Rokas Petrasiunas

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Renovation of residential building according to Finnish and Lithuanian national building codes

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Abstract

The renovation of the residential building in Finland and Lithuania is analysed in this thesis. This is done according to present national building codes. The building with same internal dimensions is analysed in Finnish and Lithuania weather conditions. The IDA ICE program is used to simulate building in Finland conditions and the manual calculations are used to simulate building performance in Lithuania.

There are three aims of this bachelor thesis. The first one is to find the energy consumptions of the residential building before and after renovation in Finland and Lithuania. The second aim is to find out what changes in the building should be done during the renovation that the building would meet an A energy class according to national building codes in each country after renovation. The third aim is to find out which of the buildings, in Finland or in Lithuania, will be more energy efficient according to national build standards after the renovation.

Subject headings, (keywords)

Renovation, national building code, IDA ICE, E-value, energy class, heat loss, heat gains, residential building;

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NOMENCLATURE

$Q_{H.w,m}$	calculated heat losses through one square meter of building wall per month (kWh/m^2 * month);
0.001	factor which converts W to kW;
24	amount of hours per day (h);
t_m	number of days of certain month;
A_{p}	area of the building which is heated (m^2);
θ_{iH}	buildings premises temperature during heating season (°C);
$\theta_{e,m}$	certain month average outside temperature (°C);
A_x	area of the calculated partition (m^2);
U_{x}	heat transfer coefficient of partition (W/m^2*K);
θ_{iC}	buildings premises temperature during unheated period, (°C);
A	floor are on the ground (m^2);
P	floor on ground perimeter (m);
$Q_{H.fg}$	calculated heat losses through ground floor (kW/m^2 * month);
A_{fg1}	floor on the ground area, then there are no thermal isolation or it is continues horizontal (m^2);
U_{fg1}	floor on the ground area, then there is no thermal isolation or it is countinues horizontal, heat transfer coefficient (W/m^2*K);
m	number of the month, for example: January – m=1, Februery – m=2 and so on;
τ	month which has the lowest temperature (τ=1);
$\hat{\theta}_e$	months amplitudes of averages minimal and maximal temperatures of certain months (°C);
β_1	index which evaluates heat stream change delay time through ground floor compared to outside air temperature change each month;
d_{t1}	the resultant floor plate thickness, expressed as a primer layer thickness (m);
w	thickness of the wall which separates floor from outside (m);
λ_{gr}	primer heat transmittance coefficient (W/m*K);
R_{se}	envelope outer surface thermal resistance (m^2*K/W);
R_f	ground floor thermal resistance (m^2*K/W);
R_{si}	envelope inner surface thermal resistance (m^2*K/W);
Ψ_{tb}	linear thermal bridges standard heat transfer coefficient (W/m*K);
l_{tb}	total lenght of linear thermal bridges (m);

ρ_{air} density of air (kg/m^3);

c_{air} specific volume of air (m^3/kg);

v_{inf} average infiltrated air amount through building envelope (m^3/m^2*h);

v_{do} infiltrated air amount because of the outside door opening (m^3/m^2*h);

A_{reH} heated building area in which ventilation supplies air (m^2);

A_{nv} area of the building to which the natural ventilation supplies the air (m^2);

v_o amount of air which is supplied for ventilation in the building (m^3/m^2*h);

η_{reH} energy efficiency of heat recovery unit;

η_{reHair} energy efficiency of AHU heating coil;

V_0 the amount of air which flows inside the building while doors are open. It is accepted that it is V_0=1.5 m^3;

A_0 area per one person in the building m^2;

k_{d1} correction coefficient which evaluates frequency of external door opening;

k_{d2} correction coefficient which evaluates door type;

$Q_{H.env}$ heat losses through the building envelope (kW/m^2 * month);

$Q_{H.w}$ heat losses through the walls (kW/m^2 * month);

$Q_{H.r}$ heat losses through the roof (kW/m^2 * month);

$Q_{H.fg}$ heat losses through the ground floor (kW/m^2 * month);

$Q_{H.wda}$ heat losses through the windows (kW/m^2 * month);

$Q_{H.d}$ heat losses through the doors (kW/m^2 * month);

$Q_{H.\Psi}$ heat losses because of the thermal bridges (kW/m^2 * month);

$Q_{H.vent.reH}$ heat losses because of the mechanical ventilation with heat recovery unit (kW/m^2 * month);

$Q_{H.vent.nv}$ heat losses because of natural ventilation (kW/m^2 * month);

$f_{PRn.E}$ non-renewable energy factor for electricity production;

Q_{PRnE} used primary energy to produce consumed electricity amount;

$Q_{E.eq}$ electrical energy consumption of electrical equipment which is located in the building heated premises (kWh/m^2 * month);

$Q_{E.lg}$ electrical energy consumptions of lightning of the building heated premises (kWh/m^2 * month);

$Q_{E.e}$ electrical energy consumptions of all electrical equipment which is located in the unheated premises of the building (kWh/m^2 * month);

$Q_{E.vent}$ electrical energy consumptions of a mechanical supply and extract ventilation fans (kWh/m^2 * month);

$Q_{C.E}$ electrical energy consumptions for the building cooling (kWh/m^2 * month);

f_E electrical energy part which is consumed in the building heated premises;

Ψ_E annual electricity consumption for the building heated area (kWh/m^2 * month);

0.5 part of electricity which is consumed in the heated premises for electrical devices;

k_m coefficient which describes electricity energy consumption for different months;

25.89 sum of k_m coefficients;

365 number of days per year;

η_E energy effiency indicator of the building lightning (lm/W);

A_{Ceq} the area of the building in which the air cooling device supplies air m^2;

η_{EER} the air cooling device energy efficiency coefficient;

Q_{hw} amount of heat energy needed per month for hot water preparation (kWh/m^2 * month);

Ψ_{hw} annual energy consumption per one square meter of the building for hot water preparation (kWh/m^2);

η_{hw} hot water preparation system energy efficiency;

$f_{PRn.hw}$ non-renewable energy factor;

Q_E external heat gains (kWh/m^2 * month);

$Q_{E.wda}$ monthly heat gains through transparent building surfaces (kWh/m^2 * month);

$Q_{E.op}$ monthly heat gains through opaque building surfaces (kWh/m^2 * month);

0.9 coefficient which evaluates obstacles for solar radiation;

A_{wd-g} rea of the glazed part of the window (m^2);

$I_{sol.wd}$ average solar radiative flux through the window (W/m^2) ;

g_{wd} total solar energy transmittance coefficient through the window (usually 0.7);

h_{se} external surface heat radiation transmittance coefficient (W/m^2 * K) (usually about 4.5);

θ_{er} average temperature difference between outside air and sky (average is about 11℃);

$Q_{N.PRnH}$ nominal primary heating energy (kWh/m^2 * month);

$Q_{N.H.env}$ nominal heat losses through building envelope (kWh/m^2 * month);

$Q_{N.H.vent}$ nominal heat losses because of the building ventilation (kWh/m^2 * month);

$Q_{N.e}$ nominal external heat gains (kWh/m^2 * month);

$Q_{N.i}$ nominal internal heat gains (kWh/m^2 * month);

$f_{N.PRn.H}$ nominal non-renewable energy factor for heating energy production;

$\eta_{N.H.gn}$ nominal heat gains efficiency factor;

$\eta_{N.H}$ nominal heat losses efficiency factor;

$F_{r.wd}$ coefficient which evaluates obstacles for solar radiation;

γ_{wda} angle between horizontal plane and transparent partition;

g_0 heat emitted by human (W);

t premises occupation time per day (h);

$Q_{PRn.H}$ primary heating energy (kWh/m^2 * month);

$Q^I_{PRn.E}$ sum of electricity energy consumption (kWh/m^2 * month);

$Q_{N.E.lg}$ nominal electricity consumption of lightning in the building (kWh/m^2 * month);

Q conduction heat loss through a building component (kWh);

U_i thermal transmittance factor for a building component (W/m^2 * K);

A_i area of the building component (m^2);

T_{ind} indoor air temperature (°C);

T_{outd} outdoor air temperature (°C);

Δt time period length (h);

1000 factor for converting the denomination to kilowatt hours;

l_k length of a linear thermal bridge caused by joints in the building components (m);

Ψ_k additional thermal bridge conductance caused by joints between building components (W/m * K);

x_j additional conductance caused by joints between building components (W/K);

J factor grouping heating energy into the different month and it also depends on the soil type (W/K);

P is the plate circumference, i. e. the sum of the plate sides facing the outdoor air, meaning the length of the plinth insulation, (m);

T_u is the difference between annual maximum and minimum temperatures divided by two;

$Q_{air\ leakage}$ energy required to heat air leakage (kWh);

ρ_i air density (1.2 kg/m^3);

c_{pi} specific heat capacity of air (1000 Ws/kg * K);

$q_{v,air\ leakage}$ air leakage flow m^3/s;

n_{50} is the air leakage number of a building with a 50 Pa pressure difference (1/h);

V air volume of a building m^3;

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

x factor which is: 20 for three and four-storey buildings;

t_d ventilation system's mean daily running time ratio (h/24h);

t_V ventilation system's weekly running time ratio (days/7days);

$q_{v.supply}$ supply air flow rate (m^3/s);

T_{ib} inblow air temperature (℃);

T_{recov} temperature after heat recovery device (℃);

$Q_{dhw.net}$ net energy need for domestic hot water (kWh);

ρ_v water density 1000 (kg/m^3);

c_{pv} specific heat capacity of water 4.2 (kJ/kg * K);

V_{dhw} . domestic hot water consumption (m^3);

T_{dhw} domestic hot water temperature (℃);

T_{cv} domestic cold water temperature (℃);

$W_{lightning}$ electric energy consumption of lighting (kWh);

E illuminance of space (lx);

β Luminaire Maintenance Factor (0.6);

η coefficient of utilization (0.35);

η_Φ lamp efficiency (lm/W);

A_{room} surface area of the room to be illuminated room (m^2);

f control factor depending on the lightning control type (1/0 – on/off control);

Q_{person} heat energy emitted by a person/s (kWh);

k building's utilization level during operation, presenting the average time people stay in the building;

Δt_{stay} length of stay (h);

n number of persons;

Φ_{person} mean heat output of person (not including evaporation level) (W/person);

Q_{solar} solar radiant energy entering the building through the windows (kWh/month);

$G_{radiant,horizontal}$ total solar energy on a horizontal surface per unit area (kWh/m^2);

$F_{direction}$ conversion factor for converting the total solar radiant energy on a horizontal surface to total radiant energy on a vertical surface by compass direction;

$F_{transmittance}$ total correction factor for radiation transmittance (usually taken 0.75);

A_{win} surface area of a window opening (including frame and casing) (m^2);

g transmittance factor for total solar radiation through a daylight opening;

$G_{radiant,vertical}$ total solar radiant energy on a horizontal surface per unit area (kWh/m^2);

E consumed energy per one square meter (kWh/ m^2*a);

$W_{lightning}$ electric energy consumption of lighting (kWh);

$Q_{heating}$ heating demand of the building (kWh);

$f_{Hprimary}$ primary energy factor for heating source;

$W_{heating}$ electrical energy used for heating purposes (kWh);

W_{vent} electrical energy used for ventilation purposes (kWh);

W_{cool} electrical energy used for cooling (kWh);

$W_{appliences}$ electrical energy used for electrical devices;

$W_{lightning}$ electrical energy used for lightning;

$f_{Eprimary}$ primary energy factor for electricity;

A_{net} total area of building area (m^2);

Q_{norm} normalized heating energy per square meter of the building (kWh/m^2 a);

S_n average of degree days;

S_{year} particular year degree days;

Q_{SH} particular year energy consumption for the space heating (kWh/m^2 a);

1. INTRODUCTION

Nowadays all the world is concerned about global warming. This phenomenon has occurred because of intense human activities which are directly related to energy production. And the most common way of energy production is burning fossil fuels. After burning process the pollutants of burned fuels are emitted to the environment. These pollutants accumulate in the atmosphere and create green-house effect which is responsible for global warming.

The Kyoto protocol was introduced in 1997 and it came into force in 2005. This protocol is based on reducing green-house gas emissions. This agreement had to be introduced to stop annual temperature rise in the earth. After that, "European Union climate and energy package" was adopted in 2008. Its goals are to lower green-house emissions by 20% compared to 1990 to increase energy efficiency by 20% and to reach 20% of renewable energy share in total energy consumption in EU by 2020.

The final energy consumption is divided into sectors: buildings, transportation and industry. Buildings use about 40 per cent, transportation and industry about 30 per cent. From these figures we can assume that the biggest final energy savings lies in the buildings sector.

There are several different ways to save energy in buildings but the best result can be achieved when methods are combined. The first aspect of building which can be improved to save energy is the building envelope. The second aspect can be said to be the installation or improvement of the engineering systems as mechanical ventilation, heating substation, renewable energy stations and others. Third, very important, aspect is utilization of internal and external heat gains. And the fourth aspect is efficiency of electrical devices which are used in the building.

Following European directives from 2016 all newly built buildings in Lithuania should be A or higher energy class. It means that these buildings will have to use about two times less energy annually than buildings which are now constructed and have B energy class. In this case almost all possible aspects of energy saving mentioned above will have to be used to meet energy performance requirements.

The renovation of the old buildings is very urgent question because old buildings sometimes consume a dozen times more final energy than a new buildings. Their condition is only going to be worse after some more years, so it is important to start their renovation now. Another reason is that later the requirements for energy classes will increase and it will be impossible or it will be too expensive to renovate old buildings which now are in a bad condition.

The evaluation of energy class of an existing building requires many calculations. First of all the determination of building envelope heat losses is necessary. It includes external walls, windows, doors, roof and even ground floor. U-values of elements must be taken by standards presented in the year building was built or it should be calculated approximately by knowing the structure of walls, roof, windows. Hot water consumption must also be calculated according to present standards.

When the building parameters are known, the renovation can be implemented. However, it is not that easy to calculate and foresee accurately what will be the renovation results. Moreover, it is even harder to evaluate the lifecycle of the renovated building and its payback time. Usually renovation payback time is 15-20 years and it does not have economical value, but in the long run it noticeably lowers the final energy use.

Simulations of the renovation of the old building help to improve energy efficiency and performance in the future and also lets designer to evaluate indoor conditions of the renovated building. In this case the optimal model is created. Simulations gives great advantages when the thermal bridges, air leakages and other minor things, which have huge impact, should be evaluated.

