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COULD A MASONRY HEATER BE THE MAIN HEAT SOURCE IN A TIGHT HOUSE?

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DESCRIPTION

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COULD A MASONRY HEATER BE THE MAIN HEAT SOURCE IN A TIGHT HOUSE?

Abstract

Masonry heaters are the oldest heating method for one family houses. Earlier houses had high leakage air-flow rates because thermal efficient insulation material was combustible by that time /20/. The masonry heater perfectly fits for air leaky houses. Nowadays, houses are more insulated and have an air tight envelope. People don’t want to spend time for supervising heating systems, that’s the reason they choose a heating system with automatism.

The main aim of my thesis is to evaluate if it’s possible to use masonry heating in tight envelope houses. With help of the literature sources I consulted and the interview with a professional masonry heater builder I will try to give an answer to that question. The secondary aim is to select a ventilation system to one family house, which has a masonry heater.

The example house I will use in this thesis will be a one family house, with a floor area of 95.4 m^2 located in Vilnius, Lithuania. I chose this house and location because of the popularity to use gas in this country. I’m going to evaluate installation and ten-year exploitation costs to have more reasonable results. The masonry heater will be compared to hydronic heating system, which is a common use in residential houses. The hydronic heating system will be separated by heating sources one is a wood and gas burning boiler. The other heating source is only a gas-burning boiler.

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MASONRY HEATER, TIGHT ENVELOPE HOUSE

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CONTENTS

1 INTRODUCTION

The thesis reviews how the masonry heater can be used in a tight envelope houses. The masonry heater is the oldest method of heating houses. Now new and renovated houses are more energy efficient. Fireplaces and masonry heaters serve a more decorative function instead of guaranteeing a comfortable indoor temperature. Nowadays, heating systems are much better than thirty or forty years ago. Some of the new systems do not need any human help. They use less fuel or renewable sources like solar radiation. The highest cost of a heating system is the installation.

In my thesis, I will compare a few heating solutions, which are most common in Lithuania. I decided to use it as an example for a couple of reasons. The house's real location is Vilnius, Lithuania, and this house was built for the predominant climate there. The second reason is the high popularity for using gas heating in Lithuania. Most of the residential houses have a connection to the district gas network. The third reason are the high wood resources and low wood prices. People use about 98 % wood fuel for heating houses therefore it's the main heat source or secondary source in Lithuanian countryside /3/. The approximate birch wood price in the year 2016 is 31 euros per cubic meter /21/. This wood has an energy content of around 2.64 MWh/m^3 /18/.

Lithuania and Finland are part of the Europe Union, but the regulations for both countries are different. That's why it is relevant to compare ventilation regulations in my thesis. Mechanical ventilation systems will be checked, because house have a tight envelope. To adjust reasonable airflow rates and combustion air to masonry heater or boilers is important, otherwise, without any reasonable solution the chimneys will work in the opposite way: the combustion air for ensuring the burning process will go to the chimney from outside and the gasses will leek to the indoor area.

2 AIMS

This bachelor's thesis consists of one general question and a few additional aims. The main thesis aim is to check if the masonry heating method can be the main heat source in a tight envelope house. According to reasonable size and location in the house will be selected the masonry heater. Fitted for the masonry heater there will be selected reasonable fuel type using literature sources and using calculation method by degree-days.

Nowadays, society is concerned about energy saving, that why this thesis is applied for tight envelope houses /22/.

In this thesis I will evaluate which ventilation methods are reasonable to ensure enough air for the burning process, as the secondary aim. For the masonry heater to maintain the burning process it needs additional air. I'm going to select the most reasonable ventilation solution according to my literature sources, which ensures combustion air going to the masonry heater. Tight houses are not leaky thanks to their construction elements that's why outdoor air needs to be delivered by additional ventilation systems.

The other additional aim is to reveal maintenance and fuel cost during a ten-year period. Furthermore, the selected reasonable masonry heater will be compared to traditional systems, which are used in residential houses. Following that I will compare it to a hydronic heating system using only a gas burning boiler. This will also show the evaluated installations cost of these heating systems.

3 METHODS

In the thesis I will use a one family house located in Vilnius, Lithuania. The reason for selecting Lithuania is the popularity of burning gas and the reasonable wood price. Also a calculation method will be used for evaluating which heating systems is more reasonable.

3.1 One family house

The house was built in 1994 and is located in Vilnius, Lithuania. Useful area of the house is 95.4 m^2. The living space is on the first floor; the second floor is an attic. The house's external walls and ceilings were renovated in 2008. For reducing heat losses through external walls there is a polystyrene 100 mm thickness layer. For the ceilings between the first floor and the attic, there is a 100 mm thickness layer of mineral wool.

In this house, there are two main and one additional heat sources and there is a sauna. For heating up the sauna room a wood burning stove is used. The main heat sources are a gas burning and a wood burning boiler. Those two heating boilers are connected to the same hydronic heating system.

3.2 Software's for calculation

To evaluate heat losses calculations will be made by the MagiCAD software. Using this software, data will be faster acquired than through calculation by hand. For other calculations like price evaluation and heat demand will be used Microsoft Excel program. In this thesis I will calculate the expenses for different heating systems, from furnace installation to gas burning boiler with all need connection cost to distribution network.

4 MASONRY HEATER

Masonry heaters were popular in one family houses in Lithuania but now they're not popular anymore. Especially for new house it's more common to install a radiator or an underfloor heating system. For using these systems, they constructed a boiler room and if this house has a connection to the gas network, they will use gas boilers. Otherwise, house owners use wood burning boilers or pallet boilers (figure 1) /25/.

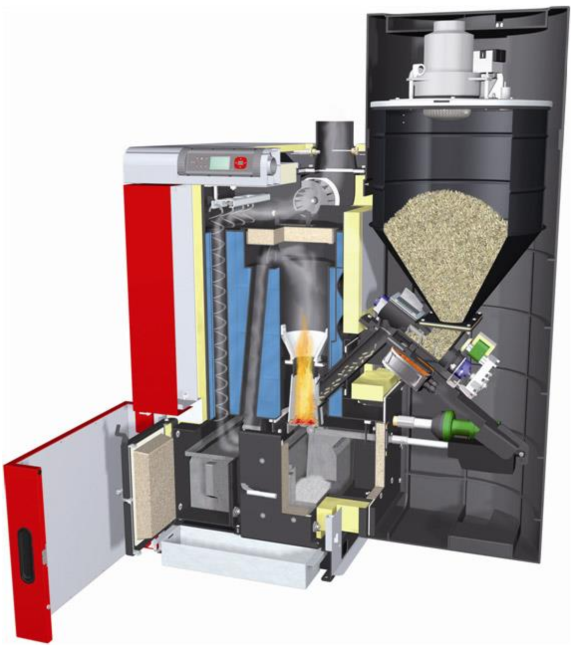

FIGURE 1. Pallet boiler construction

4.1 Background information

Masonry heating is the oldest heating system. This heating system was reasonable in old 1940-1970 for one family houses. These houses mostly made from wood, were not tight and had no thermal insulation. Masonry heaters were the only option to keep those houses warm enough. Masonry heaters are multifunctional since it is possible to install an oven or place where food can be cooked as well. Masonry heating can have various shapes; it can have a sitting area or a surface for drying food products. This system is still in use but not so much as earlier, because of the new heating solutions. Nowadays, heating systems are more independent and easy to use. On the other hand, this heating method is cheap, compared to radiator or underground heating system with a boiler. /1./

The masonry heater is high heat effective compared to regular open type fireplaces. Those heaters essential part is retaining heat in different construction. In the masonry heater the hot gases go through a special made series of chambers or channels which eventually will lead out through the chimney (figure 2). Using this method increases the heat transfer area between the hot gasses and the bricks. This means, gas temperature from the chimney is less than using open fireplace because of higher transfer area to the bricks. / 1 p. 2./

FIGURE 2. Masonry heater section of contraflow

According to my literature sources masonry heaters are 90 % efficient if it is a contra-flow system. One thesis, which checked the contraflow for masonry heater efficiency, using measurements and a calculation method, proved this theory. In this research a masonry heater with contraflow channels was used for seven days. They measured indoor and outdoor temperature as well as the fuel consumption. The result showed that the real value was 79.5 %. The lower efficiency value is due to the fact that there is an inconstant heat gain. For my further calculations I will use this efficiency figure for the contraflow masonry heater. /2./

Masonry heaters became really popular in summer cottages or small countryside houses. Those heaters are demanded because of the very cheap wood prices. In Lithuania, forests cover 33.3 % of the total country area /3/. Wood prices are reasonable, for example, one cubic meter of birch is 31 euros /21./.

