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Master thesis

SMART HOUSE

Study program: Electric Power Generation and Transportation
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- smart house concept and overview of technologies
- relation to smart grid
- methodology of economic evaluation of smart house concept
- case study of smart house
- evaluation, conclusion

Seznam odborné literatury:

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Inside the Smart Home, Richard Harper

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Student: Anastasiia Makarova
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Recommended literature:
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Declaration

I hereby declare that this master’s thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – “On maintaining ethical principles when working on a university final project, CTU in Prague“.

Date Signature

Abstract

The goal of this diploma thesis is to determine the concept of the smart house, why it is important for modern society, and which problems may be solved by implementation of the smart house technologies widely. After a literature review, some main features and possible equipment of the house were suggested and presented.

The first part of the paper shows modern technologies and approaches of the smart house system development. The relation between the smart house and smart grids, advantages of the interconnection were reviewed. The most important result of that was regulation development of efficient energy consumption. The conditions of the smart technologies implementation such as people’s attitudes, markets of devices and buildings were discussed. Economic and non-economic benefits of the smart systems penetration were represented as two different categories. Moreover, the benefits from the points of view of different involved participants were discussed.

The second part is devoted to the factors, which have influence on a decision-making process and appraising of the smart house project. Taxes, inflation rates, electricity prices, and possible sources of the project financing were figured out for the Czech Republic and Russia. A methodology of assessing the economic benefits was described and explained further. The methodology focused on discounted cash flow techniques and included several familiar appraisal approaches in current use — such as calculations of net present value, payback time, internal rate of return etc. Their strengths and weaknesses were emphasized.

Finally, the example of a possible modernization of the real house for a young family was presented. The house was partly reconstructed; nevertheless, there were places for improvements in the heating and lightening systems. Issues related to the organization of the smart systems integration were brought into the fore. The results of the economic evaluation of the house improvements did not support the expectations that penetrated systems would save money by using energy more efficiently. The money savings on the heating were observed as the largest feasible contribution to the savings, but anyway these investments would not be paid off in the end.

Important conclusions include the fact that in most cases the smart home systems and appliances are developed as luxury goods, they simplify daily routine and make the life of households much more comfortable in their daily lives.

KEYWORDS

Smart house, smart grid, smart environment, non-economic benefits, economic evaluation, NPV, PP, IRR, MIRR, economic factors

Content:

List of Abbreviations

ACER	The Agency for the Cooperation of Energy Regulators
ANN	Artificial Neural Networks
CAPM	Capital Asset Pricing Model
CF	Cash Flow
CFL	Compact Fluorescent Light
DPIA	The Data Protection Impact Assessment
DPP	Discounted Payback
DSM	Demand Side Management
EAA	Equivalent Annual Annuity
EU	European Union
FD	Federal District
FERC	The Federal Energy Regulatory Commission
HH	Household
IRR	Internal Rate of Return
MIRR	Modified Internal Rate of Return
Mtoe	Million Tonnes of Oil Equivalent
NIST	The National Institute of Standards and Technology
NPV	Net Present Value
nZEB	Near to Zero Energy Building
PI	Profitability Index
PV	Present Value
PVIFA	The Present Value Interest Factor of an Annuity
SGTF	Smart Grids Task Force
TV	Terminal value
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital

Introduction

The continuous growth of peoples' demand for energy consumption, high technologies, and comfortable life leads scientists and engineers to develop the Internet of Things. It means that many daily devices, sensors and appliances can connect each other, consequently creating a penetrate world. All devices are supposed to exchange and derive information about the environment, all-day activities, states and health of a person, and do familiar things more quickly, therefore influencing daily living. Of course, homes are places where all modern devices and systems can be introduced into. The house with the penetrated system of connected devices is usually called as an automated house or smart house.

The smart house systems can vary from simple adaptive integrated devices and their purpose is to simplify some functions in the house to a comprehensive network applied in the house, which works like a brain of the house connecting and controlling all things such as stoves, fireplaces, television, heating and lightening systems etc. Considerable amount of smart additional appliances are presented on the market of new technologies, which can be implemented. They are directly aimed at peoples' needs and wishes; therefore, they have a high level of convenience for people. The devices should be checked by serious requirement specifications based on a close analysis of user needs and technical requirements. The controlling and monitoring of the house can be realized remotely or manually depending on residents' presence.

Attempts to improve the quality of life are generally aimed for well-off families and there are a lot researches related to special housing for elderly and disabled people. In spite of this fact, decreasing prices of the technologies are leading to utilizing the smart house technologies widely.

The smart house concept illustrates a crucial step towards innovations and development in many spheres of life and technologies such as information and communication, healthcare, controlling devices and comfort of people. Moreover, the house can be a part of a smart grid system that possibly gives the opportunity to improve power management within the grid. All these and other economic and non-economic benefits of the smart house system implementation are discussed in the work and considered from different points of view such as a system, society, households etc.

Undoubtedly, the smart house technologies bring many non-economic advantages such as convenience, timesaving etc. Nevertheless, the household's decision of implementing the smart system technologies does not depend only on noneconomic benefits, therefore the financial part of the project should be also considered. One of the main aim of the work is to figure out how to evaluate whether the implementation of the new technologies is a good decision or not. Thus, the methodology of the apprising of the smart house concept is proposed in the work. The most important factors which are involved into the appraising process are investigated. Such factors contain information about a smart appliances market, inflation, taxes, reconstruction rates etc.

At the end of the work, the real house are examined. Possible solutions of improving the life of residents are proposed. The benefits of the ideas are discussed and the methodology of the economic evaluation is applied.

To sum up, the study is dedicated to illustrate the advantages of the smart house technologies, how it is related to the energy system and residents, and which benefits can be reached.

1 Smart House Concept

1.1 Incentives

New time needs new technologies, effective and efficient usage of given resources. In 2010 in Brussels a new strategy of Europe development was assigned to “fight back and come out the crisis,” the name of the strategy is Europe 2020. In the fact, during two years of the crisis twenty years of fiscal consolidation were erased, deficits at 7% of GDP on average and debt levels at over 80% of GDP were got. Of course, regardless of economic crisis itself there are also other problems such as continuous population growing, challenges in climate and never-ending price increasing of resources decrease to new solutions and actions. If scientists and researchers want to achieve one fourth (25%) of renewables sources used in power market, a fourth (25%) of growth in efficiency and even thought 20% of greenhouse gas emission reduction, new principles and technologies of living should be taken [1].

Thus, the main idea of the strategy is to achieve sustainable future, better life and to deplete unemployment rate. Five priority target directions were proposed: employment; research and innovation; climate change and energy; education; and combating poverty. They can be achieved basing on European internal and international market, budget, and policy [1].

These five target directions give the ultimate point for the strategy and it is a smart, sustainable and inclusive growth. It includes all spheres of people such as innovation, education, competitive economy, employment etc. These goals are interconnected. Moreover this strategy emphasizes exactly some spheres of life where Europe must act. They are consisted of three main spheres: innovation, education and digital society. The first one is explained as Europe spends less than the USA and Japan on research and development and because of this fact there is a small share of high-technological companies and firms. Education is mentioned because there are serious problems with poor reading competences among pupils, leaving school too early and shortage of workers who have university degree. The last sphere is digital society and Europe has only 25% of information and communication market. There is a lack of high-speed internet which influences on on-line education, e-shops and some new technologies, as smart houses. For instance if the rate of pupils, who leave school earlier than it should be, is depleted more people with education will be, therefore they can be hired for more well-paid position on job. It provides greater capacity for further science development and researching. Probably these research works will be applied in such innovations as low carbon technologies [1].

Europe 2020 is aimed at not only EU level but also at national level. For that, seven flagship initiatives were written. Some statements of these initiatives connected with smart house will be mentioned and discussed. The first flagship initiative "Innovation Union" tells about research and development promotion and different treats such as climate and demographic changes, efficiency etc. It proposes to enhance European Research Area, possibilities for innovative business, promotion of Young Innovative Companies and to run European Innovation Partnership which is destined for industrial technologies and technologies for elderly. The flagship initiative "A Digital Agenda for Europe" considers high-speed internet connection by 2020 that allows the EU to keep up with modern life and expend online services such as smart house, online shopping, health, government etc. The flagship initiative "Resource efficient Europe" should be mentioned because it forwards modernization of transport system and electrical system. It will be reached by smart management, logistic and some regulations (taxations and subsidies) regarding cars, aviation, maritime sectors and supporting implementation and usage of renewable sources. Additionally the rest of the flagship initiatives promote ideas for improving business area, technologies, education system, employment etc. [1].

Therefore, all strategy targets, themes, and flagship initiatives should allow the EU to exit from the crisis, to restart failed business and provide long term economy growth. This strategy is based on the strength properties of the EU. The high-developed agriculture sectors, huge base of industrial sector, own consideration of economic, democratic institutions, the equity of men etc. are the abilities for recovery. Europe is the first discoverer in green environment and technologies and should be beforehand with main competitors such as the USA and China [1].

What is more, some important figures should be reached. For instance, the reduction of 20-30% of emission produced by Europe and reduction of oil and gas consumption (€60 billion less) should be met in 2020 (in comparison with 1990); the most part of population should be employed etc. These all lead to enhancing of finance supplying for research and innovations in all spheres of life (including smart technologies); creating new job places; allocation of high-speed internet and development of new technologies; encouraging the usage of renewable sources and modernization and etc. [1].

The pie chart of energy consumption in the EU is presented in Figure 1.1 [2]. The most significant energy consumption accrues to transport, households, and industry consumptions. Transport consumes approximately a third part of whole energy consumption, the percentage of households' consumption is 26.2% that is more than a quarter, and just over a quarter (25.5%) is industry consumption [2].

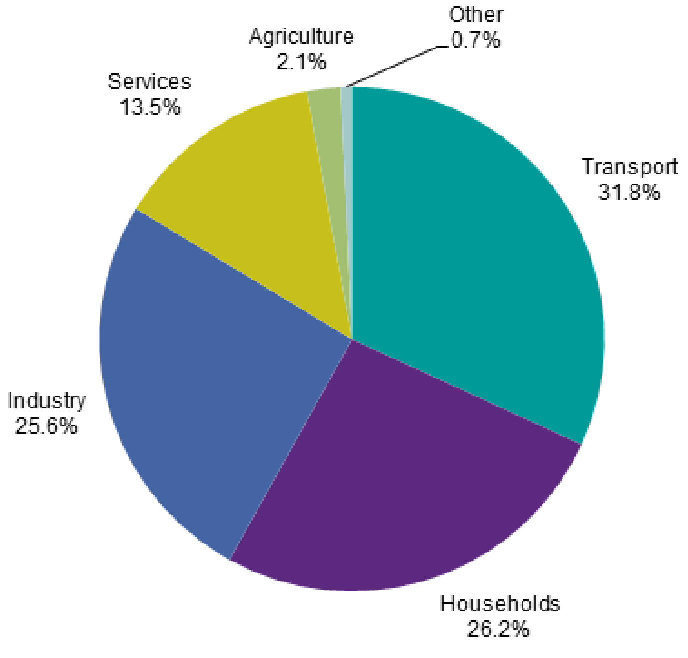

Figure 1.1 EU energy consumption, 2012 [2]

Subsequently, one of the possible fields for the further development and consideration is where people live or home, because it takes one of the considerable parts of electricity consumption in the EU. Of course, there are differences among some countries, we can observe an increase of household electricity consumption, and in the others there is a decrease of household electricity consumption during last ten years. It can be explained by demographic events and extension of usage of energy saving devices [2].

The significant part of total house energy consumption is cooling and heating, the share is between 50% and 70%. One in ten is water heating and the rest of percentages are electrical and electronic devices consumption (Figure 1.2) [3].

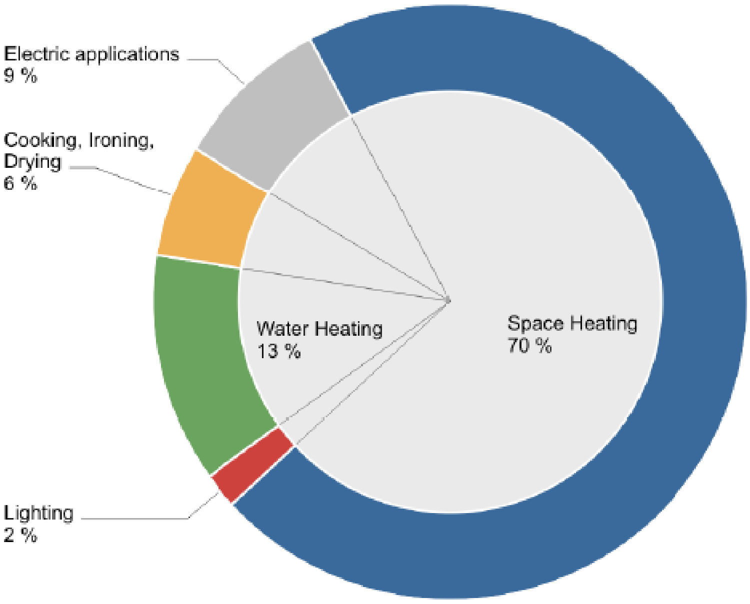

Figure 1.2 Residential End-Use Energy consumption [3]

These all facts say that we have the problems with increasing energy consumption. In addition, it should not be forgotten that every year prices of electricity, water and heating increase. All the more, due to mentioned Europen strategies about energy savings we should find a solution. It leads to developing of power saving technologies for households. This idea also supported by many countries which provide different incentives for the households, such as subsidies and grants for stimulating people to save energy and use high-efficiency equipment and devices.

One of the some good solutions could be a smart house concept. The smart house can be explained as a modern house with automation and high-technology devices developed for energy-savings, comfortable and easy life. In 1991 Mark Weiser predicted "a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives and connected through a continuous network" and it becomes a reality, everything can be interconnected through the computer and wireless systems making access to the devices from everywhere [6]. Originally, it was invented for controlling environmental systems, heating and lighting, but recently all electrical devices within the house can be added [4]. Some sensors can be implemented into houses and therefore provide continuous mobility monitoring and assistance [5].

It should be also mentioned that the smart house can be considered not only as a luxury thing, but it can be useful for elderly and it is the second idea and implementation of the smart house. Getting older means changes in vision, hearing, sense of touch, mobility, reaction time and memory. Because of these changes, there is a fear of accidents and other problems that may arise when they live alone. In addition, the biggest challenges of the modern society can be provided by moving elderly people from their present home into a smart house embedded by a health system (which includes sensors and devices for controlling health condition of habitants). In most cases it is better to stay at home rather than move to a healthcare facility. Smart houses can also be of use and support in residential care units through helping the care personnel to know about accidents or other undesired situations [7].

Moreover, the necessity of this idea can be proved by evaluated figures of different independent organizations. For example, they show that 524 million people in the world were 65 or older and it is near to 10% of whole population in 2010. In 40 years by 2050 more than 20% of population will be in “over 65” age group and this situation is taking place almost in all developed countries (European, the USA, and Japan etc.) [8].