This bachelor’s thesis has two parts. In the first part the idea of renovation and its importance will be presented. The national building codes of Lithuania and Finland also will be introduced and analysed because they play main role in setting up the required values for the final result of building renovation. In second part the renovation will be presented from practical point of view. Some calculations will be presented, analysed and in the end compared between the two countries.

In the practical part the simulations of building renovation will be done. During the simulation process the envelope of the building will be improved. Engineering systems

will be replaced and some new ones installed. After simulations the results will be analysed and compared between Finland and Lithuania.

2. AIMS AND METHODS

This bachelor's thesis has several aims. The first aim is to find out the energy consumptions of an existing example building built in 1985 in Lithuania and Finland. To find out how the energy consumption will change after present standards will be applied to the residential building.

The second aim is to find out what should be done to renovate building in Lithuania and in Finland to an A energy class. Is it enough just to apply latest requirements of national building codes or the greater improvements must be done.

The third aim is to find out which of the buildings, in Finland or in Lithuania, will be more energy efficient according to national build standards after the renovation.

The residential example building which is in Mikkeli, Finland will be created and simulated to implement the aims. The building model will be designed with MagiCAD program and then it will be transferred to IDA ICE 4.6.2 program with which the heat losses, heat gains and E-value will be calculated by specifying building properties.

The residential building which is in Vilnius, Lithuania will be analysed using national building code of Lithuania and Microsoft Excel program. The formulas will be transferred to the Excel and then energy losses, energy gains and energy class will be obtained.

In the first calculations and simulation the residential building will be created by 1985 national building codes standards. With those values it will have reference values of energy consumption and energy class.

Later the external partitions will be improved to current requirements and the mechanical supply and exhaust ventilation system with heat recovery unit installed. The energy consumption and energy class will be evaluated.

If building in Lithuania or in Finland will not have an A energy class after improvements then more simulations and calculations will be done. The aim is to find out how the

parameters of building envelope and heating system must be changed in the residential building to achieve an A energy class, which is the same as in newly built houses.

3. THEORETICAL BACKGROUND

The main purpose of a building renovation is to restore or to improve the energy performance of the building. It is needed to be done to lower final energy consumptions. This not only give economical advantages of reduced expenditures on building maintenance and operational costs, but it also helps to decrease amount of emitted CO_2. It is because less energy needs to be produced and less energy means less green-house gas emissions (GHGE).

There are several different ways of lowering energy consumptions in the buildings, but the best results are achieved when combined solutions are implemented. Building renovation can be divided into four main energy saving renovation methods:

- The insulation of external walls;
- The replacement of windows, doors and improvement of air tightness;
- The heating system renovation;
- The ventilation system renovation or a new one installation; /1./

All these methods can lower heat losses of the building and some of them can increase external heat gains level, as well as, several of them can protect from unwanted external heat gains.

3.1. The concrete sandwich panel wall renovation

External walls create the biggest area of the outer shell of the building. In this way it is responsible for a great part of the heat loss in any building. To save energy additional thermal insulation can be applied on the walls. There are many ways to do this, but the most typical one in Finland and Lithuania is installing additional thermal insulation on the external wall from inner or outer side. /1./

During the period of 1960-1985 in Lithuania and Finland multi-family buildings were usually built using concrete sandwich elements. “As a matter of fact, more than 60% of Finnish building stock has been built in the 1960’s or later (Statistics Finland 2010).“ /3, p11/. The external walls of these houses were built from two layer of concrete and between them the insulation was located. /1./ The example of such wall is shown in Figure 1.

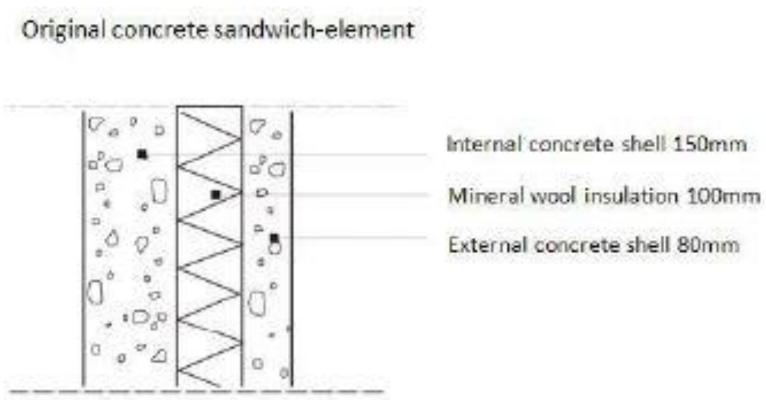

FIGURE 1. Example of typical concrete sandwich element /1/

The wall from Figure 1 can be thermally insulated in two ways. The way depends on outer concrete layer condition. If the concrete is in good shape, the thermal insulation can be directly added on it. But before applying it the outer layer of concrete must be bolted to the inner concrete layer. The usual insulation when this method is used is mineral wool or cheaper polystyrene or more advanced polyurethane. Its thickness is normally around 50 to 100 mm. /1./ The example of this renovation type is presented in Figure 2.

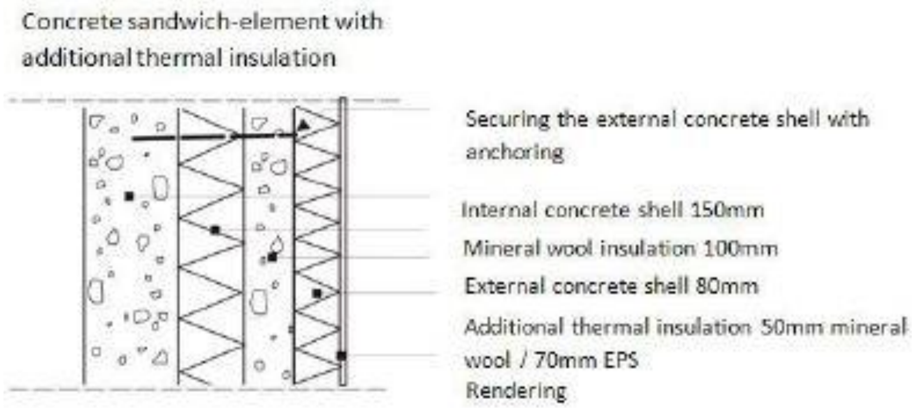

FIGURE 2. Example of external insulation layer on top of the outer concrete layer /1/

The other way of concrete sandwich element thermal insulation is presented in Figure 3. This type of wall renovation starts by taking away the outer layer of concrete and old insulation layer. This method is applied when outer concrete layer is in a bad shape. Then two primary layers are removed. The new insulation can be put on the second concrete layer. Insulation is usually selected as mineral wool and its thickness can be up to 300-350 mm. The building can reach passive-house-level when the external wall

is refurbished in this way. But it should not be forgotten to install ventilation system in building to make this refurbishment successful. /1./

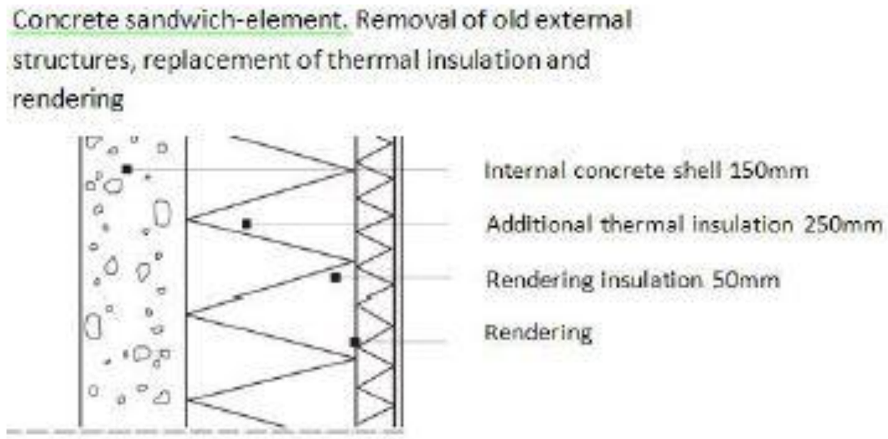

FIGURE 3. Example of external insulation layer after removing the old insulation /1/

The thermal insulation can also be fixed on the inner side of external wall as it is shown in Figure 4. It can be done because of bad façade condition. Additionally this type of wall insulation requires extra layer, called water vapor barrier, to avoid moisture concentration between new insulation and external wall. The thickness of thermal insulation usually is around 12-25 mm. This insulation method can be fitted for concrete sandwiches elements, but more often it is used for sawdust walls or logwood walls. /1./

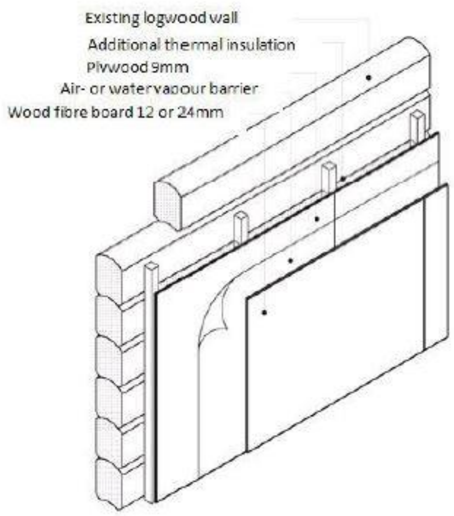

FIGURE 4. Example of insulation layer on the inner side of an external wall /1/

3.2. The renovation of flat roof

Flat roof renovation can be divided into two different methods. First one is additional insulation of flat roof. This can be done if existing water proof layer is in good condition. Then on it the additional insulation can be fixed to improve the level of energy performance. However, this renovation type has a few more rules: the inclination layer, which is made from dry expanded clay pallets, must be installed and additional thermal insulation, which can only be from mineral wool, must be at least same thickness as an old insulation layer. /1;2./ The example of this flat roof renovation is presented in Figure 5.

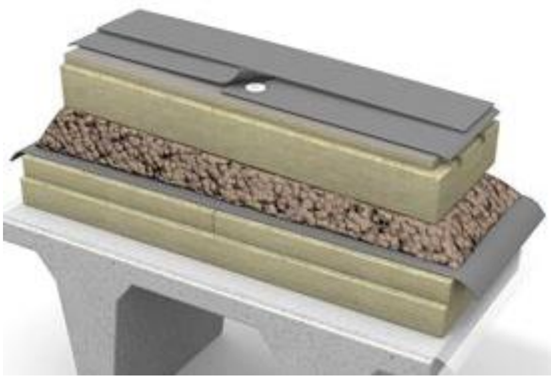

FIGURE 5. Example of additional thermal insulation on flat roof /2/

The second method of a flat roof renovation is presented in Figure 6 and is done by taking all old roof material with insulation and water proof layer and constructing a completely new roof coating which will have better thermal insulation values and will preserve thermal energy inside the building. /1;2./

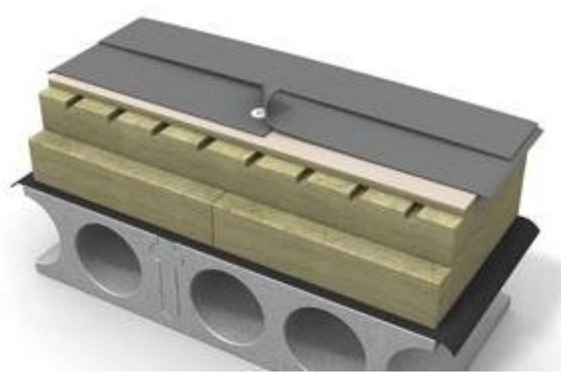

FIGURE 6. Example of a new layer of insulation on flat roof /2/

3.3 The renovation of ground floor

As with the roof renovation same with the internal base floor renovation. There are two different possibilities to improve the performance of the base floor. The first possibility is to add more insulation on top of the existing layer of insulation. Of course when this type of renovation is selected the extra work must be done to avoid condensation, which would lead to corruption of the new insulation layer. Also this type of renovation creates challenges because additional layer of the insulation raises the floor level and causes problems with doors. /1./ The example of such renovation is presented in the Figure 7.

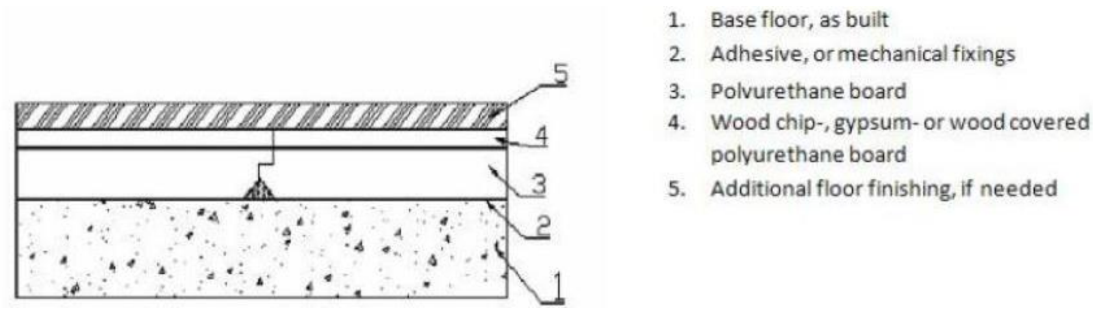

FIGURE 7. Example of the additional thermal insulation of the ground floor /1/

Second possible renovation type of internal base floor is simpler and creates less additional problems. The main idea is removing all the old insulation and installing a new one. This type of internal base floor rebuilding increases reliability and reduces possible heat losses through thermal bridges. /1/.

When internal base floor renovation is completed the works can move to the outside part of the base floor. The floor slab can also be refurbished when the aim is tighter building and less heat losses.

