CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF CIVIL ENGINEERING

DEPARTMENT OF MICROENVIRONMENTAL AND
BUILDING SERVICES ENGINEERING

BACHELOR PROJECT

Heating and ventilation system design for villa house

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BACHELOR´S THESIS ASSIGNMENT FORM

I. PERSONAL AND STUDY DATA

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Study - Renewable energy sources for villa house

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Klaus Daniel: The Technology of Ecological Building : Basic Principles, Examples and Ideas. ISBN 3764354615.
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III. ASSIGNMENT RECEIPT

I declare that I am obliged to write the Bachelor Thesis on my own, without anyone's assistance, except for provided consultations. The list of references, other sources and consultants' names must be stated in the Bachelor Thesis and in referencing I must abide by the CTU methodological manual "How to Write University Final Theses" and the CTU methodological instruction "On the Observation of Ethical Principles in the Preparation of University Final Theses".

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Declaration

I do solemnly declare that I have written the presented research thesis by myself without undue help from a second person others and without using such tools other than that specified.

Prague, 20.05.2019

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Kristina Kubicova

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I would like to thank the supervisor of my bachelor project doc. Ing. Michal Kabrhel, Ph.D. for help and support, as well as priceless advices during my work. Special thanks to the owner of ModernDream Design s.r.o., who kindly provided me with initial project documentation.

Contents

Abstract

This bachelor project is focused on the topic of designing heating and ventilation systems for the villa house in Novy Vestec, Czech Republic. The practical part primary consists of necessary computations and system layout design, as well as designing suitable technical elements for the ventilation and heating systems. The theoretical part includes the study of three main types of renewable energy sources, suitable for private family houses. The goal of study is to review the possibilities of renewable energy sourced power generating systems and look at the positive and negative aspects of each from practical point of view.

Keywords: *renewable energy sources, solar, biomass, geothermal, heating system, ventilation system, gas condensation boiler*

Abstrakt

Tato bakalářská práce je zaměřena na problematiku navrhování systémů vytápění a větrání pro vilový dům v Novém Vestcí v České republice. Praktická část se skládá z nezbytných výpočtů a návrhu dispozičního řešení systému, jakož i navrhování vhodných technických prvků pro ventilační a vytápěcí systémy. Teoretická část zahrnuje studium tří hlavních typů obnovitelných zdrojů energie vhodných pro rodinné domy. Cílem studie je přezkoumat možnosti systémů získávání energie z obnovitelných zdrojů a porovnát pozitivní a negativní aspekty každého z praktického hlediska.

Klíčová slova: *obnovitelné zdroje energie, solární energie, biomasa, geotermální energie, systém vytápění, větrací systém, plynový kondenzační kotel*

Renewable energy sources

Introduction

For the last couple of decades sustainability has been spreading the world as a big trend, penetrating into all possible aspects of our lives, from environmental to business, technology, politics and economics. Civil engineering and construction are not an exception. New technologies and innovations are being developed for building materials and construction processes in order to build better, more energy-efficient, environmental friendly buildings. New residential buildings and especially private residential houses are being build under slogan sustainable, energy effective , low-energy , passive, green.

The use of renewable energy sources has as long history as the existence of humanity itself. However, recently the interest in renewable energy sources has considerably increased. During past decades the new generation of buildings has evolved the way, that they need nearly one tenth of the amount of energy of a regular building, in order to provide better comfort. The issue with the fossil fuels, which are nowadays primarily used to produce an enormous amount of energy to heat and cool our buildings, is well known. That includes carbon and other dirty emissions, which results into poor air quality and environment pollution, not to mention the exhaustibility and increasing prices of the fossils. Therefore, the goal is to reduce the environmental impact and costs for household energies by switching to renewable energy sources.

The following graphs with the statistic data, provided by the International Energy Agency (IEA), are showing the development of renewable energy and waste in heat generation worldwide in period 1990 - 2016, and illustrate the share of the renewable energy sources in heat generation for year 2016. The provided statistic data serve as a proof, that during last two decades people have significantly increased the amount of energy, produced from alternative sources, and though the largest share belongs to the industrial and municipal waste, the use of renewable energy sources has been also scaling up.