1.2 Smart Technologies

1.2.1 What Is Smart Environment

The base of the smart house is a computing system, which is ubiquitous and pervasive. It provides users with suitable and satisfactory information at desired moment of time. All devices can communicate with each other. That connection is a cable laid throughout the whole house and known as a ‘busline’ or they can be connected wirelessly. It is possible in consequence of the high-speed access and the internet [5].

Generally, the system of the smart house must recognize some extraordinary and ordinary situations and act on them by following specially developed algorithms. Basically the smart house is controlled by algorithms which are integrated with control and communication center, heating, ventilation and conditioning system, lighting system, energy supply system, monitoring and security system [5].

According to these facts and rules of well-working smart system atmosphere of interaction of human and living place are created. And all comfortable conditions are created for people; everything is measured and controlled by the system so there is not necessity to have several remote controls to see after all counter levels and etc. The ultimate purpose of the smart home is updating all homes with more intelligence devices and creating awareness within society in order to give better conditions for home inhabitants. The smart home technologies have a user-friendly interface with ease of use, and can be utilized by anyone regardless to age and gender, since whole idea and technology developed especially for elderly people, who may have difficulties to understand and use complicated technologies and devices. This system should not be too visible and invasive but should provide laconically enjoyable rhythm of life [5].

It makes sense to write some requirements and challenges for the smart house:

- everything is computed and wirelessly connected;
- it should have adequate response, recognition and choosing abilities to the human actions;
- the core of the smart house should allow to integrate all receivable inputs, states of devices and information;
- the smart house system must recognize and distinguish different spaces and respond to events going on around;
- old computer interface should be replaced by modern speech recognition devices, machine vision, sketch recognition devises and etc.;
- the smart house must provide privacy and security for its habitants [6].

Usually the smart house is equipped with smart devices, residential gateway and network which bounds them, collects and transmits information to the Internet (Figure 1.3). Generally, it is named as smart environment and it is a small world, which is designed to create comfortable life of inhabitants and where all smart devices are connected and continuously working. Solutions of providing the smart house by effectiveness of energy usage can be classified also as **sensor-based, directive-based** (or their combination) and **Internet based**. The sensor-based solution is based on using different types of sensors (temperature, luminosity, presence of habitants etc.). The second case of the solution is conceived as the system with remote management via clouds and mobile devices. The third type of the solutions is not so popular and it is being introduced because of weather forecast, therefore it allows the smart house to get information about the weather and control the inside environment properly according to the outside weather [9].

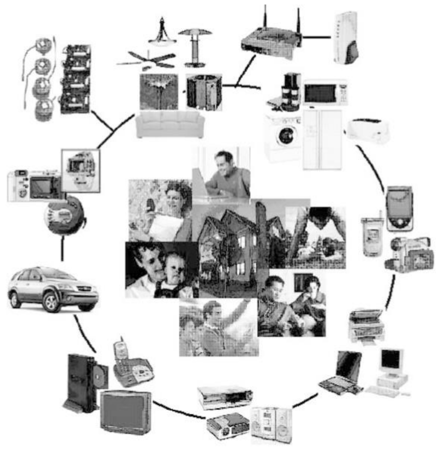

Figure 1.3 Device control in smart environments [6]

In Figure 1.4 the smart house concept is presented, there are two spheres of the smart environment: indoor and outdoor environments. The indoor environment has indoor control network, which in turn consists of white appliances (state devices such as oven, refrigerator etc.) and user interfaces include voice devices (telephone, microphone), visual devices (cameras), graphical devices (PDA, PC, Laptop) and actuators (emergency button). Network (core network and access network), service, and content providers are incorporated on the outdoor environment. Thus, the indoor environment yields the connection, obtaining, and exchange of information between objects and the outdoor environment hands over communication between the provider and the smart home [4].

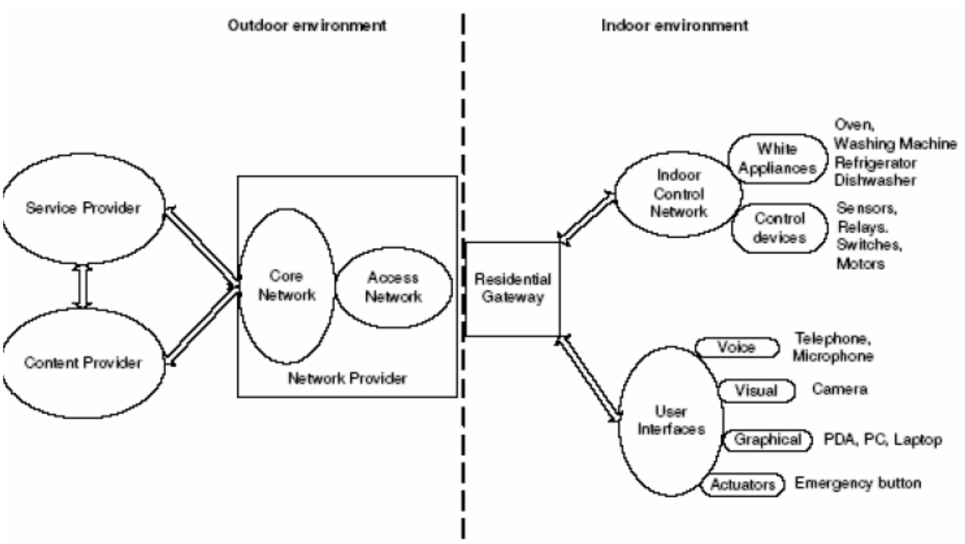

Figure 1.4 Device control in smart environments [6]

The smart indoor environment or ambient intelligence should react on all actions within a room. It includes all sensors such as temperature and humidity sensors, cameras, motion detectors, light sensors or any device, which can be used as an information source for an automated control system. After information obtaining and processing the system uses actuators to change the conditions in the place [10]. Thus, the actuators are the hands of the automated system and include pumps, electrical motors, electric switches, dimmers etc., depending on the function required.

As it was said above, in order to control and connect all components of the system the network is used. Connection joins all home sensors and actuators into one integrated system and helps the automated system to control the house equipment. Moreover, all components should be equipped with adapters in order to be integrated into the smart house infrastructure [3].

There are two main types of connection: wire and wireless. All of them have different requirements to provide desired quality of the connection. In Table 1.1 Wireless Building Automation Standards are presented, where the major characteristics are mentioned such as range, maximum speed, frequency etc. The two main open standards for wire line based building automation are KNX and LON. KNX is a European (EN50090, 2003) and international (ISO/IEC 14543-3, 2006) standard for home and building automation [3].

Table 1.1 Wireless Building Automation Standards [3]

	First Released	Range (indoor / outdoor)	Maximum Speed	Frequency	Modulation	Standard	Location Accuracy
Z-Wave	1999	30m	250 kBit/s	908.42 MHz	GFSK	IEEE 802.15.4 (*)	10m (**)
ZigBee	2003 / 2006	30m - 500m	250 kBit/s	2.4GHz (Global), 915MHz (North America), 868 MHz (Europe)	QPSK	ITU-G.9959	10m (**)
Wireless Hart	2004	50m / 250m	250kBit/s	2.4GHz	DSSS, O-QPSK	IEEE 802.15.4 (*), IEC 62591	10m (**)
MiWi	2003	20m / 50m	20kBit/s 40kBit/ 250kBit/s	868MHz, 915MHz, 2.4GHz	O-QPSK	IEEE 802.15.4 (*)	10m (**)
EnOcean	2001	30m - 300m	125kBit/s	902MHz (North America) 868MHz (Europe) 315MHz (International)	ASK	ISO/IEC 14543-3-10	N/A
DASH7 (active RFID)	2004	- 1000m	200kBit/s	433MHz	GFSK	ISO/IEC 18000-7	1m

1.2.2 Smart Environment Approaches

There are several variants of the smart environment for energy conservation and human comfort. The first one and the simplest one is a **rule-based approach** or a set of "**if-then**." Because of relatively simple idea of the system, it can be adopted to any problems. This system consists of four main components: rule-base (knowledge base); inference engine, which analysis and acts upon created rules; temporary working memory and connection with any interface. The main disadvantage of the system is that if there are a lot of rules and actions, the system cannot be able to deal with them [11]. An example of such system is regulating temperature at home depending on time of the day. The resident can easily set up desirable temperature according to presence or absence of habitants [10].

The second variant is a **fuzzy logic**. Lotfi Askar Zadeh firstly introduced the fuzzy logic in 1965. It is a branch of mathematics, which is a generalization of classical logic and set theory. The value of the fuzzy logic function can take any values in the range from 0 to 1, not strictly 0 or 1 [12]. In Figure 1.5 the fuzzy logic of temperature function is presented. Every moment of time a thermometer measures temperature in a room. The vertical line with three arrows is ambient temperature in the room. Then it is analyzed and interpreted. For example, red line has 0 value and it means that the temperature in the room is not hot, orange line has intersection point at 0.2 and may describe the temperature as "slightly warm" and blue arrow has value 0.8 and it shows that the temperature is "fairly cold".

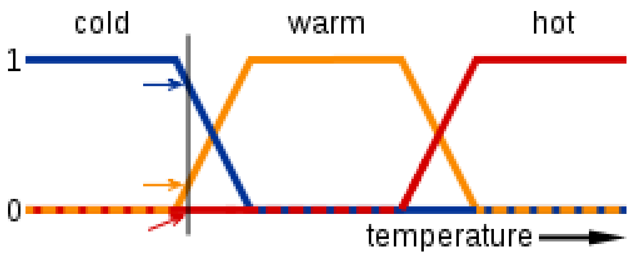

Figure 1.5 Fuzzy logic [12]

The third method of the smart environment is **artificial neural networks** (ANN). They were invented to be similar to animal's central nervous systems. The main function of the ANN is to map input values to one or several outputs. Thus, it is a system of interconnected "neurons" which can be trained and recognizes patterns [12]. In addition, the artificial neural network can be represented as "black box" where inner processes are unknown, but at the same time performs all tasks correctly. The ANN just "learns" correct outputs from an initial learning phase [10].

Finally, the fourth one is **software agents**. The software agents are special programs that are dedicated to action on the behalf of something or someone else. Thus, such actions mean agreement of performance particular actions, they can predict environment and it gives possibility to take actions to improve the ambient using controllers (Figure 1.6) [10].

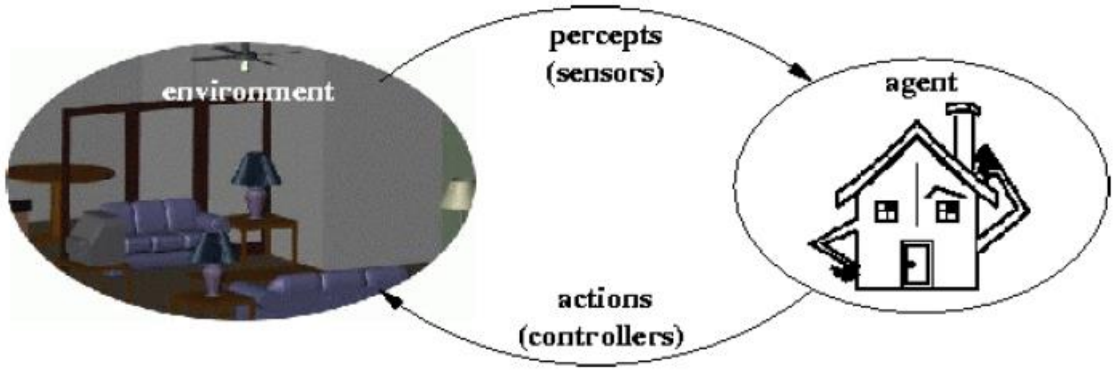

Figure 1.6 The negotiation between environment and agent [13]

If the smart house is considered then each room has its own agent, which is responsible for comfort, safety, and efficient work of all devices in the room. All agents are connected together to achieve the main goal to minimize costs and satisfy the residents. The result of the combination work of different agents is smart and comfortable environment provided to the habitants [10].

Obtained messages of information can be directly transmitted and derived by local memory or can be split into smaller units, which are also called as flow control units or flits. All these flits are controlled by the header flit, which determines the route. Such method of switching has the main advantage as the lowest latency. There is the second variant of switching scheme, which is called as virtual-cut-through. That variant uses another way of controlling and transmission of messages. All messages are delivered separately into buffers [6], [9], [14].

Because of a miscellaneous number of messages and nodes that play role of shared resources it is necessary to drive to correct decisions. There can be many different paths from the source to the ultimate goal and it means that message routing is definitely important topic. More than five variants of routing methods are and some of them are presented in this work further. The first one is fixed routing scheme, which uses routing tables. Using the tables every action is dictated the next point to be delivered to on the lines of the current message. However, the main con of the method is absence of real time circumstances. The next scheme is adaptive routing scheme, which is more preferable than the previous one because it depends on the current network status and includes all aspects like cost of transmission, reliability, congestion etc. [6], [14].

1.2.3 Prediction of Habitants' Behavior

In order to create the smart environment the smart system of a house should have integrated aspects such as prediction mechanism or algorithm, decision making, human-machine interface, wireless networking etc. It is one of the main issues of the smart house. Firstly, it should be mentioned that the smart house can have different architectures such as complex solution; interconnected architecture (all tools and devices are considered); open solution (based on industrial standards) and structure of independent devices even though without connection to the main controller. The first two architectures require prediction of habitants' behavior for demand response and resolving resource usage conflicts among the residents and decision-making for correct devices' actions. It means that the smart house should gather information about habitants accurately and extrapolate of the same habitants' choice to the future [9]. They can be learned from observation and used to predict behaviors in the future. It can be used as predicting the amount of time required to warm the home to desired temperature requires an algorithm that can effectively make use of past performance of the heating unit, the current internal and external temperatures, and thermal flow within the house. Similar models of behavior can be learned for other devices. The choice among alternatives may depend on the effectiveness of the device in achieving the desired temperature, the time required to achieve the change, and the resulting energy usage. In addition to predicting the behavior of devices in an environment, predicting an inhabitant's next action may be needed for the environment to automate selected repetitive tasks for the inhabitant, to detect anomalies that could indicate security or health concerns, and to identify ways of improving control of the environment. The information available from which to build models and make predictions will vary with the environment and may include video, power meters, motion detectors, loud sensors, device controllers, and vital sign monitors. A prediction algorithm must be able to determine which features are relevant to the model being learned and make maximal use of the information provided. The number of prediction errors must be minimal, and the algorithms must be able to deliver predictions with minimal delays for computation. The results of a prediction algorithm may ultimately be input to a decision-making algorithm that selects actions for the house to execute [9].

Prediction algorithms learn a function that maps known information about the problem, collected from past and current observations, to a hypothesized value for a future point in time. A sequential ordering of events (e.g., the inhabitant's actions) is input to the algorithm, for which actual timing information may or may not be provided. Algorithms that make use of historical information as well as current state information thus provide the greatest leverage for addressing the problem [6], [14].

