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Ventilation and Air Handling in nearly Zero Energy Buildings in Russian Climate

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DESCRIPTION

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Abstract

Nowadays European legislation requires all new buildings to be nZEB by 2020. This requirement is needed to follow the Kyoto protocol. As the law has come into effect recently, nZEB concept has not been developed thoroughly yet. As Russia signed Kyoto protocol as well, such requirements for energy performance of buildings can be expected in future.

Aim of the work is to find suitable energy saving solutions in HVAC-systems, especially in ventilation and air conditioning. These solutions should provide good indoor climate and comfort of occupants. Office buildings are in focus in this work.

In the first part of the work existing office buildings from Central and Northern Europe were studied. Their envelope properties, used systems and systems' performance were studied and descried, so to have a possibility to estimate possible parameters for Russian climate.

In the second part different energy saving solutions found in studied cases were described and possibility and rationality to use them in Russia were assessed. Also on-site energy production was dealt with.

In the third part results of energy simulation are submitted. The results allow estimating possible energy performance of buildings in Russian climate.

The conclusion is nZEBs in Russia are possible, but they require more energy than in Central Europe. All the measures decreasing heating and demands like HRU, airtight envelope with low U-value and use of free pre-heating/pre-cooling should be done. SFP-value should be low. And chilled beams as cooling distribution system to the rooms should be used.

Subject headings, (keywords)
Ventilation, Air-conditioning, Nearly Zero Energy Building, mini-CHP, free cooling, solar energy, wind energy, district heating, district cooling, heat recovery unit, pre-heating, pre-cooling, efficiency, energy consumption, energy performance

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1 INTRODUCTION

Nearly half of all buildings in Europe were built before the 1960s /1, p. 16/. At that time people were focused on very different problems. They tried to make their cars faster and houses more comfortable. They did not take care of energy consumption or energy performance of things around them. So there were only few thermal performance requirements. But later, in seventies, the first energy crisis happened. People realized that having a powerful car with a big engine or to heat a big house with poor insulation is rather expensive. The first requirements for energy performance appeared. From that days fossil fuels prices grew a lot and energy performance requirements became only higher.

Then some scientists started to speak about climate change and ecological impact caused by fossil fuel combustion. These two factors, energy price and environment, made people revise their attitude to energy consumption. The result of the revision is that up-to-date buildings consume 60% less than the old ones /1, p.16/. And there are still low energy buildings whose energy performance is much higher than energy performance of conventional buildings. These low energy buildings were built in many countries over last thirty years. Further the work will be focused on those low energy buildings.

The phenomenon has been developing for more than 20 years, as the development started different concepts appeared like passive house, sustainable buildings. Now, according to European legislation – nearly Zero-Energy Building (nZEB) is a new aim.

When people started to think about saving energy and money in building sector, they paid a lot of attention to residential buildings. Passive houses are mainly one- or two-family detached houses. But Energy Performance of Buildings Directive (EPBD) requires all kinds of buildings to be nZEB. That means that not only detached houses are in focus now, but apartment houses, shopping malls and commercial buildings, office buildings and so on should be modify. Further I am going to concentrate on office buildings.

2 AIMS

My purpose is to find suitable low energy solutions for the office buildings in northwestern Russia. I am going to discuss methods of decreasing energy consumption in HVAC-systems, especially in ventilation and air conditioning that are in use in nowadays nZEBs or low energy buildings in Europe. I think that such kind of work is needed because not every decision working in Europe will work in Russia due to more severe climate, which limits possibilities of decreasing energy consumption, for example limitation of heat recovery efficiency in very cold days to prevent frosting-up.

I am going to discuss ways of on-site power production in Nothern Climate, there are several ways of power production on site, but they require some special weather conditions. That means that not all of them are suitable in case of northern climate.

3 METHODS

The aim of the thesis is to find out ways of air handling with minimal possible energy use in climate of northwest region of Russia. The thesis is focused on office buildings. That is why first method is literature review. Existing office buildings which were designed to achieve nZEB concept and described in books and articles would be studied to find ways of energy saving in HVAC-systems. Also the information about residential nZEB buildings or other types of low energy buildings will be taken into account, because they are more widespread by now, so some additional solutions could be found. The examples of literature used in review are REHVA Journals and guidebooks.

The second method is analysis of energy saving solutions found in literature. The analysis reveals solutions for air treating, which possible in cold climate of northwestern part of Russia consume less energy and provide better indoor climate.

The third method is energy consumption simulation with IDA ICE software. The aim of the task is to check that solutions work and assess their effectiveness. Indoor climate is first-priority in my analysis, because it is senseless make buildings with high energy performance and poor indoor climate. The problem arose in earlier low energy buildings.

The concept of nZEB is a result of EPBD, which is a European law, so it is not used in Russia. EPBD supposes each Member State to adopt energy consumption level and other requirements for local conditions. This adoption obviously was not done for Russia, so Finnish implementation of EPBD is used, because likeliness of climates of southern region of Finland and northwestern region of Russia.

4 EXPLANATION OF NEARLY ZERO ENERGY BUILDING

In this work some concepts will be used, so these concepts should be defined.

> "Nearly Zero-Energy Building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."/2./

> "Energy performance of a building means the calculated or measured amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting." /2./

High energy performance of the building means low energy demand of the building. So, the building has to have heat recovery, airtight envelope with low U-values and U-values of windows and doors should be low as well. Also all the HVAC-systems installed in the building have to have high efficiency. Further it is stated in the definition, that energy should be mostly produced on-site or nearby from renewable sources. So nZEB is like a passive building with energy production, like photovoltaic panels, heat pumps, windmills or boilers on wood, for example.

The definition doesn't include any specific values, they are to be set by each Member States. The definition is given in EPBD. The Directive is a law which is made for decreasing energy consumption on a building stock, because 40 % of energy consumption of EU is caused by building sector, which is growing constantly. /2./

First Directive was made on 2002 and came into force on 4th January 2003. It was made to meet the requirements of Kyoto protocol. The goal is achieved with legislation restrictions in Member States, implementation of building certification schemes, inspections of heating and air-conditioning systems. The directive changed the approach to energy performance. The maximum U-value approach was replaced with 'whole building' approach where HVAC-systems are included /1, p.16/.

Time goes so the directive was emended repeatedly. That is why on 19th of May 2010 there was a recast of EPBD. In the recast it is said, that all new buildings should be nZEB by 2020.

Nearly Zero Energy Building is not the only concept with high energy performance. What distinguishes nZEB concept is energy calculation method, primary energy is used in energy consumption calculation. It is used in majority of Member States. /3, p.6./

> "Primary energy means energy from renewable and non- renewable sources which has not undergone any conversion or transformation process." /2./

> ”Energy from renewable sources means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases." /2./

Energy taken from the grid and measured from the building meters is net delivered energy, not primary energy. Net delivered energy has undergone transformation before it comes into the building, so primary energy is amount of energy of burnt fossil fuel needed to get necessary amount of net delivered energy. To calculate primary energy net delivered energy should be multiplied with primary energy factors. Primary energy factor depends on type of net delivered energy used (whether electricity, district heating, district cooling etc.) and on country. Each Member State has its own primary energy factor for each type of net delivered energy, e.g. in France primary energy factor for electricity is 2,58 and in Finland it is 1,7. Other Finnish primary energy factors are shown in table 1.

TABLE 1. Finnish primary energy factors.

