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IDA ICE modeling of ventilation systems in a log house: towards improving energy efficiency in buildings

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Abstract

This research paper presents a comparison of three types of ventilation systems for a log house: natural ventilation, exhaust ventilation and mechanical supply and exhaust ventilation system equipped with heat recovery. The types of ventilation systems are considered from the point of view of delivered energy for home maintenance.

A wooden residential one-storey house was modeled in the IDA ICE software package, initial parameters for modeling were introduced and three different simulations were carried out depending on the type of ventilation.

After comparing the simulation results, it was found that the least energy-consuming system is mechanical supply and exhaust ventilation system equipped with heat recovery. This ventilation system is not only the most energy efficient, but also provides the best indoor climate parameters.

Keywords

ventilation, energy efficiency, log house, energy saving, indoor climate

CONTENTS

1 INTRODUCTION

In the era of climate change and stricter requirements for energy efficiency, it is necessary to pay due attention to the choice of methods and materials for building a house. According to various expert estimates, humanity is provided with energy resources for about 100 years. About half of the energy consumed annually is consumed by residential buildings. Therefore, every year engineers come up with new and improve the previous ways to increase the energy efficiency of the building.

There are many aspects in the design of houses that are important from the point of view of energy consumption, such as the shape of the building, its orientation, the type of enclosing structures, the area and orientation of windows, the level of their shading, the choice of ventilation and heating systems also plays a huge role.

It is difficult to predict how the building will behave before it is built, namely, how much energy the house will need, what the indoor climate of the premises will be, moreover, it is almost impossible to predict what problems may arise during the operation of the structure.

Nowadays, progress has gone far ahead, so it is possible to take into account all the maximum possible factors affecting the life cycle of a house, and with the help of computer programs to simulate a building. The simulation results will sufficiently help to understand what to pay attention to, what can be improved, and so on.

Modeling is a great way to evaluate the effectiveness of a passive house, with the help of it it is possible to calculate the energy efficiency of a building based on certain factors, for example, wall construction, indoor and outdoor air temperature, type of heating and ventilation systems, and much more.

In this paper, the influence of the type of ventilation system on the energy efficiency of a wooden residential building is considered. The desire of people to create energy-efficient houses with a high ecological class and an improved indoor microclimate is growing every year. One of the main problems in the design of houses, which requires additional study, is ventilation. For this reason, it seems relevant to investigate the influence of various types of ventilation systems on the energy saving of wooden buildings.

2 AIMS AND METHODS

This section describes the aims set in the work and describes the methods by which the aims will be achieved. The object and subject of the study are also presented. The place and materials for the design of the house are marked.

2.1 Aims

The main purpose of the study is to examine which type of ventilation system will provide greater energy saving in a log house. *The object* of the research is a log house. *The subject* of the study is ventilation systems.

The main research question:

1. To study the existing types of ventilation systems and their impact on energy efficiency and the internal climate of buildings.
2. Design ventilation systems that help reduce the energy consumption of a wooden house.

An important part of creating energy-efficient wooden houses is the modeling of engineering systems at the design stage of the facility. Predicting possible situations helps to avoid further problems during the stay of people in the building. This paper considers the project of a log house, currently under construction, with the help of the IDA ICE 4 software package, the main three types of ventilation systems will be designed: natural, mechanical exhaust ventilation, mechanical supply and exhaust ventilation system equipped with heat recovery.

A single-family house is being built in Yoshkar-Ola, Russia, but the weather conditions for modeling will be considered for Mikkeli, Finland. Since the consideration of this project in Finland seems more promising, data from Finnish regulatory documents are taken as a basis. All enclosing structures of the building, as well as windows and doors, are made of wooden materials.

2.2 Methods

Research methods:

The paper uses an integrated approach and uses the following research methods:

1. Study of scientific works, normative, methodological and project materials. To do this, search for various literature mainly on the Internet will be conducted. There are many official websites with regulatory documentation in English and Finnish. Theoretical literature is taken from websites and in some educational literature in Russian. The theory on the principle of ventilation is the same for all countries, so the literature is used in different languages to study the theoretical part in more detail;
2. The method of structural analysis of the existing experience in designing ventilation systems. The experience of designing ventilation systems in different countries and at different facilities will be studied. The studied information is analyzed and the basic data is used to model the selected object;
3. Modeling using the IDA ICE 4 software package (IDA Indoor Climate and Energy); Build and investigate models of ventilation systems in a log house. At the initial stage, data is entered on all dimensions and structures

of the building, heating systems, ventilation systems, etc. After installing a specific ventilation system, a simulation of the work of the house is performed. Then the correctness of the system is evaluated. If the system is working correctly, the data on energy representation, air flows, indoor temperature, air humidity and CO_2 concentration are evaluated.

3 THEORETICAL BACKGROUND

The theoretical part describes the principles of operation of ventilation systems. This is an important part for their correct design in the house. Three main types of ventilation systems are described in detail: natural ventilation, exhaust ventilation and mechanical ventilation with a heat exchanger. In addition, the requirements for the installation of supply and exhaust vents are taken into account.

3.1 Ventilation systems

Ventilation is a set of measures and devices that provide calculated air exchange in the premises of buildings. The main purpose of ventilation is to maintain acceptable indoor air parameters: cleanliness, temperature, humidity, air velocity. A ventilation system is a set of devices for processing, transporting, supplying and removing air /1/.

There are various classifications of ventilation systems /1,2/:

1. According to the method of supplying the premises with air

- supply systems – systems that supply air to the room;
- exhaust systems – systems that remove polluted air from the room;

2. According to the method of organization of ventilation of the room•

- general exchange - a system in which the entire volume of the room is ventilated;
- local ventilation – a system that acts on a part of the volume of the room;

3. According to the method of inducing air movement:
- systems with mechanical motivation;
- systems with natural motivation (using natural forces - the effects of wind and gravity);

4. According to the method of implementation:
- ducted ventilation systems - ventilation is carried out through an extensive network of channels (ducts);
- channel-free ventilation - ventilation is carried out through openings in external fences.

Furthermore, the most popular types of ventilation systems in single-family homes are described in detail. Since this research paper is supposed to consider natural ventilation, mechanical exhaust ventilation and mechanical supply and exhaust ventilation system equipped with heat recovery, these three types are described in detail. The way ventilation works, the pros and cons of a particular type of installation have been fully studied and the most important information is presented here.

3.1.1 *Natural ventilation*

With natural ventilation, there is an unorganized inflow of air through open windows, leaks in doors and enclosing structures. Ventilation of the premises occurs due to the difference in atmospheric pressure, the difference in room and street temperature, the degree of saturation with moisture. /1/. In Figure 1 an overview of a natural ventilation is shown.

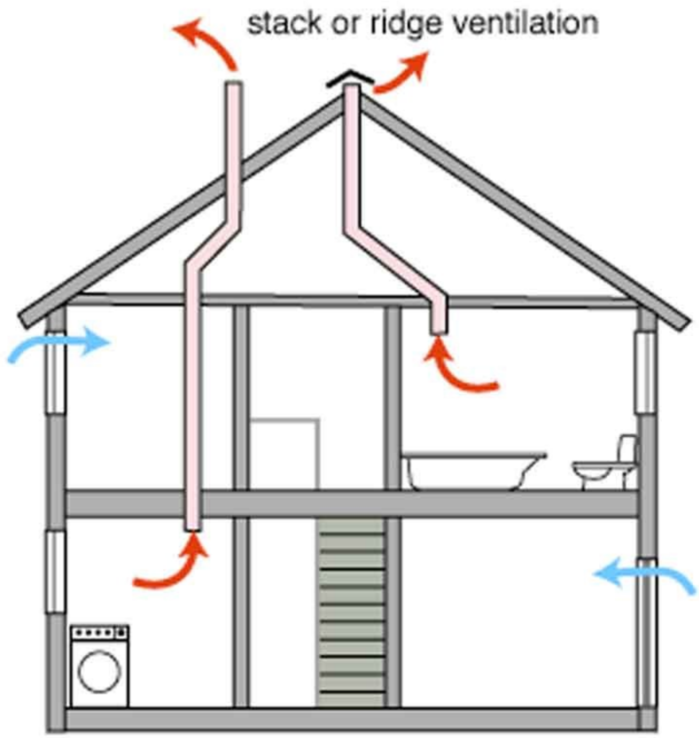

Figure 1. Natural ventilation /3/.

As we can see from Figure 1 fresh air enters the room through the joints between the window and the wall, and through leaks in the wall structure. The amount of fresh air with natural ventilation can be increased by opening a window in the room. Dirty exhaust air under the influence of gravitational forces leaves the premises into the ventilation openings.

Climate and building structure have a large impact on effectiveness of natural ventilation. Natural ventilation has to work differently for winter and summer. In winter small inflows are needed. For summer period should be enough amont of fresh air for space cooling . Features of naturally ventilated buildings include vents high in the building.

Narural ventilation system has some important advantages:

- there is no equipment, therefore there are no costs for electricity and maintenance of this system;
- No problems caused by interruptions in power supply sources.

3.1.2 Exhaust ventilation

> "Exhaust ventilation - systems work by depressurizing your home, the system exhausts air from the house while make-up air infiltrates through leaks in the building shell and through intentional, passive vents" /4/. As a rule, the exhaust ventilation system has a fan located in the center of the residential building. With the help of air ducts, this fan takes polluted air from rooms in which polluted air is mainly formed. Passive ventilation openings through windows or walls can be additionally installed in rooms to supply fresh air, since leaks in the enclosing structures may not be enough. The schematic principle of operation of such ventilation is shown in Figure 2.

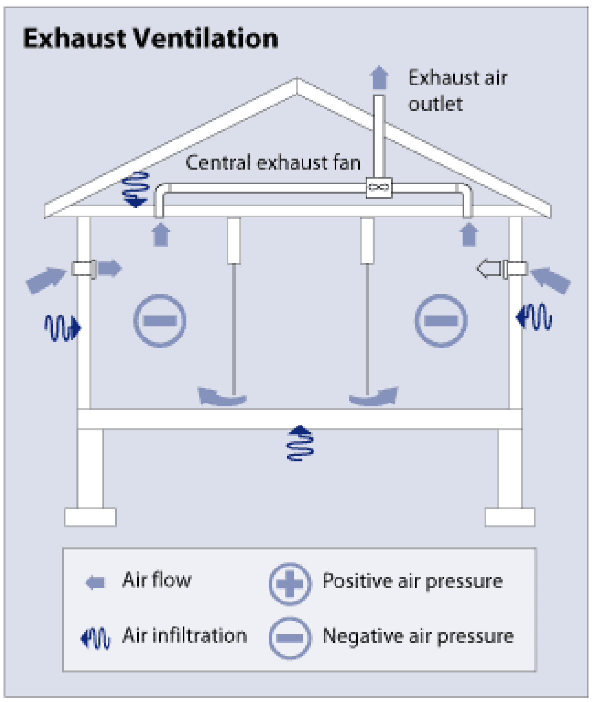

Figure 2. Mechanical exhaust ventilation /4/.

One of the most important problems associated with this type of ventilation are pollutants such as: radon and mold, dust from the attic, flue gases from a fireplace or a water heater and a furnace powered by fossil fuels. The advantage of exhaust ventilation is simplicity and low cost of installation. "But it can also contribute to higher heating and cooling costs compared with energy recovery ventilation systems because exhaust systems do not temper or remove moisture from the make-up air before it enters the house" /4/.

3.1.3 Mechanical supply and exhaust ventilation system with AHU

"This type of ventilation systems, if properly designed and installed, neither pressurize nor depressurize your home. Rather, they introduce and exhaust approximately equal quantities of fresh outside air and polluted inside air. Energy recovery ventilation systems provide a controlled way of ventilating a home while minimizing energy loss. They reduce the costs of heating ventilated air in the winter by transferring heat from the warm inside exhaust air to the fresh (but cold) outside supply air. In the summer, the inside air cools the warmer supply air to reduce cooling costs" /4/.

The main air flow patterns in this type of ventilation are shown in Figure 3. In Figure 3 it is possible to see that fresh air comes to dwelling rooms, and exhaust air goes from non-residential premises such as bathroom and kitchen. Supply and extract air have their own lines which are connected to the heat exchanger. In the heat exchanger warm extract air it gives its thermal energy to heat the cold street air to the standard temperatures of residential premises. A more detailed description of the operation of the heat exchanger is presented below.

