KAUNAS UNIVERSITY OF TECHNOLOGY

Faculty of Civil Engineering and Architecture

SUMAN KUMAR ADHIKARY

ENERGY RETROFITTING OF RESIDENTIAL BUILDINGS

Master's Degree Final Project

Supervisor

Associate professor. Dr. Ala Daugeliene

KAUNAS, 2018

KAUNAS UNIVERSITY OF TECHNOLOGY
Faculty of Civil Engineering and Architecture

ENERGY RETROFITTING OF RESIDENTIAL BUILDINGS

Master’s Degree Final Project

Master’s Degree final Project (Code 621H20001**)**

Supervisor

Dr. Ala Daugeliene (date)

Reviewer

Dr. Jurgita Cerneckiene

(signature)

(date)

Project made by

(signature) Suman Kumar Adhikary

(date)

KAUNAS, 2018

KAUNAS UNIVERSITY OF TECHNOLOGY

Department of Civil Engineering and Architecture

(Faculty)

Suman Kumar Adhikary

(Student's name, surname)

Final Degree Project 621H20001

(Title of study programme, code)

" **ENERGY RETROFITTING OF RESIDENTIAL BUILDINGS**"

DECLARATION OF ACADEMIC INTEGRITY

10th January 2018

Kaunas

I confirm that the final project of mine, **Suman Kumar Adhikary**, on the subject "**Energy retrofitting of residential buildings**" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources; all direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

I fully and completely understand that any discovery of any facts of dishonesty inevitably results in me incurring a penalty under procedure effective at Kaunas University of Technology.

(name and surname filled in by hand) *(signature)*

Suman Kumar Adhikary Energy retrofitting of residential buildings *Master's* Final Project / supervisor assoc. prof. Dr. Ala Daugeliene Faculty of Civil Engineering and Architecture, Kaunas University of Technology.

Keywords: *energy retrofitting of building, building life cycle cost, marginal costs, building retrofitting measures, residential buildings*

Kaunas, 2017. 56p.

SUMMARY

Due to worldwide concern about global warming new and effective solutions for energy saving are being developed and implemented. The final thesis addresses various challenges related to the energy retrofitting of multi-storey residential buildings and research on the efficiency of different measures for energy sufficiency improvement of residential buildings. In the first chapter of thesis the principals of energy saving, and energy retrofitting of buildings are analysed, followed by exploring of legal regulation and financial frameworks for innovative buildings modernisation methods.

The practical part of the thesis presents the research on the energy efficiency improvement measures and building retrofitting scenarios, which are adopted in European countries. Three case studies for energy retrofitting of residential buildings, located in Kaunas, were analysed and the most efficient retrofitting scenario was selected by implementing life cycle cost analysis and marginal costs method. The conducted research showed sufficiency of these for assessment of energy saving efficiency in buildings.

Suman Kumar Adhikary Gyvenamųjų pastatų energetinis atnaujinimas

Baigiamasis magistro darbas / vadovas aso. prof. Dr. Ala Daugelienė

Statybos ir architektūros fakultetas, Kauno technologijos universitetas

raktiniai žodžiai: *pastatų energetinis atnaujinimas, pastatų gyvavimo ciklo kaštai, ribiniai kaštai, pastatų atnaujinimo priemonės, gyvenamieji pastatai*
Kaunas, 2017.56 p.

SANTRAUKA

Pasaulinis susirūpinimas dėl globalinio atšilimo sudarė palankias sąlygas naujų ir efektyvių energijos taupimo metodų vystymui ir taikymui. Pastatų atnaujinimas šiuo atveju turi didelę reikšmę energijos taupymui, kadangi pastatų naudojimas yra siejamas su dideliu energijos suvartojimu ir šiltnamio efektą sukeliančių dujų emisija. Nulinės energijos pastatai, pasyvieji namai, tvarūs namai ir senų pastatų atnaujinimas yra efektyvūs būdai taupyti energiją darant mažesnį poveikį aplinkai. Baigiamajame projekte yra analizuojami iššūkiai, susiję su daugiaaukščių gyvenamųjų namų atnaujinimu, bei nagrinėjamas įvairių energinio efektyvumo didinimo priemonių ekonominis tikslingumas. Pirmojoje baigiamojo projekto dalyje yra pateikti energijos taupimo pastatuose ir pastatų atnaujinimo principai, jų teisinis reglamentavimas bei finansavimo priemonės.

Praktinėje darbo dalyje yra nagrinėjamos energinio efektyvumo didinimo priemonės ir gyvenamųjų pastatų atnaujinimo scenarijai. Efektyviausio atnaujinimo scenarijaus parinkimas yra atliktas praktinių pavyzdžių pagrindu. Buvo analizuojami trijų daugiabučių pastatų Kaune atnaujinimo scenarijai, kurių efektyvumas buvo įvertintas taikant pastatų gyvavimo ciklo kaštų analizę ir ribinių kaštų metodą. Atliktas tyrimas parodė, kad pritaikyti metodai yra tinkamas ir patogus būdas energijos didinimo priemonių efektyvumo vertinimui.

Table of Contents

Abbreviations

CO_2 - Carbon dioxide

OCED - Organization for Economic Co-operation and Development

IEA - International Energy Agency

m^2 - Meter square

W/m^2K -Watt/meter square kelvin

IEE - Intelligent Energy Europe

EU - European Union

EC - European Commission

EPBD - Energy Performance of Buildings Directive

HVAC- Heating, ventilation, and air conditioning

% - Percentage

PV - Photovoltaic

SPSC - Statybos produkcijos sertifikavimo centras

MEV - Mechanical extract ventilation

EIB - European Investment Bank

ENEF - Energy Efficiency Fund

BEMS - Building Energy Management and Monitoring System

GSHP- Ground source heat pump

kwh/m^2- Kilowatt-hours per square

DHW- Domestic Water Heater

MEV - Mechanical extract ventilation

MVHR - Mechanical ventilation heat recovery

EEC - European Economic Community

BEMS - Building energy management system

BMS - Building management system

LCC - Life cycle cost

LCC - Life cycle cost Analysis

MCA - Multi-criteria approaches

DCF - Discounted cash flow

LCF - Life Cycle flow

NPV - Net present value

IRR- Internal rate of return

MVS - Mechanical ventilation system

Contents of figures table and graphs

List of figures

List of tables

List of graphs

Introduction

Entire world is suffering from global warming, because of excess carbon emission. Our oil resources and other natural energy resources are going to finish in next few decades. Because of excess using of non-renewable energy resources and increasing pollution, global temperature and CO_2 quantity in air is increasing tremendously. According to data from NASA, the amount of CO_2 was 32billion metric ton on 2012, and it was predicted the value will reach up to 43.2 billion metric ton by 2040. Generally building sector is one of top sector of generating greenhouse gases [1]. Building construction is highly related to large energy consumption and it have significant impacts on the environment. During construction heavy amount of energy required to complete the construction activities. Building activities are also related to waste generation, greenhouse gases production, and large amount of water consumption. According to data in Australia almost 7.6% of total primary energy consumed on the time of construction of buildings (both nonresidential and residential buildings). And almost 6% of greenhouse gases produced along with large amount of construction waste [2]. According to international outlook 2016 (U.S. energy admiration) data energy consumption of entire world is increased by 37% in the last 25 years. OCED (Organization for Economic Co-operation and Development) countries will increase 20% of energy consumption from 2012 to 2040, where non OCED countries having 70% of increasing energy consumption [3]. Entire world nowadays is more concentrated on energy saving and toward greater use of renewable energy resources. Global trends like green buildings, zero energy buildings, passive house and energy retrofitting buildings can provide large contribution towards energy savings. In all IEA (International Energy Agency) counties up to 40% of total energy is consumed by buildings, including human activities [2]. Buildings are generally responsible for high energy consumption, most of the energy used by thermal systems and humans comfort systems and other building services equipment's. Day by day science and technology improves and lots of electronic gadgets are coming in the market for human comfort and our energy consumptions also increasing day by. So, energy saving become a big challenging matter, 40% of total energy goes on building, so it can be reduced up to 50% and in some case, it can be reduced 100% by proper management.

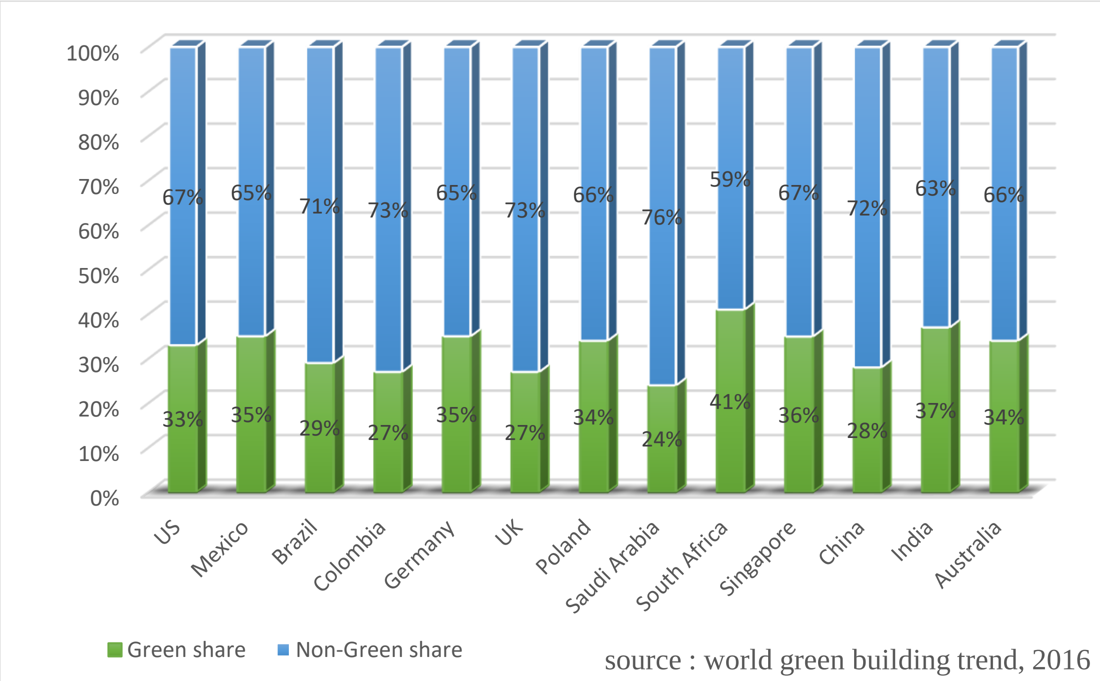
Buildings retrofitting can provide from 20% to more than 50% of energy saving in buildings. So, it can make a large contribution toward protecting our world from excess carbon emission. And it not only provides contribution towards energy savings, it also saves our money

1. ENERGY RETROFITTING OF RESIDENTIAL BUILDINGS

1.1 Energy saving strategies and build environment

Building energy can be saved in several ways using proper measures. Nowadays the concepts of passive house and sustainable building become more and more popular in term of building energy saving.

Green Building Trend: Green energy trend means using of renewable energy and less consumption of energy. Green building trend, is become so popular and being accepted by entire world. Green building technique is subjected to bigger energy and money savings. Few countries like Mexico, Germany, Poland, South Africa showing great contribution towards the green building shares. Average share of green building project by country in 2015 by dodge data and analytics is listed below [3].



1.fig: Share of green and non-green buildings around the world

Green building trend in Europe: From last few years In Europe, green building trend become so popular. And European countries are accepting this technique. In tern of green share projects UK hold higher green shares than any other European countries. Because of environmental regulations and future growth in UK, more than 60% green growth in projects. The top sectors of global green growth are new commercial construction, new institutional construction, and retrofitting of existing buildings. Where new commercial construction is the top sector among those three sectors. Green shares in new commercial sectors is more popular and widely using in China, India, Saudi Arabia, Colombia, Brazil, Poland and in Germany. Where Singapore has highest percentage of green shares in new institutional project (48%). In other hand Germany (39%), China (40%) and Saudi Arabia (42%) has moderate percentage of new institutional green growth projects. While India (26%) and Mexico (25%) has very less contribution in new institutional green growth projects [5]. Retrofitting of existing buildings become so popular and wildly using. The aspects of building retrofitting are to reduce the energy consumptions and to save the natural resources.

Passive house: Without compromising the indoor comfort of buildings with low heating demand are considered as passive house. The heating demand should be less then 15Kwh/m^2 per year. Passive house is a concept of constructing buildings. Passive house can reduce up to 75% of total heating cost of building [6]. Passive house generally means energy efficient building. Passive house concept was developed in early 1990 by Wolfgang Feist and Professor Bo Adamson**,** and in 1990 worlds first passive house prototype was built in Reichstein, Germany**.**

Requirements for passive house:

There are several requirements for constructing passive house.

1. Total space heating energy requirements of the building should not exceed 15kwh per square meter.
2. Renewable primary energy demand on domestic application should not exceed 60kwh per square meter.
3. Airtightness should be properly maintained

And main basic principles of passive house are listed below–

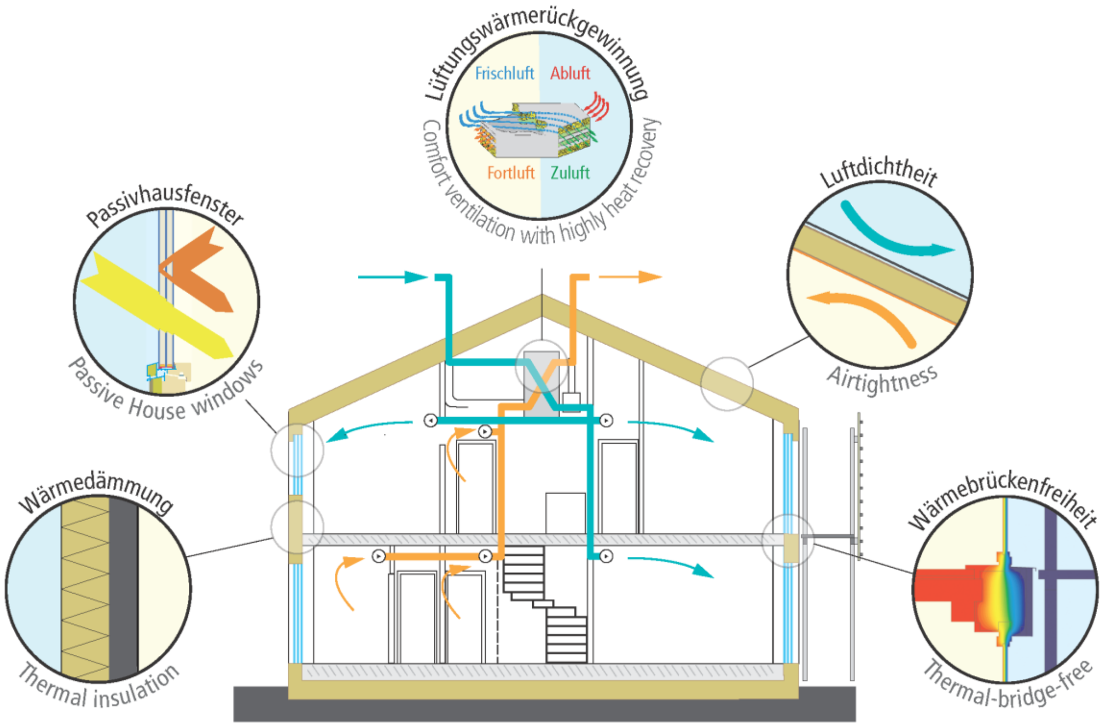
Thermal insulation: Building should be well insulated. And the maximum heat transfer coefficient (U-value) is 0.15 W/(m^2K) for wall.

Passive house windows: U of 0.80 W/(m^2K) should be maintain

Ventilation heat recovery: proper heat recovery system required

Airtightness: At 50 pascals pressures maximum unrestrained leakage gaps shouldn't exceed 0.6 % of the total house volume.

Thermal bridges: thermal bridges related to heat loss, thermal bridges should be minimized.