Fossil fuel	1
District heating	0,7
District cooling	0,4
Electricity	1,7
Renewable energy	0,5

Reading literature, concepts resembling Nearly Zero Energy Building can be easily found, like Net Zero Energy Building and Nearly Net Zero Energy building. Based on the directive’s definition, nearly zero energy building is technically defined through the net zero energy building, which is a building using 0 kWh/(m^2 a) primary energy/3, p.7/. Nearly Net Zero Energy Building corresponds to national cost optimal energy use of > 0 kWh/(m^2 a) primary energy /4,p.7/.

5 IMPLEMENTATION OF ENERGY PERFORMANCE OF BUILDING DERECTIVE IN FINLAND

Finnish Ministry of the Environment hasn’t developed performance and energy consumption requirements yet. That is why an overview of Finnish passive houses and nZEBs will be given and some value will be chosen as the reference one.

Paroc company which is a producer of thermal insulation from Finland made their recommendations for energy consumption of passive houses. So, in Nordic countries it is recommended to use from 20 to 30 kWh/m^2 annually for heating and cooling depending on location of the building, and 130 – 140 kWh/m^2 of primary energy. The recommendations are for residential buildings, so exactly these values can’t be use for office buildings. /5./

Also Paroc company developed advisable values for thermal performance of building envelope elements. They are shown in table 2 below. In table 2 there are also values of residential nZEB built in Kuopio provided by VTT and D3 values from 2012.

TABLE 2. Required and advisable U-values /5/.

Envelope element	Paroc U-value W/(m^2 K)	VTT U-values W/(m^2 K)	U-value acc. D3 W/(m^2 K)
Exterior wall	0,06-0,10	0,08	0,17
Base floor	0,06-0,1	0,1	0,16
Roof	0,06-0,1	0,07	0,09
Window	0,70-0,90	0,8	1
Fixed window	0,60-0,80	—	—
Entrance door	0,40-0,70	0,76	1
Airtightness	—	0,4 1/h	2 1/h

According to Finnish regulation part D3 E-value of the office building should be not more than 170 kWh/m^2 of primary energy.

6 CASE STUDIES IN DIFFERENT COUNTRIES

In the following chapter buildings from central and northern Europe will be described. The aim of the chapter is to find out HVAC-systems and energy sources used in nZEBs across the Europe.

6.1 France

A good example of low energy building which comes rather close to net zero energy building concept is built in Dijon, France. Elithis tower emits sixth part of green house gases compared to conventional building /6, p. 53/.

The tower was designed and built in such a way to use available natural resources as much as possible. Building envelope data are given in table 3. Natural lighting is utilized a lot, so the building is in an open place to avoid shading. 75 % of facade surface is glazing. The tower is of a rounded shape. The building itself can be seen at figure 1 below. The shape reduces building envelope surface, as a consequence, heat losses and sun gains are lower, and infiltration is lower as well. Utilization of sun light poses a problem of heat gains. The problem is solved with shading shield. /6, p. 55./

FIGURE 1. Elithis tower, Dijon, France /6, p. 53/.

TABLE 3. Building envelope data /6, p. 54/.

Window U-value	1,1 W/(m^2 K)
Window g-value	0,4
Exterior wall U-value	0,32 W/(m^2 K)
Base floor U-value	0,39 W/(m^2 K)
Roof U-value	0,22 W/(m^2 K)

In the building mechanical supply and exhaust ventilation with heat recovery is installed. The ventilation system can work in three modes. It can be seen from figure 2. Operation mode depends on the season. In normal winters, when temperatures are higher than 0°C, ventilation with limited heat recovery is in use to heat supply air up to 16-18°C. During extremely cold winters with temperature lower than 0 °C and hot summers with temperature higher than +26°C full capacity of heat recovery is used. In mid-seasons the second ventilation strategy, so-called triple flow ventilation, is used, which is Elithis' innovation. There are 32 ventilation openings or air intakes on the facade on each level, and low-pressure fan in the central atrium. So in mid-seasons these air intakes are open, low-pressure fan works and mechanical supply and exhaust ventilation is on. This mode provides additional free cooling, because air coming through the openings takes away surplus heat. The third operation mode of ventilation is cooling at summer nights, when air intakes are open and low-pressure atrium fan works. /6, p.45./

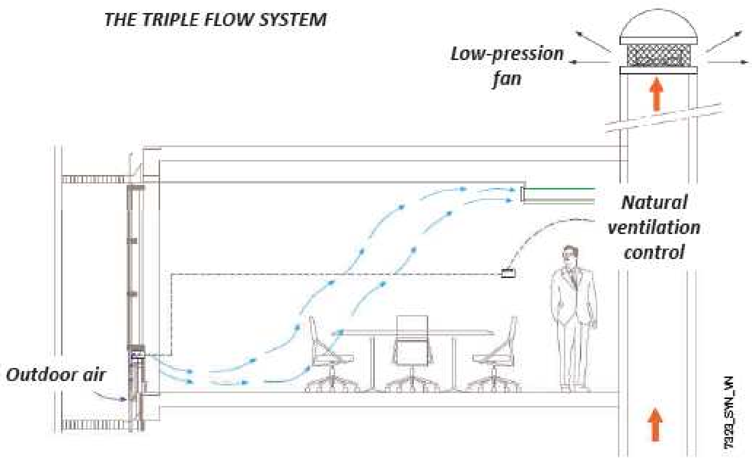

FIGURE 2. Triple flow system /6, p. 56/.

Heating demand is mainly covered with internal heat gains, but if internal heat gains are not enough, there is "one very low-power wood boiler" /6, p. 56/ and one more boiler for back-up. Cooling demand is mostly covered with triple flow ventilation, but if it is not enough adiabatic cooling based on water evaporation is used. For extremely hot weather with outdoor temperature more than 30°C heat pump is used. Energy performance of the building can be seen from the table 4.

Chilled beams are installed in the rooms. They are terminal devices for heating, cooling and ventilation. As supply nozzle is integrated into chilled beam, chilled beam is of an active type. /6, p. 56./

TABLE 5. Simulated and measured energy performance of the building after the first year of operation. All specific values are per net floor area /6, p. 57/.

	Design phase			Measured 2009
	Net delivered energy use, kWh/(m^2 a)	Primary energy factor	Primary energy use, kWh/(m^2 a)	Primary energy use, kWh/(m^2 a)
Space, water and ventilation heating, wood boiler	3,7	0,6	2,2	7
Cooling, electricity to heat pumps	4,6	2,58	11,9	6,9
Fans	5,7	2,58	14,7	15,7
Pumps	0,4	2,58	1	2,9
Lighting	4,5	2,58	11,6	10,5
Elevators	1,5	2,58	4,0	4,0
Appliances (plug load)	10,3	2,58	26,6	60
PV power generation	-17,8	2,58	-45,9	-44,7
Total	13,2		26,4	62,7

Due to more severe climate, so big share of glazing causes great heating demand. nZEB in Russia shouldn't have so big share of glazing. Mixed ventilation can be sensible in Russian climate in summer time. Chilled beams are very good way of surplus heat removal. It can be used successfully in Russia as well. It will be discussed thoroughly in chapter 7.

6.2 Switzerland

The International Union for Conservation of Nature (IUCN) built its new headquarters in Gland, Switzerland. IUCN wanted its office to be as environmental friendly as possible, so they use iterdisciplinary design to achieve best performance. The result is the building complies with Swiss Minergie-P-ECO standard and occupants can enjoy comfortable indoor climate with possibility to adjust it. The budget of the project was tight. /7, p. 58./

As a previous case, passive solar heat gains were taken into account but share of glazing is less, it is 25% of façade in this project. This share of glazing and outside corridors, that give shading, provides sufficient amount of natural lighting and decreases thermal losses and cooling needs. The photo of the building is on Figure 3. Properties of the building envelope are in table 5. In summer surplus solar gains are limited by means of movable blinds that are closed from bottom to top. /7, p. 59./

FIGURE 3. North-east façade IUCN headquarter /7, p.58/.