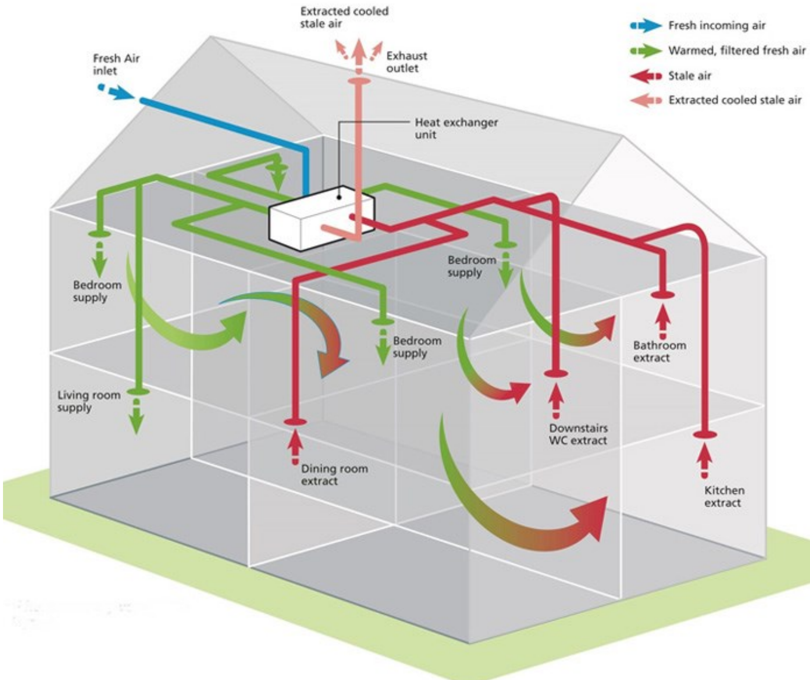

Figure 3. Mechanical supply and exhaust ventilation system equipped with heat recovery /5/.

The efficiency of most ventilation systems with heat recovery is from 70 to 80%. However, it is worth noting that they are most economical in climates with cold winters or warm summers, as well as where fuel costs are high. “To be effective, mechanical ventilation systems must be able to: exchange indoor air with outdoor air; distribute ventilation air to most rooms of the house and exhaust air from kitchens, bathrooms and laundry rooms; circulate ventilation air within the rooms; and treat the ventilation air so that it is acceptable to the occupants” /6, p. 2/. Ventilation systems strive for a balance between supply and exhaust air flows in order to avoid an increase or decrease in pressure. Balanced systems not only reduce infiltration and exfiltration, but also usually provide better indoor air quality, more effective ventilation control, and reduce the movement of pollutants from one room to another.

“Buildings are intended to be conditioned to a comfortable temperature and relative humidity for human occupancy. Heating can account for over 50% of annual energy consumption in houses. Since typical ventilation systems introduce unconditioned outdoor air and exhaust conditioned indoor air, there is potential for energy savings by incorporating heat transfer between the two air streams. This can work both during the winter, when warm exhaust air pre-heats the intake air, and during the summer, when cooler air-conditioned exhaust air precools the intake air” /6, p. 8/.

“The entering vents bring in new air from out of the home. As the air enters through the roof, it passes within the heat exchanger. They include two ventilation channels operating near one another, moving between the inside and the outside of a home. One transfers fresh, cold air in; the other carries humid, old air out. The important matter is that the airflows operate through a system called a heat exchanger in which two air lines pass, while fresh and exhaust air do not mix with each other. Typically, there is a fan in each channel that can be turned down or up either automatically or manually or depending on the temperature and moisture rates. The entering air reserve may also have a bypass way assembled to it so that in summer months, when it is cooler out than in, cold outside air can be moved straight into the home without mixing outgoing air” /7/. The main components and the principle of operation are shown in Figure 4.

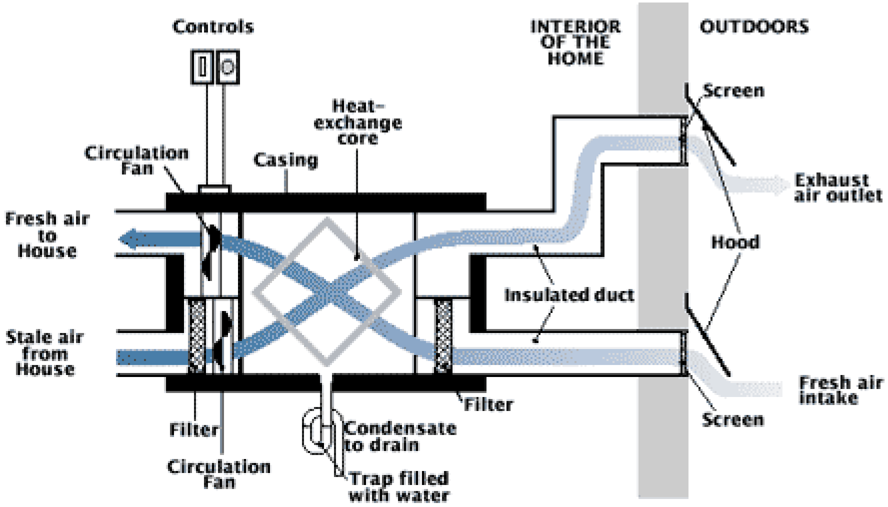

Figure 4. Parts of a heat recovery ventilator /8/.

“A heat recovery ventilation system consists of the following components which are shown in Figure 4:

- An airtight insulated case
- Supply and exhaust fans
- Outdoor air inlet from outside (shown with insulated duct connected)
- Outdoor supply air outlet (shown with duct connected)
- Exhaust air inlet (shown with duct connected)
- Exhaust air outlet to outside (shown with insulated duct connected)
- Heat exchanger
- Condensation drain pan connecting to a drain
- Sensors and controls
- Removable /cleanable filters
- In some cases motorized dampers to aid in defrost” /6, p.8/

“The most important component of the recuperator unit is the heat exchanger. Presently, there are many different types of recuperator units with different structure, air flow direction, degree of recovery and application. Typically there are two primary classifications for heat exchangers based on the flow arrangement: parallel flow and counter flow heat exchangers, known as inline and crossflow, respectively. In inline type of exchanger, hot and cold fluids flow parallel to each other. If they move in the same direction, they are called parallel or co-current, and if they move opposite each other, they are named counter-current counter flow heat exchangers. Counter flow heat exchangers are more efficient than parallel exchangers, and it is all because of a uniform temperature difference between fluids over the whole exchanger and fluid paths" /9/. "Counter-flow heat exchangers are specifically developed for heat recovery in balanced ventilation systems. These heat exchangers allow efficient use of extract air energy for heating or cooling, thus optimizing ventilation and providing healthy indoor climate. Due to the unique heat exchanger design and the shape of the heat exchanging plates the heat exchange surface is maximized and the pressure losses are minimized. This heat exchanger type is compatible with nearly all ventilation systems. The supply and extract air streams move in opposite directions toward each other. The heat energy is transferred through the thin plates. Heat recovery efficiency exceeds 90 %" /10/.

Ventilation systems with heat recovery require more maintenance than other ventilation systems. They must be cleaned regularly to prevent deterioration of ventilation and heat recovery, as well as to prevent the appearance of mold and bacteria on the surfaces of heat exchangers.

3.2 Supply and extract valves

A sufficient supply of fresh air, ensuring air exchange is necessary for human health and to prevent the development of fungus, mold, and to exclude the destruction of wooden structures. Air intake and circulation are provided by ventilation openings, which are necessarily installed for the foundation, residential and attic premises.

When placing supply and exhaust vents on the premises, the following recommendations should be followed /1/:

1. Supply and exhaust vents should not create blowing in the room;
2. With the minimum size of the holes and their corresponding design, the resistance to air passage should be minimal;

3. Exhaust vents should be located as close as possible to the places of air pollution;
4. The design of exhaust and supply openings should not violate the interior of the ventilated room.

There are certain requirements for residential buildings where the supply and exhaust air valves must be located. Therefore, extract air valves are located in the kitchen, bathroom, sauna, utility room, walk-in closet and storage room, and supply valves are located in the bedrooms, living rooms, sauna and dressing room. Exhaust vents in residential buildings should be located at a distance of 0.5 ... 0.7 meter from the ceiling.

4 REQUIREMENTS FOR INDOOR CLIMATE IN A RESIDENTIAL BUILDING

The internal balance of the human body depends on air conditions. The microclimate plays an essential role in the formation of immunity, efficiency, and the ability to relax comfortably. The state of the internal environment of a building can affect human health not only from a positive point of view but also have a negative impact. Thus, the longer a person stays in a room with an uncomfortable microclimate, the more it affects the work of our body.

The microclimate of any premises is characterized by air temperature, humidity, and airflow. The microclimate is created with the help of heating and ventilation systems so that people live in comfortable conditions. The climatic conditions of the area are taken into account, the heat loss of the room is calculated, then the calculation and design of heating and ventilation systems are carried out.

4.1 Air temperature

Temperature is the most important indicator of comfort. Depending on the air temperature set in the room, the following types of microclimate are distinguished: comfortable or neutral, uncomfortable — heating or cooling. Low temperatures reduce the protective functions of the human body. Excessively high temperatures can also lead to sad consequences, for example, heatstroke.

Temperature measurement is carried out using conventional thermometers or sensors, which are usually part of a climate control system. Radiators and air conditioning systems are used to maintain a comfortable temperature in an apartment, house, or any room.

“The design temperature for the heating season that is normally used for room temperature in the occupied zone is 21°C. The design temperature for the summer season that is normally used for room temperature in the occupied zone is +23°C” /13, p. 8/.

4.2 Air flows

Airflow is also an important characteristic. If there is air movement in the room, the room temperature will be felt differently by people. However, due to the risk of drafts, this criterion should be carefully considered. Comfort standards set sufficiently low values for the maximum permissible air velocity to achieve better comfort.

The outdoor flows of the entire dwelling are dimensioned so that the following minimum requirements are met:

1) outdoor flow per living area is at least 0.35 $dm^3/s.m^2$ (equivalent ventilation factor 0.5 1/h at 2.5 m height);
2) the total outdoor flow of the dwelling is at least 18 dm^3/s;
3) the external flow of each living room is at least 0.35 dm^3/s,m2;
4) at least 8 dm3/s of outdoor air must be brought into each living room, for bedrooms over 11 m2 is 12 dm^3/s;
5) if the apartment has a sauna, add 6 dm_3/s to the total external airflow /11, p. 5/.

For energy calculations supply air flow in zones should be 0.4 l/s/m^2. Exhaust air flow is the same. As far as we make energy calculations, this data will be used /12/.

According to the Classification of indoor environment 2018, the air velocity at a temperature of 21 °C should not exceed 0.15 m/s /13, p. 8/. If the air velocity exceeds this value, a draft may appear. The appearance of a draft has a bad effect on the health of the residents of the house, so it is important to monitor this parameter.

4.3 Air humidity

The air in an apartment or a house is not only warm or cold but also dry or wet. In general, air humidity is the amount of water vapor in the air, which is measured from 0 to 100%, where one hundred percent is the "dew point". Humidity is affected by various factors such as the season, the area of residence, climatic conditions indoors, therefore, this value is variable, it can change even during the day.

“The classification does not specify a target value for humidity, since it can be very low at cold outdoor temperatures during the heating period. Humidifiers can be used to humidify the air. It should be noted that when using global humidification, the relative humidity of the air should be below 60%, and humidification should not cause a risk of damage by moisture and microbes. When humidifying the air, special attention should be paid to humidifiers that do not increase impurities in the air” /13, p. 8/.

4.4 CO_2 CONCENTRATION

“Carbon dioxide CO_2 is a natural constituent of atmospheric air, where it is present on average at a content of a little over 0.03% (volume fraction; equal to about 600 mg/m3). CO_2 content measured in air is usually reported in the unit parts per million (1ppm as a volume fraction 1µmol/mol), 0.03% as volume fraction being equivalent to 300 ppm. CO_2 is colourless, odourless and without taste, readily water soluble and chemically stable under standart conditions" /14, p.1/.

"CO_2 concentration in indoor air must be restricted to 0.1% volume fraction, equivalent to 1000 ppm. At this value, which is known as the Pattenkofer number, the indoor air pollution due to human exhalation is said to be limited to an extent safe for health. The value has been used for decades as a criterion of good air quality indoors and for calculating the design of room conditioning systems for ventilating indoor areas" /14, p.11/. Table 1 below shows classification of indoor air quality and CO_2 concentration according to standard.

Table 1. General classification of indoor air quality and CO_2 concentration indoors /14/.

Description	Increase of CO_2 concentration relative to ambient air CO2 concentration, ppm
Special indoor air quality	≤400
High indoor air quality	400-600
Medium indoor air quality	600-1000
Low indoor air quality	>1000

5 BUILDING MODELING IN IDA ICE SOFTWARE

This section provides the initial building data necessary for designing a house in software. The plan and view of a wooden house are shown. The process of modeling both the building envelope and various types of ventilation systems is shown. As a result of the simulation, the process of simulating work at home is started.

