00	6,64	6,64
24	T-branch TAG 200-200-100	pcs	3,00	12,15	42,00	7,05	21,14
25	T-branchTAG 200-200-160	pcs	5,00	15,15	42,00	8,79	43,93
26	T-branch TAG 250-250-100	pcs	1,00	15,85	42,00	9,19	9,19
27	T-branchTAG 250-250-160	pcs	2,00	19,23	42,00	11,16	22,31
28	T-branch TAG 250-250-200	pcs	1,00	21,30	42,00	12,35	12,35
29	T-branch TSHFL 250-250-250	pcs	1,00	21,40	40,00	12,84	12,84
30	T-branch TAG 315-315-100	pcs	1,00	16,76	42,00	9,72	9,72
31	T-branch TAG 315-315-125	pcs	1,00	18,64	42,00	10,81	10,81
32	T-branch TAG 315-315-160	pcs	1,00	20,90	42,00	12,12	12,12
33	T-branch TAG 315-315-250	pcs	1,00	25,70	42,00	14,91	14,91
34	T-branch TSHFL 315-315-315	pcs	1,00	32,50	40,00	19,50	19,50
35	Coupling NVG 100	pcs	1,00	3,46	45,00	1,90	1,90
36	Coupling NVG 250	pcs	2,00	6,18	45,00	3,40	6,80
37	Coupling NVG 315	pcs	1,00	7,30	45,00	4,01	4,01
38	Reducer/Expander RCU 125/100	pcs	1,00	5,10	45,00	2,80	2,80
39	Reducer/Expander RCU 160/100	pcs	1,00	5,42	45,00	2,98	2,98
40	Reducer/Expander RCU 160/125	pcs	9,00	5,42	45,00	2,98	26,83
41	Reducer/Expander RCU 200/125	pcs	1,00	6,84	45,00	3,76	3,76
42	Reducer/Expander RCU 200/160	pcs	4,00	6,98	45,00	3,84	15,36
43	Reducer/Expander RCU 250/160	pcs	1,00	9,30	45,00	5,11	5,11
44	Reducer/Expander RCU 250/200	pcs	3,00	9,48	45,00	5,21	15,64

Appendix 6/2

Page 2 of UAB Leovira commercial offer for ventilation ducts and fittings (separate systems)

45	Reducer/Expander RCU 315/200	pcs	1,00	15,10	45,00	8,30	8,30
46	Reducer/Expander RCU 315/250	pcs	2,00	13,82	45,00	7,60	15,20
47	Square to round SAP 800x400-315	pcs	1,00	82,00	37,00	51,66	51,66
48	Reducer/Expander SLP 150x150 (125x125/125x125)	pcs	1,00	22,30	37,00	14,05	14,05
49	Reducer/Expander SLP 200x200 (160x160/160x160)	pcs	1,00	25,60	37,00	16,13	16,13
50	Outdoor grille LGC 800x400 (RIS-E-800x400)	pcs	1,00	92,00	38,00	57,04	57,04
51	Outdoor grille USAV 200 (RISD-200)	pcs	1,00	7,43	44,00	4,16	4,16
52	Supply air device ZN 100	pcs	4,00	5,59	60,00	2,24	8,94
53	Supply air device ZN 125	pcs	2,00	6,84	60,00	2,74	5,47
54	Supply air device ZN 160	pcs	5,00	10,56	60,00	4,22	21,12
55	Supply air plenum box MBL 100-100	pcs	4,00	54,00	38,00	33,48	133,92
56	Supply air plenum box MBL 125-125	pcs	2,00	61,00	38,00	37,82	75,64
57	Extract air device ZW 100 (E1)	pcs	6,00	5,59	60,00	2,24	13,42
58	Extract air device ZW 125 (E1)	pcs	5,00	6,84	60,00	2,74	13,68
59	Extract air device ZW 160 (E1)	pcs	5,00	10,56	60,00	4,22	21,12
60	Extract air device ZW 200 (RKT 63)	pcs	1,00	13,38	60,00	5,35	5,35
61	Exhaust air device SMT 315 (KEPURE1)	pcs	1,00	44,80	38,00	27,78	27,78
62	Silencer TSA 315-900	pcs	2,00	113,00	45,00	62,15	124,30
63	Insulation VENTILAM ALU 100	m2	155,00	16,22	0,00	16,22	2 514,10