Prediction algorithms:

- Pattern-matching technique. The algorithm uses historical event information to predict the next event in the sequence.
- The IPAM system of Davison and Hirsch collects sequential pairs of events and encodes the likelihood of transitioning from one event to the next in a table.
- "Mixture of experts" approach. It combines evidence supplied by various refinements to the basic matching algorithm.
- A separate approach. It employs a k-nearest-neighbor scheme to form a prediction in the ONISI system, where the sequence match length between the immediate event history and earlier history subsequences is used as the distance criterion.
- Markov Decision Process. At each time step, the agent perceives the current environment state and selects an action to execute. The result of the action is modeled as a probability distribution over states and possibly yields a reward from the environment [6].

1.2.4 Location Estimation

By definition, the smart environment is context-aware. It means that by combining inputs from multiple surrounding sensing devices and applications, the smart system should be able to intelligently guess the intent or attributes of an individual without explicit manual input. Perhaps the location is one of the earliest and still the most common example of such context [6].

In addition, the smart environment must be able to both determine and predict the location of the individual. In the conventional cellular telephony environment (for which most of the early work on location management was carried out), the location prediction is used only as an intermediate step to improve the efficiency of the location determination process [6].

The literature contains a lot of possibilities and ways of the location estimation. It can be timed updating (at appropriate time intervals), distance updating (when the distance is more than acceptance threshold), movement updating (mobile nodes update information after any residential movement) and reporting center-based updates (mobile nodes update information in specific circumstances like visiting certain places by habitants) [6].

All these methods can be referred to two main operations for determining the habitant location based on mobile or device using:

- Location Update or Registration. This operation uses mobile nodes which continuously find the user, the updating occurs when the user changes the location or according to a timer (see Figure 1.7);
- Paging. The system (cellular network elements) searches the mobile nodes with nonzero possibility of habitant presence (Figure 1.7) [6].

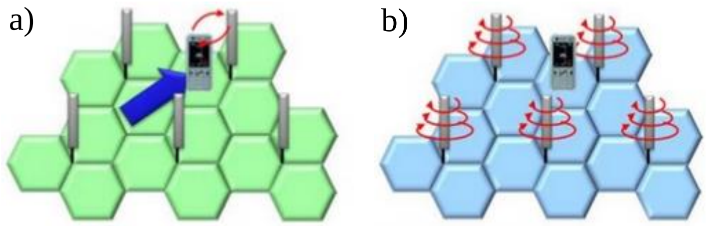

Figure 1.7 a) The location update and registration; b) Paging [15]

One of the latest released devise in 2014 for the location determination was IBEACON (Apple Inc.). These devices allow finding where their owners are. Bluetooth Low Energy (or Bluetooth Smart) technology is used for connection and determination. Each iBeacon (Figure 1.8) transmits its own number and control system (in this case it can be any Apple device as iPhone, iPad or iPod) derives and analyses the location of the user [16], [17].

Figure 1.8 IBEACON [17]

1.2.5 Smart Devices

Some examples of future and working-prototype appliances can be divided into several groups regardless to functions. Because of the interconnection between devices within the smart house environment, some groups include the same appliances.

- Operational and control

Usually the smart house has a main server, which connects all devices by wires or wirelessly (Figure 1.9) and can be in control of people. The server is connected with touchscreens with a unified and very intuitive user interface, starting with any television, computer, notebook, or mobile telephone. Sometimes a smart memory can be applied in the smart house [18]. The smart memory is purposed for recording and therefore remembering all conditions preferred by residents. It includes lightening, humidity, sounds, temperature etc. information. Then it can be used to create appropriate atmosphere in the house [19]. All activities can be controlled and monitored through the Internet from any place and at any time.

Figure 1.9 Miniserver (Loxone) [20]

- <u>Security</u>

The security is provided by an alarm system, fire detectors, camera system, infra-light bolts etc. The habitant can easily activate or turn off the devices when he or she wants. It can be done by one screen touch. For instance, when the habitant leaves home she or he can activate the alarm system, pull down the blinds, switch off the lights, turn off the selected sockets etc. [18].

- <u>Heat engineering</u>

The savings from heating can be the biggest part of all savings from the smart house technologies implementation. These savings can be provided by efficient water heating and space heating systems. It should be intelligent heating control by automatically managing room temperature based on time, outside temperature, and presence. It is general practice to apply the thermostatic valves for radiators or thermostats for the heating systems [3]. The device is connected with the internet, every habitant can control and change all of the settings remotely or the device can lower the temperature when the last resident has left home and heats up when any resident nears home. The connection of the thermostat and heating system is not complicated (Figure 1.10) and can work in the houses, apartments with gas central heating district heating or a boiler in the basement [21].

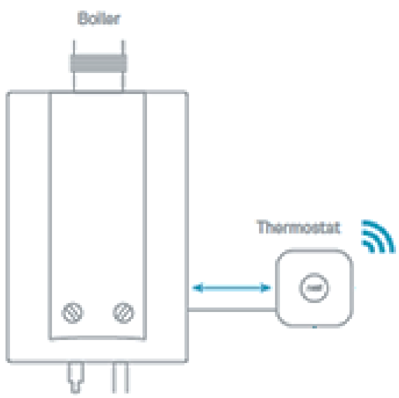

Figure 1.10 Connection of the thermostat and boiler [22]

- <u>Lightening</u>

Smart lighting system manages illumination based on location estimation and prediction: presence detection, sunrise, or sunset timing and room function [3]. Controlling the lightening is achieved by controlled light switches and dimmers (Figure 1.11), which are connected with the server.

Figure 1.11 Dimmer [20]

- <u>Entertainment</u>

The entertainment can be presented by a media center that includes TV or home cinema, audio system etc. This media center ensures the distribution of sound and visual signals into the selected rooms. Moreover, it provides comfortable atmosphere by regulating lights, air, and temperature [18].

Different useful devices also were developed such as a gate reminder, smart pen, smart greenhouse, smart refrigerator, smart wardrobe, smart bed, smart pillow, smart mat, smart table and etc. (Figure 1.12, Figure 1.13) [19].

Figure 1.12 The smart pillow and house reminder [19]

Figure 1.13 The refrigerator and the smart greenhouse air purifying system [19]

There is a miscellaneous number of projects prepared with the mentioned devices and still are being developed by companies as Siemens, Schneider Electric SA, TELETASK, ABB Ltd. and etc. in different countries such as Germany, France, the USA, Belgium, Switzerland, etc. Moreover, there are demonstration projects which most of them have been built at universities and science centers [4].

Some examples of the smart house projects:

- The Adaptive House (University of Colorado);
- ComHOME (The Interactive Institute, Sweden);
- House_n (Massachusetts Institute of Technology);
- The Aware Home (Georgia Institute of Technology) [4].

These smart house projects showed great success in saving power energy consumption and creating comfortable conditions in some cases. Usually there are not any user interfaces beyond the smart system – no touch pads, no speech input, no gaze tracking or hand gesturing etc. Everything is controlled, monitored, predicted, and altered by the system. If there are some problems connected with predicting, inhabitants always can change some parameters via ordinary user interfaces like switches [23].

1.3 Passive House as a Kind of Smart House

In the book [24] the definition of the passive house was given: “Passive House (Passivhaus) is a standard and a scientific design tool that achieves exceptionally comfortable and heathy living and working conditions combined with low energy demand and minimal carbon emissions.” The main idea of the passive house is to reduce energy demand; therefore, the passive house is aimed to decrease electricity consumption, especially specific space-heat demand to the minimum or ideally to zero-consumption (maximum 15 $kWh/m^2/year$). The first indication of the passive house method occurred in 1960^{th} in the UK and Germany. Using effective insulation and draught in the passive house, very low energy costs can be achieved. The idea of the passive house can be implemented for both new and reconstructed buildings of all types and sizes.

The major elements of the passive house are location of the house; shape of the house; insulation; hermetically sealed home; draught-free construction; high-performance windows and doors; heat-recovery ventilation; solutions for both cold and hot climates; energy independence by means of using the renewable sources (Figure 1.14) [24].

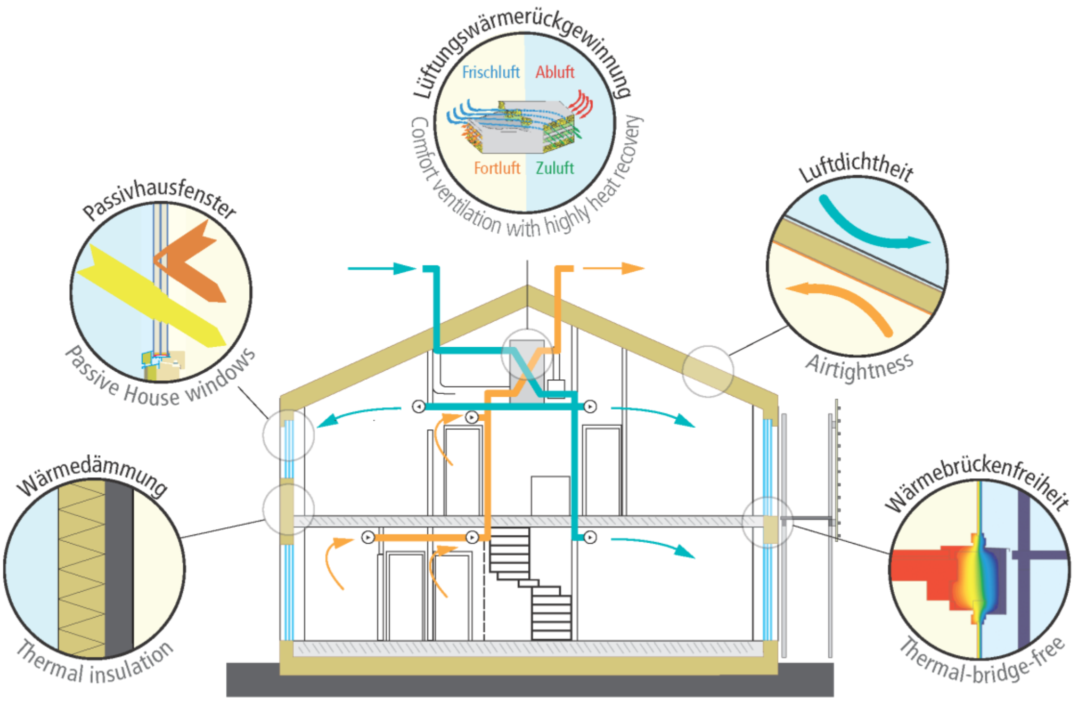

Figure 1.14 The basic principles applied for the construction of Passive House [25]

In the book [24], results of implementation of the passive houses were shown and sometimes they were even better than required. For instance, the results monitored during the first year (2012) of one passive house are presented in Figure 1.15, in overall energy consumption was 12.2 kWh/m^2/year and it is less than set maximum 15 kWh/m^2/year. Moreover, if we compare the results of the passive house consumption with the residential end-use energy consumption (Figure 1.2) then we can see that total energy savings are significant, especially for the heating reduction [24].

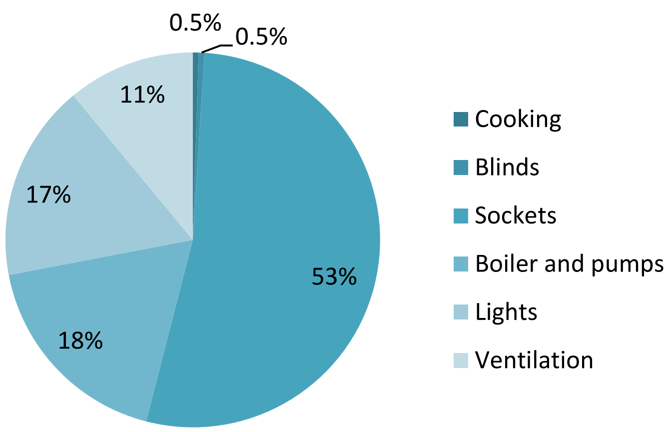

Figure 1.15 Breakdown of electricity consumption by end user [24]

In Figure 1.16 the overview of different energy standards for buildings is presented. Five different types of buildings are considered. Moreover, Table 1.2 shows general characteristics of the five current building types [26].

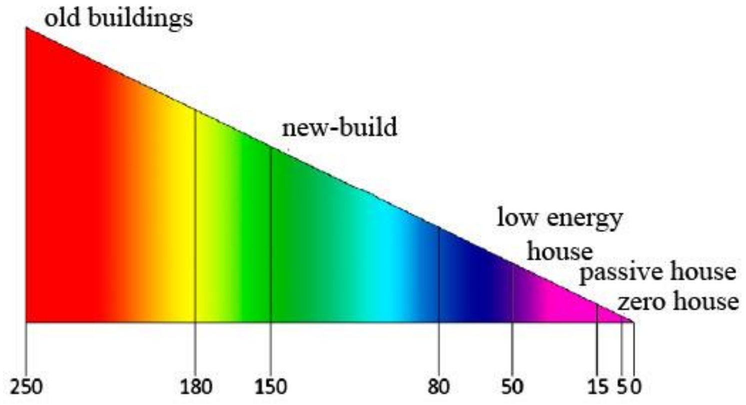

Figure 1.16 Overview of different energy standards for buildings [26]

Table 1.2 The main characteristic of current buildings [26]

Old building	New-build	Low energy house	Passive house	Zero house
Old heating system; heat is the main source of emission; non-insulated; poor quality of windows	Classic heating system with a gas boiler; ventilation by opening windows; standard level of requirements	Low power heating system; usage of renewable sources; well insulated construction; controlled ventilation	Heat-recovery ventilation; excellent insulation; high-performance windows and doors; draught-free construction	Minimal parameters at the level of a passive house; big amount of power is generated by solar panels or other renewable sources
Heat demand [kWh/m^2/year]				
More than 200	80-140	Less than 50	Less than 15	Less than 5

Generally, the passive house is not considered as a smart house, but using automated systems means that the passive house and smart house concepts could be easily combined in one building. The passive house concept has been developed for different types of climate. The passive house method can be applied not only for our homes, but also for non-domestic buildings. The passive house allows people to live comfortably, cheaply (especially in the long run), with minimal energy demand and reach significant reduction of carbon footprint. Large amounts of money can be also be saved by reducing the need for new power stations and for long-term storage of nuclear waste [24]. As almost any project, the passive house project undoubtedly has disadvantages. The main disadvantages are very few designers (or builders) have the required knowledge or experience; dependence on renewable sources; risk of overheating; a thermal exchanger and regular maintenance are necessary [27], [28].

1.4 Connection with Energy System and Impact on It

1.4.1 Smart Grid Concept

Smart grids are electric networks that are able to effectively link the behavior and actions of all users connected to them (producers, consumers, consumer with own production) to ensure economically efficient sustainable energy systems operating with low losses and high reliability of supply and safety [29], [30]. Thus, the concept of the smart grid is development of network infrastructure to ensure reliable and safe operations, introduction, and connection of distributed generation (such as renewable energy sources) to the grid. Because of unpredictable energy generation or new fluctuating energy sources, implementation of accumulating sources and the purpose of improving energy efficiency the grid needs specific requirements. The Czech Republic as a member of EU, where the idea of the smart grids has been developed for a long time, has brought into action the National Action Plan for Smart Grid [29]. The requirements in the National Action Plan for Smart Grid were based on the following areas:

- Renovation and development of resources for remote power management, distributed generation and energy storage based on the principles of smart grids and smart metering;
- Development of systems and tools to effectively control the power system using both new technology (smart grid), support the development of distributed and centralized storage systems;
- Ensuring infrastructure development, expanding power management options to customers at low voltage systems as part of the smart grid;
- Implementation of technologies for effective and reliable management and network [29].

