Elena Zolotareva

MECHANICAL SUPPLY AND EXHAUST VENTILATION IN HIGH RISE RESIDENTIAL BUILDINGS IN RUSSIA

Bachelor's Thesis
Building Services Engineering

December 2011

MIKKELIN AMMATTIKORKEAKOULU
Mikkeli University of Applied Sciences

DESCRIPTION

MIKKELIN AMMATTIKORKEAKOULU
Mikkeli University of Applied Sciences

Date of the Bachelor's Thesis
14.01.2012

Author(s)
Elena Zolotareva

Degree programme and option
Building Services Engineering

Name of the Bachelor's thesis
Mechanical supply and exhaust ventilation in high rise residential buildings in Russia

Abstract

Improving the quality of occupants' life in modern Russian high rise residential buildings by developing mechanical supply and exhaust ventilation is a common trend of Russian engineers. This type of ventilation doesn't take place in Russian housing today. Construction companies who want to design such systems are running against a lot of special requirements for their projects in national ventilation standards.

The aim of my Bachelor's thesis was to find solution to the integration mechanical supply and exhaust ventilation into high rise residential buildings. 14 floor residential building which is in the project stage now was selected as a case study.

Case study was carried out in such way to find problematic paragraphs in the Russian standards and to try to solve them in my designs. Supply and extract ducts are protected from possible fire spreading. Ventilation automatic system prevents influence of stack effect on the air flow rates and controls all parameters of the air movement inside the investigated residential building.

Quality of indoor air is achieved by evaluation optimal air flow rates for each apartment. In the investigated building supply air will be produced by the air handling unit, which includes plate heat recovery unit and is situated on the technical floor on the top of the building.

Design project presented in this thesis can become a basis for construction mechanical supply and exhaust ventilation in investigated building. Results of my Bachelor's thesis could be applied into Russian housing and could be useful for the HVAC engineers in Russia.

Subject headings, (keywords)
Mechanical supply and exhaust ventilation , mechanical supply ventilation, mechanical exhaust ventilation, natural ventilation, heat recovery, indoor climate, inadequate ventilation, high rise residential buildings, air handling unit, SBS, Russian norms, fire spreading prevention system, flow control

Pages	Language	URN
64	English	

Remarks, notes on appendices

Tutor	Employer of the Bachelor's thesis
Veuro Martti	

CONTENTS

1 INTRODUCTION

Some Russian construction companies have started to think about improving the quality of occupants' life recently. These companies are ready to put a lot of efforts and money for providing good indoor climate in flats. But very often Russian norms bring a lot of changes in the foreign design decisions.

To improve the quality of our life many foreign companies integrate their national products and technologies into Russian building industry. They try to adapt their norms and practices to Russian building industry. As a result air infiltration valves and mechanical exhaust ventilation are already used in new buildings in Saint-Petersburg.

Mechanical supply and exhaust ventilation in high rise residential buildings has been used in European countries for many years, but in case of Russia, natural ventilation is still common nowadays. It doesn't mean that people don't want to achieve good indoor climate. The first reason of using natural ventilation is old norms, which don't include any information about designing and maintaining mechanical ventilation systems in block of flats. On the other hand you can easily find all instructions which are needed to design natural ventilation (including hygienic, sanitary and fire spreading prevention norms) in Russian laws. The second reason is the small number of good HVAC specialists who can design mechanical supply and exhaust ventilation for high rise buildings and also can save living area as much as possible.

Nowadays mechanical exhaust ventilation has started to appear in Saint-Petersburg housing. Big exhaust fans are installed on roof. Air comes into the dwellings from the outdoors through the air infiltration valves. It helps to avoid high level of CO_2 in the room, outdoor air is under the bad influence of cars exhaust, different flue gases and other pollutant sources.

The aim of my Bachelor's thesis is to find solution to the integration mechanical supply and exhaust ventilation in high rise residential buildings. Main special requirements in Russian norms for design, installation, and maintenance mechanical supply and exhaust ventilation will be found. Fire spreading prevention system for ventilation will be designed for the investigated building to meet Russian requirements of occupants' life safety. And study case of mechanical supply and exhaust ventilation with heat recovery unit on the roof will be designed for 14 floor residential building according to the current Russian norms.

2 THEORETICAL BACKGROUND

In this chapter problems of indoor air quality which forces engineers to find newest ventilation solutions are described. It is also discusses types of ventilation systems in general, comparing these types. Advantages and disadvantages of different ventilation systems are shown.

2.1 Inadequate ventilation

The majority occupants in big cities thinks that they get enough fresh air through the natural leakages. HEPAC engineers very often say "You should open the window" or "You are living in the old leaking house, you have no reason to make mechanical ventilation" or something like that. But in real life natural ventilation is not reliable for providing good indoor climate and favorable concentration of contaminants because of very low exchange rates. /1, p.1./

In houses with natural ventilation the fastest way of changing the indoor air is to open the windows and the doors. It helps to exchange old air with a lot of odors and harmful contaminants from furniture and people activities by outdoor fresh air. But we need to close windows in the hot summer time to achieve cooler temperature inside the building than outside and in winter to avoid cold drafts inside the room. An aeration affects the temperature inside the building and the energy consumption of the building as well. /2/. People need to choose: should they stand in the aired room or in good temperature conditions, because natural ventilation is not able to bring sufficient amount of exchange air.

Traditionally people only air their flats a few times per day in big cities. Natural ventilation occurs constantly through cracks and holes in the windows, doors and walls. The infiltration rate depends on many parameters: construction of the house, its age, weather, by the season and climate of the region. It is impossible to control ventilation rate in each situation. Problems in controlling of infiltration rates causes problems with exceed amount of pollutant sources in the flat. /2./

2.2 SBS problems

In many cases ventilation rates in flats with natural ventilation are inadequate to maintain inhabitant's health and comfort in a proper way. Inadequate ventilation is very important factor of the Sick building syndrome (SBS). The term "sick building syndrome" describes situations, when occupants feel themselves bad, when they are in their house without having any specific illness. Complaints may relate to one room or space or to whole building./3./

Poor ventilation causes problems in physical and psychological health of occupants. While hazardous contaminants are accumulating and mixing in places with low air exchange rates they cause such hazards as:

- Low levels of oxygen, high levels of carbon dioxide.
- High level of biological and chemical contaminants.
- Bacterial and mold growth.
- Moisture caused problems.
- Headaches, irritations and fatigue.
- Legionnaire's disease, Pontiac fever and Humidifier fever.
- Discomfort caused by excessive odors.
- Skin rashes, irregular breathing and even asthma.
- Problems with nervous system./4./

Beside mold and bacteria, low ventilation rates can lead to the excess of contaminants amount in the indoor air like a carbon dioxide (CO_2). CO_2 is a natural air component. CO_2 is released by humans while breathing and by combustion of fuels. It needs to notice that carbon dioxide concentration is an indicator of the air quality. Normal concentration of carbon dioxide in the atmospheric air is 350-400 particles per million (ppm). /5./

While breathing people reduce amount of oxygen and produce carbon dioxide in concentration about 35000 to 50000 ppm. It is 100 times higher than concentration of CO_2 in outdoor air. In case of inadequate ventilation rates CO_2 continuously generated is accumulating in the living spaces. Carbon dioxide concentration not exceed 5000 ppm is not harmful, but in places with elevated CO_2 levels we feel drowsiness, lethargy and sense of stale air. /6./

According to the National building code of Finland D2, the maximum permissible CO_2 concentration in occupancy must not exceed 1200 ppm. /7, p.9./

2.3 Characteristics of good indoor climate

Nowadays people spend more than 90% of the time staying indoors. It means that every 9 of 10 breaths we take indoors. That's why achieving good indoor air quality is even more important than quality of outdoor air. Symptoms of the sick building syndrome are reduced by providing good indoor climate. /8./

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) prescribes to provide minimum 7 $dm^3/s\cdot$ person to achieve acceptable indoor air quality. /3./ This amount of fresh air is enough for people to feel themselves comfortable and to be sure about their health.

Ventilation should be designed in such a way to provide a healthy, safe and comfortable indoor air quality in rooms during periods of occupancy. There should be also a possibility to control air flow rates in the ventilation systems according to the quality of air and to the loads. According to D2 outdoor air flow in dwellings should be at least 6 $dm^3/s\cdot$ person or 0.5 $dm^3/s\cdot m^2$. Air change rate for dwelling areas should be designed to be at least 0.5 1/h. /7, p.13, 32./

Finnish Classification of Indoor Climate divides IAQ into the three categories: S1 “individual indoor climate”, S2 “good indoor climate” and S3 “satisfactory indoor climate” (building code level). These three categories are based on client's and engineer's viewpoints, air velocities, operative temperature, carbon dioxide and radon concentrations, targets for acoustic, emissions of materials, lightning and others. /8/.

In houses classified by S1 category the user of the space could control the thermal conditions in his flat by himself. The indoor air quality can be improved by homeowners just by increasing the ventilation rates. Thermal conditions satisfy requirements for very sensitive people, elderly people and people with respiratory illnesses.

Category S2 requires the good indoor air quality without draughts. Temperature could rise above comfortable levels in the hottest summer days. Buildings classified by S3 category should only fulfill all the requirements of current building codes. It may be stuffy and draughty sometimes. Variation of temperatures and air velocities is higher than in two previous categories. /8/

2.4 Achieving good indoor climate

Nowadays one of the goals of architects and engineers is to develop modern ventilation system (based on the modern materials and technologies) which will reach a good indoor climate. We need to understand how ideal ventilation system looks like if we want to develop modern ventilation system. Designing such system is not an easy job. It is closely related with insulation and vapor barrier of walls, ecology and thermal comfort inside the room. And everything is complicated by a number of differences in the standards./9, p.368-369./

To achieve good indoor climate and to calculate loads and energy consumption of ventilation system we have to know the air flow patterns into and inside a building. Correct calculating of air flow patterns also gives us a possibility to save space for living areas while dimensioning duct sizes and spaces for air handling equipment. In the absolute majority of cases it means that we can save a huge amount of money by correct dimensioning of ventilation system. Air flow is influenced by several moving forces. Thermal buoyancy, pressure differences caused by wind, ductwork characteristics and inhabitant behavior are among of them. In Figure 1 impacts which cause differences in pressure distribution inside a building are introduced./10./

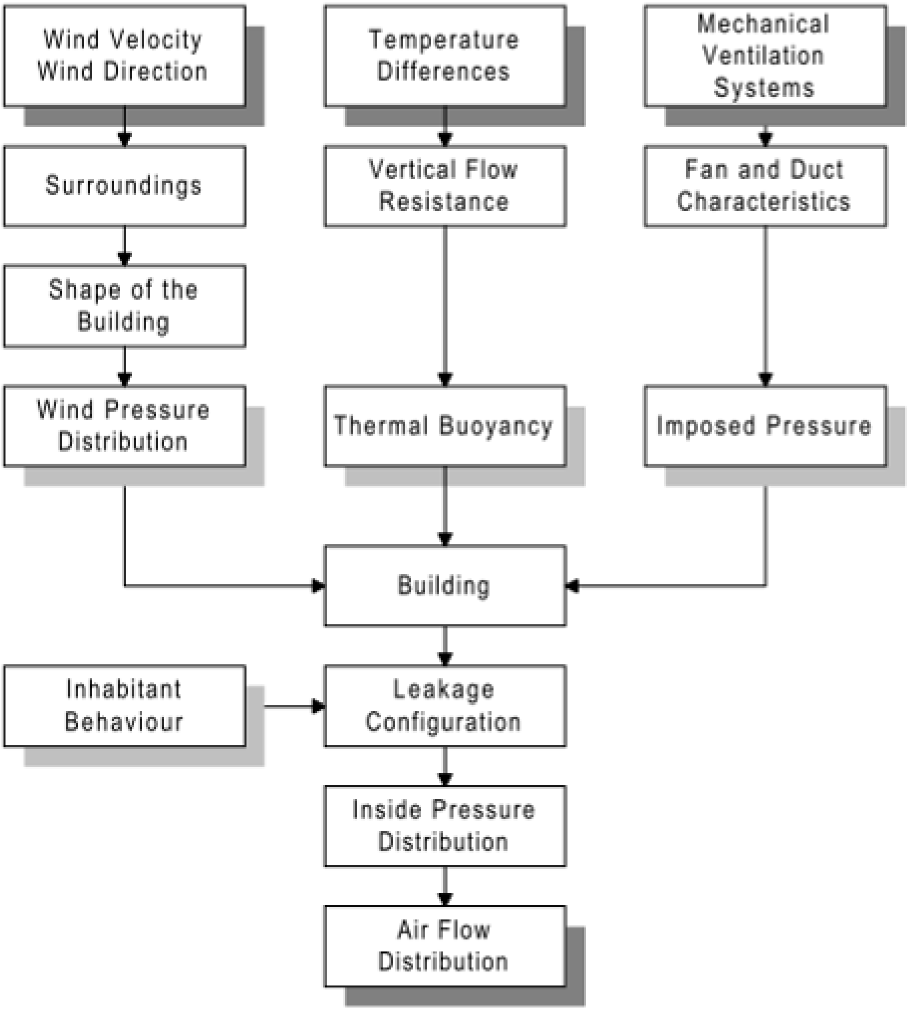


FIGURE 1. Air flow distribution in buildings /10/

Houses have to breathe like every organism. It is needed not only for occupants' health, but at the same time for the health of the building. Building's ventilation removes pollutants from the air and replaces old air with the fresh one. Ventilation is necessary for the prolongation building's life; it prevents excessive humidity and the growth of mold and fungi on the materials. It is even more important to have good ventilation in block of flats because in this type of residential apartments good IAQ is more complicated to achieve. Designing ventilation in high-rise buildings is serious problem, but this problem can be solved by cooperation of engineers, architects, scientists and contractors./11./

2.5 Natural ventilation

There are two main purposes of ventilation. They are to maintain good IAQ by providing enough air change rates and to achieve exact thermal conditions which we can't achieve by using only heating systems. /12./

There are several types of ventilation systems available for designers. Basically there are two types – natural and mechanical ventilation. Mechanical ventilation is divided into mechanical supply ventilation; mechanical exhaust ventilation and mechanical supply & exhaust ventilation. Designing mechanical ventilation system is more complicated task for designer and these systems would be described further.