2.fig: Measures of passive house

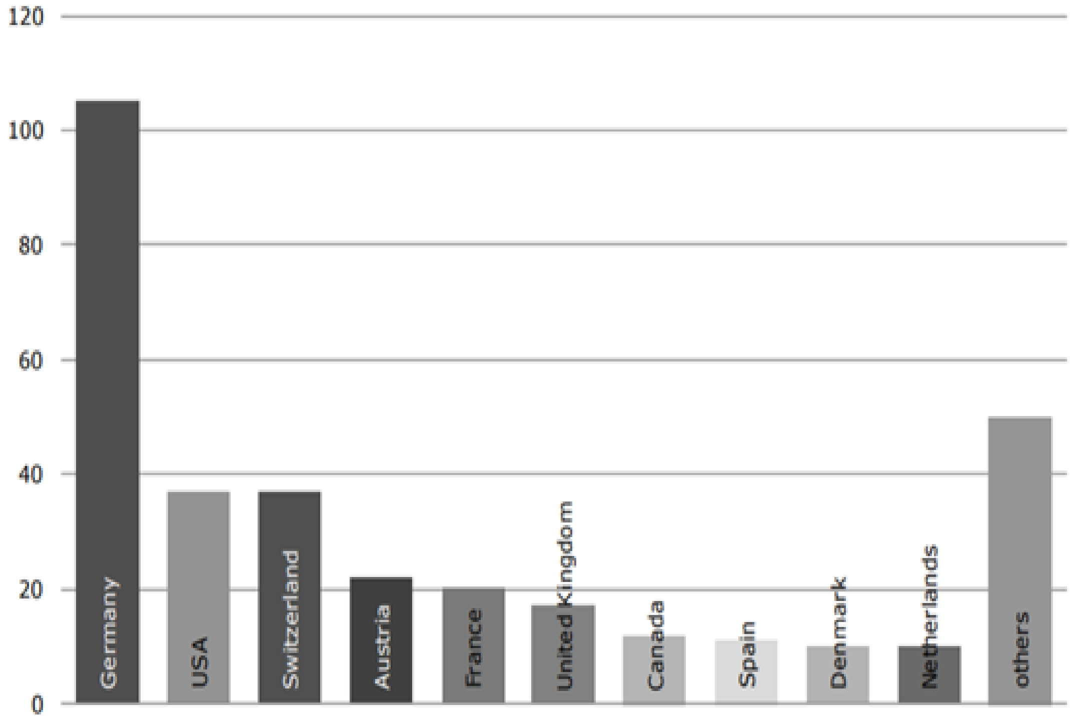
Passive House and EU Support: Passive house trend has been for presence from few years. This passive house techniques were developed in Germany, and this concept is widely used in central Europe. The benefits of passive house came in front of everyone from the past few years. The first energy program Referred to as Intelligent Energy Europe(IEE)-1 ran from 2003 to the quilt of 2006 and aimed to conquer economic cultural and administrate barriers to reduce energy intake in Europe. With a price range of €250 million, it became a policy aid degree that observed various Directives on strength use in addition to the funding for research through the 6th framework program (2002-2006) [8]. In the direction of cease, the IEE -1 program and EU commission followed an action plan for energy performance containing measures to lessen international primary electricity use by 20% by 2020, compared with the baseline scenario. Current running passive house program under the IEE projects is as follows: in the 2010 the European commission adopted a recast of the strength overall performance of buildings directive [9], and in 2012 it followed a new energy efficiency directive [10]. Both directives feature articles that focus on increasing the rate of renovation of existing buildings, including deep renovation as well as step-by-step refurbishment.

3.fig: First Passive House in the world, Germany [11]

Nearly zero energy building: according to the Article 2(2) of the EPBD recast, 2010 a nearly zero energy building is a building which has very good energy performance or efficiency, and very low amount of energy required to cover the all building energy requirements. And the covered energy for primary energy consumption (space heating and domestic hot water) should come from renewable energy resources. The renewable energy resources can be onsite or nearby to the project. The energy performance of the nearly zero energy building is defined as the energy required to meet the energy demand of the building. Which include heating energy, required energy for cooling, hot water, ventilation and lighting [12]. The energy requirement for the building can be very low or nearly zero, but it's partly depend on the user's needs, behavior and level of comfort. And the suggested measures for nearly zero energy building are usage of energy efficient windows, increase the thickness of insulation layers, high efficiency HVAC systems, and use of photovoltaic panels [13]. According to the article 9 of directive 2010/31/EU,19th May 2010 of European parliament and council of all European member state should ensure two requirements:

- By 31st December 2020, all new buildings should be nearly zero energy building.
- After 31st December 2018, all public owned and newly occupied buildings should be nearly zero buildings.

There are few zero-energy buildings in the world. Following figure shows the frequency of known zero energy-building in the world.



4.fig: Frequency of zero energy buildings as per country [14]

1.2 Building energy retrofitting practice in European countries

Building retrofitting and constructing nearly zero energy building was on existence from last few decades. Building energy retrofitting came in attention in building sector to enhance using of the renewable energy resources and to help reducing the climate change. European commission always remarking the need of improving building energy performance [15]. From the centuries buildings were constructed for getting certain comfort within their built environment. Nowadays new construction technologies, inventions and more efficient materials came into the market, which are widely used.

Few European countries list which have great contribution towards environment [16] –

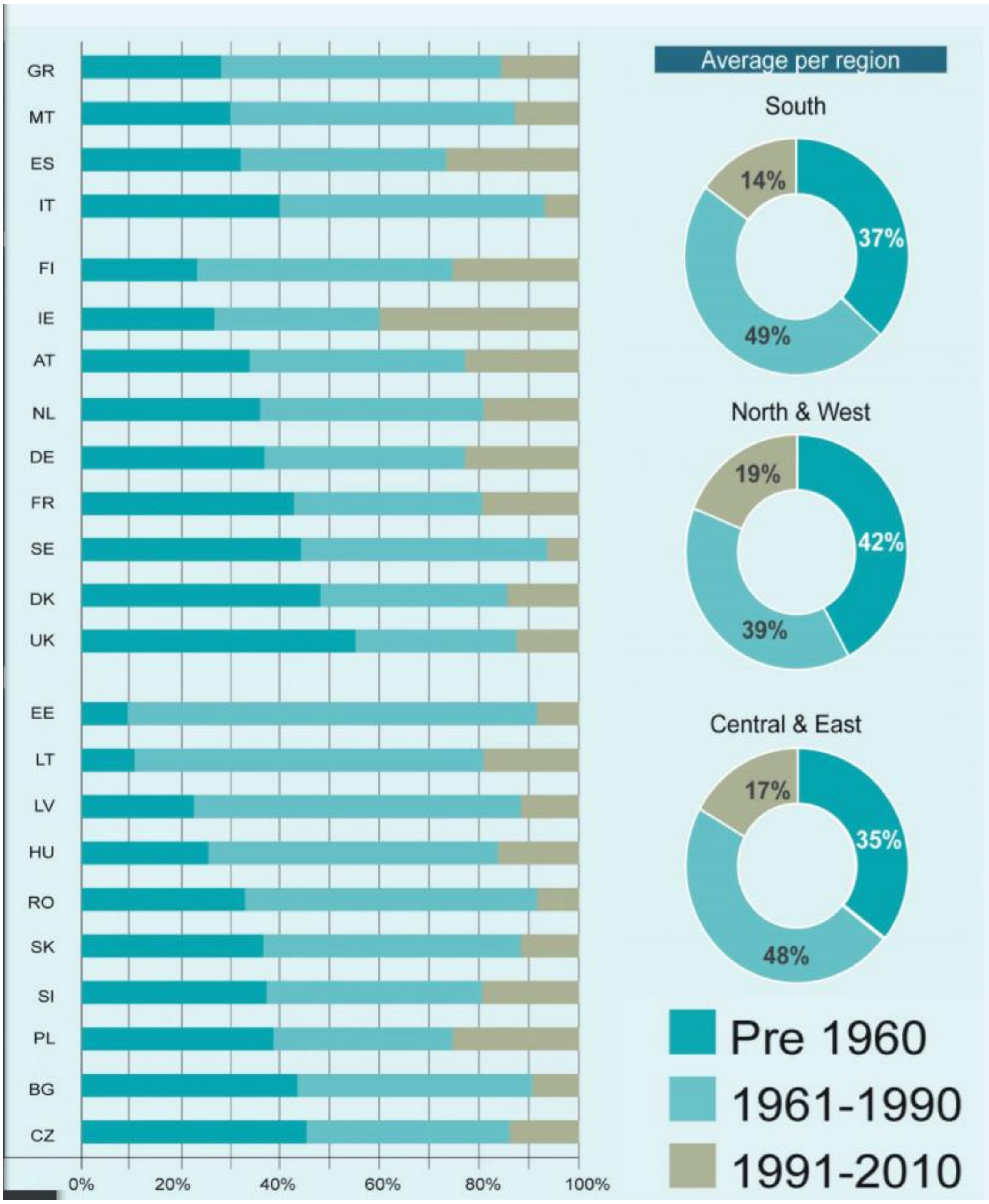
- Norway (69.4% renewable energy resources)
- Sweden (52.5 renewable energy resources)
- Finland (39.3 % renewable energy resources)
- Latvia (37.6 % renewable energy resources)
- Austria (33% renewable energy resources)
- Denmark (30.8% renewable energy resources)
- Croatia (29% renewable energy resources)
- Estonia (28.6% renewable energy resources)

- Portugal (28.0 renewable energy resources)
- Lithuania (25.8 renewable energy resources)

In the year of 2007 in Italy energy uses in residential sector was reduced 20%. The improvement came because of using efficient lighting, proper thermal insulation and efficient air conditioning system. From the 2005 to 2012 almost 3.79 Mtoe/y, energy saved. In Italy almost 62% large buildings were built before 1970s [17]. US also showing the improvements in reduction of building energy. According to data, US reduced space heating consumption by 12%, in 1991 it was 53% and on 2011 it was 41% [18]. According to International energy agency report US, EU, and Russia showed huge improvement in energy consumption. On 1990 total energy consumption of those country was US (21%), EU (18%), Russia (10%), and by the 2011 it had huge improvement and reduced the energy consumption to 17%(US),13%(EU),5%(Russia) [19]. It has been observed that newly constructed buildings are consuming less energy for heating compared to before. Because Newly constructed building should follow the European norms. Following figure shows the figure of heating energy consuming data according to the building construction time. Germany, Portugal and Slovenia showed huge development in term of building energy saving [20].

5.Fig: Building heating energy (kwh/m^{2}a) consumption as per year of construction

In Europe almost 40% of total building constructed before 1960, those building have low insulation level. That's why those buildings required retrofitting to increase the energy efficiency. In Lithuania almost 12% of building constructed before 1960 and almost 70 % of total building constructed during 1960 to 1990. In Europe almost 40% of the total buildings was constructed before 1960, so retrofitting of building is the most important and essential, because constructing new building will be much more expansive than retrofitting of existing building.



6.Fig: Share of building in EU as per year of construction [21]

Space heating of building consumes lots of energy. In 2013 the space heating contributed 62% of total energy consumption of buildings in the Europe. Therefore, proper energy efficient retrofitting can provide better result in decreasing energy consumption [22].

From the year of 2009 European Commission started retrofitting of existing government owned buildings, and structures. European commission set target to renovate at least 3% of total floor area of government owned buildings, and this process to continue till 2020 [23]. Energy efficient building retrofitting became popular and widely used throughout the Europe. Countries like Denmark, Sweden, Germany, Netherlands, Austria, Latvia and some others took part in the collaborative initiative, targeting at dissemination of good practice in retrofitting projects. There are following few retrofitting projects showing bellow [24].

Retrofitting Project, no 1: This project is the one of the oldest project in European country. The building was built in 1925 at Oesterbro, Denmark. That build was retrofitted on 1994-1995 because of excess consumption of energy. The building was retrofitted to reduce the heating energy costing. No mechanical ventilation system was used in the building before retrofitting. Building was fully retrofitted with mechanical ventilation system, improved solar heating system, extra insulation on external wall, heat recovery ventilation system, good quality of windows having U value 0.7 W/m2k, and glassed balcony. 178-meter square solar wall was constructed to decrease the demand of heating energy. After retrofitting 51% of energy saved. (EI-EDUCATION PROGRAM,2007, EI-EDUCATION, conducted under the intelligent energy Europe program, it is an e-learning program which gives information about energy – intelligent retrofitting)

Retrofitting Project, no 2: This project is about an apartment block, which was constructed in 1970 in gaardsteen, Sweden. The building was retrofitted in the year of 2000 to improve the energy consumption efficiency. Few measures were applied on this building like, Insulation layer was applied to the building wall and on the roof, solar collector was installed for pre-heating, windows were replaced with low energy goals and timber frame. After the full retrofitting as a result building energy almost 44% was saved (EI-EDUCATION PROGRAM,2007).

Retrofitting Project, no3: This project is about an apartment block, which was built in raamsdonk, Netherlands in between year of 1963 to 1969. The building was retrofitted in 2002 to improve the energy consumption and living standard. During the retrofitting process solar collector were installed to the building, extra insulation layers were installed on wall and roof, windows were replaced, mechanical ventilation system was installed along with a new boiler. As a result, 70% of gas was saved, which was used for main heating purposes (EI-EDUCATION PROGRAM,2007).

Retrofitting Project 4: This project is about an apartment block, which was built in Hague, Netherlands. The building was retrofitted in the year of 1987 with the measures of replacing with high energy efficient doors and windows, insulation layers for wall, roof and floor, PV system, solar collector and along with a new boiler. As a result, 56% of energy saving were calculated (OTB, 2004).

Retrofitting Project 5: This project is about a 3-story apartment block building, which was situated in Ludwigshafen, Germany. The building was constructed between 1960-1962. To satisfy the energy efficiency regulations of Germany, the buildings was retrofitted on the year of 2005. During the retrofitting process PV system was replaced, insulation layers was installed on the walls and on the roof, low temperature heating system combined with heat power equipment was installed. As a result, 94% of energy saved compared to previous energy consumption (EI-EDUCATION PROGRAM,2007).

1.table: The scenarios of retrofitted building projects [25]

Building energy retrofitting scenarios	Total saving rate in %	51	44	70	46	94
	Energy Efficient lighting				*	
	Wind turbine					
	Solar collector		*	*	*	
	Improved heating and cooling system	*		*	*	*
	Set point temperature					*
	PV system				*	*
	Solar wall	*				
	Thermal insulations	*	*	*	*	*
	Energy Efficiency windows	*	*	*	*	*
	Glazed balcony	*				
	Sun space	*	*			
Descriptions of projects	Year of retrofitting	1995	2000	2002	1987	2005
	Year of construction	1925	1970	1969	1954	1962
	Location	Denmark	Sweden	Netherlan	Netherlan	Germany
Project no		1	2	3	4	5

1.3 **Legal regulation and financial support for building energy retrofitting in Lithuania**

As per European norms all buildings should maintain certain thermal efficiency norms. According to the building thermal energy efficiency there are category of building types, for which building should comply with some minimum requirements. European Union lunched several programmes and policies regarding energy savings in buildings and put some legal rules to be implemented in the building energy system. New European rules are dealing with systematic implication and implication rules.

European energy efficiency rules and regulation as per European commission are:

European commission establish several directives for the use of nonrenewal energy resources and to increase the building energy efficiency. Directive 2010/31/EU was established to increase the building energy efficiency and to increase the uses of renewable energy resources. Building heating system and building air-conditioning system played a vital role in term of building energy performance. European commission set specific requirements for the heating and air-conditioning system. According to Directive 2009/91/EC all buildings should meet the heating and air-conditioning requirements.

Directives for new and existing building: according to the Directive 2009/91/EC, article 4 all the members of European commission should take some necessary measures to ensure that all the newly constructed buildings are fulfilling the nominal energy performance requirements. For new buildings, all European members should ensure technical, economic and environmental feasibility before and after construction. And following considerations should consider.

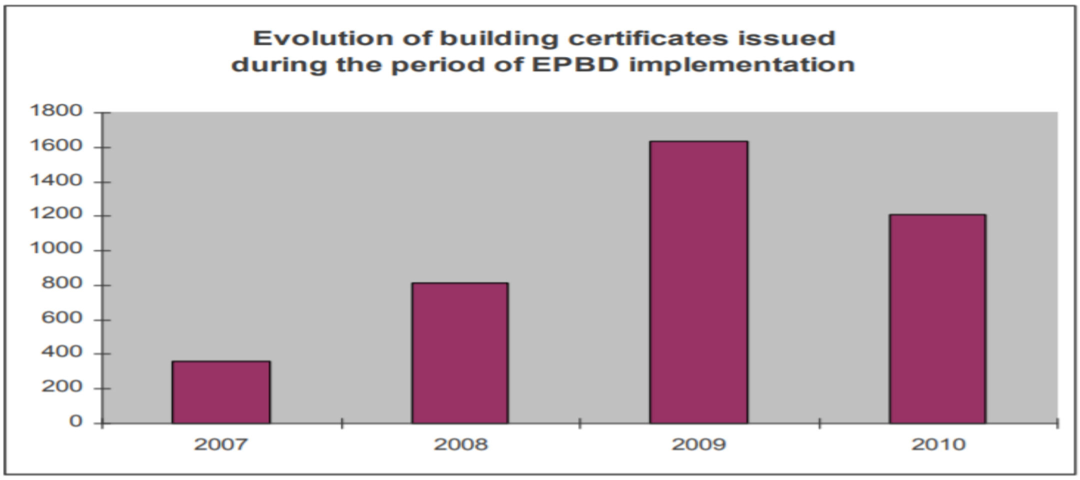
- Decentralised energy supply system, eased on partially or fully renewable energy resources.
- District heating and cooling systems should be based on fully or partially renewable energy system.
- Cogeneration
- Heat pump

According the European commission norms all buildings should go through a verification process. For existing buildings European commission apply few regulations.

Whenever any building goes through any major renovation, all the members of EU, should ensure that the buildings are fulfilling the nominal energy performance requirements. And according to the article 4 of Directive 2010/30EU all the members should determine the minimum energy performance requirements. And all the buildings should go through inspection of heating and air-conditioning system. According the Directive 2009/72/EC of 13 July 2009, all member should encourage the introduction of intelligent metering system.

Many European countries has developed their building energy efficiency systems. Lithuanian government also take initiatives for nearly zero energy building and on retrofitting. According to the legal requirements of the Republic of Lithuania all new constructed buildings must be certified by the Ministry of Environment of the Republic of Lithuania [26]. And minimum certification should be class B. No new building can be constructed lower than class B. This law has been in action since January 1st, 2007. This certification can be issued after the completion of the project or construction. If any building design can't satisfy all the energy efficiency requirements, then the permit to construct the project will not be granted.