There are two types of floor slab insulation and the example of them can be found in Figure 8: horizontal and vertical. Both are frost protective and heat loss diminishing solutions which protect building foundation. It is profitable to perform floor slab insulation then the floor surface needs to be replaced. /1./

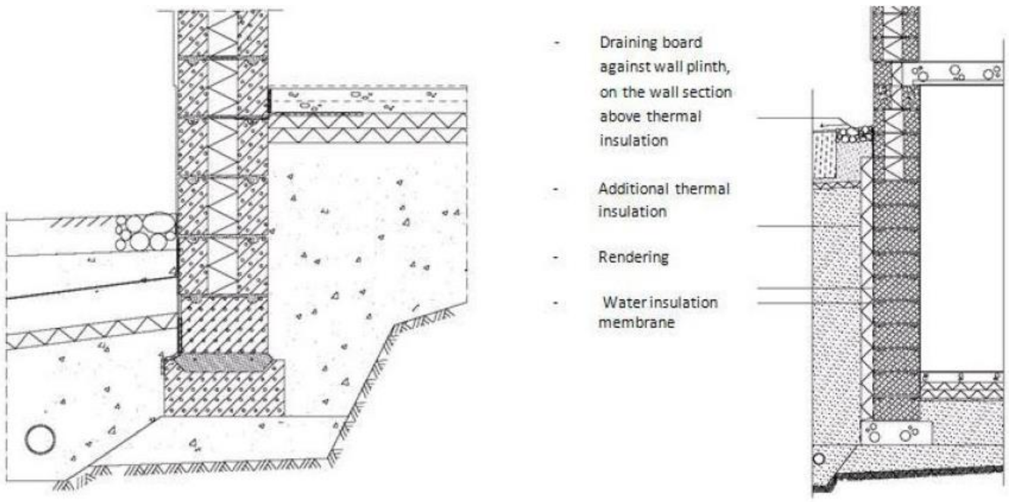

FIGURE 8. Example of additional thermal insulation of floor slab /1/

3.4. The replacement of window

Windows area usually is 10-15% of the total external wall area and they are relatively small, but because of high thermal conductivity the heat losses through this external partition are great. The best decision is to replace the windows when the renovation of the house is performed. It is because glass and windows frames have improved drastically in the last few decades. The thermal transmittance coefficient of the new windows is up to 3 times smaller in comparison with an old windows. Windows replacement also improves the tightness of buildings because thermal bridges are eliminated. /1/. The example of modern windows is presented in Figure 9.

FIGURE 9. Example of modern window frame and glass set-out /1/

3.5. Renovation of heating systems

During the renovation of the heating system of a multi-family building which is connected to the district heating system the sub-station is rebuilt. New heat exchangers for space heating and domestic hot water are installed. All pipes, control valves, sensors, pumps in the sub-station are replaced. This helps to avoid accidents and the unwanted heat losses in the supply network of the heat energy. /1./

After installing a new heating system initial adjustments must be done. All pre-set values must be recalculated, because of increased efficiency of all units and possibly renovated building. The heat demand should be much lower, so the supplied energy should also decrease. /1./

3.6. Renovation of an existing ventilation system

The multi-family residential buildings in 1960-1985 were usually built from concrete sandwich panels and were using natural or mechanical supply and exhaust ventilation systems. This type of ventilation systems provided 0.3-0.55 air-change rate (1/h) (including air-leakage). There were no heat recovery systems in this kind of buildings. /1./

Ventilation system which takes care that the building is provided with fresh air and ensures good conditions for building structures can be called well-functioning. “The ventilation system must be able to remove the impurities which are produced to the inside air (smells, moisture, carbon dioxide) and inorganic compounds evaporating from the interior materials”. /1, p75/.

There are three possible ventilation options nowadays. The first option is called natural ventilation. In this type of the ventilation there are no mechanical parts or other moving parts which can break so it is long lasting system. It is working because of pressure difference which occurs then density difference between internal and external air exists. Also the wind can be the working force of this type of the ventilation system. /1./

The second option of ventilation system for building is mechanical supply and exhaust ventilation. This system has no heat recovery unit and only moves the air from outside

to inside the building and vice versa. However, neither first ventilation system nor the second can ensure good indoor climate in the premises. /1./

The third ventilation system is the most practical and energy efficient. It is called mechanical supply and exhaust ventilation system with heat recovery unit which helps to save heating energy. The air is supplied and extracted by fans which ensures constant and weather independent air flow. /1./

As it was mentioned before in 1960-1985 building ventilation system was either natural or mechanical supply and extract. When the renovation is performed in the building the ventilation renovation can not be forgotten, because the building after renovation will be tighter and will need more advanced ventilation system to ensure comfort.

The most beneficial renovation type of ventilation system is upgrading it from existing condition to mechanical supply and exhaust system with a heat recovery unit. It is the most beneficial because the heat is regenerated from extracted air in the heat exchanger and in this way heating energy is saved. Of course this renovation is the most expensive one, but without this upgrade the building can not reach an A energy class.

There are two types of mechanical supply and exhaust ventilation system with heat recovery unit which can be implemented in renovation of the building. One is centralized and the second one is distributed ventilation system. Their application depends on building type and needed amount of air. /1./

Air handling unit (AHU) in centralized ventilation system can be installed on the roof of the building. This AHU distribution ducts can be fitted in the staircase or in existing ventilation channels. Centralized system is installed when more or less all premises in the building have same properties and no extra filtering, humidifying or drying is needed. /1./

When in a building every flat has its own ventilation system and independently takes care of supplied and extracted air is called distributed ventilation system. This system AHU can be installed in kitchen, toilet or other premise because it is very small. One more advantage of this system is easier installation of ventilation ducts. However, it is more expensive to install and maintain this kind of system. /1./

4. NATIONAL BUILDING CODES IN LITHUANIA AND FINLAND

4.1. Lithuanian national building code (STR)

This building code determines norms of any kind of building which is being built or renovated or demolished in Lithuania. STR specifies values for building performance and indoor climate regulations. Also it presents methods for evaluation and calculation of building structures, heat losses, heat gains, indoor air parameters, materials which are used in building and etc. This is the main law in Lithuania which determines all building from A to Z.

Heat loss calculations are a complex process. During it many envelope parts of the building must be evaluated. The thermal resistance, thermal bridges, air infiltration, ventilation and other factors must be determined. The values and calculations accuracy must be two numbers after a comma.

In the beginning the type of the building must be determined. When the type is known the values needed for calculation can be chosen. These values are presented in the tables in STR. /4./ For this bachelor's thesis only residential buildings data will be analysed and presented. It is because this thesis analyse only the renovation opportunities of this type of the buildings.

4.1.1 Building walls, roof, windows and doors

The heat losses through external walls, roof, windows and doors can be calculated by one formula. In this formula only the area and U-value of the building partition must be changed to represent partitions parameters. By this formula the heat losses are calculated per one square meter per month. The formula is presented below /4/:

$$Q_{H.x} = \frac{0.001 * t_m * 24}{A_p} * A_x * U_x * \left(\theta_{iH} - \theta_{e,m}\right); \tag{1}$$

where U_x is a heat transfer coefficient (W/m^2*K), A_x area of the calculated partition (m^2); θ_{iC} is a buildings premises temperature during unheated period, (℃);
0.001 is a factor which convert W to kW; 24 is an amount of hours per day (h); $Q_{H.x}$ is a calculated heat losses through one square meter of building envelope element per month (kW/m^2 * month), t_m is a number of days of certain month,

A_p is an area of the building which is heated (m^2), θ_{iH} is a buildings premises temperature during heating season (°C), $\theta_{e,m}$ is a certain month average outside temperature (°C),

By this formula the heat losses are calculated per one square meter per month. Amount of energy needed for building cooling per month, because of heat gains, is calculated by the same formula as heat losses of the building envelope, just the building premises temperature during the heating period (θ_{iH}) is changed to the building premises temperature during the cooling period (θ_{iC}).

4.1.2 Ground floor

Calculations of heat losses through ground floor is more complex. It is because in this step more variables are included and temperature of ground is not homogeneous under all perimeter of the ground. Heat losses through the ground floor are calculated by following formula /4./:

$$Q_{H.fg} = \frac{0.001 * t_m * 24}{A_p} * \left(\sum_{x=1}^{n} \left[A_{fg1} * \frac{2\lambda_{gr}}{\pi B_1' + d_{t1}} \ln\left(\frac{\pi * \frac{A_{fg1}}{0.5 * P}}{d_{t1}} + 1 \right) * \left(\theta_{iH} - \theta_{e,m}\right) + \hat{\theta}_e * \cos\left(2\pi * \frac{m - \tau - \left(1.5 - 0.42 * \ln\left(\frac{\delta}{\left(w + \lambda_{gr} * \left(R_{se} + R_f + R_{si}\right)\right) + 1} \right) \right)}{12} \right) * 0.37 * P * \lambda_{gr} * \ln\left(\frac{\delta}{d_{t1}} + 1 \right) \right] \right); \quad (2)$$

where $Q_{H.fg}$ heat losses through the ground floor (kW/m^2 * month); A is an area of the floor which is on the ground (m^2); P is a floor on ground perimeter (m); $Q_{H.fg,m}$is a calculated heat losses through ground floor (kW/m^2 * month); U_{fg1} is a floor on the ground heat transfer coefficient (W/m^2*K); m is a number of the month, for example: January – m=1, February – m=2 and so on; τ is a number of a month which has the lowest temperature (τ=1); θ_{iH} is a design internal temperature during the heating season (°C); $\theta_{e,m}$ is a certain month average outside temperature (°C); $\hat{\theta}_e$ is a months amplitudes of averages minimal and maximal temperatures of certain months (°C); β_1 is an index which evaluates heat stream change delay time through ground floor compared to outside air temperature changes; d_{t1} is the resultant floor plate thickness, expressed as a primer layer thickness (m); w is a thickness of the wall which separates floor from outside (m); λ_{gr} is a primer heat transmittance coefficient (W/m*K); R_{se} is an envelope outer surface thermal resistance (m^2*K/W); R_f is a ground floor thermal resistance

(m^2*K/W); R_{si} is an envelope inner surface thermal resistance (m^2*K/W); t_m is a number of days of certain month, 0.001 is a factor which converts W to kW; 24 is an amount of hours per day (h); A_p is a heated area of the building (m^2);

Amount of energy needed for building cooling per month, because of heat gains, is calculated by the same formula as heat losses of the ground floor, just the building premises temperature during the heating period (θ_{iH}) is changed to the building premises temperature during the cooling period (θ_{iC}).

4.1.3 Thermal bridges

Heat losses should be evaluated through thermal bridges /4./:

- Between building external walls and ground floor;
- The perimeter of window frame;
- The perimeter of entrance doors;
- Between building external walls and roof;
- In the inner and outer corners of the façade;
- Between external wall and balcony floor;
- In those places were ceiling and external walls meets;
- Perimeter of transparent partitions;

The thermal bridges heat losses calculations should be performed in two cases. The first case is when heat losses are calculated in relation to heating demand and the second case is when heat losses are calculated in relation to cooling demand. /4./

The formula for thermal bridges heat losses calculation in relation to heat demand /4./:

$$Q_{H.\Psi} = \frac{0.001 * t_m * 24}{A_p} * \left(\theta_{iH} - \theta_{e,m}\right) * \sum_{x=1}^{n} [\Psi_{tb} * l_{tb}]\,; \qquad (3)$$

where $Q_{H.\Psi}$ heat losses because of the thermal bridges (kW/m^2 * month); Ψ_{tb} is a linear thermal bridges standard heat transfer coefficient (W/m*K); l_{tb} is a total lenght of linear thermal bridges (m); t_m is a number of days of certain month, 0.001 is a factor which converts W to kW; 24 is an amount of hours per day (h); A_p is a heated area of the building (m^2); θ_{iH} is a buildings premises temperature during heating season (°C); $\theta_{e,m}$ is a certain month average outside temperature (°C);

Amount of energy needed for building cooling per month, because of heat gains, is calculated in the same way as heat losses of the building thermal bridges, just the building premises temperature during the heating period (θ_{iH}) is changed to the building premises temperature during the cooling period (θ_{iC}).

4.1.4 Ventilation

If in the building natural ventilation systems is installed, then the heat losses because of natural ventilation can be calculated by following formula /4./:

$$Q_{H.vent.nv} = \frac{A_{nv}}{A_p} * 0.001 * t_m * 24 * \rho_{air} * c_{air} * v_o * (\theta_{iH} - \theta_{e,m}); \quad (4)$$

where $Q_{H.vent.nv}$ heat losses because of natural ventilation (kW/m^2 * month); t_m is a number of days of certain month, 0.001 is a factor which converts W to kW; 24 is an amount of hours per day (h); A_p is a heated area of the building (m^2); ρ_{air} is a density of air (kg/m^3); c_{air} is a specific volume of air (m^3/kg); A_{nv} is an area of the building to which the natural ventilation supplies the air (m^2); v_o is an amount of air which is supplied for ventilation in the building (m^3/m^2*h); θ_{iH} is a buildings premises temperature during heating season (°C); $\theta_{e,m}$ is a certain month average outside temperature (°C);

If building is equipped with mechanical supply and exhaust system which have heat recovery unit and heating coil then the following formula is used /4./:

$$Q_{H.vent.reH} = \frac{0.001 * t_m * 24 * \rho_{air} * c_{air} * (\theta_{iH} - \theta_{e,m})}{A_p} * \left[\left(v_{inf} + \left(\frac{V_0}{24 * A_0} * k_{d1} * k_{d2}\right)\right) * A_{reH} + (v_o - v_{inf} - v_{do}) * \sum_{x=1}^{n}[A_{reH} * (1 - \eta_{reH})]\right]; \quad (5)$$

where $Q_{H.vent.reH}$ heat losses because of the mechanical ventilation with heat recovery unit (kW/m^2 * month); t_m is a number of days of certain month, 0.001 is a factor which converts W to kW; 24 is an amount of hours per day (h); A_p is a heated area of the building (m^2); ρ_{air} is a density of air (kg/m^3); c_{air} is a specific volume of air (m^3/kg); v_{inf} is an average infiltrated air amount through building envelope (m^3/m^2*h); v_o is an amount of air which is supplied for ventilation in the building (m^3/m^2*h); θ_{iH} is a buildings premises temperature during heating season (°C); $\theta_{e,m}$ is a certain month average outside temperature (°C); v_{do} is an infiltrated air amount because of the outside door opening (m^3/m^2*h); A_{reH} is a heated building area in which ventilation supplies air (m^2); η_{reH} is an energy efficiency of heat recovery unit; V_0 is an amount of air which flows inside the building while doors are open. It is accepted that it is V_0=1.5 m^3; A_0 is an area per one person in the building; k_{d1} is a correction

coefficient which evaluates frequency of external door opening; k_{d2} correction coefficient which evaluates door type;

The following formula is used when the heat energy for supplied air heating to room temperature has to be found. It can be used then AHU have heat recovery unit and heating coil inside /4./:

$$Q_{H.vent.reH} = \frac{0.001*t_m*24*\rho_{air}*c_{air}*(\theta_{iH}-\theta_{e,m})}{A_p} * \left[(v_o - v_{inf} - v_{do}) * \frac{A_{reH}*(1-\eta_{reH})}{\eta_{reHair}}\right];$$

(6)

where $Q_{H.vent.reH}$ heat losses because of the mechanical ventilation with heat recovery unit (kW/m^2 * month); t_m is a number of days of certain month; 0.001 is a factor which converts W to kW; 24 is an amount of hours per day (h); c_{air} is a specific volume of air (m^3/kg); A_p *is a heated area of the building* $(m2)$; ρ_{air} is a density of air (kg/m^3); θ_{iH} is a buildings premises temperature during heating season (°C); $\theta_{e,m}$ is a certain month average outside temperature (°C); η_{reHair} is an energy efficiency of AHU heating coil; v_o is an amount of air which is supplied for ventilation in the building (m^3/m^2*h); v_{do} is an infiltrated air amount because of the outside door opening (m^3/m^2*h); v_{inf} is an average infiltrated air amount through building envelope (m^3/m^2*h); A_{reH} is a heated building area in which ventilation supplies air (m^2);

Amount of energy needed for building cooling per month, because of heat gains, is calculated in the same way as heat losses of the building because of the ventilation, just the building premises temperature during the heating period (θ_{iH}) is changed by the building premises temperature during the cooling period (θ_{iC}).