4.2 Advantages

Masonry heaters have many advantages. Fuel for these heaters is mostly renewable like wood. Depending on the size and location masonry heater can be main heat source in a house. It's also very easy to operate the heater. In cold winter, it is enough to load the heater two time per day with wood to insure a warm indoor climate. If the masonry heater has thick walls, it can provide enough heat for 24-hour period. Compared to stoves, the surface of a masonry heater is cooler, due to this it is possible to create space where people can sit or put something to dry. /4./

There is a minimum possibility for masonry heaters to have creosote fire, because the burned gases do not go straight to the chimney. Creosote fire is a highly flammable consistence, which arise from burning fuel. If this compound ignites the consequences are very dangerous. After this kind of fire house owners often have to build new chimneys, because fire opens new cracks in the chimney. Using a creaked chimney is very risky because it's possible for fire and smoke to occur inside the building. /5./

Air in masonry heaters is heated indirectly, to provide better indoor climate. Installing a damper in the chimney helps to prevent a draft. If the customer wishes for it, it is possible to install a glass door to the masonry heater or also to make an oven with a cooking stove for pots and pans. The masonry heater can be built in different shape because they are handmade.

4.3 Disadvantages

Masonry heaters need human supervision since you have to load the chamber with wood multiple times per day to keep up the burning process. Depending on the density of bricks or stones and also the wall thickness in the masonry heater the indoor temperature changes with a long delay. To select a reasonable size for the heater is important because the weight of the heater can reach up to 5,4 tons. Therefore, it's needed to have a beefed-up foundation. During the constructing period, the builders have to make an airtight heater, otherwise smoke will go through the cracks. After construction when a masonry heater is drying it shrinks, so the materials should be flexible enough. Also the place of the masonry heater is very important, the best place for it is in the middle of the house. A good location ensures a better heating load to the heating area. This can be a reason though to masonry disturb owners, but this heating system will ensure thermal comfort. /4./

5 VENTILATION SYSTEM

Reasonable working ventilation systems in insulated house are one of the main parts to ensure good indoor climate. Leakage air in those houses are very low. Leakage air or infiltration is additional air from outside which is going through cracks or other leaky construction parts. Those parts mostly are windows, doors, some cases chimney. Ventilation systems in renovated or new tight building should work; otherwise, many problems can occur for inhabitants and for the building construction. The consequences of insufficient indoor air quality are increased health problems. Nowadays, many health-related complaints are described as sick building syndrome (SBS). To predict that house has a sick building syndrome is simple. Symptoms of SBS are headache, fatigue, difficult breathing, irritation of eyes and chest tightness. /6 p. 41./

In this thesis we assume that the leakage air number of the building with 50 Pa pressure difference will be n_{50} = 1.5 [1/h]. This air tightness number belongs to B energy efficiency class according to Lithuanian standards. For A, A+ and A++ energy efficiency buildings according to Lithuanian regulation testing pressure difference is 50 Pa between outside and inside. In residential houses air change rate between indoors and outdoors should not exceed 0.6 1/h. For the lowest energy efficiency class this regulation is not valid. /7./

5.1 Existing system

In the one family house, which I am using in this thesis, ventilation is natural. In it live two persons most of the time. In the kitchen and bathroom, there is mechanical exhaust system. In the kitchen there is a cooker hood installed, and for the bathroom a mechanical ventilator. Both systems works manually by pressing a switch. In the sauna room, there is an extract duct, but it doesn't have a ventilator. Ventilation works by gravity force.

5.2 Air flows using Lithuanian regulations

In Lithuania, there is a building technical regulation where can be found lot of information about airflows, construction rules, and other information about building. For this thesis will be using the STR 2.09.02:2005 regulation. This regulation is about heating, ventilation and air conditioning systems. And about the requirements on how to select and install those systems.

When calculating airflows in the ventilation system there is an (50.91 dm^3/s – 31.91 dm^3/s = 19.0 dm^3/s) imbalance, according to Lithuanian standards. In Lithuania, there are regulations that the exhaust airflow should be 5 % higher than the supply airflow /8/. To keep ventilation system in balance to the air supply devices should be added more airflow. In the kitchen and the bathroom airflow values indicates when the boost mode is working. In reality, when they are not working all the time can be reduced the boost mode values. In the kitchen, airflow value is the same as before because the kitchen has 16.07 m^2 area, which is shared with the entry room. To the living room and the bedroom can be added airflows, because these rooms have the biggest area. After changing airflow rates to one family house it gets 4 % under pressure. This value is correct, because it is around 5 % under pressure. In the table 1 it is air flow values depending in floor area, number of people or appliance.

TABLE 1. Airflow according to Lithuanian regulations

Residential building	Lithuanian regulations

Room No.	Room purpose	Area, m^2	Number of people	Project airflow value, dm^3/s		Airflows, dm^3/s	
				Supply	Extract	Supply	Extract
1	Kitchen	16.07	2		20		20
2	Bathroom	2.43	1		15		14
3	Living room	39.99	2	4		20	
4	Boiler room	7.83	2				
5	Sauna	3.96	2	2	2	7.92	7.92
6	Laundry room	7.99	2	1	1	7.99	7.99
7	Bedroom	17.13	2	4		12	
95.4					Σ	47.91	49.91

The highest supply airflow rate is in the living room 20 dm^3/s, because the area of the room is 39.99 m^2. The highest extract airflow rate is in the kitchen with 20 dm^3/s.

5.3 Air flows using Finnish regulations

For calculating airflow rates, according to Finnish standards, I will use Finnish regulations (D2. Indoor Climate and Ventilation of Buildings Regulations and Guidelines.2003). In these regulations there are requirements on how to ensure acceptable indoor climate and ventilation in buildings. I will use airflow rates for residential houses. In the table 2 there are default values for each room and also already calculated airflows. Calculating airflow rates using Finnish regulation the exhaust airflow was 16 dm^3/s higher. In the ventilation system there is more airflow added to living room and bedroom space to have more of a balance.

TABLE 2. Airflow according to Finnish regulations

Residential building				Finland regulations			
Room No.	Room purpose	Area, m^2	Number of people	Project airflow value, dm^3/s		Airflows, dm^3/s	
				Supply	Extract	Supply	Extract
1	Kitchen	16.07	2		25		25
2	Bathroom	2.43	1		15		15
3	Living room	39.99	2		6	21	
4	Sauna	3.96	2	2	2	7.92	7.92
5	Laundry room	7.99	2	1	1	7.99	7.99
6	Bedroom	17.13	2	4	6	16	

	Σ	52.91	55.91

In the residential houses, airflow rates for extract boost are controlling separately according to Finland Building Code D2 and the air change rate should not exceed 0.7 1/h. The airflow change rate will be calculated by formula 1. /9 p. 31./

$$n = \frac{q_v}{V} \tag{1}$$

Where:

n- air change rate, 1/h

q_v – extract airflow rate, m^3/h

V- room volume, m^3.

$$n = \frac{55.91 \cdot 3.6}{258} = 0.78\ (1/h)$$

In the kitchen and the bathroom will be reduced airflow rates to have lower air change rate. Also for balancing the ventilation system according to the Finnish regulations, it is required to have less than 13 Pa under pressure. In table 3 will be given a value of corrected airflow values.

TABLE 3. Correct airflow rates by Finnish regulations

Residential building				Finland regulations			
Room No.	Room purpose	Area, m^2	Number of people	Project airflow value, dm^3/s		Airflows, dm^3/s	
				Supply	Extract	Supply	Extract
1	Kitchen	16.07	2		25		20
2	Bathroom	2.43	1		15		12
3	Living room	39.99	2	6		18	
4	Boiler room	7.83	2				
5	Sauna	3.96	2	2	2	7.92	7.92
6	Laundry room	7.99	2	1	1	7.99	7.99
7	Bedroom	17.13	2	6		12	
		95.4			Σ	45.91	47.91

Comparing results with table 2 data the supply airflow decrease 7 dm^3/s and the extract 13 dm^3/s. The biggest airflow difference is in the kitchen 5 dm^3/s and in the bathroom 3 dm^3/s. Using formula 1, air change rate is correct in table 3, which is 0.67 1/h.