Furthermore, the smart grid should initiate the electricity consumers to have greater freedom and independence in decision making to ensure their energy needs. For example, more and more customers generate their own energy for own consumption and part transmission into the grid, which should be measured and directed to other consumers. Those electricity consumers, who install their own electricity generation, are so-called "prosumers." Therefore, two-way facility for the grid should replace a unidirectional transport facility and it should be provided by the smart grid [29].

In addition, there is a problem with continuously increasing demand, now this problem is being solved by traditional ways, but after several years, it can be more complicated to solve with the same traditional technologies. By the smart grid implementation, the demand can be allocated and the customers will be supplied by electricity without any interruptions. Moreover, the concept of the smart grid intends rational and effective power use. Results of these approaches can lead to intelligent and reliable electricity network with bigger capacity. It should be provided with own intelligence for rectifying errors, remote controlling, monitoring and measurements [31].

Thus, the concept of the smart grid is development and design of the intelligent electrical grid, which is able to manage billions of connected consumers, energy sources and prosumers; reduce costs; provide better energy management of unpredictable energy demand; supply flexibility and security; support new energy sources and increase of efficiency of energy use [32]. Moreover, it is supposed to decrease the dependence on imported fossil fuels and limit carbon pollution [33].

In some regions of Russia the smart grid technology is already in use. However, the main purpose of developing the smart grid technologies in Russia is to reduce losses within the grid. In Russian grids, the current distribution infrastructure loses 12 percent of its transmitted energy, in comparison the electrical network losses rest at only 4-9 percent in Europe. The losses are considerable and caused by old equipment (power plants, transmission lines, and substations), also the energy market has many loopholes, and limitations, which smart grid technology can eliminate. Thus, the upgrade of the grid in Russia could reduce electricity losses up to 25 percent and save as much as 35 billion kWh of power [34].

Regulation

The smart grid includes many different programs and devices. Obviously, they have to be provided by hundreds of rules and standards. Some of them are crucial and more urgently needed than the others. Regulations in the smart grid area correspond to several documents and organizations: SGTF, ACER, DPIA Template, FERC etc. (see Table 1.3).

Table 1.3 Explanation of the regulatory organization activities in EU

Document/ organization	Purpose
SGTF	Determination of key recommendations for standardization, consumer data privacy and security [35].
ACER	Assisting regulators EU countries in implementing their national regulatory problems at Community level; Coordination of regulatory authorities of EU Member States; Participation in efforts to strengthen energy security [36].
FERC	Regulations of the interstate transmission of electricity, natural gas, and oil [37].
DPIA Template	Supporting by an evaluation and decision-making tool for entities planning or executing investments in the smart grids sector. It helps them identify and anticipate risks to data protection, privacy and security [33].
EC	Adaptation of standards, recommendations and projects [33].
NIST	Building a solid framework and roadmap for smart grid interoperability standards. Research, development, and innovation in smart grids [38], [39].

NIST has emphasized eight main recommendations of the FERC for the smart grid deployments in the EU:

1) Demand response and consumer energy efficiency. The awareness and understanding of efficient behavior of all consumer sectors (business, residential, industries) are necessary parts of energy consumption decreasing especially during times of peak demand or outrages.
2) Wide-area situational awareness. Controlling and monitoring wide areas in real time to prevent and respond to problems before outrages.
3) Energy storage. Using proper storage and developing new technologies of storage.
4) Electric transportation. Providing large-scale integration of electric vehicles and the possibility to charge them everywhere.
5) Network communications. The identification of performance metrics and core operational requirements of different applications, actors, and domains, development, implementation, and maintenance of appropriate security and access controls.
6) Advanced metering infrastructure. Providing near real-time monitoring of power usage, and is a current focus of utilities. Implementation of residential demand response including dynamic pricing.
7) Distribution grid management. Minimization of losses and outrages, maximizing performance of all system objects, supplying of all demand regions.
8) Cybersecurity. Supporting of confidentiality, integrity, and availability of the electronic information communication systems and the control systems necessary for the management, operation, and protection [40].

1.4.2 Interconnection between Smart House and Smart Grid

The smart grid as the smart house requires high-technology devices and systems. Whereas, the smart grid includes smart object networks: sensors (e.g., measuring the current, voltage, phase, or reactive power) and actuators (e.g., circuit breakers, etc.) to efficiently monitor and control the power grid, sensing in smart meters to measure power consumption [32].

Also there are necessary standards for communication and integration of the smart house into the smart grid because the smart house is a part of the smart grid, they can be grouped into three categories: in-house technologies (within the smart house which includes a number of smart devices that communicate via specialized energy management devices with the grid for efficient energy management), house-to-grid technologies (connection, monitoring and controlling), house/grid-to-enterprise technologies (coupling the information generated within the smart house or the smart grid with enterprise services) [39].

All devices will be able to interact over the Internet protocol and participate in bidirectional collaboration with other devices and enterprise services (Figure 1.17). The work of smart house and smart grid will be controlled and monitored by different optimization and control algorithms. And it is extremely important that all devices within the system are kept within requirements [41].

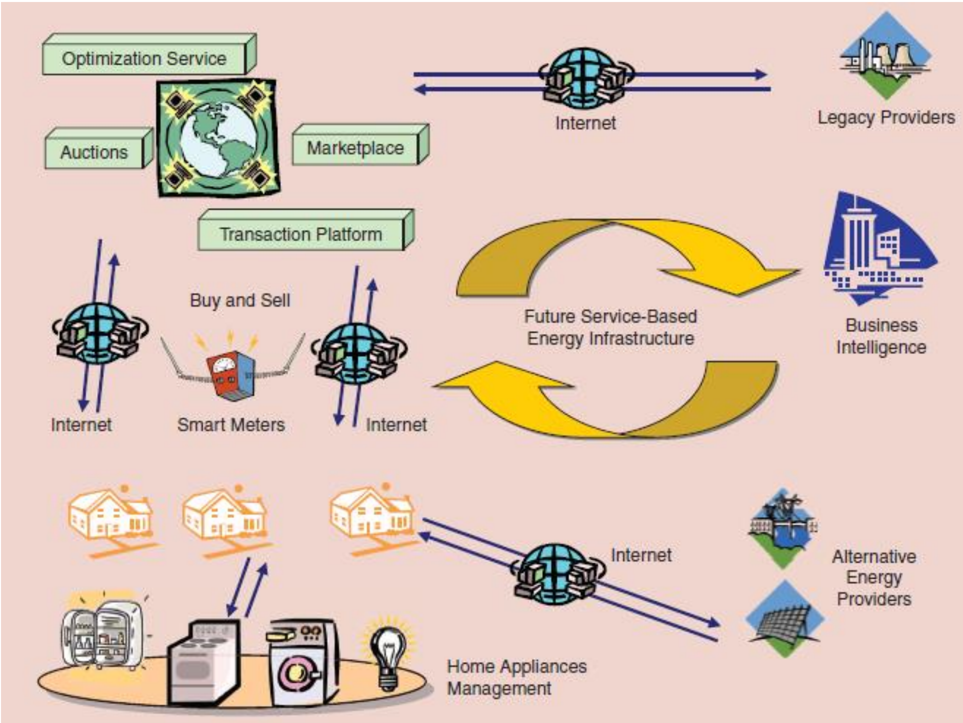

Figure 1.17 The service-based ecosystem based on smart houses and smart grids [41]

As a result of interconnection of the smart house and the smart grid, it is expected increase of reliability, efficiency and the penetration of renewable sources, improvement of power management and decreasing of losses [39].

1.5 Smart Home Market

To understand the size of the possible smart house market extension, different characteristics and features should be taken into account. In the following text a long-term assessment of the adoption of the smart systems, renovation and construction rates, and attitude of people to the smart house concept are considered.

Initially, a breakdown of the smart homes was examined in Western Europe. The Western Europe countries are considered as ones of the most developed countries in the world and if the new technologies appear and it means that, they will be utilized firstly in the developed countries. The "Outlook for the Smart Home in Western Europe" prepared by Parks Associates presented the market for home monitoring and controls in Europe. The behavior of the market significantly changed [42]. Widely deployed broadband, smartphones, tablets, and computers transformed the ways of our communication, shopping, paying bills etc. Moreover, implementation of the different technologies becomes popular in houses; it allows people to connect individual devices with house devices [42].

The company undertook the survey and found out several market trends, which were driving consumer adoption:

- Interest in alternative energy supplies;
- Ever-rising energy costs;
- Increasing security concerns;
- Aging populations;
- The use of smartphones and apps.

These trends can be a solid motivation for companies of different spheres such as caretaking, energy management, security service etc. to develop new technologies, that means increase in business rivalry and decrease in prices of these technologies [42].

In the Outlook, the surveys of preferences and desires of people were held in 2013. For example, consumers were questioned about their opinions about specific devices and their associated price points (Figure 1.18). The highest ranks were given for security-related devices and the lowest ranks were for lighting control modules and appliance switches. Consumers found the security-related devices more useful and important [42].

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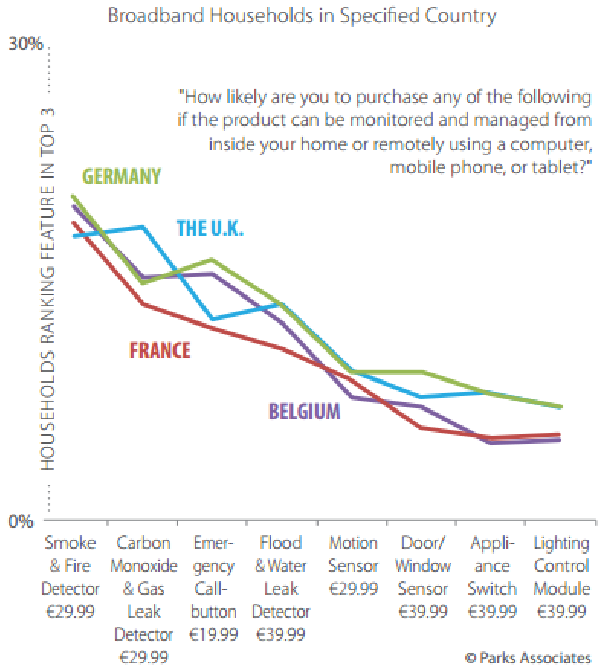

Figure 1.18 Intend to Purchase Home Control Devices [42]

Moreover, the trend of the smart house systems adoption was rising and it was predicted, that, 30% of broadband households would have some type of the smart system (security, lighting control etc.) by 2022. The growth of implementation is shown in Figure 1.19. The growth will be driven by self-monitoring and control services and appliances offered by broadband service and remote-enabled entertainment providers. It is important to note that this forecast was for 'net' households with smart systems. A household with one system will likely acquire multiple systems for different applications over time. In fact, it was expected that approximately 65% of households would have multiple systems by 2017 [43].

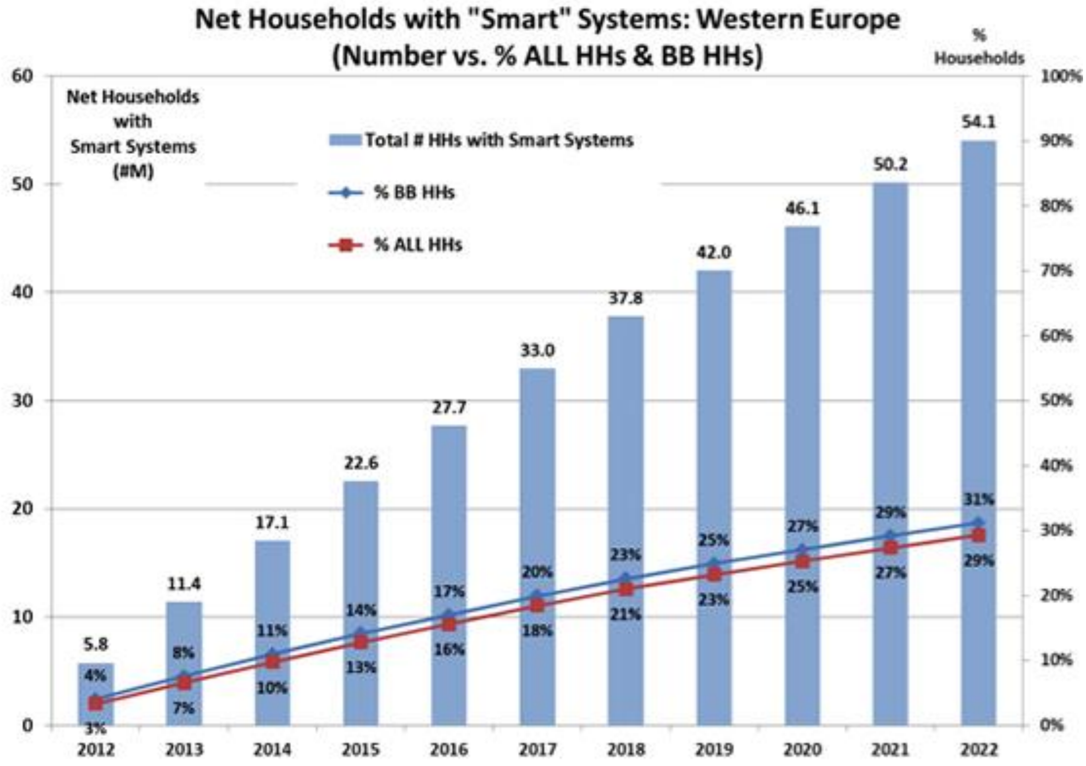

Figure 1.19 Net households with smart systems in Western Europe: 2012 to 2022 [43]

Thus, the tendency of the smart technologies is growing up and people are intending to buy and use new technologies in order to protect the house and decrease costs.

Moreover, the renovation and construction rates have considerable influence on the smart house system penetration. These rates are analyzed below for two countries: the Czech Republic and the Russian Federation.

Renovation and construction rates

There is little data on the numbers of renovations being undertaken, their depth, or indeed trends in renovation rates. The renovation rate is comprehensive to estimate and usually all data available based on the past few years. In the article [44] renovation rates across different countries in the EU are investigated. In Figure 1.20 the share of dwellings built before 1980 in total stock is presented. Many of the European countries have constructions, which are older than 35 years. It refers to the Czech Republic, Germany, and Italy etc. [45]. The result of that is the low renovation rate in the Czech Republic. The average renovation rates were estimated in [46] for single-family and multi-family residences and they were equal to 2.4% and 3.6% respectively. It was said that logically, renovation rates would rise with higher energy prices and running costs and decrease with lower prices and costs (Figure 1.21, Figure 1.22). Of course, significant influences can have employment factor, policy, subsidies, and other factors [46].