The simplest way of providing ventilation is providing natural one by opening doors, windows and leakages in building envelope. The natural ventilation could be based on stack effect or on the cross flow through the building. Cross ventilation is ventilation based on opening windows in the opposite parts of the flat to reduce indoor temperatures or to change air mass rapidly. It is based on pressure differences of air on the opposite sides of the building and it is used mainly during the highest ventilation peak loads. Fresh air in extreme concentrations goes through the house from one window to another one and takes unnecessary warmth like it is shown in the Figure 2. /13./

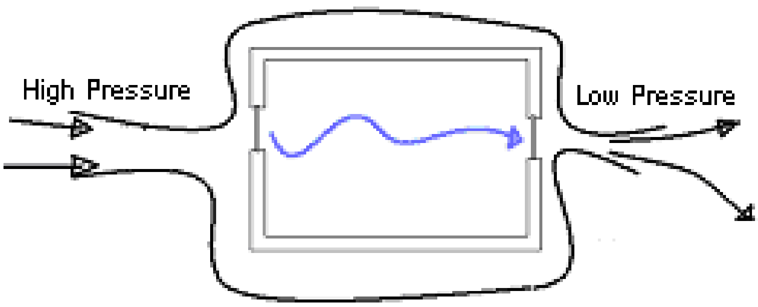


FIGURE 2. Cross ventilation /13/

Natural ventilation works normally if the ventilation openings are situated in the different air pressure levels. Figure 3 is illustrated natural ventilation of the house which is based on the pressure differences. Pressure differences could be a result of wind influence or when outside temperature is lower than inside the room. The most suitable height between extract air duct on the roof of the building and infiltration valve is 5 -7 meters. It is difficult to design such long ducts in small buildings and also in high-rise buildings very long ducts cause high extract air speeds in exhaust system. /10./

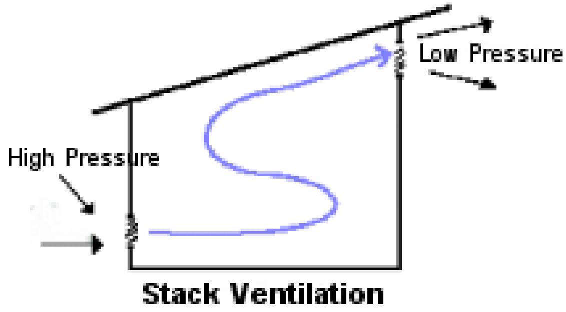


FIGURE 3. Stack ventilation /13/

Air movement in case of the stack natural ventilation is based on the temperature, density and pressure differences of the air. Warmer air usually goes upwards while colder one goes down. This principle works well in the cold seasons, when temperature differences between indoor and outdoor air are rather high. But in summer time natural ventilation effect decreases or even disappears totally. /10./

The main driving force for the air moving in natural ventilation in high rise buildings is stack effect. Air enters inside apartments through the cracks, holes and opening the windows and outputs through vertical ventilation shaft. Lifting forces due the differences of air density between outdoor and indoor air are caused by stack effect phenomen. Stack effects mainly appears in countries with cold climate inside ventilation systems of high-rise buildings. The principle of this fact is that warm air goes up to the roof and inside air is also warmer and less dense than outside one.

Cold air on the contrary falls down. And when outside air is warmer than building's air, so called reverse stack effect moves air down through the shaft. If the inside temperature is higher than outside, in the first floors infiltration appears. It causes moving of air patterns up to the upper floors and also exfiltration through the cracks near the top of the building. The stack effect mainly appears in the elevator shafts and vertical ventilation ducts. The main problems of the stack effect are big energy losses, uncontrolled air velocities in the ducts, the sticky elevator doors and also noise from the exhaust air ducts. And this effect is as strong as cold climate we have and as high is building.

Designing natural ventilation is quite difficult task in our climate - this system is very weather dependent. Dimensioning of natural ventilation systems and adjusting necessary air flow rates in different seasons cause inadequate ventilation and increasing amount of bacteria during the summer and draughts and high energy losses in winter time. Besides weather-dependent air flow and difficulties in dimensioning, natural ventilation can't be used with heat recovery. Another problem is possibility of changing air flows in the wrong direction if e.g. somebody has installed cooker hood in kitchen or fan in the WC, persons who live upper floors may feel unpleasant odors from lower floors due to changes of pressure in the system. Air flows going in wrong direction are shown in Figure 4.

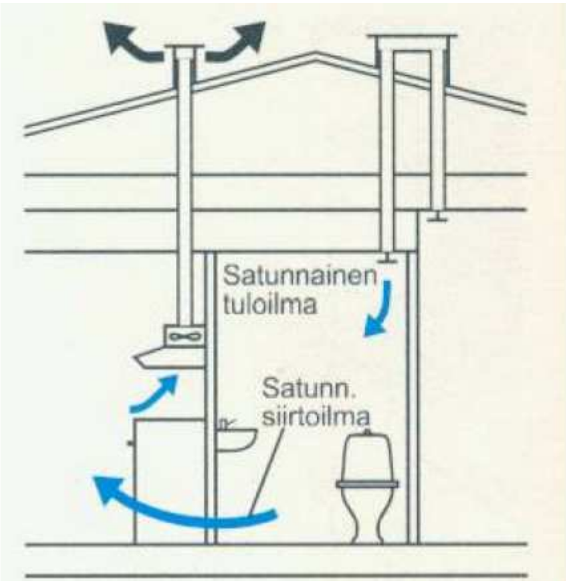


FIGURE 4. Air flows in wrong direction /14, p.123/

Natural ventilation is attractive for designers because it is easy to maintain such systems, there are no difficult automation systems, fans, heating/cooling coils and different filters; these solutions save capital cost; maintenance is needed less often than in the case of mechanical ventilation systems and also system which was designed in proper way is quiet and brings comfort for occupants. Energy demand in houses with natural ventilation is also lower than in houses with mechanical one because of lower air change rates. In winter people usually want to adjust comfortable temperature conditions without draughts that’s why they try to prevent all leakages, close all windows and infiltration valves.

2.6 Mechanical ventilation

Mechanical ventilation is designed to adjust air flow rates in our houses to bring enough fresh air for occupants. If it is designed and tuned well, air flow rates through the ventilation terminal units would be the same as in project documentation and will not vary too much according to the weather conditions.

Basically mechanical ventilation is divided into three forms: mechanical exhaust ventilation, mechanical supply ventilation and mechanical supply and exhaust ventilation. The main advantages of mechanical systems comparing to natural systems are that airflows in such systems have a minimal dependence on weather conditions, air can be boosted to the required rates, smaller duct diameters could be adjusted and also they give more freedom for designers. In mechanical systems kitchen boost could be used also in combination with ventilation system of other rooms without danger of return flows.

In mechanical exhaust ventilation the air flow rates are produced by a fan, which could be roof mounted or placed somewhere in the exhaust duct. Supplying of fresh air is implemented through the gaps and cracks in building envelope or through the wall mounted supply air valves. Figure 5 shows the common design of mechanical exhaust ventilation for multistory building. /14/.

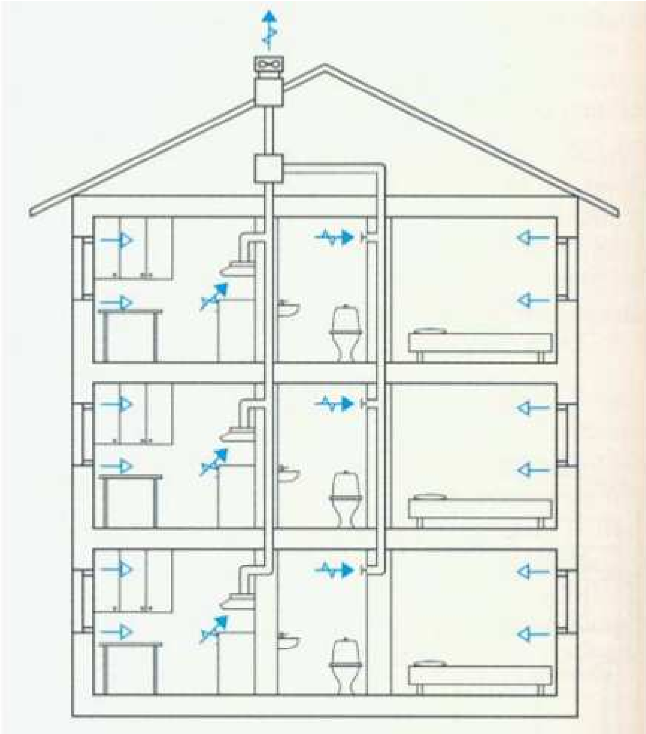


FIGURE 5. Mechanical exhaust ventilation in multistorey apartment house /14, p.123/

Mechanical exhaust ventilation is a common solution for buildings at the end of 20th century. Exhaust ducts from apartments could be joined into the main duct or the exhaust ducts could be drawn separately up to the roof, where they could be joined into one collector before the blowing fan.

But mechanical exhaust systems aren't considered to be the best systems. It is so because these systems are subjected to the influence of draughts while cold outside air is coming to the room; they can be rather noisy by themselves and also they could transport noise from one apartment to another. There is a lack for routes for transferring air and high operating costs because of the lack of heat recovery./14./

Another point about exhaust system that is worth of mentioning is possibility to create underpressure to the building. Modern houses become so airtight that if you close infiltration valve and then you pump out air indoor pressure becomes very low. This fact can cause some problems e.g. with natural chimney effect in fireplace, flue gases will not go to right direction in chimney. Thus people should take care to the adequacy of air supply to the premises with the simultaneous working fireplace and exhaust ventilation systems to prevent harmful effects to the occupants.

Mechanical supply ventilation works by providing a positive pressure inside the building instead of the exhaust systems, which make building to be on under pressure every time. These systems work the same as exhaust systems, but fan is blowing outdoors fresh air through the ducts into the room like it is shown in the Figure 6. Extracting of dirty air is carried out through the cracks, holes or exhaust valves in the external walls. /15/.

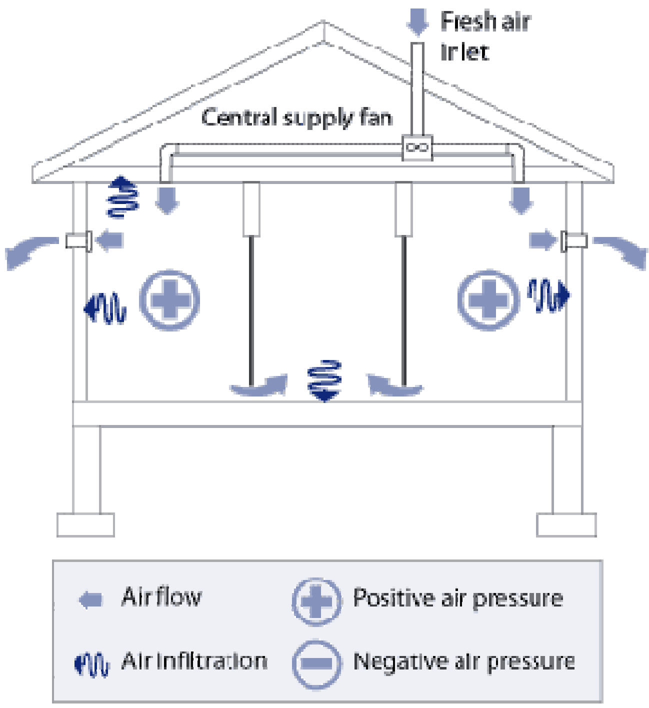


FIGURE 6. Mechanical supply ventilation /15/

A typical supply ventilation system is simple, inexpensive and consists of a fan and duct system for introducing fresh air into one or several rooms where people spend a lot of time (such as living rooms and bedrooms). Supplied air could be cleaned by filters and also heated in coils. By pressurizing the flat it is easier to remove all pollutants and bacteria from the living areas. Supply systems better control amounts of fresh air than mechanical exhaust and natural ventilation systems, but they are forbidden in countries (for example in Russia), where you can’t eject pollute air on the same level as surrounding windows are located.

Supply ventilation systems are a good idea for hot countries, but in the North continuous pressuring of the house could lead to the moisture problems. Warm humid air in winter time while leaking through the holes in the external walls could become a reason of reducing thermal insulation properties of outer walls or even appearing mold and decay. Like an exhaust one, mechanical supply systems can’t be used with heat recovery systems. They may cause draughts if outdoor air is not preheated, otherwise such systems have high operating costs for heating outdoor air in cold climates. /15/.

2.7 Mechanical supply & exhaust ventilation

Mechanical supply and exhaust ventilation introduces the best level of indoor air quality to our houses. There are two types of mechanical supply and exhaust ventilation, they are apartment based supply and exhaust air ventilation and centralized mechanical supply and exhaust ventilation. For mechanical supply and exhaust ventilation we have possibility to have heat recovery system, it’s the most effective way to save costs while achieving a good indoor air quality.

Apartment based supply and exhaust ventilation becomes more and more popular for renovation old designed houses with natural ventilation. For the occupants of high rise residential buildings this system is the easiest way to make adequate ventilation in their houses. There is a possibility to adjust as good parameters of indoor air quality as in central supply and exhaust ventilation systems, but your decision of installing new equipment will not be stopped by persuasion the rest occupants.

The principle of operation in apartment based system is shown in Figure 7.

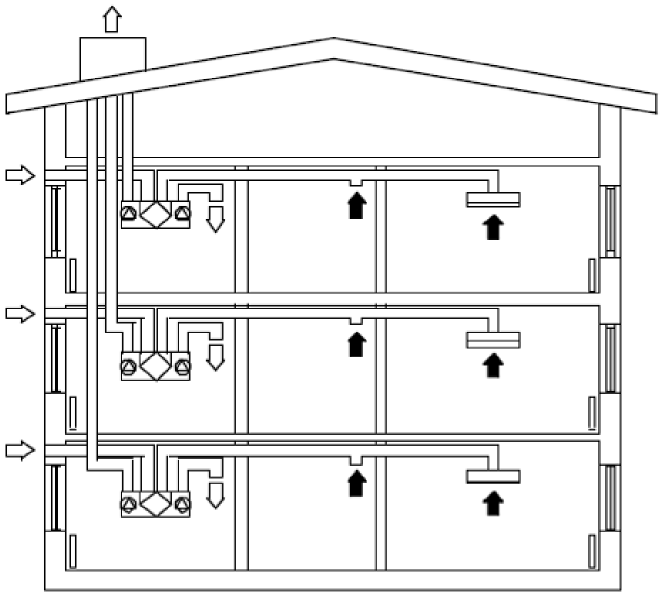


FIGURE 7. Apartment based supply and exhaust air ventilation /16/

Apartment based air handling unit and centralized air handling unit contains the same set of equipment: fans, heating and cooling coils, filters, dampers and silencers. Little heat recovery unit which is suitable for apartment based mechanical supply and exhaust ventilation is shown in Figure 8. /17/

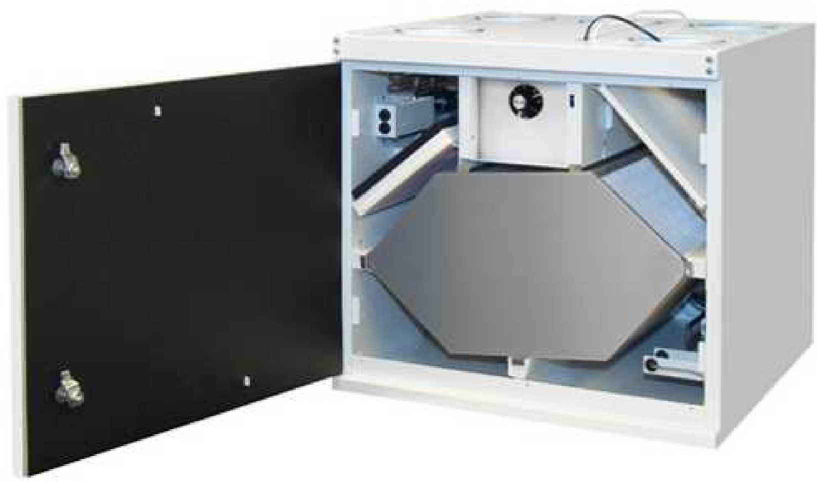


FIGURE 8. Heat recovery unit for one apartment or one-family house Swegon CASA W80 Premium /17/

Centralized air handling units are bigger than apartment ones, they are usually located under the roof on the technical floor. Centralized air handling units are controlled by the automation system and numerical parameters of air processes can be adjusted from the computer in technical office. All warnings of such systems are also displayed on the central computer with building automation.

In spite of using filters in both systems centralized system usually provide supply air quality better than apartment based one. Supply air to the apartment based system come from the façade of the building, usually in the big cities there is city's smog which contains exhaust gases from the automobiles, pollutants, heavy metals, but density of contaminants decreases with the height. That’s why supply air intake from the roof provides better quality of air than intakes from the façade.