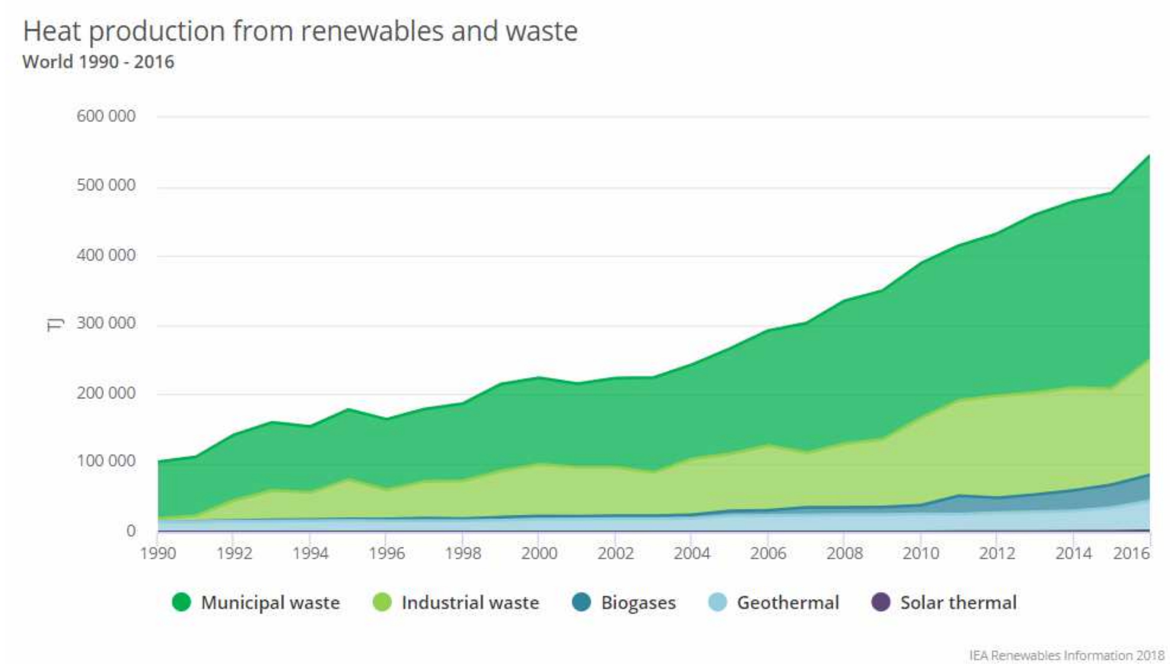

Figure 1- Heat production from renewables and waste

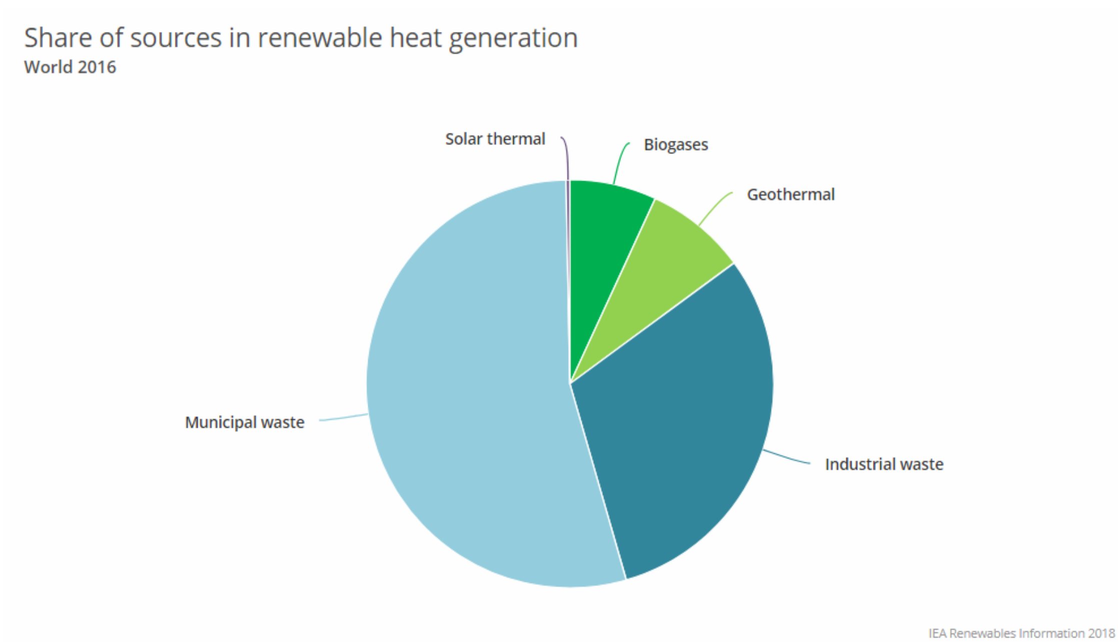

Figure 2 – Share of sources in renewable heat generation

According to the most common definition, renewable energy is the energy produced by using a resource that is quickly replenished as a result of a natural or naturally incessant process. It is potentially inexhaustible, though the amount of energy available per time unit is limited. It includes solar, wind and water energies, biomass, heat accumulated in the earth, air or water.

Further paragraphs will specify the renewable energy sources, that are applicable for household heating system, cover the underlying concepts, describe the principle of obtaining energy, conclude positive and negative aspects of each in terms of environmental and practical point of view.

Biomass

Biomass is an organic material, produced from agricultural residues, forestry and organic wastes or energy corps, which were grown for this purpose specifically. There are two ways to produce the energy from the raw materials: direct combustion or further processing into energy products, such as biogas, biodiesel or bioethanol. The last are mostly used as a transportation fuel.