5.1 INITIAL DATA FOR BUILDING

5.1.1 Common data for building

The building is a one-storey single family house located in Mikkeli. Basic information on modeling and building construction are presented below.

Window and door sizes are shown on the floor plan. Thermal bridges were taken according to Energiatehokkuus /15/ and they are presented in Figure 5. Occupancy period was taken into account according to decree 1010/2017 /12/.

Table 3.1 Design values for the extra conductance of a linear thermal bridge in joints between external wall and upper floor / roof, external wall and intermediate floor and external wall and base floor with some frame materials (W / m K).

External wall construction	Extra conductance Ψ_k W / (m K)									
	Roof material (outer corner)			Intermediate floor material			Base floor material			
	concrete	light concrete	wood	concrete	light concrete	wood	concrete against ground	concrete crawling space	light concrete crawling space	wood crawling space
concrete	0,08		0,04	0,0			0,24	0,28		
light co	0,18	0,06	0,04	0,1	0,0		0,09	0,08	0,03	
light wa	0,13		0,04	0,07			0,15	0,11		
brick	0,08		0,04	0,0			0,17	0,06		
wood			0,05			0,05	0,10			0,06
log			0,04			0,0	0,11			0,09

Table 3.2 Design values for the extra conductance of a linear thermal bridge in joints between external walls in corners and in joints between windows and doors with external walls with some frame materials (W / m K).

Joint	Extra conductance Ψ_k W / (m K)					
	Frame material of external wall					
	concrete	light conr	light w. a.	brick	wood	log
external wall, outer corner	0,06	0,05	0,05	0,05	0,04	0,05
external wall, inner corner	-0,06	-0,05	-0,05	-0,05	-0,04	-0,05
window and door joints, at the insulation	0,04	0,04	0,04	0,04	0,04	0,04
window and door joints, at other cases	0,15	0,07	0,10	0,10	0,07	0,07

Figure 5. Thermal bridges /15/.

Heating and cooling systems in model:

The heat source of the designed building is district heating. Underfloor heating was chosen to deliver heat to rooms with a maximum supply water temperature of 35 °C. The designed model does not provide for DHW circulation, the efficiency of DHW transfer η_{dhw} is 0.78. Ideal cooler will be used to cool air.

The floor plan and a view of the single-family house are shown below. Figure 6 shows the floor plan of the house with the signed names of the premises and their area. In Figure 7 the building view is presented. The height of the rooms at the wall is 2.7 m.

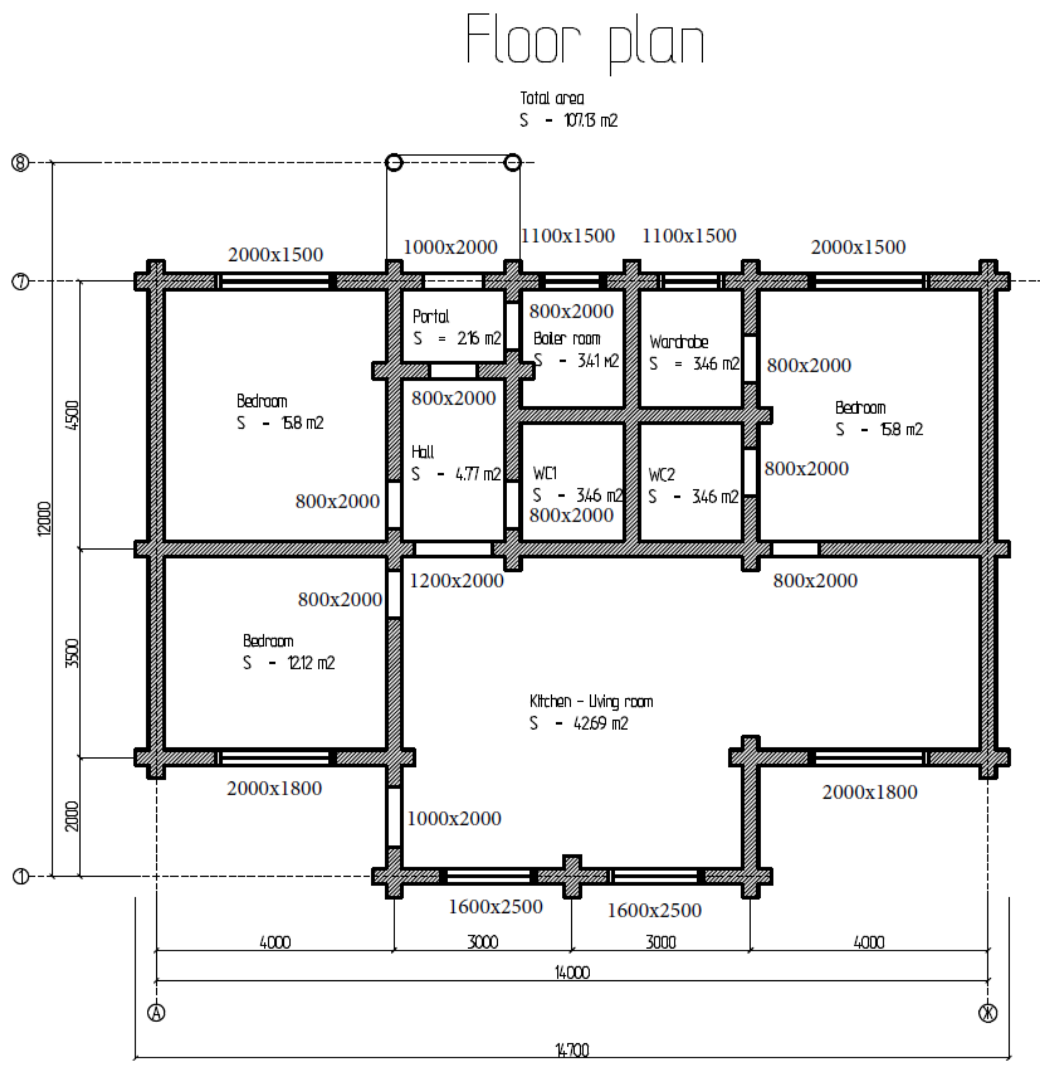

Figure 6. Floor plan.

Figure 7. View of building.

5.1.2 Building construction

The construction of roof, walls and external floors are presented in Figures 8, 9, 10. The figures also show the layer thickness. These data were used to make the building construction during IDA ICE modeling.

Roof:

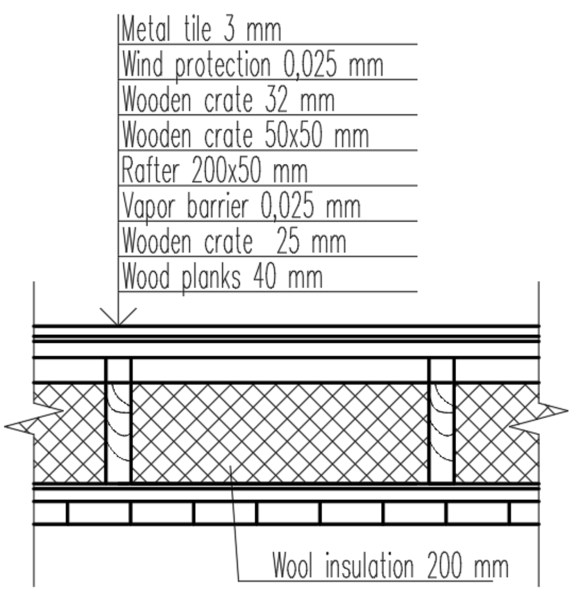

Figure 8. Roof construction.

External and internal walls:

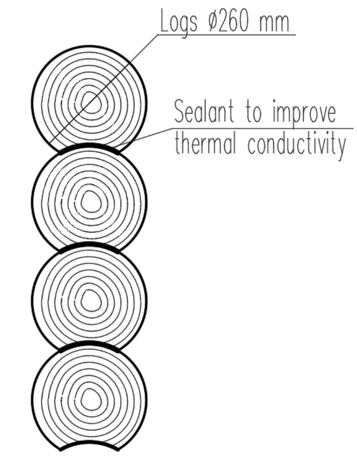

Figure 9. Construction of external and internal walls

External floors:

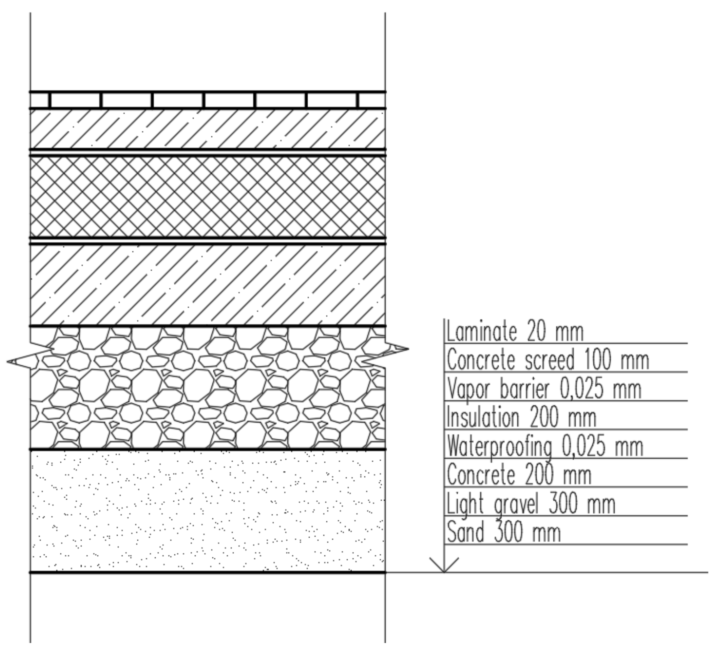

Figure 10. Construction of external floors.

5.2 Initial data in IDA ICE

To make a successful modeling and obtain reliable results IDA ICE software requires some initial data such as:

1) Defaults
2) Site shading and orientation
3) Thermal bridges
4) Ground properties
5) Infiltration
6) Pressure coefficients
7) Extra energy and losses
8) Air handling unit
9) Plant

Building defaults were taken according to building constructions, and IDA ICE calculated the U-value and the total thickness for all of them. Site orientation was chosen so that the entrance of the house is to South-East, it is shown in Figure 11. Thermal bridges were taken according to Figure 5, data from IDA ICE are shown in Figure 12. Ground properties are according to ISO-13370 – sand with following properties ρ = 2000 kg/m3, cp = 1000 J/kgK and ρ= 2,0 W/mK.

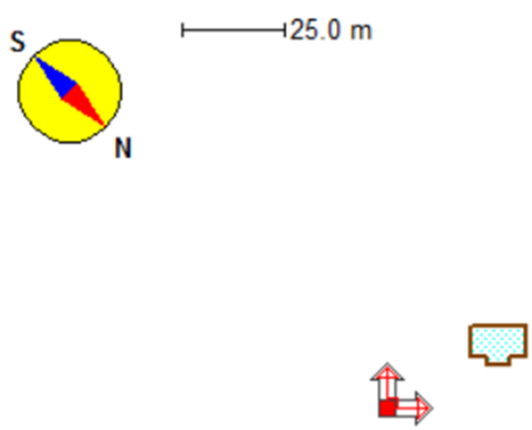

Figure 11. Orientation of the building – entrance to South-East.

Figure 12. Thermal bridges.

Infiltration

One of the most important issues in log houses is infiltration. “Infiltration is the uncontrolled flow of air into a space through adventitious or unintentional gaps and cracks in the building envelope. The corresponding loss of air from an enclosed space is termed 'exfiltration'“ /16/.

According to chapter 3.3.2 Energiatehokkuus (in Finnish) for calculating flow the following formula has to be used:

$$q_{v,air\ leakage} = \frac{q_{50}}{3600*x} A \qquad (1)$$

Where:

“q_{50} – air leakage number of the building shell, $m^3/(hm^2)$;

x – factor, which is 35 for a one-storey building;

3600 – factor, which converts air flow from unit m^3/h to unit m^3/s;

A – surface area of the building shell (including floor), m^2” /15/.

According to Vertia calculations that were done in 2012-2015 q_{50} can be 1.64 $m^3/(hm^2)$ for small log houses /17/. Therefore, $q_{v,air\ leakage}$ for IDA ICE is calculated and shown below.

$$q_{v,air\ leakage} = \frac{1.64}{35} = 0.0469\ m^3/(hm^2)$$

Extra energy and losses

There is no domestic hot water circulation in the designed building. The heating system is a hot water floor heating system with ideal heaters with a maximum supply water temperature of 35 °C. According to Figure 13 annual efficiency for zone heating is 0.85. Data that are used in IDA ICE are shown in Figure 14.