Supply air is preheated by the heat recovery unit and then is heated up to the desired temperature in coils by using power from district heating pipes. Heat recovery system greatly reduces energy consumption of ventilation heating systems. Temperature ratio of heat recovery can be up to 50-80%, it depends on type of heat recovery system. Heat recovery unit have also limitations for use, e.g. temperature after heat recovery shouldn’t be less than 0^{o}…$+5^{o}$ C to prevent freezing. Temperature ratio should be reduced if temperature coming below this temperature. For cases when air preheated by heat recovery is warmer than it is needed we also decrease temperature ratio of heat recovery. Basically there are three main types of heat recovery systems: rotary heat recovery, cross-flow plate heat recovery and coil heat recovery.

Rotary heat recovery also known as rotary air-to-air enthalpy wheel or thermal wheel is type of regenerative heat exchanger (Figure 9). Supply and exhaust flows go through the rotor towards each other. Exhaust air gives heat to the wheel’s sector through which it goes. When this heated sector meets to the cold supply air flow wheel’s sector gives its heat to the flow, supply air becomes warmer, wheel cools down. Temperature ratio of thermal wheel heat recovery depends on rotating speed of the wheel. This type of heat recovery system has the highest temperature ratio because of the possibility of transfer both sensible and latent heat. But because of mixing flows thermal wheels are not suitable for many cases, e.g. in hospitals and residential houses.

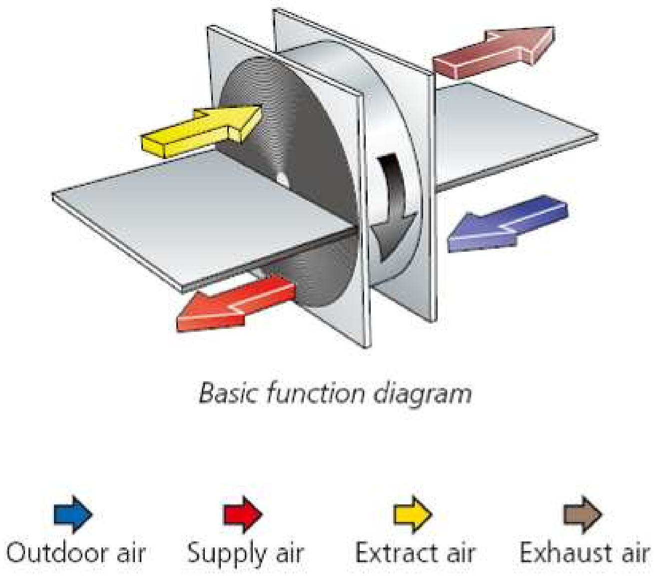


FIGURE 9. Rotary heat recovery /18/

Cross-flow plate heat recovery and coil heat recovery are recuperative heat exchangers and air flows are not mixing in them at all. They are widely used almost everywhere. There is also no moisture transfer in these heat recovery units.

Coil heat exchanger looks like two coils with the heat-transfer liquid circulated between them like it is shown in Figure 10 below. One coil is situated inside the exhaust duct and another inside supply one. The heat is transferred to the liquid in coil (exhaust) and then it is transferred from liquid to another coil in another end of the pipe work. The opportunity of the coil heat recovery is that supply and exhaust ducts could be placed far from each other. But temperature ratio of the coil heat recovery units is less than temperature ratio of rotary or cross-flow plate heat recoveries.

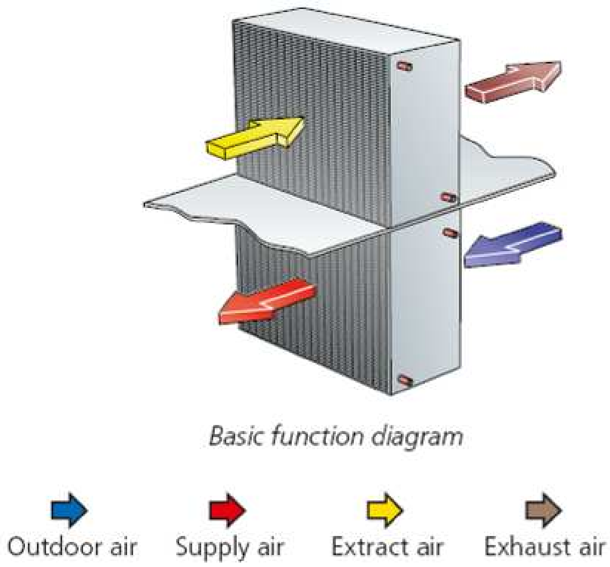


FIGURE 10. Coil heat recovery /18/

Cross-flow plate heat recovery looks like a set of aluminium plates, which create a system of channels for the air. Cross flow through the heat exchanger gives a possibility to have higher temperature ratio, because inlet air is heated firstly by almost cooled air and only in the end of passing through the channels between plates it is heated with extract air with indoor temperature. Temperature ratio in coil and cross-flow plate heat recoveries can be decreased by using bypass line. Cross-flow plate heat recovery is shown in Figure 11.

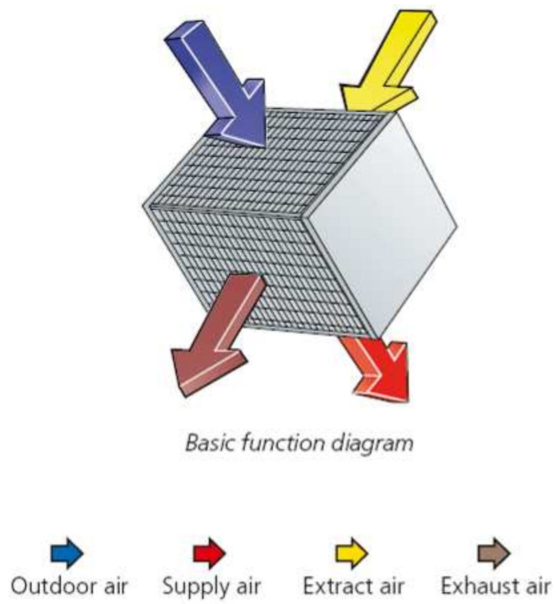


FIGURE 11. Cross-flow plate heat recovery /18/

Usually heat recovery system is already included in air handling unit, AHU also may contain heating and cooling coils, different filters, humidifier and dehumidifier, fans, silencers, dampers, inspection openings and different measuring devices and automation system. Manufacturers have wide range of standard sets of equipment and typical sizes, engineer should only calculate air flow rate for whole building and choose own set of equipment. In the Figure 12 typical centralized mechanical exhaust and supply ventilation is introduced.

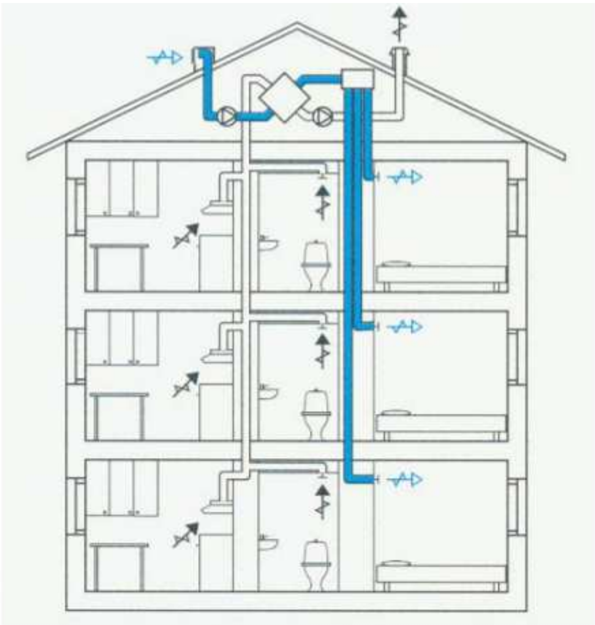


FIGURE 12. Centralized mechanical exhaust and supply ventilation for block of flats /14, p.123/

Mechanical supply and exhaust systems like any real product have a lot of advantages and disadvantages. Possibility of using heat recovery and lower risks of draught because of heated supply air we could count to advantages of such systems. They also can have flat-specific air flow control – it is possibility for occupants to control air flow rates in the flat in a small range with the aid of specific valves. The required flow of supply air could be delivered directly into the living rooms or bedrooms; humid and pollute air could be extract from places where it was produced. With using mechanical supply and exhaust ventilation systems it is possible to keep apartments in the approximately neutral pressure levels. Such systems also increase energy efficiency of the building envelope, because we don’t need to have valves and holes in the envelope and we can make it as tight as possible to prevent any leakages through it. /14./

Equipment investment costs are the main disadvantage of mechanical supply and exhaust ventilation systems. They also takes a lot of space to be installed: you need to locate air handling unit somewhere and also amount of ducts become twice more. These systems have electricity consumption costs and are in want of qualified maintenance personal. /14./

2.8 Main difficulties in the design of ventilation system in high rise buildings

The biggest part of the residential buildings which are under construction in Moscow and Saint-Petersburg are high rise buildings. Certainly high rise buildings have specific particularities for designing building services. Nowadays the most popular type of ventilation in high rise residential buildings in Russia is still natural ventilation based on stack effect. Design temperature for calculation of air flows in natural ventilation is $5^{o}C$ and design wind velocity is v=0 m/s /22/. This temperature is too low for the normal functioning of the system in summer and it is too high to prevent big draughts in winter time. New airtight windows and prevention of leakages through the building envelope reduce amount of supply air. Ventilation calculations become even more inaccurate. Effect of the wind and flat position against to windward and leeward sides also changes the calculated airflows.

For mechanical ventilation systems we should also take into account this natural moving force – stack effect. Stack effect of natural ventilation causes big problems in balancing mechanical ventilation. Stack effect appears due to density differences between warm air on the lowest floors and cold outside air. In summer time reverse stack effect appears when outside air is warm and inside air is colder. It’s important to isolate ventilation ductwork as much as possible to prevent stack effect, because if we don’t have differences of temperature and density in the shaft and ambient air we don’t have stack effect.

Mechanical supply and exhaust ventilation with heat recovery is better than others because we have higher pressure difference in the ductwork system in both supply and extract sides, in this case pressure difference produced by stack effect have less influence to the system. Whole duct system should be isolated from the ambiance to prevent leakages. Also it is very important to prevent leakages through the building envelope - it reduces wind influence to balanced ventilation system.

There are several different methods of controlling stack effect in the mechanical supply and exhaust ventilation. I'll try to describe two methods (suitable for constant air flows in the system). Firstly in the highest part of each vertical duct we should install pressure sensors. Information from this pressure sensors should be transferred to the main automation system. In the first method according to pressure sensor readings we try to adjust and keep the calculated air flow. The second method is to control pressure differences all through the system. According to the pressure sensor readings rotation speed of the fan changes by frequency control to adjust needed pressure difference.

Often due to high pressure difference in the system pressure drop on the terminal devices is not enough to make balancing of the system. In this cases in is necessary to install dampers on the branches of system where pressure difference exceeds acceptable values. Further make balancing of the system by adjusting pressure drop on the terminal units.

3 CASE STUDY

Questions of designing and maintaining mechanical supply and exhaust ventilation system will be discussed in the following main chapter. The main special requirements for the design, installation and maintenance of mechanical supply and exhaust ventilation in Russian current norms would be determined and tried to solve in favor of mechanical exhaust and supply systems.

The research work in my Bachelor’s thesis will be divided into several steps:

1. Selecting the high rise residential building for the case study
2. Define required air flows according to Russian and Finnish standards
3. Calculating air flows according to Russian and Finnish standards
4. Dimensioning the duct work system
5. Selecting flow control equipment
6. Designing the fire spreading prevention system
7. Designing the air handling unit

3.1 Selecting the high rise residential building

For the case study 14-floor residential building was selected. This building belongs to the business class housing estate “Swedish Krona” (Russia, St. Petersburg, Fermskoe shosse, 22 B). Now it is on the project stage. In Figure 13 investigated building is shown.

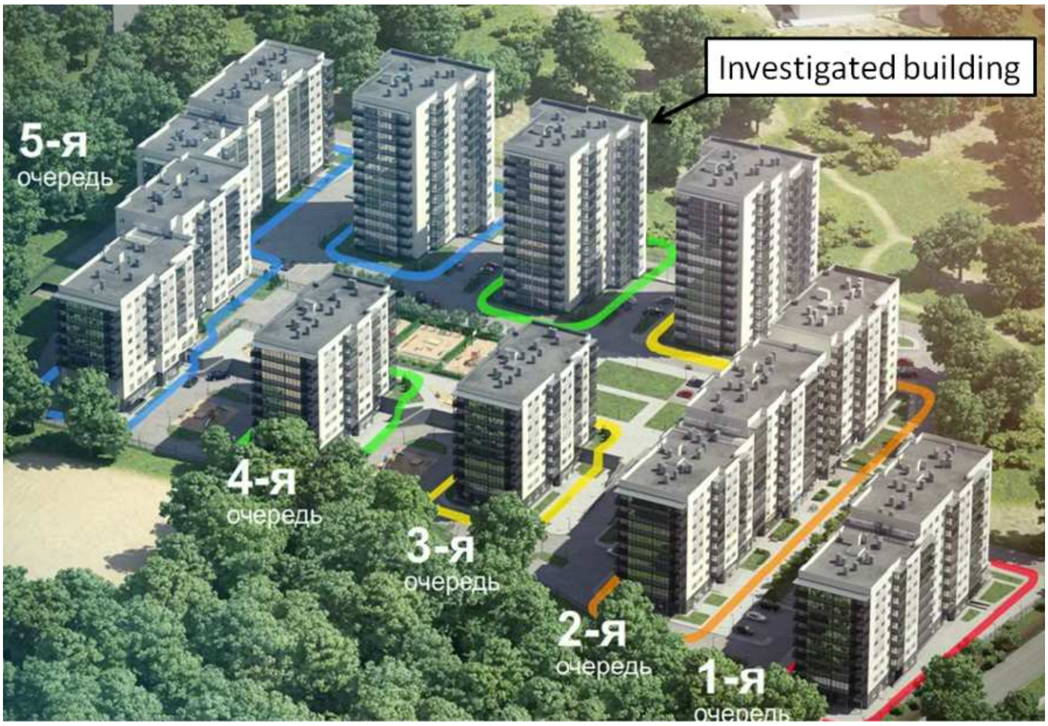


FIGURE 13. Housing estate “Swedish Krona” /19/

Selected building is almost 42 meters high, the gross floor area is 455.5 m^2, the total area of the building is 8239 m^2, and construction volume is 25547 m^3. It consists of total 78 apartments including 26 one-room apartments, 13 two-room apartments, and 39 three-room apartments. Apartments are situated on 13 floors and the height of rooms is 2.6-2.8 meters(floor height is 3 meter).

3.2 Calculation of the air flows

Designing ventilation system for the chosen high rise apartment building will be made in my thesis. The purpose of my studies is to develop mechanical supply and exhaust ventilation for the living premises. The ventilation of the commercial first floor, corridors, entry and stairs is designed already as a separate ventilation system.

Firstly it is needed to determine airflows in each room of the house and to calculate total air flow rates for the supply and exhaust air according to the Russian set of rules SP 54.13330.2011 based on the SNIP 31-01-2003 /20, p.18/. Obtained air flow rates are compared to the recommendations of the National building code of Finland D2 /7, p.32/. The highest flow between recommended is taken into design calculations as a minimum requirement. Calculating of the airflows is based on the plan of the typical floor which is shown in Figure 14.