Vilniaus

Object: Oulu, Finland. System 301

Price without discount:	5 618,77
Discount:	1 257,74
Price without VAT :	4 361,03
VAT 0,00 %:	0,00
SUM:	**4 361,03 EUR**

The offer is valid only when purchasing the full range and quantities included in the commercial offer.

The offer is valid for 30 days

Normantas Virbickas, +37065916769, normantas.virbickas@leovira.lt

Parašas : ____________________

Appendix 7

UAB Leovira commercial offer for air handling unit (separate systems)

LEOVIRA

COMMERCIAL OFFER

No. *2020-01788*

2020-04-28

Payment term : *0* d.

Seller :	Buyer :
UAB LEOVIRA, e. c.:124921964	***Kajus Laurynas Motekūnas, 1994.10.03***
Address : *Žarijų str. 4, Vilnius*	Address :
A./s. : LT227044060000388381, AB SEB bank, Bank code: 70440 LT724010049501382371, Luminor Bank AB, Bank code: 40100	A./s. :

**Price without VAT*

Row No.	Name (products, services)	Units	Quantity	Price* *EUR*	Disc. (%)	Price with discount without VAT	Price without VAT *EUR*
1	*Air handling unit Lesstro R1200VE-DE CV034E-01S02*	*vnt*	*1,00*	*3 019,00*	*38,00*	*1 871,78*	*1 871,78*

Vilnius

Object: Oulu, Finland. System 301

Price without discount: *3 019,00*

Discount: *1 147,22*

Price without VAT: *1 871,78*

VAT *0,00* %: *0,00*

Offer is valid only when buying all the specified goods with their respective quantities

SUM: ***1 871,78 EUR***

Offer is valid for 30 days

Mantas Rotmanas, +37063048623, mantas.rotmanas@leovira.lt

Parašas : ______________________________

28-04-2020 9:32

Appendix 8/1

Page 1 of UAB Leovira commercial offer for ventilation ducts and fittings (combined system)

LEOVIRA

COMMERCIAL OFFER

No. 2020-01777

2020-04-27

Terms of payment : 0 d.

Seller :	Buyer :
UAB LEOVIRA, į. k.:124921964	**Kajus Laurynas Motekūnas, 1994-10-03:**
Address : Žarijų str. 4, Vilnius	Adresas :
A./s. : LT227044060000388381, AB SEB bank, Bank code: 70440 LT724010049501382371, Luminor Bank AB, Bank code: 40100	A./s. :