SPSC (Statybos produkcijos sertifikavimo centras) is an independent state enterprise. SPSC established in 1996 by the Ministry of Construction and Urban Development, which is currently under Ministry of Environment. The main goal of SPSC is to provide service of certification of production products, assessment of consistency of performance, checking out and evaluation of inner production upon customer's packages. Providing these services SPSC follows the necessities of felony acts and requirements of the Republic of Lithuania and of the EU prison acts and standards. The following figure no.8 shows that the yearly issued building energy certificates in Lithuania. In the year of 2007 the number of issued certificate was near about 400 and the number increased to almost 1600 in the year of 2009. Until November of 2010 over 4000 numbers of energy performance certificates provided by Lithuanian government. Approximately hundred to hundred fifty certificates were issued monthly [27].



7. fig: Distributed building energy certificates during EPBD period [28]

According to the Lithuanian laws and other legal requirements buildings are being allocated to the energy efficiency class by compliance with 8 different rating parameters.

The rating parameters are as follows –

- Heat loss of the building envelope
- Total required energy for building heating purposes.
- Airtightness of the building
- Technical indicators or MEV (mechanical extract ventilation) along with heat recovery system
- Thermal properties used between spans and floor partition
- C value
- Using of renewable energy resources

All the above requirements are very much and equally important for calculating the building energy efficiency rating. Any kind of priority are not subjected to given to any specific parameter. All the parameters are equally considered.

- Class A, if $C < 0,5$;

- Class B, if $0,5 \leq C < 1$;

- Class C, if $1 \leq C < 1,5$;

- Class D, if $1,5 \leq C < 2$;

- Class E, if $2 \leq C < 2,5$;

- Class F, if $2,5 \leq C < 3$;

-Class G, if $C \geq 3$.

Where c value is changes according to conditions

When $\frac{\text{Qsum}}{\text{QN.sum}} \leq 1, \;\; C = \frac{\text{Qsum}}{\text{QN.sum}}$

When $\frac{\text{Qsum}}{\text{QR.sum}} \geq 1, \quad C = 1 + \frac{\text{Qsum}}{\text{QR.sum}}$

In the other cases $C = +\frac{\text{Q.sum}-\text{QN.sum}}{\text{QR.sum}-\text{QN.sum}}$

$QN_{\ sum}$= Building normative kwh/m^2.year

$QR._{sum}$ = reference kwh/m2.year and $Q_{sum}\ =\ calculated\ kwh/m^2.year$

Insulation system: For maintaining U-value, we should change our insulation system. Day by day technology is improving, lots of new innovative insulation materials came into the market. Although the initial costs are higher, the material can provide longer durability with proper working condition. We should use best insulation properties within economic cost. Where Economic cost means best product within the price range. The U values for Lithuania are-

2.table: Energy performance requirements for buildings in Europe [29]

Building element	U-values, W/m^2. K			
	Class A++	Class A+	Class A	Class B
Roof Flooring in contact with air	0.080 k	0.10 k	0.10 k	0.16
Building elements in contact with ground Flooring over unheated basements and crawl	0.10 k	0.14 k	0.14 k	0.25
External walls	0.10 k	0.13 k	0.12 k	0.20
Windows and transparent building elements	0.70 k	1.0 k	1.0 k	1.6
Doors and gates	0.70 k	1.0 k	1.0 k	1.6

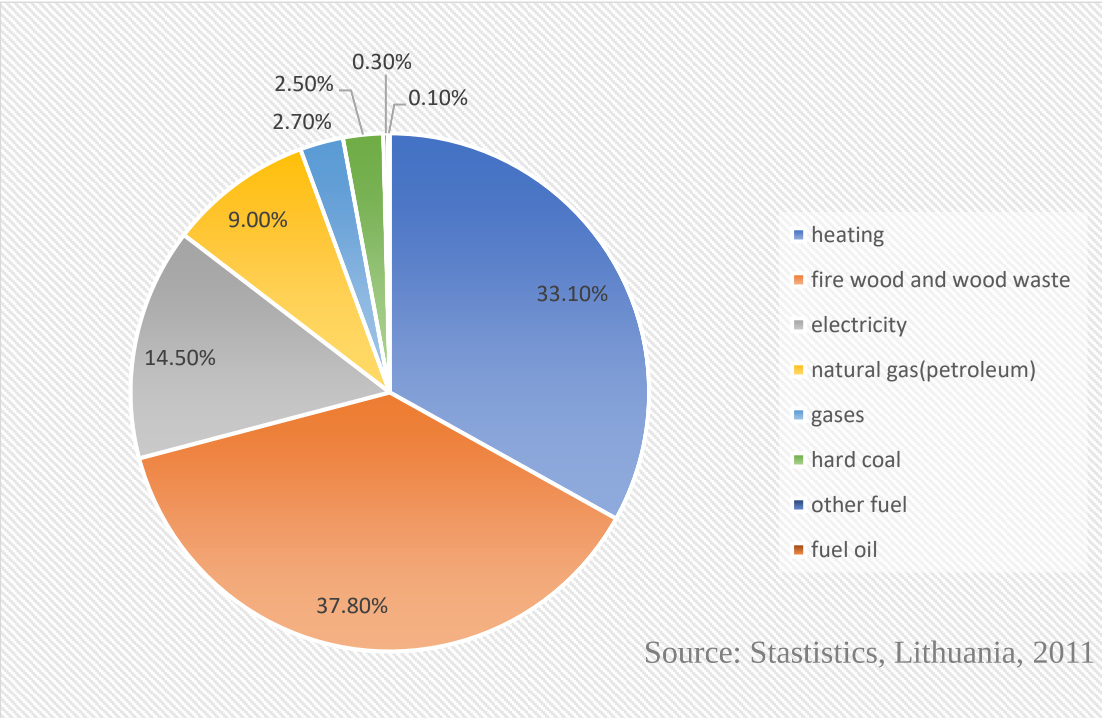
In the figure 9, the value of $k = 20/(\theta_i - \theta e)$; where k is temperature correction factor. And θ_i Is denoted as the indoor air temperature in °C and θ_e is outdoor air temperature in °C. In example if the indoor air temperature $\theta_i = 40$°C and outdoor temperature $\theta_e = 0$°C, then the value of k =0.5.

Energy efficiency of Lithuanian housing sector

Total population of Lithuania is 2.8 million, and 38,000 multi-family buildings are counted. Number of flats in multi-family buildings are 800,000 and 385 number of flats per 1000 inhabitants. Structure of buildings by years are following below

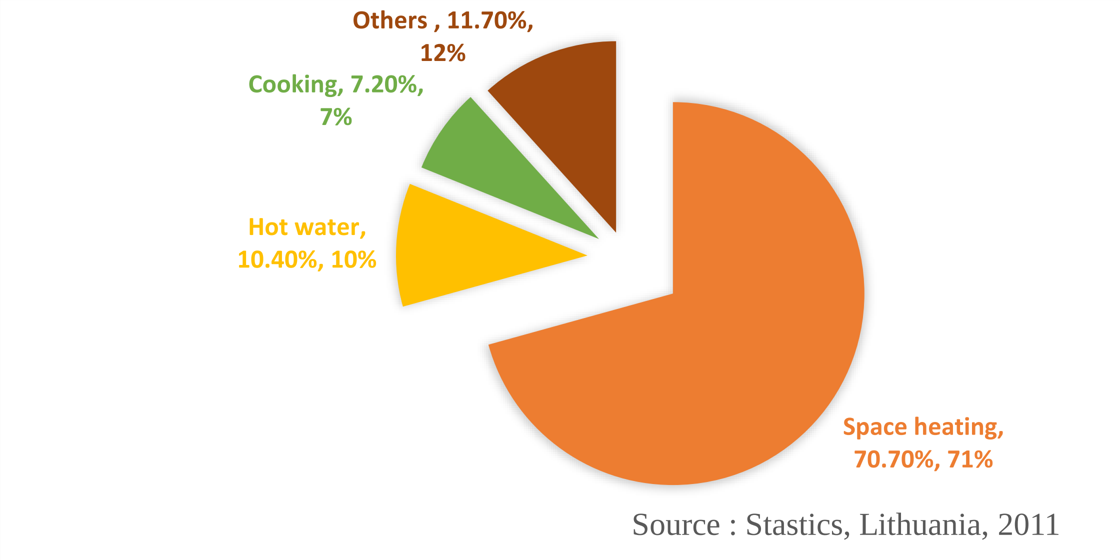
– Almost 12% of total building built before 1960
– Almost 70% of total building built during 19601–1990
– Almost 18% of total building built during 1991-2010

In Lithuania currently the most energy efficient residential building consumed per year 19 kwh/m^2 energy only for heating. And around total 49 kwh/m^2 energy consumed by the residential buildings. But in the other hand non-renovated multi-apartment buildings consumed more energy compared to renovated energy efficient buildings. Non-renovated buildings consumed almost 6.5 times higher energy compared to energy efficient buildings [30]



8.fig: Overall household energy intake by energy type

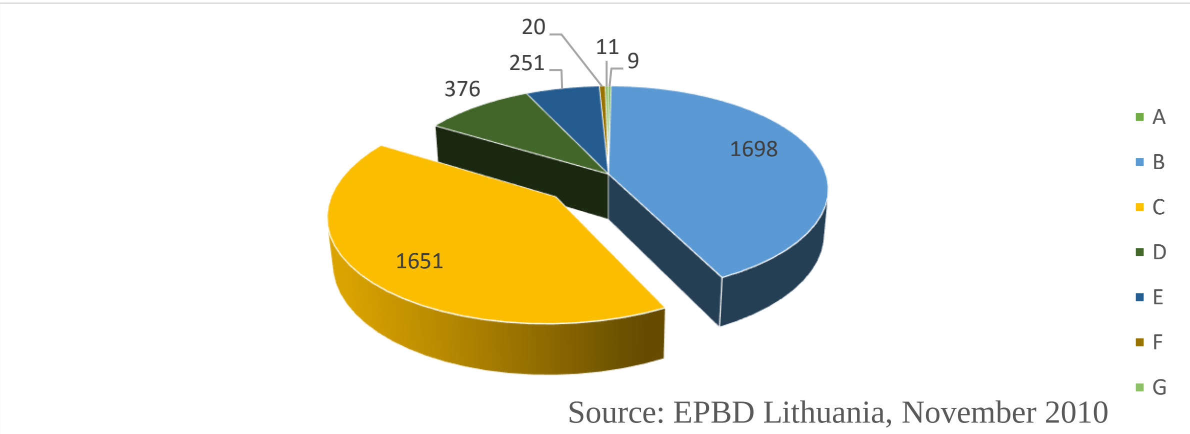
The above figure shows the overall households energy intake, by energy type. Different types of energy resources are used in Lithuania as a source of energy like electricity, natural gases, hard coal, fuel oils etc. Fire wood and wood waste occupy the highest proportion in term of energy resources. Almost 15% of total energy comes from electricity supply.



9.fig: Household energy consumption by purpose

Above figure shows the proportion of household energy used by purposes. In Lithuania almost 70% of total household energy goes on space hating purposes. And almost 10% of total energy goes on water heating. In Lithuania more than 57% of households are not satisfied. Most of the buildings are in poor condition, heating systems are inefficient, lack of management, quality of roof and windows are also not good.

For constructing new buildings in Lithuania according to government laws minimum permissible building energy class is B. And for existing buildings after major renovations the energy performance class should not be lower than D. Until 2010 almost 4000 building energy certificates issued. Most of the buildings was certified as class B and class C. The flowing figure no.12 shows the numbers of certifications according to the building energy performance classes.



10.fig: Numbers of building with various energy performance classes

As a part of its energy saving policy the Republic of Lithuania has adopted and developed different measures for supporting initiatives for retrofitting of old buildings and delivery of new sustainable buildings.

JESSICA holding fund: The JESSICA holding fund in Lithuania turned into mounted in 2009. The JESSICA holding fund amount was €227 million. The fund targets at offering loans and offers to citizens of Lithuania for energy refurbishment of multifamily residential buildings and higher education institutions. JESSICA fund effectively attracted non-public finance and as a result, 690 buildings had been renovated with 60 % energy financial savings [31]. According to data European investment bank and sauliu bank have agreed to support Lithuanian multi-apartment buildings. The news of the funding released on 16th march, 2017.The fund will be given under Jessica fund. Total fund of Jessica-ii will be 90 million euros [32].

EIB (European investment bank): European investment bank in May 2015 signed a contract on the Jessica II fund. Total amount of the Jessica-II will be1.3 billion euros. And the total period of the project will run from 2014 to 2020.

Advantages of the use of monetary unit for energy performance in buildings are [33] –

- Guarantees greater green use of public sector sources,
- Offers more leverage capability and brings economic area into the project,
- Permits to mix with technical guide

Energy efficiency fund (ENEF) -Lithuania: The energy efficiency fund was established on February 18, 2015 by the ministry of finance of Lithuania, the public investment development agency (VIPA) is the manager of the fund [34]. This fund provides financial loans for the renovation of central government's own buildings, and for the modernization of Street lights. This program operates by Lithuanian government. The main aims of the project are to increase the energy efficiency and ensure the obligation of EU parliament and European council Directive 2012/27/EU. Total fund of the project is 65 million euros for the renovation of central government buildings. And 14.5 million euros for the modernization of street light projects [35].

2. EFFICIENCY OF RESIDENTIAL BUILDING ENERGY RETROFITTING

In the Europe lots of buildings were constructed few decades before, so retrofitting of existing building came in existence and widely used.

Retrofitting: Retrofitting of buildings is a concept of reconstruction of building, where old energy inefficient buildings are updated to a modern energy efficient building [36]. Energy retrofitting of building is called when an older building system turns into 20 % to >50% energy saver building system adding modern technology. Generally, energy retrofitting of building is classified into three different classes according to percentages of energy savings [37]. And those are-

- Normal retrofitting
- Standard retrofitting
- Deep retrofitting

Normal retrofitting: Normal retrofitting is generally saves energy up to 25% with low investment and it is easily obtained by renovation. Basically, thermal insulation system and some few systems are upgraded in this category.

Standard retrofitting: Standard retrofitting saves energy from 25% to 45% with moderate investment cost and upgrading few systems, like replacement of doors and window, thermal insulation system, airtightness, wall insulation both outside and inside, etc. Generally standard retrofitting widely used because of low initial investment.

Deep Retrofitting: Deep retrofitting is most popular and lots of research are going on it, how to reduce more energy consumption. Generally, it saves more than 50% of energy. In this renovation, we need to add renewable energy systems, upgrading old mechanical systems like gas, heating system and remote sensing system to control lighting systems. Deep renovation is high initial investment and provides big savings for several years, although it is high initial investment, but preferable because of long payback periods. And sometimes few buildings can be developed as zero energy building.

There is lots of buildings energy retrofitting measures, which may be used to reduce the consumption of the constructing energy:

- Energy performance improvement measures (insulation, heat-insulating door and window frame, building shape, etc.)

- Renewable energy resources (ground source heat pumps, solar panels, photovoltaics)
- Movements for the development of indoor comfort situations (mechanical ventilation combined with heat recovery, efficient use of multi-functional equipment, improvement of boilers and air conditioning)
- Use of building energy management and monitoring system
- Use of energy efficient home equipment and compact lighting

2.1 **Residential buildings energy retrofitting measures**

Selection of energy retrofitting measures for residential building is individual and based upon the preferences and capabilities of the residents. The most popular measures used in the residential construction are as following [38]:

- Energy performance enhancement measures (proper insulation system, good heat-insulating doors and windows frames, and shape of building).
- Renewable energy resources (solar, panel, ground heating).
- Heating and cooling loads decreasing measures (passive heating and cooling technologies).
- Measures for increasing internal comfortless of building (mechanical ventilation system combined with heat recovery system, improving or replacing old boilers and air conditioning).
- Uses of BEMS (Building Energy Management and Monitoring System)
- Energy efficient appliances and efficient lightning.

Replacement or improvement of insulation system: For maintaining appropriate U-value, the old insulation system of building must be replaced after its economic life. Requirements for insulation of different structures like walls, roof and floor differs, therefore the properties of insulation materials also differ, as well as their U- values. The requirements for U values in Lithuania [39] are as follows-

A.U-Value for wall at Lithuania: U-Value for wall in Lithuania is from 0.20 W/m²K (Class B) to 0.10 k (CLASS A++), we should maintain this U value. Better material can provide more resistance to heat loss and can be more efficient. Polyurethane Foam, Polyurethane Insulation, Mineral Wools are used for wall insulation.

B. U-value for roof: U-Value for roof in Lithuania is 0.16 W/m²K (class B) to 0.080 k (CLASS A++). Most of the heat goes from the roof so it should be protected. Fiber glass, cotton, sheep's wool or mineral wools are used for roof insulation.

C. U-value for floor: U-Value for floor in Lithuania is 0.25 W/m²K (class B) to 0.10 k (CLASS A++). Spray foam, Rigid panels, Fiberglass batts and blankets and other materials are used for floor insulation.

Where k is the temperature co-efficient, $k = 20/(\theta i - \theta e)$

θi = is indoor temperature and θe = is out door temparature in°C

The values of U are varying as per country to country norms. The values of U are showing below in the figure.