5.4 Special ventilation systems

Masonry heaters needs additional air to maintain the burning process. New and renovated houses are air tight, so it should be find solution how to ensure enough air to the house. If house use air produced just from air handling unit, it means when the chimney damper is open air goes through the chimney inside the house. The direction of hot gas direction is a major problem for burning process, because it goes to house's living space. Additional air duct, which should be directed to the masonry heater, has to be installed to avoid opposite air movement in the chimney. The easiest and the cheapest solution is to install a duct from outdoor air through the external wall to the masonry heater. A duct should be insulated with mineral wool layer to prevent condense on the outer duct surface. For an aesthetic view near the inner wall can be installed duct and all duct can be covered by a gypsum board.

Ventilation in a boiler room is very similar to the one of a masonry heater. However, the boiler room, which is in the house, uses a gas-burning boiler and a wood burning boiler. To ensure the burning process those heat sources also need air. In the boiler room, there is a system, which in overpressure. Boiler room need have to have a weak point where the explosion force can be directed to in a case of explosion. The reason for the weak point is to secure people inside the building and do less damage to the house construction. Weak points mostly are windows installed in the external wall. In the Lithuanian regulations, the window area depends on the volume of the boiler room. Regulations state that the connection between windows area and boiler room volume has to be $0.05 m^2$ per $1 m^3$. The window size of the house in Lithuania is ($1.10x1.0 = 1.10 m^2$) and the area of the boiler room is $21.3 m^3$. For evaluating the window size we have to multiply the boiler room volume with the coefficient which is given in the regulations. $21.3x0.05 = 1.06 m^2$. It is possible to open the window, so there is no need to install ducts to maintain the burning process. Cold air goes down to the floor level during the winter period. Use diffusers to deliver cold air to boilers to avoid a cold floor. /10./

6 EXISTING HEATING SYSTEM

In this one family house, there is two heat sources: wood burning boiler and gas burning boiler. The heating system in the house is hydronic-closed system. Domestic hot water before the boiler room renovation prepared in the electric water heater installed in the bathroom. Now domestic hot water preparation is in the boiler room and heated up with a gas-burning boiler.

6.1 Hydronic heating system

The hydronic heating system is a system when using water thermal properties is heat up in the heat generator. In this case in the boiler or water heater. Using pumps and pipes hot water transported to the heat emitters (radiators, convectors). In heating systems water has been using because, it has the best heat storage properties comparing with other fluids. Other benefits of water use for heating systems is easy ability to buy it, it is incombustible and innocuous. In the radiators or convectors heat distribute to the space where those units location is. The heat emitters located in room spaces depending on heat load. Heat emitters often located near places with high heat losses like windows or external doors**.** The house used in thesis has a closed heating system. Closed water system is one of the systems where is only one interface point with surface or compressible gas. Difference between the open and the close water system is that in the closed water system is fill of water in all heating system, pumps will not provide static lift. In those systems are expansion tanks mostly with rubber diaphragm between water and air. Nowadays, hydronic heating systems is closed./11./

Distribution system purpose is to connect the heating system equipment and transport hot water to heat emitter and return chilled water to heating source. There is two distribution systems: one pipe and two pipe systems. In this project, it is two-pipe system. This system has two separate pipes: one is for supply heating water, the other for return chilled heating water to the heating source. Using this system each heat emitter has the same temperature. Installing two pipes system needs very precise design and calculation for dimension pipe size. Installation cost for this system requires more money, because there is two parallel pipes instead of one-pipe system. For having a same heating water temperature in all heat emitters two-pipe system are more common in the hydronic heating system (figure 3). /11./

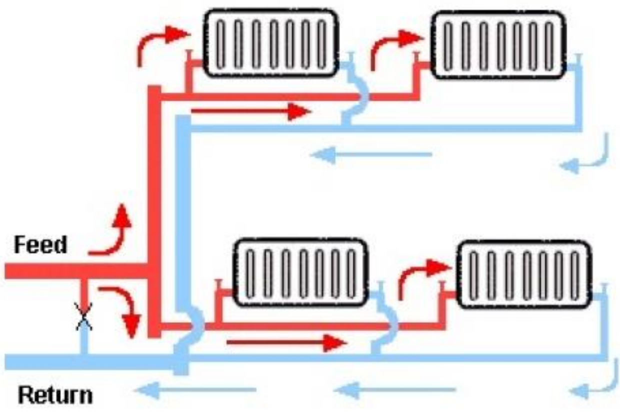

FIGURE 3. Two-pipe system

Concept of hydronic water system reach the end of 14th century. Of a monastery of Greenland uses hot spring water to heat up buildings. Sir Martin Triewald suggest to warming up greenhouses with hot water in 1653. M. Bonne-main in France made the hot water heating system using boiler as heat source in the late 1700s. /12./

The thermostat controls, which located in each room, help to keep constant indoor air temperature. The thermostat controls connected to the radiators thermostats, which adjust heating needs for the radiators. Radiator thermostat automatically regulates heating valve position, which adjust hot water flow in the radiator, according to required indoor air temperature. This system which allow to maintain desirable indoor air temperature also save energy and this kind of system already works around 40 years./10./

The hydronic heating systems nowadays are more smaller and economic comparing with earlier centuries. Basic concept of the hydronic heating system doesn't change a lot. Modification of the heating systems has huge influence for saving money and energy. Radiators now have bigger transfer area, which allows emitting more heat to indoor air. Circulation pumps allows to reduce pipe diameter and water temperature. Using general heat demand equation to have same heating capacity it easy to see if we increase water flow, the temperature difference is smaller (formula 2) /13/. Comparing with older systems, which works using gravity force, has huge advantages.

$$\Phi = q_v \cdot c_p \cdot \rho \cdot \Delta T \quad (2)$$

Where

Φ – capacity, kW

q_v – flow, dm^3/s

c_p – specific heat capacity, kJ/kg K

ρ - density, kg/dm^3

ΔT – temperature difference, K

6.2 Wood burning boiler

Wood burning boiler was installed in year 2012. Fuel for this boiler can be wood, peat or sawdust briquette. Boiler model is ATMOS DC 25S, efficiency of this boiler is 80-89 %. Area of heat exchanger is 2.3 m^2 and water volume in this boiler is 58 dm^3. Burning chamber volume is 100 dm^3. Now this model boiler is possible to buy for 1376.75 €. For heating season fuel consumption is 5 m^3. In Lithuania for residential one family houses very popular to heat by burning wood. Wood fuel uses 98% of the houses as a main or secondary heat source in the Lithuanian countryside and residential houses /3/.

6.3 Gas burning boiler

Gas boiler was a solution, which could compete with a wood burning boiler, to be a main heat source. The gas burning boiler benefits are higher than a wood burning boiler. To install gas-burning boiler is simple. This boiler can be connect to the same hydronic heating system. The gas-burning boiler efficiency is 92 % but some cases it can reach 109.5 % (using condensing gas-burning boilers). The boiler works automatically without any person supervision. The exhaust gasses from the chimney mostly consist of water vapor, so it will not be any creosote content in the chimney. In Lithuania, gas price in 2016 was 0.42 €/m^3. Gas network developed widely in Lithuania, length of this network is around 10313 kilometers /24/./23./

In one family house, there is a gas boiler, which is working all year. During the summer period, gas-burning boiler is for preparation domestic hot water. Model of the gas boiler is "Protherm Bear 50" which maximum efficiency is 92%. Maximum capacity of the boiler is 35 kW and minimum 10.5 kW. Residential houses have regulation from the gas vendor what every house have to use 500 m^3 gas per year if they have installed gas boiler. In this case gas burning boiler is more of maintain minimum room temperature if wood burning boiler stops working, because gas price in 2016 is 0.61 €/m^3. Gas price in 2006 then house was connected to gas network cost 0.15 €/m^3, so it was more than 4 times cheaper than now. /14./

7 CALCULATIONS

In this part will be calculated heating losses for one family house. Heat loss calculation will check if heating system is reasonable in this house. One family house does not have information about the heating losses. For selecting new radiators and calculated fuel consumption using only gas-burning boiler will be used this information. Heat losses will be calculated by using AutoCAD additional program MagiCAD. Heat demand for one family house will be calculated by degree-days in Vilnius city.