*Price without VAT

Row No.	Name (products, services)	Units	Quantity	Price* EUR	Discount (%)	Discounted price without VAT	Price without VAT EUR
1	Circular duct OSL 100 C-0,4	m	6,00	2,11	25,00	1,58	9,49
2	Circular duct OSL 125 C-0,4	m	25,00	2,67	25,00	2,00	50,06
3	Circular duct OSL 160 C-0,4	m	30,00	3,39	25,00	2,54	76,27
4	Circular duct OSL 200	m	9,00	4,11	25,00	3,08	27,74
5	Circular duct OSL 250	m	15,00	5,27	25,00	3,95	59,29
6	Circular duct OSB 315 C-0,45	m	21,00	7,18	25,00	5,38	113,08
7	Circular duct SOP 800x400 L-1250	pcs	1,00	73,00	37,00	45,99	45,99
8	Circular bend SAG-30° d-160	pcs	2,00	9,18	42,00	5,33	10,65
9	Circular bend BU-45 d-160	pcs	1,00	8,69	45,00	4,78	4,78
10	Circular bend SAG-45° d-250	pcs	4,00	11,20	42,00	6,50	25,98
11	Circular bend SAG-45° d-315	pcs	2,00	16,00	42,00	9,28	18,56
12	Circular bend BU-90 d-100	pcs	3,00	6,38	45,00	3,51	10,53
13	Circular bend BU-90 d-125	pcs	14,00	7,62	45,00	4,19	58,67
14	Circular bend SAG-90° d-160	pcs	18,00	10,36	42,00	6,01	108,16
15	Circular bend SAG-90° d-200	pcs	1,00	12,58	42,00	7,30	7,30
16	Circular bend SAG-90° d-250	pcs	1,00	15,04	42,00	8,72	8,72
17	Circular bend SAG-90° d-315	pcs	8,00	21,10	42,00	12,24	97,90
18	Rectangular bend SAL-90° 800x400	pcs	1,00	124,00	37,00	78,12	78,12
19	Circular bend SAG-21° d-315	pcs	1,00	16,65	42,00	9,66	9,66
20	T-branch TAG 125-125-100	pcs	1,00	10,71	42,00	6,21	6,21
21	T-branch TAG 160-160-100	pcs	2,00	10,07	42,00	5,84	11,68
22	T-branch TAG 160-160-125	pcs	5,00	11,25	42,00	6,52	32,62
23	T-branch TSHFL 160-160-160	pcs	3,00	11,06	40,00	6,64	19,91
24	T-branch TAG 200-200-100	pcs	1,00	12,15	42,00	7,05	7,05
25	T-branch TAG 200-200-125	pcs	1,00	13,43	42,00	7,79	7,79
26	T-branch TAG 200-200-160	pcs	4,00	15,15	42,00	8,79	35,15
27	T-branch TSHFL 200-200-200	pcs	2,00	15,31	40,00	9,19	18,37
28	T-branch TAG 250-250-125	pcs	1,00	18,04	42,00	10,46	10,46
29	T-branch TAG 250-250-160	pcs	1,00	19,23	42,00	11,15	11,15
30	T-branch TSHFL 250-250-250	pcs	2,00	21,40	40,00	12,84	25,68
31	T-branch TAG 315-315-125	pcs	1,00	18,64	42,00	10,81	10,81
32	T-branch TAG 315-315-160	pcs	2,00	20,90	42,00	12,12	24,24
33	T-branch TAG 315-315-200	pcs	2,00	23,00	42,00	13,34	26,68
34	T-branch TAG 315-315-250	pcs	1,00	25,70	42,00	14,91	14,91
35	X-branch KA 250-125	pcs	1,00	99,00	38,00	61,38	61,38
36	Coupling NVG 250	pcs	3,00	6,18	45,00	3,40	10,20
37	Coupling NVG 315	pcs	2,00	7,30	45,00	4,02	8,03
38	Reducer/Expander RCU 160/125	pcs	5,00	5,42	45,00	2,98	14,90
39	Reducer/Expander RCU 200/125	pcs	1,00	6,84	45,00	3,76	3,76
40	Reducer/Expander RCU 200/160	pcs	7,00	6,98	45,00	3,84	26,87
41	Reducer/Expander RCU 250/125	pcs	1,00	9,16	45,00	5,04	5,04
42	Reducer/Expander RCU 250/200	pcs	4,00	9,48	45,00	5,22	20,86
43	Reducer/Expander RCU 315/250	pcs	2,00	13,82	45,00	7,60	15,20
44	Square to round SAP 800x400-315	pcs	1,00	82,00	37,00	51,66	51,66
45	Outdoor grille LGC 800x400	pcs	1,00	92,00	38,00	57,04	57,04
46	Supply air plenum box MBL 125-125 (NOVA alternative)	pcs	10,00	122,00	38,00	75,64	756,40

Appendix 8/2

Page 2 of UAB Leovira commercial offer for ventilation ducts and fittings (combined system)