In terms of a household application of biomass for heating and hot water preparation purposes, the dry process – combustion – is commonly used. That makes wood and other related materials, like pellets, wood chip and wood logs, the most popular raw material for this type of heating system.

The classic way of using wood as fuel is logs, and though nowadays there are various types of convenient low-emission wood log boilers and stoves, the better alternative for the medium and large boiler systems is wood chip. The main reason behind, is that logs are simply more difficult to transport, store and refill to the system, which requires quite lot of manual handling. Chip boilers are better to use in a larger scale (from 30kW, the best 200kW and more). For example, in Finland some pedestrian streets in the shopping area of the downtown are warmed up by the chip-based system. The pellet-based system is, therefore, the "winner" for the domestic usage. From the practical point of view, thanks to the small size, pellets are easier to store and transport, moreover some units with the advanced system allow to use automatic loading to the system. They are dry and dense, they easily ignite, and they produce less ash and emissions, in comparison with wood chips and logs. Basically any clean wood by-product can be used to produce the pellets, most popular source is the sawdust from the sawmills.

The wood pellet stove system with a back boiler is the most suitable option for the domestic or small commercial building usage. In this scenario only 20%-60% of the heat will be available for distribution by the hot air fan, the rest heat load will be taken over by a boiler and distributed through the pipes to the heating bodies or underfloor heating system, or simply to the taps with hot water. This type of system is very well compatible with the radiant floor heating.

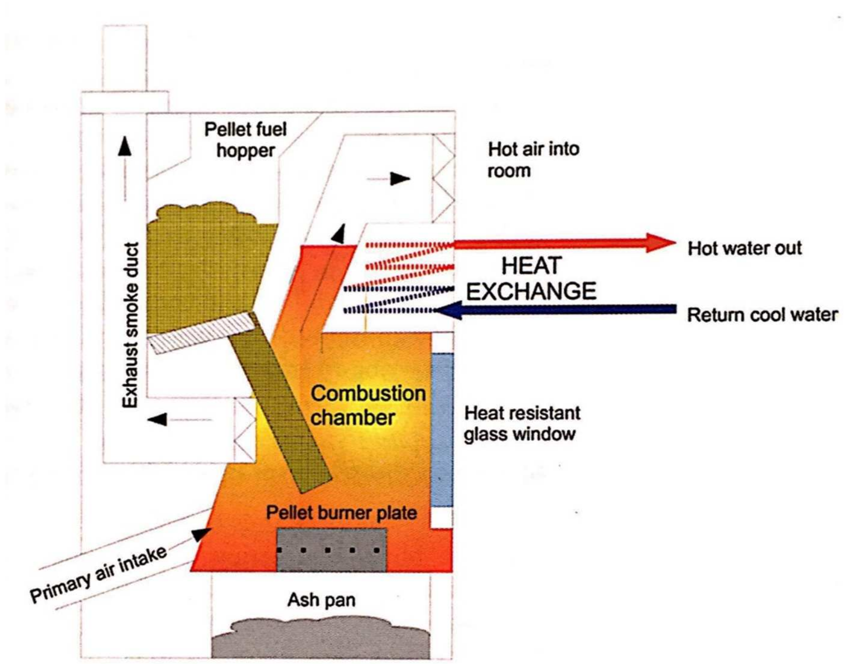

Figure 3 – Diagram of wood pellet stove with back boiler

Wood pellets, that comply with EU standards, are called virtually carbon-neutral, as the CO2 production from burning biomass is mostly balanced out by the CO_2 consumption through biosynthesis, while growing the energy corps for biomass. However, the system still contributes to the air pollution, and it is not the most convenient due to necessity to transport, store, fill up the pellets, and do some periodical cleaning (empty the ash pan).

Solar energy

Solar energy is a radiation from the sun in a shape of light and heat. There are two ways, how this energy can be collected – passive and active.

The passive solar contribution was known since ancient Romans, when they used large glazed south-facing openings for heat gaining in winter. Nowadays, passive way of obtaining solar energy can be used for the house heating purpose, however it requires specific conditions for it to be efficient. This system is based on following principle: the solar gains have to be bigger than the heat losses. To achieve the effectiveness of passive solar contribution, the structure should be air-tight and highly insulated, with large superior glazed windows, with more than half of facades south-oriented, with heat recovery mechanical ventilation. The experience and research results however prove, that passive solar method is not effective in the areas, where the outdoor temperature can vary around 0 °C, as even high-performance south-oriented windows are not able to keep more of solar gains, than the heat losses of the building. The energy amount, required for heating and hot water preparation is enormous in comparison with what the passive solar energy can contribute. That is why passive method is primary used in a combination with other energy source, for example geothermal heat pump, biomass or gas boiler.

The active solar system is more efficient, as under certain conditions it is able to cover up to 50% of the total amount of energy, required for hot water preparation in the house. Though in case of both heating and hot water preparation, the energy demand is out of solar thermal system capacity, and it is necessary to use some backup energy source.