4.1.5 Sum of building heat losses

The sum of building heat losses are found by summing heat losses through walls, roof, ground floor, windows, doors, thermal bridges and ventilation. The concept is presented in formula below /4./:

$$Q_{H.env} = Q_{H.w} + Q_{H.r} + Q_{H.fg} + Q_{H.wda} + Q_{H.d} + Q_{H.\Psi} + Q_{H.vent.nv} + Q_{H.vent.reH}$$

(7)

where $Q_{H.env}$ heat losses through the building envelope (kW/m^2 * month); $Q_{H.w}$ heat losses through the walls (kW/m^2 * month); $Q_{H.r}$ heat losses through the roof (kW/m^2 * month); $Q_{H.fg}$ heat losses through the ground floor (kW/m^2 * month); $Q_{H.wda}$ heat losses through the windows (kW/m^2 * month); $Q_{H.d}$ heat losses through the doors (kW/m^2 * month); $Q_{H.\Psi}$ heat losses because of the thermal bridges (kW/m^2 * month);

$Q_{H.vent.reH}$ heat losses because of the mechanical ventilation with heat recovery unit (kW/m^2 * month); $Q_{H.vent.nv}$ heat losses because of natural ventilation (kW/m^2 * month);

4.1.6 Electricity energy consumption in the building

The electricity consumptions are calculated per month. The electrical equipment in the heated spaces, lightning in the heated spaces, electricity consumption for all needs in the unheated spaces, electricity consumption for ventilation system and the electricity for building cooling must be taken into account when the electricity consumption are calculated /4./

Every month primary energy consumption of an electricity for a building is calculated like this if it is taken from the electricity grid /4./:

$$Q_{PRnE} = \left(Q_{E.eq} + Q_{E.lg} + Q_{E.e} + Q_{E.vent} + Q_{C.E}\right) * f_{PRn.E} = \left(\left(\frac{t_m}{365} * 0.5 * f_E * \Psi_E\right) + \left(\frac{k_m}{25.89} * 0.5 * f_E * \Psi_E * \frac{1}{A_p} * \sum_{x=1}^{n}\left[A_p * \frac{15}{\eta_E}\right]\right) + \left(\frac{t_m}{365} * \Psi_E * (1 - f_E)\right) + \left(\frac{0.001 * t_m * 24 * (v_o - v_{inf} - v_{do})}{A_p} * \sum_{x=1}^{n}[A_{reH} * G_{reH}]\right) + \left(Q_C * \frac{1}{A_p} * \sum_{x=1}^{n}\left[\frac{A_{Ceq}}{\eta_{EER}}\right]\right)\right) * f_{PRn.E}; \tag{8}$$

where Q_{PRnE} is a used primary energy to produce consumed electricity amount; $f_{PRn.E}$ is a non-renewable energy factor for electricity production; $Q_{E.eq}$ is an electrical energy consumption of electrical equipment which is located in the building heated premises (kWh/m^2 * month); $Q_{E.lg}$ is an electrical energy consumptions of lightning of the building heated premises (kWh/m^2 * month); $Q_{E.e}$ is an electrical energy consumptions of all electrical equipment which is located in the unheated premises of the building (kWh/m^2 * month); $Q_{E.vent}$ is an electrical energy consumptions of a mechanical supply and extract ventilation fans (kWh/m^2 * month); $Q_{C.E}$ is an electrical energy consumptions for the building cooling (kWh/m^2 * month); f_E is an electrical energy part which is consumed in the building heated premises; Ψ_E is an annual electricity consumption for the building heated area (kWh/m^2 * month); 0.5 is a part of electricity which is consumed in the heated premises for electrical devices; k_m is a coefficient which describes electricity energy consumption for different months 25.89 sum of k_m coefficients; η_E is an energy efficiency indicator of the building lightning (lm/W); A_{Ceq} is an area of the building in which the air cooling device supplies air m^2; η_{EER} is an air cooling device energy efficiency coefficient; v_o is an amount of air which is supplied for ventilation in the building (m^3/m^2*h); v_{do} is an infiltrated air amount because of the outside door opening (m^3/m^2*h); v_{inf} is an average infiltrated air amount through building envelope (m^3/m^2*h); A_{reH} is a heated building area in which ventilation supplies air (m^2); t_m is a number of days of certain month; A_p is a heated area of the building (m^2); 365 is a

number of days in the year; G_{reH} is an electrical energy required to transfer one cubic meter of air (kW/m^3);

4.1.7 Energy consumption for hot water preparation in the building

The formula below is used when the primary energy consumption from non-renewable energy sources should be found. It is applied when in all building there is only one hot water preparation system /4./

$$Q_{PRn.hw} = \left(\frac{\left(\frac{\Psi_{hw} * t_m}{365} \right) * \frac{1}{\eta_{hw}}}{\eta_{hw}} \right) * f_{PRn.hw}; \quad (9)$$

where η_{hw} is a hot water preparation system energy efficiency; $f_{PRn.hw}$ is a non-renewable energy factor; Ψ_{hw} annual energy consumption per one square meter of the building for hot water preparation (kWh/m^2); t_m is a number of days of certain month; 365 is a number of days in the year;

4.1.8 The building heat gains

To evaluate heat gains of the building premises the transparent and opaque building surfaces must be investigated. The following formula describes the composition of heat gains /4./:

$$Q_E = Q_{E.wda} + Q_{E.op}; \quad (10)$$

where Q_E external heat gains (kWh/m^2 * month); $Q_{E.wda}$ is a monthly heat gains through transparent building surfaces (kWh/m^2 * month); $Q_{E.op}$ is a monthly heat gains through opaque building surfaces (kWh/m^2 * month);

The following formula shows how the heat gains through transparent partitions are calculated:

$$Q_{E.wda} = \frac{0.001 * t_m * 24 * 0.9}{A_p} * \sum_{x=1}^{n} \left[A_{wd-g} * I_{sol.wd} * g_{wd} \right] - \frac{0.001 * t_m * 24 * R_{se} * h_{se} * \theta_{er}}{A_p} * \sum_{x=1}^{n} \left[F_{r.wd} * A_{wd} * U_{wd} \right]; \quad (11)$$

where $Q_{E.wda}$ heat gains through transparent partitions (kWh/m^2 * month); t_m is a number of days of certain month; 0.9 is a coefficient which evaluates obstacles for solar radiation; A_{wd-g} is an area of the glazed part of the window (m^2); $I_{sol.wd}$ is an average

solar radiative flux through the window (W/m^2) ; g_{wd} is a total solar energy transmittance coefficient through the window (usually 0.7); h_{se} is an external surface heat radiation transmittance coefficient (W/m^2 * K) (usually about 4.5); θ_{er} is an average temperature difference between outside air and sky (average is about 11℃); $F_{r.wd}$ is a coefficient which evaluates obstacles for solar radiation; 0.001 is a factor which converts W to kW; 24 is an amount of hours per day (h); A_p is a heated area of the building (m^2); A_{wd} area of a window (m^2); U_{wd} is a thermal transmittance coefficient of a window (W/m^2*K);

When the calculations are performed to find heat the gains through opaque surfaces the same formula is used as formula 11. The only difference is that the areas and U-values of opaque building partitions must be inserted into formula instead of same values for transparent partitions.

4.1.9 The building internal heat gains

By the following formula internal heat gains can be calculated:

$$Q_I = 0.001 * t_m * \frac{g_0 * t}{A_0} + Q_{E.eq} + Q_{E.lg} \qquad (12)$$

where t_m is a number of days of certain month; 0.001 is a factor which converts W to kW; 24 is an amount of hours per day (h); $Q_{E.eq}$ is an electrical energy consumption of electrical equipment which is located in the building heated premises (kWh/m^2 * month); $Q_{E.lg}$ is an electrical energy consumptions of lightning of the building heated premises (kWh/m^2 * month); g_0 is a heat emitted by human (W); t is a premises occupation time per day (h); A_0 is an area per one person in the building m^2;

4.1.10 The energy class calculations by STR

To find energy class in Lithuania the following calculations must be performed. These calculations will let to obtain C_1 and C_2. First coefficient depends on heating energy, electricity energy, ventilation and hot water production. When these values are inserted in formula 16 then the C_1 coefficient is found. It shows to which energy class building is assigned. C_2 factor is very important when the energy classes higher than B is calculated. It only depends on how water system and is calculated by formula 19.

$$Q_{N.PRn.H} = \frac{Q_{N.H.env} + Q_{N.H.vent} - \eta_{N.H.gn} * (Q_{N.e} + Q_{N.i})}{\eta_{N.H}} * f_{N.PRn.H}; \qquad (13)$$

where $Q_{N.PRnH}$ is a nominal primary heating energy (kWh/m^2 * month); $Q_{N.H.env}$ are a nominal heat losses through building envelope (kWh/m^2 * month); $Q_{N.H.vent}$ are a nominal heat losses because of the building ventilation (kWh/m^2 * month); $Q_{N.e}$ are a nominal external heat gains (kWh/m^2 * month); $Q_{N.i}$ are a nominal internal heat gains (kWh/m^2 * month); $f_{N.PRn.H}$ is a nominal non-renewable energy factor for heating energy production; $\eta_{N.H.gn}$ is a nominal heat gains efficiency factor; $\eta_{N.H}$ is a nominal heat losses efficiency factor;

$$Q_{PRn.E}^{I} = \left(\sum_{m=1}^{12} Q_{E.lg} + \sum_{m=1}^{12} Q_{E.vent} + \sum_{m=1}^{12} Q_{C.E}\right) * f_{PRn.E}; \tag{14}$$

where $Q_{PRn.E}^{I}$ a sum of electricity energy consumption (kWh/m^2 * month); $Q_{E.eq}$ is an electrical energy consumption of electrical equipment which is located in the building heated premises (kWh/m^2 * month); $Q_{E.lg}$ is an electrical energy consumptions of lightning of the building heated premises (kWh/m^2 * month); $Q_{C.E}$ is an electrical energy consumptions for the building cooling (kWh/m^2 * month); $f_{PRn.E}$ is a non-renewable energy factor for electricity energy production;

$$Q_{PRn.H} = \frac{\left(Q_H - \frac{Q_H}{Q_{H.env}+Q_{H,vent}} * (Q_{H2.vent.reH} * \eta_{reH})\right)}{\eta_1 * \eta_2} * f_{PRn.hs} + \left(1 - \frac{Q_H - \frac{Q_H}{Q_{H.env}+Q_{H,vent}} * (Q_{H2.vent.reH} * \eta_{reH})}{Q_H}\right) * (Q_{H2.vent.reH} * \eta_{reH}); \tag{15}$$

where Q_{PRnH} is a primary heating energy (kWh/m^2 * month); Q_H are a total heat losses of the building; $Q_{H.env}$ are a heat losses through building envelope (kWh/m^2 * month); $Q_{H.vent}$ are a heat losses because of the building ventilation (kWh/m^2 * month); η_{reH} is an energy efficiency of heat recovery unit; $Q_{H2.vent.reH}$ are a heat losses because of the mechanical ventilation with heat recovery unit (kW/m^2 * month); $f_{PRn.hs}$ is a non-renewable energy factor for heating energy; η_1 is a efficiency factor of the building heating system adjusting devices; η_2 is a efficiency factor for the building heating system;

Coefficient C_1 evaluates the energy class of the building. Table 1 presents the energy classes range in respect of C_1 coefficient /4./:

TABLE 1. Energy classes by STR standards /4/

A++ class	$C_1 < 0{,}25$ and $C_2 \leq 0{,}70$
A+ class	$0{,}25 \leq C_1 < 0{,}375$ and $C_2 \leq 0{,}80$
A class	$0{,}375 \leq C_1 < 0{,}5$ and $C_2 \leq 0{,}85$
B class	$0{,}5 \leq C_1 < 1$ and $C_2 \leq 0{,}99$
C class	$1 \leq C_1 < 1{,}5$

D class	1,5 ≤ C_1 < 2
E class	2 ≤ C_1< 2,5
F class	2,5 ≤ C_1 < 3
G class	C_1≥ 3

$$C_1 = \frac{\sum_{m=1}^{12} Q_{PRn.H} + Q_{PRn.E}^{I}}{\sum_{m=1}^{12} Q_{N.PRn.H} + \sum_{m=1}^{12}(Q_{N.E.lg} * f_{N.PRn.E})}; \quad (16)$$

where $Q_{PRn.H}$ is a primary heating energy (kWh/m^2 * month); $Q_{PRn.E}^{I}$ a sum of electricity energy consumption (kWh/m^2 * month); $Q_{N.PRn.H}$ is a nominal primary heating energy (kWh/m^2 * month); $Q_{N.E.lg}$ is a nominal electricity consumption of lightning in the building (kWh/m^2 * month); $f_{N.PRn.E}$ is an electricity primary factor;

Coefficient C_2 is calculated when B, A, A+ and A++ classes are calculated. It evaluates energy used for hot water preparation. The lower the coefficient C_2 the better the hot water supply system is. Coefficient C_2 can be determined by following formula /4./:

$$C_2 = \frac{\sum_{m=1}^{12} Q_{PRn.hw}\left(\frac{Q_{hw}}{\eta_{hw}}\right) * f_{PRn.hw}}{\sum_{m=1}^{12} \frac{\Psi_{hw} * t_m}{365 * \eta_{N.hw.eq}} * f_{N.PRn.hw}}; \quad (17)$$

where $Q_{PRn.hw}$ is a primary energy for hot water preparation (kWh/m^2 * month); Q_{hw} is an energy for hot water preparation (kWh/m^2 * month); η_{hw} is a hot water preparation system energy efficiency; $f_{PRn.hw}$ is a non-renewable energy factor; Ψ_{hw} annual energy consumption per one square meter of the building for hot water preparation (kWh/m^2); t_m is a number of days of certain month; 365 is a number of days in the year; $\eta_{N.hw.eq}$ is a standard efficiency coefficient of hot water preparation system (in mu multi-family residential buildings – 0.88-0.93); $f_{N.PRn.hw}$ is a nominal non-renewable energy factor for hot water preparation;

4.2 Finnish national building code

Finnish national building code is divided into 7 parts which are named after first seven alphabet letters (A, B, C, D, E, F, G). Each part provides regulations and instructions for the building constructions, energy performance, indoor climate and etc. In other words, this is the main law of Finland which describes and specifies the building performance.