7.1 Basic data about location and degree-days.

House location is Vilnius; project temperature in this region is -27°C. Ground temperature set by average annual air temperature in Vilnius city, which is 6.7°C. Building heat losses was evaluated by heat demand formula 2. /13./

$$\Phi = U \cdot A \cdot (t_2 - t_1) \tag{3}$$

where:

Φ – capacity, kW

U – thermal transmittance, W/(m^{3}K)

t_2 – temperature inside the building, °C

t_1 –project outside temperature, °C

The Heating Degree Days (HDD) is rough method for evaluate the heating demand for the building. This value got from outside air temperature measurements. MagiCAD program cannot calculate heat demand. This program calculate heat conductance (W/K). Heat demand will be calculated using Heating Degree Days from 2006 to 2016 in Vilnius, Lithuania (table 4)/14/. Heating demand calculated using formula 3./19./

$$Q = H \cdot 24 \cdot HDD \tag{4}$$

Where:

Q – heating demand, Wh

H – heat conductance, W/K

HDD- heating degree days, days,K.

TABLE 4. Heating Degree Days in Vilnius, Lithuania

Year	Heating Degree Days, days ,°C	Heat demand for heating, MWh
2006	5054.7	6.054
2007	4818.9	5.772
2008	4772.5	5.716
2009	5148	6.166
2010	5299.3	6.347
2011	4898.4	5.867
2012	5272.6	6.315
2013	4998.9	5.987
2014	4827.8	5.782
2015	4622.3	5.536
2016	3704.1	4.436
Σ	53417.5	63.978

The highest heat demand reached in 2010, when it was 6.347 MWh. The lowest heat demand in one family house is during 2016 (4.436 MWh) because 2016 year has not ended yet.

7.2 Heating systems installation cost

Heating system is very important to select properly especially in the north Europe countries like Finland or Lithuania. There are many heating system, which can be use for heating the house. The installation cost will be evaluated of masonry heater and exist hydronic heating system.

7.2.1 Masonry heater

Built the masonry heater needs a professional worker and good foundation where the masonry heater will be build. The masonry heater have to have independence foundation because masonry heaters weight can be from 2700 to 5400 kilograms /1/. Basic estimation for the masonry heater presented at table 5. Prices of the materials are according to the Lithuanian companies prices.

TABLE 5. Masonry heater material price

Masonry heater			
Materials	Quantity	Price per 1 unit, €	Price, €
Clay bricks	450	1.5	675
Firestone bricks	150	1	150
Clay	5	5.95	29.75
Dampers	2	13.21	26.42
Doors	1	40	40
Cleaning doors	3	30	90
Safety duct	5	21	105
Safety duct connection parts	1	116.6	116.6
Oven	1	75	75
Air duct D125 3m	2	11.79	23.58
Bend 90°	2	5.49	10.98
Damper for ventilation duct	1	30.12	30.12
Outdoor air grill 125mm	1	13.17	13.17
Mineral wool	1	12.85	12.85
		Σ	1398.47

The bricks are essential part of the masonry heater construction looking from the table 5. Clay bricks are using for the heat conductivity to indoors, conductivity coefficient of clay brick have λ= 0.65 W/(m*K). The firestone bricks mostly are using there is open fire, because it have fire resistant until 1690 °C and thermal conductivity is λ= 0.95 W/(m*K). Clay and water mixture needs for connect bricks to each other. Dampers let to avoid the cold air coming from the chimney when the fire is over. Avoiding sparks from the fire to inside a room are using doors, which can be with solid metal or with glass. The cleaning dampers are required they are installed on the lowest point to clean the ashes and impurities form the chimney and channels. The safety duct is to prevent impurities collection in the chimney walls. Using safety duct inside the chimney will be avoided danger of creosote fire. These ducts made from stainless steel which heat resistance are 600 °C. In masonry heater can be installed an oven. Separate insulated air duct should be installed to supply additional air for masonry heater. Insulation for an air duct need to avoid condensation in duct outside surface. The masonry heater concept, which are similar by used materials are in figure 4. In the masonry heater can be installed stove, oven, and bench to warm up depending on customer need. Furthermore, customer can select decoration of the masonry heater. Every masonry heater mostly is unique, because they are handmade. Build this kind of masonry heater takes 2 – 3 week working by one person. Two-person team to make this masonry heater can take one week. Price for make this masonry heater are 900 €. Price is the same if the work done by one or two persons, the only difference is duration how fast heater will be finish./15./

FIGURE 4. Masonry heater with oven /16/

In the photo, there is a masonry heater, which has an oven. On the floor lever near fire chamber can be seen part of foundation for masonry heater. This area always left without flammable materials to avoid fire in the house.

7.2.2 Hydronic heating system

Heating system in one family house made in 2000. All the radiators made around 1970s from the cast iron. Including materials and equipment price in nowadays market price will be estimated installation cost. In this case, some equipment will be changed to new keeping equipment properties the same. Using this method will be reasonable to compare heating systems. The boiler room has been renovating in year 2012. Price list of the hydronic heating system equipment has given in table 6. In this system is changed gas boiler, all pipes and pipe parts, radiators and thermostatic valves, because product, which are in the house heating system are not in the market.

TABLE 6. Gas burning and wood burning boilers system

Hydronic heating system			
Materials	Unit	Price per 1 unit, €	Price
Boiler Atmos DC 25S	1	1357.32	€ 1,357.32
Gas boiler Protherm Gepard Condens 25MKO	1	930	€ 930.00
Expension tank	1	37.1	€ 37.10
Acumulation tank CORDIVARI 500l	1	656.2	€ 656.20
Pump Wilo 25/2	1	102	€ 102.00
Pipe Fe-35 DN 10	83.8	2.62	€ 219.56
Pipe Fe-35 DN 15	2.1	1.91	€ 4.01
Pipe Fe-35 DN 25	1.3	3.48	€ 4.52
Bend 90 DN 10	36	1.82	€ 65.52
Bend 90 DN 15	2	2.17	€ 4.34
Bend 90 DN 25	1	3.89	€ 3.89
T-Braches 10/10	8	3.82	€ 30.56
T-Braches 10/10/15	1	4.46	€ 4.46
T-Braches 10/10/25	1	6.36	€ 6.36
Reduction DN 20/15	1	1.38	€ 1.38
Reduction DN 25/15	1	2.26	€ 2.26
Purmo C22-300-1400	3	85	€ 255.00
Purmo C22-900-1100	1	134	€ 134.00
Purmo C22-500-1400	1	110	€ 110.00
Purmo C22-900-900	1	123	€ 123.00
Thermostatic valves Danfoss RA 2990	6	69	€ 414.00
Valve and measuring equipment			€ 200.00
		Σ	€ 4,465.48

The hydronic heating system have 25 kW power wood burning boiler and the same capacity gas-burning boiler, but just a new generation. It is condensing gas-burning boiler which efficiency is 108.5 %. The expansion tank capacity is the same as old expansion tank. The wood burning boiler on maximum capacity have best efficiency. For this reason was installed accumulation tank. Volume flow of this tank is 500 liters. Pipes and pipe connections selected again because there are no correct data about pipe lengths. Radiators are from the Purmo manufacturer. I selected two plates radiators C22 because old cast iron radiators also had two plates. In all radiators are connected thermostatic valves Danfoss RA2990. For manometers, thermometers, shut off valves and safety valves are given 200 €.

Heating system plan should be prepared for installing hydronic heating system. In one family house there is other communication, for example, tap water, electricity, gas pipes. The house owner has to collect drawings of site plan for connection to the gas network. The next step is delivery of site plan and filled the application form. Depending on the plan house owner pays connection fee, and installation price. Gas burning boiler will use more than 500 m^3 gas for space heating and domestic hot water. Fee of connection is 242.96 € and installation cost is 14.18 €/m. One family house is 91 meter from the distribution line. The house owner will pay $242.96\ € + (14.18\ €/\text{m} \cdot 91m) = 1533.34\ €$ in total for connection and installation cost. Term then gas pipe connected to owner takes from 135 to 200 days. If the gas pipe is installing during winter season work extend extra 135 days. Cost for installation heating system in this house is 732 €. The biggest part of work price is the boiler room installation, it is 650 €. The last part of the work price is radiators and pipe installation. /17./

If in one family house would be just the gas-burning boiler, installation price be 2012.14 € lower. The Wood burning boiler price is the biggest part of saved money, which is 1357.32 €. Installing just the gas-burning boiler there are no need to install accumulation tank, because boiler can regulate heating needs. Cost of installation just the gas-burning boiler is 450 € lower than installing both boilers.