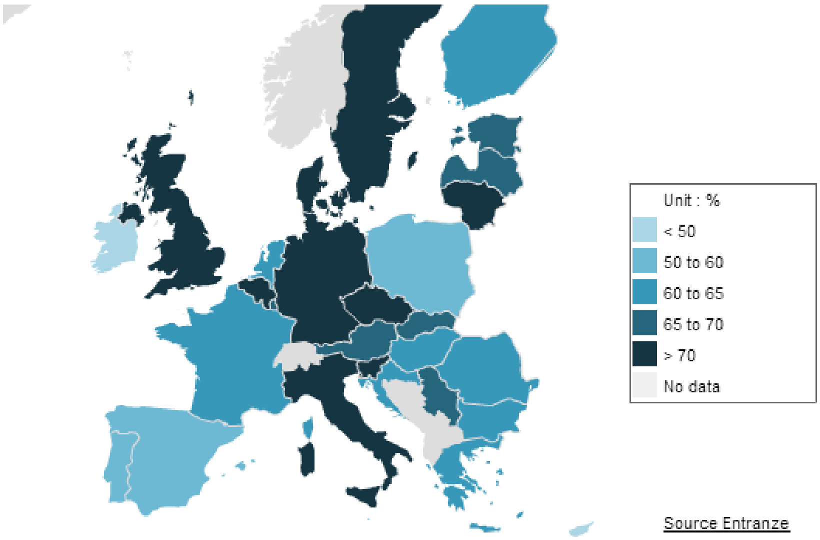

Figure 1.20 Share of dwellings built before 1980 in total stock [45]

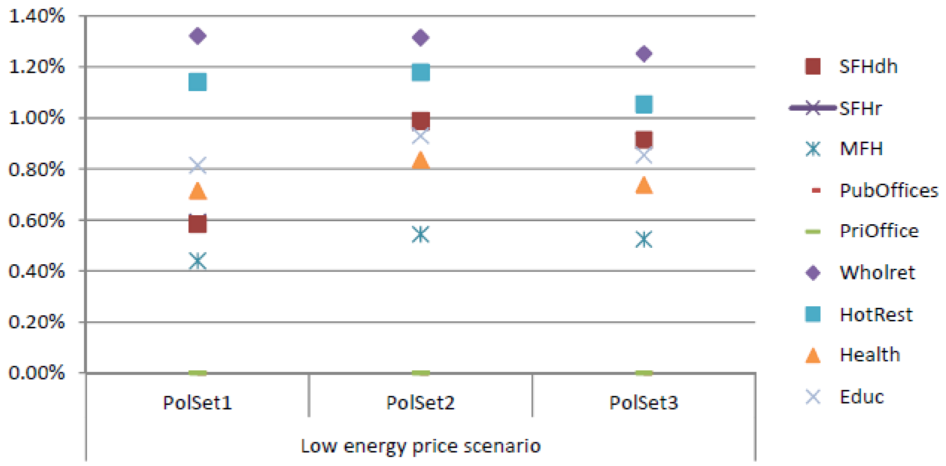

Figure 1.21 Renovation rates for different types of buildings under low energy price scenarioc [46]

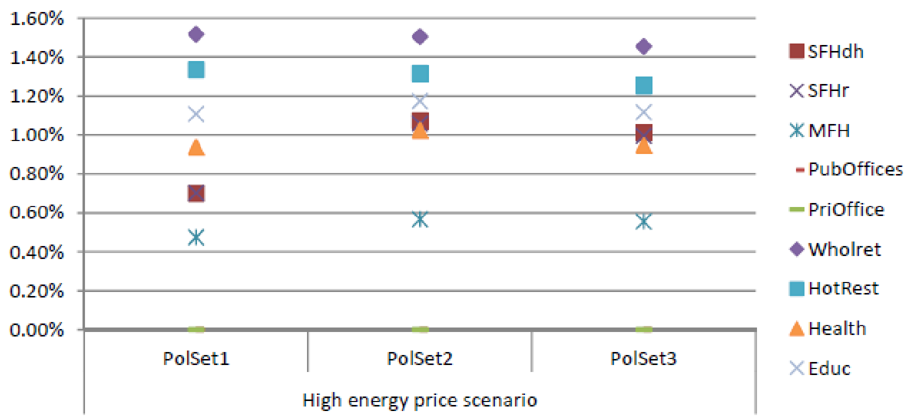

Figure 1.22 Renovation rates for different types of buildings under high energy price scenario [46]

The construction market in the Czech Republic shown relatively stable 10-year growth until 2009, heavily boosted by direct foreign investment, private residential mortgages, public sector investment, and EU funding, resulting in construction output increasing by 5-8% per annum over a number of years (Figure 1.23) [47].

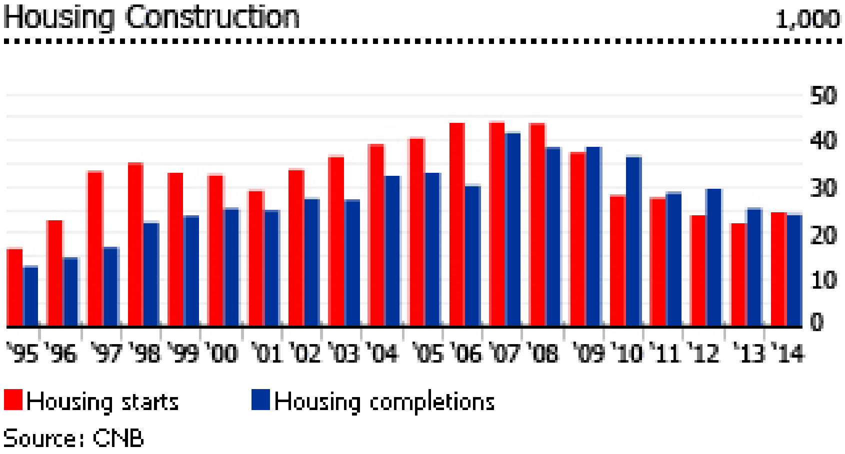

Figure 1.23 Housing construction in Czech [48]

Renovation rate in Russia is much less and as it was estimated in the article [49]. It was approximately equal to 0.6%. Moreover, it was investigated that if some actions to increase the number of the low-energy buildings were taken then energy consumption would decrease from 111.5 Mtoe to 80.5 Mtoe in 2050 (Figure 1.24). This would be equivalent to 17.4 Mt CO_2 annual emissions reduction (Figure 1.25) and would require on average €2 billion investments per year [49].

Under these circumstances, by 2050 only 24 % of the stock would be renovated. The final energy consumption per construction period would vary from 350 kWh/m^{2}year to 260 kWh/m^{2}year. The low-energy buildings scenario, which assumed an increase of rate of energy renovation, allowed for the renovation of the entire existing building stock by 2050. The total annual final energy consumption of the existing building stock would drop to 21.2 Mtoe (Figure 1.24) and CO_2 emissions would drop to 71 Mt CO_2 in 2050 (Figure 1.25). In the low-energy buildings scenario, nominal annual investments needed increase from €2 billion/year in 2013 to reach a peak in 2030 at €19 billion/year while the average annual investment needed over the retrofit period is €16 billion/year (Figure 1.26). In the low-energy buildings scenario the overall existing stock, all construction periods combined would reach 80 kWh/m^{2}year by 2050 (Figure 1.27) [49].

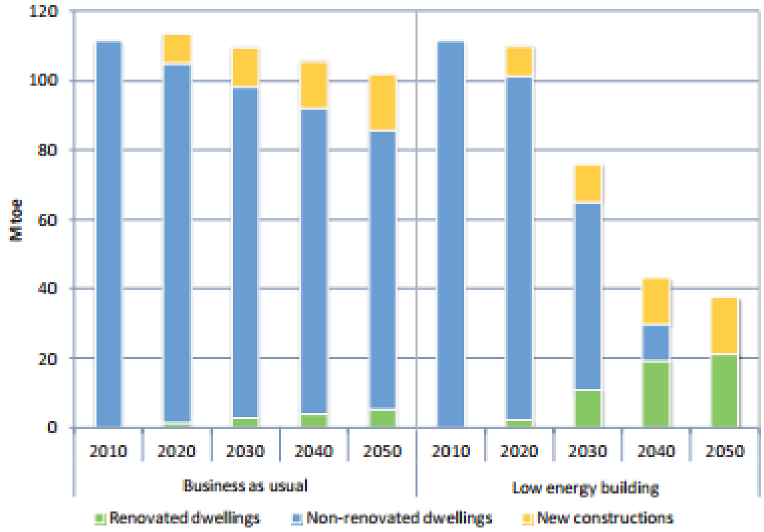

Figure 1.24 Total final energy consumption for all end uses of the whole stock by 2050 in each scenario [49]

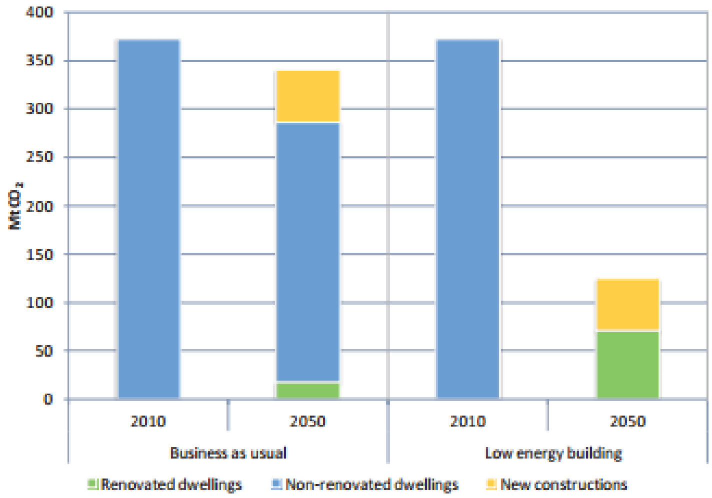

Figure 1.25 CO_2 emissions in each scenario [49]

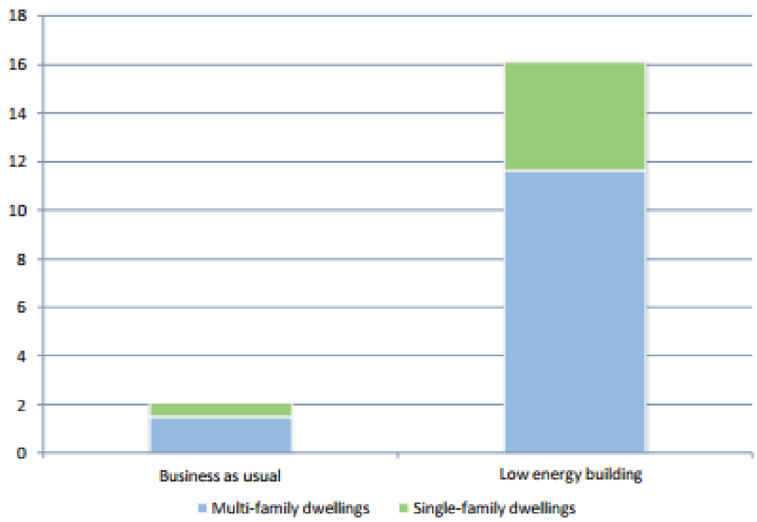

Figure 1.26 Average annual investments needs in billion Euro [49]

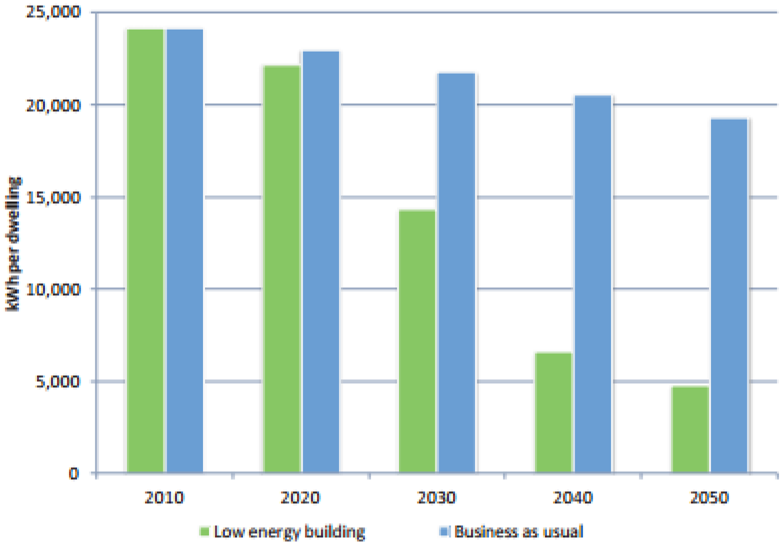

Figure 1.27 Average total final energy consumption for all end uses per dwelling [49]

Recently, the important progress has been made in order to increase efficiency of both new constructed and old buildings in Russia. The new design of energy efficiency policies was prepared, but in some cases, specific decrees to ensure effective implementation and sectorial approach are still missing. Russia has to address simultaneously the challenges of renovating the existing building stock and reducing the energy consumption of new buildings, due to its high construction rate. From 2000 to 2014, each year between 35 and 80 million m^2 of additional new residential stock was built (Figure 1.28). Between 2004 and 2009, 320.4 million m^2 of residential buildings were constructed, which corresponded to about 10 % of all residential building stock in Russia, of course it varied depending on regions [49].

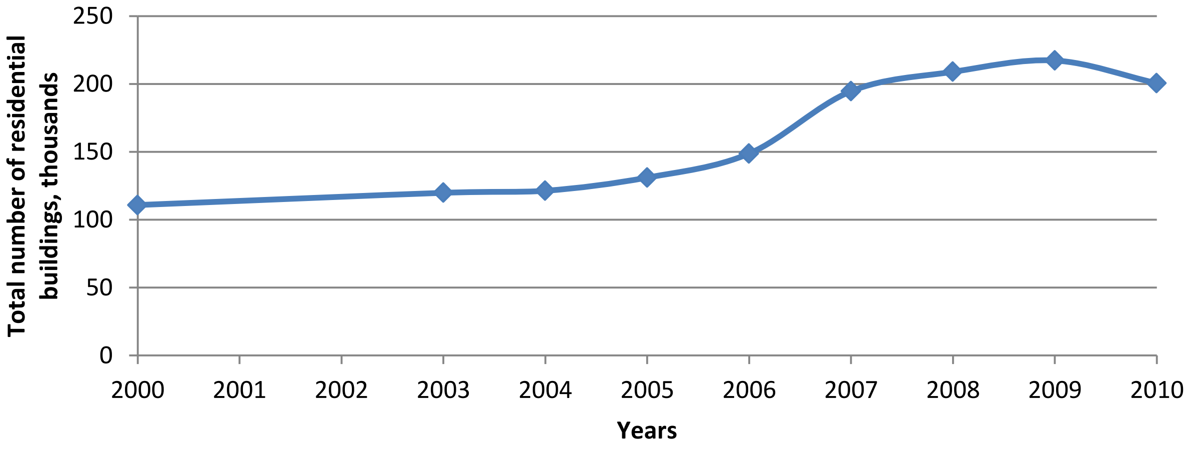

Figure 1.28 New build construction in Russia [50]

Overall, the high construction rates in both countries may lead to suitable conditions to implement the smart house technologies, because it is much easier to implant them when the house is under construction than when the old house needs reconstruction and everything should be replaced or repaired. What is more, the final decision of implementation of new technologies is more successful and possible to realize when the house is only in the mind, plans are being researched and the future household wants to have a new modern house with all up to date appliances. On the contrary with the construction rates, the renovation rate is low in the Czech Republic and it is much less in Russia. It means that it is not so desirable to do home improvements among households.