TABLE 5. Building envelope data /7, p.64/.

Window U-value	0,7 W/(m^2 K)
Walls with triple glazing	0,5 0,7 W/(m^2 K)
Exterior wall U-value	0,1 W/(m^2 K)

The occupation varies a lot, so constant air flow ventilation doesn't make any sense, variable air flow ventilation in traditional way would be rather expensive, so decentralized system was used. Use of individual ventilation system provides better comfort for workers. There is a supply air unit in the floor near to external wall. The unit consists of outdoor air intake, filter, fan, heating/cooling coil. Supply air flow is controlled according to CO_2 concentration in exhaust air. CO_2 is measured with a sensor installed in exhaust air damper. Supply air ductworks are not needed in the system. If room is not occupied during the day, fresh air and good air quality are provided with two flushes. /7, p. 59./

Heating demand is very low, only ventilation supply air has to be heated. To pre-heat supply air heat pumps are installed in exhaust ducts. These heat pumps are reversible, so they can cover small cooling needs. Internal gains are usually bigger than heating demand of spaces, so cooling is needed. Geothermal energy from free cooling reservoir is used for cooling purposes in the building. 30% of cooling needs are covered with free cooling. The rest are produced with the reversible heat pump. So the pump works for cooling in summer and can be used for heating supply air in winter. /7, p. 59./

To deliver necessary thermal power, whether cooling or heating, ceiling panels are used. Panels are depicted on figure 4. These panels include exhaust air damper, lightning, and hydraulic circuit of pipes. /7, p. 60./

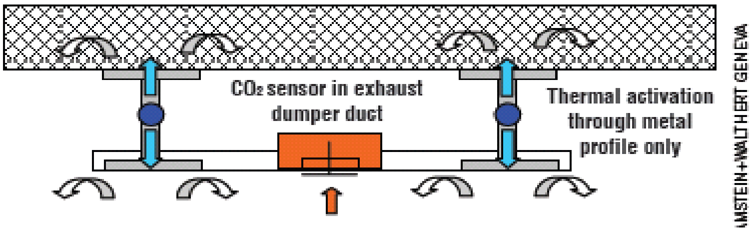

FIGURE 4. Ceiling panel for heating and cooling, with integrated extract air terminal /7, p. 60/.

Very interesting decision was made to use thermal inertia of ceiling. Nearly 50% of ceiling was left uncovered to activate ceiling flagstones. It helps to reduce peak power by 35%. /7, p. 60./

To produce some energy on site photovoltaic panels are used. There are 1 400 m^2 of those panels on the roof of the building. Overproduction goes to the electric grid. /7, p. 59./ Energy performance of the building can be seen from the table 6.

TABLE 6. Simulated energy performance of the building. All specific values are per net floor area /7, p. 62/.

	Net delivered energy use, kWh/(m^2 a)	Primary energy factor	Primary energy use, kWh/(m^2 a)
Space, water and ventilation heating, electricity to heat pumps	6,0	2	12,0
Cooling, electricity to heat pumps	6,7	2	13,4
Fans	5,3	2	10,5
Pumps	2,8	2	5,6
Lighting	16,3	2	32,6
Appliances (plug loads)	26,8	2	53,6
PV power generation	-30,9	2	-61,8
Total	33		66

External shading is a very efficient way of reducing cooling needs in summer so it must be used in Russian offices to provide low energy consumption. Ceiling panels are alternative for passive chilled beams, active ones can't be used in this case due to individual air supply. As in Russian climate it is better to use centralized ventilation system, these ceiling panels should be replaced with active and passive chilled beams. Variable air volume is a measure to be used in nZEB in all countries. Free cooling is strongly recommended to use.

6.3 Holland

One more example of green building is situated in Hoofddorp, Holland. It is an office of TNT Group. The aim of the stakeholders was to create CO_2 emission free building, and design should get more than 1000 points of Dutch sustainability certification program and be LEED Platinum certified. The philosophy of the architect was not erect building that saves energy, but the building where employees feel themselves comfort. /8, p. 67./ Photo of the building is on figure 5.

Daylight is utilized as much as possible. North façade is completely glazed. Solar louvers are used to prevent undesirable heat gains. /8, p. 68./

FIGURE 5. TNT Green Office /9/.

Constructors made heating demand as low as economically reasonable. The U-values can be found in table 7 below. As nowadays cooling needs can be rather high, even higher than heating demand, internal heat gains were minimized as much possible. Final energy consumption for cooling is 3,3 kWh/(m^2 a) and for heating is 9,8 kWh/(m^2 a). Heating and cooling are carried out with heat pumps, which means previous values are electricity consumption. /8, p.69./

TABLE 7. Building envelope data /8, p. 70/.

Window U-value	1,4 W/(m^2 K)
Window g-value	0,27/033
Base floor U-value	0,24 W/(m^2 K)
Roof U-value	0,24 W/(m^2 K)

Ventilation is provided with 4 centralized Air Handling Units (AHU). Outdoor air is filtered, then heated up or cooled down with run around heat recovery unit, efficiency of heat recovery can be regulated with three-way valve. Supply air then treated with heating/cooling coil Scheme of the system is on figure 6. When possible natural ventilation is in use, otherwise mechanical ventilation operates. Heat pumps are used for cooling and heating purposes. A long term energy storage is used, excessive heat of heat pump working in cooling regime (or vice versa, excessive cold when heat is produced) is accumulated in aquifer, and then utilized, when season changes. /8, p.70./

In this case rather interesting way of producing energy on site was chosen. Electricity and heat are produced with bioCHP. As all heating needs of this particular building are satisfied with heat pumps, all the heat produced goes to the offices nearby. For peak demands some green electricity is purchased. The bioCHP uses wastes of slaughter house as a fuel. The electrical efficiency of bioCHP is 40%, total fuel efficiency is 86%. /8, p. 71./ Energy performance of the building can be found in table 8.

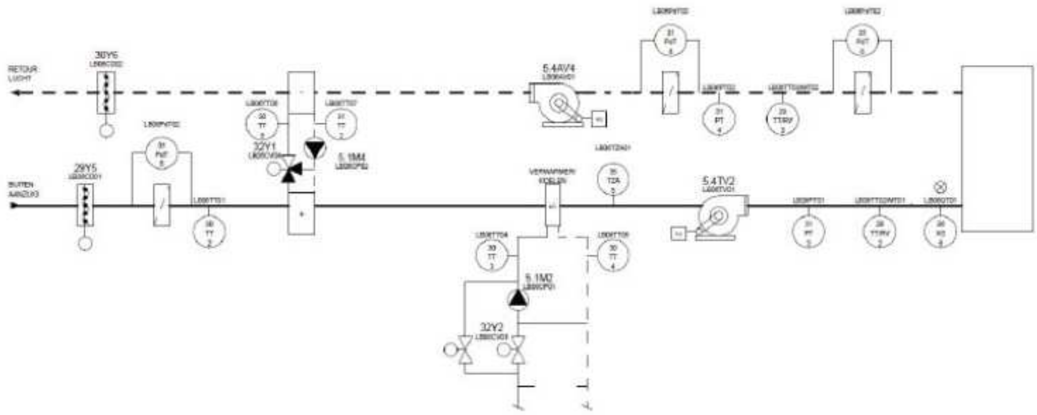

FIGURE 6. Ventilation system of TNT Green Office /8, p. 69/.

TABLE 8. Simulated energy performance of the building. All specific values are per net floor area /8, p. 70/.