The active solar contribution implies using special equipment, such as photovoltaic panels or solar collectors. Effectiveness of both depends on several aspects, those include location of the installation, orientation with respect to cardinal points, the inclination and exposure to the sunlight. Important also the climate conditions of the area, as it determines the length of the heating season.

In comparison with solar heating system, the PV panels (photovoltaic panels) convert solar energy directly into electrical energy. Different semiconductor materials inside the PV cell each absorb different spectrum of sunlight. The typical PV semiconductor is made of pure silicon, which are purposely produced with specific impurities, as it increases the ability of material to conduct electricity. The current flow is created between the positive and negative conductors, due to big amount of free electrons on negative-charged side, which the positive-charged side is accepting. That way the concentration gradient is being created, which makes two semiconductors create the electric field.

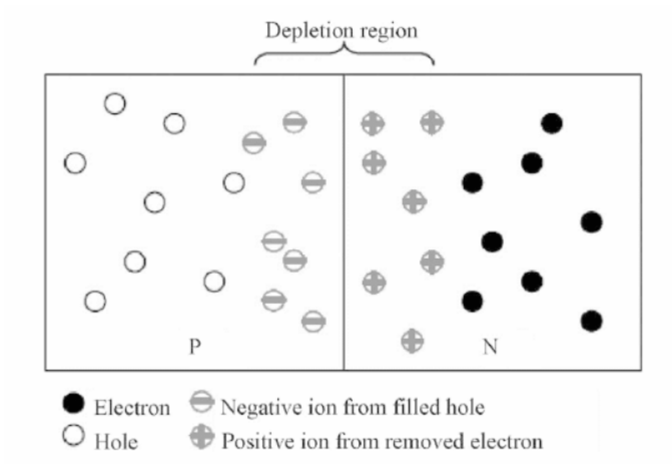

Figure 4 – Electron hole migration

The PV cells are assembled into modules, and several modules already compose a PV array, which we meet in every-day life being installed on the buildings' rooftop or integrated into a portable electronic device. PV systems are still in the research stage from the efficiency point of view, as they do not have a high capacity in harnessing the solar energy. In addition the production is pretty costly and demanding.

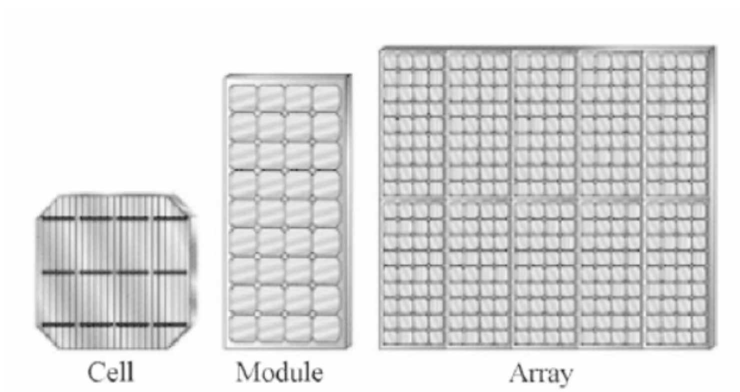

Figure 5 – Solar cell assemblies

Solar collectors harness the solar energy and convert it into usable heat. Those can be divided to covered absorber collectors and uncovered absorber collectors, as this factor influences the performance of the system.

FPC (flat-plate collectors) and ETC (evacuated tube collectors) are typical examples of covered solar collectors. During high temperature levels the transparent glazing causes the reduction of thermal convective exchange, making the system more efficient. Therefore, FPCs and ETCs are suitable for providing heating and hot water preparation for the house with no need for a heat pump in summer period. Thanks to superior insulation and possibility to rotate tubes individually to ideal absorber inclination angle , ETCs have very low heat losses and are able to produce heat even during the winter period, when the sun radiation is lower.

UC (unglazed solar collectors) have the simplest design. Absence of glazing results into large solar gains, and at the same time high convective heat exchange, making it not so effective during high temperatures. However, during the lower temperatures above mentioned features increase the performance of the collector.

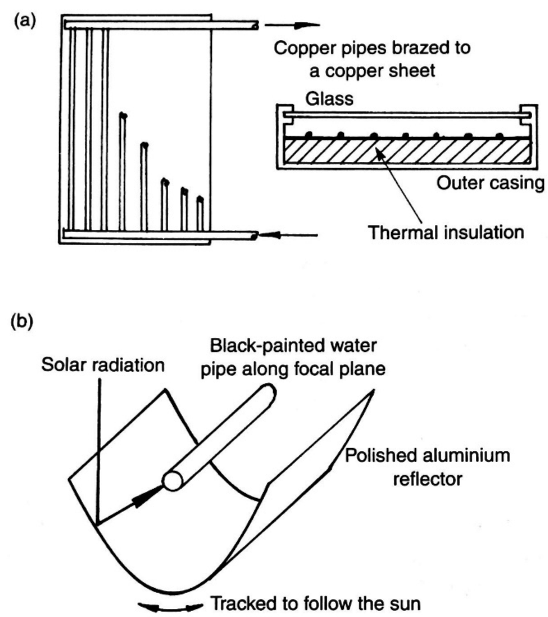

Figure 6 – (a) Flat-plate solar collector; (b) parabolic through concentrating solar collector

As mentioned before, in practice PVs and solar thermal systems are used as an additional clean source of energy, as they can cover the house energy demand only partially. Solar systems can be combined with gas boilers, biomass combustion systems or heat pumps, and take over some percentage of the energy load, required for the house operation. Based on the survey, FPCs and ETCs are the most popular option for the solar subsystem, as they are flexible in terms of user requirements, which means they can be integrated into different system designs, and they are reasonably cheap.