Attitude of people about smart home applications

In the article [51] the surveys of attitude of people about smart home applications were carried out. They revealed that the cost of the appliances for people from Europe can be considered to be the biggest worry and the Asian answerers were found to be more worried about the reliability, practicability, and cost than the answerers from Europe. In addition, some privacy concerns were found from both the European and the Asian answerers. Furthermore, the article shows that majority of people had already known about some smart technologies and their functions. People were interested in versatile smart home applications, but they had doubts about availability of information recorded such as habits, movements of residents.

On the whole, the smart house market has positive signs of development and utilization. Many people would like to have the assistance in the smart technologies form. Usually the smart house technologies are easier to implement at the beginning of the house construction period and the conditions of the two counties are suitable for that. On the other hand, there is a lot of old houses and manufacturers must continue to look for ways of equipping those houses [52].

1.6 Benefits and Classifications of Points of View

All key benefits of the smart house can be classified as economic and non-economic. Certainly, the economic benefit of the smart house is energy savings that can be considered as the main and precisely evident benefit within the economic benefits. It can be explained by smart and accurate management of heat and electricity consumption according to models, scenarios, and date. Sophisticated technology gives customers complete flexibility in scheduling energy consumption to fit their schedules and decrease fuse level and it is a way to decrease network costs. Thus, right and conscious management gives a great opportunity to choose the best variants of a tariff and network, therefore to contract costs [53]. There are several types of demand side management (DSM), which can be provided by smart appliances: peak clipping, strategic conservation, valley filling, strategic load growth, load shifting, and flexible load shape (Figure 1.29) [54].

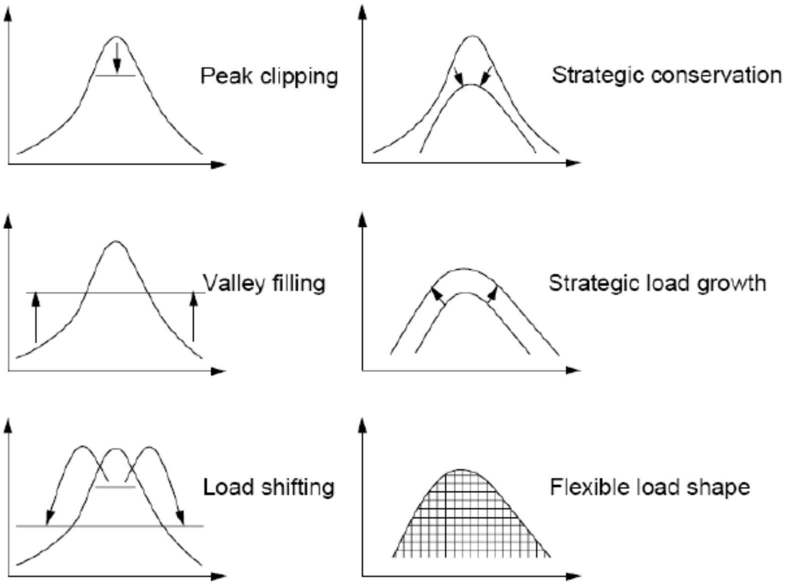

Figure 1.29 Applications for Grid Load Management by Demand Side Measures [54]

On the other hand, the money saved from the energy saving cannot cover all the investments, which the smart house needs. Usually people who purchase the smart house do not care about the energy savings, because it is a luxury thing, where electricity bills are not important at all.

The biggest benefits of the smart appliances penetration can be got by the national systems. Fuel savings of gas fired balancing capacities can explain the benefits gained. The economic benefits will be increased also by further deployment of intermittent generation and network balancing. In the article [54] WP 4 was a work package in which the total DSM penetration rate of 30 GW for the size of European electricity systems (38% of the total average load by appliances of 79 GW for 2010) was constantly available. And for 2015, overall load for the modelled penetration rate of 33 GW amounted for 50% of the expected total average load of 60 GW. In Figure 1.30 total annual economic gross benefits from balancing capacity for WP 4 “best choice” DSM penetration rate in the EU27+NO+CH for 2010 and 2025 are presented and the lower price scenario was based on a fuel price of 23.19 EUR/MWh, whereas the upper price scenario was based on a fuel price of 34.4 EUR/MWh.

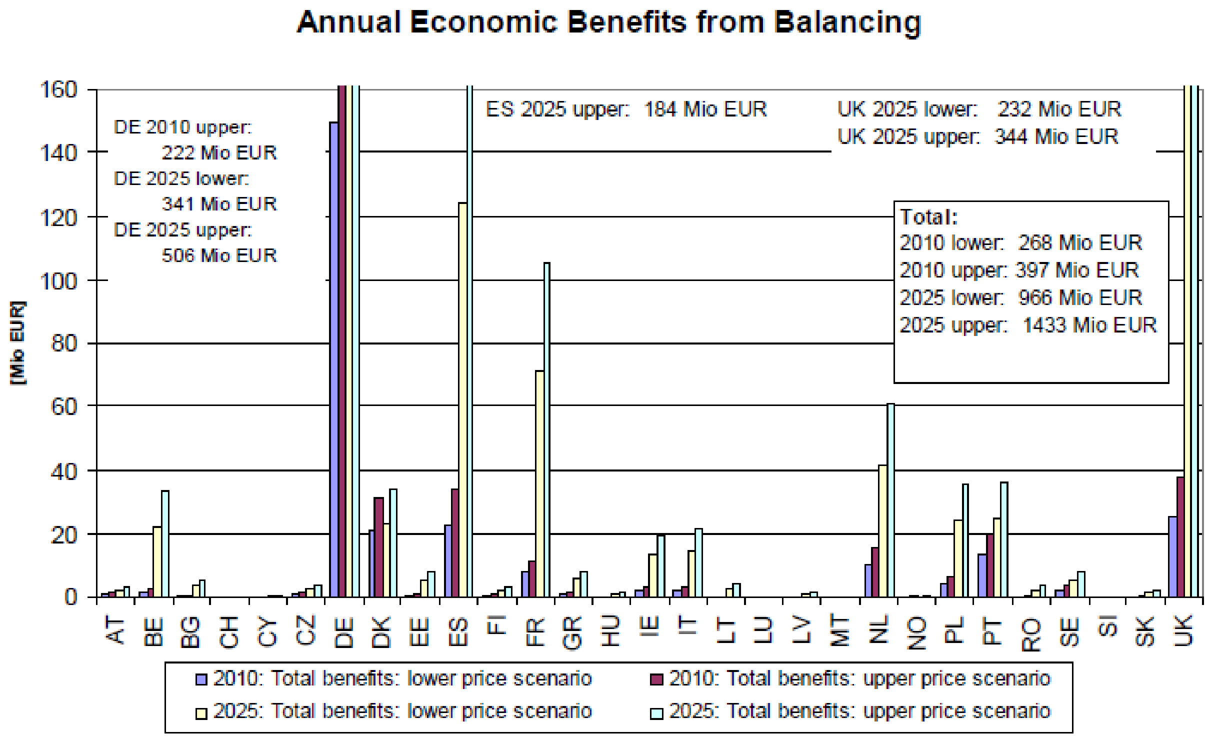

Figure 1.30 Total annual economic gross benefits from balancing capacity for WP 4 "best choice" DSM penetration rate in the EU27+NO+CH, 2010 and 2025 [54]

Besides the economic benefits, the most considerable nonfinancial benefits for all participants in energy chain are presented and explanations are given further. Some of them are exactly about the smart house and a part of them is relatively connected to the smart house.

In the article "Load management from an environmental perspective," the optimal scheme of non-economic benefits was presented (see Figure 1.31); moreover, different points of view were considered. For instance, smart appliances can bring benefits to customers, producers, retail companies etc. [55].

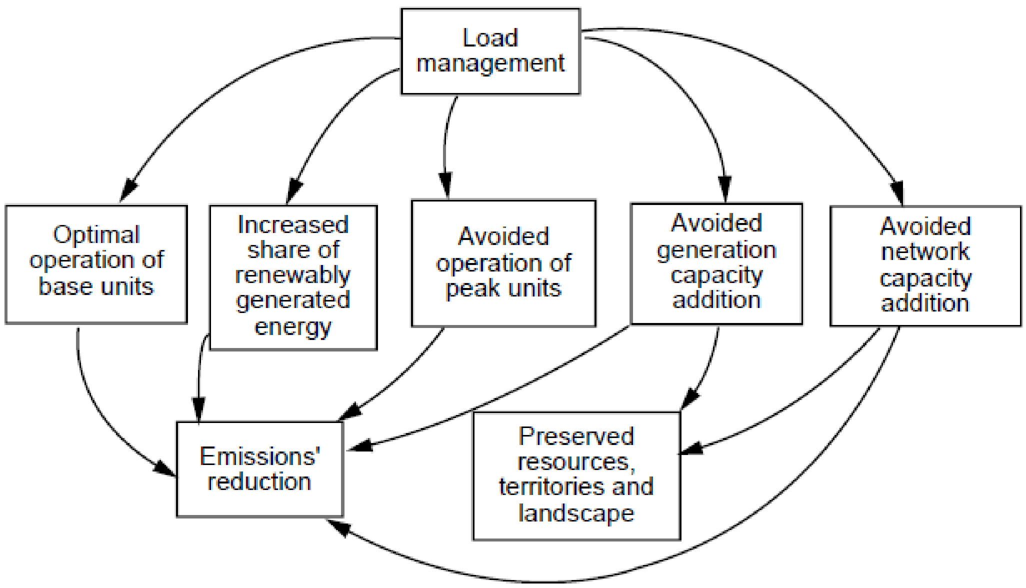

Figure 1.31 The ways load management could influence the environmental performance of electricity markets [55]

Firstly, it can be considered from the points of view of utilities, producers, and operators. In addition, it was concluded that the smart load management provides lower risks (when purchasing power on pot market and appearing of capacity problems), fulfilling goals established by environmental certification programs (e.g. ISO 14001), avoiding use of peak units and new network constructions. Secondly, from the point of view of society the advantageous ways of the load management globally are sustainable power supply, power accessibility, and equal conditions for all members of society, increasing share of the renewable sources and decreasing CO_2 emission [55]. The increasing share of renewable sources and CO_2 savings can be always transmitted into monetary values. In the article, the predicted annual economic gross benefits from balancing (including avoided CO_2 Emission Cost) are shown (Figure 1.32). The lower price scenario was based on a fuel price of 23.19 EUR/MWh and CO_2 emissions price of 22 EUR/t CO_2, whereas the upper price scenario was based on a fuel price of 34.4 EUR/MWh and CO_2 emissions price of 47 EUR/t CO_2 [54].

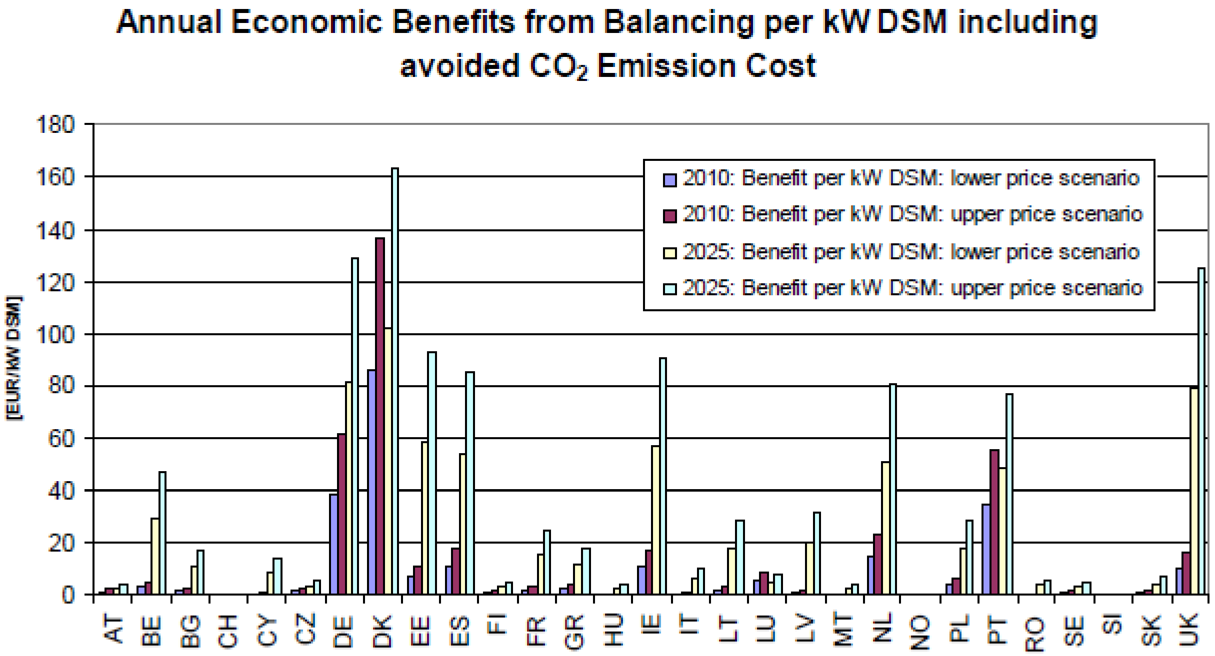

Figure 1.32 Annual economic gross benefits from balancing (including avoided CO_2 Emission Cost) per kW controllable DSM capacity for WP 4 "best choice" DSM penetration rate in the EU27+NO+CH, 2010 and 2025 [54]

Finally, for the customer, in the work [56] a user benefit mode was applied to evaluations of IT functions in the home environment (see Figure 1.33). The model shows three main ideas: usability, usefulness, and accessibility. These three concepts include other benefits for the customer.