	Net delivered energy use, kWh/(m^2 a)	Primary energy factor	Primary energy use, kWh/(m^2 a)
Space and ventilation heating	9,8	2	19,6
Hot water heating	3,5	2	7,1
Cooling	3,3	2	6.6
Fans	16,8	2	33,7
Pumps	0,7	2	1,5
Elevators	0,8	2	1,5
Lighting (interior)	21,1	2	42,2
Lighting (exterior)	0,8	2	1,6
Appliances (plug loads)	19,2	2	38,3
BioCHP electricity generation	-73,8	2	-148
BioCHP fuel consumption	184	0,5	92,2
Heating energy exported to other buildings	-50	0,5	-25
Total	137		72

BioCHP could be used in Russia, especially when simultaneous production of electricity is needed.

6.4 Finland

Next example of a nZEB is situated in the city of Helsinki. It was completed in 2011. The Environment Centre building Ympäristötalo is the best office building in respect of energy performance in Finland. /10, p. 44./

In this case much better building envelope performance is needed than in Central Europe. That is why glazing area is smaller compared to office buildings of milder climates, here share of windows’ area is 23 % of total façade area. The main façade, which is faced on south, is done like a double façade and it serves at the same time like a solar shield and surface for photovoltaic panels. Exterior of the building can be studied from the figure 7. The double façade can be opened from the bottom. The double façade has in total 30 ventilation openings. These openings help to reduce cooling need and are opened manually from reception and closed automatically according to weather control system. /10, p.45./ The U-values can be found in table 9 below.

FIGURE 7. The Environment Centre building Ympäristötalo exterior /10, p.46/.

TABLE 9. Building envelope data /10, p. 45/.

Window U-value	0,8 W/(m^2 K)
Window g-value	0,3
Exterior wall U-value	0,17 W/(m^2 K)
Base floor U-value	0,16 W/(m^2 K)
Roof U-value	0,09 W/(m^2 K)
Air leakage rate at 50 Pa	0,56 1/h

Heating power is provided with district heating. Heating load consists of ventilation heating demand, space heating and production of hot domestic water. There is a free cooling with water from 25 boreholes in the building. That is enough to cover all the cooling needs, which are delivered with passive and active chilled beams, for cooling supply air. There is mechanical supply and exhaust with regenerative heat recovery in the building. Ventilation system consists of three main AHU (with volume flows 2,4, 4,0 and 4,2 m^3/s) and small AHUs for toilets with heat recovery to avoid additional heat losses. Supply air flow equals to exhaust air flow. The scheme of the ventilation system can be seen on Figure 8. /10, p.45./

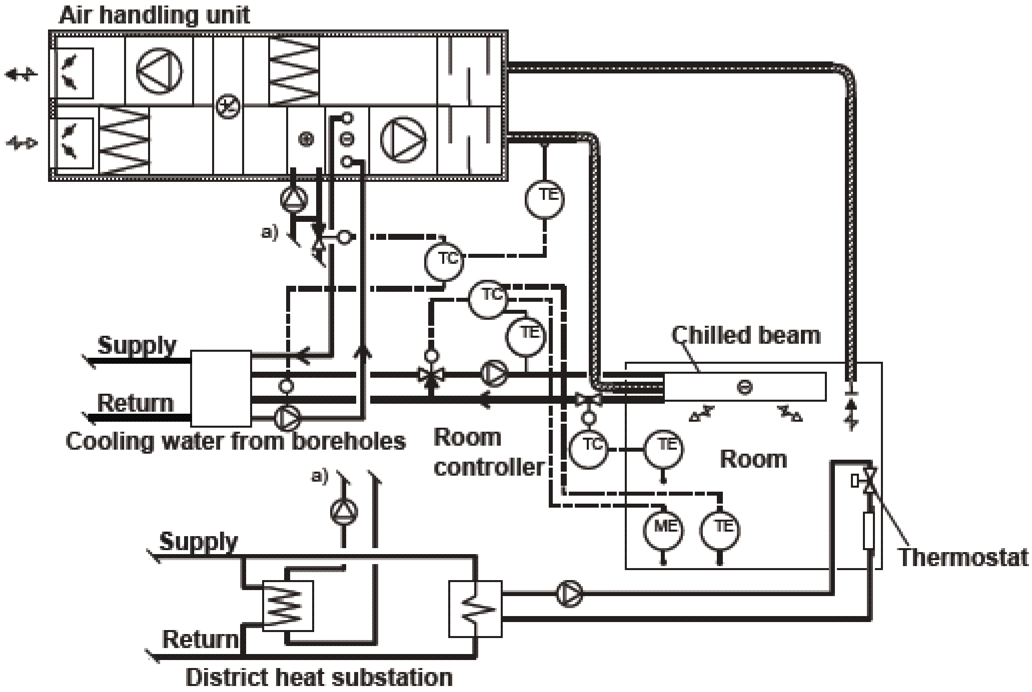

FIGURE 8. Ventilation system of Centre building Ympäristötalo /10, p.45/.

Every room has a chilled beam. In cellular office rooms active chilled beams are used, open plan office rooms and other rooms have passive chilled beams. Passive chilled beams cool down the building during night, what reduce peak cooling demand. All rooms are heated with water radiators. Ventilation air flow is constant in offices and variable in meeting rooms, lobbies and workshop area (controlled with CO_2 and temperature sensors). /10, p.49./ Energy performance of the building can be seen from the table 10.

TABLE 10. Simulated energy performance of the building. All specific values are per net floor area /10, p. 45/.

	Net energy need, kWh/(m^2 a)	Delivered energy, kWh/(m^2 a)	Primary energy factor	Primary energy use, kWh/(m^2 a)
Space and ventilation heating	22,6	32,2	0,7	22,6
Hot water heating	4,7	6,1	0,7	4,3
Cooling	10,6	0,3	1,7	0,5
Fans and pumps	9,4	9,4	1,7	16
Lighting	12,5	12,5	1,7	21,3
Appliances (plug loads)	19,3	19,3	1,7	32,7
PV power generation	—	-7,1	1,7	-12
Total	83	73		85

On-site renewable energy production: PV power generation 7,1 kWh/(m^2 a) + free cooling from boreholes 10,6 kWh/(m^2 a)

6.5 Sweden

The last example of nZEB comes from northern climate as well. It is a building Hagaporten III in Solna, Sweden. It was finished in 2008 and emits half the amount of conventional office building in Sweden. /11, p. 89/

Natural lighting is utilized as much as possible in the building. Façade of the building is made of glass and there is a well for daylight in the centre of the building. Windows have respectively low G – value to make cooling demand in summer low./11, p. 91./ Properties of the building envelope can be found in table 11.

TABLE 11. Building envelope data /11, p. 89/.

Window U-value	1,4 W/(m^2 K)
Window g-value	0,4
Exterior wall U-value	0,32 W/(m^2 K)
Roof U-value	0,13-0,15 W/(m^2 K)
Air tightness	0,5 l/(s m^2)

District heating and cooling are used as sources of energy, because their efficiency is higher compared to local systems. District heating is provided with wastewater treatment and combustion of wood briquettes. Cooling energy to the grid is taken from Baltic Sea and chillers. /11, p. 90./

Three AHU for offices with volume flow 13 m^3/s each provide sufficient ventilation for the building. One more AHU with heat recovery with volume flow 8 m^3/s is used on kitchen Face velocity in AHUs is as low as 1,6 m/s. There is a pre-heating coil connected to chilled beams, so heat removed with chilled beams stays into the building. Efficiency of the coil is 69%. For further air treatment district cooling or heating is used. Air flow is constant. All the measures let achieve comparatively low SFP value 1,4 kW/m^3. Low face velocity allows not using sound attenuators because they are not necessary. /11, p. 91./

Exhaust air from offices flows through garage as supply air for garage. Exhaust air from the garage is equipped with run around heat recovery. /11, p. 91./

Pressure in the ductwork is kept constant with fans’ round speed. Pressure in ducts is 100 Pa, pressure dampers are not used, needed air flow in rooms is provided only with air terminal units and chilled beams. /11, p. 90./ Measured energy consumption can be found in table 12.