7.3 Exploitation and maintenance of heating systems

Choosing reasonable heating system is important to evaluate not only installation price but live cost during the ten-year period. Fuel price, maintenance cost and in some cases, cost of changing new equipment should be evaluated during live cost analysis.

7.3.1 Masonry heater

Long-term cost calculation for the masonry heater is simpler than the hydronic heating system because where are no mechanical equipment for this heating system. Fuel in this masonry heater can be almost any wood. In Lithuania most popular wood for masonry heaters and boilers are birch or oak. It depends on the person what kind of wood he selects. The oak wood give 290 kWh/m^3 more energy than the birch but price of one cubic meter wood is 3 euros higher. The other option like the spruce or the pine is not reasonable to use because of very low energy content per one cubic meter of wood value comparing with oar and birch. Column with wood energy value is important because wood is requiring storage place, which have to be secure from rain and snow. Loading frequency indicates energy content column too. Wood should be dry to have a good wood thermal properties; water content should be around 20 %. Wood thermal parameters when water content is 20% is given in table 7. /17 p. 30-31./

TABLE 7. Energy content of logwood

Wood type	Energy value in MWh/m^3	Price in Lithuania €/m^3	Price in Finland €/m^3
Oak	2.93	34	-
Birch	2.64	31	34.33
Spruce	1.87	21.7	20.48
Pine	2.15	23.2	21.12

The Masonry heater will use birch wood in this case. Wood consumption is 4 m^3 during the heating period. Chimney cleaning is mandatory to evaluate before every heating season. Cost of this service is 58 € for two chimneys (Second chimney is for the sauna). Wood prices in Lithuania is changing every year. To evaluate how much money needs to spend for heating will be used data from 2006 to 2016 (table 8).

TABLE 8. Annual price for heating using birch wood

Year	Wood price, €/m^3	Heat demand, MWh	Price for space heating, €
2006	16.80	6.05	48.76
2007	25.20	5.77	69.74
2008	30.70	5.72	84.14
2009	34.46	6.17	101.89
2010	34.75	6.35	105.77
2011	39.10	5.87	109.98
2012	27.51	6.31	83.31
2013	36.20	5.99	103.93
2014	42.00	5.78	116.44
2015	38.00	5.54	100.87
2016	31.00	4.44	65.94
	Σ	63.98	990.77

The highest price for heating using the masonry heater was in year 2011. The lowest price was in year 2006, when wood price was very low (16.80 €/m^3). The average annual cost during the ten-year period using birch wood is 90.07 €/a. The masonry heater efficiency is 79.5 %.

7.3.2 Combined wood burning and gas burning boilers

In real heating system, which is in one family house are wood-burning and gas-burning boilers. In this system installed accumulation tank, which save energy surplus. The accumulation tank is mandatory part of the heating system using wood burning boiler because boiler works without temperature regulation. The energy surplus will be collected in the accumulation tank. In the radiators will be supplied required temperature water all the time when in system is accumulation tank.

Price of ten-year period consist of wood and gas fuel prices. For equal comparison will be used the birch and the natural gas price during the 10-year period. The gas boiler efficiency is 92%. Energy of both boilers presented in table 9.

TABLE 9. Wood and gas burning boilers

Year	Gas price, €/m^3	Heat demand, MWh	Wood price, €/m^3	Price for gas burning boiler, €	Price for birch, €	Price, €
2006	0.148	6.05	16.80	59.24	7.08	66.33
2007	0.208	5.77	25.20	83.28	6.00	89.28
2008	0.457	5.72	30.70	182.92	5.80	188.71
2009	0.370	6.17	34.46	148.16	7.53	155.70
2010	0.374	6.35	34.75	149.44	8.29	157.73
2011	0.260	5.87	39.10	104.00	6.36	110.36
2012	0.330	6.31	27.51	132.00	8.15	140.15
2013	0.374	5.99	36.20	149.60	6.82	156.42
2014	0.420	5.78	42.00	167.98	6.04	174.02
2015	0.420	5.54	38.00	167.98	5.15	173.13
2016	0.420	4.44	31.00	168.00	1.87	169.87
		63.98	Σ	1512.61	69.10	1581.70

Gas consumption is 21.9 times higher than used the birch wood, comparing ten year period. Reason of high difference between fuels sources are because of contract with the Gas Company. In the contract there is minimum value how much house owner should consume gas. The average price during ten-year period is 143.79 €.

7.3.3 Gas burning boiler

Gas burning boiler system was evaluated to see how is reasonable to use it as a main heat source, for ten-year term. Natural gas calorific value is 10.41 kWh/m^3 according to the Lithuanian gas distributor. The condensing gas boiler efficiency is 108.5%. In this system, there are many mechanical systems so it after long term this equipment can break. Using formula 5 will be calculate how much gas consumed per year.

$$V_{gas} = \left(Q_{need}/\eta_{heating\ system}\right)/Q_{cal.v/m^3} \quad (5)$$

Where:

V_{gas} – gas volume, m^3

Q_{need} – annual energy need for one family house, kWh/a

$\eta_{heating\ system}$- heating system efficiency of gas burning boiler

$Q_{cal.v/m^3}$ – calorific value for natural gas in Lithuania, kWh/m^3

According to the Lithuanian gas market from 2006 to 2016 for estimate price for heating will be evaluated gas price. The natural gas prices every year are recalculating because of the international gas market. To Lithuanian gas network from year 2014 was connected the gas tanker "Independence". Gas price increased 0.05 €/m^3 for ship expenses and gas quota. Result of yearly and ten-year period are presenting in table 10.

TABLE 10. Gas burning boiler annual cost

Year	Gas price, €/m^3	Heat demand, MWh	Price
2006	0.15	6.05	€ 85.79
2007	0.21	5.77	€ 114.96
2008	0.46	5.72	€ 250.08
2009	0.37	6.17	€ 218.50
2010	0.37	6.35	€ 226.87
2011	0.26	5.87	€ 145.94

2012	0.33	6.31	€	199.38
2013	0.37	5.99	€	214.23
2014	0.42	5.78	€	232.32
2015	0.42	5.54	€	222.43
2016	0.42	4.44	€	178.27
	Σ	63.98	€	2,088.76

The highest gas price during the ten year period is in 2008, it was 0.46 €/m^3. The lowest price was in 2006 (0.15 €/m^3). Total price during ten-year period for space heating in one family house is 2088.76 €.

8 RESULTS

In this thesis was answering the question if the masonry heater could be a main heat source in tight envelope house. For a theoretical part and the essential information for the fuel properties was used the literature sources like previous thesis, books, articles and the Lithuanian and the Finnish regulations. The price of installation the masonry heater and the hydronic heating system was evaluated by 2016 years equipment prices in the Lithuania. Work of installing the heating system also is given by 2016 prices.

8.1 Masonry heater use as main heat source

The masonry heater is possible to use as a main heat source in tight envelope houses. In this thesis was used 95.4 m^2 one family house, which location is Vilnius, Lithuania. The masonry heater located in the middle of the house. Heat emission from the masonry heater depends on the masonry heater construction. The Masonry heater has additional channels where hot air goes through and after those channels, hot air exit to the chimney to produce as much heat as possible. Hot gases gives 70 % of heat and 30 % from the fire using this method. In the regular fireplace, without any additional channels this 70 % of heat exits though the chimney. The masonry heater surface temperature is from 38 °C to 66 °C /1 p.3/.The earlier studies show that masonry heater efficiency is 79.5 %. The concept of the tight house means low air leakage ratio. In this case air leakage number was assumed q_{50} = 1.5 (m^3/h m^2).

8.2 Ventilation solutions

To ensure enough air to the burning process was installed the additional air duct, which takes outdoor air to the masonry heater. In the thesis, there is two ventilation cases using masonry heater as a main heat source.

The first ventilation case in one family house where mostly live two persons is using the natural ventilation according to the Lithuanian regulation. If the supply or the exhaust air do not need to clean and the indoor air quality will be maintain is allowed to use the natural ventilation. /8./

The second ventilation case is to use the mechanical ventilation with a heat recovery. The airflow rates is selected by room purpose. Between the Lithuania and the Finland regulations will be compared the airflow rates because these countries are in the Europe Union (EU). The supply air flow values have been given per person for the living room and the bedroom and for the sauna and the laundry room values are for one square meter.