47	*Supply air plenum box MBL 160-160 (NOVA alternative)*	pcs	6,00	152,00	38,00	94,24	565,44
48	*Extract air device ZW 100 (E1)*	pcs	4,00	5,59	60,00	2,24	8,94
49	*Extract air device ZW 125 (E1)*	pcs	7,00	6,84	60,00	2,74	19,15
50	*Rectangular duct SOL 200x200 L-1500 (POLMANS EX)*	pcs	6,00	45,00	41,00	26,55	159,30
51	*Exhaust air device SMT 315 (KEPURE1)*	pcs	1,00	44,80	38,00	27,78	27,78
52	*Flow damper SOM 125*	pcs	9,00	11,03	33,00	7,39	66,51
53	*Flow damper SOM 160*	pcs	15,00	12,11	33,00	8,11	121,71
54	*Flow damper SOM 200*	pcs	1,00	16,83	33,00	11,28	11,28
55	*Flow damper SOM 250*	pcs	1,00	22,00	33,00	14,74	14,74
56	*Gears for flow dampers 227S-230-05E*	pcs	26,00	67,00	10,00	60,30	1 567,80
57	*Silencer TSA 315-900*	pcs	2,00	113,00	45,00	62,15	124,30
58	*Insulation VENTILAM ALU 100*	m2	150,00	16,22	0,00	16,22	2 433,00

Vilniaus

Object: Oulu, Finland. System 301-1

Price without discount:	9 424,89
Discount:	2 189,94
Price without VAT :	7 234,95
VAT 0,00 %:	0,00
SUM:	**7 234,95 EUR**

The offer is valid only when purchasing the full range and quantities included in the commercial offer.

The offer is valid for 30 days

Normantas Virbickas, +37065916769, normantas.virbickas@leovira.lt

Parašas : ______________________________

27.04.2020 15:45

Appendix 9

UAB Leovira commercial offer for air handling unit (combined system)

LEOVIRA

COMMERCIAL OFFER

No. *2020-01787*

2020-04-28

Payment term : *0* d.

Seller :	Buyer :
UAB LEOVIRA, e. c.:124921964	***Kajus Laurynas Motekūnas, 1994.10.03:***
Address : *Žarijų str. 4, Vilnius*	Address :
A./s. : LT227044060000388381, AB SEB bank, Bank code: 70440 LT724010049501382371, Luminor Bank AB, Bank code: 40100	A./s. :

**Price without VAT*

Row No.	Name (products, services)	Units	Quantity	Price* *EUR*	Disc. (%)	Price with discount without VAT	Price without VAT *EUR*
1	*Air handling unit Lesstro R1400VE-DE CV034E-02S03*	*vnt*	*1,00*	*3 161,00*	*38,00*	*1 959,82*	*1 959,82*
2	*Extension module EA-V21 2/1kPa*	*vnt*	*3,00*	*157,89*	*30,00*	*110,52*	*331,57*
3	*Temp. sensor C5 10k 5m.*	*vnt*	*16,00*	*17,68*	*30,00*	*12,38*	*198,07*

Vilnius

Object: Oulu, Finland. System 301-1

Price without discount: *3 917,62*

Discount: *1 428,16*

Price without VAT: *2 489,46*

VAT *0,00* %: *0,00*

Offer is valid only when buying all the specified goods with their respective quantities