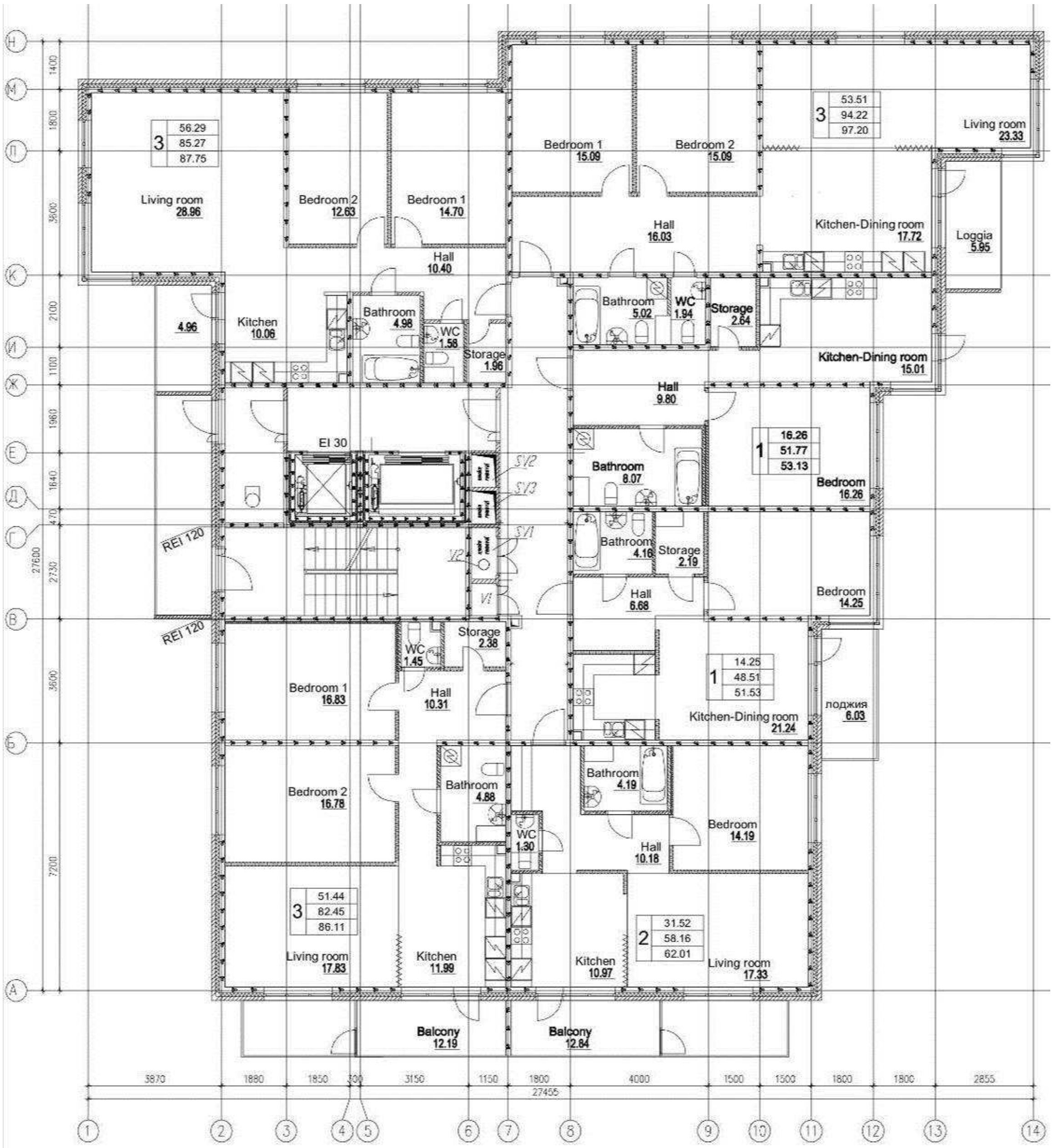


FIGURE 14. A typical floor

As it is shown in Figure 14, flats in the typical floor consist of bedrooms, kitchens, combined kitchens and dining rooms, living rooms, halls, water closets, bathrooms, loggias, balconies and storage rooms. Ventilation isn't needed only for balconies and loggias. For the other rooms ventilation rates are calculated in Appendix 1. In the Appendix 1 air flows of the supply and exhaust ventilation are calculated in accordance to the Russian and Finnish recommendations, air change rates of each apartment are shown and total air flows through the floor are summarized.

Calculation of air flows was carried out according to two methods: air flow rate per person and air flow rate per room area. Number of occupants in each flat for the first method of calculation was determined according to the current Russian law /21/ as 1 person per 18 square meters of flat area. The recommendation of Russian set of rules SP 54.13330.2011 is air change at least 30 m^3/h in bedrooms, living rooms and other dwelling rooms /20, p.18/. Finish D2 standard recommends outdoor air flow equal to 6 dm3/s·person for these types of rooms /7, p.32/. Amount of supply air based on the second calculation method was determined according to the Russian set of rules as 3 $m^3/h{\cdot}m^2$ of dwelling areas. And as 0.5 $dm^3/s{\cdot}m^2$ according to D2. The comparative table of recommended air flows is shown below in Table 1.

TABLE 1. Minimum required air flows

Air flow:	Supply air flow				Extract air flow	
Standard:	Russian	Finnish	Russian	Finnish	Russian	Finnish
Method:	Per person		Per square meter			
Space \ Units	l/s (m^3/h)	l/s (m^3/h)	l/s (m^3/h)	l/s (m^3/h)	l/s (m^3/h)	l/s (m^3/h)
Living area	8,3 (30)	6 (21,6)	0,8 (3)	0,5 (1,8)		
Kitchen					16,7 (60)	20 (72)
Bathroom					6,9 (25)	15 (54)
WC					6,9 (25)	10 (36)
Storage					0,2 1/h	3 (10,8)
Hall						

Dirty air should be extracted from the kitchen equipped with electric cooker with amount of at least 60 m^3/h. Amount of extract air from toilets and bathrooms is 25 m^3/h, for storage rooms extract air change rate should be at least 0.2 h^{-1}. /20, p.18./ And D2 recommends extract air from the kitchen with amount of 20 dm^3/s, from the storage room 3 dm^3/s, 15 dm^3/s from bathrooms, and 10 dm^3/s from the toilets. /7, p.32./ Table 2 below shows accepted air flow rates in each room of the typical floor.

Air flow rates shown in the Table 2 are also recorded to the typical floor plan in Appendix 2.

TABLE 2. Accepted air flow rates in the typical floor

Flat No	Room No	Space type	Supply air flow		Extract air flow		Air change rate, 1/h
			dm³/s	m³/h	dm³/s	m³/h	
1	1	Living room	25	90			
	2	Bedroom	15	54			
	3	Bedroom	16	58			
	4	Kitchen			30	108	
	5	Bathroom			15	54	
	6	WC			10	36	
	7	Storage			3	11	
	8	Hall					
		Total:	**56**	**202**	**58**	**209**	**0,87**
2	9	Bedroom	13	47			
	10	Bedroom	13	47			
	11	Living room	25	90			
	12	Hall					
	13	Kitchen-Dining			30	108	
	14	Bathroom			15	54	
	15	WC			10	36	
		Total:	**51**	**184**	**55**	**198**	**0,75**
3	16	Storage			3	11	
	17	Hall					
	18	Kitchen-Dining	20	72	30	108	
	19	Bathroom			15	54	
	20	Bedroom	25	90			
		Total:	**45**	**162**	**48**	**173**	**1,19**
4	21	Bathroom			15	54	
	22	Storage			3	11	

	23	Hall					
	24	Bedroom	25	90			
	25	Kitchen-Dining	20	72	30	108	
		Total:	**45**	**162**	**48**	**173**	**1,27**
5	26	Bathroom			15	54	
	27	WC			10	36	
	28	Hall	8	29			
	29	Bedroom	22	79			
	30	Kitchen			30	108	
	31	Living room	22	79			
		Total:	**52**	**187**	**55**	**198**	**1,22**
6	32	Bedroom	16	58			
	33	WC			10	36	
	34	Storage			3	11	
	35	Hall					
	36	Bedroom	16	58			
	37	Bathroom			15	54	
	38	Living room	22	79			
	39	Kitchen			30	108	
		Total:	**54**	**194**	**58**	**209**	**0,90**
		Total per floor:	**303**	**1091**	**322**	**1159**	

As it is indicated in the Table 2 above and in Appendix 1, total supply air flow is 255 dm^3/s per each floor; total extract air flow is 269 dm^3/s per each living floor. Supply air is coming out through the air supply valves located mainly in the sleeping areas of the flat and then it moves through the hall to the “dirty” spaces like kitchen and bathroom. Exhaust air valves are used to extract air from apartments with constant adjusted flow.

Designed air flows in all apartments are higher than the minimum required. Air change rates range from 0.75 h^{-1} to 0.90 h^{-1} per one flat for large apartments and from 1.19 h^{-1} to 1.27 h^{-1} for small flats. It meets the recommendations of D2 /7/, where it is noted that the extract air flows in apartments should be normally designed in such way to be higher than the guide-line values and the air change rate of the apartment should be at least 0.5 l/h.

3.3 Dimensioning ventilation ducts

In each floor of the building there are 6 supply and 6 exhaust vertical ducts – 1 of each duct per each flat. Air distribution ductwork in apartments is connected to these vertical ducts above the level of the false ceiling. For providing exhaust air in each flat there are 3 vertical ducts: the main air duct and 2 air pockets. Exhaust ductworks are connected to these air pockets. Air pockets are individual for each flat and their height should be at least 2 meters before their connection to the main vertical exhaust air duct /22, section 7.11.1/. The first air pocket is for connection the cooker hood and the second one is for the exhaust air from the toilet, bathroom and the storage room. In Appendix 3 plan of the typical living floor with the duct work layout is shown.

3.3.1 Dimensioning the duct work system

Dimensioning of the duct work system in each floor is based on the calculation of noise levels produced by air flow inside the duct. Maximum permissible equivalent sound levels in ventilation systems of dwellings with advanced comfort level are taken from the Russian SNIP 23-03-2003. According to this document, sound level should not rise over the 35 dBA from 7 a.m. to 11 p.m. and over the 25 dBA from 11 p.m. to 7 a.m. every day. The maxim acceptable noise level in dwellings with advanced level of comfort should not exceed 50 dBA in day time and 40 dBA in night time. /23, table 1./

Ventilation ducts inside the flat are made of sheet steel with wall thickness 0.5 mm. They don’t have any noise insulation. That’s why they have to be designed in such way to have velocities lower than maximum acceptable. In Figure 15 below correlation between duct diameter, sound level, air velocity, air flow, and pressure losses in ducts is shown.

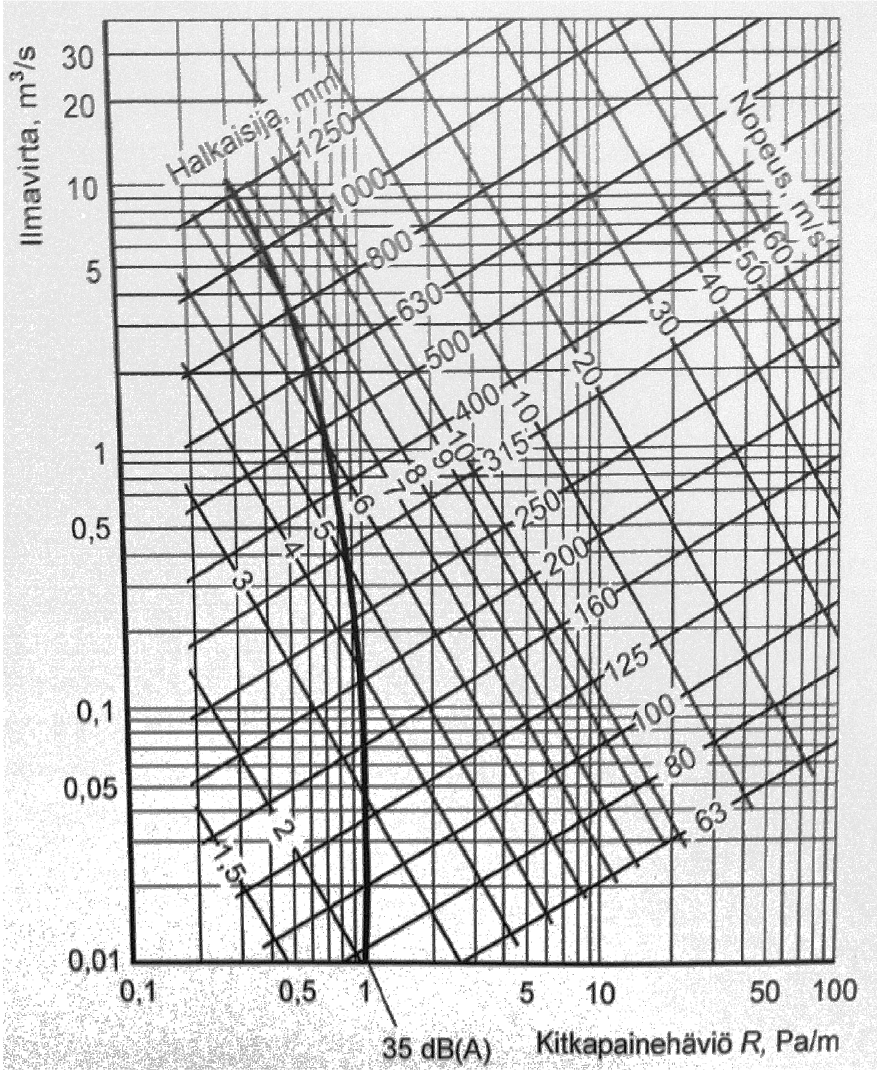


FIGURE 15. Correlation between duct diameter, sound level, air velocity, air flow, and pressure losses in round ducts /24, p.117/

Duct sizing was carried out according to the plan of the typical floor in Appendix 2. For each supply duct the velocity was calculated and sound level was checked. In the Table 3 below results of dimensioning the supply ductwork system on the typical floor is presented.

TABLE 3. Sizing of the supply ductwork system

Flat	Air flow		Diameter	Area	Velocity
	dm³/s	m³/h	mm	cm²	m/s
1	25	90	125	122,7	2,0

	31	112	125	122,7	2,5
2	25	90	125	122,7	2,0
	26	94	125	122,7	2,1
3	25	90	125	122,7	2,0
	20	72	125	122,7	1,6
4	25	90	125	122,7	2,0
	20	72	125	122,7	1,6
5	22	79,2	125	122,7	1,8
	30	108	125	122,7	2,4
6	22	79,2	125	122,7	1,8
	32	115,2	125	122,7	2,6

As it is shown in Table 3 above, diameters were calculated for the highest air flow through them. Diameter of ducts inside flats is unified and is equal to 125 mm to save space under the ceiling and to make the installation process easier and to exclude big amount of transitional elements. Number of ducts laying under the ceiling in each flat is 2. Connection of supply ducts to the vertical main distribution ducts is made with diameter 160 mm. Velocity calculation is shown in Table 4.

TABLE 4. Sizing of ducts connected to the main vertical distribution ducts

Flat	Air flow		Diameter	Area	Velocity
	dm^3/s	m^3/h	mm	cm^2	m/s
1	56	202	160	201,1	2,8
2	51	184	160	201,1	2,5
3	45	162	160	201,1	2,2
4	45	162	160	201,1	2,2
5	52	187	160	201,1	2,6
6	54	194	160	201,1	2,7

It is better to make only one connection to the main duct because we need to install expensive automatic fire dampers near each connection point between the vertical air distribution duct and horizontal flat’s ductwork. Diameter 160 mm is changing to the diameter 125 mm after the fire damper to increase height of rooms. Extract air ducts are also calculated according to the Figure 15. Results of dimensioning extract ducts are presented in Table 5.