Taulukko 6.1 Lämmitysjärjestelmien lämmönjaon ja -luovutuksen vuosihyötysuhteiden ja apulaitteiden ominaissähkönkäytön ohjearvoja.

Lämmitysratkaisu	Vuosihyötysuhde $\eta_{lämmitys,\ tilat}$ -	Sähkö e_{tilat} kWh/(m² a)
Vesiradiaattori 45/35 °C		
jakojohdot eristetty	0,90	2
jakojohdot eristämätön	0,85	2
Vesiradiaattori 70/40 °C		
jakojohdot eristetty	0,9	2
jakojohdot eristämätön	0,8	2
Vesiradiaattori 70/40 °C jakotukilla	0,80	2
Vesiradiaattori 45/35 °C jakotukilla	0,85	2
Hot water floor heating system 40/30 °C		
Building butts against the ground	0,8	2,5
ryömintatilaan rajoittuvassa rak.	0,8	2,5
ulkoilmaan rajoittuvassa rak.	0,75	2,5
lämpimään tilaan rajoittuvassa rak.	0,85	2,5
Kattolämmitys (sähköinen)		

Figure 13. Annual efficiency and auxiliaries of heat distribution and supply of heating systems specific electric operating guide values /15/.

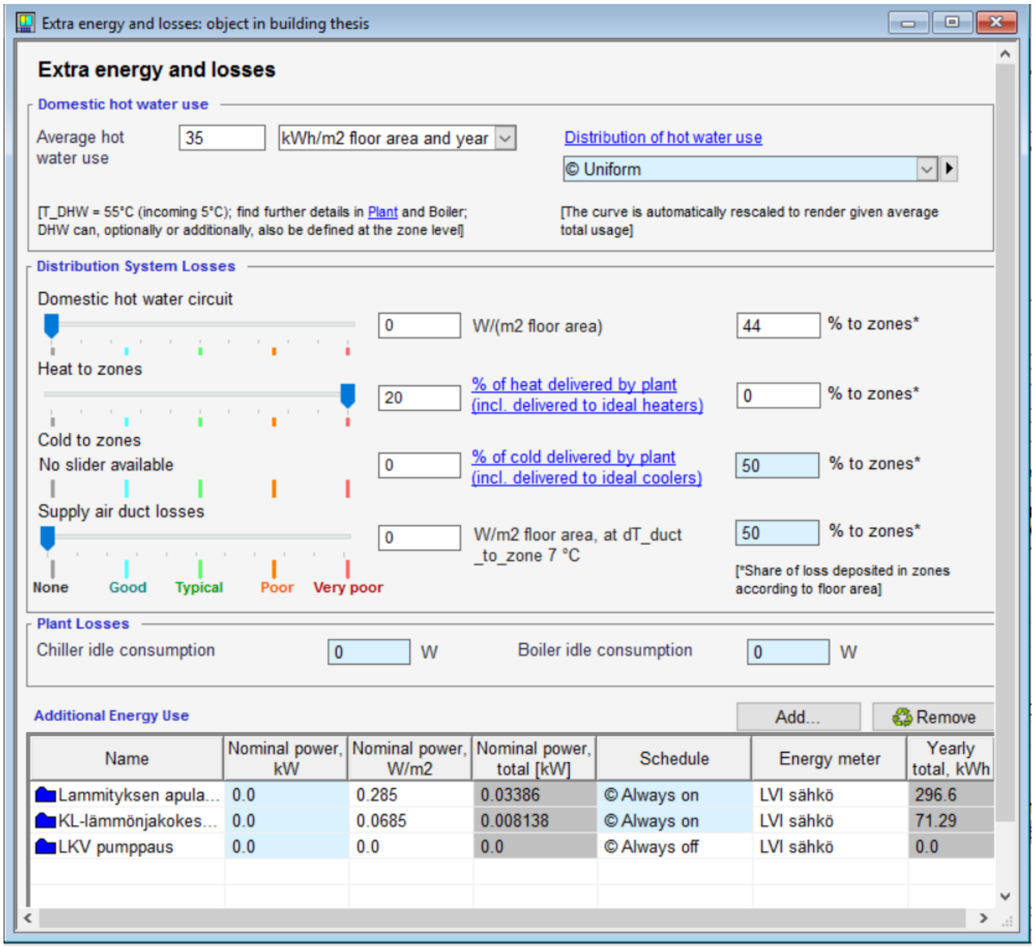

Figure 14. Extra energy and losses in IDA ICE.

Plant

Setpoint values were chosen according to K1/2013. District heating of buildings Regulations and guidelines. Designed new building has an underfloor heating system so the rated temperatures of the heat exchangers for the secondary side are 30 °C return and 35 °C supply. The heat exchanger of ventilation has 30 °C return and 60 °C supply temperatures. Figure 15 shows the table from K1 regulation.

Table B. The rated temperatures for the heat exchangers of heating and ventilation in rated outdoor temperatures – new buildings

	RATED TEMPERATURES OF HEAT EXCHANGERS °C			
	PRIMARY		SECONDARY	
	SUPPLY	RETURN	RETURN	SUPPLY
Heat exchangers of heating, radiator heating - recommended	115	33 (max)	30 (max)	45 (max)
Heat exchangers of heating, radiator heating - exceptions	115	33 (max)	30 (max)	60 (max)
Heat exchangers of heating, underfloor heating	115	33 (max)	30 (max)	35 (max)
Comfort underfloor heating for wet rooms	70	28 (max)	25 (max)	30 (max)
Heat exchangers of ventilation	115	33 (max)	30 (max)	60 (max)
Note	The return temperature on the primary side may be a maximum of 3°C higher than that of the secondary side			

Figure 15. The rated temperatures for the heat exchangers of heating and ventilation in rated outdoor temperatures – new buildings /18/.

5.3 Ventilation modeling

The plan of the house and the view of the model in IDA ICE software are shown in Figure 16 and Figure 17. For modeling, all initial data are entered. It remains to complete only one point, to simulate each type of ventilation in a separate file. Additional data for each ventilation type are presented below. After that energy simulation can be done. IDA ICE software makes the simulation by itself, the results will be described and compared in the next chapter of this research paper.

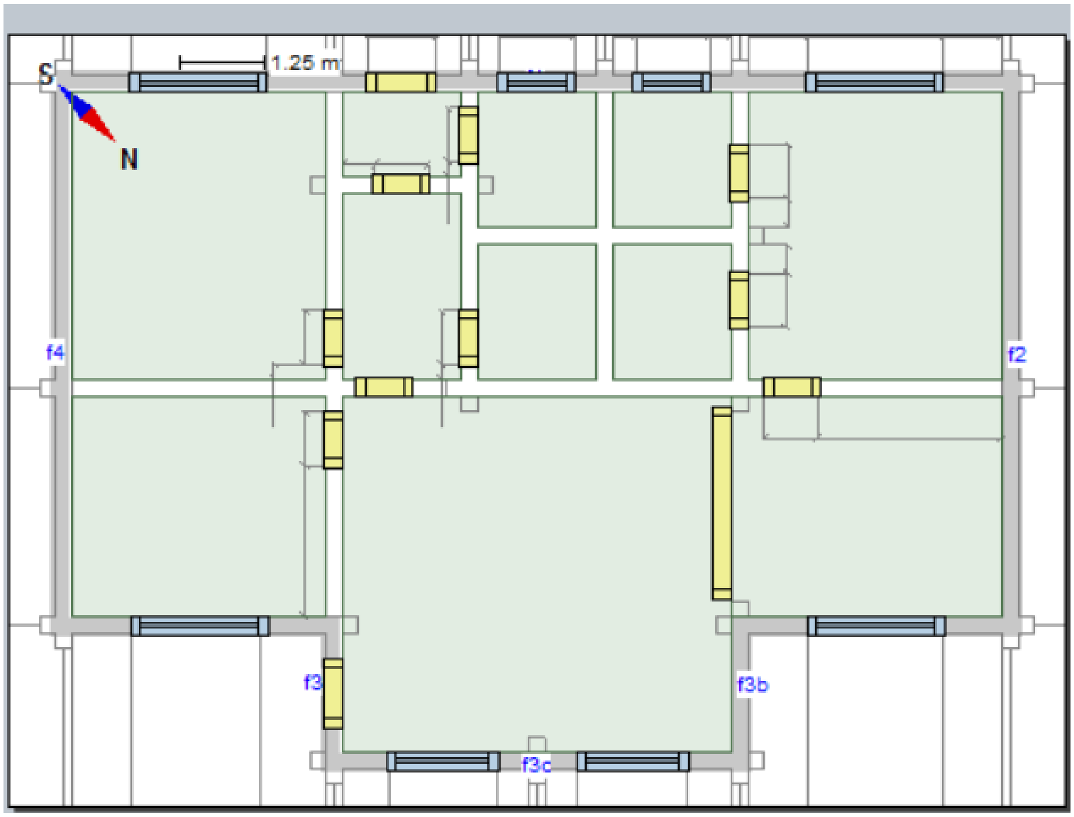

Figure 16. Floor plan in IDA ICE

Figure 17. View of house model in Ida Ice.

5.3.1 Natural ventilation

When designing natural ventilation, no mechanical parts are installed in the building, since this type of ventilation provides for uncontrolled air movement due to the difference in air pressure indoors and outdoors. To ensure the movement of air, it is necessary to install leaks for fresh air in the exterior walls, as shown in Figure 18, as well as chimneys in the roof to remove exhaust air, this is shown in Figure 19. Leaks are installed in living rooms: bedrooms and living room. Uncontrolled air movement is planned between the rooms. Hoods are installed in rooms with high air pollution such as WC, kitchen, dressing room and boiler room.

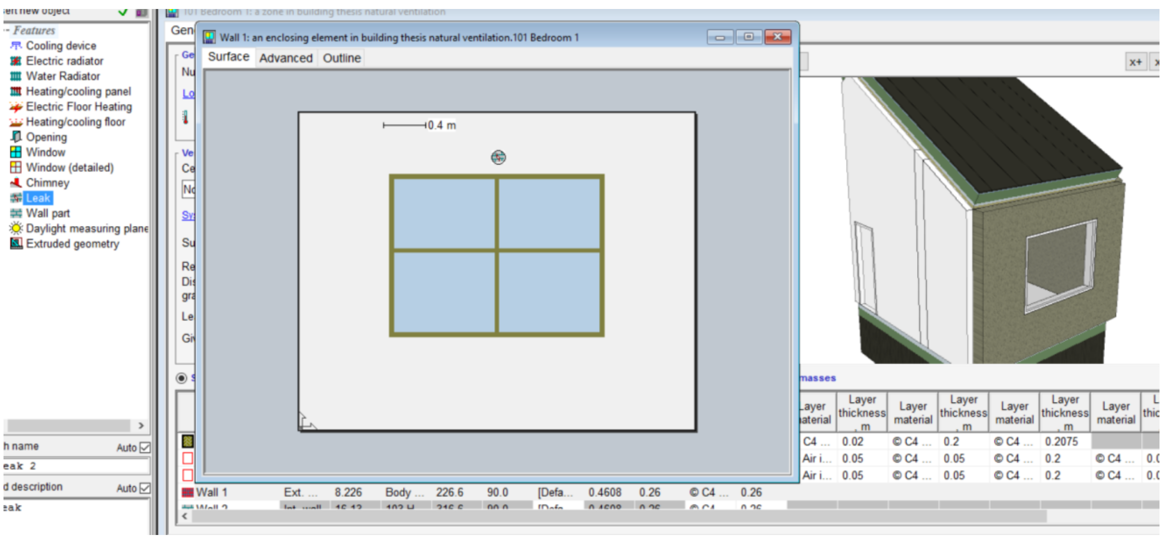

Figure 18. Leak on the external wall.

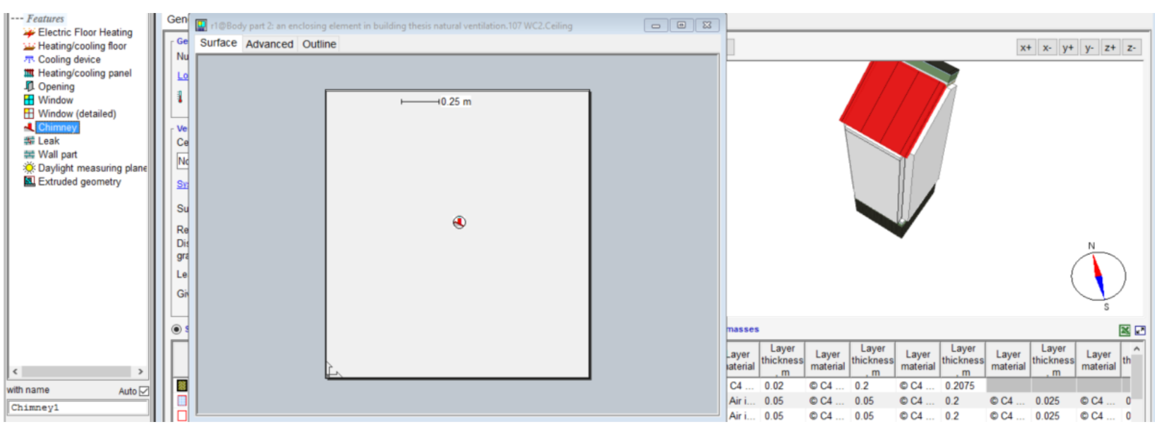

Figure 19. Chimney on the roof.