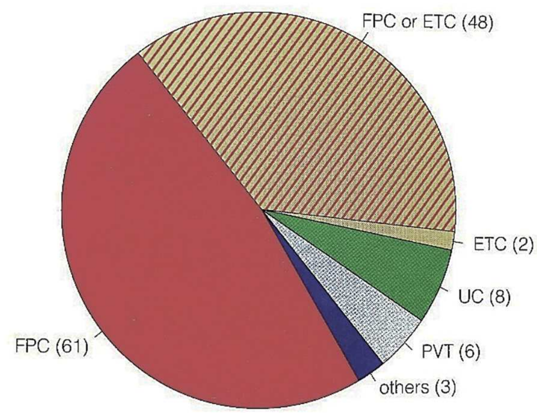

Figure 7 – Share solar energy absorbers types

Geothermal Energy

Geothermal energy is another renewable energy source. The heat from the Earth's crust is serving as a source point for electricity generation and providing of direct heat.

An example of a large scale application of geothermal energy is power plants. The principle is based on running water through extremely hot rocks, where steam is being generated, which then spins the turbines, resulting into production of electricity. Due to this fact, the system is applicable mostly in the specific areas, where the volcanic activity is close to the surface.

In a context of household application of geothermal energy we refer to geothermal heat pumps. Those generally can be divided into horizontal (shallow) systems and vertical systems. In both cases the ground characteristics define the principle of system functioning. The ground temperature from 6m to 50m beneath the surface is usually a mean annual ambient temperature in that specific location, so it is relatively constant throughout the year. Meaning, that in winter the underground temperature is higher than the above air temperature, and the heat is extracted from beneath the ground. When in summer, on the contrary, the shallow ground temperature is lower than the above one, so the heat is exhausted back to the depth, where it cools down.

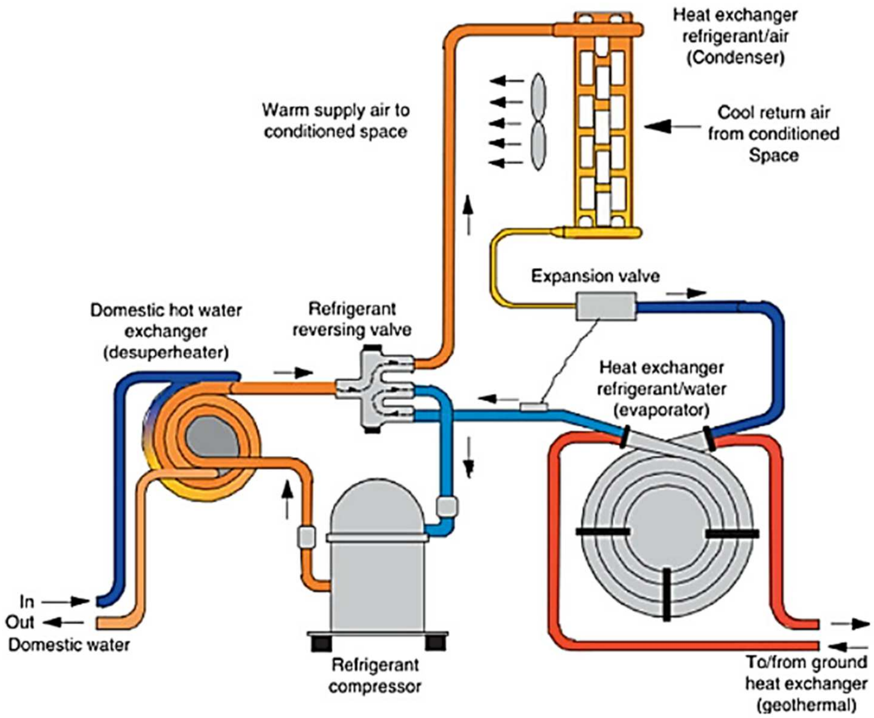

Figure 8 – Geothermal heat pump in heating mode

The horizontal system represents the pipes, laid out horizontally under the frost level of the soil, where the above-pipes area of the land stays exposed to sun and rain, meaning no construction allowed. There are several options for the piping layout, the pattern is usually chosen based on specific conditions. For example, when there is a lack of space and no chance of installing true shallow system, a slinky loop pattern is applied. Depending on heat pumps' run fraction, climate and soil, the overlapping pipe layout can save up to two thirds of the required trench length.