	MT	CY	PT	GR	ES	IT	LV [1]	FR	BG	BE	NL	IE	HU	SI
HDD[5]	560	782	1 282	1 663	1 842	1 907	1 970	2 483	2 686	2 872	2 902	2 906	2 922	3 053
Roof	0.59	0.85	0.9-1.25	0.35-0.5	0.45-0.65	0.32-0.65	0.2κ-0.35κ	0.2-0.25	0.3	0.3	0.4	0.25	0.25	0.2
Walls	1.57	0.85	1.45-1.8	0.4-0.6	0.57-0.94	0.33-0.62	0.25κ-0.5κ	0.36-0.40	0.35	0.4	0.4	0.37	0.45	0.28
Floor	1.57	2		0.45-0.5	0.62-0.69	0.29-0.38	0.2κ-0.35κ	0.37-0.40	0.5	0.6	0.4	0.37	0.45	0.9
Window/ Door	5.8	3.8		2.6-3.2	3.1-5.7	1.3-3.7	1.8κ-2.4κ	1.7-1.9	1.8	2.5	4.2	2.2	1.6	1.1 -1.6

	UK[3]	RO	DE	SK	CH[2]	DK	CZ	AT	PL	LT	EE	SE[4]	NO	FI
HDD	3 115	3 129	3 239	3 453	3 482	3 503	3 571	3 573	3 616	4 094	4 444	5 444	5 646	5 850
Roof	0.2	0.2	0.24	0.19	0.17 or 0.2	0.2	0.24	0.2	0.25	0.16	0.15-0.2		0.18	0.09
Walls	0.3	0.56	0.24	0.32	0.17 or 0.2	0.3	0.3	0.35	0.3	0.2	0.2-0.25		0.22	0.17
Floor	0.25	0.35	0.3		0.17 or 0.2	0.2	0.45	0.4	0.45	0.25	0.15-0.2	0.4-0.6	0.18	0.16
Window/ Door	2	1.3		1.7	1.3	1.8	1.7	1.4	1.7	1.6	0.7-1.4		1.6	1.0

NOTES

(1) Depending on type of building (residential, public, industrial etc.) where κ is a temperature factor, κ = 19/(Tin-Tout), Tin and Tout denote indoor and outdoor temperatures, respectively.
(2) Depending on evidence of thermal bridges
(3) For England & Wales
(4) Depending on type of building (residential and non residential) & type of heating (electric and non electric). These represent overall U values
(5) Mean HDD values for period 1980-2004 based on Eurostat data

LEGEND
HDD: Heating degree days.

11.fig: U(W/m²K) values of wall, roof, floor and windows as per European individual country norms [40]

Reduce air leakage or air seal: Air leakage is one of the main reason for heat exchange. Building should be airtight to prevent heat loss. Generally old buildings have this problem that should be sort out. Proper management can prevent it. Proper airtightness can provide more savings. If building is airtight then there will be less heat exchange. And helps to reserve the insidious heat for longer time. Airtightness of buildings are varying country to country norms. The values are showing below in the figure.

AT	In naturally ventilated buildings, maximum n_{50} is 3.0. In mechanically ventilated buildings, maximum n_{50} is 1.5.
BE	Default value of 12 m^3/hm^2 is used in methodology if no pressure test is available. Actual test result is used in the calculation if available.
BG	In apartments with high airtightness, $n_{50}<2.0\ h^{-1}$, with medium airtightness $n_{50}=2.0\text{-}5.0\ h^{-1}$ and with low $n_{50}>5h^{-1}$. In SFH with high airtightness, $n_{50}<4.0h^{-1}$, with medium airtightness$n_{50}=4.0\text{-}10.0\ h^{-1}$ and low airtightness$n_{50}>10.0\ h^{-1}$.
CY	Not regulated in building codes.
CZ	Recommended maximum for common buildings is 4.5 h^{-1}, low energy buildings 1.5 h^{-1} and passive houses 0.6 h^{-1}.For mechanically ventilated buildings w/o heat recovery 1.5 h^{-1}, with heat recovery 1.0 h^{-1}.
DE	For naturally ventilated buildings, n_{50} is 3.0h^{-1} and for mechanically ventilated buildings, n_{50} is 1.5h^{-1}.
DK	Airtightness must be better than 1.5 l/sm^2, tested @ 50 Pa.
ES	Air permeability of windows and doors depend on the climatic zone. For zones A and B (Class 1, 2, 3 and 4), maximum air permeability is 50 m^3/hm^2. For zones C, D and E (class 2, 3 and 4), maximum air permeability is 27 m^3/hm^2.
EL	Air penetration for the reference building, is taken equal to 5.5 m^3/hm^2 frame.
EE	For small buildings, maximum airtightness is 6 m^3/hm^2 (for new buildings) and 9 m^3/hm^2 (for existing buildings). For large buildings, maximum airtightness is 3 m^3/hm^2 (for new buildings) and 6 m^3/hm^2 (for existing buildings).
FI	n_{50} equal to 2.0 is used for reference building heat loss in Finnish Building Code. For EPC, n_{50} of 4 is considered unless the measured value is different. Air change rate in new apartments should be at least 0.5 h^{-1}.
FR	Airtightness under 4Pa of building envelope is limited to 0.8 $m^3/hm^2$for SFH, 1.2 $m^3/hm^2$for other residential buildings, offices, hotels educational and health care buildings and 2.5 m^3/hm^2 for other buildings.
HU	Not regulated in building codes.
LT	For naturally ventilated building, maximum $n_{50}=3\ h^{-1}$, for mechanically ventilated buildings, maximum $n_{50}=1.5\ h^{-1}$.
LV	Maximum n_{50} in dwellings is 3 m^3/hm^2, 4 m^3/hm^2 in public buildings, 6 m^3/hm^2 for industrial buildings. For ventilated buildings, maximum n_{50} is 3 m^3/hm^2.
MT	Not regulated in building codes.
NL	For residential buildings, 200 dm^3/s @10 Pa and for non-residential buildings 200 dm^3/s per 500 m^3 @10 Pa.
NO	Maximum n_{50} is 3.
PT	For residential buildings, the requirement is 0.6h^{-1}. Requirements for non residential buildings with mechanical ventilation exist depending on type of use.
SI	For naturally ventilated buildings, maximum n_{50} is 3.0, for mechanically ventilated buildings, maximum n_{50} is 2.0.
SK	For SFH with high quality windows, maximum n_{50} is 4 h^{-1} and for all other buildings is 2 h^{-1}. Other values apply for buildings with double glazed windows with seals or single glazed windows without seals.
UK	Maximum $n_{50}=10\ m^3/hm^2$

12.fig: Values of airtightness as per country norms

Heat insulating door windows frame: According to Lithuanian legal rules minimum heat exchange for windows is 1.6kw/m^{2}k. Double glazing and triple glazing glass windows are best choice for retrofitting. Best quality of windows is preferable. The term “k” is the temperature correction factor (k =20/(Φi–Φe), where Φi-indoor air temperature and Φe- outside air temperature. The requirements apply even though a single window replaced. If the overall area of windows and other transparent constructing element exceeds 25% of total wall area, the U-value of transparent element even shall not exceed 1.3 W/(m^{2}k) [41].

Shape of building: building’s compactness allows us to compare volumetric and plan solution of building and decide the capacity of a building for energy saving and raw materials. It’s been observed that the geometric performance of a building relies upon both on its size and proportions. The bigger building has the weaker impact of its proportions on both geometric and energy performance (in comparison that of smaller buildings), and that is proved by way of the outcomes from the assessment of electricity losses [42].

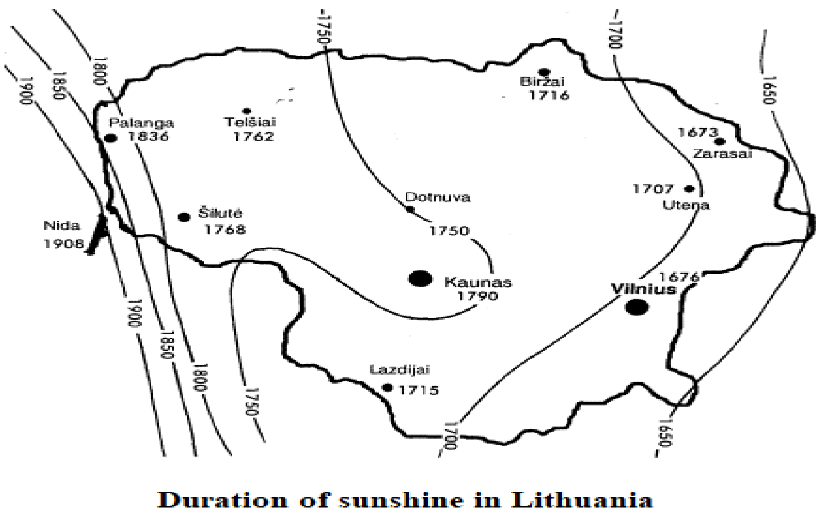
Use of renewable resources: According to the laws of Republic of Lithuania, government should implement measures promoting the renewable energy resources. From 31 December 2014, new buildings and present buildings which are concerned with retrofitting or renovation need to observe necessities for the usages of energy from renewable sources [43].

There are lots of renewable resources that are using in the building:

Ground source heat pump: Nowadays the GSHP system have been broadly utilized in residential and commercial buildings. It is calculated that the Ground source heat pump device installations have risen continuously from 10 to 30% yearly in recent years within the global [44]. A ground source heat pump absorbs warmness from the ground by circulating water all through piping inside the ground and transfer the heat into the building via circulating warm all through radiator or under floor piping circuits. The figure shows the process.

13.fig: ground heat pimp system [46]

Solar energy: Lithuania is located among 54-56° of northern latitudes, and it is like the United Kingdom, southern Denmark and southern Sweden. Worldwide radiation has been measured at places in Lithuania: that is in Kaunas at 54.54 N and silute 55.21N, 200 and 40 km from the west coast respectively. Average yearly sun radiation on the horizontal surface is 968 kwh/m^2 in Silute and 1025 kwh/m^2 in Kaunas.



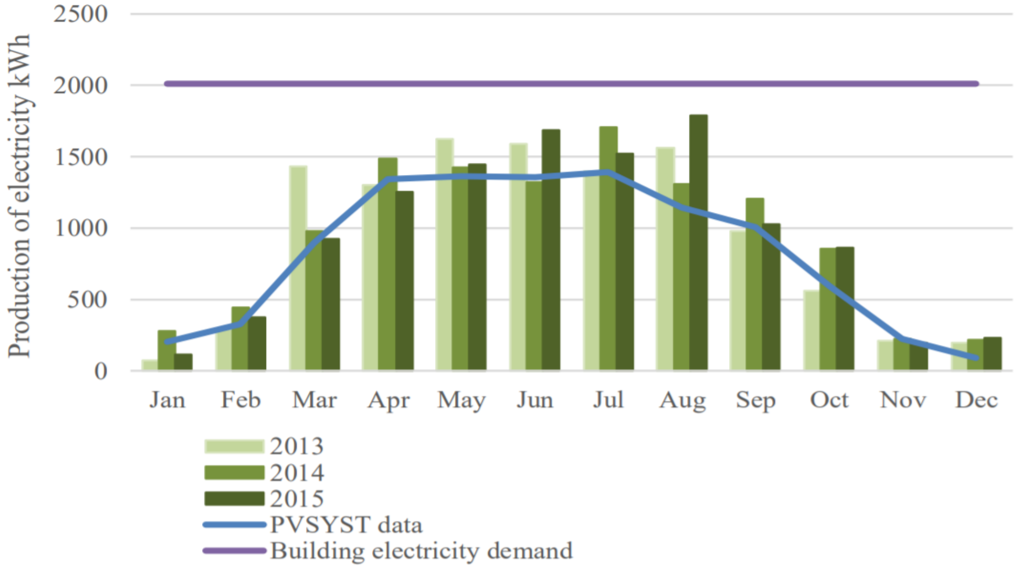
14.fig: duration of sunshine in Lithuania [47]

Solar heating systems in Lithuania consist of solar collector systems for use in commercial and residential applications generating warmth 120ºC. It used for home warm water (DHW) for single-own family homes in addition to multifamily houses, and lighting purposes. Uses of Solar collector in Lithuania increasing day by day. According to data the numbers of solar collector increase 122 to 150 from 2000 to 2001. Several types of panels are available in Lithuania and those are Copper piping rolled into an aluminum plate, Channel plate made of stainless steel, Plastic piping (polypropylene) fixed on fiber board. Semitransparent with day lighting type of photovoltaic systems and crystalline-based solar panels are generally used in Lithuanian residential sector. Lithuania have (2,340) solar plants which produce 73.68 MW of power.

Solar collector of the DHWS system on the roof of Lithuanian Energy Institute

15.fig: Solar collector [48].

In Lithuania integration of PV (photovoltaic) was used in a case study of building energy retrofitting, three story residential building was retrofitted in Kaunas. The area of the house was 1108.64 m^2. In 2015 the power consumption was 146.08 mwh/per year, and the thermal water heating costs was 97.87 mwh/ per year. Before retrofitting total annual heating cost of building was 243.95 mwh. And 25.82mwh/per year electric energy was consumed after the renovation. The measures are used in the building was walls and roof insulation, replacement of windows and alternative energy sources, and lots of solar collector was used in the building. Swiss photovoltaic solar system PVSYST V6.49 was used to access the production electricity. 10 kW photovoltaic solar plant was used, and solar plants were instigated on the roof and wall. According to PVSYST V6.49 modeling result only from roof solar plant on summer time (April to September) 32% of total electricity demand was covered, by using these solar plants. And yearly 41% energy demand was covered from roof solar plant. And wall instigated solar plants covered 20% electricity demand during summer time (April - September), and around 29% electricity demand was covered yearly.

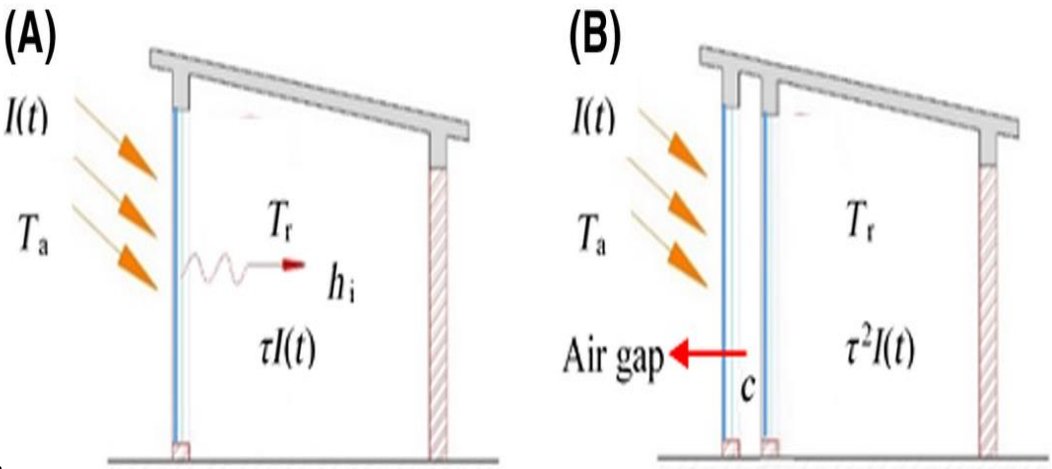


16.fig: electricity production from the solar photovoltaic power plant [49]

Passive house heating and cooling techniques: Passive strategies stand out most of the oldest possible solution to reduce energy demand. They surely represent the oldest way to lessen heating and cooling cost. And these days are superior for having repeatedly proved to be sustainable alternatives to modern conventional strategies. However, their effectiveness relies upon the weather, as well as the availability of detailed statistics about the target building and approximately the indoor comfort expectancies. [50]

Direct Solar Gain:

Direct solar gain is the heat from the solar being collected and contained in an occupied area. This heat can be retained through the building's thermal mass, or can be averted with reflective materials. Direct solar gain is directly depending on the solar strength. The solar can provide heat to the interior area throughout the day and year. Daylight can heat a space through the solid partitions or roofs of the envelope. Daylight additionally enters the gap via home windows, and heats indoor surfaces



.