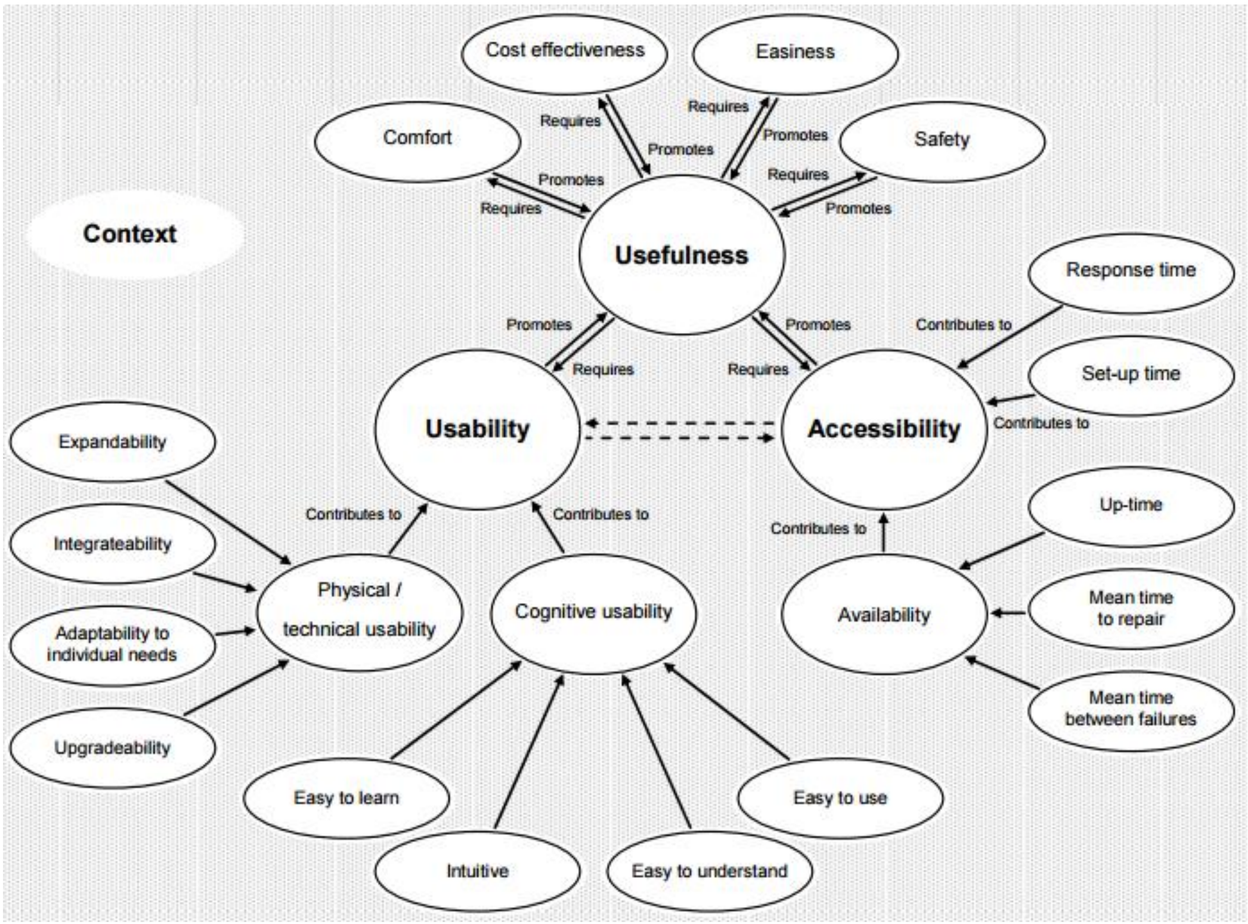

Figure 1.33 The map of the benefits [56]

To sum up, after all read references the list of noneconomic benefits can be presented below:

1. Comfort and convenience (easiness of use);
2. Safety and security [57];
3. Avoiding fuse problems [55];
4. Usefulness and individuality;
5. Easiness of load management and supervision;
6. Increased independency of energy supply;
7. Increased competition in energy markets;
8. Higher reliability and longer lifetime of equipment and the system in general;
9. Combination of separate functions in a single system;
10. Flexibility of technologies and possibility of introducing new functions;
11. Large variety of design and decoration components;
12. Time-saving;
13. Higher value of the building [58].

People always desire to feel comfortable and not have signs of discomfort as they go about their daily tasks and routines. Comfort is usually an optimal criterion for purchasing a particular product. Comfort gives expectation of productivity, healthy and enjoyment of inhabitants in the house. As for all non-economic benefits it is quite difficult to make generalized model for estimation of comfort. Myriad researches were conducted to measure comfort and respectively discomfort. Some measurement methods are based on objective outcomes using electronic equipment, while others are subjective and based on people's perception. There is a review, which was written by de Looze et al. [59] telling about measurements of comfort\discomfort for sitting on a chair and includes both ways. However, it does not depend on what it is considered because that theory can be applied for all stuffs, not only for chairs. The theory consists of three key components that have impact on comfort\discomfort: (a) the human, (b) the product, and (c) the environment. In addition, it can be developed more deeply: a) fit of the product to the person, (b) the features of the product itself, (c) the time spent with the product, (d) the subjective questions, and (e) the objective measurements. For all parameters, preferences should be applied and then a conclusion can be reached. But it is not so easy to generalize all smart houses. Each smart house built should be checked by all necessary measurements and analysis case by case. It can be easier to put one concept (one result) of estimated comfort for series of the smart houses into practice, but anyway, this task is quite complicated.

The smart house usually provides a home security system, which gives the household anytime access for controlling and monitoring the house. The security system can integrate cameras, alarms, triggers and so on. It means that the family and home are in safety [60].

It is also emphasized in the article "Load management from an environmental perspective" [55] that optimal load demand for the customer could help to avoid the unexpected fuse problems and it helps to service ensuring power specific accessibility customer and equal needs.

As it was mentioned in the list before, the smart house provides usefulness and individuality. Individuality can be demonstrated by meeting individual requirements of everyone. All optimal particular settings can be provided by a home automation complex for unique and the best desirable options [61]. Usefulness has almost the same function and it supports the user in fulfilling a task or satisfying a need [56].

Eventually, the last non-economic benefit is timesaving and there are a lot of approaches of calculating the monetary value of the time-saving, but almost all of them are dedicated to travel time savings. Anyway, it can be compared with the time-savings which are derived from the using smart technologies. The time value considerably varies depending on individual characteristics and how people value their time. The article [62] emphasizes the importance of people's decisions such as where to live, where to work, and how to travel between home and work and so on. The main idea of the valuating the time saved is to consider the opportunity cost of the time. This means that the person would accept to spend a certain quantity of money in order to save her or his time. Sometimes, the salary of the person can be taken as the opportunity cost of the time. Thus, the time-savings directly depend on the individual or alternative choices [62].

Actually, many non-economic advantages might be assigned into monetary values, but for that, different comprehensive techniques should be used.

One questionable benefit of the non-economic benefits is high value of the smart house. On the one hand, the smart house is usually supposed to be greener and it means that investing in the smart house is investing in the future. On the other hand, as practice shows the price of the modern technologies is more expensive now than in the future, it means that today investment in the future does not mean future return [58].

Disadvantages

The smart house provides all necessary controls and meters and it could allow criminals to get additional information. This information gives data about when a person leaves home and possibility to steal belongings. It means that the resident should pay for installation and a monthly maintenance fee, just as for a burglar alarm. This imbalance provides incentives against choosing the smart houses [53].

However, the prior disadvantage is the high price of all modern devices. Individuals who do not put enough value on the future will be less likely to invest in the technologies with a high initial cost as they do not take future benefits (in terms of, e.g., potential savings in the energy bill) into account [63].

2 Methodology of Evaluation

In the previous chapter, we discussed the main purposes and technologies of the smart house. There is a lot of evidence that the smart house has many advantages in comparison with a usual house. As a consequence of the implantation of high technologies into the house, it gives the smart house various benefits, from all points of view, such as the system, household, society etc. The most part of the benefits belongs to the nonfinancial benefits. Mostly, it is comprehensive to evaluate the monetary value of the nonfinancial gains, but it does not cancel the desire of people to use the new technologies in their houses. Conversely, the smart house should be considered from the financial part and all costs and savings should be calculated. The financial part is one of the significant factors that influence on the decision whether to build the smart house or not.

2.1 Introduction to economic evaluation methodology

Before appraising the project all necessary data should be gathered or examined. There are two types of project data: individual and general data in an economic environment. All these data are needed for the project apprising and decision-making.

Individual data includes:

- Investment cost;
- Evaluation period (lifetime of the project);
- Operating cost;
- Financing (equity, subsidies, bank loans etc.).

General data consists of:

- Inflation;
- Taxes (depreciation, policy);
- Discount rate;
- Exchange rate.

All these data are discussed in the chapter later.

The usual first step in the project economic evaluation is to determine the sources of an investment. Potential investor choose the project based on their economic (and other) constrains (investment limiting) and economic evaluation. Behind the definition of the investor, different points of views can be considered. In general, five different **types of the investors** are identified for the smart house project:

- system (“state”);
- private person (household),
- cooperatives,
- municipality,
- developers and business companies.

The project concept can be evaluated from the system point of view (or state) i.e. from the point of view of balance of total sources needed and the benefits generated. The other four investors have various rights, restrictions, and conditions to run the business and in this work, only two types of the investor and differences between them are discussed: the household and the business company.

When the business company or the household are choosing whether to build the smart house or not they both should adopt the long-term decision. The long-term decision is the decision, which is based on value-based measures, investment appraisal techniques, which are reviewed later, and with a time horizon greater than 5 years. It means the long-term decisions can involve large sums of monetary value, they have influence on all strategies and objectives, and making wrong decisions can lead to financial ruin for the investor [64].

2.2 Major Factors Influencing on Decision-Making

As it should be mentioned one of the dominant roles in appraising the project takes ratios and parameters. They should be considered very carefully. Moreover, in the case when there are two types of points of view, there are differences in calculating components of the evaluation model. The following main features are acknowledged further.

2.2.1 Financing of the Project

The ordinary person like a household can use his or her own money saved before to build the smart house or in most cases, people borrow money from a bank. It is commonly that banks offer households to receive special loan for building a house - mortgage. Mortgage is a form of a credit that is given to people with the following purposes: investment in real estate; purchase of real estate; construction of real estate; reimbursement (repayment) of an investment into real estate not older than 1 year already made by the client etc. [65]. Banks have diverse lists of offers with different conditions for a borrower. Next criteria are included when the banks check household's capability to take a loan: household's income; evidence of the income and in some cases the first deposit is required to put down; all necessary documents. The main rule of the consideration of the income is that the monthly payment with interest should take up no more than 50% of household's net monthly income. The standard requirement of the deposit amount is normally 10%-20% of the property price or less up to 0%. Maturities of the mortgage are also various from 5 years to 30 years. Usually an age limit of the potential household is from 18 to 65 years. The mortgages can be offered at a fix rate for a certain period, or variable rates. There is a tradeoff between higher interest rates offered with fixed rates, or lower interest rates with variable payment periods. Consequently, if the fixation period is longer, the borrower will have to pay higher interest rate and vice versa. Thus, the borrower has to fix the period and then there is a certainty, because rates cannot be changed. Some banks, but not all, require life assurance to be set up for them to grant the mortgage [66], [67].

In the Czech Republic is relatively low the interest on mortgages (see Figure 2.1) in comparison with Russia. Now the mortgage interest rate is near to 2%, that depends on the bank, which provides the mortgage, the person, who borrows, because the banks always check the credit story, age, income, insurance presence of the borrower. In addition, the rates are dropping for both fixed and floating types of the rate [68].

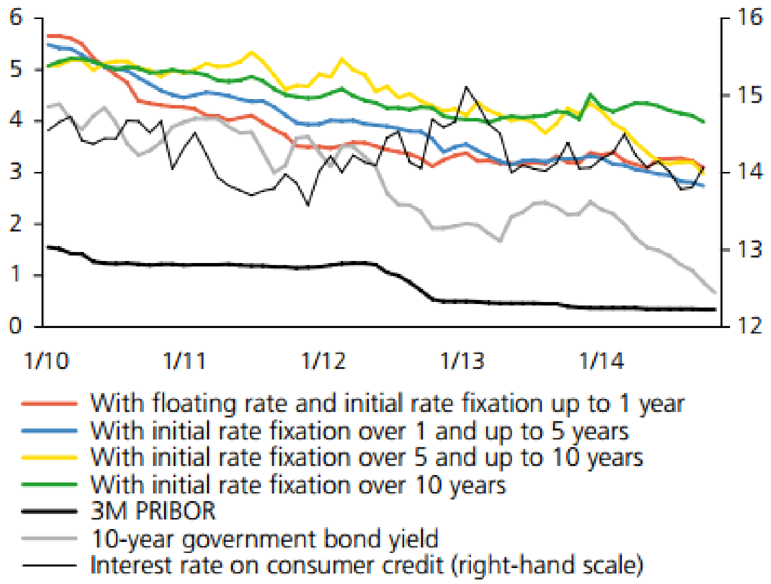

Figure 2.1 Interest rates of commercial banks on loans provided to households for house purchase [68]

The financing of the projects for the companies also can be provided by the bank loans. If the company takes the bank loan for the projects then it is decided by the bank which interest rate will be put on the loan, often it is almost 3% (see Figure 2.2) [68], [69]. Generally, the bank loan depends on the cash flows and creditworthiness of the company and the widgets or service that it sells [70].

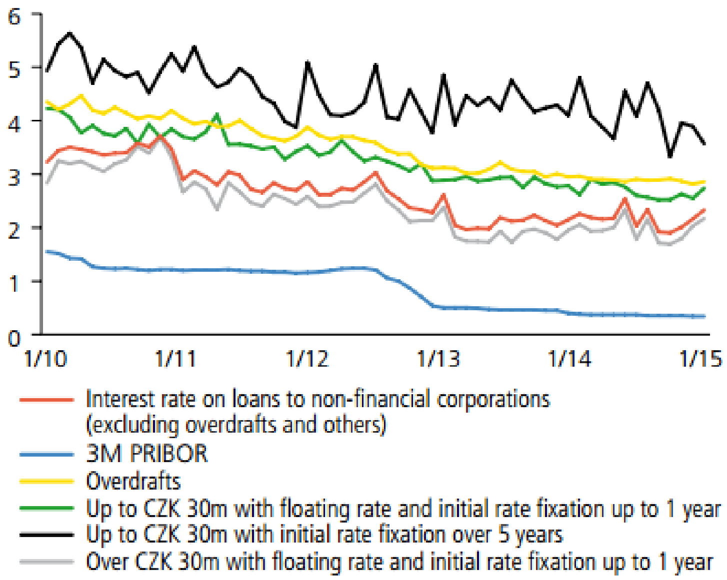

Figure 2.2 Interest rates on loans to companies [68]

In Russia in view of the circumstances, the requirements are quite the same as in the Czech Republic, but the interest of the mortgage is completely different and it can vary from 14% up to 25%. There are some social governmental programs, which decrease the rate for households, but nevertheless it does not compensate fully the interest rate, the minimum rate is equal to 11.9%. The same situation is for companies, now the rate on credit is approximately 18.5%, and it creates difficult circumstances for business to survive. In addition, the credit offers require many conditions to be fulfilled such as an initial payment, confirmed documents, an insurance etc. [71].

Undoubtedly, the state can also have a big role in the project development. Because the government sets regulations, requirements, obligations and support programmes. Subsequently, the support programs can be considered as external investments to the future smart house. The households and business companies can get grants and subsidies from the state. For instance, now in the **Czech Republic** several programmes are applied and recently the new Green Savings Programme has been started.

The Green Savings Programme objective is to increase efficiency of buildings and therefore to decrease greenhouse gas emissions. The Programme is direct subsidy programme and will support households to build houses with low energy demand and to install high-efficiency equipment [72].