TABLE 12. Simulated and measured energy performance of the building. All specific values are per net floor area /11, p. 92/.

	Delivered energy target (simulated), kWh/(m^2 a)	Measured delivered energy, kWh/(m^2 a)
Heating	39	43
Cooling	26	18
Service power (excluding lighting and tenant power)	20	17
Process cooling	—	12
Tenant power	—	53
Total	85	143

7 SAVING POSSIBILITIES IN HVAC-SYSTEMS ENERGY CONSUMPTION IN NORTHWESTERN RUSSIA

7.1 Ventilation

As ventilation is integral part of sustainable office building with good indoor climate, a thorough discussion of its saving potential is needed. All the components of the ventilation system should be chosen on criteria of Life Cycle Costs (LCC) instead of first cost criteria.

On the LCC basis the best decision is to install AHU with low face velocities e.g. 1,5 m/s, velocities in ducts should be kept low as well, and with lower pressure losses of components. To prevent impact of thermal forces on ventilation system, pressure losses can’t be too small (something like 100 Pa). These measures decrease pressure losses and, as a result, energy demand of ventilation system.

Nearly 40% of energy is consumed by fans. That is why they have to have high efficiency. In general it means that all components of fan assembly (impeller, motor, variable frequency drive and so on) should have high efficiency. There are EC motors

(motors powered by direct current) with integrated variable frequency drive (VFD) available on the market. These EC motors should be used where possible, otherwise AC motors with external VFD should be used. These motors let reduce motor speed when less air flow is needed and can be adjusted with the automation, the adjustment saves energy. /12, p.26./

Backward curved centrifugal fan without casing is the best option for installing in AHU. Despite fan with casing has a little bit higher efficiency, inappropriate installation inside the AHU affects its efficiency significantly, that is why option without casing is preferable. /12, p.23./

Size of the fan is right if its operational point is as close as possible to highest efficiency with the least energy consumption of motor.

As variable air volume (VAV) systems let reduce volume flow and thus save energy they should be used if occupation varies much. It is a good idea to use those in meeting rooms or other spaces, where presence of people changes during the time. To choose the right fan for those systems can be a difficult task for designer. When choosing such fan not only the worst conditions (biggest air flow) of operation should be taken into account but part load with its duration as well. The biggest flow is needed very short period of time in such systems, that is why highest efficiency of the fan shouldn't be achieved with the biggest air flow. Highest efficiency of the fan should be achieved with the most common air flow. Fan must be available to provide maximum air flow as well. Also when fan operates at the part load it starts to rumble. This kind of noise is difficult to silence. /12, p.26./

In VAV systems it is better to choose duct sizes not according to constant pressure losses, like it is done traditionally. Sizing for a final pressure drop in VAV systems is preferable. In this method ducts of one size are used on each floor, so at the end of the duct dynamic pressure converts to static. Flexibility to changes during operation periods is better in this case. Total pressure losses are smaller in this case and for air flow adjustment only terminal units are used. /12, p. 67./

Another important value to take into account is specific fan power (SFP). SFP shows how much electric power in kW is needed for the fan or system fans to deliver 1 m^3/s of the air through the system. Not long ago usual SFP value was rather high 4-10 kW/(m^3/s), it had been dramatically going down to 2,0 kW/(m^3/s) during couple of years If SFP is low enough it ensures good design of the system. This SFP value is used to prevent installation of too small AHU with high energy consumption. According to Finnish regulations SFP shouldn't be more than 2 kW/(m^3/s), but it is better to have lower SFP value, for example, in a range 1,3-1,5 kW/(m^3/s).

7.1.1 Centralized mechanical ventilation with heat recovery

In one of four case studies there was not centralized ventilation system with heat recovery. It is not reasonable to do such systems in Nordic countries because heat recovery unit (HRU) saves at least 50% of thermal energy used for air heating and cooling. There are four common types of heat recovery units, which are in use now. They are run around heat exchanger, plate heat exchanger and rotating wheel heat exchanger. All those types can be seen on figure 9 below.

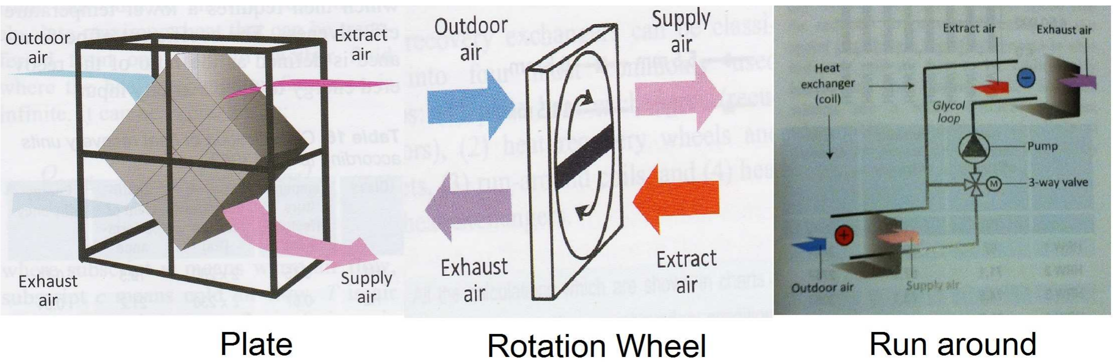

FIGURE 9. Different types of heat recovery heat exchangers. /12, p. 44-49/.

The most efficient HRU is rotating wheel heat exchanger. It also transfers moisture to the supply air from the exhaust. There are following types of rotating wheel heat exchangers: condensation heat exchanger, hygroscopic heat exchanger, sorption heat exchanger. Main difference between them is moisture transfer method. The first and second heat exchangers transfer moisture only when condensation occurs in exhaust air. The third type has special covering which allows transferring moisture all the time with high effectiveness. Also sorption wheel heat exchangers are good to use because there is no need to stop HRU or use some special equipment for defrosting of the HRU, and frost protection decreases total efficiency of HRU and ventilation system in general. HRU is worth using because it is easy to control and regulation of supply air temperature is simple. /12, p. 41-51./

When there is no possibility to use sorption wheel heat exchanger, like in hospitals or other places where leakages from exhaust to supply are not permitted, any other type of heat exchanger with high effectiveness can be used. To remain total efficiency of the system high, pre-heating with ground heat exchanger or with ground water can be utilized.

7.1.2 Pre-heating and pre-cooling with ground heat exchanger and ground water

Pre-heating with the ground heat exchanger is a good idea for preventing freezing of heat recovery. When frost protection is not needed ground heat exchanger helps to save energy for heating of incoming air. In summer time air is cooled down in heat exchanger, what covers small part of cooling need for supply air /13/. Additional costs are rather low comparing to saving potential. What needed is a pipe for air buried in the ground and some extra watts of power from the fan to make the air run through the pipe.

As everything, the ground heat exchanger has its pros and cons. Pros are obvious. Cons are possibility for moisture condensation and accumulation, it promotes microbes and bacteria growth, and radon can come into the ventilation system through the pipe. There are solutions for these problems, but as health and comfort of the occupants are of the highest importance, it is better to use pre-heating and pre-cooling with ground water or pipes buried in the ground in which water-glycol mixture is circulating. The choice depends on ground water availability.