17.fig: direct gain of single glazing and double glazing [51]

Q = rate of heat transfer into the room

And $Q = (\frac{1}{U_t} + \frac{L}{K} + \frac{1}{h_i})^{-1}(T_{sa} - T_r) = U_L(T_{sa} - T_r)$

Where,

$T_{sa} = \frac{\tau I(t)}{U_t} + T_a and U_t = (\frac{1}{h_0} + \frac{1}{h_i})^{-1}$

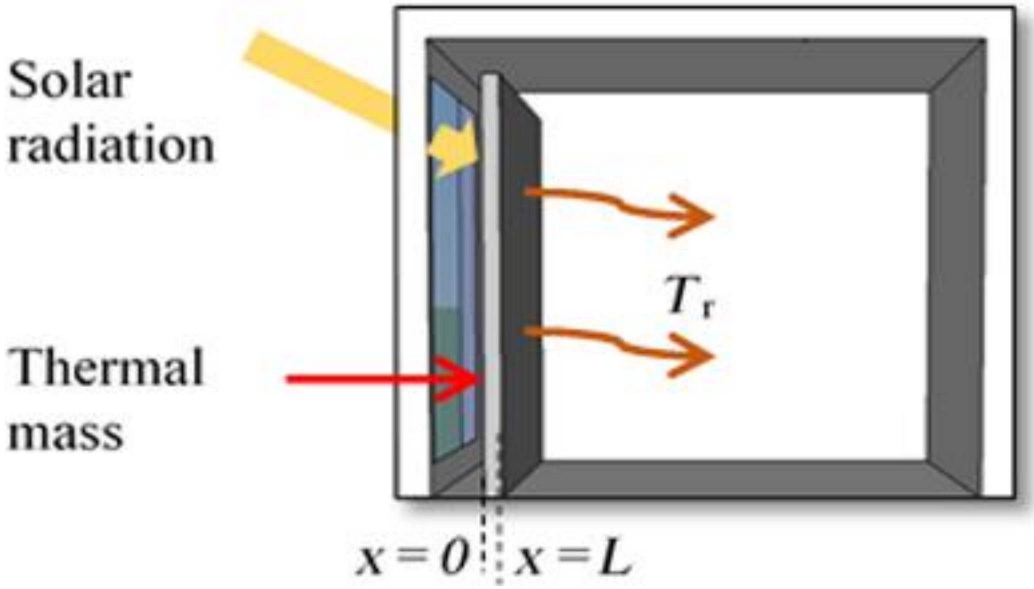
For single glazing system rate of useful energy

$q_u = \tau I(t) - U_t(T_r - T_a)$ where, $U_t = \left[\frac{1}{h_0} + \frac{L_g}{K_g} + \frac{1}{h_i}\right]^{-1}$

For double glazing system the rate of useful energy

$q_u = \tau^2 I(t) - U_t(T_r - T_a)$ where, $U_t = \left[\frac{1}{h_0} + \frac{1}{c} + \frac{1}{h_i}\right]^{-1}$

Indirect gain: In this process the heat is transferred into the room through conduction and convection process. In the first step the solar heat energy enters through the glazing system and stored in a thermal mass as shown in the figure below. And the heat energy transferred to the room. In this process generally, dark color thermal masses are used to get maximum efficiency. Dark color absorbs more solar radiation compared to others. The efficiency also depends upon the thickness of the thermal mass, thermal properties, and types of materials. There are various concepts which is being used in indirect gain like Trombe wall, trans wall and water wall.



18.fig: the figure shows indirect solar gain [52]

The rate of heat transfer in indirect solar gain process is

$$Q = \left(\frac{1}{U_t} + \frac{L}{K} + \frac{1}{h_i}\right)^{-1}(T_{sa} - T_r) = U_L(T_{sa} - T_r)$$

Where, $T_{sa} = \frac{\alpha\tau I(t)}{U_t} + T_a$

Passive cooling systems: Passive house cooling system is a technique or a design system which helps to cool the building by consuming nominal energy. In building system there are various method which used in passive cooling system, like shading system, phase change material, passive cooling shelter, heat sink, and night ventilation system [53].

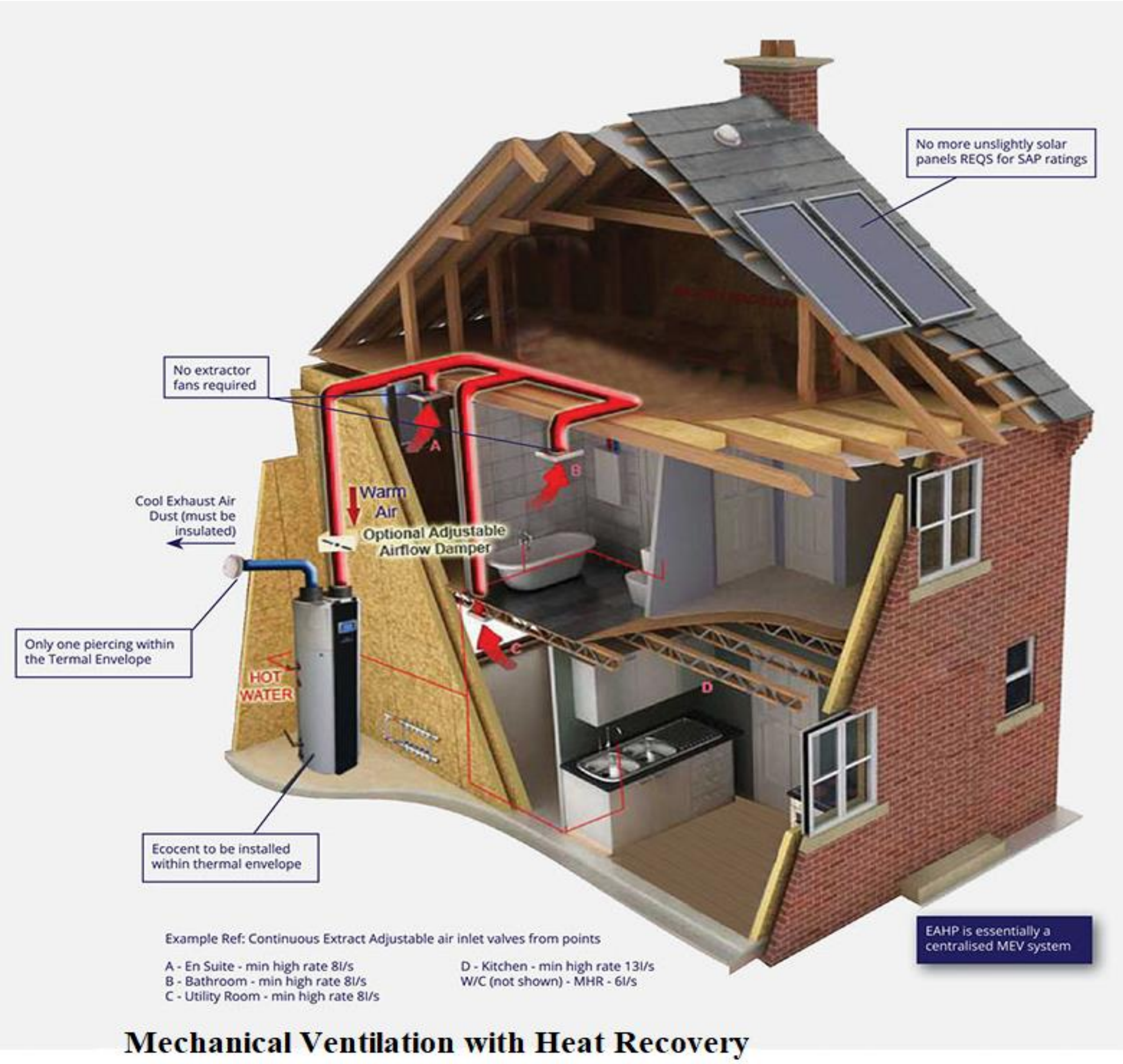
Shading system: Generally building shading provide to control the sun heat radiation during day time. Are various types of shading that can be applied to the building system. Most popular shadings are overhang shading, rolling shading, eaves shading, and self-shading.

Passive cooling shelter: passive cooling shelter generally control the indoor and outdoor temperature fluctuation. In this method pipelines are distributed on the building system. Generally, pipelines distributed on the wall, floor and roof. The pipe line contains fluid which is cooled during the night time, and that helps in the day time to cool the building.

Night ventilation technique: night ventilation technique is a very useful technique to control the indoor and outdoor temperature. During night time this ventilation systems permits to exchange the indoor and outdoor air. Buildings generally during day time stores hot air inside the building, and using night ventilation system outdoor cooled air exchanged with indoor temperature and helps to keep cool the building in the night time. This technique strongly related to indoor and outdoor temperature difference, if the temperature difference is very low then efficiency will be also less.

Measures for increasing internal comfortless of building:

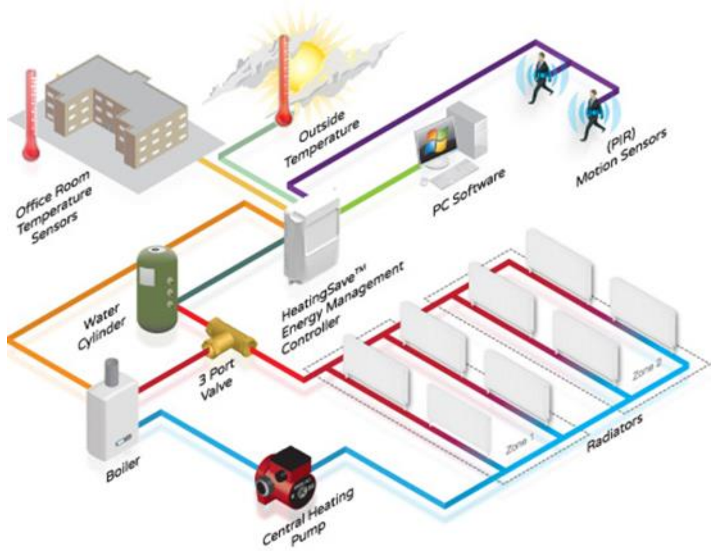
MEV (mechanical extract ventilation) combined with heat recovery system: MVHR (mechanical ventilation heat recovery) supplies and extracts air constantly at a low rate with raise facility to extract pollutants and supply clean out of doors air at a better charge as required manually through single or multiple switches automatically, typically through humidity or different sensors those ought to be clearly marked and located in an available area in or near to wet rooms , commonly the MVHR unit is sited remotely in a loft space or cupboard and ducted via rigid duct to out of doors at the usages of the most cost efficient course [54]. If the air permeability fee of living is under $5m^3/h/m^2$, history ventilators usually inside the shape of window vents proving $2500mm^2$ must be placed in the head of window frames. Those need to be outfitted in each room besides moist rooms from which air is extracted. If the air permeability is more than this charge trickle vents aren't required. Following pic shows the mechanical ventilation system.



19.fig: Mechanical ventilation with heat recovery system [55]

Improvement of boilers and air conditioning: There are two diverse types of old boilers gas boilers and oil boilers that are used in the building sectors. Most of the old boilers lose their efficiency with the time, so boilers need to restore or replace within its economic time. According to European commission's Directive 92/42/EEC all hot water boilers should meet the EU's eco-design requirements. Old boilers are subjected to increasing electricity consumption. Because of fast growing technology the situations of electric equipment's have changed. Modern technologies came in the market which are energy efficient along with more workability.

Use of building energy management (BEMS): Sometimes building energy system is called building management system. BMS are computer-primarily based control system that manage and monitor the building, mechanical and electrical system along with heating, airflow lighting fixtures, energy structures' is connected to the building services, and which is connected to the central computer system. BEMS controls the on-off system, building humidity and temperature. Software program gives manage features, tracking, alarms and permits the operators to optimize building performance. Fully functional building monitoring system can identify the fault and gives proper report to the owner of the building. Lightning controlling sensor system, temperature optimization of boilers, alarms are the function of the BEMS [56]. Following photo show the building energy monitoring system



20.fig: Building energy management [57].

Use of energy efficient appliances and compact fluorescent system:

Use less energy consumption electrical equipment's: Superior quality of equipment can save more energy. According to European energy rating system A++ electrical equipment can save more energy and money. It saves more energy compared to less energy rating grade equipment with same run time. Those equipment's are generally little high initial cost, but it provides more saving in term of long time, people only think about initial investment but in term of long time it saves more money. For deep retrofitting, higher energy rating equipment's should be preferable. As per European commission EU directive 92/75/EC [58] energy leveling scheme on every heavy electrical gadget should have energy consumption ratings. The energy ratings are available class A+++ to G. The energy rating classes vary according to the appliances type.

2.2 **Assessment of building energy retrofitting efficiency**

From past few decades several papers and studies introduced the effective solution in building retrofitting sector. In the year 2012 the European Commission established Delegated Regulation [59]. To determine the cost optimum level of nominal energy performance of buildings, and European commission provide a guidance documents to implement the methodology at the national level. Building energy performance can be calculated by several methods like life cycle cost (LCC) methods, marginal cost method, Discounted cash flow(DCF) analysis method, multi-criteria approaches (MCA), Present cost value methides. Marginal costing method is so popular to calculate the energy performance efficiency.

Life cycle cost of building: Building life cycle refers to the use of full operation of building. In other word, the construction to demolition period is called life cycle of building (LCC). LCC is a tool which is used to calculate the overall cost performance of a project over time, which includes the initial investing cost of project and cost of maintenance along with cost of disposal. It is mainly used to evaluate different economic alternatives. In the building sector LCC method has been used from the early 90s. LCC method is a very important tool to access the environment building performance.

Life cycle cost (LCC): Life cycle cost of building can be referred as the total cost of build in its entire life cycle. Life cycle cost(LCC) consist of design cost, planning cost, construction cost maintenance cost, repairing cost, operation cost, social cost, environmental cost and disposal cost etc. The costs are discussed below:

Life cycle cost analysis (LCCA): LCCA is a method to calculate the total or overall cost of the building, which provides the best economical alternative. The primary cost elements in the LCC calculation model are the following: The following equation has been developed for calculating the LCC in term of energy retrofit [60]

$$LCC_{ES}=IC_{PV}+NFOMC_{PV}+NRC_{PV}+RC_{PV}\pm SV_{PV}-\Delta EC_{PV}$$

Where

LCC_{ES} = Present value of energy system LCC

IC_{PV} = present value of investment cost

$NFOMC_{PV}$ = present value of annually recurring non-fuel operational and maintenances cost

NRC_{PV} = present value of non-recurring non-fuel operational and maintenance cost

RC_{PV} = present value of recurring non-fuel operational and maintenances cost

SV_{PV} = present value of salvage value

ΔEC_{PV} = present value of annual energy saving costing

For calculating retrofitting effect on life cycle cost of building. Several methods are used like Life cycle cost (LCC), Discounted cash flow analysis (DCF), multi – criteria approaches (MCA). LCCA Tool also used to calculate the assess life cycle cost, LCCA tool was used in Empire state building energy retrofitting in 2008 [61]. LCC can estimate the overall costing of retrofitting and gives alternative solution. Along with it LCC can provide the optimal thickness of insulation material in building envelope and helps to get optimum solution for building energy solution [62].

Marginal cost method: In economics, marginal cost is the growth or decrease in the overall value of a manufacturing run for making one additional unit of an item. In other word that is the cost of producing another production. Within the short run, the marginal cost is equal to the extra amount of variable factor that the organization must employ to increase the production, multiplied with the aid of how much the organization need so that it will get an extra variable aspect at every level of production at that time. Marginal cost method was first time used in swiss case study in term of building energy renovation [63].

$$M_{CE} = \frac{(CapCost_n - CapCost_{n-1})}{(Denergy_n - Denergy_{n-1})}; \text{ and}$$

$$AC_{EE} = \frac{a_n.Ivc\ Cost_n - a_0.Ivc\ Cost_0}{Denergy_n - Denergy_{n-1}}.$$

Where Cap cost and Ivc Cost was the initial investment cost and capital cost the project. Denergy factor was the energy demand factor of the building, where n, n-1, and 0 was the energy demand level.

DCF method: Discounted cash flow method is used to calculate investment of a project for the retrofitting building, which is related to the increment of energy efficiency [64]. Discounted cashflow method was introduced to quantify the outflow cash, and to quantify the creation of value where cash inflow and out flow both was considered. Where the cash flow was fully covered by the Life Cycle flow or LCF, and on the other hand the value creation was managed by the internal rate of return (IRR) and net present value (NPV). Those two ratios jointly called the ratio of discounted cash flow. Where LCF used to minimize the initial investment. Expressing the present cost of future flow of discounted values all through a time horizon on the end of the investment. The discounted cash float technique (DCF) taken into consideration in the occurrence of flow over the years. To optimize the retrofitting of buildings through maximizing NPV and via splitting incentives among buildings proprietors and users. The DCF technique has currently been implemented in techno-economic assessment method [65]. The use of a life cycle assessment (LCA) and a life cycle cost (LCC) application in case study including 8 scenarios to define the finest the funding solution in the renovation of existing building to reduce the energy consumption and gas emission has been currently analyzed [66].

From the investment, DCF considered the accumulation at the initial time zero of the cash flow, where the considerations were total financial cash flow (FI) for period t$\epsilon[0, OT]$, rate of discount was I, time as t, and investment time horizon OT.