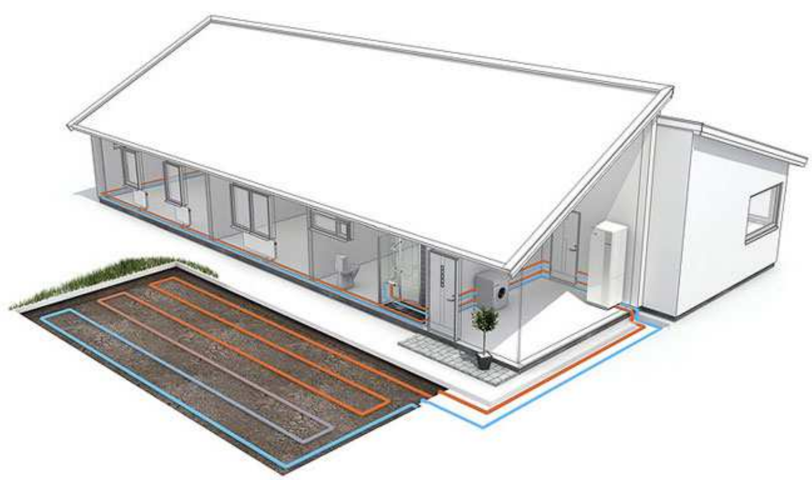

Figure 9 – Horizontal collector NIBE

The vertical system accordingly represents the closed pipe loop, going vertically deep into the ground. The depth usually can vary from 22 m to 150m (or even deeper) depending on the soil condition, the spacing between the bore holes is usually 5m - 6m. In order to magnify the heat transfer from the surrounding rock and at the same time protect the borehole from pollution, the bentonite grouting is used to fill the borehole. This system type is mainly sourced by the natural geothermal energy, coming from the Earth's core. Deep drilling is pretty costly, that is why this option is considered in case of very area-restricted conditions.

Figure 10 – Vertical collector NIBE

Ground heat exchangers are widely used due to environmental reasons, particularly carbon emissions reduction and big potential in energy saving.

Important to notice, that air sourced and groundwater sourced heat pumps are also functional and effective. However, according to recent studies for the Central Europe region, the ground sourced heat pump has shown the highest performance of all, with seasonal performance factor 3.9, into comparison with 2.9 for the air sourced system. This proves the performance of geothermal heat pumps to be approximately 20% - 30% higher, than the comparable air soured heat pumps.

Renewable energy sources for private household

In order to reach the goal and implement the usage of renewable energy sources into the society, it is necessary to switch to renewables with not only commercial and industrial building with high energy consumption, but also private households. According to the year 2017 report of Ministry for Local Development in Czech Republic, which covers the statistics for habitant facilities in the country, there are almost 2 mln family houses in the country. Taking into account the approximate number of country's population 10.58 mln people, and counting that more than one person is occupying the household, the conclusion can be made, that nearly a half of people in Czech republic live in private family houses. That means, that in case of switching each family house energy supply to renewable energy source, it would drastically influence the carbon emission statistic numbers in the scope of the country.

The climatic conditions of Czech republic unfortunately are not perfectly suitable for choosing solar panels or solar collectors as a single source, as they simply do not have the capacity to cover necessary energy demand, especially in winter period. Solar systems, however, are starting to be installed as an additional clean source, creating a combo-system, usually being paired with gas boiler or wood logs stoves. Similar situation with biomass. Pellet or wood chip stoves being installed in private households to cover the energy demands only partially, while operating in combination with the gas boiler, which takes on at least half of energy generation. Though recently government has supported the biomass stoves installation by issuing subsidies for that. Concluding the topic, the results of evaluation show that geothermal heat pump has the biggest potential for the family houses in Czech Republic. It has no obstacles in regards of climatic conditions, it is carbon emission free, and the variety options for collectors installation makes it available for almost any type of land parcel. Its' high price is a disadvantage and the pay-off time is significantly longer, than for example for the gas boiler system.

Ventilation and heating systems design for villa house in Novy Vestec

Ventilation system design for the villa house

In a context of energy-efficient or passive houses installation of forced ventilation system is rather important. The reason for that is the air quality in the habitat spaces is decreasing due to pollution sources, present in the building, such as appliances, building materials, general household operations and occupants themselves. The air-tight construction of the passive house is only worsening the situation with degraded air, that way contributing into the negative impact on occupants' health. The forced ventilation system guarantees the necessary amount of fresh air in order to maintain healthy and comfortable indoor microenvironment.

The forced ventilation system with recuperation is a suitable option, if it is necessary to keep up to the concept of the energy-efficient building. This kind of system is able to minimize or even eliminate heat losses, thanks to the return air heat recovery unit.

The supply and exhaust air are both running through the different channels of counterflow heat exchanger opposite directions, which allows the warm exhaust air heat up the cool outdoor air, before it enters the interior. The technologies nowadays have reached the results of high performance heat recovery, providing market with recuperation units with more than 90% efficiency.