TABLE 5. Sizing of the exhaust air pockets

Flat	Duct	Air flow		Diameter	Area	Velocity	Pressure loss
		dm³/s	m³/h	mm	cm²	m/s	Pa/m
1	AP 1.1	30	108	125	122,7	2,4	0,07
	AP 1.2	28	101	125	122,7	2,3	0,65
2	AP 2.1	30	108	125	122,7	2,4	0,70
	AP 2.2	25	90	125	122,7	2,0	0,55
3	AP 3.1	30	108	125	122,7	2,4	0,70
	AP 3.2	18	65	125	122,7	1,5	0,35
4	AP 4.1	30	108	125	122,7	2,4	0,70
	AP 4.2	18	65	125	122,7	1,5	0,35
5	AP 5.1	30	108	125	122,7	2,4	0,70
	AP 5.2	25	90	125	122,7	2,0	0,55
6	AP 6.1	30	108	125	122,7	2,4	0,70
	AP 6.2	28	101	125	122,7	2,3	0,65

AP 1.1 means air pocket 1 in the flat 1, AP 1.2 means air pocket 2 in the flat 1. Extract air ducts inside each flat have the same diameter as air pockets and they are the same for each flat. As it is shown above, diameter of each duct inside the flat is 125 mm.

3.3.2 Dimensioning the main air ducts

The size of vertical ducts is changing from one floor to another because of the difference in air flows through them and because of ambition to increase the area of each flat. Main vertical ducts firstly were designed as round ducts with help of Figure 15. Design values for round vertical exhaust ducts in the flat 1 are shown in Table 6.

TABLE 6. Sizing the round vertical exhaust ducts

Floor	Duct	Air flow		Diameter	Area	Velocity	Final Ø
		dm³/s	m³/h	mm	cm²	m/s	mm
3	ED1	58	209	160	201,1	2,9	250
4		116	418	200	314,2	3,7	
5		174	626	250	490,9	3,5	
6		232	835	315	779,3	3,0	315
7		290	1044	315	779,3	3,7	
8		348	1253	315	779,3	4,5	
9		406	1462	315	779,3	5,2	
10		464	1670	400	1256,6	3,7	400
11		522	1879	400	1256,6	4,2	
12		580	2088	400	1256,6	4,6	
13		638	2297	400	1256,6	5,1	
14		696	2506	400	1256,6	5,5	
AHU		754	2714	500	1963,5	3,8	500

In the Table 6 above, ED1 means vertical exhaust duct in the flat 1 (it is marked in Appendix 3), AHU means duct size which is laying on the technical floor in direction of the air handling unit. Table 7 shows design values for the round vertical supply ducts in the first flat, where SD1 means supply vertical duct in the first flat.

TABLE 7. Sizing of the round vertical supply ducts

Floor	Duct	Air flow		Diameter	Area	Velocity	Final Ø
		dm³/s	m³/h	mm	cm²	m/s	mm
AHU	SD1	728	2621	500	1963,5	3,7	500
14		672	2419	400	1256,6	5,3	400
13		616	2218	400	1256,6	4,9	
12		560	2016	400	1256,6	4,5	
11		504	1814	400	1256,6	4,0	
10		448	1613	400	1256,6	3,6	

9		392	1411	315	779,3	5,0	315
8		336	1210	315	779,3	4,3	
7		280	1008	315	779,3	3,6	
6		224	806	315	779,3	2,9	
5		168	605	250	490,9	3,4	250
4		112	403	200	314,2	3,6	
3		56	202	160	201,1	2,8	

As it is shown in Tables 6 and 7, maximum diameter of ducts going through first flat is 400 mm. The first flat has the highest air flow of supply and exhaust air. In the other flats air flows are smaller, that's why, diameter of the supply and exhaust ducts can be unified to the diameters of ED1 and SD1. There are three main diameters: 250 mm from 3 to 5 floor, 315 mm from 6 to 9 floor and diameter 400 mm from 10 to 14 floor. It is not economically effectively to use such a big diameter as 400 mm, because in connection points of the different diameters of vertical ducts their axises should coincide and also because these ducts will be covered with rectangular plaster walls after mounting them into correct position. To increase area to sell, it is needed to change vertical round ducts to the rectangular ones. But one problem is that there are no figures or tables to calculate sound levels in rectangular ducts.

To find right duct sizes for the rectangular ducts using Figure 15 it was needed to equalize rectangular ducts to the equivalent round ducts in pressure losses. Pressure losses, noise level and air velocity depends on the size of the duct. Equivalent diameters were calculated using Equation 1 below.

Equation 1: $$d_{eq} = \frac{2ab}{a+b}$$ /25, p.283/.

In Equation 1 "a" and "b" are dimensions of the rectangular duct, d_{eq} is equivalent diameter of the round duct. Possible dimensions of manufactured rectangular ducts were taken from Russian normative document GOST 24751-81 /26, p.2-3/. Real mean velocities in rectangular ducts were calculated using equivalent diameters. Then, according to Figure 15, the dimensions of rectangular ducts were selected so, that the noise level for the equivalent diameter of selected duct should be less than 35 dBA.

Design values for the rectangular main exhaust vertical ducts are shown in Appendix 4.

Sizing was made in such way to provide the most compact dimensions of ventilation block, which consists of exhaust and supply vertical ducts. Designing the vertical ventilation blocks is shown in the chapter 3.3.3. Selected dimensions of rectangular ducts were unified to exclude big amount of fittings and to make work of plumbers easier. Design values for the rectangular main supply vertical ducts are shown in Appendix 5. Final diameters of supply and exhaust ducts are also shown in Table 8.

TABLE 8. Final dimensions of rectangular vertical ducts

Floor	Dimensions, mm
3 - 5	400 x 160
6 - 8	400 x 250
9 - 14	400 x 400

Unification was carried out according to number of size changing equal to 3. Dimensions of the main vertical ducts change only 3 times while going through the floors to exclude big number of different fittings and to avoid any troubles during the construction period. Following results are obtained after the unification: for 3-5 floors is applied diameter 400x160, for 6-8 floors is applied diameter 400x250, for 9-14 floors is applied diameter 400x400. After 14th floor each vertical rectangular ducts are changed to the circular ducts. In Appendix 6 schematic picture of the vertical exhaust and supply main ducts is shown.

3.3.3 Designing vertical ventilation blocks

Sizing the vertical air ducts was made in such way to provide the most compact dimensions of the ventilation block, which consists of exhaust and supply vertical ducts. As it is shown in Figure 16, each ventilation block consists of two air pockets with diameter 125 mm, exhaust rectangular duct with variable size and supply vertical duct with variable size.

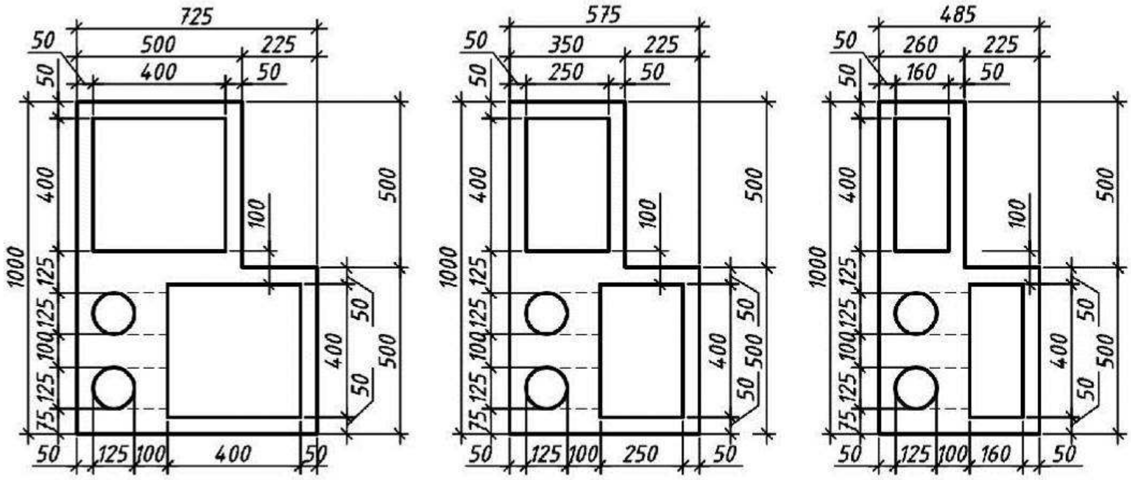


FIGURE 16. Ventilation blocks

As it is shown above, there are three typical sizes of ventilation block. The first one is used on the upper floors. Air flows in this block are high and dimensions of supply and exhaust rectangular ducts are 400 x 400 mm. The area of this ventilation block is 0,6125 m^2. The second type consists of rectangular ducts with dimensions 400 x 250 mm. It will be used in the middle of the building from 6^{th} to 8^{th} floor and the area of it is 0,4625 m^2. The third type is used on the first floors of the investigated house. Supply and exhaust vertical rectangular ducts are 400 x 160 mm in this block. It is the smallest one – 0.3725 m^2. These three types of ventilation block are located one over another in the building and provide efficiently using of living area.

Ducts with overflying traffic inside will be covered by special fire proof material to adjust necessary fire resistance time period in danger of a fire. To attach more convenient and unitized shape of the ventilation blocks, they are covered with plaster walls along the perimeter.

3.3.4 Flow control equipment

Flow control through the whole system is achieved by the AHU automation, pressure control, automatic and manual dampers. Firstly we should balance 6 exhaust and 6 supply vertical ducts by pressure control system, it was installed on the highest part of vertical duct on the technical floor. Because of constant air flows in this system we can program pressure control to certain pressure difference(also constant air flows). Pressure control system is connected to frequency control of fan in AHU.

Controlling the flow inside apartments is carried out by using supply and exhaust valves with varied flow through them. Pre-setting of each valve will be carried out according to the designed flow rates in correspond rooms. If pressure drop on the terminal unit is not enough for balancing manual damper should be installed like it is shown in Appendix 6.

In each kitchen hood filters against cooking impurities should be installed. Grease from the kitchen negatively affects on ductwork system and control equipment. Grease accumulated inside extract ducts could also be a reason of spreading the fire between the flats through the vertical ducts. If high quality filters are installed in each cooker hood, frequency of cleanings and changing filters in AHU can be reduced in times, also important thing is that filters should be cleaned or changed timely.

3.4 Designing fire spreading prevention system

Standardized fire-resistance rating of main air ducts is EI 30 for dwellings according to the Russian normative document SP 60.13330.2010 “Heating, ventilation and conditioning”. It means that ventilation ducts passing through the floor should have passive fire protection in a such level to withstand standard fire resistance test for 30 minutes. Air distribution ducts inside the flat don’t have any prescriptions about their fire resistance rating. Fire resistance rating of ducts on the technical floor is EI 30. For steel ducts with standardized fire-resistance rating, minimum wall thickness is 0.8 mm. /22, table 2./

According to prescriptions above main air ducts are covered with Rockwool Fire Duct Slabs /27/. The thickness of selected slabs is 40 mm. It gives fire resistance 30 minutes and could be installed on ducts sizes up to 1500x1500 mm. Fire Duct Slab provides fire protection, thermal and acoustic insulation rectangular steel ductwork. Slabs are covered with reinforced aluminium foil.

In horizontal air ducts following fire protection systems for prevention of fire spreading from one area to another should be installed:

- Air pockets – in connection points between extract air ductwork of dwellings and main vertical ducts. Their height should be at least 2 meters.
- Fire safety valves – in in connection points to the vertical main duct if air pockets cannot be installed. /22, chapter 7.11./

In my designs in each floor extract air ductwork is connected to the air pockets as it was explained earlier. Horizontal extract ducts on the 14th floor are connected straightly to the vertical extract duct. To achieve necessary fire protection, fire dumpers are installed before connection point. And also to prevent back flow into the flat check valves are installed before the fire safety valve in each apartment on the 14th floor of the investigated building. Fire spreading prevention system on the 14th floor is shown schematically in Appendix 6.

In buildings with height more than 28 meters “normally open” fire dampers should be installed at the end of each vertical extract main duct in before connection them to the horizontal collection duct. Fire resistance of fire dampers should not be less than fire resistance of protected ducts. /22, chapter 7.11./

Investigated building is 42 meters height. At the end of each extract vertical duct “normally open” fire dampers are installed. In case of a fire part of the system which is under the fire will be closed without switching off another parts of the ventilation system.

In ventilation systems which are working 24 hours per day 365 days per year achieving desired air quality should be provided by at least two air handling devices. In case when one air handling unit is broken, another one should provide 50% of designed flow. /22, chapter 7.2./

In my designs additional roof fan is installed in the extract air system before the air handling unit and in emergency case it is blowing extract air straightly to the outdoors. Amount of extracted by this fan air is 50% of total extract air flow (2093 l/s). This fan is working only in emergency situations and is shown in Figure 18. Normally closed damper is installed before this additional fan to prevent flow going through it in normal cases. Supply air in emergency case will be provided by opening windows.

In supply air ducts fire dampers have to be installed in each crossing between the duct and surface with normalized fire resistance. /28, chapter 6.16./ In my designs fire dampers are installed on each floor before the connection of horizontal distribution ducts to the main vertical ducts like it is shown in Appendix 6. In danger of a fire in the flat, building's automation system will close supply and exhaust dampers to prevent suction the smoke and transferring the flame from this flat to others.

3.5 Designing the air handling unit

Designing the air handling unit is divided into two steps. First is to select a suitable air handling unit from the manufacturer's alternatives. And the second part is to design duct system on the technical floor.

Firstly for selecting air handling unit we should know initial data about the system: supply and extract flows, suitable type of heat recovery system, needed set of equipment by the customer's instructions, operational time of the system. For this high rise building design value for the supply air flow is 14180 m^3/h (3939 dm^3/s), for extract air flow is 15070 m^3/h (4186 dm^3/s). According to the dwelling building's type we should select heat recovery without mixing supply and extract flows. Plate heat recovery system was selected because of higher temperature ratio than in coil heat recovery.

According to GOST 30494-96 Table 1 optimal mean indoor temperature in bedrooms and living rooms is 20-22^oC in winter time, in kitchen and toilet 19-21^oC, in bathrooms 24-26^oC, for summer time in bedrooms is recommend temperature 22-25 ^oC./28./ For design indoor temperature we'll choose 21^oC, for temperature of supply air 18^oC. Higher temperatures in bathrooms are adjusted by using towel dryers is each bathroom. Operational time in residential buildings is 24 hours 7 days per week. Air handling unit will be located on the heated technical floor above the 14th floor.

Selected air handling unit is Swegon Silver Modular air handling unit, size 11 (1350x1350 mm). This AHU isn't standard example, whole equipment of AHU is selected according to the customer's needs. Selected AHU contains: plate heat recovery, direct-driven axial-flow fans, dampers with damper blades which are driven by a damper motor, bag filter section, air heater for hot water, air cooler for water, silencer section, inspection section with inspection windows, pressure, temperature and relative humidity sensors and other extra accessories. The fan motor is designed for operation with a frequency inverter. /18./ Swegon Silver Modular air handling unit is shown in Figure 17.

FIGURE 17. Swegon Silver Modular air handling unit/18/.

For air intake we use special device Snow screen LSJ Fläkt Woods manufacturer, this snow screen is designed to prevent coming snow into the intake duct. “The vertical blades form a kind of labyrinth for the inflowing air, which efficiently prevents the penetration of snow, regardless of e.g. wind direction.” /29/ Air intake is designed on the north side of a technical floor on the roof. Snow screen LSJ is shown in Figure 18.

FIGURE 18. Snow screen LSJ /29/

For the exhaust air diffuser we use EYMA-2 Fläkt Woods manufacturer. The main advantage of these type of exhaust air devices is principle of work. Exhaust air from the device pushes straightly up at a high velocity. This fact prevents settling odours and contaminants near the air diffuser, contaminated air goes straightly to the wind flow. Also that principle of work prevents snow melting around exhaust device./30./ Exhaust air diffuser EYMA-2 is shown in Figure 19.

FIGURE 19. Exhaust air diffuser EYMA-2 Fläkt Woods /30/

Minimum distance between air intake and air outlet should be at least 10 m horizontally or less than 10m if vertical distance is more than 6 m. /22, 10.5/ In this study case distance is about 12m.