In parts C and D all the information needed for the building energy performance calculations can be found. The material from these standards is used to display calculation methods and requirements for calculation of energy demand of the building.

4.2.1 Heat losses through the building external components

Building envelope consists of walls, windows, doors, ground floor and roof. Conduction heat losses through each building component are calculated separately. For windows, walls, doors and roof the following formula can be used /6./:

$$Q = \sum U_i * A_i * (T_{ind} - T_{outd}) * \frac{\Delta t}{1000}; \quad (18)$$

where Q is a conduction heat loss through a building component (kWh); U_i is a thermal transmittance factor for a building component (W/m^2 * K); A_i is an area of the building component (m^2); T_{ind} is an indoor air temperature (°C); T_{outd} is an outdoor air temperature (°C); Δt is a time period length (h); 1000 is a factor for converting the denomination to kilowatt hours;

Because of the joints which are between building components the thermal bridges occurs. Heat losses through those places must be calculated. The formula for thermal bridges calculations is presented below /6./:

$$Q_{thermal\ bridges} = \left(\sum l_k * \Psi_k + \sum x_j\right) * (T_{ind} - T_{outd}) * \frac{\Delta t}{1000}; \quad (19)$$

where l_k is a length of a linear thermal bridge caused by joints in the building components (m); Ψ_k is an additional thermal bridge conductance caused by joints between building components (W/m * K); x_j is an additional conductance caused by joints between building components (W/K); T_{ind} is an indoor air temperature (°C); T_{outd} is an outdoor air temperature (°C); Δt is a time period length (h); 1000 is a factor for converting the denomination to kilowatt hours;

The following formula presents heat losses calculations through the ground floor which is on the ground/soil (no air gap) /6./:

$$Q_{ground,month} = \left[U_{ap} * A_{ap} * (T_{ind} - T_{outd}) + J * P * T_u\right] * \frac{\Delta t}{1000}; \qquad (20)$$

where U_i is a thermal transmittance factor for a building component (W/m^2 * K); A_i is an area of the building component (m^2); J is a factor grouping heating energy into the different month and it also depends on the soil type (W/K); P is the plate circumference, i. e. the sum of the plate sides facing the outdoor air, meaning the length of the plinth insulation, (m); T_u is the difference between annual maximum and minimum temperatures divided by two (℃); T_{ind} is an indoor air temperature (℃); T_{outd} is an outdoor air temperature (℃); Δt is a time period length (h); 1000 is a factor for converting the denomination to kilowatt hours;

4.2.2 Heat losses because of air leakage

The heat which is lost through the building envelope because of inappropriate tightening of elements or mechanical damage of building components is called air leakage heat losses. These losses can be calculated by formula which is presented below /6./:

$$Q_{air\ leakage} = \rho_i * c_{pi} * \left(\frac{n_{50} * V}{3600 * x}\right) * (T_{ind} - T_{outd}) * \frac{\Delta t}{1000}; \qquad (21)$$

where ρ_i is an air density (1.2 kg/m^3); c_{pi} is a specific heat capacity of air (1000 Ws/kg * K); n_{50} is the air leakage number of a building with a 50 Pa pressure difference (1/h); V is an air volume of a building m^3; 3600 is a factor which converts air flow from unit (m^3/h) to unit (m^3/s); x is a factor which is: 20 for three and four-storey buildings; T_{ind} is an indoor air temperature (℃); T_{outd} is an outdoor air temperature (℃); Δt is a time period length (h); 1000 is a factor for converting the denomination to kilowatt hours;

4.2.3 Heat energy needed for supply and make-up air heating

In Finland the energy needed for supplied air heating is calculated by following formula. This formula is used only when AHU has heat recovery unit /6./:

$$Q_{iv} = \rho_i * c_{pi} * t_d * t_V * q_{v.supply} * \left(T_{ib} - \left(T_{outd} + \eta_{t,a} * (T_{ind} - T_{outd})\right)\right) * \frac{\Delta t}{1000}; \qquad (22)$$

where ρ_i is an air density (1.2 kg/m^3); c_{pi} is a specific heat capacity of air (1000 Ws/kg * K); T_{ind} is an indoor air temperature (°C); T_{outd} is an outdoor air temperature (°C); Δt is a time period length (h); 1000 is a factor for converting the denomination to kilowatt hours; t_d is a ventilation system's mean daily running time ratio (h/24h); t_V is a ventilation system's weekly running time ratio (days/7days); $q_{v.supply}$ is a supply air flow rate (m^3/s); T_{ib} is an inblow air temperature (°C) $\eta_{t,a}$ is heat recovery unit annual efficiency;

The energy needed for make-up air heating can be calculated by following formula /6./:

$$Q_{iv,make-up\ air} = \rho_i * c_{pi} * (\sum t_d * t_V * q_{v.exhaust} - \sum t_d * t_V * q_{v.supply}) * (T_{ind} - T_{outd}) * \frac{\Delta t}{1000}; \qquad (23)$$

where ρ_i is an air density (1.2 kg/m^3); c_{pi} is a specific heat capacity of air (1000 Ws/kg * K); T_{ind} is an indoor air temperature (°C); T_{outd} is an outdoor air temperature (°C); Δt is a time period length (h); 1000 is a factor for converting the denomination to kilowatt hours; t_d is a ventilation system's mean daily running time ratio (h/24h); t_V is a ventilation system's weekly running time ratio (days/7days); $q_{v.supply}$ is a supply air flow rate (m^3/s); $q_{v.exhaust}$ is a exhaust air flow rate (m^3/s);

4.2.4 Net energy needed for domestic hot water production

The net energy calculation for heating of domestic hot water includes only energy which is used for cold water heating to required temperature. No energy losses of supply water system are included. The following formula presents calculation method of the energy needs for domestic hot water preparation /6./:

$$Q_{dhw.net} = \frac{\rho_v * c_{pv} * V_{dhw} * (T_{dhw} - T_{cw})}{3600}; \qquad (24)$$

where $Q_{dhw.net}$ is a net energy need for domestic hot water (kWh); ρ_v is a water density 1000 (kg/m^3); c_{pv} is a specific heat capacity of water 4.2 (kJ/kg * K); V_{dhw} is a domestic hot water consumption (m^3); T_{dhw} is a domestic hot water temperature (°C); T_{cv} is a domestic cold water temperature (°C); 3600 is a factor which converts air flow from unit (m^3/h) to unit (m^3/s);

4.2.5 Electrical energy consumption

Electrical energy consumed by devices, light or persons can be found in Table 2 /7./:

TABLE 2. Electrical energy consumption /7/

Type of building	Period of use hours	h/24h	d/7d	Degree of use -	Lighting W/m^2	Devices W/m^2	Persons[a] W/m^2	Density of persons m^2/person
Separate small house and terraced and linked house	00:00-24:00	24	7	0.6	8[b,c]	3	2	43
Residential building block	00:00-24:00	24	7	0.6	11[b,c]	4	3	28

The heat load of lightning and electrical appliances which are in the building is calculated by formula presented below /6./:

$$Q_{electric} = \frac{\frac{E}{\beta*\eta*\eta_{\Phi}}*A_{room}*\Delta t*f}{1000} + W_{appliances}; \quad (25)$$

where $Q_{electric}$ is a heat load of electricity; $W_{lightning}$ is an electric energy consumption of lighting (kWh); E is an illuminance of space (lx); β is a luminaire maintenance factor (0.6); η is a coefficient of utilization (0.35); η_{Φ} is a lamp efficiency (lm/W); A_{room} is a surface area of the room to be illuminated room (m^2); f is a control factor depending on the lightning control type (1/0 – on/off control); Δt is a time period length (h); 1000 is a factor for converting the denomination to kilowatt hours;

4.2.6 Heat loads

Heat load from people can be found by following formula /6./:

$$Q_{person} = k * n * \Phi_{person} * \frac{\Delta t_{stay}}{1000}; \quad (26)$$

where Q_{person} is a heat energy emitted by a person/s (kWh); k is a building's utilization level during operation, presenting the average time people stay in the building; Δt_{stay} is a length of stay (h); n is a number of persons; Φ_{person} is a mean heat output of person (not including evaporation level) (W/person); 1000 is a factor for converting the denomination to kilowatt hours.

Solar energy heat gains are direct and indirect. Direct gains are when solar energy enters the building through the windows and indirect gains are when solar energy is absorbed by window. The following formula presents the calculation method of solar energy gains /6./:

$$Q_{solar} = \sum G_{radiant,horizontal} * F_{direction} * F_{transmittance} * A_{win} * g = \sum G_{radiant,vertical} * F_{transmittance} * A_{win} * g; \quad (27)$$

where Q_{solar} is a solar radiant energy entering the building through the windows (kWh/month); $G_{radiant,horizontal}$ is a total solar energy on a horizontal surface per unit area (kWh/m^2); $F_{direction}$ is a conversion factor for converting the total solar radiant energy on a horizontal surface to total radiant energy on a vertical surface by compass direction; $F_{transmittance}$ is a total correction factor for radiation transmittance (usually taken 0.75); A_{win} is a surface area of a window opening (including frame and casing) (m^2); g is a transmittance factor for total solar radiation through a daylight opening; $G_{radiant,vertical}$ is a total solar radiant energy on a horizontal surface per unit area (kWh/m^2);

4.2.7 E-value calculation

Building E-value can be calculated by following formula /6./:

$$E = \frac{(Q_{heating} * f_{Hprimary}) + ((W_{heating} + W_{vent} + W_{cool} + W_{appliences} + W_{lightning}) * f_{Eprimary})}{A_{net}}; \quad (28)$$

where E is a consumed energy per one square meter (kWh/ m^2*a); $W_{lightning}$ electric energy consumption of lighting (kWh); $Q_{heating}$ is a heating demand of the building (kWh); $f_{Hprimary}$ is a primary energy factor for heating source; $W_{heating}$ is an electrical energy used for heating purposes (kWh); W_{vent} is an electrical energy used for ventilation purpose (kWh); W_{cool} is an electrical energy used for cooling (kWh); $W_{appliences}$ is an electrical energy used for electrical devices; $W_{lightning}$ is an electrical energy used for lightning; $f_{Eprimary}$ is a primary energy factor for electricity; A_{net} is a total area of building area (m^2);

5. SIMULATIONS AND CALCULATIONS OF RESIDENTIAL BUILDING RENOVATION

This part of work is divided into calculations with Microsoft Excel and simulation with IDA ICE. The simulation program is based on EN (Euronorms). It means it is using formulae which are presented by European legislation.

In Finland national building code the EN (Euronorms) formulae and E-value calculations were adopted with minimal changes. /5./ This is why the IDA ICE program can be used to simulate building in Finland conditions. Also the Finnish localization was added to the program, so it helps to ease the simulation process.

In Lithuania the EN (Euronorms) were adopted with more changes in formulas and energy class calculations. All the sequence of calculations and energy class evaluation was presented in Chapter 4.1. This is why the Microsoft Excel program will be used to calculate building performance in Lithuanian conditions.

The residential house which is used in simulation and calculations is an existing example building. Its internal dimensions are the same in Lithuania and in Finland. External dimensions of the building depends on Lithuanian and Finnish national building codes.

The block of flats, with the same internal dimensions, were built in 1985 in Mikkeli, Finland and Vilnius, Lithuania. The buildings were built according to national building standards which were applied in that year. In Finland and Lithuania they were different so the external dimensions and their performance will differ.

The building construction is made from concrete sandwich panels which were very popular in 1960-1985. The roof of the building is flat. It was chosen because it was and it is the most common roof type used in residential building. The building construction from 1960-1985 was taken because during that period a lot of multi-family houses were built in Lithuania and Finland and nowadays these buildings make up the majority of residential buildings. Also these buildings are already old and they need renovation because they use a lot of energy and they are not capable to ensure good indoor climate. /1./

The studied building which has three floors. The first floor is on the ground, second floor is intermediate and the third floor is the top one with a roof construction on it. This floor arrangement was created because it represents all possible floor location in the building and heat losses through different partitions of the building.

The created residential building has four external walls. One walls is oriented to the North, one to the East, one to the South and last one to the West. This building envelope wall orientation have a significant impact on the building solar gains and internal temperatures during the cooling and heating periods.

In the building there are eleven flats of approximately 80 square meters. In each flat there are 5 windows and one door to the heated staircase. The area of the windows is about 12 percent of the floor area. Also there are staircase which is located in the center of the building, storage room and boiler room.

The Figure is taken from simulation program IDA ICE. It is presented to show the design of the building shell.