Forced ventilation systems with heat recovery can be generally divided to centralized and decentralized. Both have its' advantages and disadvantages. Decentralized recuperation units can be installed directly through the exterior wall, eliminating the ductwork. They work in pairs, operating with opposite directions of air flow, which changes every 70 seconds (depending on provider). In order to provide sufficient air quality in a big family house with decentralized recuperation units, it is necessary to install at least 8 pieces or more, which is very costly.

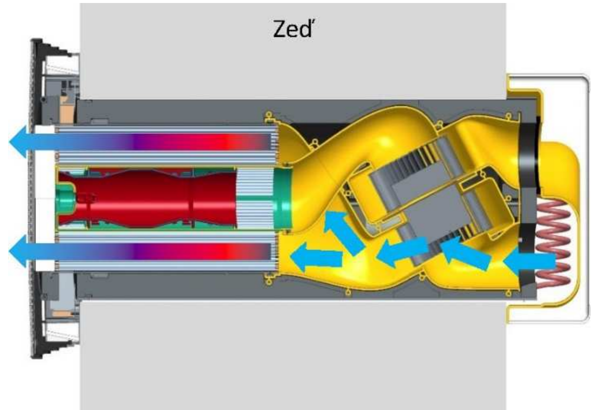

Figure 11 – Decentralized recuperation unit

Centralized recuperation units are more affordable, they require a duct network to each ventilating space. The unit can be installed on the wall or under the ceiling, the ductwork can be placed either in flooring, or hanging under the ceiling. Additionally the unit can be installed with humidity sensor and CO2 sensor, as well as the carbon fiber filter, to clean the supply air prom pollutants and odors. As for my project I designed the centralized ventilation system with heat recovery.

Figure 12 - Centralized recuperation unit

Centralized forced ventilation with recuperation design

Fresh Air Supply 25m³/h per person				Exhaust air from sanitary rooms			
First floor				First floor			
1.06	Living room with Kitchen	150	m³/h	1.06	Living room with Kitchen	150	m³/h
1.08	Hobby room / Gym	75	m³/h	1.03	WC	50	m³/h
1.01	Entrance hall	50	m³/h	1.09	Shower and WC	75	m³/h
		275	m³/h			275	m³/h
Second Floor				Second Floor			
2.02	Bedroom	75	m³/h	2.04	Bathroom	100	m³/h
2.05	Office room	50	m³/h	2.08	Bathroom	100	m³/h
2.06	Room I	50	m³/h	2.10	Bathroom	100	m³/h
2.07	Room II	50	m³/h				
2.09	Guest Bedroom	75	m³/h				
		300	m³/h			300	m³/h
					Total Air Flow Volume	575	m³/h

Figure 13 – Table of fresh air supply estimation

Design: DUPLEX 570 EC5.RD5.CF

Figure 14 – Centralized ventilation unit with recuperation DUPLEX 570 EC5.RD5.CF

Due to the rough calculation and roughly exceeded input parameters of the fresh air demand, the design ventilation unit with the air flow volume 570m³/h is sufficient. The maximal Recuperation efficiency of the unit is 94%. The recuperation unit will be installed in the technical room on the ground floor. The ductwork will be redistributed from the technical room and placed directly under the ceiling slab, covered with the gypsum board hanging ceiling structure.

Duct dimensions estimation: $S * \nu = V$

… where … S – area of duct cross section [m^2]

ν – air velocity in ductwork [m/s]

V – air flow rate [m^3/s]

For the rough estimation the air velocity in the ductwork system is considered $\nu =$ 3 m/s, as the average maximum velocity for the main branches in the apartment building.

50	m^3/h	=	0.01389	m^3/s	100	m^3/h	=	0.02778	m^3/s
	S	=	0.00463	m^2		S	=	0.00926	m^2
	d	=	0.07680	m		d	=	0.10861	m
	$_{min}$ d		77	mm		$_{min}$ d		109	mm
75	m^3/h	=	0.02084	m^3/s	150	m^3/h	=	0.04167	m^3/s
	S	=	0.00695	m^2		S	=	0.01389	m^2
	d	=	0.09406	m		d	=	0.13302	m
	$_{min}$ d		94	mm		$_{min}$ d		133	mm
300	m^3/h	=	0.08334	m^3/s	575	m^3/h	=	0.15974	m^3/s
	S	=	0.02778	m^2		S	=	0.05325	m^2
	d	=	0.18812	m		d	=	0.26044	m
	$_{min}$ d		188	mm		$_{min}$ d		260	mm

Figure 15 – Table of duct dimension estimation

Energy source and heating system design for villa house

Given the floor plans and details of structures compositions of the villa house, the heat transfer coefficient (U) was calculated for each type of designed structure.