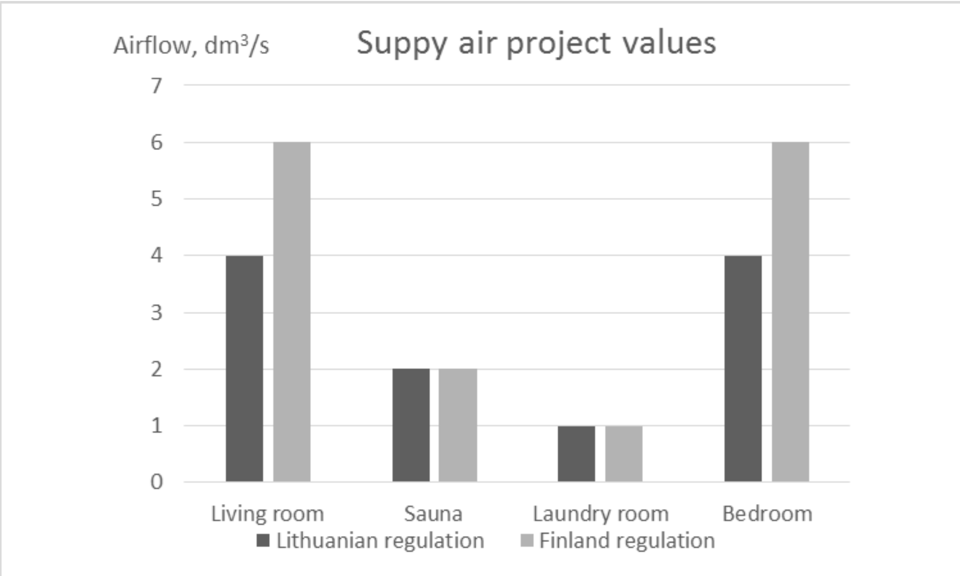

FIGURE 5. Project values for supply air

Looking to figure 5 airflow rates in the sauna and the laundry room are the same. In the bedroom and the living room in the Lithuanian regulation required 4 dm^3/s airflow per person. In Finland regulation for the bedrooms and the living rooms requires 2 dm^3/s per person more air than in Lithuanian regulations.

The extract airflow rates difference from the Lithuanian regulations but only in the kitchen zone, where it is 5 dm^3/s higher. In other zones, airflow rates are the same. The boost airflows in both cases are in the kitchen and in the bathroom. In those zones airflow values are given per unit. The sauna and laundry room airflows are per one square meter of floor area (figure 6).

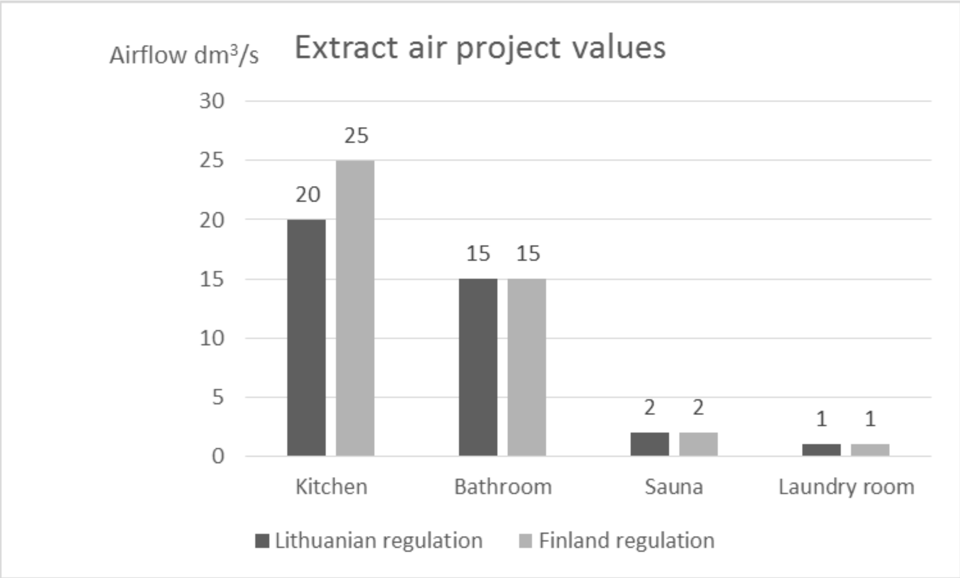

FIGURE 6. Project values for extract air

The extract airflow was higher than the supply airflow during the calculation by the Lithuanian and the Finnish regulations in one family house. The extract air should be 5% more than the supply air by the Lithuanian regulation. House should be under pressure not more than 13 Pa by the Finnish regulation. To have a balance in the ventilation system with 5% under pressure it needs to add more airflow to supply air devices. In the Lithuanian regulations there are no information about the air change rate (ACR). The air change rate was 0.78 (1/h) in the extract airflow according to the Finnish airflows. In the Finnish regulation D2 is given value for the air change rate in residential house and it should not exceed 0.7 (1/h). Airflows in the kitchen and the bathroom can be reduced by decreasing the ACR because in real case both systems will not work in boost mode at the same time. The difference between the Lithuanian and the Finnish regulations are minor. Using Finnish building code D2 airflow rates in the supply and the extract air are 2 dm^3/s less than using the Lithuanian regulation.

The doors with air gabs improves hot air circulation from the masonry heater in each room. An air duct will provide combustion air to the masonry heater. Duct for the combustion air to the masonry heater is insulated with nonflammable insulation – mineral wool. Wool insulation prevents water condensation in the duct surface during winter period. The damper with rubber edges prevent cold air from the combustion duct when burning process is over. Combustion air to stove gets from the open window in the boiler room. The doors for add wood to the stove are in boiler room.

8.3 Heating system comparison

The masonry heater is compared with the hydronic heating system using a wood and a gas burning boilers and only the gas burning boiler as a main heat source. There is two criteria to compare those three heating systems. The first is installation price and the second is exploitation expenses during the ten-year term.

8.3.1 Installation cost

The installation cost consist of material price and professional work price. All prices is taken from the Lithuanian companies. Figure 7 presents installation cost of the masonry heater, the wood burning and a gas burning boilers. Also heating system using only a gas burning boiler is taken to account.

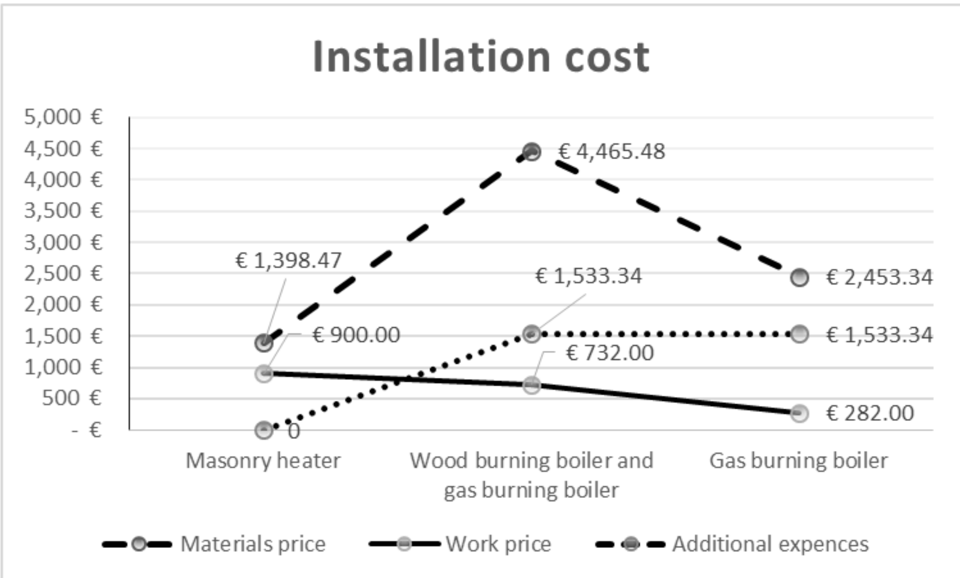

FIGURE 7. Price of installation a heating system

The masonry heater installation is 1.86 times more expensive than installing the hydronic heating system with a gas-burning boiler. Advantages of installing the masonry heater is 1.75 times lower material price and no extra expenses. Additional expenses in this case is a gas pipe connection from the house to distribution network. Wood and gas burning boilers are the most expensive heating system. Materials are most expensive than the masonry heater or the gas burning boiler. Difference between the wood burning boiler and a gas-burning boiler with only a gas-burning boiler is a wood burning boiler and accumulation tank expenses. The house owner without those two components save 2013.52 € just in material price. Work cost for installing the hydronic heating system with a gas-burning boiler also would be 2.6 times lower than installing both boilers and accumulation tank.