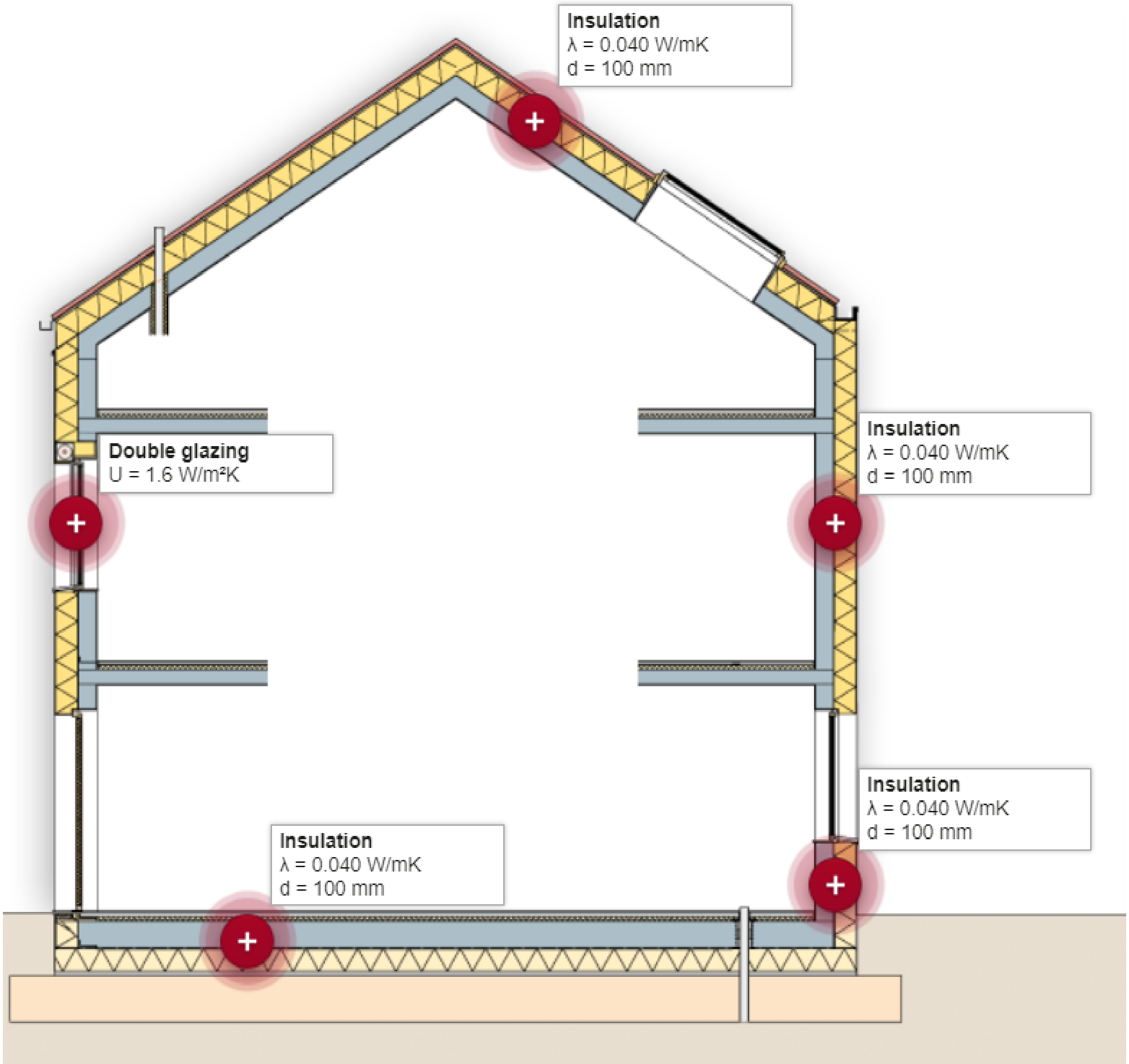
$$FL_0=\sum_{t=0}^{OT} (\frac{FI_t}{(1+i)^t}$$

In the other hand for the discounted cash flow method, were total financial cash flow (FO), for every time t$\epsilon[0, OT]$

$$FO_0=\sum_{t=0}^{OT} (\frac{FO_t}{(1+i)^t}$$

DCF discounted cash flow is used to evaluate the recovery of initial cash flow of the project by its payback period. Net present value method also widely used to calculate the economic performance for retrofitting in residential and commercial building sector [67]. Multi objective optimization MCA has been implemented for decision making of retrofitting.

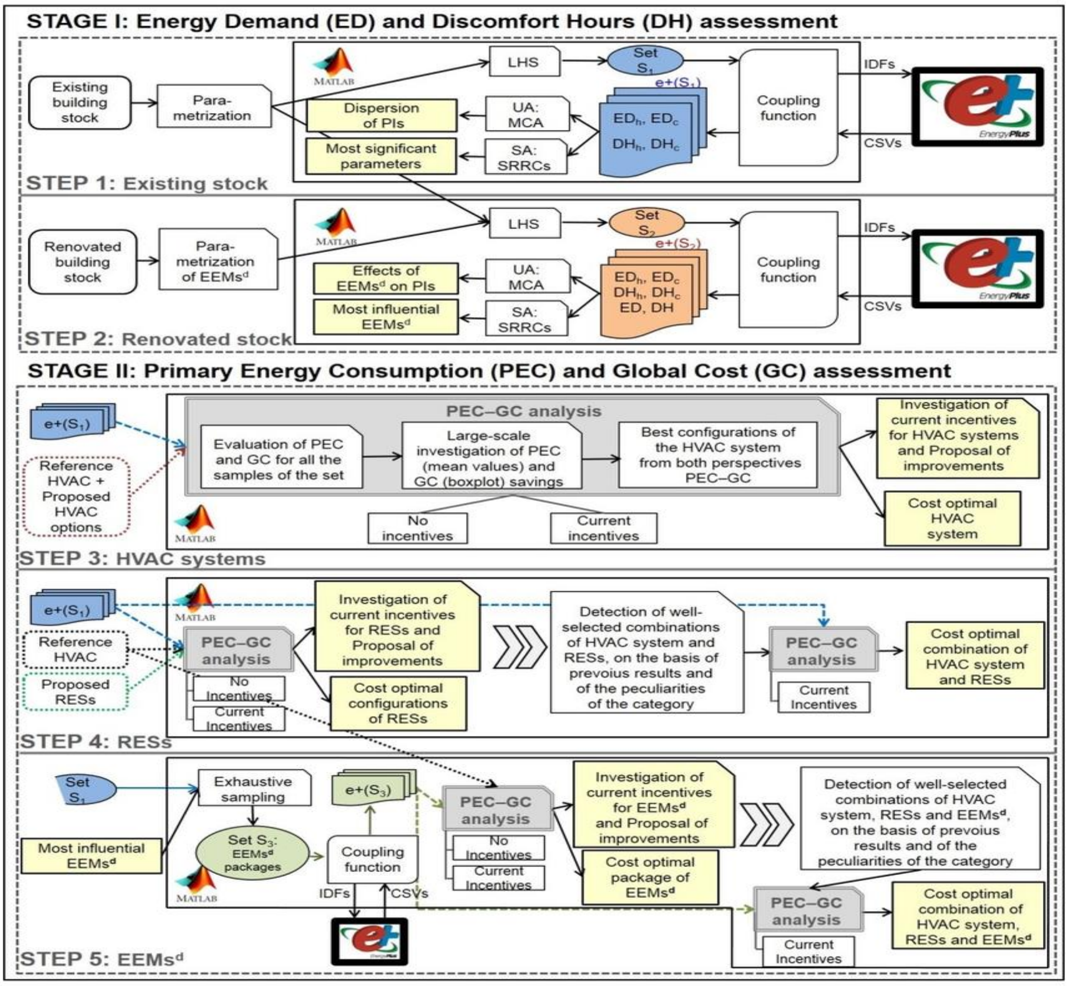
Now a day for calculating the energy efficiency software tool kits are widely used. There are hundreds of software toolkits to calculate the energy efficiency. European commission had ENPER-EXIST program to finding out the building those need to improve their energy performance applying EPED (Energy Performance of Building Directive). HAT program started on 2005 and end on 2007 [68]. Building energy performance tool kits are using different attributes according to the country, there are several software to calculate the building energy efficiency. According to the Lithuanian government regulation all building performance measured by computer running program named NRG-sert [69], which calculate the energy consumption of the building and the certification done by the SPSC. Following figure shows the example of the building energy tool kit how it works



21.fig: Building energy calculator

SLABE: Simulation-based Large-scale uncertainty/sensitivity Analysis of Building Energy performance (SLABE) also used to identify the package of energy retrofit actions [71]. SLABE allows to assess the effectiveness of the state policy of monetary incentives directed to energy retrofit movements. SLABE is combination of MATLAB® and Energy Plus [72]. Energy plus is a program which used to calculate the whole building energy. It has ability to simulate the building performance. SLABE is very useful tool in case of building renovation.

In the first level SLABE, inspect the existing building to identify the optimal representative building sample and the parameters most affecting energy demand. And few energy efficient measures are proposed to improve the energy efficiency. In the stage two by assessing the impact on primary energy consumption (kwh/a per building) and global cost the implementation of new efficient HVAC (heating, ventilating and air conditioning) systems is investigated. And renewable energy resources implementation is investigated. The implementation of the most influential energy efficiency measure investigated. And on this step, it allows to provide the effectiveness on energy efficiency measure for the reduction of thermal energy demand. Following picture shows the stages.



ED=Thermal Energy Demand [kWh/m2 a]
DH=Percentage of Discomfort Hours [%]
GC=Global Cost [€ per building]
PEC=Primary Energy Consumption [kWh/a per building]
HVAC=Heating, Ventilating and Air-Conditioning
RES=Renewable Energy Source
EEMd=Energy Efficiency Measure for the Reduction of Thermal Energy Demand

22.fig: Sages of SLABE [73].

2.3 Marginal cost of building energy retrofitting measures and impact on LCC

Considered measures: The main area of research is to provide better energy performance of buildings and to calculate the energy savings by the different scenarios of retrofitting. We consider 5 different scenarios for retrofitting of buildings, taking into account the building shape and size (square meter area). The main research area is concentrated on the thermal insulation of building and improvement of engineering systems. Therefore, the calculation of the energy saving is performed according to the different scenarios and comparison of the pre- and post- retrofitting energy consumption values is delivered for different case studies.

Scenario A: Providing better insulation system on interior and exterior wall of the building.

Scenario B: Better insulation on roof and floor.

Scenario C: Replace or installing better insulate windows, door (double triple glazing), thermostatic valves.

Scenario D: Installing or replacing building energy monitoring system or BEMS

Scenario E: Installing BEMS AND MEV (mechanical extract ventilation) and photoelectric panels.

Methods and limitations of retrofitting: The calculation process and methods are taken from LAURA GABRIELLI's paper ("Marginal cost and benefits in building energy retrofitting"), who has worked on this topic before and conducted a study on the retrofitting of buildings in Italy. Marginal cost method has been used to calculate the benefit of various retrofitting measures. The paper presents 5 different scenarios of retrofitting and calculation and three case studies along with all data. Proposed calculation method is applied in the practical part of the thesis. Marginal cost method is the most effective way to define the efficiency of building energy retrofitting. Five scenarios of residential buildings retrofitting are used in this work:

Scenario i: Providing better insulation system on external walls of building.

Scenario ii: Providing better insulation of roof and floor.

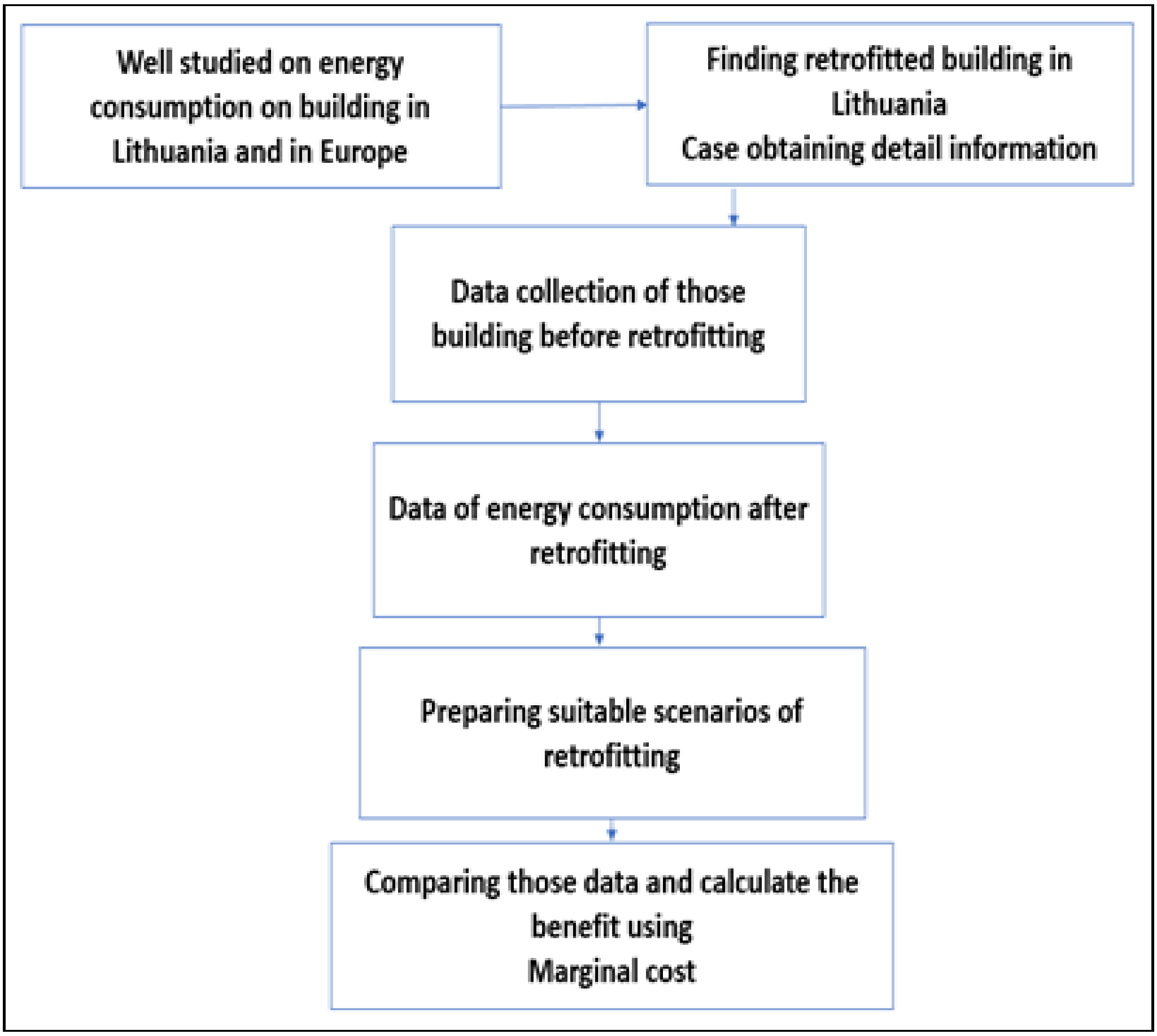
Scenario ii: Replacing or installing better windows and doors (double triple glazing), introducing thermostatic valves.

Scenario iv: Installing or replacing building energy monitoring system or BEMS

Scenario v: Along with previous scenarios installing BEMS AND MEV (mechanical extract ventilation) and photoelectric panels.

There are several methods to calculate the benefits of the retrofitting and more scenarios can be used, but selected five scenarios show the best results within economic range. More structural elements of building can be replaced or restored, but the total cost of the project will get higher and annual benefits or energy reduction will become less.

Steps of retrofitting



23.fig: Steps of retrofitting

How LCCA helps to decision making for retrofitting, and retrofitting impacts on LCC: Using this LCCA methodology we can easily find out the performance year of building, annual operational expenses like energy costs, water consumption costs, maintenance, insulation costs, solar panel maintenance costs. Generally, the maintenance and operational costs are increasing every year. And in case of renovation of building, modernization costs after its useful life can be calculated according to the condition of building structures. Generally, life cycle cost of buildings calculates for 20 to 30 years. In simple word life cycle costs of buildings are the total cost of building, which include construction or renovation costs, maintenance and operating costs and annual energy costs. So, considering the total costs of building huge financial value is experienced every year, where electricity takes a sizable portion of it. Therefore, proper retrofitting can give bigger savings, that can really reduce life cycle costs of building.

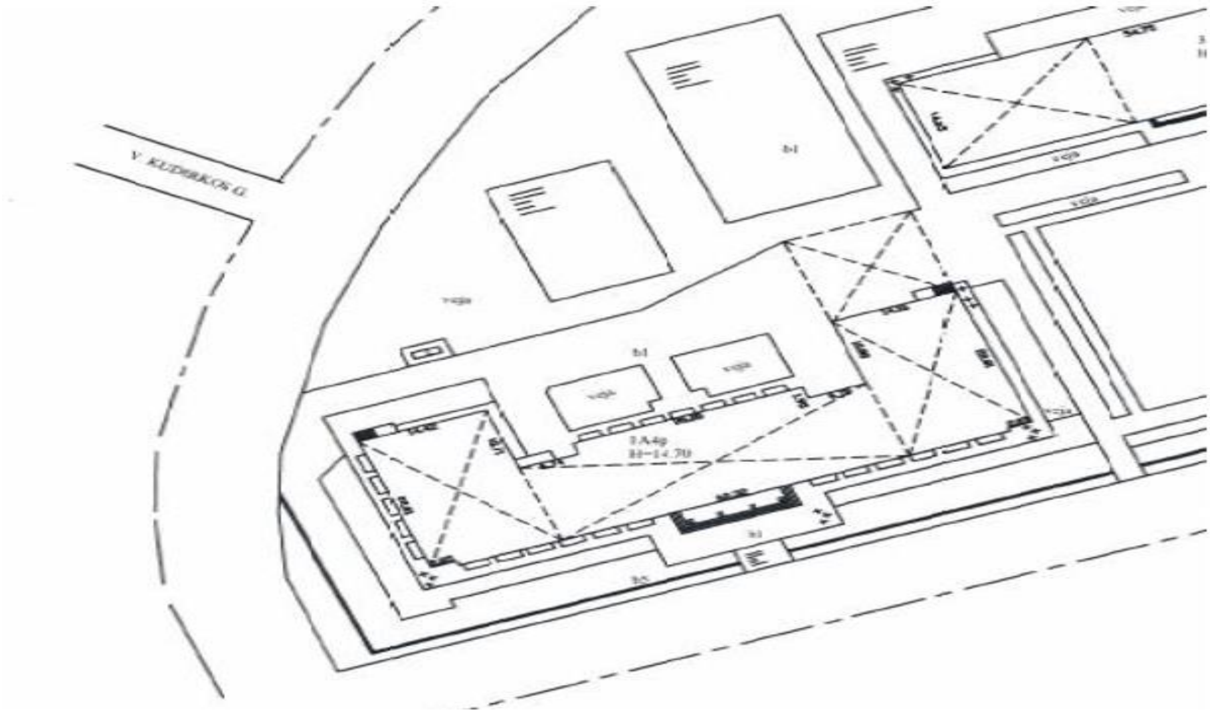
3. MARGINAL COST OF BUILD ING ENERGY RETROFITTING

3.1 **Case studies for the assessment of retrofitting measures efficiency**

The analyzed case studies are multi-story residential buildings in Kaunas, which are used for student residential purposes. Three apartments building case studies described below.