5.3.2 Exhaust ventilation

In the exhaust ventilation, fresh air enters uncontrollably through the external enclosing structures of the building. To provide the rooms with enough air, it is necessary to install leaks above the windows. This solves the problem with the supply of air to the living rooms. Mechanical exhaust ventilation is installed throughout the house in rooms with polluted air such as kitchen and WC. We do not need to install it manually in the program, since the software package itself thinks out how to do it. An example of installing a leak in an external wall is shown in Figure 20. The operation scheme of the exhaust ventilation is presented in Figure 21.

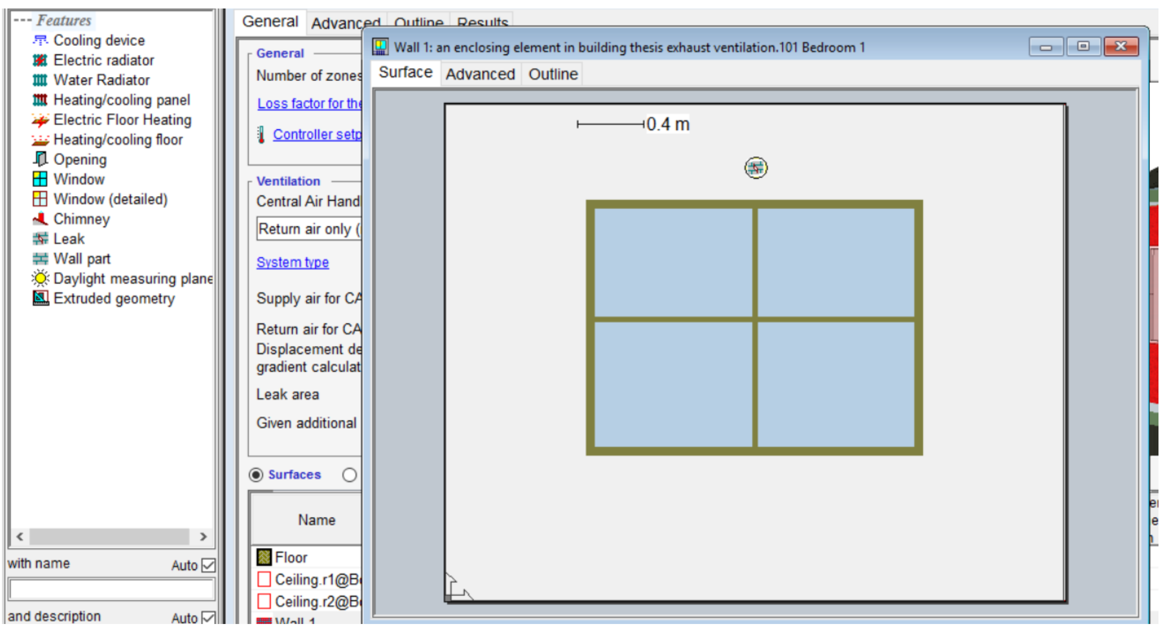

Figure 20. Leaks for fresh air.

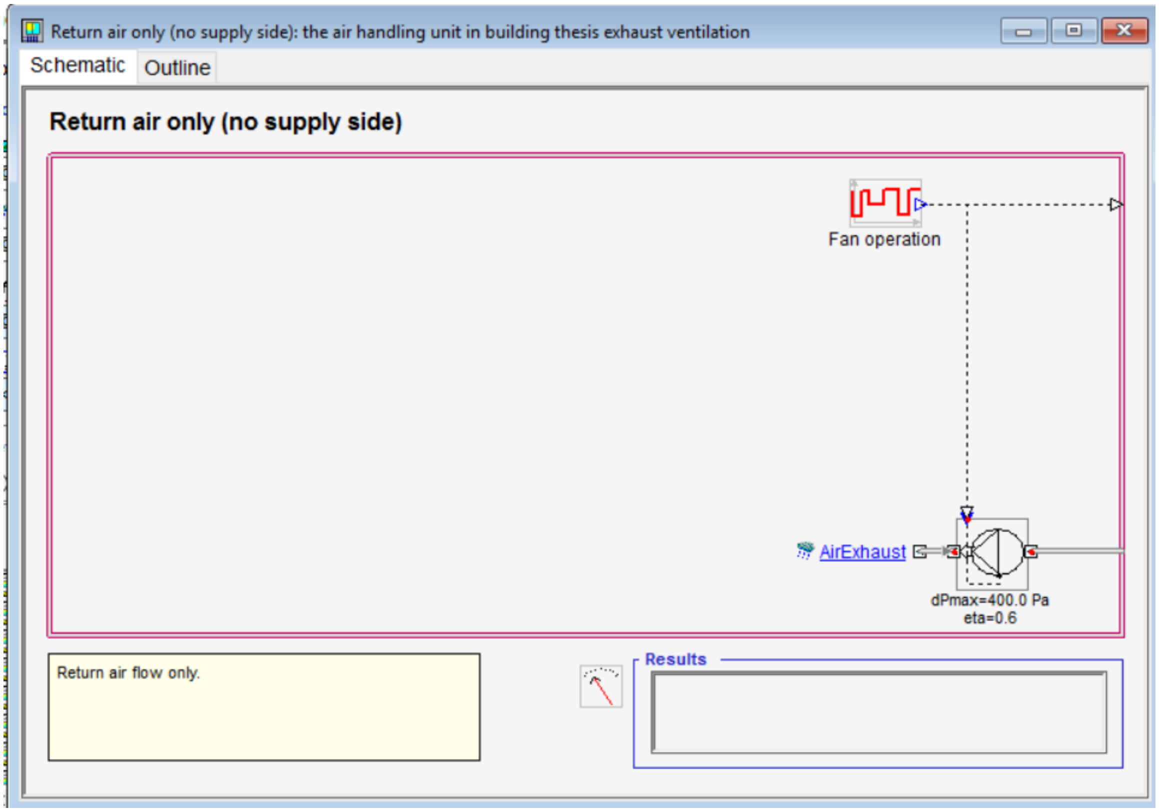

Figure 21. Exhaust ventilation in IDA ICE.

5.3.3 Mechanical supply and exhaust ventilation system with AHU

To install mechanical ventilation in the program, in the HVAC systems section, we select the Air Handling Unit. IDA ICE independently designs the ventilation system in the house, in such a way that dwelling rooms have an inflow of external fresh air and permises with polluted air have outflows. Each component of the AHU that is shown in Figure 22 is included in the operation of the system. This system includes: a heat exchanger with an efficiency of 0.75, heating and cooling coils and fan.

One of the most important parts that has to be checked before modeling it is air flows in permises. The program suggests 0.4 l/s.m^2. For energy calculations it is the correct value, therefore we leave the same value.

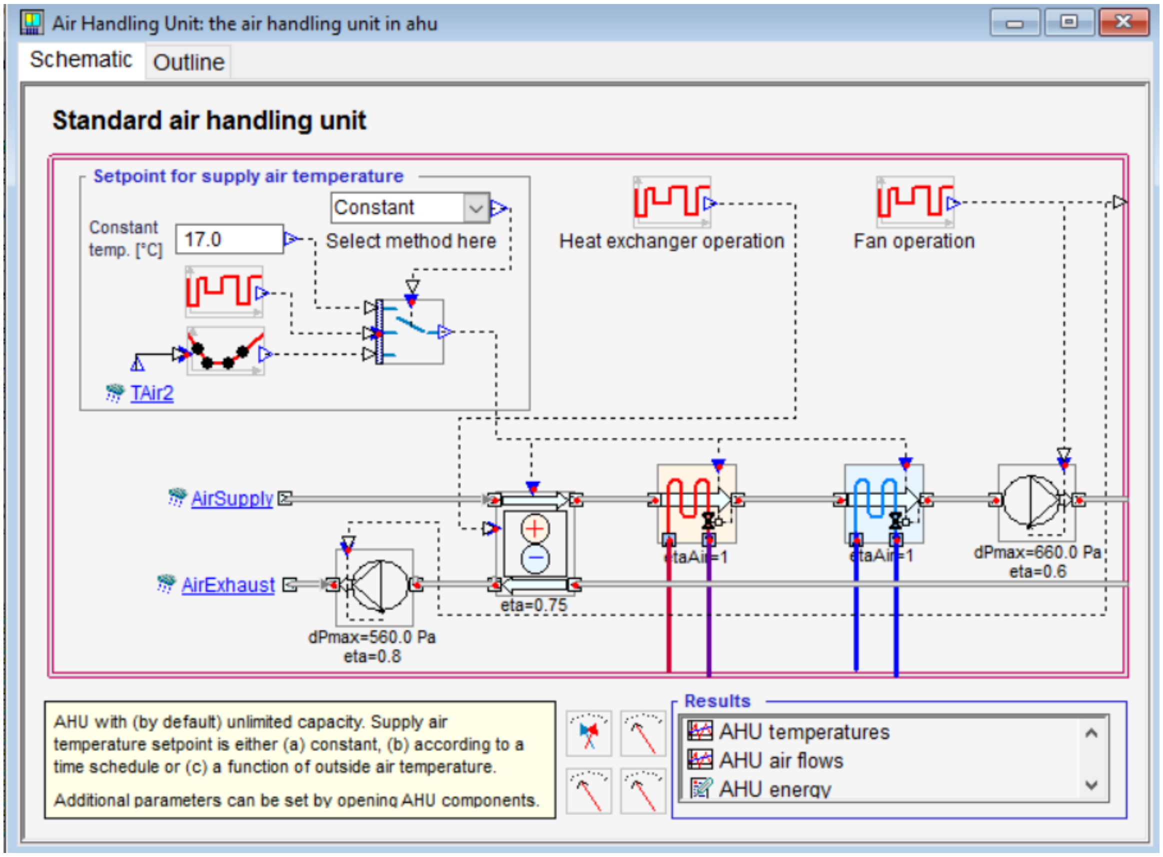

Figure 22. Standart air handling unit

Various types of ventilation systems are designed in the IDA ICE software package. To get the results, you need to start the simulation process. The simulation of each case was carried out successfully. The results and comparison of the obtained data are given in the following part.

6 RESULTS AND ANALYSIS OF RESULTS

This section of the research paper presents the results of modeling three types of ventilation systems. For a more accurate comparison of the data, the total energy consumption of the building will be given, as well as the indoor climate data for bedroom 101. To assess the correct operation of ventilation systems, we will trace how the air flow in the premises changes.

6.1 Results

6.1.1 Natural ventilation

Natural ventilation is the simplest type of ventilation in terms of installation. This type of ventilation does not require additional energy for its maintenance, but additional costs are required for heating the house during the cold period. Table 2 shows the energy costs of the house. According to the results obtained, the required energy is 35106 kWh. And the energy perfomance of the building E-value is 164.4 kWh_E/m^2.

Table 2. Natural ventilation. Delivered energy overview.

		Purchased energy		**Peak demand**	**Primary energy**	
		kWh	**kWh_E/m^2**	**kW**	**kWh**	**kWh_E/m^2**
	Lightning, real estate	616	5.2	0.07	739	6.2
	Cooling	0	0.0	0.0	0	0.0
	HVAC electricity	365	3.1	0.04	439	3.7
	Total, Facility electric	981	8.3		1178	9.9
	Heating, district heating	32953	277.4	12.73	16477	138.7
	HVAC, district heating	5633	47.4	0.65	2816	23.7
	Total, Facility district	38586	324.8		19293	162.4
	Total	39567	333.0		20471	172.3
	Equipment, resident	1847	15.6	0.21	2217	18.7
	Total, Tenant electric	1847	15.6		2217	18.7
	Grand total	**41414**	**348.6**		**22688**	**191.0**

Figures 23 and 24 show the patterns of air movement in the premises of the building in January and July. As we can see from Figure 23, the air flow through the installed leaks and irregularities in the exterior walls is about 10-20 l/s. During summer ventilation almost does not work, air flows are around 0-5 l/s. In general, the system works correctly, fresh air enters the living quarters, and the exhaust air leaves through rooms such as the toilet, kitchen, etc., in which the air itself is already polluted.