Designing the ductwork system is based on calculating air flows through the duct work system and after that on selecting sizes of the rectangular ducts according to the noise levels of the equivalent round ducts. The duct sizing was carried out according to Figure 20. Sizes of the extract air ducts from ED1to ED6 and from SD1 to SD6 are given in tables 6 and 7 correspondingly.

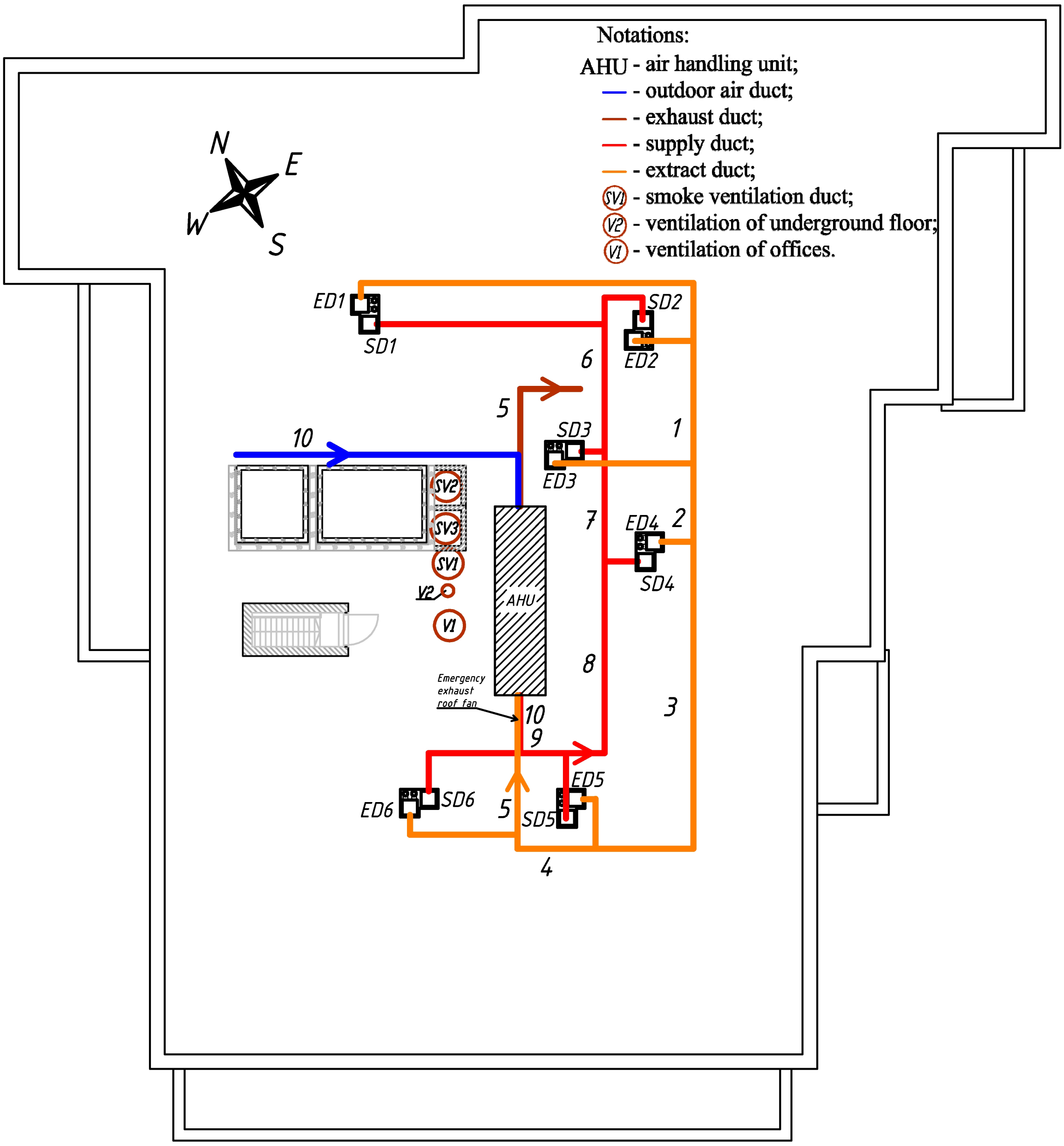


FIGURE 20. Numbering parts of the main duct system on the technical floor.

SV1-SV3 means smoke ventilation fans on the roof, V1 and V2 – ventilation exhaust fans from the first floor. Blue lines mean ducts with fresh outdoor air inside, brown lines – exhaust air ducts from the AHU to the exhaust device, yellow lines – extract air ducts, and red lines mean supply air ducts. As it is shown in figure 20 above, there are 10 marked sections which are needed to determine. In the Table 9 below diameters of the duct work system on the technical floor are calculated.

TABLE 9. Sizing of the duct work system on the technical floor

Section	Main ducts	Flow, l/s	Diameter, mm	υ, m/s
-	ED1	754	500	3,8
-	ED2	715	500	3,6
-	ED3	624	400	5,0
-	ED4	624	400	5,0
-	ED5	715	500	3,6
-	ED6	754	500	3,8
-	SD1	728	500	3,7
-	SD2	663	400	5,3
-	SD3	585	400	4,7
-	SD4	585	400	4,7
-	SD5	676	400	5,4
-	SD6	702	400	5,6
1	ED1+ED2	1469	630	4,7
2	ED1÷ED3	2093	800	4,2
3	ED1÷ED4	2717	800	5,4
4	ED1÷ED5	3432	800	6,8
5	ED1÷ED6	4186	1000	5,3
6	SD1+SD2	1391	630	4,5
7	SD1÷SD3	1976	630	6,3
8	SD1÷SD4	2561	800	5,1
9	SD1÷SD5	3237	800	6,4
10	SD1÷SD6	3939	1000	5,0
Emergency roof fan		2093	630	6,7

According to the Table 9 above, diameter of the air inlet and outlet ducts is 1000 mm. Ducts on the technical floor are situated in a such way to avoid crossings and to minimize length of ducts. Designed duct work is shown in Figure 21.

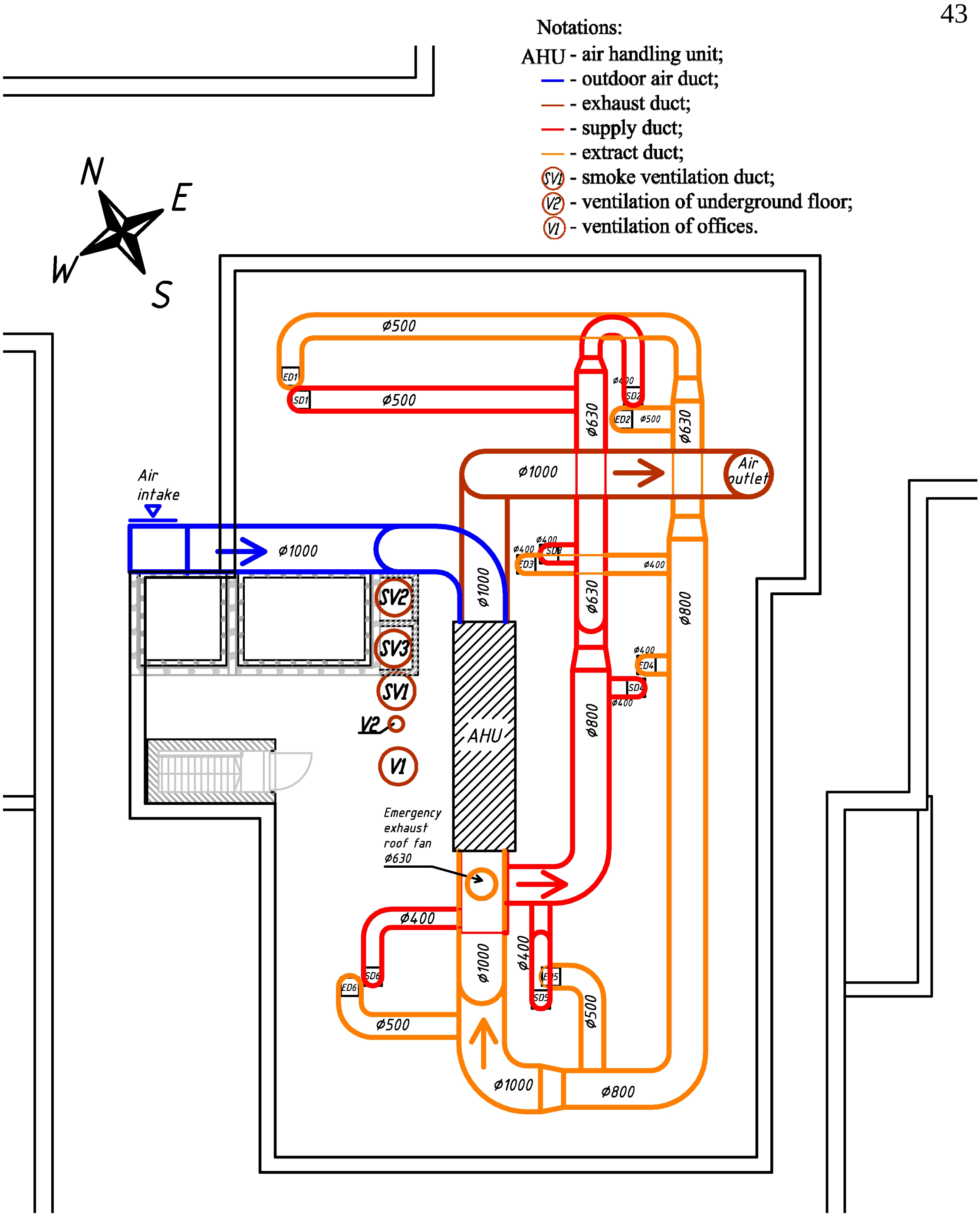


FIGURE 21. Designed main duct system on the technical floor

Blue duct in Figure 21 above is air intake duct with fresh outdoor air inside, brown duct – exhaust air ducts from the AHU to the air outlet device, yellow ducts – extract air ducts, and red ducts mean supply air ducts. Direction of flow inside ducts is shown by arrows.

4 DISCUSSION

In my Bachelor's thesis main types of ventilation systems which are common today were described. Advantages and disadvantages of natural and three variations of mechanical ventilation were analyzed. Mechanical supply and exhaust ventilation was viewed as a new trend in improving the quality of occupant's life in modern high rise residential buildings in Russia.

Investigation process was schemed in a such way to solve two main interweaving problems. The first problem was to find special requirements in Russian norms in design mechanical supply and exhaust ventilation. And the second problem was to solve the first one by development a landmark decision of ventilation design project.

14-floor residential building which belongs to the business class housing estate "Swedish Krona" (Russia, St. Petersburg, Fermskoe shosse, 22 B) was chosen to be a study case for the investigation. Desired indoor climate for selected study case was determined by selecting the best one after comparing Russian and Finnish national standards in this branch of knowledge. Comparative tables were presented and air flow rates in dwellings were designed according to the optimal requirements for indoor air quality.

Ventilation system was designed in a such way to have supply and extract ductwork system in each flat which are connected to the vertical main rectangular ducts. Vertical ducts are made of sheet steel and have only three different sizes for unification purposes. Vertical ducts going through each flat are connected together on the technical floor before the air handling unit.

Suitable air handling unit was selected from the manufacturer's catalog to provide good air quality and desired air flow rates to the investigated building. Air inlet and outlet are located on the roof of the building in a such way that exhaust air will not affect the fresh air coming into the ventilation system.

Air flow rates are controlled manually by supply and extract air valves in each flat and with additional dampers where pressure difference is too high and by pressure control system of the air handling unit. Pressure control system helps to smooth the differences of the air flow caused by stack effect in high rise buildings.

In emergency situations when AHU is broken bypass exhaust duct can be opened and air from dwellings can be extracted straightly to the atmosphere. Exhaust fan for emergency situations is designed only for 50% of designed flow, which meets the requirements of current Russian laws. If supply air ducts are closed in emergency situations, 50% of designed air flow could be achieved by leakage air through the building surfaces and opening windows.

Fire spreading protection system is designed to prevent any leaking of smoke and flame from the burning areas during the required time period. Transit vertical ducts are covered with fireproof isolation and have fire dumpers in all required points of the system. Fire dampers are normally opened and are programmed to close problematic parts of the system in emergency situations.

Mechanical supply and exhaust ventilations system which was designed in my Bachelor’s thesis could be used as a project case for real construction. Solutions presented of my Bachelor’s thesis could also serve the development of HVAC engineering in Russia.

BIBLIOGRAPHY

1. Cooke G. Natural versus mechanical ventilation. HVI. WWW document. www.hvi.org/assets/pdfs/HPAC_CookeJanFeb05.pdf. Last updated 02.2005. Referred 13.09.2011.

2. Natural ventilation advice. Holistic interior designs. WWW document. www.holistic-interior-designs.com/natural-ventilation-advice.html. No update information available. Referred 14.09.2011.

3. EPA. Indoor air facts No4 (revised) Sick Building Syndrome. WWW document. www.epa.gov/iaq/pubs/sbs.html. Last updated 30.09.2010. Referred 13.09.2011.

4. Ventilation. CUPE National Health and Safety Branch. WWW document. www.cupe.ca/health-and-safety/Ventilation. Last updated 02.05.2011. Referred 14.09.2011.

5. Inadequate ventilation and High CO_2 levels. OSSTF. WWW document. www.osstf.on.ca/Default.aspx?DN=083ea3cb-7819-4451-bdb3-dfc3a4d6bee6. No update information available. Referred 14.09.2011.

6. Prill R. Why measure carbon dioxide inside buildings. Healthy Facilities Institute. WWW document. www.healthyfacilitiesinstitute.com/a_43-Why_Measure_Carbon_Dioxide_Inside_Buildings. Last updated 01.07.2011. Referred 13.09.2011.

7. D2 National building code of Finland. Indoor climate and ventilation of buildings. Helsinki, Finland. Ministry of the Environment on the indoor Climate and ventilation of buildings. 2002.

8. Classification of Indoor Environment 2008. Target Values, Design Guidance, and Product Requirements. Finnish Society of Indoor Air Quality and Climate. FiSIAQ publication 5. Trinklet Oy. Helsinki 2010.

9. Яковлев Р.Н. Новые методы строительства. Москва. Аделант. 2002.

10. Feustel H.E., Diamond R.C. Flow distribution in a high-rise residential building. Stockholm, Sweden. The 6th Annual International Conference on Air Conditioning. 1998.

11. Tartakovsky I. Make sure your high-rise is breathing easily. Daily journal of commerce. WWW document. www.djc.com/news/re/11187281.html. Last updated 08.03.2007. Referred 02.10.2011.

12. Kuismanen K. Climate and ventilation. ECONO. WWW document. www.kuismanen.fi/VentEn.pdf . Last updated 09.02.2007. Referred 02.10.2011.

13. Natural and mechanical ventilation in cooling strategies. House-energy. WWW document. www.house-energy.com/House/Ventilation.htm. No update information available. Referred 03.10.2011.

14. Seppänen O., Seppänen M. Rakennusten sisäilmasto ja LVI-tekniikka. Sisäilmayhdisty. Jyväskylä. Sisäilmayhdistys ry. 1997.

15. Whole-house supply ventilation systems. Energy savers. WWW document. www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11880. Last updated 02.09.2011. Referred 04.10.2011.

16. Saari M., Laine J., Karjalainen S., Hamström K. Comparison of different HVAC systems in multistory apartment buildings in Helsinki. Proceedings of Healthy Buildings 2000, Vol. 2. 675-681. 2000.