SUM: ***2 489,46 EUR***

Offer is valid for 30 days

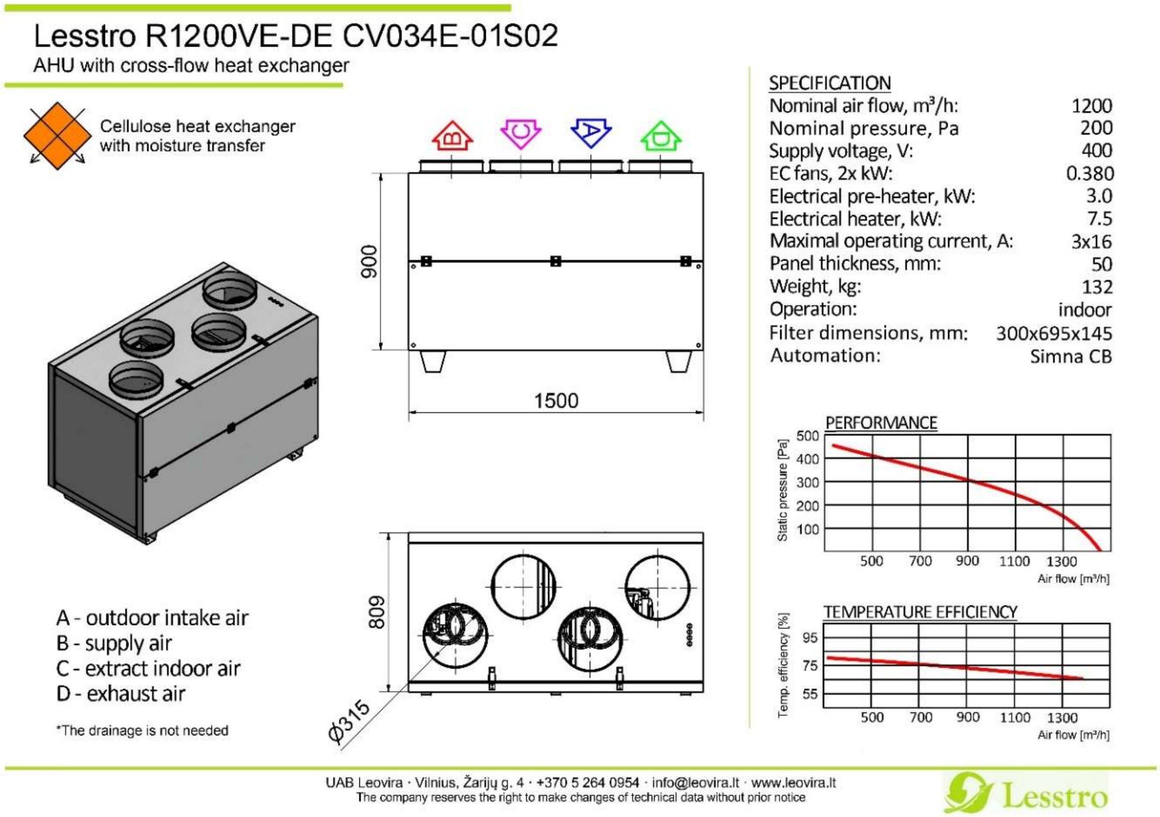
Mantas Rotmanas, +37063048623, mantas.rotmanas@leovira.lt

Parašas : ______________________

28-04-2020 9:46

Appendix 10

Specifications of Lesstro R1200VE air handling unit suggested by UAB Leovira for separate systems



Lesstro R1200VE-DE CV034E-01S02

AHU with cross-flow heat exchanger

Cellulose heat exchanger with moisture transfer

SPECIFICATION	
Nominal air flow, m³/h:	1200
Nominal pressure, Pa	200
Supply voltage, V:	400
EC fans, 2x kW:	0.380
Electrical pre-heater, kW:	3.0
Electrical heater, kW:	7.5
Maximal operating current, A:	3x16
Panel thickness, mm:	50
Weight, kg:	132
Operation:	indoor
Filter dimensions, mm:	300x695x145
Automation:	Simna CB