Pre-heating and pre-cooling with a ground water prevents HRU freezing and covers some cooling demand without any risks for occupants, but bigger investments needed, like pumping ground water and digging down to water.

7.2 Cooling

There are different ways to remove surplus heat from the room. They are cooling with supply air, using of active and passive beams, floor heating and cooling, chilled ceilings and thermal active building systems.

Cooling with supply air was used for many years and is still popular. It is not good from the economical point of view. To remove excessive heat air flows are made bigger so ventilation system consumes more energy. Occupants can easily feel draft with enlarged air flow of a lower temperature. This way of removing surplus heat is not recommended.

Chilled ceiling is pipes with chilled water suspended between concrete slabs and ceiling. See figure 10 below. Pipes are not inside concrete like in thermal active building system described below. Typical cooling output 50-70 W/m^2. It doesn't consume a lot of energy, and doesn't cause any draft. Temperature of water can be rather high, so it is suitable for free cooling. Condensation is possible in this case, so temperature must be kept above dew-point. Chilled ceiling is slow to adjust. Noise is possible. This is not the best option to choose. /11, p. 44./

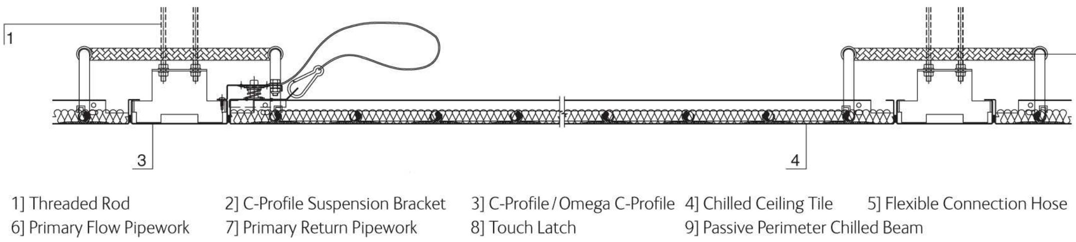

FIGURE 10. Chilled ceiling /14/.

Thermal active building systems (TABS) are pipelines or ducts embedded into concrete slab. The system is shown on figure 11 below. TABS don't differ greatly from chilled ceiling but their advantages are decrease of peak cooling/heating demand as thermal inertia of the building is utilized. Low/high temperature heating/cooling is easily done with TABS, so they are working well with heat pumps. There are risks of condensation poor sound performance, pipes can't be replaced after installation, reaction to changes is very slow. Floor heating and cooling are also very slow. Comfort of occupants can't be ensured. /11, p. 45./

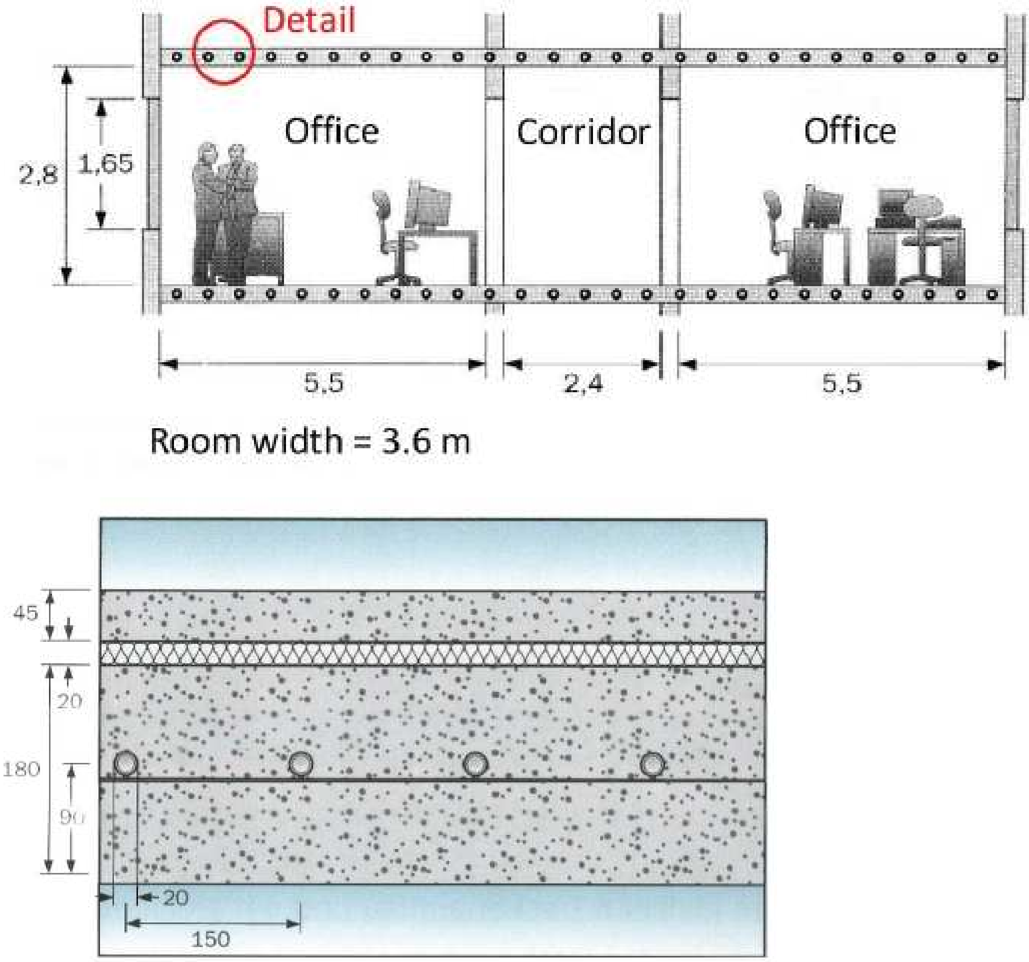

FIGURE 11. Picture of Thermal Active Building Systems /15, p. 25/.

The best decision for cooling in nZEB offices is combination of active and passive chilled beams. In this case quiet and draught-free operation is guaranteed. Usage of free cooling and heat pump with high coefficient of performance is possible. Passive beams reduce peak loads operating during the night. Condensation must be prevented. /11, p. 46./

7.2.1 Solar shading

Solar gains do not depend much on geographical location of the building /12, p. 94/. They are main cause of cooling need in summer. At the same time, solar gains during winter reduce heating load, and should be used. So, solar shading is an important task for nZEB designers and architects. To reduce solar gains screen or sun blinds for windows can be used. Sun blinding for windows provide more comfort, because they could be adjusted according to weather, season and occupant's wish.

G-value is the main criterion for assessment of solar shading effectiveness. G – value is a share of thermal energy coming through panes and shading.

Solar shading installed on the external side of window has the lowest G – value. But it has to bear difficult weather conditions, so it can often be broken, repair or replacement can be expensive. Installation of solar shading inside the room is almost useless, because shading is heated up by radiation and then transfers the heat to the room by convection and radiation. Installation of shading between two panes is somewhere in the middle, but the most reasonable way is to install solar shading between one pane and double glazing. This option gives low U-value, occupant's satisfaction and prevent excessive solar gains. /12, p. 98./

7.2.2 Free cooling

Free cooling in this case means use of cold water from the ground in different HVAC-systems. It will be discussed further. Also use of ambient air in winter to cool down water in water chillers systems can be called free cooling. As there are no cooling needs in northern climate, it won't be discussed here.