8.3.2 Cost of ten-year exploitation heating system

Not only installation price is major criteria to decide which heating system is better. Fuel prices have also big influence of selecting the heating systems. In the Lithuanian case gas price was very low (0.148 €) in year 2006. The exception of fuel prices have only people who have private forests. The fuel prices recalculated every year but there are no centralized wood price market in Lithuania. Mostly, people, who have private forest have private license for selling wood. To find wood prices in previous years is complicated because there are no data in the Lithuanian statistics department. To have accurate evaluation of heating system was collected gas and birch wood prices from 2006 to 2016. In figure 8 it can be seen the gas and the birch price per 10 years.

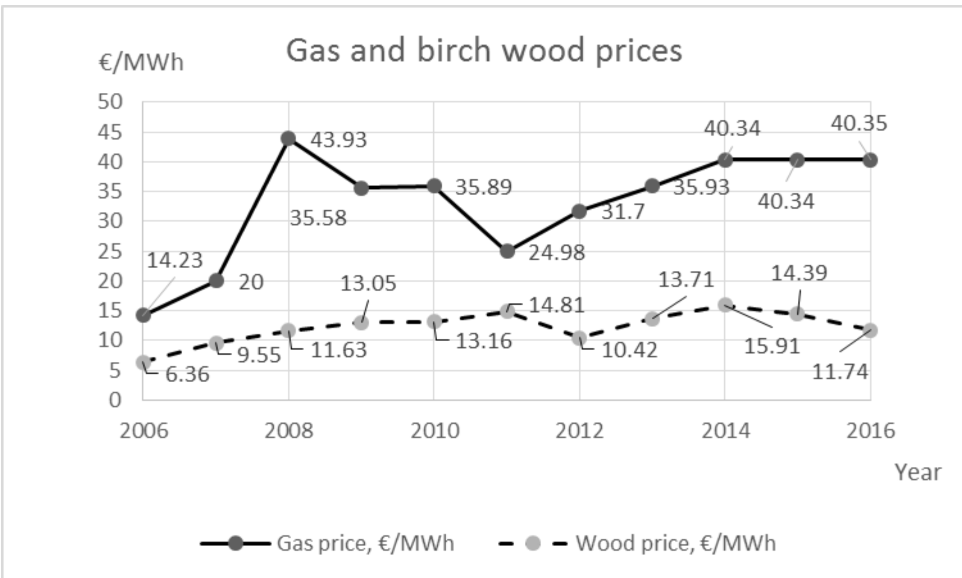

FIGURE 8. Gas and birch wood price in Lithuania

Comparing fuel prices per 1 MWh from 2006 to 2016 in Lithuania, the highest prices difference reached between year 2006 and 2008. The Gas price during two years increases 3.09 times and the birch wood increases 1.83 times. The Lowest price difference between these fuels after 2007 reached in 2011 then gas was 10.17 €/MWh (69 %) more expensive than birch wood.

Maintenance and additional expenses for changing equipment also evaluated depend on heating system. The masonry heater do not have any mechanical part, which can break during long term. In other two systems, there is mechanical parts like circulation pumps thermostatic valves, which can break during this term. The masonry heater maintenance per ten-years is 290 €. The hydronic water system with wood and gas burning boilers cost is the same as masonry heater. Gas burning boiler maintenance price is 0 €. However, in last two systems can break mechanical equipment during long-term use.

In this thesis are comparing three heating systems. Each system has their own heat production efficiency. Figure 9 presents how much changes cost using three different heating systems during ten-year period including fuel prices.

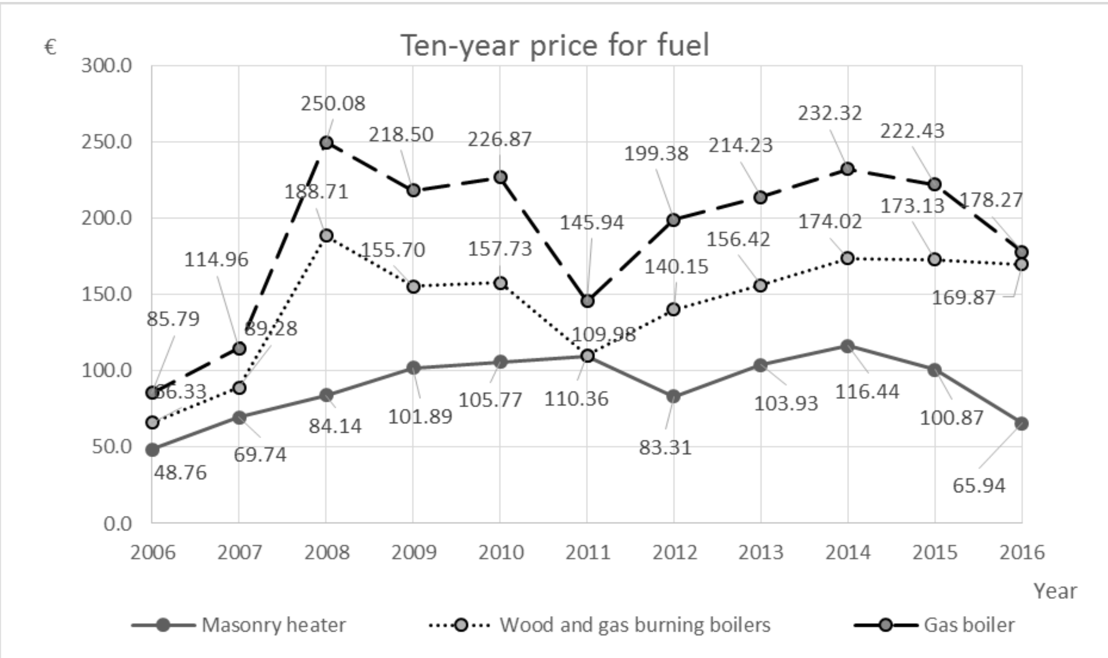

FIGURE 9. Ten-year heating system evaluation by fuel

The cheapest heating method by fuel price is the birch wood price comparing with three heat sources (figure 9). Only in 2011 heating with a wood and a gas burning boilers fuel price was almost the same as a masonry heater. Using only a gas-burning boiler from 2006 to 2016 the gas price was all the time higher than a birch wood.

8.3.3 Total ten years heating system evaluation

The total heating system comparison consist of installation price and ten-year fuel and maintenance expenses (figure 10). The masonry heater total expenses is 3579.24 € for ten-year period. The wood burning boiler and a gas burning boiler price is 140 % (8602.52 €) higher than the masonry heater. The price using only a gas burning boiler is 77 % (4108.83 €) higher.