A - outdoor intake air
B - supply air
C - extract indoor air
D - exhaust air

*The drainage is not needed

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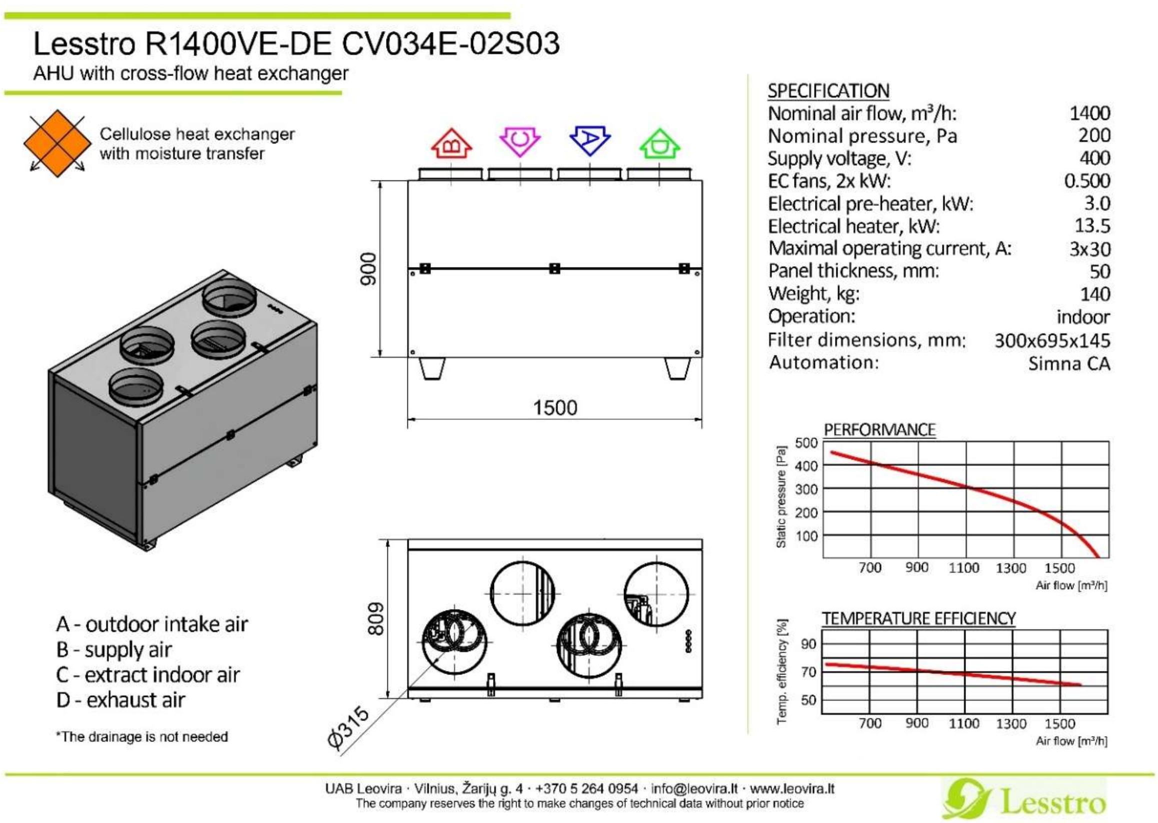
The company reserves the right to make changes of technical data without prior notice

Lesstro

Specifications of Lesstro R1400VE air handling unit suggested by UAB Leovira for combined system



Lesstro R1400VE-DE CV034E-02S03

AHU with cross-flow heat exchanger

Cellulose heat exchanger with moisture transfer

SPECIFICATION	
Nominal air flow, m³/h:	1400
Nominal pressure, Pa	200
Supply voltage, V:	400
EC fans, 2x kW:	0.500
Electrical pre-heater, kW:	3.0
Electrical heater, kW:	13.5
Maximal operating current, A:	3x30
Panel thickness, mm:	50
Weight, kg:	140
Operation:	indoor
Filter dimensions, mm:	300x695x145
Automation:	Simna CA

A - outdoor intake air
B - supply air
C - extract indoor air
D - exhaust air

*The drainage is not needed

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The company reserves the right to make changes of technical data without prior notice