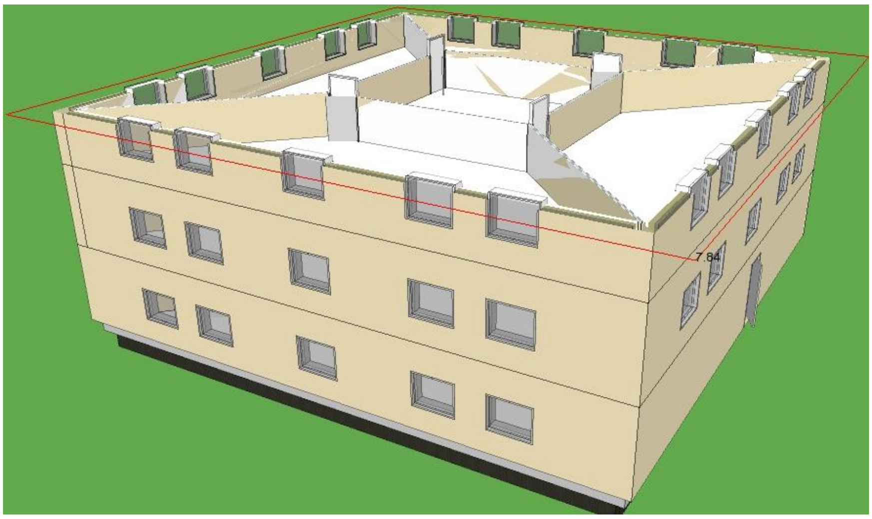

FIGURE 10. Simulated house image from IDA ICE program /9/

In Figure 10 the Northern and Eastern sides of the building can be seen. In the Northern side on the first floor there are only doors and no windows. It is because in that part of the building the technical room and storage room are designed and there is no need to install windows in those premises. Also that side is directed to the North so it means that there are a little solar gains through that side of a building so windows in those

premises would only increase heat losses and would let very small amount of solar energy inside.

The possible building envelope renovation methods were represented in Chapter 3. For this house the renovation is implemented by removing old insulation from roof, external walls and ground floor. It means that a new layer of insulation is put on the building supportive construction. The new windows and doors are installed in the building. Also the insulation of hot water supply pipes and heating pipes is improved. Heat exchangers in heating substation are changed. Mechanical supply and exhaust ventilation system with heat recovery unit, heating and cooling coils installed.

5.1 Building in Lithuania

In the beginning the calculation made with Microsoft Excel is presented. The calculations are analyzed. The building in Lithuania before and after renovation is compared.

Table 3 which is presented below shows the thicknesses and U-values of the building, which was built in 1985 in Vilnius, Lithuania, envelope parts. These U-values were taken from the latest version of STR 2.01.09.2012 and they are used to evaluate old buildings which were built up to 1993. The thickness of envelope parts were calculated and not necessarily match the concrete-sandwich houses standards from 1960-1985’s.

TABLE 3. Parameters of the existing building

U-values and thicknesses of the existing building partitions before renovation							
	External wall	Internal wall	Roof	Ground floor	Internal floor	Window	Door
Thickness, m	0.28	0.11	0.26	0.6	0.23	-	-
U value, W/m^2*K	1.30	0.64	0.88	0.42	0.65	2.5	2.2

With values presented in Table 3 building heat energy losses because of building heat conduction can be calculated. The obtained heat losses lets to evaluate building energy class. The obtained energy class is the reference value for evaluating renovation benefits.

Table 4 represents the external partitions and U-values of the renovated building which was built in 1985. The U-values are taken from latest Lithuanian building code, which is related to building energy performance, STR 2.01.09.2012. The thickness of partitions were calculated to meet the U-value. These U-values meets A energy class requirements for a new buildings in Lithuania.

TABLE 4. Parameters of the renovated building

U-values and thicknesses of the building partitions of existing building after renovation							
	External wall	Internal wall	Roof	Ground floor	Internal floor	Window	Door
Thickness, m	0.47	0.11	0.56	0.80	0.23	-	-
U value, W/m^2*K	0.12	0.64	0.10	0.14	0.65	1	1

It can be seen that after a renovation the external partitions of the building have become thicker compared to parameters presented in Table 3. It is because the insulation layer on the external partitions is very thick after renovation. Thanks to improved insulation the thermal transmittance decreased many times. Walls have almost 11 times lower thermal transmittance, roof almost nine times and ground floor have almost 6 times lower thermal transmittance in comparison with values presented in Table 3.

TABLE 5. Areas of the building external partitions

Internal areas of the building external partitions, m^2								
	External Wall N.	External Wall E.	External Wall S.	External Wall W.	Roof	Ground floor	Win-dows	Doors
Areas	159.0	153.0	153.0	153.0	392.3	390.9	99.0	3.0

Table 5 present constant values of internal dimensions of the studied residential building. These values does not change neither in Lithuania nor in Finland even after renovation. Only external dimensions change because of increased insulation layers on all building envelope.

TABLE 6. The heat losses of the building built in 1985 in Lithuania

Heat losses (Q), kWh/m^2							
	Walls	Roof	Ground floor	Windows	Doors	Thermal bridges	Ventilation
January	13.0	5.6	1.6	4.0	0.1	1.6	12.1
February	11.4	4.9	1.4	3.5	0.1	1.4	10.6
March	10.8	4.7	1.3	3.3	0.1	1.3	10.0
April	7.5	3.2	1.0	2.3	0.1	0.9	6.9
May	4.5	2.0	0.7	1.4	0.0	0.5	4.2
June	2.7	1.2	0.5	0.8	0.0	0.3	2.5
July	2.1	0.9	0.4	0.7	0.0	0.3	2.0
August	2.4	1.0	0.4	0.7	0.0	0.3	2.2
September	4.4	1.9	0.7	1.4	0.0	0.5	4.1
October	6.9	3.0	0.9	2.1	0.1	0.8	6.4
November	9.1	3.9	1.2	2.8	0.1	1.1	8.5
December	11.6	5.0	1.4	3.6	0.1	1.4	10.8
Sum	86.4	37.2	11.5	26.7	0.7	10.4	80.4

In Table 6 the heat losses of the building from 1985 are presented. The losses are presented for every month per one square meter of heated building area. As can be seen from the Table 6 the biggest part of heat is lost through the walls. It is because external walls have the greatest surface area and the thermal transmittance (Table 1) is very big.

The roof transmits less heat energy than walls because the surface area and U-value is smaller. Through the ground floor less heat energy is conducted than through the roof despite the fact that areas of these partitions are similar size. It is because ground temperature is higher than air temperature during the heating period and because ground floor has better insulation.

The windows play a very important role in the heat loss calculations. Despite the fact that they take only about 6.5 percent of all the building envelope they transmit about 11 percent of total heat energy losses. The doors have similar heat transmittance value as windows, but the heat losses through doors are quite small compared to windows. It is because their area takes only 0.2 percent from total building envelope area.

Natural ventilation system is installed in the building. It has neither mechanical exhaust nor mechanical supply. Also no heat recuperation system is installed. It means all the heat energy from the building is emitted to the outside and all supplied air to the premises has the same temperature as outdoor air. That is why ventilation heat losses in Table 6 are so great.

Through thermal bridges almost the same amount of heat is lost as through the ground floor. That means places where two external partitions meet are not air tight.

TABLE 7. The heat losses of the building built in 2015 in Lithuania

Heat losses (Q), kWh/m^2							
	Walls	Roof	Ground floor	Windows	Doors	Thermal bridges	Ventilation
January	1.2	0.6	0.7	1.6	0.0	0.2	5.1
February	1.1	0.6	0.6	1.4	0.0	0.2	4.5
March	1.0	0.5	0.6	1.3	0.0	0.2	4.2
April	0.7	0.4	0.4	0.9	0.0	0.1	2.9
May	0.4	0.2	0.3	0.6	0.0	0.1	1.7
June	0.3	0.1	0.2	0.3	0.0	0.1	1.0
July	0.2	0.1	0.2	0.3	0.0	0.0	0.8
August	0.2	0.1	0.2	0.3	0.0	0.0	0.9
September	0.4	0.2	0.3	0.5	0.0	0.1	1.7
October	0.7	0.3	0.4	0.8	0.0	0.1	2.7
November	0.9	0.4	0.5	1.1	0.0	0.2	3.6
December	1.1	0.6	0.6	1.4	0.0	0.2	4.6
Sum	8.3	4.2	5.0	10.7	0.3	1.6	33.6

Table 7 present the heat losses of the residential building after renovation in 2015. As Table 6 so Table 7 presents heat losses per every month of the year per one square meter of the heated building area.

The heat losses through external walls have diminished significantly compared to Table 6. Same happened to the heat losses through the roof and ground floor. Improved insulation of these three partitions saved heat losses of an almost 120 kWh per one square meter of the building annually.

The transmittance of heat through the doors and windows has not decreased so drastically, because their area is small compared to walls, roof or a ground floor. Also the required U-value of windows and doors by Lithuanian STR does not change as much as for the other partitions.

It can be seen that thermal bridges heat losses have decreased more than 6 times. It is a sharp decrease of heat losses. It occurred because thermal insulation layers were joined more properly at points were ground floor and external wall meets, roof and external wall meets, windows and doors were installed in the thermal insulation layer.

Less heat losses through thermal bridges makes building more air tight. It means additional ventilation is needed. After renovation building has mechanical supply and extract ventilation system with heat recovery unit and heating coil. It ensures constant air change in the premises and a good indoor climate. At the same time the heat losses of ventilation system are lowered more than twice.

TABLE 8. Heat gains of the building built in 1985 in Lithuania

Heat gains (Q), kWh/m^2			
	Internal	External	Hot water supply pipes
January	5.4	0.7	1.0
February	4.7	2.3	0.9
March	4.9	4.6	1.0
April	4.6	5.5	0.9
May	4.6	8.6	1.0
June	4.4	8.1	0.9
July	4.5	8.5	1.0
August	4.6	7.0	1.0
September	4.7	4.7	0.9
October	5.0	2.5	1.0
November	5.2	0.6	0.9
December	5.5	0.2	1.0
Sum	58.1	53.2	11.5

In Table 8 can be found internal, external and hot water supply pipes heat gains to the building premises. Internal heat gains and heat from hot water supply pipes are almost

constant every month during all year. Only slight deviations can be seen. For internal gains they occur because during the heating period (October to March) more electricity in the premises are used to compensate lack of light and heat.

The heat gains because of hot water supply pipes deviate because months have not equal number of days. Also these gains are quite great because by 1985 Lithuanian standards hot water supply pipes were barely insulated. /4./

The external heat gains increases during the cooling period (March to September). It happens because the days are longer and more sun energy enters the building premises through opaque and transparent building partitions. Also environment temperature is high and heat transfer from outside to inside occur.

TABLE 9. Heat gains of the building built in 2015 in Lithuania

Heat gains (Q), kWh/m^2			
	Internal	External	Hot water supply pipes
January	3.3	0.9	0.5
February	2.9	1.9	0.4
March	3.1	3.4	0.5
April	3.0	3.8	0.5
May	3.0	5.8	0.5
June	2.9	5.4	0.5
July	3.0	5.7	0.5
August	3.0	4.8	0.5
September	3.0	3.4	0.5
October	3.2	2.1	0.5
November	3.2	0.8	0.5
December	3.3	0.6	0.5
Sum	36.9	38.6	5.7

All types of heat gains presented in Table 9 are smaller than in Table 8. It is because the building envelope has been improved and hot water supply pipes insulated by the latest Lithuanian building code.

Internal heat gains in Table 9 are almost the same every month and there is no increasing of them during the heating season. It is because more advanced electrical devices have been installed in the building and they emit less heat energy. Then mainly internal heat gains depends only on occupants emitted heat in the premises.

External heat gains decreased during the summer months but stayed almost the same during all other months. It is because internal shadings were installed on the windows during renovation process and they prevent a solar radiation to the premises during the summer, but not decrease solar energy radiation during other months. It is because shadings can be left open and let solar radiation to the building premises.

Hot water supply pipes after renovation conducts 2 times less heat energy to the premises compared with a situation before renovation. It happened because poor insulation of supply pipes was changed to a modern one which has lower thermal transmittance value and it is thicker.

TABLE 10. The primary energy consumption of electricity, hot water and heating energy in the building built in 1985 in Lithuania

Primary energy consumption of electricity, hot water and heating energy preparation (Q_{PRn}), kWh/m²			
	Electricity	Hot water	Heating energy
January	8.4	2.9	50.4
February	7.2	2.6	41.8
March	6.9	2.9	35.8
April	6.3	2.8	20.5
May	6.1	2.9	6.4
June	5.9	2.8	2.0
July	6.0	2.9	1.0
August	6.3	2.9	1.6
September	6.6	2.8	8.7
October	7.3	2.9	21.2
November	8.0	2.8	33.7
December	8.8	2.9	45.1
Sum	84.0	33.6	268.2

TABLE 11. The sum of primary and delivered energies

Sum of delivered energies, kWh/m²	Sum of primary energies, kWh/m²
262.2	385.5

It can be seen in Table 10 that the biggest primary energy share in the building which was built in 1985 in Lithuania is taken by heating energy. It consumes 268.2 kWh/m^2 annually of primary energy.

During summer months and first autumn and last spring months it the heat energy consumption decreases to very small amount. It is because in Lithuania there are four seasons in the year: winter, spring, summer and autumn and during the warm summers there is no need to heat the building.

In Table 10 it can also be seen that primary energy for hot water production is constant during all year. Because in the calculations it is taken that one person consumes constant amount of water every month. And the decimal deviation between months is because months has not equal amount of days.

As can be seen in Table 10 electricity primary energy increases in autumn and winter. It is because during those months there is less sun in Lithuania and it is colder. With electricity people are compensating a lack of light and heat.

TABLE 12. The primary energy consumption of electricity, hot water and heating energy in the building built in 2015 in Lithuania

Primary energy consumption for electricity, hot water and heating energy preparation (Q_{PRn}), kWh/m^2			
	Electricity + cooling	Hot water	Heating energy
January	8.0	2.6	7.4
February	7.1	2.3	5.0
March	7.5	2.6	2.7
April	7.2	2.5	0.5
May	7.3	2.6	0.0

June	7.1	2.5	0.0
July	7.3	2.6	0.0
August	7.4	2.6	0.0
September	7.3	2.5	0.0
October	7.6	2.6	1.0
November	7.7	2.5	4.1
December	8.1	2.6	6.4
Sum	96.2	30.1	27.1

TABLE 13. The sum of primary and delivered energies

Sum of delivered energies, kWh/m²	Sum of primary energies, kWh/m²
78.4	153.4

In Table 12 the electricity primary energy is combined with primary cooling energy. This is done, because cooling system in the building is air to air heat pump. It consumes electricity to produce cool. Also electricity is used to heat up the heating coil in the air handling unit and to operate fans which supplies and extracts air from premises.

These improvements lead to increased electricity consumptions after building renovation. However, the increase is not great, because lightning and electrical appliances used in the building have been improved and consumes less energy than they did before the renovation.