SUMMARY OF EVALUATED SCTRUCTURES			
Teplo 2017 EDU	(CSN 730540, EN ISO 6946, EN ISO 13788)		
Name	R [m2K/W]	U [W/m2K]	Ma,max[kg/m2]
Exterior envelope wall...	4.57	0.211	0.0233
Interior wall 140 mm...	0.536	1.257	no condensation
Interior wall 240 mm...	0.816	0.929	no condensation
Interior wall 115 mm...	0.57	1.205	no condensation
Exterior wall (in livi...	3.628	0.263	no condensation
St1 Roof...	5.796	0.168	0.0099
St2 Roof with terace...	4.545	0.213	0.0092
St3 Roof...	3.727	0.259	0.0092
P1a Floor...	4.993	0.194	0.1042
P1b floor...	4.978	0.194	0.1093
P2a Floor...	1.858	0.472	0.0298
P2b Floor...	1.857	0.472	0.0497

Figure 16 – Table of heat transfer coefficient for evaluated structures

**the values overtaken from free software Teplo 2017 EDU*

*** for detailed report of transmission heat loss coefficient calculation see Attachment 2*

Total transmission heat losses for the building $\Phi_T = 7.091$ *kW*

**the value overtaken from free software RauCAD/TechCON*

Annual energy demand for heating $Q_{H,a} = 18\ 423$ *kw*

Annual energy demand for hot water preparation $Q_{HW,a} = 11\ 655$ *kW*

Annual energy demand for ventilation with recuperation $Q_{V,a} = 13\ 295$ *kW*

Total annual energy demand $Q_A = Q_{H,a} + Q_{HW,a} + Q_{V,a} = 43\ 372$ *kW/year*

Based on the daily hot water demand per person for residential building (CSN 06 0320), and assuming the house has 6 inhabitants,

V_{2P} = 82 l/person.day

V_{2P} = 492 l/day

energy demand for the hot water preparation resulted into

E_{2P} = 38.6 kWh/day

Based on the daily hot water demand the minimum size of hot water storage tank was determined

V_Z = 138 l

The minimum required volume of expansion vessel was determined based on total volume of water in the system, including boiler, piping and heat emitters (EN 12 828)

V_e = 9.4 l

The heat source was designed based on the required thermal output of the heater, which was determined based on previously calculated energy demands for heating, hot water preparation and heat up of the recuperated air to the room temperature

Q_P = 19.03 kW

Designed heat source: gas condensation boiler CerapurModul (ZBS30/150S-3MA)

The boiler has embedded a powerful circulation pump, expansion vessel with volume 12 l and a hot water storage tank with volume 150 l. Though the maximum output of the gas boiler is 30.5 kW, which is a bit higher than the required output, it is a suitable and convenient combination. First of all the built-in expansion vessel, circulation pump and hot water storage tank allow the system to be compact and tidy, the volume of both is sufficient. Secondly, the boilers' parameter of maximum flow rate of hot water is relatively high - 16.4 l/min, which is practical and convenient in every-day life.

**the values overtaken from Attachment 1 - Technical report, sec. Calculations*

Conclusion

The goal of this bachelor project was to design the heating and ventilation system for the villa house and perform a study on renewable energy sources for villa house. The overall review was provided on the renewable energy sources, further were specified three types of renewables, that are suitable for household application. Those are solar energy, biomass, and geothermal energy. For each of listed were described general details, principle of obtaining energy and operating in the system, applicability under certain conditions, output capacity, efficiency and costs. It was concluded, that for the middle European region probably the biggest potential shows the systems with geothermal heat pumps, and if each private family house in Czech Republic would switch to the renewable energy soured heat and power generation, it would give a significant impact on the environmental clauses within the countrys' scope.

For the villa house in Novy Vestec has been designed the centralized forced ventilation system with heat recovery. After the estimation of the required amount of fresh air supply, was chosen the unit with parameters of 570m^3/h air flow rate and 94% of maximum heat recovery efficiency.

For the heating system design necessary calculations were done, such as transmission heat losses, heat transfer coefficient for the structures, annual energy demand for heating, hot water preparation and ventilation. As well as daily hot water demand, required size of hot water storage tank, required size of expansion vessel, and required energy output of the heat source. Based on calculation result was designed a condensation gas boiler with maximum output 30.5 kW and maximum flow rate of hot water 16.4 l/min. The boiled has a built-in expansion vessel and water storage tank, which volumes satisfy the requirements.

The technical report and necessary technical drawings were created, where were described details of system installation, explained performed calculations and illustrated the layout of the heating and ventilation system across the house, including a detailed illustration of technical room arrangement.

List of Figures

List of Sources

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Attachments

Attachment 1 - Technical report (including calculations)

Attachment 2 - Heat transfer coefficient (U)

Attachment 3 - Heat losses

Attachment 4 - RAUCAD-TechCON, Heating system design

Attachment 5 – Technical lists of equipment

Attachment 6 – Ventilation system 1NP

Attachment 7 – Ventilation system 2NP

Attachment 8 – Heating system 1NP

Attachment 9 - Heating system 2NP

Attachment 10 – Heating system – Section

Attachment 11 – Plan and section of technical room