Lesstro

Appendix 11

Bill of materials with prices for hydronic system

Name (products, services)	Size	Series	Product code	Quantity	Length, m	Thickness, mm	Unit price, EUR	Total price, EUR
Pipe	10	Fe-35			213,4		2	426,8
Pipe	15	Fe-35			36,5		2,15	78,5
Pipe	20	Fe-35			29,6		3,15	93,2
Pipe	25	Fe-35			5,8		4,36	25,3
Bend-90	10	Fe-35		157			1,84	288,9
Bend-90	15	Fe-35		4			2,13	8,5
Bend-90	20	Fe-35		11			2,41	26,5
Bend-90	25	Fe-35		7			3,29	23,0
T-branch-90	10/10	Fe-35		18			3,26	58,7
T-branch-90	15/15/10	Fe-35		18			3,51	63,2
T-branch-90	20/20/10	Fe-35		12			3,77	45,2
T-branch-90	20/20/25	Fe-35		2			4,37	8,7
Reducer/Expander	40/20			2			3,15	6,3
Reducer/Expander	40/25			2			3,36	6,7
Reducer/Expander	15/10	Fe-35		4			1,18	4,7
Reducer/Expander	20/15	Fe-35		3			1,34	4,0
Reducer/Expander	25/20	Fe-35		1			1,44	1,4
Heating radiator		C21	C21-400-600	1			60	60,0
Heating radiator		C21	C21-450-1200	6			93	558,0
Heating radiator		C21	C21-450-700	2			66	132,0
Heating radiator		C33	C33-900-2000	1			365	365,0
Heating radiator		KON 33-AB	KON33-286-1000-AB	2			95	190,0
Heating radiator		RAD4	C11-400-500	1			37	37,0
Heating radiator		RAD5	C22-400-1000	2			82	164,0
Heating radiator		RAD5	C22-400-1200	2			93	186,0
Heating radiator		RAD5	C22-400-800	1			70	70,0
Heating radiator		RAD5	C22-450-1000	1			82	82,0
Heating radiator		RAD5	C22-500-1200	4			95	380,0
Heating radiator		RAD5	C22-500-700	1			67	67,0
Heating radiator		RAD5	C22-600-1200	2			102	204,0
Zone valve	20	ZV1	AT1310-20	1			39,33	39,3
Zone valve	25	ZV1	AT1310-25	1			61,59	61,6
Radiator valve	10	TRV3	Calypso TRV-3 DN10	26			7,82	203,3
Stop valve	25	SV1	AT3600-25	1			12,29	12,3
Other valve	20	V5832	V5832A4016	1			13,5	13,5
Insulation/Pipe	10	21	Serie 20...60mm		185,4	20	3,56	660,0
Insulation/Pipe	15	21	Serie 20...60mm		36,5	20	3,93	143,4
Insulation/Pipe	20	21	Serie 20...60mm		15,1	20	4,08	61,6
Insulation/Bend-90	10	21	Serie 20...60mm	134		20	0,66	88,4
Insulation/Bend-90	15	21	Serie 20...60mm	4		20	0,69	2,8
Insulation/T-branch-90	10/10	21	Serie 20...60mm	16		20	0,54	8,6
Insulation/T-branch-90	15/15/10	21	Serie 20...60mm	18		20	0,67	12,1
Insulation/T-branch-90	20/20/10	21	Serie 20...60mm	12		20	0,73	8,8
Insulation/T-branch-90	20/20/25	21	Serie 20...60mm	2		20	0,41	0,8
Insulation/Reducer/Expander	15/10	21	Serie 20...60mm	4		20	0,44	1,8
Insulation/Reducer/Expander	20/15	21	Serie 20...60mm	3		20	0,51	1,5
Insulation/Reducer/Expander	21/20	21	Serie 20...60mm	1		20	0,55	0,6
Heat Exchanger	25	25	XB37H-1 50	1			451	451,0
Circulation Pump	25/0,5-12	PN10	Wilo Yonos MAXO	1			892	892,0
Expansion tank			ERE-CE	1			256,27	256,3
							Total cost:	**6584,5**