The primary energy for hot water preparation did not changed a lot in 2015 building compared to 1985 building because the same amount of water per person was used in both calculations. However, slight decrease of needed power is seen and it was reached because of modern heat exchangers in district heating substation. They have better efficiency of heat transfer.

The different situation of primary energy for heating can be seen in the Table 11 compared with Table 12. The primary energy for heating have decreased by more than 220 kWh/m^2 annually. It is a significant change then the higher energy class needs to be obtained.

This reduction of primary energy for heating purposes was achieved by improving building envelope insulation, changing windows and doors. Also by upgrading heating substation according to a present standards. The more efficient heat exchanger for the building heating was installed.

TABLE 14. Primary energy factors which were used in calculations

Primary energy factors f_{PRn}	
Electricity	2.8
Central heating and hot water	1.3

In Table 14 the primary energy factors which were used in the calculations are presented. The electricity primary factor is 2.8 and the central heating as well as the hot water primary factor is 1.3. These factors values are this high because in Lithuania there are a lot of heat only boiler (HOB) power plants which produce only heat energy. It means that electricity is produced separately or by small amount in electricity power plants (CHP). So presented values gives the average Lithuanian primary energy factors.

TABLE 15. Obtained C_1 and C_2 factors for energy class calculations

1985	2015	
C_1	C_1	C_2
1.52	0.47	0.77
D	A	A+

The C_1 coefficient for 1985 was calculated by using 13, 14 15 and 16 formulae. Also the tables 6, 8, 10 and 12 were taken to have values which are needed to be inserted in formulas.

Obtained C_1 value are then compared with the values presented in Table 1. It can be seen that building built in 1985 in Lithuania reaches D energy class. It is not the worst energy class presented in Table 1, though the parameters of the building envelope are really low. There is one very important reasons for this. It is that air infiltration rate through the building envelope is low (0.5-0.8 change of total volume of building per hour) knowing that building is 30 years old and was built according building standards from 1985.

The values for a house built in 2015 were taken from 7, 9, 11 and 12 tables to obtain C_1 coefficient. Those values were putted into 13, 14, 15 and 16 formulas to obtain the number 0.47. This value in the table 1 shows that building is an A energy class.

The C_2 value was calculated by taking value of primary energy for hot water preparation from table 11 or by obtaining it by formula 9 and then inserting it into formula 17. From formula 17 the calculated value for building built by 2015 building code values was 0.77. With this C_2 value residential building reaches A+ energy class by Table 1.

5.2 Building in Finland

In this chapter residential building in Finland will be presented. Simulation data form IDA ICE program will be analyzed. The obtained energy classes of the residential building will be discussed.

The residential building built in 1985 before renovation is equipped with mechanical supply and exhaust ventilation. It has neither heat recovery unit nor heating or cooling coils. This ventilation system supplies and extracts 0.5 liters per second per square meter of the building. The air change ratio in the building because of infiltration air through the building envelope is 32 liters per second.

After the renovation by nowadays Finnish standards the building is equipped with mechanical supply and exhaust ventilation system which has heat recovery unit and heating and cooling coils. This system also supplies 0.5 liters per second per square meter of the building area. Air change ratio because of air infiltration to the building was lowered to 0.023 liters per second.

TABLE 16. Residential building from 1985 specifications before renovation /9/

Building envelope	Area [m²]	U [W/(K m²)]	U*A [W/K]	% of total
Walls above ground	611.17	0.28	171.31	27.43
Roof	392.25	0.22	86.37	13.83
Floor towards ground	390.89	0.20	78.25	12.53
Windows	99.00	2.09	206.91	33.13

Doors	3.00	1.40	4.21	0.67
Thermal bridges			77.49	12.41
Total	1496.31	0.42	624.55	100.00

In Table 16 the data of the building which was built in 1985 in Mikkeli, Finland by Finnish building code from 1985 is presented. Here can be found all the buildings external partitions names, areas, U-values, specific heat transfer and its percentage part. By this data the heat losses of the house was determined.

TABLE 17. Residential building from 2015 specifications after renovation /9/

Building envelope	Area [m²]	U [W/(K m²)]	U*A [W/K]	% of total
Walls above ground	611.17	0.17	105.37	31.99
Roof	392.25	0.09	35.02	10.63
Floor towards ground	390.89	0.12	45.03	13.67
Windows	99.00	1.01	99.99	30.36
Doors	3.00	1.03	3.09	0.94
Thermal bridges			40.87	12.41
Total	1496.31	0.22	329.37	100.00

In Table 17 the data of the residential building built in 2015 is presented. Internal dimensions of external partitions of the building are the same as in the house built in 1985. The thermal transmittance values were changed by the Finnish standards which came in to force in 2012. /8./

TABLE 18. Delivered and primary energies of 1985 residential building /9/

	Delivered energy		Primary energy	
	kWh	kWh/m²	kWh	kWh/m²
Lighting, facility	11546	9.6	19628	16.4
Cooling	0	0.0	0	0.0
HVAC aux	11216	9.4	19067	15.9
Total, Facility electric	22762	19.0	38695	32.3
Space heating	176588	147.6	123612	103.3
Domestic hot water (DHW)	47133	39.4	32993	27.6

	Total, Facility district	223721	187.0	156605	130.9
	Total	246483	206.0	195300	163.2
	Tenant lighting, facility	25185	21.1	42814	35.8
	Total, Tenant electric	25185	21.1	42814	35.8
	Grand total	271668	227.0	238114	199.0

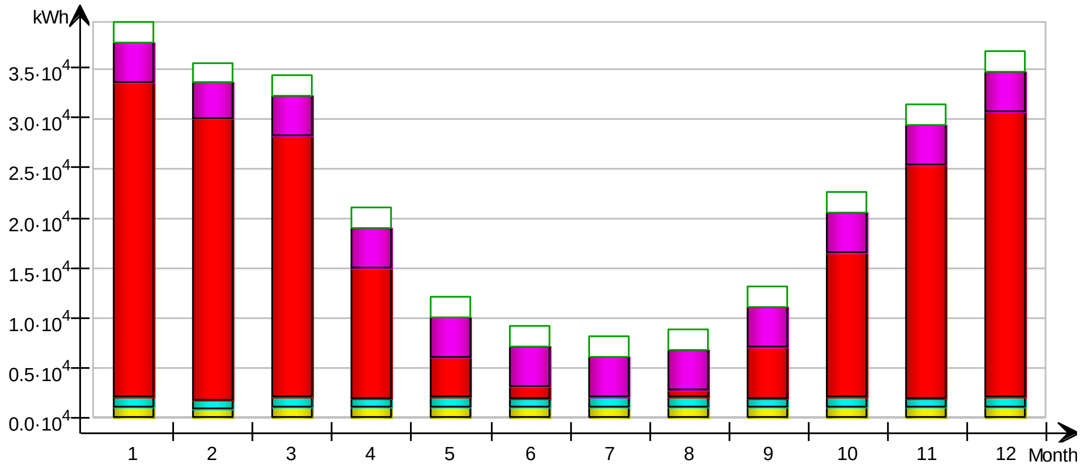

FIGURE 11. Monthly delivered energy of residential building built in 1985 in Finland /9/

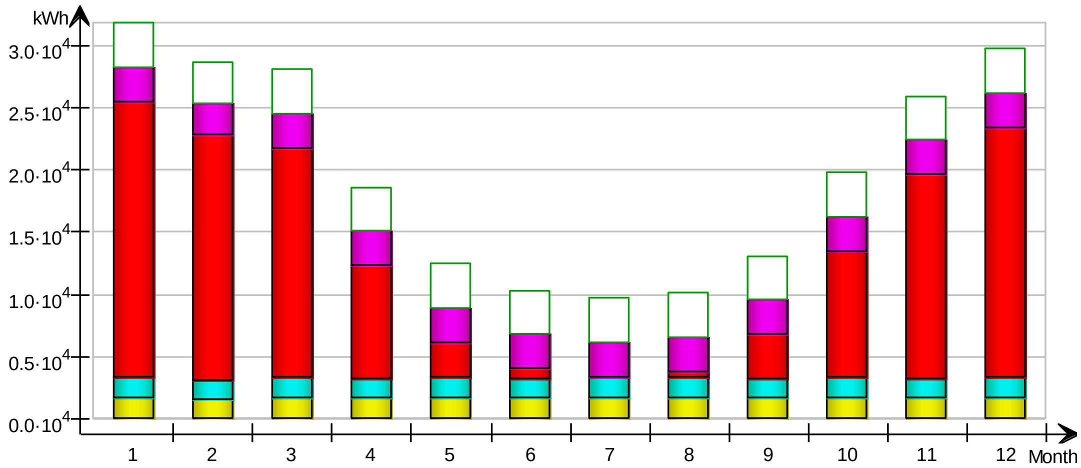

FIGURE 12. Monthly primary energy of residential building built in 1985 in Finland /9/

In Table 18 the delivered and primary energies are presented. It can be seen that delivered heating energy is smaller than primary heating energy. It is because the heat source of the building is district heating. The primary energy factor of district heating is 0.7 by the latest Finnish building code D5. With electricity the situation is vice versa, because

electricity primary energy factor is 1.7. So the delivered electricity energy to the building is lower than the primary electricity energy.

In Figure 12 it can be seen that part of primary energy of heating is smaller then delivered heat energy part in Figure 11. Also the same is with hot water energy. It is because district heating water comes to the residential building and then it divides to space heating heat exchanger and to domestic hot water heat exchanger. So it means that same energy source produces two heat types in the building.

In Figure 12 all types of electricity energies takes bigger parts than in Figure 11. It is of the same reason which was mentioned before. The primary energy factor of electricity is 1.7, so delivered energy of electricity is smaller than primary electricity.

Also from Figures 11 and 12 it can be seen that electricity and hot water consumptions not vary a lot during the year. It is because the water and electricity consumption do not depend on a time of the year, it is taken average per person per month or per square meter of the building. So the amount is constant.

In Table 18 the sum of primary energies (E-value) in the residential building built in 1985 is 199 kWh/m^2 annually. This value is compared with values presented in Table 19. The obtained energy class is F. It is low by today standards and the assumption that this building needs to be renovated can be done.

TABLE 19. Energy class classification /10/

A	E-luku ≤ 75
B	76 ≤ E-luku ≤ 100
C	101 ≤ E-luku ≤ 130
D	131 ≤ E-luku ≤ 160
E	161 ≤ E-luku ≤ 190
F	191 ≤ E-luku ≤ 240
G	241 ≤ E-luku

The following Table 20 and Figures 14 and 15 presents existing example of renovated building by latest Finnish building standards. After the visual presentation of building parameters the analysis of data can be found.

TABLE 20. Delivered and primary energies of renovated residential building /9/

	Delivered energy		Primary energy	
	kWh	kWh/m²	kWh	kWh/m²
Lighting, facilities	11520	8.7	19584	14.8
Cooling	1089	0.8	1851	1.4
HVAC aux	9907	7.5	16842	12.7
Total, Facility electric	22516	17.0	38277	28.9
Space heating	52952	39.9	37066	27.9
Domestic hot water (DHW)	55115	41.5	38580	29.1
Total, Facility district	108067	81.5	75646	57.0
Total	130583	98.4	113923	85.9
Tenant lighting, facility	25137	18.9	42733	32.2
Total, Tenant electric	25137	18.9	42733	32.2
Grand total	155720	117.4	156656	118.1

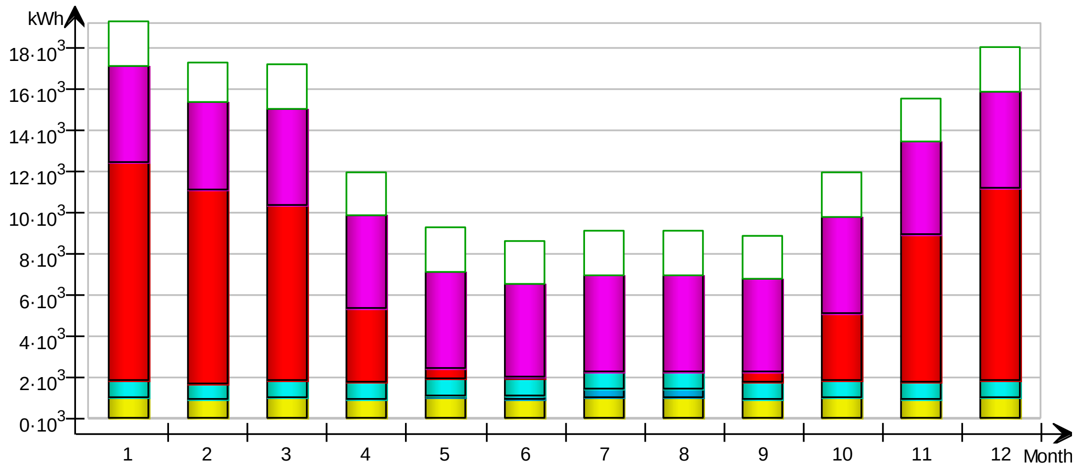

FIGURE 14. Monthly delivered energy for renovated residential building in Finland /9/

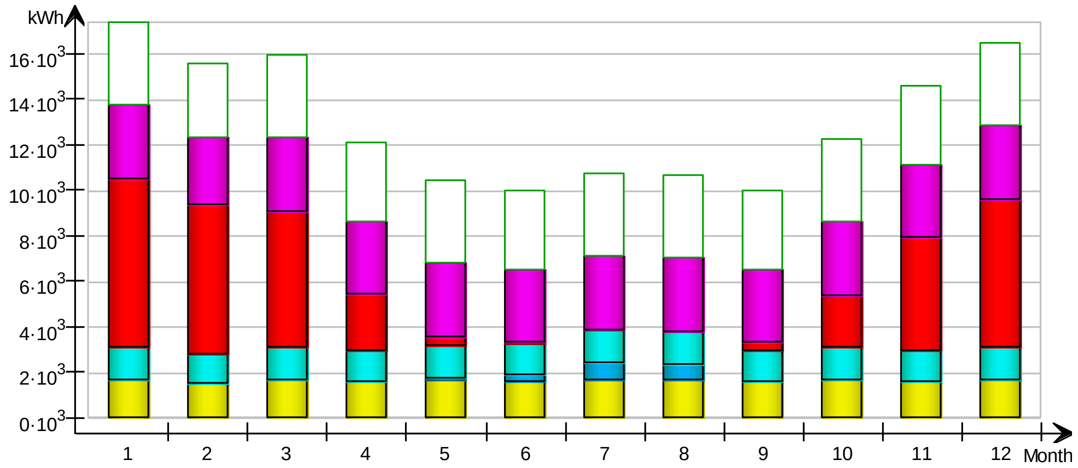

FIGURE 15. Monthly primary energy for residential building built in Finland /9/

In Figures 14 and 15 it can be seen that scale of energy consumptions have decreased a lot after the building renovation by latest Finnish building standards. Total primary energy decreased by 80 kWh/m^2 and all energy was saved because the primary energy consumption for space heating decreased significantly.