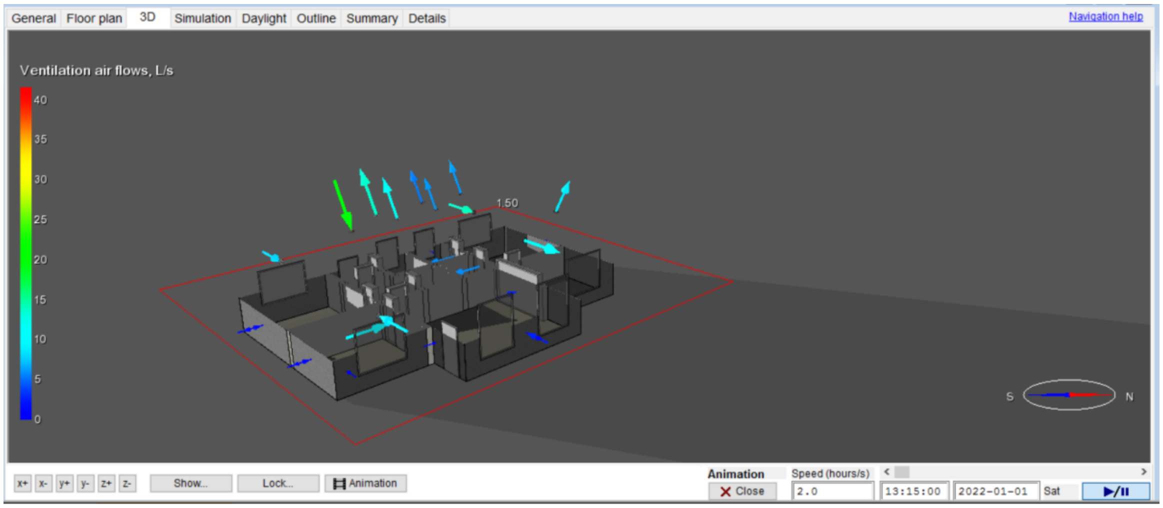

Figure 23. Natural ventilation. Ventilation air flows in January.

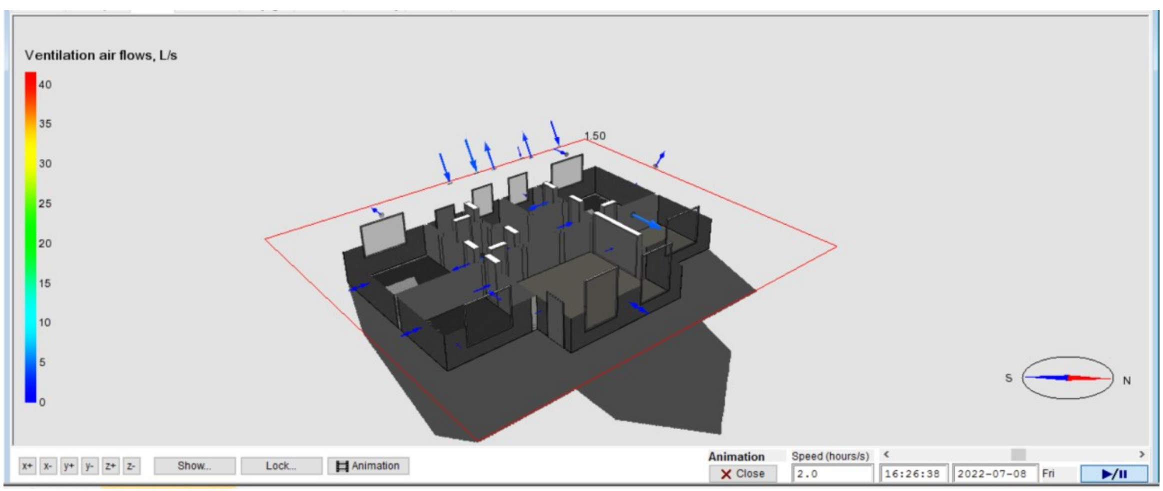

Figure 24. Natural ventilation. Ventilation air flows in July.

Figure 25 shows a graph of the change in the air temperature inside bedroom 101 throughout the year. From September to May, the indoor air temperature is within the normal range, about +21 °C. But with the onset of the summer period, the temperature sharply exceeds the norm, which is interconnected with the high temperature of the outside air. Natural ventilation does not cool the incoming air, so it is logical that the indoor air temperature is far from the comfortable temperature required by the standards.

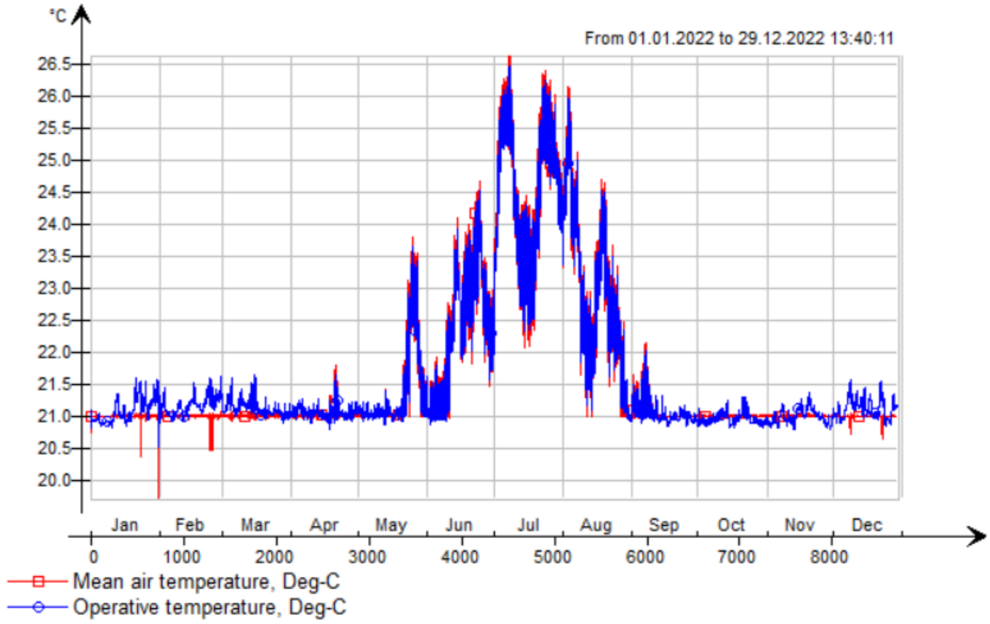

Figure 25. Natural ventilation. Mean air temperature in Bedroom 1.

Figure 26 presents 2 important graphs: relative humidity and CO_2 concentration. In winter, the humidity is in the range of 10…40%, in spring and autumn 20…60%, in summer 40…70%. In this climate, these are common indicators of humidity. Often the air is very dry during the cold period. The CO_2 concentration throughout the year is in the range of 600…1400 ppm, in summer the air quality is low, and the rest of the time – average air quality, according to Table 1.

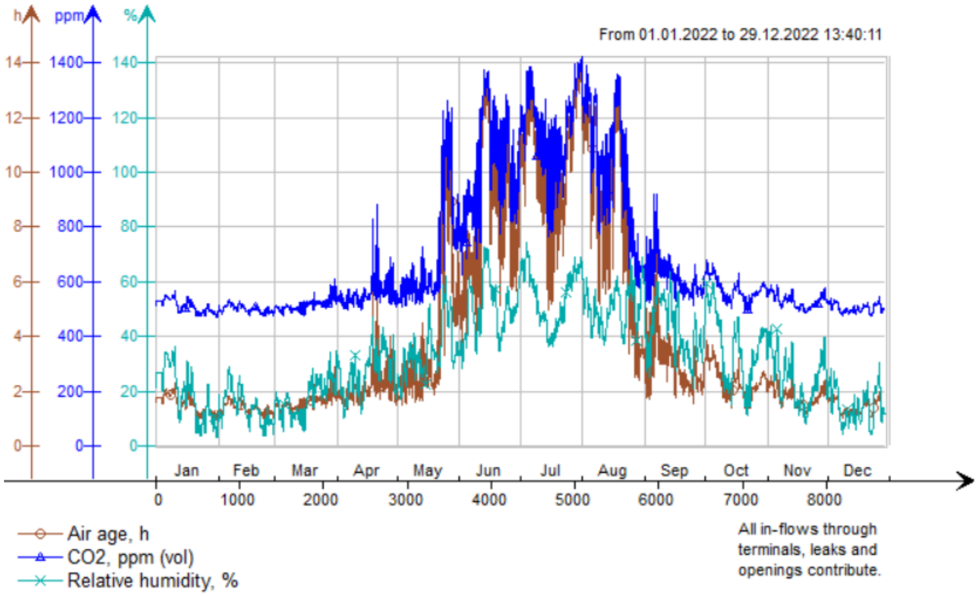

Figure 26. Natural ventilation. CO_2 concentration and relative humidity in Bedroom 1.

6.1.2 Exhaust ventilation

Exhaust ventilation is the ventilation system designed next. Table 3 presents the delivered energy overview of the house. According to Table 3, the required energy is 29748 kWh. The energy perfomance of the building E-value is 142.6 kWh_E/m^2.

Table 3. Exhaust ventilation. Delivered energy overview.

		Purchased energy		**Peak demand**	**Primary energy**	
		kWh	**kWh_E/m^2**	**kW**	**kWh**	**kWh_E/m^2**
	Lightning, real estate	616	5.2	0.07	739	6.2
	Cooling	0	0.0	0.0	0	0.0
	HVAC electricity	640	5.4	0.07	769	6.5
	Total, Facility electric	1256	10.6		1508	12.7
	Heating, district heating	28165	237.1	10.37	14082	118.5
	HVAC, district heating	5633	47.4	0.65	2816	23.7
	Total, Facility district	33798	284.5		16898	142.2

	Total	35054	295.0		18406	154.9
	Equipment, resident	1847	15.6	0.21	2217	18.7
	Total, Tenant electric	1847	15.6		2217	18.7
	Grand total	**36901**	**310.6**		**20623**	**173.6**

Figures 27 and 28 present air movement in the premises of the building in January and July. The ventilation system works right. Fresh air comes through leaks in the living area, and exhaust air is removed via mechanical parts of exhaust ventilation. As we can see in the figures below inflow is around 3 l/s, that is a really small amount for comfortable life. Outflow seems the same as inflow, and the intake and outflow of air clearly do not meet the requirements.

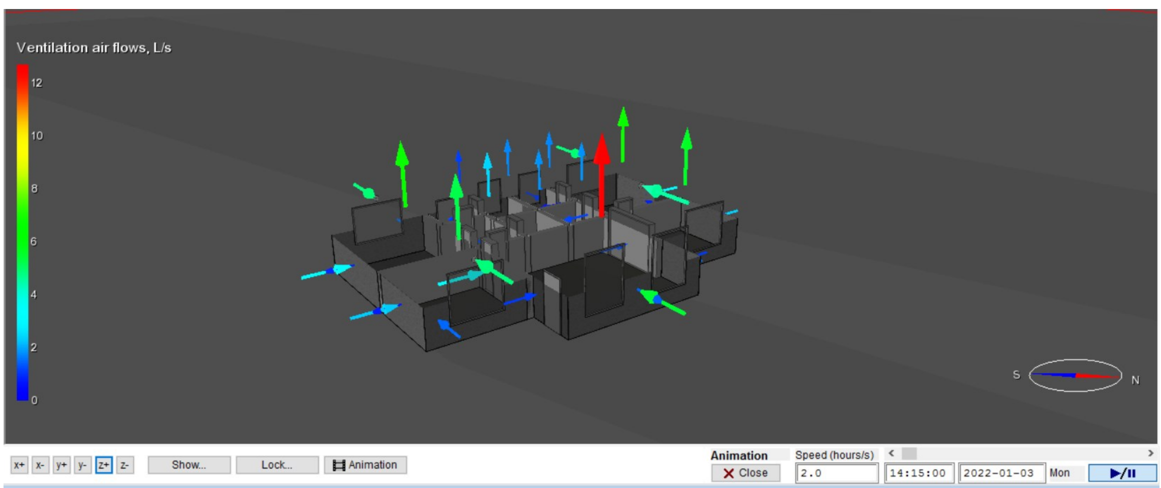

Figure 27. Exhaust ventilation. Ventilation air flows in January.