17. Swegon AB. Swegon products. WWW document. http://swegon.com/en/Products/Home-Ventilation/Ventilation-Units/Supply-and-extract-air-handling-units/Counter-flow-plate-heat-exchanger-W-series/Swegon-CASA-W80-Premium/. No update information available. Referred 03.10.2011.

18. Swegon AB. Swegon products. WWW document. http://swegon.com/Global/PDFs/Air%20handling%20units/Swegon%20SILVER/_en/SILVER_overview.pdf. No update information available. Referred 03.10.2011.

19. Swedish Krona. Apartments on sale. WWW document. www.swedishkrona.ru/apartments/. No update information available. Referred 23.11.2011.

20. СП 54.13330.2011. Здания жилые многоквартирные. Москва. Министерство регионального развития Российской Федерации. 2011.

21. Постановление Правительства РФ от 29.08.2005 N 541 "О федеральных стандартах оплаты жилого помещения и коммунальных услуг". Москва. 2005.

22. СП 60.13330.2010. Отопление, вентиляция и кондиционирование. Москва. СантехНИИпроект. 2010.

23. СНИП 23-03-2003. Защита от шума. Москва. Госстрой России. 2004

24. Seppänen O. Ilmastoinnin suunnittelu. Forssa. Forssan Kirjapaino Oy. 2004.

25. Староверов И. Справочник проектировщика промышленных, жилых и общественных зданий и сооружений. Вентиляция и кондиционирование воздуха (внутренние санитарно-технические устройства) Часть II. Москва. Издательство литературы по строительству. 1969.

26. ГОСТ 24751-81. Оборудование воздухотехническое. Москва. Государственный комитет СССР по стандартам. 1981.

27. Rockwool. Fire duct systems. WWW document. www.guide.rockwool.co.uk/products/industrial-(rti)/fire-duct-systems.aspx. No update information available. Referred 03.12.2011.

28. ГОСТ 30494-96. Здания жилые и общественные. Параметры микроклимата в помещениях. Москва. СантехНИИпроект. 1999.

29. Fläkt Woods Group. Snow screen LSJ. WWW document. www.flaktwoods.com/3700801f-1f7a-4276-9269-f5b5cbf01696. No update information available. Referred 02.12.2011.

30. Fläkt Woods Group. Exhaust air diffuser EYMA-2. WWW document. www.flaktwoods.com/64eb99dc-4e73-42f8-89f2-d2f744c78142. No update information available. Referred 02.12.2011.

APPENDIX 1. Air flow rates in the typical floor

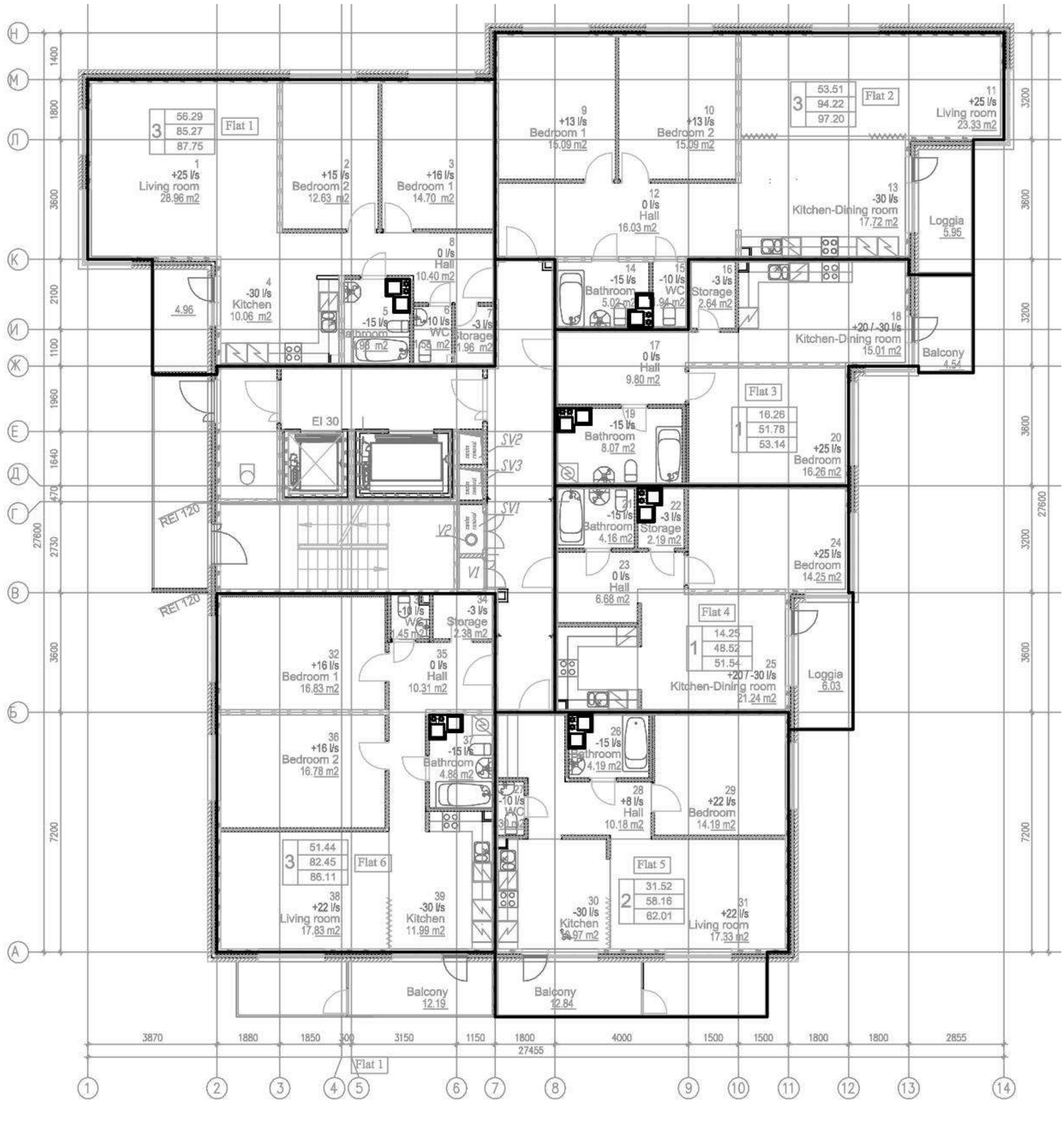
Flat №	Room №			Air flow:	Supply air						Extract air				Air change rate, 1/h
				Standard:	Russian	Finnish	Russian	Finnish	Selected flow		Russian	Finnish	Selected flow		
				Calculation method:	Per person		Per square meter								
		Space type	Area, m^2	Persons	dm^3/s	dm^3/s	dm^3/s	dm^3/s	dm^3/s	m^3/h	dm^3/s	dm^3/s	dm^3/s	m^3/h	
1	1	Living room	28,96	2	17	12	24	14	**25**	**90**					
	2	Bedroom	12,63	1	8	6	11	6	**15**	**54**					
	3	Bedroom	14,70	1	8	6	12	7	**16**	**58**					
	4	Kitchen	10,06								17	20	**30**	**108**	
	5	Bathroom	4,98								7	15	**15**	**54**	
	6	WC	1,58								7	10	**10**	**36**	
	7	Storage	1,96								0,3	3	**3**	**11**	
	8	Hall	10,40												
		Total:	**85,27**	**4**					**56**	**202**			**58**	**209**	**0,87**

Flat №	Room №			Air flow:	Supply air						Extract air				Air change rate, 1/h
				Standard:	Russian	Finnish	Russian	Finnish	Selected flow		Russian	Finnish	Selected flow		
				Calculation method:	Per person		Per square meter								
		Space type	Area, m²	Persons	dm³/s	dm³/s	dm³/s	dm³/s	dm³/s	m³/h	dm³/s	dm³/s	dm³/s	m³/h	
2	9	Bedroom	15,09	1	8	6	13	8	**13**	**47**					
2	10	Bedroom	15,09	1	8	6	13	8	**13**	**47**					
2	11	Living room	23,33	3	25	18	19	12	**25**	**90**					
2	12	Hall	16,03												
2	13	Kitchen-Dining	17,72								17	20	**30**	**108**	
2	14	Bathroom	5,02								7	15	**15**	**54**	
2	15	WC	1,94								7	10	**10**	**36**	
		Total:	**94,22**	**5**					**51**	**184**			**55**	**198**	**0,75**
3	16	Storage	2,64								0,5	3	**3**	**11**	
3	17	Hall	9,80												
3	18	Kitchen-Dining	15,01	2	17	12	13	8	**20**	**72**	17	20	**30**	**108**	
3	19	Bathroom	8,07								7	15	**15**	**54**	
3	20	Bedroom	16,26	2	17	12	14	8	**25**	**90**					
		Total:	**51,78**	**2**					**45**	**162**			**48**	**173**	**1,19**

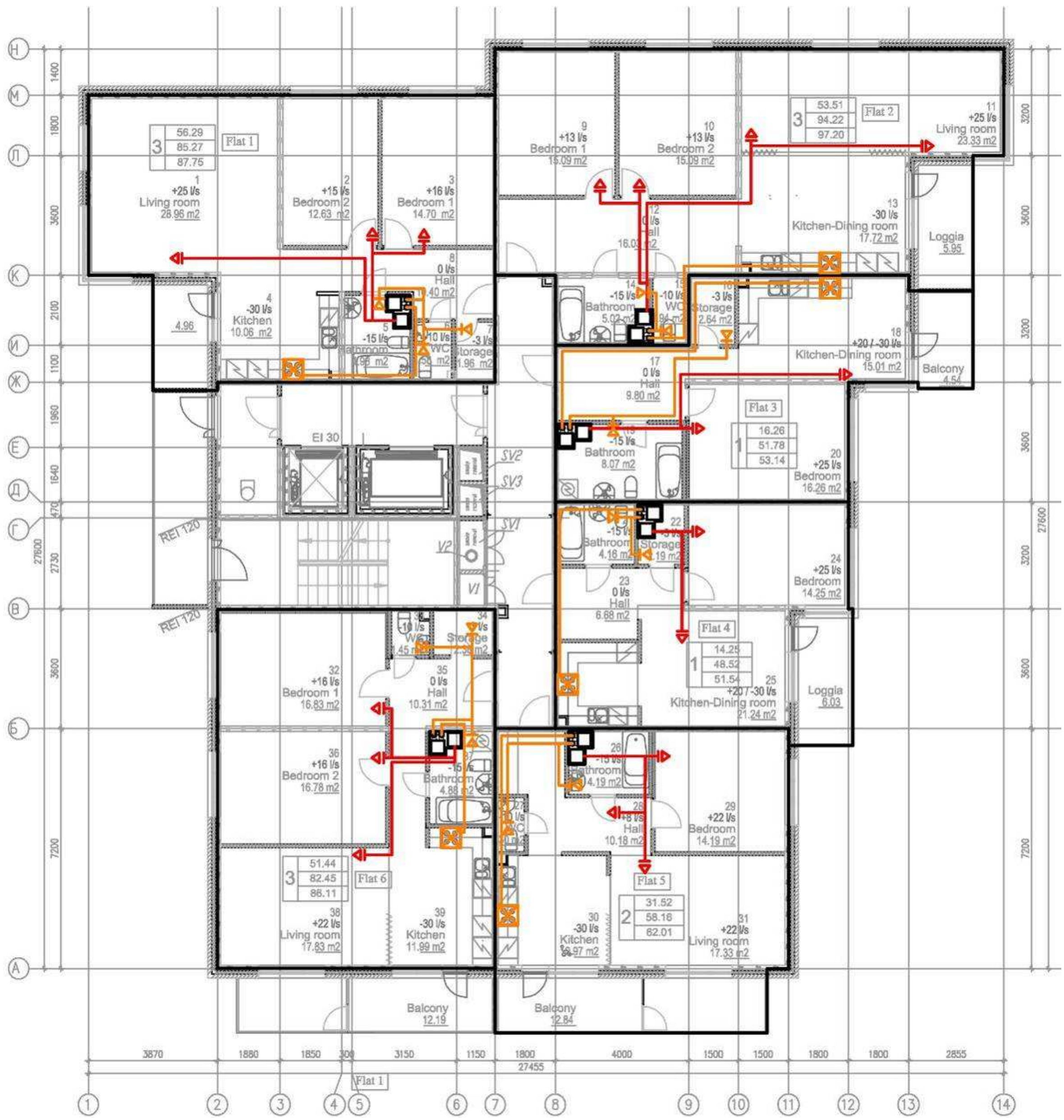
Flat №	Room №			Air flow:	Supply air						Extract air				Air change rate, 1/h
				Standard:	Russian	Finnish	Russian	Finnish	Selected flow		Russian	Finnish	Selected flow		
				Calculation method:	Per person		Per square meter								
		Space type	Area, m²	Persons	dm³/s	dm³/s	dm³/s	dm³/s	dm³/s	m³/h	dm³/s	dm³/s	dm³/s	m³/h	
4	21	Bathroom	4,16								7	15	**15**	**54**	
	22	Storage	2,19								0,4	3	**3**	**11**	
	23	Hall	6,68												
	24	Bedroom	14,25	2	17	12	12	7	**25**	**90**					
	25	Kitchen-Dining	21,24	2	17	12	18	11	**20**	**72**	17	20	**30**	**108**	
		Total:	**48,52**	**2**					**45**	**162**			**48**	**173**	**1,27**
5	26	Bathroom	4,19								7	15	**15**	**54**	
	27	WC	1,30								7	10	**10**	**36**	
	28	Hall	10,18						**8**	**29**					
	29	Bedroom	14,19	2	17	12	12	7	**22**	**79**					
	30	Kitchen	10,97								17	20	**30**	**108**	
	31	Living room	17,33	2	17	12	14	9	**22**	**79**					
		Total:	**58,16**	**3**					**52**	**187**			**55**	**198**	**1,22**

Flat №	Room №			Air flow:	Supply air						Extract air				Air change rate, 1/h
				Standard:	Russian	Finnish	Russian	Finnish	Selected flow		Russian	Finnish	Selected flow		
				Calculation method:	Per person		Per square meter								
		Space type	Area, m^2	Persons	dm^3/s	dm^3/s	dm^3/s	dm^3/s	dm^3/s	m^3/h	dm^3/s	dm^3/s	dm^3/s	m^3/h	
6	32	Bedroom	16,83	1	8	6	14	8	**16**	**58**					
	33	WC	1,45								7	10	**10**	**36**	
	34	Storage	2,38								0,4	3	**3**	**11**	
	35	Hall	10,31												
	36	Bedroom	16,78	1	8	6	14	8	**16**	**58**					
	37	Bathroom	4,88								7	15	**15**	**54**	
	38	Living room	17,83	2	17	12	15	9	**22**	**79**					
	39	Kitchen	11,99								17	20	**30**	**108**	
		Total:	**82,45**	**4**					**54**	**194**			**58**	**209**	**0,90**
TOTAL PER FLOOR:			**420,40**						**303**	**1091**			**322**	**1159**	