After renovation the building has cooling coil in air handling unit. The energy consumption of this equipment can be found in section of facility electric in Table 20. The cooling energy needed for residential building is rather small and does not increase electricity consumption a lot. In Figures 14 and 15 the cooling energy appears in 5, 6, 7, 8 months when the heat gains of the building are greatest and building needs cooling to maintain maximum 27 °C which are allowed by Finnish building code.

With parameters of the residential building obtained after renovation the energy class can be evaluated. Sum of primary energies in Table 20 are equal to 118 kWh/m^2 annually. It means that existing example of renovated building, as Table 19 presents, now has a C energy class. It is a good result, but renovated building envelope by latest Finnish building code D5 did not let to reach an A energy class as it was done with Lithuanian building. Residential building in Lithuania after renovation according to latest STR had an A energy class.

The obtained results leads to two questions. The first question is what can be done more to the building in Finland to reach an A energy class by Finnish requirements. The second question is which building, in Finland or Lithuania, is more energy efficient despite the fact that their energy classes differ.

5.3 Improving the C energy class building in Finland

In this chapter the possibilities of improving residential building up to A energy class by Finnish standards will be presented. The simulation of renovation of existing example building will be discussed. It will be implemented step by step and all the changes will be analyzed. In Table 21 the final results after all steps of the building improvements are presented.

TABLE 21. Delivered and primary energies of additionally renovated residential building in Finland /9/

	Delivered energy		Primary energy	
	kWh	kWh/m²	kWh	kWh/m²
Lighting, facilities	11520	8.6	19584	14.6
Cooling	128	0.1	217	0.2
HVAC aux	9986	7.5	16977	12.7
Heating, heat pump	25658	19.2	43619	32.6
Total, Facility electric	47292	35.3	80397	60.0
Total	47292	35.3	80397	60.0
Tenant lighting, facility	25137	18.8	42733	31.9
Total, Tenant electric	25137	18.8	42733	31.9
Electrical energy produced by photovoltaics	-13786	-10.3	-23437	-17.5
Total, Produced electric	-13786	-10.3	-23437	-17.5
Grand total	58643	43.8	99693	74.5

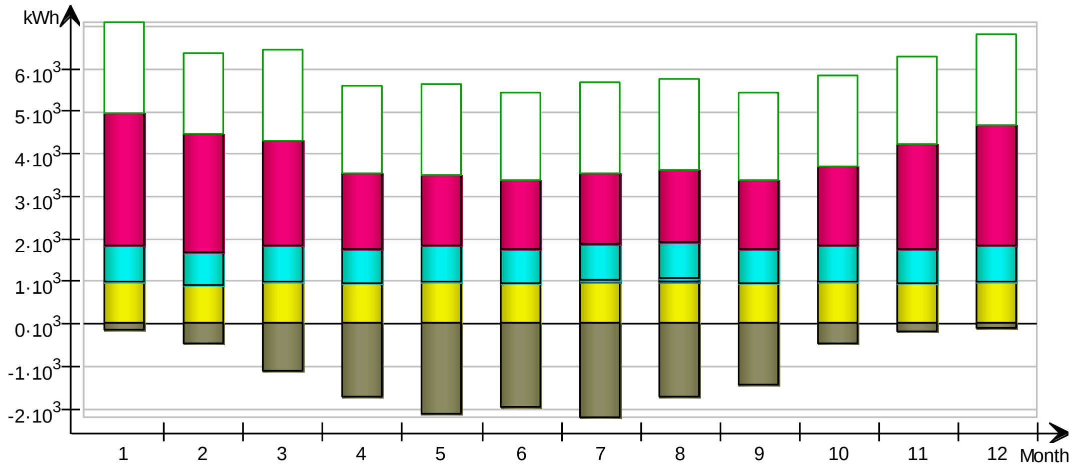

FIGURE 16. Monthly delivered energy of additionally renovated residential building in Finland /9/

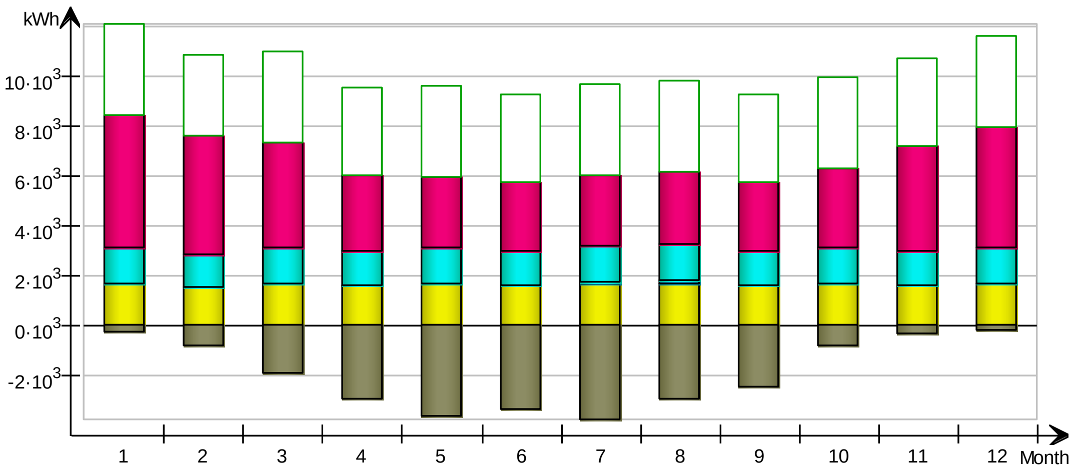

FIGURE 17. Monthly primary energy of additionally renovated residential building built in Finland /9/

The data of delivered and primary energy presented in Table 21 and Figures 16 and 17 are of an A energy class building in Finland. The A energy class was obtained by improving the building which was renovated up to a C energy class in Mikkeli, Finland.

The A energy class has been reached by improving building step by step in IDA ICE and performing series of simulations. It was done to find out what specifications should the building have to be evaluated as an A energy class residential building in Finland.

In the beginning the building insulation was improved, windows and doors were changed to lower the building heating energy consumptions. Simulation was performed. The obtained result was 114 kWh/m^2 of primary energy annually. It is only by 4 kWh/m^2

less energy used compared to Table 20 total energy consumption. The idea of this improvement was refused because the investment cost is very high and the savings are very small.

In the beginning the minor changes which requires small investments were carried. The first improvement was lowering infiltration rate (q_{50}) two times from 4 to 1 $m^3/h*m^2$. The second improvement was installing more efficient heat recovery unit. The annual efficiency was raised from 0.45 to 0.75. After these improvements the energy consumption has decreased from 118 (Table 20) to 107 kWh/m^2 annually. With these improvements the existing example of the renovated building still had the C energy class.

Later the existing central heating energy source was replaced with the heat pump which is working with 4 bore holes of 150 m depth. The heat pump is the heat source for space heating and domestic hot water (DHW). Introducing the renewable energy source to the building allowed to lower primary energy consumption to the 92 kWh/m^2 annually. This improvement let the building to reach a B energy class (Table 19).

The last improvement of an existing example building was installing 125 m^2 of photovoltaics on the building roof. They helped to save about 17.5 kWh/m^2 annually of primary energy. It was done because electricity energy factor is 1.7 in Finland. But all the electricity energy produced by renewable energy source has a factor 0.5. /7./ This makes a significant change in total primary energy consumption. After this improvement building consumes 74.5 kWh/m^2 annually and according to Table 19 it fulfills an A energy class requirements.

According to the Figures 16 and 17 the residential building primary energy needs can almost be fulfilled with an electrical energy produced by photovoltaics mounted on the roof during the summer. It can cover DHW and electricity needs. It means the building can run of the grid and save occupants money.

5.4 Normalized performance indicator

To answer the second question which was presented in the end of Chapter 5.2 the normalized performance indicator (NPI) will be calculated. The calculation formula of this indicator is presented below:

$$Q_{norm} = \frac{\frac{S_n}{S_{year}} * Q_{SH}}{A}; \quad (29)$$

where Q_{norm} is a normalized heating energy per square meter of the building (kWh/m^2 a); S_n is an average of degree days; S_{year} is a particular year degree days; Q_{SH} is a particular year energy consumption for the space heating (kWh/m^2 a);

The normalized energy consumption for space heating will be calculated for the renovated building in Vilnius with an A energy class and for the renovated building in Mikkeli which has a C energy class. In the calculations the delivered heating energy is used. It is because primary energy factors of heating energy in Lithuania and Finland differ. So more informative and logical comparison can be done between delivered heating energies in both countries.

The normalized energy consumption of delivered energy will be compared between the countries. The domestic hot water and all electrical energy is not included into normalized performance indicator calculations. It is because these parameters have fixed values in simulations and calculations, so the normalization of DHW and electrical energy is meaningless.

The average of degree days (DD) in Vilnius was calculated by the following formula /11./:

$$DD = z * (t_v - t_{is}); \quad (30)$$

where z is the duration of the heating season (d); t_v is an average premises temperature during heating season (°C). By an agreement it is taken as 18 °C; t_{is} is an average outside temperature during the heating period (°C); /12./

The number of DD were taken by 2014-2015 heating season. /13./

$$Q_{norm\,Vilnius\,A} = \frac{\frac{4005}{3676} * (23.3 * 1198.2)}{1198.2} = 25.4\ \frac{kWh}{m^2 a};$$

For building in Mikkeli the reference value of DD is Lapperanta town. /14./ The DD of the particular year were taken from the heating season of 2014-2015.

$$Q_{norm\,Mikkeli\,C} = \frac{\frac{4510}{4046} * (39.9 * 1198.2)}{1198.2} = 44.5\ \frac{kWh}{m^2a};$$

According to the obtained results of the normalized heating energy consumption it is seen that the building in Lithuania use less energy for heating annually. The reason for this is shorter period of heating season in Lithuania and the climate in Vilnius is milder than in Mikkeli. However, it is interesting how much heating energy would be used in the building in Vilnius if the normalized heating period was the same like in Mikkeli.

$$Q_{norm\,Vilnius} = \frac{\frac{4510}{3676} * (23.3 * 1198.2)}{1198.2} = 28.6\ \frac{kWh}{m^2a};$$

To calculate $Q_{norm\,Vilnius}$ the annul heating energy in Vilnius in 2014-2015 heating season was taken and divided by degree days of heating season from the same year. Then obtained result was multiplied by the degree days in the year 2014-2015 in Mikkeli. Then $Q_{norm\,Vilnius}$ was calculated according normalized degree days in Mikkeli. The result of this calculations shows that the heating energy would increase because of extended heating period. However, the increase is not very great, so the main factor is the weather in Mikkeli is colder than in Vilnius.

It is not possible to answer the question which building in Lithuania or in Finland is more energy efficient because they are located in different climate zones. The heating periods and the outside temperatures differ so the energy consumption differ too. Also for NPI calculations only delivered energy can be taken into account because the primary energy factors of electricity and heating energy in Lithuania and Finland differ a lot. It means that no normal comparison of calculation which would let to say that one or another building is more energy efficient can not be done.

6. DISCUSSION

The existing example of the building was built according to 1960-1985's building trends. The construction of residential building walls, roof and ground floor were made to be the same as in the 1960-1985's. It was places in Lithuanian and Finland weather conditions. Building before and after renovation had the same internal dimensions.

The renovation of the residential building was implemented in Finland and Lithuania according to countries latest legislations. The aim was to reach an A energy class in both counties. However, it was assumed that the building according to Lithuanian or Finnish legislations will not be able to achieve an A energy class. So the additional improvements will be needed for the building to reach the aim.

In the residential building in Lithuania and Finland the insulation of walls, roof and the ground floor were improved. The new windows and doors were installed. Also mechanical supply and extract ventilation system with heat recovery unit and heating and cooling coils installed. Also the heating system was updated. That gave the better energy efficiency of all substation and distribution systems.

After the renovation according to national building codes it was found out that building in Finland does not reach an A energy class. To implement one of the thesis aims the additional improvements of the building in Finland had to be done. The improvements step by step were presented in Chapter 5.3.

In the end the calculations of the normalized heating energy consumptions were done. These calculations showed that building with C energy class in Finland use more heating energy than building with an A energy class in Lithuania. But it was realized that it is not possible to compare the efficiency of the building in Vilnius and Mikkeli after renovation because of different climate conditions and latest legislations differences.

7. CONCLUSIONS

Using renovation methods presented in Chapter 3 the norms of the building energy consumption according to Lithuanian and Finland national building codes can be achieved. It was done using Microsoft Excel and IDA ICE simulation program.

It was found that the building in Lithuania and Finland after the renovation according to latest legislations of national building codes has a different energy class. In Finland a C and in Lithuania an A energy class.

The primary energy consumption in Finland is always lower than in Lithuania. Before renovation building in Finland consumes 199 kWh/m^2 annually and in Lithuania 385.5 kWh/m^2 annually. After the renovation according to present national building codes the building in Mikkeli consumes 118.1 kWh/m^2 annually and in Vilnius 153.4 kWh/m^2 annually. It is because the primary energy factors in Lithuania are greater than in Finland.

An A energy class building in Mikkeli consumes 5 times (227-43.8 kWh/m^2 annually) less delivered energy compared to the results before renovation. The building in Vilnius consumes 3.4 (262.2-78.4 kWh/m^2 annually) times less delivered energy after the renovation. It means that the renovation of both buildings have great influence in lowering the amount of consumed energy.

The residential building which undergoes renovation in Finland should be equipped with renewable energy sources to achieve an A energy class. In the analyzed building the heat pump and photovoltaics were installed to decrease primary energy consumption to an A energy class level.

The normalized heating energy was calculated to find out in Lithuania or in Finland the building after the implemented latest legislations is more energy efficient. The obtained result showed that the building in Mikkeli use more of delivered heating energy than building in Vilnius. But it is not clear in which country the renovated building is more energy efficient because only delivered heating energy was compered. Also the climates are different in analyzed countries and latest legislations presents different norms for buildings in Lithuania and Finland.

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