The example from Helsinki shows that it is possible to cool down office building in Nordic climate with free geothermal energy stored in ground water. Capital costs are not big for the system, because only boreholes of necessary capacity, piping and pump are needed. The most expensive part is borehole, because digging of a deep well can cost a lot, but small operational costs and saving potential is great. Water from borehole can be used in pre-cooling of ventilation air in summer and for pre-heating in winter, in active and passive chilled beams, underfloor cooling, ceiling cooling or thermal active building systems.

Free cooling with additional ventilation at night can help to reduce peak loads. It can be done with natural ventilation or natural ventilation assisted by mechanical ventilation. For natural ventilation special openings, controlled by automation should be used. Automation should close the openings when temperature becomes too low. Use of passive chilled beams seems to be enough for decreasing peak load. So natural ventilation at night should be used if passive chilled beams are not utilized.

7.2.3 Absorber cooler

Absorber cooler is a cooling device which doesn't need electricity for compression, only thermal heat. Its operation is based on evaporation cycle. There is Lithium-Bromide water solution which absorbs water, evaporating water causes temperature decrease, when temperature of the solution is increased, and the solution releases previously absorbed water. Water pump is needed to provide water circulation, its electricity consumption is low comparing to cooling output, so it can be negligible.

This technology allows provide cooling with solar heat or excessive heat of mini-CHP in summer. The second option is a so-called tri-generation, which allows increasing efficiency of the system and reducing CO_2 generation.

8 ON-SITE ENERGY SOURCES

There are several possible sources of on-site energy. They are heat pump, mini Combined Heat and Power Production Plant (mini-CHP), solar energy, energy of wind and district heating and cooling. /11, p. 63./

8.1 Heat pump

Heat pump is a device that transfers thermal energy from a heat source to heat sink, but temperature of heat source is lower than temperature of heat sink. The operational principle of heat pump is compression cycle. To run the cycle electric energy is needed. Efficiency of heat pump is produced thermal power to electric power ratio, where thermal power is output of condenser and electric power is power consumed by compressor. Efficiency of heat pump is called coefficient of performance (COP) and depends on temperatures of condensation and evaporation. As outdoor temperature changes all the time, evaporation temperature has to be changed as well. So efficiency of heat pump changes during its operation. To assess average efficiency during operation seasonal COP is used, which is all heat, transferred in the course of some period divided with supplied electricity during the same period of time.

Air-to-air heat pump uses ambient air as a heat source and heats up air in the room. Air-to-water heat pump uses ambient air as a heat source and heats up water circulating in a heating system. As outdoor temperature varies a lot COP of these types of heat pumps fluctuates in a wide range. Efficiency is low if outside temperature is below 7°C /11, p. 66/. In Russian climate it doesn't make any sense to use this kind of heat pump, because in heating period temperatures are most of the time lower than 7°C.

Ground source heat pump uses energy stored in soil or ground water and transfers it to water in heating system. Outdoor temperature affects its efficiency, the lower outdoor temperature, the lower coefficient of performance is, but temperature of soil or ground water changes much less and temperature difference is small during the year. This type of heat pump works well even with low temperatures, so it is suitable for Russian climate. Seasonal coefficient of performance (seasonal COP) or seasonal performance factor (SPF), which is the same, is somewhere between 3 and 3,5, so it produces 3,5 times more thermal energy than consumes electricity. This kind of power production can be recommended for use in sustainable office.

8.2 On-site combustion

Energy can be produced on site with so called mini-combined heat and power production plants (mini-CHP). Mini-CHP is a system, where fuel is burnt and released energy of fuel is converted to electric energy and thermal energy. Power output of such systems is in the range from 1 kW to 50 kW, and thermal power will be nearly twice as much. There are several possible technologies to be used in mini-CHP, like internal combustion engine, stirling engine, steam or gas turbines, but mainly internal combustion engines are used.

Stirling engines are used in small cases, as they are more suitable for one family house or other buildings with low electric power demand. Stirling engine is an external combustion engine, in with volume gain of gas or liquid with temperature is used for piston movement. To run the engine any kind of heat source is possible to use and any heat sink is needed. Engines of this type were known in theory as many internal combustion engines, but they have started to be used comparatively recently. Existing examples must be developed a lot, because their efficiency is far from desirable now. Potential of technology is great, because any kind of heat can be used.

Mini-CHP is a good option if constant generation of electricity and heat needed, because it should operate sufficient hours to be cost effective and have acceptable payback time /16/. A possibility to use renewable bio-fuel, e.g. wastes of stutter house, makes this option attractive from ecological point of view. Mini-CHP combined with absorber cooler has better annual efficiency, because excessive heat from CHP would be used for cooling spaces. As mini-CHP is installed on site, so many transmission losses, which can be very high, but efficiency of it is lower than efficiency of bigger scale plants. This option is attractive when grid connection is not done.

8.3 Solar energy

Nowadays solar energy is used for short –term heat accumulation and electricity production. Heat accumulation is done with water or other fluid going through the pipes. Temperature of the fluid increases. Accumulated thermal energy is used for domestic hot water (DHW) production, and space heating. Also absorber cooler can run with solar heat.

Most common way to get electricity from solar energy is photovoltaic (PV) panels. Now there are possibilities of using solar energy as a heat source for stirling engine For electricity production. It is difficult to say whether it will work well or not, bu this concept is being developed now.

Solar power production in Russia doesn’t seem to be efficient enough, due to big investment costs of solar panels, low price for electricity (comparing to Europe) and comparatively low amount of sunny days in the region discussed. But as prices are more about policy of government, so it is a good way to produce energy without harming the environment. Some discounts or tax remissions should be used by government to promote it.

8.4 Wind energy

Windmills allow transform kinetic energy of the wind to electricity. This system is rather common in Germany or Holland, and big wind power station are done in regions where strong wind is often.

High investment costs, great fluctuation of electricity production and long payback period make wind generators not attractive to building owner in Russia or even Finland.

8.5 District heating and cooling

District heating doesn't require any investment costs from the customer if the system has already been built. It is reliable, doesn't require any maintenance costs and efficiency of the system is high. To provide all these convenience great amount of work should be done. District heating needs developed infrastructure, so this kind of systems is not always available. If heating demand is low, share of fixed fee becomes too high and district heating becomes expensive for the customer. To sum it up, district heating and cooling is suitable for low energy buildings in general and offices in particular, it can be used if available and economically reasonable.

8.6 Summary

At first site ground source heat pump, district heating and mini-CHP are left for climate in question. If primary energy factor is taken into account, then to deliver same amount of energy for space heating less primary energy will be consumed with ground source heat pump than with district heating. It is true for Finnish primary energy factors, it a question of policy again. So if primary energy factors are changed the situation can be vice versa. On one hand, efficiency of mini-CHP varies a lot from manufacturer, it is impossible to choose any particular value, but efficiency of district heating is higher. On the other hand mini-CHP lets use renewable fuel, what is very important is nZEBs, when fuel for district heating can't be chosen by customer. So heat pump is a preferable option for office building in Russia, where electricity price is lower than in Finland. If heat pump can't be used for some reason, mini-CHP with renewable fuel is better in that case.

There is a problem. Electricity in Northwestern part of Russia and in Finland is mainly produced on Combined Heat and Power (CHP) production plants. The co-generation is a key-factor for the plant's high efficiency. So if everybody will change district heating for heat pump, then efficiency of the system will be low. If electricity is produced on hydroelectric power plant, then heat pump is better, but when electricity is produced on CHP, district heating must be used in some buildings.