APPENDIX 2. Plan of the typical floor with air flows



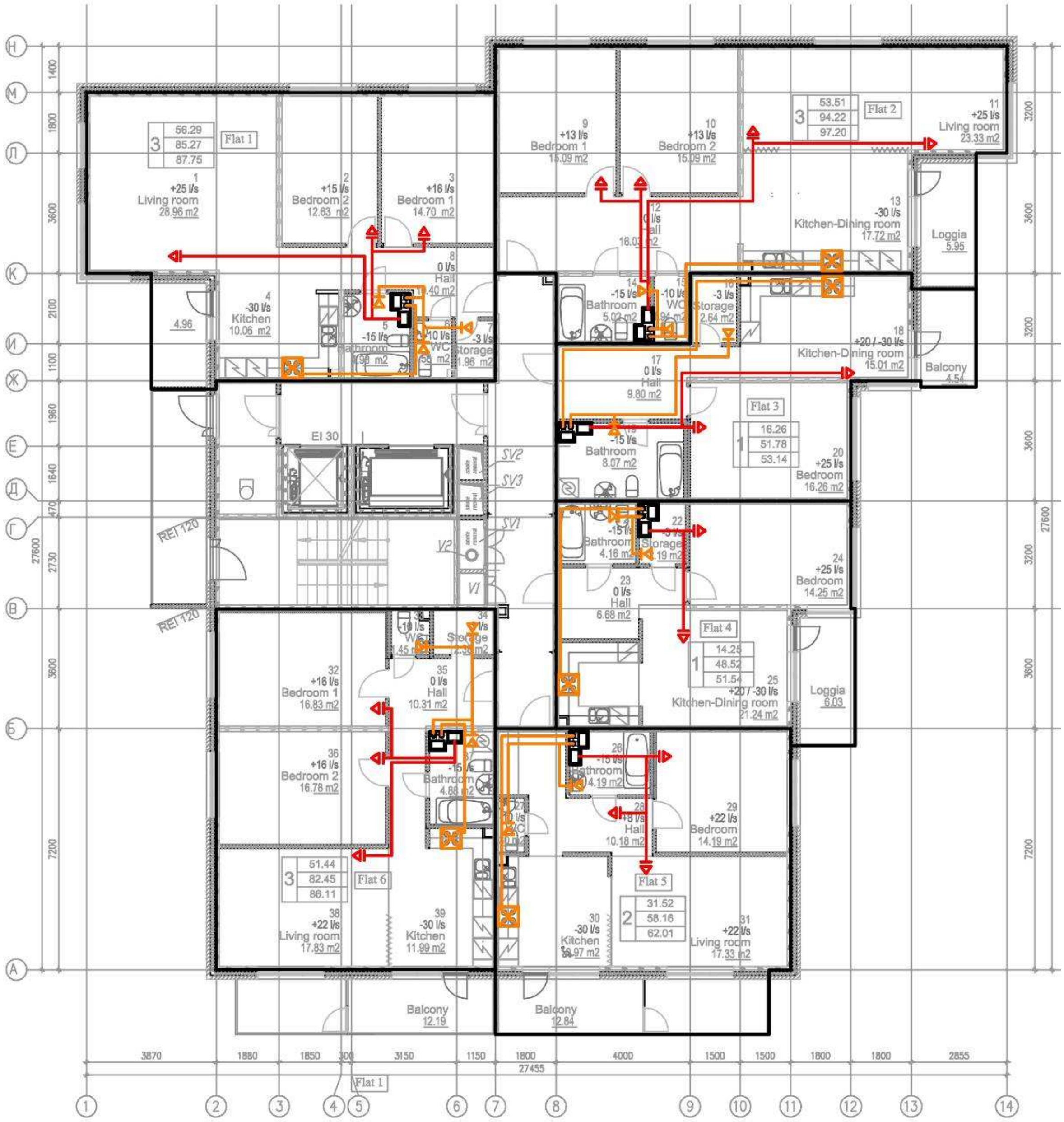
APPENDIX 3.1. Ductwork system on the 9-14 floors



Notations:

- supply air valve;
- extract air valve;
- kitchen hood;
- supply duct;
- extract duct;

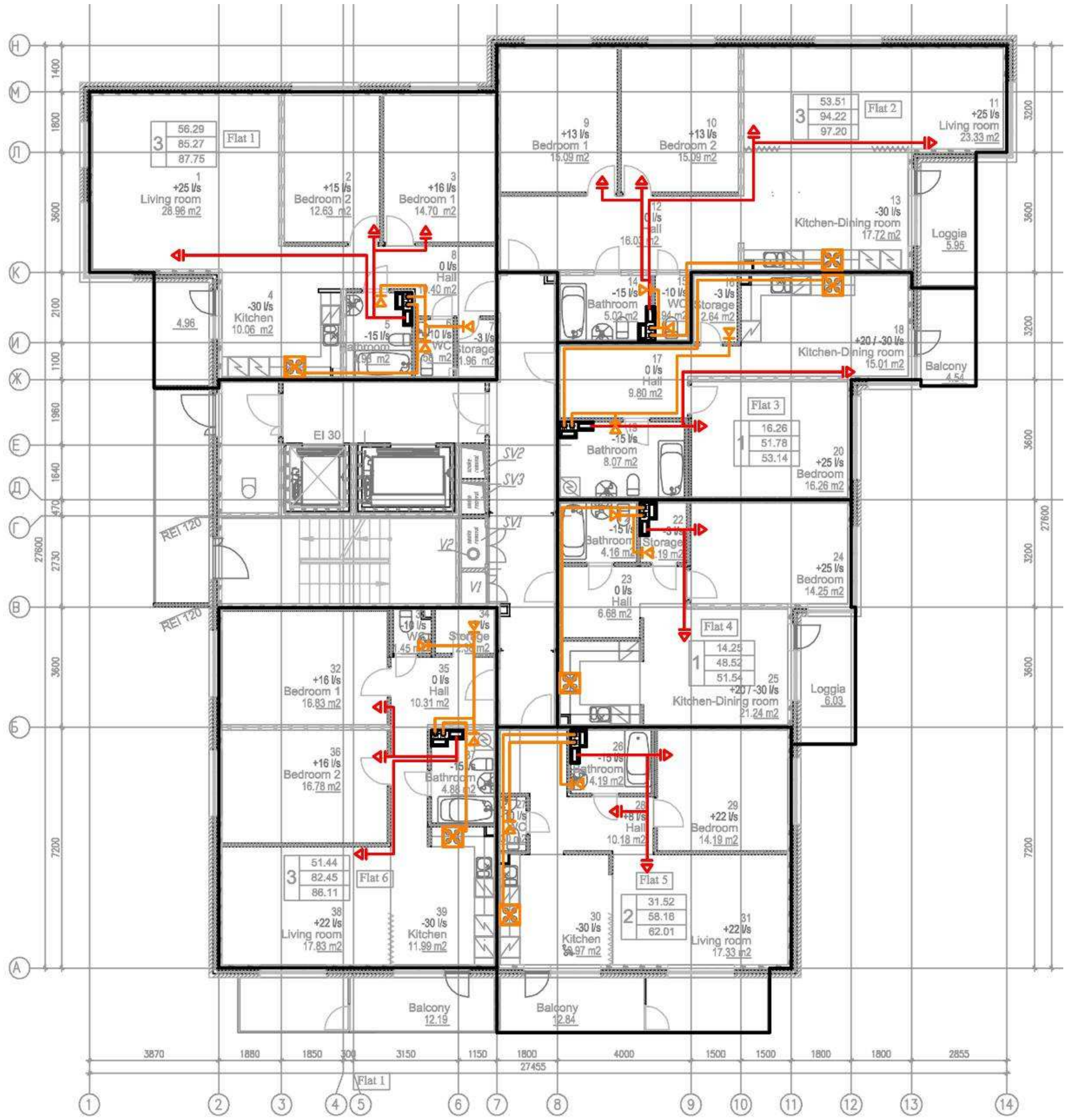
APPENDIX 3.2. Ductwork system on the 6-8 floors



Notations:

- supply air valve;
- extract air valve;
- kitchen hood;
- supply duct;
- extract duct;

APPENDIX 3.3. Ductwork system on the 3-5 floors



Notations:

- supply air valve;
- extract air valve;
- kitchen hood;
- supply duct;
- extract duct;

APPENDIX 4. Sizing of the rectangular vertical exhaust ducts

Floor	Duct	Flow	Dimensions		Area	Eqv. Ø	υ	Final size	Final υ
		dm³/s	mm	mm	cm²	mm	m/s	mm x mm	m/s
3	ED1	58	400	100	400	160	2,9	400x160	1,4
4		116	400	160	640	229	2,8		2,8
5		174	400	160	640	229	4,2		4,2
6		232	400	200	800	267	4,2	400x250	3,1
7		290	400	250	1000	308	3,9		3,9
8		348	400	250	1000	308	4,7		4,7
9		406	400	315	1260	352	4,2	400x400	3,2
10		464	400	315	1260	352	4,8		3,7
11		522	400	400	1600	400	4,2		4,2
12		580	400	400	1600	400	4,6		4,6
13		638	400	400	1600	400	5,1		5,1
14		696	400	400	1600	400	5,5		5,5
3	ED2	55	400	100	400	160	2,7	400x160	1,3
4		110	400	160	640	229	2,7		2,7
5		165	400	160	640	229	4,0		4,0
6		220	400	200	800	267	3,9	400x250	3,0
7		275	400	250	1000	308	3,7		3,7
8		330	400	250	1000	308	4,4		4,4
9		385	400	315	1260	352	3,9	400x400	3,1
10		440	400	315	1260	352	4,5		3,5
11		495	400	315	1260	352	5,1		3,9
12		550	400	400	1600	400	4,4		4,4
13		605	400	400	1600	400	4,8		4,8
14		660	400	400	1600	400	5,3		5,3
3	ED3	48	400	100	400	160	2,4	400x160	1,2
4		96	400	125	500	190	3,4		2,3
5		144	400	160	640	229	3,5		3,5
6		192	400	200	800	267	3,4	400x250	2,6
7		240	400	200	800	267	4,3		3,2

8		288	400	250	1000	308	3,9		3,9
9		336	400	250	1000	308	4,5	400x400	2,7
10		384	400	315	1260	352	3,9		3,1
11		432	400	315	1260	352	4,4		3,4
12		480	400	315	1260	352	4,9		3,8
13		528	400	400	1600	400	4,2		4,2
14		576	400	400	1600	400	4,6		4,6
3	ED4	48	400	100	400	160	2,4	400x160	1,2
4		96	400	125	500	190	3,4		2,3
5		144	400	160	640	229	3,5		3,5
6		192	400	200	800	267	3,4	400x250	2,6
7		240	400	200	800	267	4,3		3,2
8		288	400	250	1000	308	3,9		3,9
9		336	400	250	1000	308	4,5	400x400	2,7
10		384	400	315	1260	352	3,9		3,1
11		432	400	315	1260	352	4,4		3,4
12		480	400	315	1260	352	4,9		3,8
13		528	400	400	1600	400	4,2		4,2
14		576	400	400	1600	400	4,6		4,6
3	ED5	55	400	100	400	160	2,7	400x160	1,3
4		110	400	160	640	229	2,7		2,7
5		165	400	160	640	229	4,0		4,0
6		220	400	200	800	267	3,9	400x250	3,0
7		275	400	250	1000	308	3,7		3,7
8		330	400	250	1000	308	4,4		4,4
9		385	400	315	1260	352	3,9	400x400	3,1
10		440	400	315	1260	352	4,5		3,5
11		495	400	315	1260	352	5,1		3,9
12		550	400	400	1600	400	4,4		4,4
13		605	400	400	1600	400	4,8		4,8
14		660	400	400	1600	400	5,3		5,3
3	ED6	58	400	100	400	160	2,9	400x160	1,4
4		116	400	160	640	229	2,8		2,8

5		174	400	160	640	229	4,2		4,2
6		232	400	200	800	267	4,2	400x250	3,1
7		290	400	250	1000	308	3,9		3,9
8		348	400	250	1000	308	4,7		4,7
9		406	400	315	1260	352	4,2	400x400	3,2
10		464	400	315	1260	352	4,8		3,7
11		522	400	400	1600	400	4,2		4,2
12		580	400	400	1600	400	4,6		4,6
13		638	400	400	1600	400	5,1		5,1
14		696	400	400	1600	400	5,5		5,5

APPENDIX 5. Sizing of the rectangular vertical supply ducts

Floor	Duct	Flow	Dimensions		Area	Eqv. Ø	υ	Final size	Final υ
		dm³/s	mm	mm	cm²	mm	m/s	mm x mm	m/s
14	SD1	672	400	400	1600	400	5,3	400x400	5,3
13		616	400	400	1600	400	4,9		4,9
12		560	400	400	1600	400	4,5		4,5
11		504	400	315	1260	352	5,2		4,0
10		448	400	315	1260	352	4,6		3,6
9		392	400	315	1260	352	4,0		3,1
8		336	400	250	1000	308	4,5	400x250	4,5
7		280	400	250	1000	308	3,8		3,8
6		224	400	200	800	267	4,0		3,0
5		168	400	160	640	229	4,1	400x160	4,1
4		112	400	160	640	229	2,7		2,7
3		56	400	100	400	160	2,8		1,4
14	SD2	612	400	400	1600	400	4,9	400x400	4,9
13		561	400	400	1600	400	4,5		4,5
12		510	400	315	1260	352	5,2		4,1
11		459	400	315	1260	352	4,7		3,7
10		408	400	315	1260	352	4,2		3,2
9		357	400	250	1000	308	4,8		2,8
8		306	400	250	1000	308	4,1	400x250	4,1
7		255	400	200	800	267	4,6		3,4
6		204	400	200	800	267	3,7		2,7
5		153	400	160	640	229	3,7	400x160	3,7
4		102	400	125	500	190	3,6		2,5
3		51	400	100	400	160	2,5		1,2
14	SD3	540	400	400	1600	400	4,3	400x400	4,3
13		495	400	315	1260	352	5,1		3,9
12		450	400	315	1260	352	4,6		3,6
11		405	400	315	1260	352	4,2		3,2
10		360	400	250	1000	308	4,8		2,9

9		315	400	250	1000	308	4,2		2,5
8		270	400	250	1000	308	3,6	400x250	3,6
7		225	400	200	800	267	4,0		3,0
6		180	400	200	800	267	3,2		2,4
5		135	400	160	640	229	3,3	400x160	3,3
4		90	400	125	500	190	3,2		2,2
3		45	400	100	400	160	2,2		1,1
14	SD4	540	400	400	1600	400	4,3	400x400	4,3
13		495	400	315	1260	352	5,1		3,9
12		450	400	315	1260	352	4,6		3,6
11		405	400	315	1260	352	4,2		3,2
10		360	400	250	1000	308	4,8		2,9
9		315	400	250	1000	308	4,2		2,5
8		270	400	250	1000	308	3,6	400x250	3,6
7		225	400	200	800	267	4,0		3,0
6		180	400	200	800	267	3,2		2,4
5		135	400	160	640	229	3,3	400x160	3,3
4		90	400	125	500	190	3,2		2,2
3		45	400	100	400	160	2,2		1,1
14	SD5	624	400	400	1600	400	5,0	400x400	5,0
13		572	400	400	1600	400	4,6		4,6
12		520	400	315	1260	352	5,3		4,1
11		468	400	315	1260	352	4,8		3,7
10		416	400	315	1260	352	4,3		3,3
9		364	400	250	1000	308	4,9		2,9
8		312	400	250	1000	308	4,2	400x250	4,2
7		260	400	200	800	267	4,7		3,5
6		208	400	200	800	267	3,7		2,8
5		156	400	160	640	229	3,8	400x160	3,8
4		104	400	125	500	190	3,6		2,5
3		52	400	100	400	160	2,6		1,3
14	SD6	648	400	400	1600	400	5,2	400x400	5,2
13		594	400	400	1600	400	4,7		4,7

12		540	400	400	1600	400	4,3		4,3
11		486	400	315	1260	352	5,0		3,9
10		432	400	315	1260	352	4,4		3,4
9		378	400	315	1260	352	3,9		3,0
8		324	400	250	1000	308	4,4		4,4
7		270	400	250	1000	308	3,6	400x250	3,6
6		216	400	200	800	267	3,9		2,9
5		162	400	160	640	229	3,9		3,9
4		108	400	125	500	190	3,8	400x160	2,6
3		54	400	100	400	160	2,7		1,3

APPENDIX 6. Schematic picture of main vertical ducts