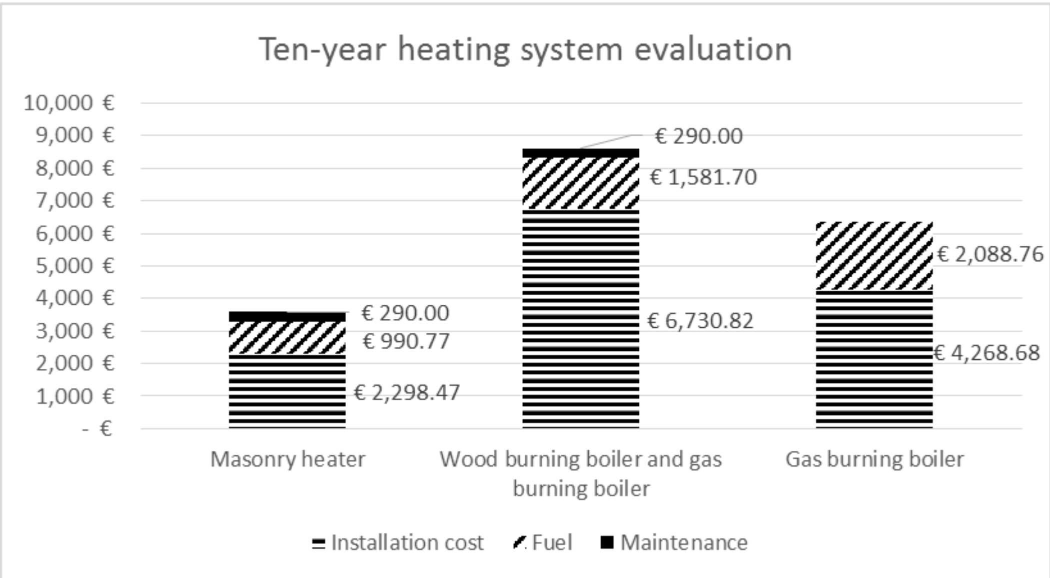

FIGURE 10. Cost of heating systems in ten-year term

The masonry heater is the most reasonable heating method comparing with the hydronic water system evaluating the total price. The hydronic heating system cost during ten-year period is 2245.09 € lower using just a gas burning boiler as a main heat source (figure 10). If the house owner wants to have a hydronic heating system in his house, it should be a gas-burning boiler because this system works automatically with minimal person supervision. In the ten-year investment, this heating system with a gas-burning boiler is cheaper than wood and gas burning boilers.

9 CONCLUSION

The essential part of the thesis is answer the question if the masonry heater could be main heat source in a tight envelope one family house. The masonry heater do not require any electricity, this heating method is good for summer cottages and houses which have problems with unstable electricity connection. House owner has many options, which space heating system he wants to have for his future house. His decision depends on many factors: installation cost, fuel consumption, maintenance, ecstatic view.

The masonry heater is one of the solution how to ensure desirable indoor temperature. Size and location should be rationally selected for masonry heater to ensure enough heat with two wood loads per day. The Masonry heater can accumulate heat for a longer time because clay and firestone bricks can accumulate heat. Correct masonry heater sizing can make companies, which install those heating systems. Wood prices in Lithuania and Finland is low because both countries have big wood resources.

The masonry heater is one of the reasonable solution for one family houses. To prove that masonry heater is cheap heating method masonry heater was compared with hydronic system. The hydronic system is modeling with MagiCAD program, which calculate heat losses of one family house. Although, MagiCAD cannot calculate heating demand. Heat demand of one family house in Vilnius (Lithuania) was calculated by degree-days during the ten-year period. The masonry heater is the cheapest heating method for a tight envelope house comparing with hydronic heating system.

Airflow should be set to require value to avoid high overpressure or under pressure inside the house. The house can be slightly under pressure according to the Lithuanian standard by 5% and the Finnish standard by 13 Pa. Combustion airflow rate shouldn’t be included to mechanical ventilation system air handling unit (AHU) because it is unnecessary to heat up combustion air in the heat recovery unit. Otherwise, airflow rates will be higher and that requires bigger AHU. The easiest solution is to install additional air duct, which takes air from outside to the masonry heater.

10 DISCUSSION

In my opinion, the masonry heater will ensure heating demand for the one family houses. Heat from the masonry heater is spreading to room spaces unequally, if the house shape is rectangular.To maintain required indoor temperatures to the furtherest rooms helps additional fan installed near the masonry heater. This system is based on masonry heater surface temperature, when it is higher than set value fans turn on and starts to blow hot air to thermal insulated air ducts. The ducts are located just to most farthest points of the house.

Masonry heater is better to build during the new house construction. If I build the house, I will concern about inner wall thermal properties. I think it is better to use pillar construction and use lighter construction inner walls with gypsum board with sound insulated materials. Channel for additional air to masonry heater is better to make during the floor construction.

The house owner should concern about the time consumption for heating system maintenance and supervision. The masonry heater requires supervision, because this heating system do not have mechanical systems, which can secure the masonry heater from harmful damage. In my opinion, masonry heater is profitable for people, who return at home in the same day, because masonry heater need to load with wood at least two times per 24 hours to maintain reasonable indoor air temperature.

In general, person, who want to install masonry heater to his house have to evaluate few factors before selecting this heating method. He has to evaluate time, which he will spend for supervising the masonry heater. The fuel storage location where burning fuel should be secured from the weather conditions. If those factors are accepted, he could chose masonry heater as a main heat source. This heating system is cheap to install and reliable for a long term, comparing with hydronic heating systems, which use gas burning boilers or gas and wood burning boilers as a main heating source.

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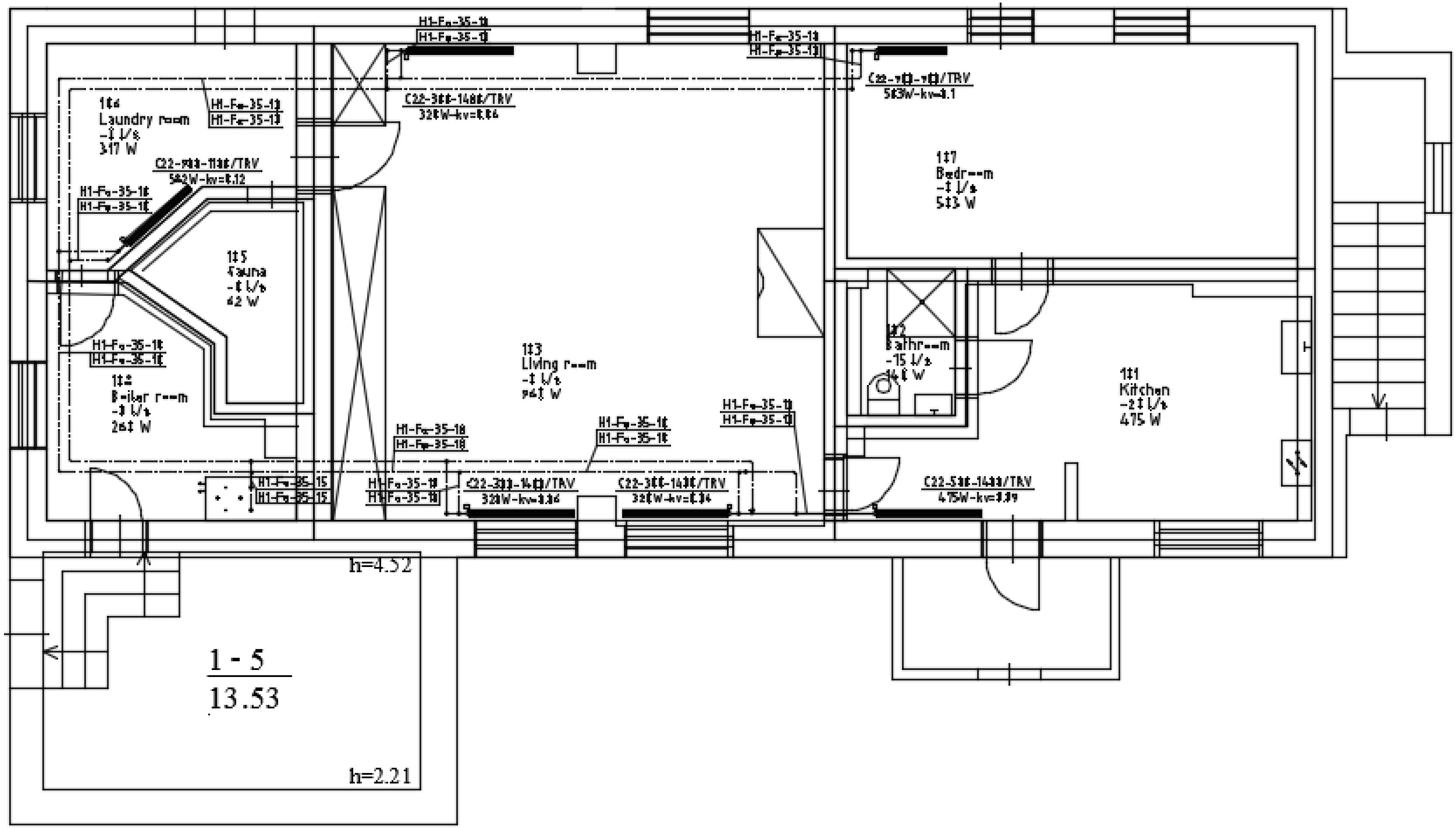
APPENDIX 1.

Appendix on one page



APPENDIX 2(1).

Appendix on several pages