As wind and solar power generation units are expensive, payback period is likely to be very long, but this kind of systems can be utilized to provide renewable energy use, which is necessary due to nZEB definition. But in case of solar and wind energy production its usefulness is a question of tariff policy. Environmental-friendly ways of energy production are still require additional investments. The lower the prices for energy from the grid, the longer pay back period, the less people use those. Not energy prices should grow but special governmental policy should be used to promote harmless ways of energy production.

9 BUILDING SIMULATION

To check that nZEB building is possible in Russia energy consumption simulations were done with IDA ICE 4.0 software. Two storeys building located in Saint-Petersburg was simulated with different U-values (table 13) and HVAC-systems efficiencies (table 14). In this case both U-values and efficiencies are just estimations, done basing on average values and cases studied during this work. Exterior of the building is shown on figure 12. Cases with and without solar shading were done. The results of simulations are given in table 15 and 16. Finnish primary energy factors were used in primary energy calculation, values for them can be found in chapter 5 table 1.

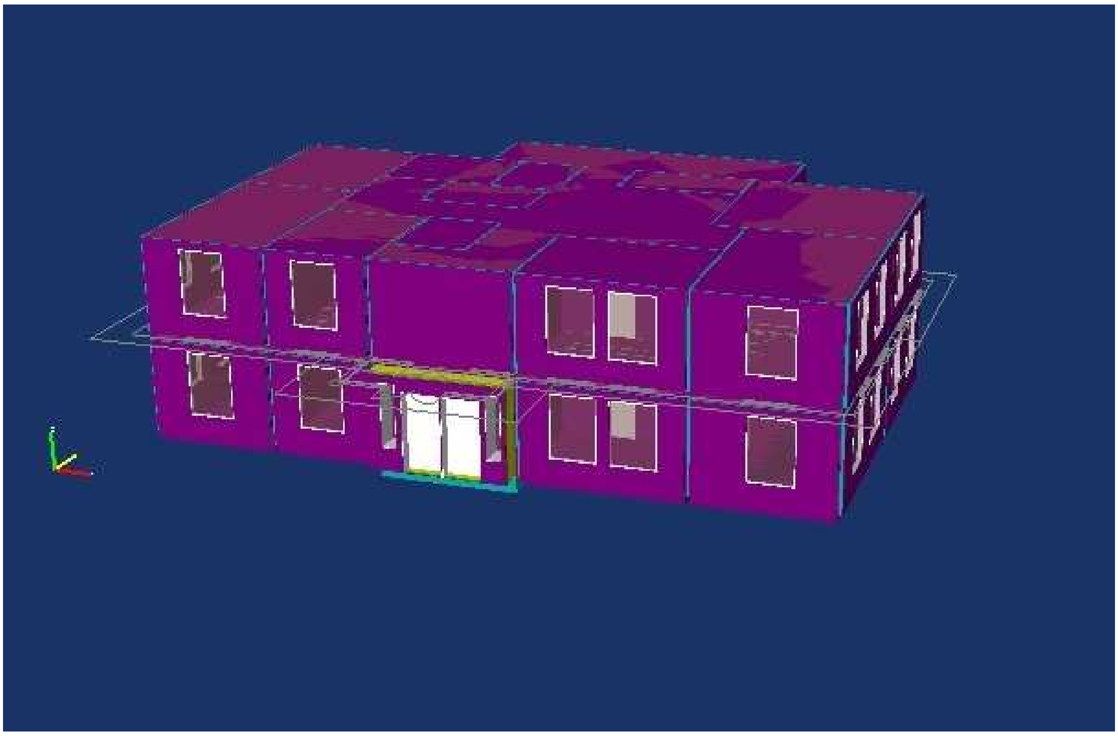

FIGURE 12. 3D view of simulated building.

For energy calculation ASHRAE climate data was used, available in IDA ICE 4,0 software. Floor area of the model is 350,9 m^2, volume is 888,4 m^3, ground area is 177,4 m^2, area of envelope is 647,0 m^2, share of glazing is 9,7%. Occupants are present from 7 a.m. to 6 p.m.

TABLE 13. Building envelope properties.

Envelope element	1 case	2 case
Exterior wall, W/(m^2 K)	0,09	0,08
Base floor, W/(m^2 K)	0,19	0,07
Roof, W/(m^2 K)	0,09	0,08
Window, W/(m^2 K)	1/0,55	0,6/0,2
Solar shading (U-value multiplier/g-value)	0,87/0,39	0,87/0,39
Entrance door, W/(m^2 K)	0,75	0,70
Air tightness(q_{50}), m^3/(h m^2)	4	2
Average U-value, W/(m^2 K)	0,23	0,17

TABLE 14. HVAC-systems performance.

	Initial	Improved
Heating COP	3,1	3,5
Cooling COP	6 (free cooling)	7 (free cooling)
DHW COP	2,3	2,6
HRU efficiency/ temp. limit	60%/1°C	90%/-26°C
Pressure	600 Pa	100 Pa

TABLE 15. Results of simulation.

	Primary energy, kWh/m^2	
	U-value case 1	U-value case 2
Building in question in St.-Petersburg climate	151,0	142,7
Solar shading between panes added	149,7	140,7
HRU improved	—	129,1
Pressure improved	—	112,5
Heat pump performance improved	—	108,7

TABLE 16. Simulated energy use.

	Delivered energy		Primary energy	
	kWh	**kWh/m^2**	**kWh**	**kWh/m^2**
Lighting, facility	7854	22.4	13352	38.1
Equipment, facility	7854	22.4	13352	38.1
Cooling	411	1.2	699	2.0
HVAC aux	1134	3.2	1928	5.5
Heating	4153	11.8	7060	20.1
Domestic hot water	1037	3.0	1763	5.0
Total, Facility electric	22443	64.0	38154	108.7
Total	22443	64.0	38154	108.7

From the results it is clear, that cooling need in Russian climate is rather low, unlike in Central Europe. Architects and designers meet different challenges. Also, share of lighting and occupants' equipment in energy consumption becomes significant. HRU and pressure losses in ventilation system had the biggest effects on energy performance of studied building. So these two should be cared a lot.

Primary energy consumption is rather high in this case, because share of lighting and equipment is significant. But heating demand is low in these case, and if lighting and equipment were changed to better one, than the building would achieve nZEB requirements.

To sum up, it seems to be possible to make nZEBs in Russia, but they will consume more energy than in countries with softer climate. That is why use of renewable source in a scale of whole country should be developed, especially taking into account availability of hydroelectric resources.

10 CONCLUSION

First of all, construction of nearly Zero Energy Building in northwestern climate is possible. To make a nZEB office in northwestern part of Russia, airtight envelope with low U-values of building envelope elements is needed to provide low heating demand.

Ventilation with heat recovery unit has to be used. Sorption wheel heat recovery unit is the best option due to its high efficiency and frosting free operation, if it is not possible other heat recovery unit with high efficiency and pre-heating with ground water should be used. Air handling unit with SFP = 1,3 – 1,5 should be used to ensure low pressure losses and low energy consumption in fan motor. Fan size should be chosen correctly, Variable air volume systems should be used in rooms with non-constant occupation when possible. Final pressure drop duct dimensioning should be used.

To provide good indoor climate in summer, free cooling with cold ground water should be used. Much attention should be paid on solar shading to prevent additional cooling load. Combination of active and passive chilled beams should be used for providing low energy consumption and occupants' comfort at the same time.

Question of energy to be used is rather difficult because tariff policy of government plays an important role here. Nowadays heat pump seems to be the cheapest option as price for electricity is rather low in Russia and Finland. Energy for space heating should be taken from ground source heat pump when possible; otherwise mini-CHP with renewable fuel should be used. Heat pump has high efficiency and geothermal energy used in heat pump is renewable. Use of renewable energy is compulsory condition in nZEB concept.

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