Case study 1: The building is situated in Gričiupio str. 13, Kaunas. This 12^{th} floor building was renovated under Jessica fund. Building was constructed in 1980s with having 518m^2 of built up area and 3061.42m^2 floor area. The building was constructed using brick masonry, acrylic concrete. Buildings total facade area (expect windows and hole area) is 3536.11m^2. The facade wall heat transfer coefficient was 0.9 and 1.16 W/m^2K. Total useful area of the building is 3061m^2. Covering roof area is 622m^2 and heat transfer coefficient was 0.216 W/m^2K. The building was renovated from June 2014 to September 2015. In 2013 building was consuming 168.73 kWh/m^2/year energy for heating and 21 kWh/m^2/year energy for preparing hot water. 210.84 kWh/m^2 per year in total thermal energy was consuming by the building. The building was upgraded with various energy measures. Buildings plinth area and wall area was insulated using polystyrene panels. The thickness of the layer was 18cm for exterior surface. Roof was fully insulated followed by the thermal insulation norms. Windows was changed and few of them was upgraded. Doors were replaced, and leakage area were sealed. The maximum heat transfer coefficient for external doors in Lithuania is 1.4 W/m2. Heating and hot water systems like piping exhaust were replaced. Ventilation systems and heat recovery systems were also replaced. Cold water systems also replaced and upgraded. And along with measures new HVAC system was installed and energy efficient bulb was used. After upgrading building was consuming 60.36 kWh / m^2 energy per year for heating.

24. fig: Energy retrofitting measure used in case study 1



25.fig building plan of case study building 2

Case study 2: The building is situated in Vydūnas al. 25A, Kaunas. The building renovation was approved by Ministry of the Environment of the Republic of Lithuania under Jessica fund. The 4^{th} floor apartment building was constructed in 1960s. Building was certified as D Energy class in 2013. Total use full area of the building is $3784.52m^2$. Total floor area of the build is $3784.52m^2$. Total façade wall area (except windows and hole area) is 2150.24 m^2 and the façade wall heat transfer coefficient was 1.05 W/m^2 K. Covering roof area is $1161.19m^2$ and heat transfer coefficient was 0.25 W/m^2 K. The building was renovated from June 2014 to September 2015. Building was consuming 161.64 kWh/m^2/year energy for heating. The building was upgraded with various energy measures. Buildings plinth area and wall area was insulated using polystyrene panels. The thickness of the layer was 18cm for exterior surface. Roof was fully insulated followed by the thermal insulation norms. Windows was changed and few of them was upgraded. Doors were replaced, and leakage area was sealed. The maximum heat transfer co-efficient for door in Lithuania is 1.4 W/m2. Heating and hot water systems like piping exhaust were replaced. Ventilation systems and heat recovery systems were also replaced. Cold water systems also replaced and upgraded. And along with measures, new HVAC system was installed, and energy efficient bulb was used. After upgrading building was consuming 47.20 kWh / m^{2} energy per year for heating.

26.fig: Energy retrofitting measure used in case study 2

Case study 3: The building is situated in Vydūnas al. 25, Kaunas. The 4^{th} floor apartment building was constructed in 1960 with brick masonry materials. Building was certified as D Energy class in 2013. Total useful area of the build is 3658.54m^2. Total facade wall area (expect windows and hole area) is 2160.09 m^2 and the façade wall heat transfer coefficient was 1.05 W/m^2 K. Covering roof area is 1180.77m^2 and heat transfer coefficient was 0.25. The building was consuming 171.93 kWh/m^2/year thermal energy before renovation. Building was consuming 129.88 kWh/m^2/year energy for heating and 21.05 kWh/m^2/year energy for preparing hot water. The building was upgraded with various energy measures. Buildings plinth area and wall area were insulated using polystyrene panels. The thickness of the layer was 18cm for exterior. Roof was fully insulated followed by the thermal insulation norms. Windows was changed and few of them was upgraded. Doors were replaced, and leakage area was sealed. The maximum heat transfer co-efficient for door in Lithuania is 1.4 W/m2. Heating and hot water systems like piping exhaust were replaced. Ventilation systems and heat recovery systems were also replaced. Cold water systems also replaced and upgraded. And along with measures new HVAC system was installed and energy efficient bulb was used. After upgrading building was consuming 57.01 kWh / m^2 per year for heating.

27.fig: Energy retrofitting measure used in case study 3

3.2 Marginal costs of different retrofitting scenarios

The following energy retrofitting scenarios were used in case studies:

1. S0-building as is
2. S1-Improvement of building thermal coating of walls and roof
3. S2-Replacement of windows and doors
4. S3-Replacement of heating system
5. S4-Replacement of MVS

3.table: Scenarios cost and energy requirements case study 1

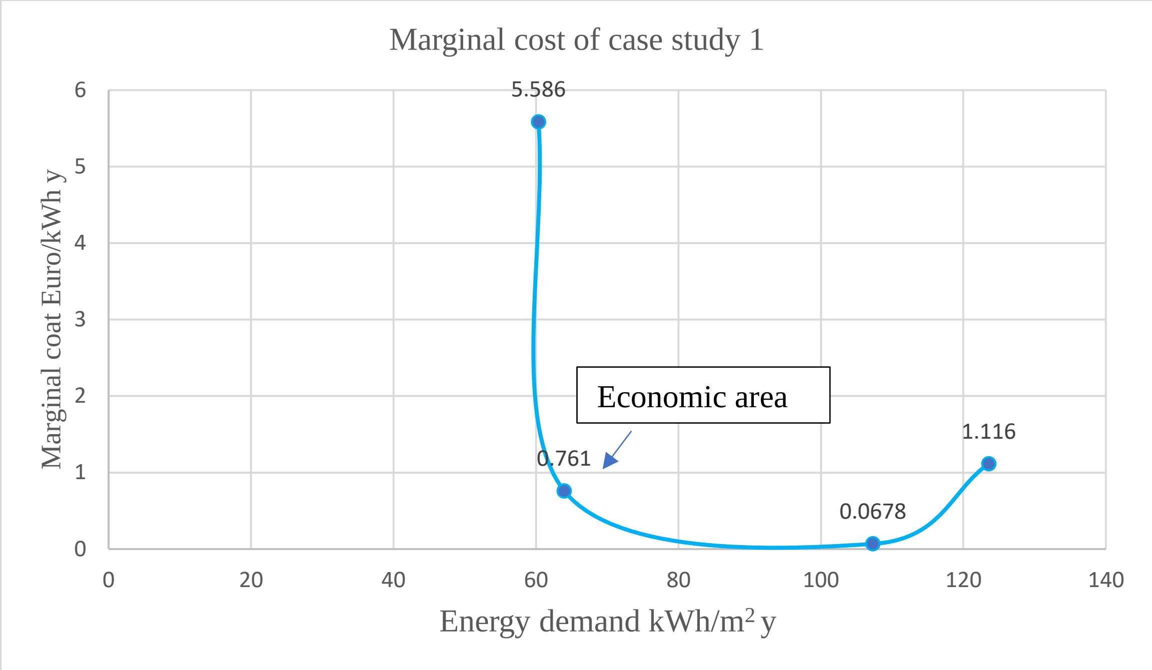
Scenarios and energy efficiency measures	Investment cost in Euro	Energy requirements kWh/m^2/year	Energy savings kWh/m^2/year	Per unit cost of investment Euro/m^2
S0-building as is	0	168,73	-	
S1-building thermal coating wall and roof	214214	123,57	45,16	50.418
S2-Replacement of windows and doors	218905	107,31	61,42	51.52
S3-Replacement of heating system	359072	63,96	104,77	84.51
S4-replacement of MVS	444507	60,36	108,37	104.62

Marginal cost calculation

Case Study 1

$M_{CE} = \frac{(CapCost_n - CapCost_{n-1})}{(Denergy_n - Denergy_{n-1})}$,

For S4: $M_{CE} = 5.586$, S3: $M_{CE} = 0.7610$,S2:$M_{CE} = 0.0678$, S1:$M_{CE} = 1.116$



1.graph: Marginal cost data for case study 1

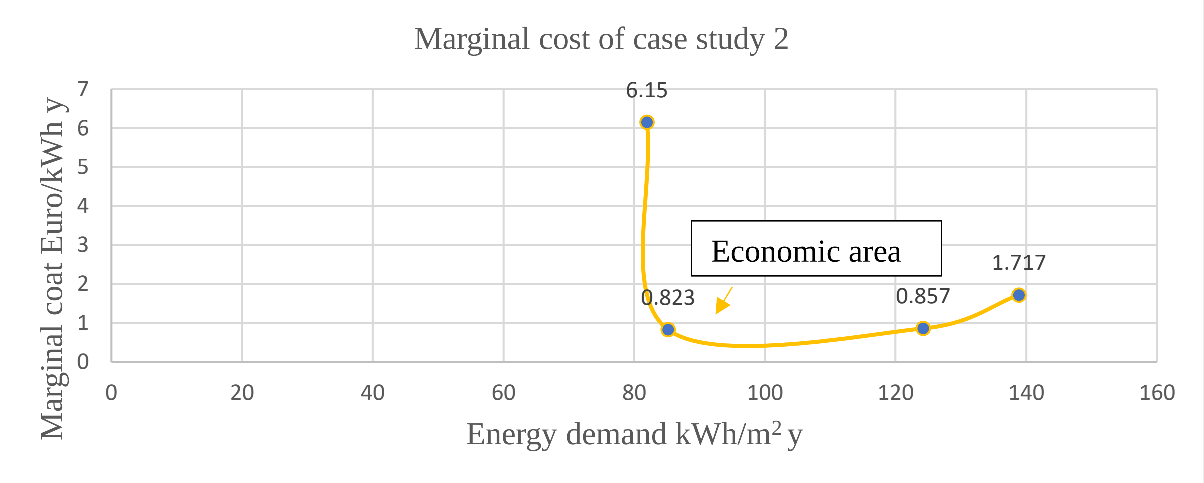
4.table: Scenarios, investment cost and energy requirements for case study 2

Scenarios and energy efficiency measures	Investment cost in Euro	Energy requirements kWh/m²/year	Energy savings	Per unit cost of investment Euro/m²
S0-building as is	0	161,64	-	
S1-building thermal coating wall and roof	147883	138,88	22,76	39.07
S2-Replacement of windows and doors	195331	124,24	37,40	51.61
S3-Replacement of heating system	317055	85,21	76,43	83.77
S4-replacement of MVS	392689	81,96	79,68	103.76

Case study 2

$M_{CE} = \frac{(CapCost_n - CapCost_{n-1})}{(Denergy_n - Denergy_{n-1})},$

For S4, $M_{CE} = 6.150$, S3: $M_{CE} = 0.823$, S2:$M_{CE} = 0.857$, S1:$M_{CE} = 1.717$



2.graph: Marginal cost data for case study 2

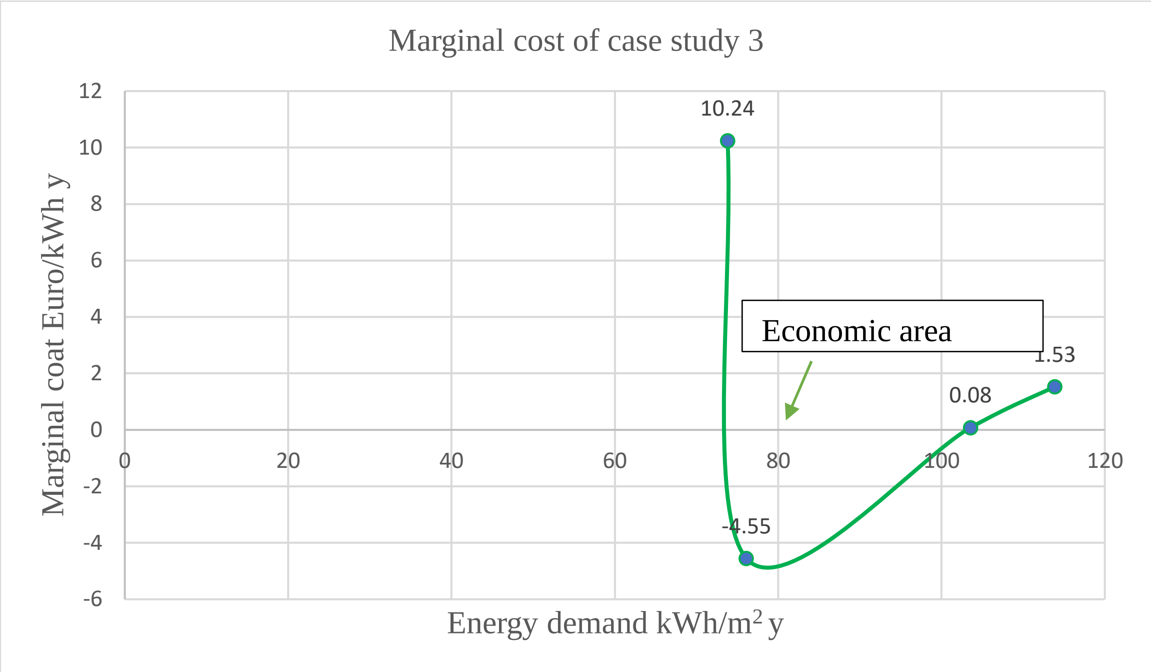
5.table: Scenarios, investment cost and energy requirements for case study 3

Scenarios and energy efficiency measures	Investment cost in Euro	Energy requirements $kWh/m^2/year$	Energy savings	Per unit cost of investment $Euro/m^2$
S0-building as is	0	129.88	-	
S1-building thermal coating wall and roof	147422	113.86	26,32	40.295
S2-Replacement of windows and doors	157809	103.56	61,42	43.134
S3-Replacement of heating system	285216	76.10	53,78	77.96
S4-replacement of MVS	371048	73.81	56,07	101.41

Case study 3

$$M_{CE} = \frac{(CapCost_n - CapCost_{n-1})}{(Denergy_n - Denergy_{n-1})},$$

For S4: $M_{CE} = 10.240$, S3: $M_{CE} = -4.55$, S2:$M_{CE} = 0.080$, S1:$M_{CE} = 1.53$



3.graph: Marginal cost of case study 3

Above figures show the marginal costs method results. All three case studies show that after small renovation as per application of measure S1, energy efficiency increases insignificant. After using measure S2 all three case study buildings save bigger amount of energy. After providing energy measure S3 all the case study buildings showing significant benefits. And on average almost 70kWh/m^{2}y energy was consumed. But measure S4 is showing optimum level of energy performance because of bigger investment than required by the other measures. For all the case study buildings 1, 2 and 3, the preferable scenario is S3 - Replacement of heating system.

3.3 LCC calculation for case studies

For calculating life cycle cost of buildings, we consider the present value of maintenance and operating cost is 15% of total investment cost. Growth rate is considered as 3.5%. We don't have the salvage data. So, considering it as 0. And assumed unit price of electricity as 0.25 Euros/kWh. The equation of the energy life cycle costing of the buildings for 20 years will be.