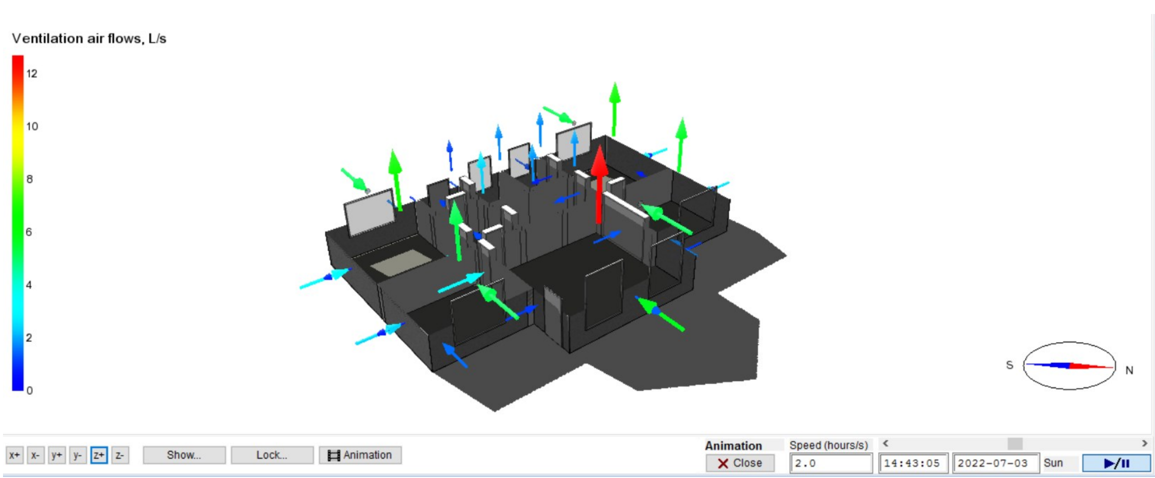

Figure 28. Exhaust ventilation. Ventilation air flows in July.

Figure 29 shows a graph of the change in the air temperature inside bedroom 101. The indoor air temperature is within the normal range, about +21 °C winter, spring and autumn. But during the summer period the temperature can exceed +26.5 °C, which is more than target values.

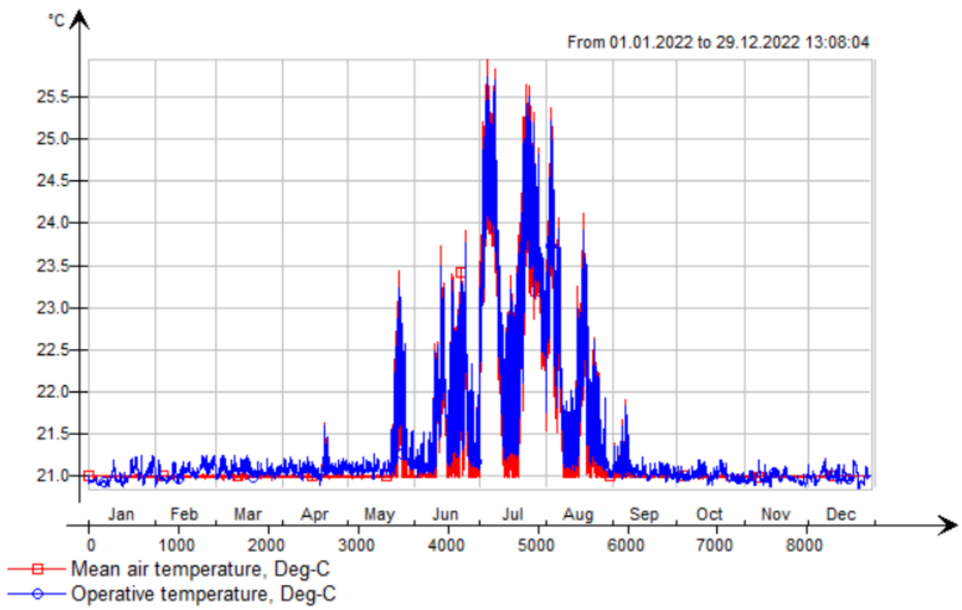

Figure 29. Exhaust ventilation. Mean air temperature in Bedroom 1.

Relative humidity and CO_2 concentration are presented in Figure 30. In winter, the humidity is in the range of 10…40%, in spring and autumn 20…55%, in summer – 30…70%. CO_2 concentration is around 800 ppm during the year. According to Table 1 it is medium indoor air quality.

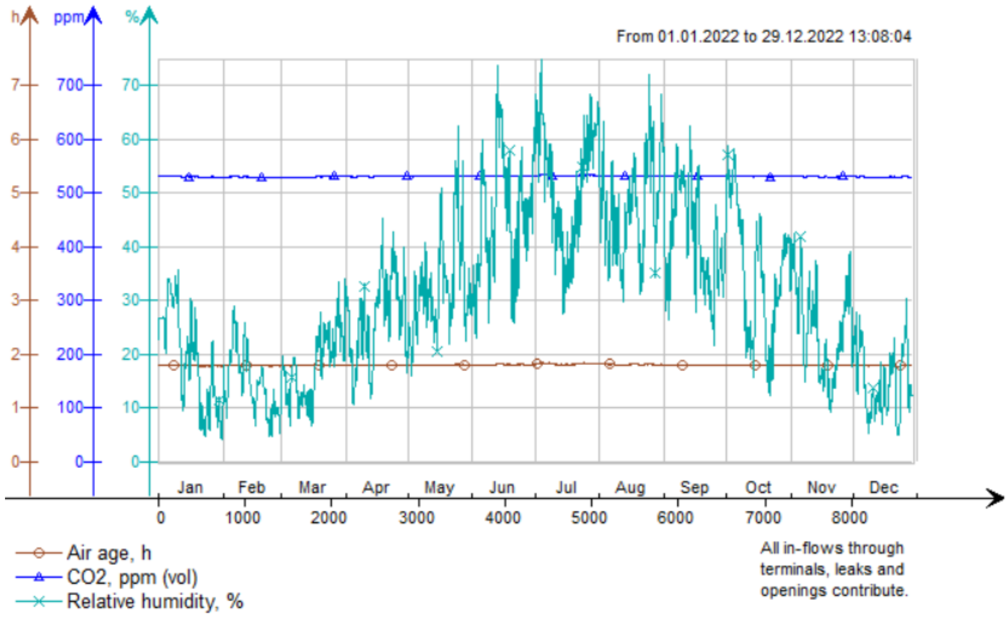

Figure 30. Exhaust ventilaion. CO_2 concentration and relative humidity in Bedroom 1.

6.1.3 Mechanical supply and exhaust ventilation system with AHU

The mechanical supply and exhaust ventilation system equipped with heat recovery is the best ventilation system these days. It can require more energy, but indoor air parameters will be the best compared to other ventilation types. The delivered energy overview is presented in Table 4. Total purchased energy is 31778 kWh. Energy performance is 153.1 kWh_E/m^2.

Table 4. Mechanical ventilation with AHU. Delivered energy overview.

		Purchased energy		**Peak demand**	**Primary energy**	
		kWh	**kWh_E/m^2**	**kW**	**kWh**	**kWh_E/m^2**
	Lightning, real estate	616	5.2	0.07	739	6.2
	Cooling	84	0.7	0.3	101	0.9
	HVAC electricity	1099	9.3	0.13	1318	11.1
	Total, Facility electric	1799	15.1		2158	18.2
	Heating, district heating	20004	168.4	8.1	10002	84.2
	HVAC, district heating	5633	47.4	0.65	2816	23.7

	Total, Facility district	25637	215.8		12818	107.9
	Total	27436	230.9		14976	126.1
	Equipment, resident	1847	15.6	0.21	2217	18.7
	Total, Tenant electric	1847	15.6		2217	18.7
	Grand total	**29283**	**246.5**		**17193**	**144.7**

Air flows in January and July are presented in Figures 31 and 32. Ventilation system works correctly. Regardless of the season of the year, the air supply to the living quarters is the same according to the requirements. According to Figures 31 and 32 air inflow is around 8 l/s for bedrooms and 12 for living room. This type of ventilation ensures a constant inflow and outflow of air.

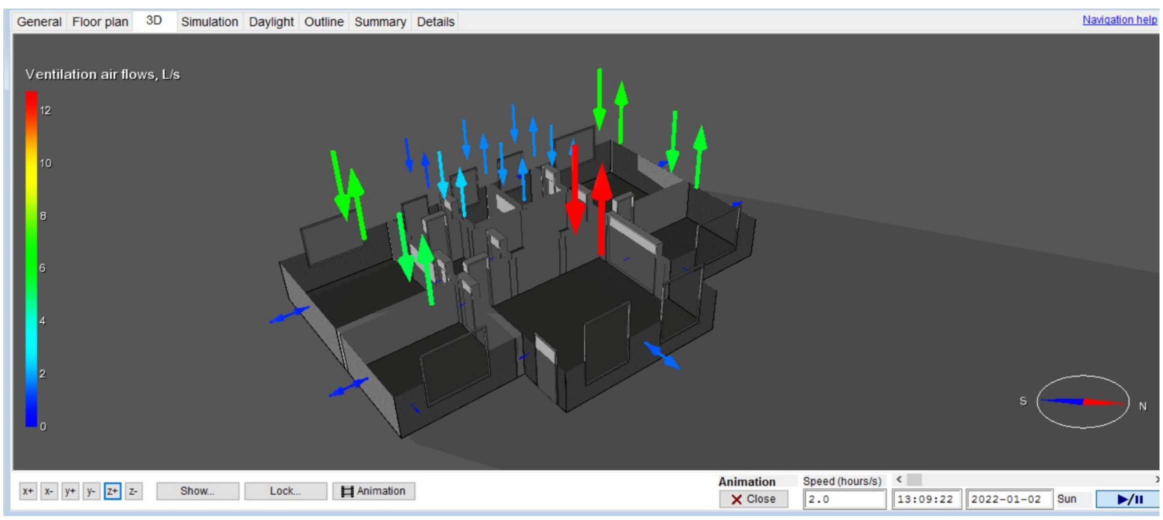

Figure 31. Mechanical ventilation with AHU. Ventilation air flows in January.

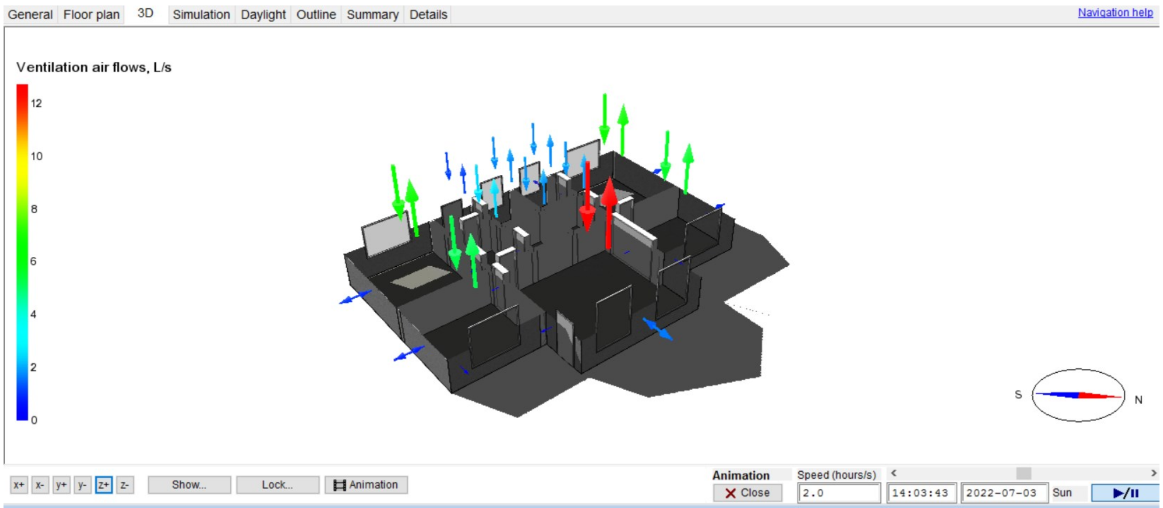

Figure 32. Mechanical ventilation with AHU. Ventilation air flows in July.

The mean air temperature is presented in Figure 33. Throughout the year, with the exception of summer, the air temperature of bedroom 101 is within +21 °C. In summer, ventilation cannot cool the outside air to 21 °C, so the indoor air temperature in summer ranges from +21 to +25.5 °C.

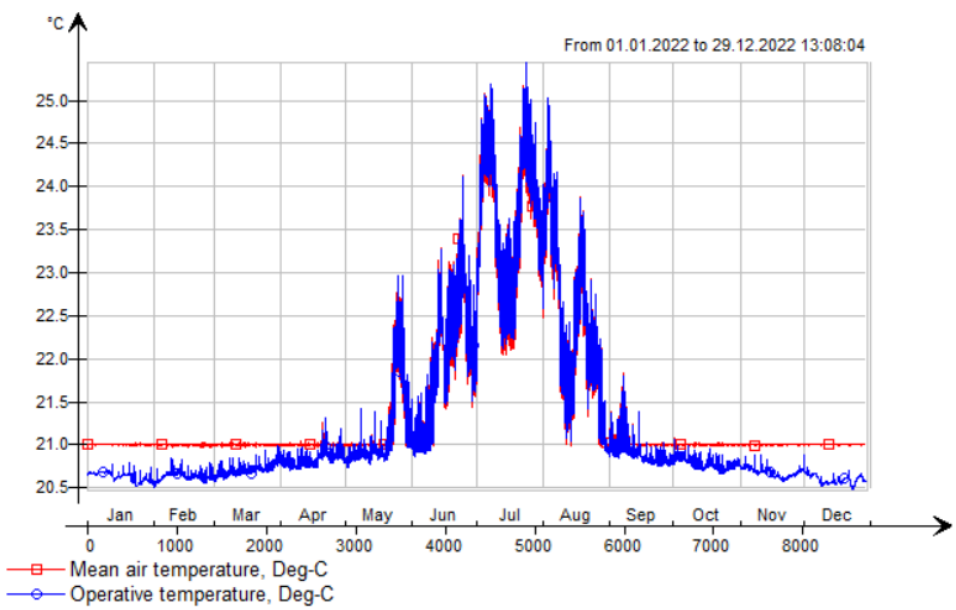

Figure 33. Mechanical ventilation with AHU. Mean air temperature in Bedroom 1.

Figure 34 presents two important graphs: relative humidity and CO_2 concentration. In winter, the humidity is in the range of 5…35%, in spring and autumn 10…45%, in summer 30…70%. The CO_2 concentration is the same every month of the year and it equals 580 ppm. According to Table 1 it is high indoor air quality.

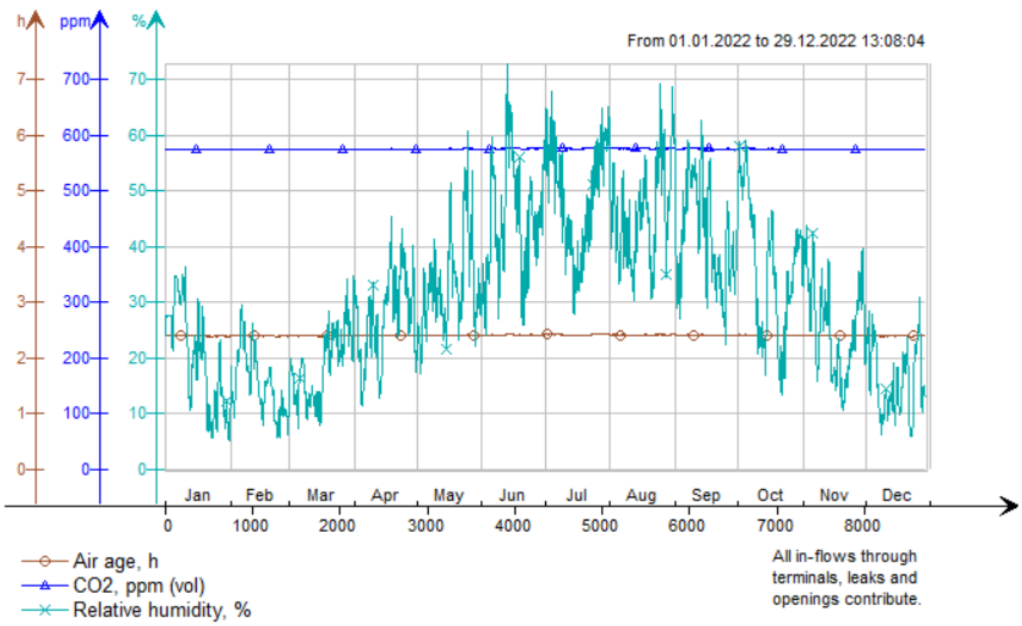

Figure 34. Mechanical ventilation with AHU. CO_2 concentration and relative humidity in Bedroom 1.

6.2 Analysis of results

The energy performance of the wooden house with different types of ventilation is presented in Table 5. The most important part of the table for comparison is the lower part of the table, which provides data on the total energy consumption of the building. The most energy-efficient system is mechanical ventilation with AHU with a value of E=144.7 kWh_E/m^2, the next most energy-efficient system is exhaust ventilation, where E=173.6 kWh_E/m^2. The least energy-efficient is natural ventilation, E=191.0 kWh_E/m^2. According to the results obtained, the best system for the overall energy efficiency of the house is mechanical ventilation with heat exchanger. For a reliable comparison, it is also necessary to study other factors, such as indoor air temperature, humidity, CO_2 concentration and air movement. This must be done because a high energy efficiency indicator of the system does not necessarily provide a good indoor climate in residential premises.

Table 5. Delivered energy. Comparison table.

		Natural ventilation	Exhaust ventilation	Ventilation with AHU
		kWhE/m²	kWhE/m²	kWhE/m²
	Lightning, real estate	6.2	6.2	6.2
	Cooling	0.0	0.0	0.9
	HVAC electricity	3.7	6.5	11.1
	Total, Facility electric	9.9	12.7	18.2
	Heating, district heating	138.7	118.5	84.2
	HVAC, district heating	23.7	23.7	23.7
	Total, Facility district	162.4	142.2	107.9
	Total	172.3	154.9	126.1
	Equipment, resident	18.7	18.7	18.7
	Total, Tenant electric	18.7	18.7	18.7
	Grand total	**191.0**	**173.6**	**144.7**

Indoor air temperature is an important characteristic of the indoor climate, as it has a strong influence on the people living in the building. Table 6 shows the air temperatures for bedroom 101 in different months with different types of ventilation. According to part 4.1 of this research paper, the room air temperature in summer should not exceed +23 °C, and in winter +21 °C. The average values for the year practically do not differ from each other, but when natural is installed, the temperature in summer exceeds the required value and is equal to +24.6 °C. Exhaust ventilation and the mechanical supply and exhaust ventilation system equipped with heat recovery meet the requirements, the average temperature in summer is around +23 °C, the rest of the time it is +21 °C.

Table 6. Mean air temperature, °C. Comparison table.

	Type of ventilation system		
	Natural ventilation	**Exhaust ventilation**	**Mechanical ventilation with AHU**
January	20.98	21.0	20.63
February	20.99	21.05	20.63
March	21.0	21.06	20.7
April	21.01	21.08	20.82
May	21.35	21.25	21.15
June	22.32	21.64	21.92
July	24.58	23.31	23.66
August	22.88	22.01	22.37
September	21.05	21.07	20.9
October	21.0	21.0	20.77
November	21.0	20.98	20.68
December	20.99	21.01	20.59
mean	21.61	21.38	21.25
min	20.98	20.98	20.59
max	24.58	23.31	23.66

The next important factor is CO_2 concentration. Human health depends on this, since various diseases can appear if you are in a room with poor air quality for a long time. Table 7 shows the values for CO_2 concentration. With natural ventilation, there is an increased level of CO_2 concentration, and in the summer, the air quality in the room is very poor. The average value for the year is 690 ppm, which corresponds to the medium indoor air quality. With exhaust ventilation, the CO_2 concentration value during the year is 530 ppm, which is high indoor air quality. In the mechanical ventilation with a heat exchanger the average value of CO_2 concentration is 580 ppm that is high indoor air quality. It should be concluded that exhaust and mechanical ventilation are capable of providing high air quality, it depends on the fact that the air in the rooms is constantly changing, and fresh air is constantly brought into the rooms.

Table 7. CO_2 concentration, ppm. Comparison table.

	Type of ventilation system		
	Natural ventilation	**Exhaust ventilation**	**Mechanical ventilation with AHU**
January	511.5	530.8	574.9
February	500.6	530.6	574.7
March	515.4	530.8	574.8
April	560.5	531.1	575.2
May	700.4	531.4	575.4
June	1014.8	532.1	576.0
July	1166.7	533.2	576.4
August	1000.8	532.3	576.1
September	614.8	531.6	575.7
October	570.4	531.4	575.5
November	530.7	531.0	575.1
December	503.5	530.6	574.7
mean	685.3	531.4	575.4
min	500.6	530.6	574.7
max	1166.7	533.2	576.4

Table 8 shows the relative humidity of the air. As we can see from the table, the humidity values are approximately the same for any type of ventilation system. A characteristic feature for them is dry air in winter, spring and autumn, which is due to the operation of heating devices, and in summer there is a comfortable humidity in the room.

Table 8. Relative humidity, %. Comparison table.

	Type of ventilation system		
	Natural ventilation	Exhaust ventilation	Mechanical ventilation with AHU
January	18.77	19.15	19.95
February	14.13	14.71	15.5
March	17.53	17.85	18.61
April	27.03	26.63	27.39
May	34.95	32.84	33.32
June	49.87	45.84	44.97
July	54.61	51.83	49.16
August	50.88	47.58	46.36
September	42.33	41.17	41.84
October	36.01	35.44	36.17
November	24.86	24.9	25.69
December	14.5	15.01	15.82
mean	32.35	31.29	31.43
min	14.13	14.71	15.5
max	54.61	51.83	49.16

The air flows during natural and exhaust ventilation do not meet the requirements as we can see from the previous chapter. This is understandable, since an uncontrolled inflow of air can rarely provide the necessary air flows. Only with mechanical ventilation with AHU is the necessary air movement achieved, since the supply and outflow of air are strictly controlled by the ventilation system.

7 DISCUSSION

In this research paper, the question of the influence of the ventilation system on the energy efficiency of a log house is studied. For a reliable result, the project of a single-storey log house was selected and three types of ventilation systems were designed using IDA ICE software: natural ventilation, exhaust ventilation and mechanical ventilation with heat recovery. This structure is designed for the climatic conditions of the city of Mikkeli, Finland. The theoretical part sets out the basic principles of operation of various ventilation systems for the purpose of their future correct design in IDA ICE. The requirements for the parameters of the indoor climate of the premises are also considered, as this is an integral part in the design of buildings. Much attention is paid to the internal climate of the building, since first of all people should feel comfortable when living in the house. To assess the indoor climate of the house, the following main parameters are taken: air temperature, air humidity, CO_2 concentration and air flows.

The log house with a total area of 107.13 m2 is designed in the IDA ICE software, all the initial data for successful modeling are entered. Three types of ventilation were simulated and a simulation of the operation of the building was launched. It should be noted that the program managed with modeling situations, and our task is to study the results obtained after the simulation process, and choose the most optimal variant of the ventilation system, taking into account energy consumption and characteristics of the internal climate.

According to the data obtained, mechanical ventilation with AHU is the most effective in terms of energy consumption, exhaust ventilation is less preferred. Natural ventilation loses in all parameters in comparison with the other two types of ventilation, therefore, it can be concluded that natural ventilation is not recommended for installation as the main ventilation system of a wooden house. Taking into account the comfortable living conditions and energy consumption, the best type of ventilation system is mechanical ventilation. It is the type of ventilation that meets all the requirements of microclimate standards. Mechanical ventilation provides high indoor air quality and constant air flow to permises as well. Mechanical ventilation will make permanent residence in the house comfortable and will not entail the appearance of any diseases in residents. It is clear that the maintenance of such a system will be more expensive, but in the future, this ventilation system is definitely capable of creating living conditions close to ideal.

This research paper can serve as a good basis for those who wish to study this issue in more detail. The choice of a ventilation system depends on many factors: climatic conditions, the size of the building, the type of enclosing structures, the wishes of the customer and much more. Wooden houses will always be popular among those who want to have their own residential building, and the task of designers these days is to design not only an eco-friendly house in terms of materials, but also corresponding to national standards regulating the parameters of the indoor climate. The most important final task is to reduce energy consumption at home as much as possible. The ventilation system plays an important role and requires additional research on real objects.

This work shows the theoretical side of the design of the house, as ventilation systems are designed for a virtual object. Such modeling does not give completely reliable and correct results that can be used to design all types of single-family houses. When modeling, all the real conditions of the building's existence are not taken into account. This issue requires additional research on existing facilities. Energy efficiency is affected by the density of wood, the quality of the sealant between the logs, the wind, the operation of the heating system and many other factors. Due to the influence of many factors, the actual data on energy consumption may differ. For this reason the study of existing objects will show the most correct results.

As a theoretical study, a good topic, for example, will be «The dependence of the energy efficiency of a building on the number of floors». The results for one type of ventilation system or for different types can be compared. Another interesting topic is «The influence of building enclosing structures on the energy efficiency of the house when installing any ventilation system».

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