$LCC_{ES}=IC_{PV}+TMC_{PV}+\Delta EC_{PV}$

Where

LCC_{ES} = Present value of energy system LCC

TMC_{PV} = Present value of total maintenance cost

IC_{PV} = present value of investment cost

ΔEC_{PV} = present value of 20 years energy cost

For case study 1

S1 _LCC_{ES}=214214+32132.1+148552.70 = 2612013.7 Euros

S2 _LCC_{ES}=1541816.49 Euros

S3_ LCC_{ES} =1181856.92 Euros

S4_ LCC_{ES} =1236828.14 Euros

For case study 2

S1 _LCC_{ES}=2234314.29 Euros

S2 _LCC_{ES}=2071277.89 EUROS

S3_ LCC_{ES} =1631165.63 Euros

S4_ LCC_{ES} =1669808.71 Euros

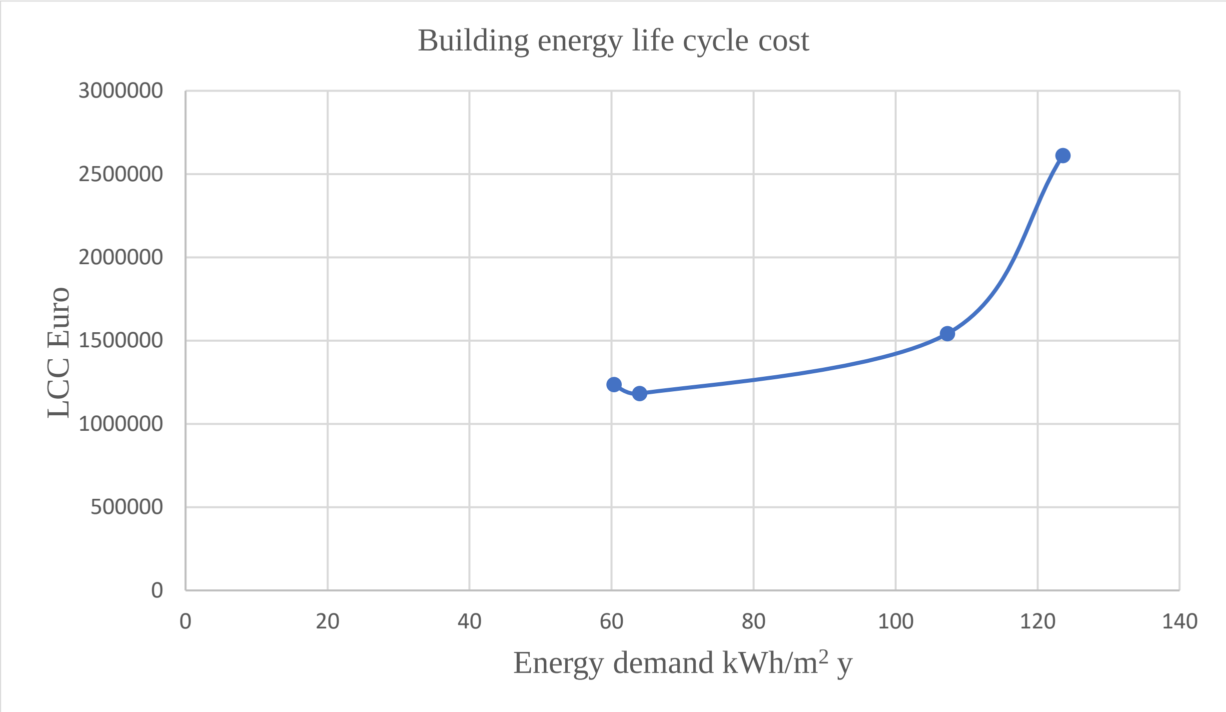
for case study 3

S1 _LCC_{ES}=1805563.11 Euros

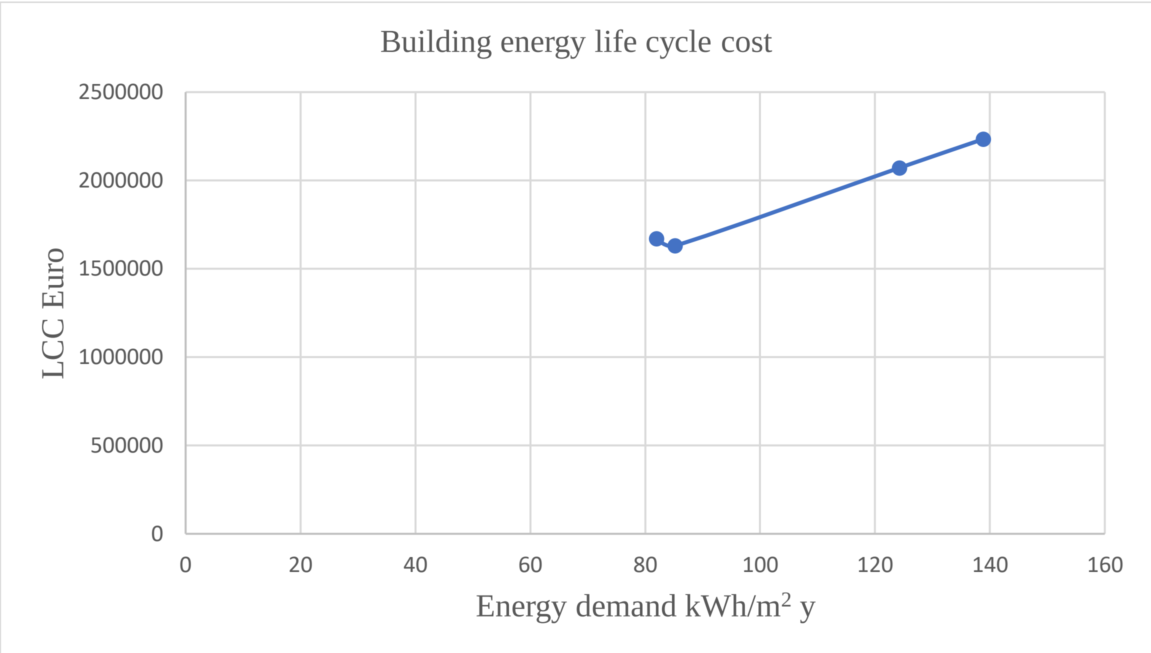
S2 _LCC_{ES}=1669510.04 Euros

S3_ LCC_{ES} =1421461.21Euros

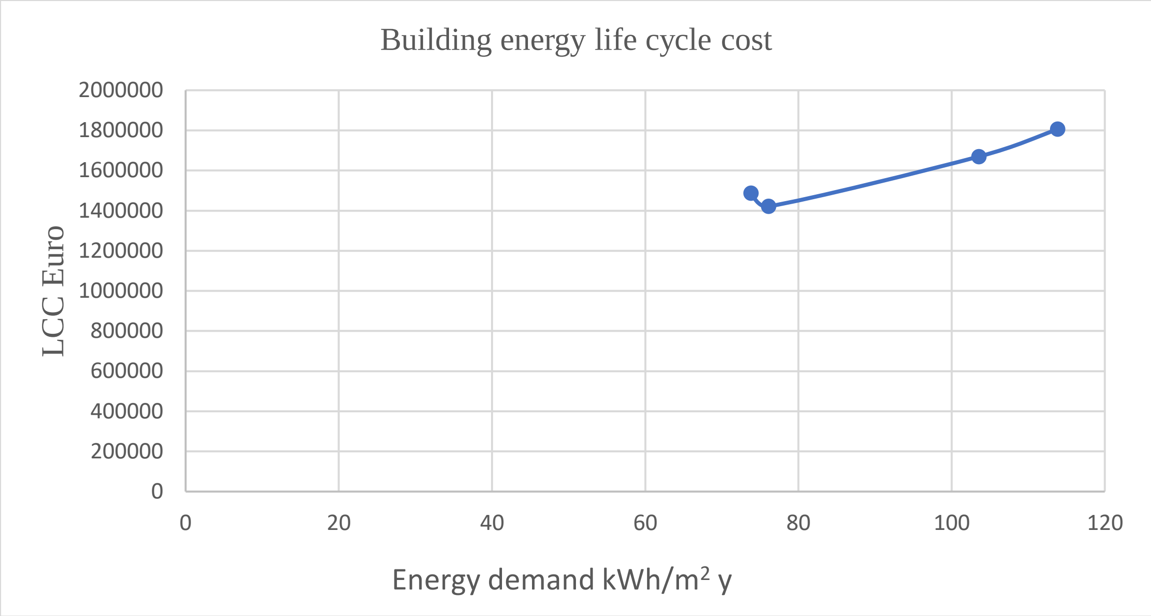
S4_ LCC_{ES} =1487263.76 Euros



4.graph: Energy life cycle cost of case study 1



5.graph: Energy life cycle cost of case study 2



6.graph: Energy life cycle cost of case study 3

To calculate the most efficient and economic scenario, the LCC method has been adopted. Building energy life cycle costs are calculated for 20 years. Generally, the construction or retrofitting may require high investment cost, but in term of life cycle period it can provide better saving result. In the case study of all three buildings, low investment in measure S1 and S2 shows higher lifecycle cost value. Where by implementing scenario S3, life cycle costs drop very impressively. Due to high initial investment for S4, which had comparatively the same energy requirements as S3, its life cycle costs in all case studies increased compared to S3. Although the energy efficiency rate is little better for S4, S3 provides more savings in terms of its 20 years life cycle period. And S3 scenario provides almost similar energy consumption on all three buildings.

Conclusions

1. To improve the building energy performance, marginal cost and LCC method can be applied for definition of the best scenario or combination of measures. In the old existing buildings and new constructed buildings, it can help to reduce the total life cycle costs with satisfactory energy consumption rates.
2. For assessment of efficiency of retrofitting scenarios different strategies were analyzed. The most popular and adopted scenarios are S2 - Replacement of windows and doors, S3- Replacement of heating system and S4 - Replacement of MVS.
3. Analyzed case studies showed what scenario S3 is the most efficient scenario for building retrofitting under the defined conditions due to significant energy savings.

Energy saving of S3 is higher than of scenarios S1 and S2. And the total life cycle cost for S3 is less than S4.

4. Sometimes initial investment of retrofitting measures can be higher and marginal cost can rise fast, but it can provide better results in terms of long time energy savings. In term of long payback period for owner, it may be difficult to handle the project because of high investment costs. The scenarios having higher energy savings along with high financial investment might not be best option. LCC helps to give the best scenarios choice for energy savings.

References

1. Achieving carbon neutrality in commercial building developments – Perceptions of the construction industry by JianZuo, BenRead, Stephen Pullen, and QianShi
2. Balancing act: A triple bottom line analysis of the Australian economy, The University of Sydney and CSIRO, Foran, M. Lenzen, C. Dey
3. International energy outlook 2016, U.S. Information Administration
4. WORLD GREEN BUILDING TRENDES 2016, dodge data and analytics http://fidic.org/sites/default/files/World%20Green%20Building%20Trends%202016%20SmartMarket%20Report%20FINAL.pdf
5. Http://www.czgbc.org/Download/World%20Green%20Building%20Trends%202016%20smartmarket%20Report%20FINAL.pdf
6. https://passipedia.org/basics/what_is_a_passive_house
7. Http://www.passivehouse.com/02_informations/01_whatisapassivehouse/01_whatisapassivehouse.htm
8. Passive House and EU Support: Past, Present, Future. Philippe MOSELEY MA(RCA) MSc RIBA, Project Advisor, Executive Agency for Small and Medium-sized Enterprises (EASME), European Commission.
9. Directive 2010/31/EU Energy Performance of Buildings (recast), http://eurlex.europa.eu/legalcontent/EN/ALL/;ELX_SESSIONID=fzmjthllzfxmmmcqgp2y1s2d3tjwtd8qs3pqdkhxzbwqgwlgy9kn!2064651 424?Uri=CELEX:32010L0031
10. Directive 2012/27/EU on Energy Efficiency, http://eurlex.europa.eu/legalcontent/EN/TXT/?Qid=1399375464230&uri=CELEX:32012L0027
11. Https://passipedia.org/examples/residential_buildings/multifamily_buildings/central_europe/the_world_s_first_passive_house_darmstadt-kranichstein_germany
12. http://eurlex.europa.eu/legalcontent/EN/TXT/HTML/?uri=CELEX:32016H1318&from=EN
13. embodied energy in residential buildings-towards the nearly zero energy building: a literature review, panagiotis chastast heodoros, theodosiou, dimitriosbikas
14. Https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf
15. IEA, International Energy Agency, energy policies of IEA countries -Italy 2009 overview international energy agency 2009
16. Share of renewables in energy consumption in the EU rose further to 16.7% in 2015. Eurostat News Release, 14 March 2017.

17. http://dati-censimentopopolazione.istat.it/Index.aspx
18. EU, European Commission, EU Energy, Transport and GHG emissions Trends to 2050, 2013.16.2 EIA, U.S. Energy Information Administration, International Energy Outlook, U.S. Department of Energy, 2014.
19. EIA, U.S. Energy Information Administration, International Energy Outlook, U.S. Department of Energy, 2014.
20. http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf
21. Https://www.energyagency.at/fileadmin/dam/pdf/veranstaltungen/TABULA/01_Oliver_Rapf.pdf
22. Http://www.bresaer.eu/building-retrofits-critical-to-europes-low-carbon-pathway/
23. http://cordis.europa.eu/article/id/400003-retrofitting-buildings_en.html
24. Retrofitting Existing Mass Housing for Energy Efficiency: A Case Study in Gaziemir Emlak Bank Housing Area, Izmir, Turkey, Byyusuf Yildiz
25. Retrofitting existing mass housing for energy efficiency by Yusuf yildiz,2008
26. BUILDING TECHNICAL REGULATION STR 2.01.09.2005 Energy Performance of Buildings. Certification of Buildings Energy Performance. Vilnius, Ministry of Environment, 2005
27. Http://www.epbd-ca.org/Medias/Pdf/country_reports_14-04-2011/Lithuania.pdf
28. Implementation of EPBD in Lithuania, November 2010
29. . Energy performance requirements for buildings in Europe, Marina Economides Buildings Performance Institute Europe Senior Energy Efficiency Expert, march,2012 article
30. http://web.cut.ac.cy/cost1/wp-content/uploads/sites/13/2017/03/49.pdf
31. http://www.energy-cities.eu/IMG/pdf/infinite_solutions_lithuania.pdf
32. http://www.eib.org/infocentre/press/releases/all/2017/2017-066-lithuania-new-support-for-energy-efficiency-in-multi-apartment-buildings.htm
33. City nest capacity building workshop minutes Focus country: Lithuania, Date and place: 17.05.2016, Vilnius
34. The European Portal for Energy Efficiency In Buildings, http://www.buildup.eu/en/explore/links/energy-efficiency-fund-enef-lithuania-
35. http://vipa.lt/page/enefen
36. http://www.house2home.ie/about-us-our-model/what-is-retrofitting/

37. STR 2.01.09:2012 normative requirements for thermal insulation of residential constructing envelopes
38. marginal costs and its benefits in building energy retrofitting by Laura Gabrielli
39. international energy outlook 2016, U.S. Information Administration,
40. http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf
41. Minimum performance requirements for window replacement in the residential sector, By: Dr Andreas Hermelink, Bernhard von Manteuffel, Jan Grözinger Date: 11 May 2017
42. The relationship between the shape of a building and its energy performance Josifas Parasonis1, Andrius Keizikas1* and Diana Kalibatiene21 Department of Architectural Engineering, Vilnius Gediminas Technical University, Sauletekio av. 11-303, LT-10223 Vilnius, Lithuania 2 Department of Information Systems, Vilnius Gediminas Technical University, Sauletekio av. 11, SRL-I, 424, LT-10223 Vilnius, Lithuania
43. Republic of Lithuania Law on Energy from renewable sources,2011 May 12, No xi-1375 Vilnius, Article 50. Use of Energy from Renewable Sources in Buildings
44. Using Ground-Source Heat Pump Systems for Heating/Cooling of BuildingsIoan Sarbu[1] and Calin Sebarchievici
45. http://www.icax.co.uk/How_Ground_Source_Heat_Pumps_Work.html
46. According to Ministry of Energy of the Republic of Lithuania, https://enmin.lrv.lt/en/sectoral-policy/renewable-energy-sources
47. http://www.lei.lt/Opet/Res/solar_energy.htm
48. Building Integrated Photovoltaics in the overall building energy balance: Lithuanian Case Rokas Tamašauskas, Rosita Norvaišienė , Vytautas Sučyla
49. Assessing the applicability of passive cooling and heating techniques through climate factors: An overview Author links open overlay panelanatejero-gonzálezmanuelandrés-chicotepaolagarcía-ibáñezeloyvelasco-gómezfrancisco javierrey-Martínez
50. Https://sustainabilityworkshop.autodesk.com/buildings/passive-heating
51. review of passive heating/cooling systems of buildings, by neha gupta, and gopal n. Tiwari,14th sept,2016
52. http://www.sciencedirect.com.ezproxy.ktu.edu/science/article/pii/S1364032117313084?via%3Dihub
53. http://www.vent-axia.com/files/Installation%20Guide%20Self%20Build.pdf
54. http://www.earthsaveproducts.co.uk/2016/11/29/ecocent-mev-hot-water-mechanical-extraction-ventilation-system/

55. Building Management Systems, department of climate change and energy efficiency , Australian government
56. https://www.tensor.co.uk/news/building-energy-monitoring-systems-can-help-prevent-energy-billing-errors/
57. Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances". Europa (web portal). Retrieved 24 April 2011.
58. European commission," delegated regulation (EU) no. 244/2012 supplementing directive 2010/31/EU, 2012
59. A. Sharma, A. Saxena, M. Sethi, V. Shreelife cycle assessment of buildings: A review Renew. Sustain. Energy Rev., 15 (2011), pp. 871-875, 10.1016/j.rser.2010.09.008
60. Strategies and Challenges for Energy Efficient Retrofitting: Study of the Empire State Building, M. Mukherjee, B. Deemail
61. KAYNAKLI, O., "A review of the economical and optimum thermal insulation thickness for the building applications", renewable and sustainable energy reviews
62. https://www.research-collection.ethz.ch/handle/20.500.11850/150015
63. Essays in economics of energy efficiency in residential buildings an empirical analysis, byjokob,martinKumbaro ˘glua, G.; Madlenerb, R. Evaluation of economically optimal retrofit investment options for energy savings in buildings. Energy Build. 2012
64. Pomboa, O.; Allackerb, K.; Rivelac, B.; Neilaa, J. Sustainability assessment of energy saving measures: A multi-criteria approach for residential buildings retrofitting—A case study of the Spanish housing stock. Energy Build. 2016
65. Petersen, s., Svendsen, s, "method for component – based economic optimization for use in design of new low-energy buildings", renewable energy
66. http://www.enper-exist.com/index.html
67. http://www.spsc.lt/cms/index.php?Option=com_content&view=article&id=321%3Apastatu-energinio-naudingumo-sertifikavimo-ekspertai&catid=43%3Apen-sertifikavimas&Itemid=66&lang=lt
68. Pic reference http://building-efficiency-guide.com/#/calculator
69. A new methodology for investigating the cost-optimality of energy retrofitting a building category Author links open overlay panel
70. US Department of Energy, Energy Efficiency and Renewable Energy officebuilding Technology Program, energy plus 8.0.

71. https://www.researchgate.net/figure/294733707_fig11_Figure-41-Framework-of-the-developed-methodology-SLABE-The-symbol-e-indicates