Three basic support areas are mentioned in the Programme:

1. Reducing energy performance in existing family houses;
2. Building family houses with very low energy performance;
3. Efficient use of energy resources [72].

As applicants can be homeowners and house builders (individuals and legal entities). And they can choose appropriate materials from the given list of suppliers and technologies [72]. In the programme all standards and recommendations are given. Average level of subsidies is about 57%, but can vary depending on measures.

Furthermore, there are more programmes working as economic instruments for initiating the development of near to zero energy buildings (nZEB) in both residential and public sectors:

- Operational Programme Environment (OPŽP) is a direct subsidy programme and aimed at public buildings improvements (till 2013);
- Eco-Energy is a direct subsidy programme for existing commercial buildings improvements (average subsidy is 33%);
- Panel programme is a soft loans programme for existing apartment buildings (Average level of subsidy 2% of the interest rate reduction) etc.

The purposes of all subsidy schemes are to support people with improvements in buildings in order to decrease the dependence on fossil fuels and cut down the CO_2 emissions [46].

Moreover, it is expected that the subsidies for renovation will grow as it is presented in Figure 2.3 and it gives strong incentives for building nZEBs or refurbishment of old buildings according to standards. Following graph shows expected cumulative amounts of investment to the renovation regarding the overall building sector (residential and non-residential buildings together) for the three policy sets (differences between them are in obligations and subsidies), for both low and high energy prices and for periods till 2020 and 2030 in relation to base year 2008 [46].

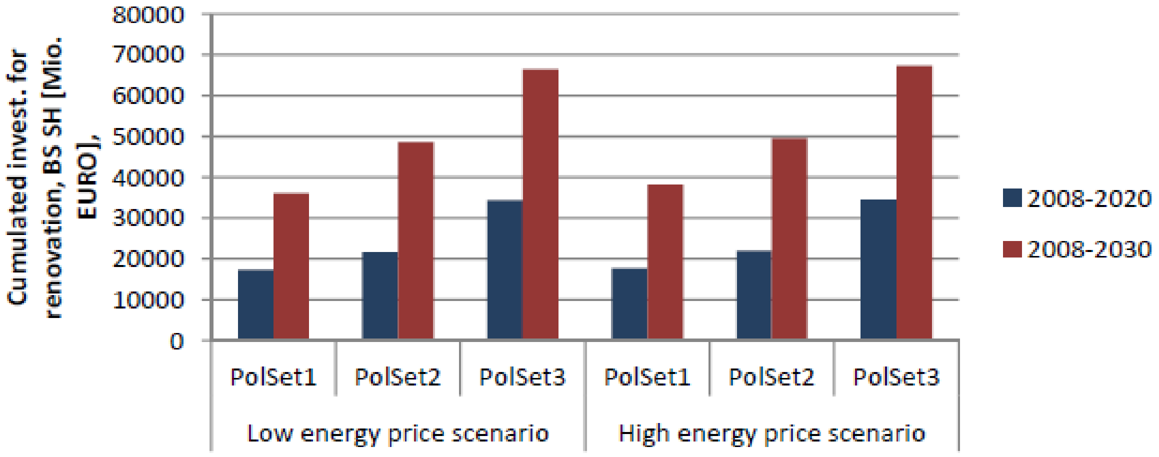

Figure 2.3 Cumulative investments for renovation [46]

In **Russia** there is also the Programme which is aimed at energy consumption reduction, the name of the Programme is "Energy saving and increase of energy efficiency for the period till 2020." The duration of the Programme is divided into two phases: Phase I (2011-2015) and Phase II (2015-2020). "Federal law on energy conservation and energy efficiency" supports the Programme [73].

The main objectives of the Programme:

1. Significantly reduce specific energy losses;
2. Reduce the energy intensity of produced goods;
3. Develop an appropriate infrastructure to coordinate energy efficient management and monitoring resources;
4. Marketing of ideas and mechanisms aimed to increase the implementation of energy efficient opportunities;
5. Stimulate the scientific and engineering communities to implement best available Russian energy efficient techniques and technologies;
6. Develop a mechanism for stimulating the activity of energy service companies;
7. Increasing the energy use efficiency in industries and residential areas etc. [73].

The expected results of the Programme are: economy of primary energy, gas, electricity, thermal power; decreased greenhouse gas emissions; increased energy potential and so on [74].

2.2.2 Value Added Tax (VAT)

The VAT is generally due on a supply of goods or services with the place of supply in a country and in our case, it is the Czech Republic carried on by a taxable person in the course of economic activities. The taxable supply usually means goods or services provided for a consideration. However, certain transactions carried out for no consideration represent also a taxable supply, e.g. private use of business assets and provision of gifts [75].

Regarding to the Czech Income Tax Act, which regulates the taxation of individuals, the private person as an end-user (final consumer) pays the VAT. The standard rate of the VAT in the Czech Republic as from 1 January 2013 is 21% and 15% for permanent living [76]. In addition, the property as the smart house means that the owner of land and buildings are liable to an annual immovable property tax.

The business company in our case is considered as a contactor or a builder of the smart house. It provides everything including all aspects or stages of the project. At the end of the project they sell ready-for-usage houses. The VAT is not paid because it is ultimately borne by the end-user. Companies are obliged to add VAT to the prices of their goods or services and to invoice their customers accordingly [77]. Generally, the companies firstly pay the VAT, but at the end of the taxable period, they can deduct the VAT and thus they return the money paid. However, if it is produced abroad the Czech Republic the company has to pay the VAT.

The VAT in Russia in most cases is 18%. The VAT is charged on goods and services in Russia as well as on imports into Russia. The threshold for the VAT registration is a turnover exceeding RUB 2 million in the previous three months. The VAT returns are made once in a quarter. The payment is made up until the 20th day after the current quarter, paying the VAT due by up to three installments [78].

2.2.3 Income Tax

The income tax is a tax that governments impose on financial income generated by all entities within their jurisdiction. By law, businesses and individuals must file an income tax return every year to determine whether they owe any taxes or are eligible for a tax refund. The income tax is one of key sources of funds that the government uses to fund its activities and serve the public [79].

The tax base is calculated from the taxable profit/loss shown on the relevant financial statements, prepared according to the Czech accounting legislation.

There are two different types of income taxes: progressive and flat. In the Czech Republic, the flat income tax is employed. A corporate income tax rate is 19% for businesses. A corporate income tax rate of 5% applies to investment funds, unit funds and pension funds [77]. In comparison, in the Russian Federation the income tax is equal to 13% for residents and 30% for non-resident taxpayers [80].

On the part of the household there is no any income taxes connected with the house, because he or she is not considered as a generating profit entity.

The income tax is included into Cash Flow Statement, Income Statement and current liability/asset in Balance Sheet that is why it is a crucial component of the NPV calculating.

2.2.4 Inflation

Inflation has one of the strongest effects on the investments and interest rates. Inflation has impact on your money and value of them especially if you have constant income and inflation rate is increasing. Certainly, it is not so important if the economy of the country is growing up, company’s revenue is increasing and consequently earnings also are going up. However, it is not the same situation if there is stagflation in the country. Thus, inflation of the country should be taken into account in any cases during the analysis of investments, payback periods, calculating of NPV etc., because it is one of the crucial components of the decision-making process regarding to the project. The right estimation of the inflation will not lead to wrong thinking about value of the company, purchasing power and choosing the proper interest rate [81], [82].

Inflation can be explained by miscellaneous causes and several of them are presented below:

1) The first cause of inflation is the expended money supply that outpaces economic growth in the country. Because the value of money is determined by the amount of currency that is in the circulation and the public's perception of the value of that money. The value of money can decreased when the Federal Reserve decides to put more money into the circulation at a rate higher than the economy's growth rate. Thus, this devaluation will force prices to be increased because each unit of currency is now worth less.

2) The second cause of the inflation can be a demand-full effect. Due to increase in wages, the demand for products and services is boosted; subsequently people have raising products' prices and the inflation.

3) The next significant factor is the cost-push effect. It is said that when companies are faced with increased input costs (raw goods and materials or wages), they will compensate their profitability by increasing the prices for an end-consumer [83].

There are also other causes of inflation as debts of government, policy and so on.

In the inflation report of the Czech central bank, information about net inflation and adjusted inflation can be found. Because in 2014 fuel and food prices switched from modest growth to annual decline the annual net inflation went down slowly to 0.8% on average (Figure 2.4). In comparison, adjusted inflation excluding fuels continued to go up because of the pass-through of the weakened exchange rate of CZK and a slightly inflationary effect of the real economy and the labor market [68].

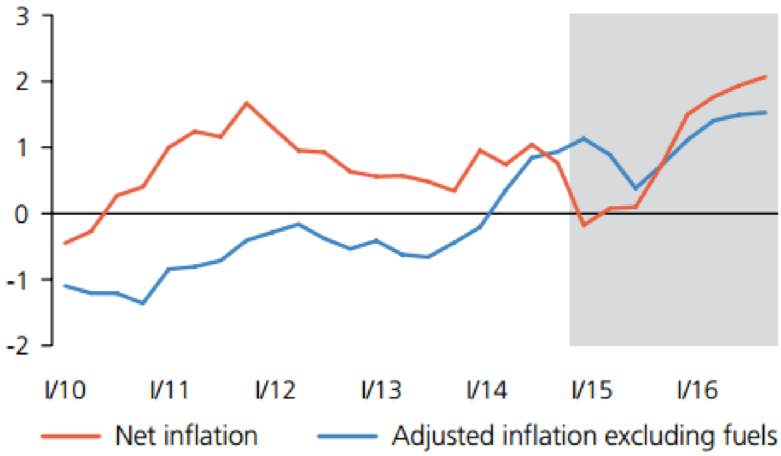

Figure 2.4 Net inflation and adjusted inflation excluding fuels [68]

Inflation situation in the Czech Republic is shown in Figure 2.5. During last 5 years, inflation in the Czech Republic has been tending to the stable rate. In 2014, inflation was below the forecast over the entire period. In 2015, inflation rate is equal to 0.1%.

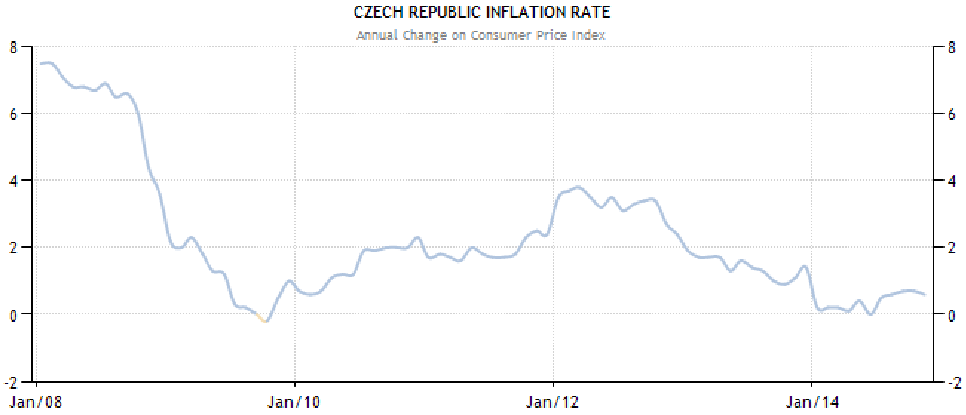

Figure 2.5 Czech Republic inflation rate [84]

The forecast for inflation in the Czech Republic is presented in Figure 2.6. The forecast expects inflation to be at zero or slightly negative levels in 2015 and then rise to the 2% target in 2016. The overall upward pressures on consumer prices will almost disappear in the near term, as a decline in producer prices in the euro area coupled with a fall in global prices of energy commodities will result in a substantial decrease in costs stemming from import prices [68].

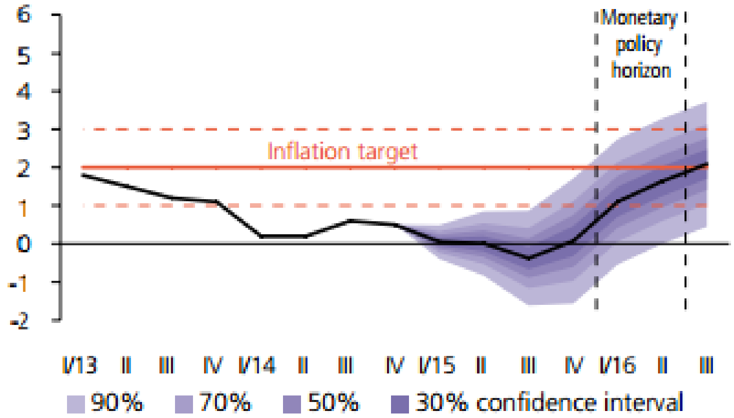

Figure 2.6 Inflation forecast for the next year [68]

The situation in Russia is completely different and unstable, the inflation in Russia missed the target inflation rate last year (about 7%) and it reached the value of 11%. It was caused by policy of the Russian Government, myriad sanctions and significant drop in oil prices and so on [85]. Moreover, it is continuously climbing, in February the inflation value was 16.7% (see Figure 2.7) [86]. There are many economic forecasts for the Russian inflation, but they are different from each other and vary from 7% up to 20%.

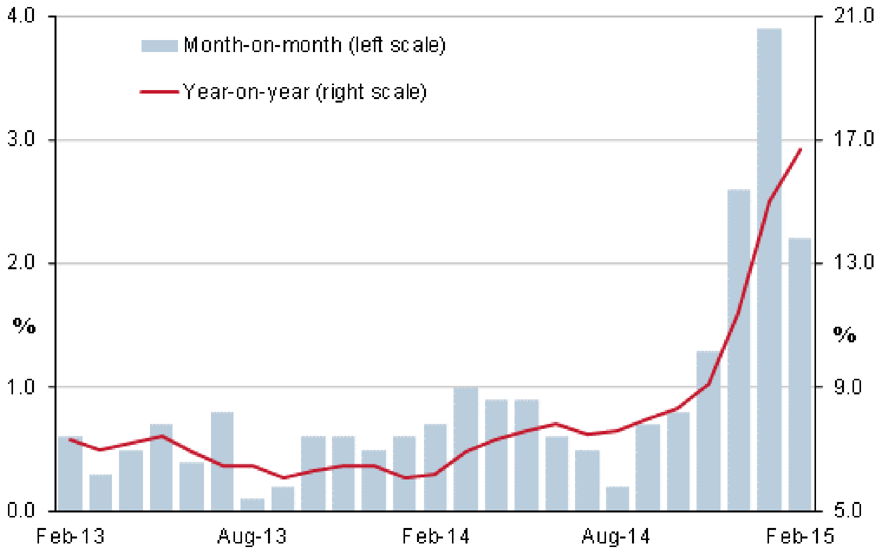

Figure 2.7 Russian inflation chart [86]

Escalation rate

It should be mentioned, that the escalation rate is an important factor when the project assessment is carried out. Escalation refers to a continual growth in price levels of specific commodities, goods, or services driven by underlying economic conditions. Escalation reflects changes in price-drivers such as productivity, technology, environment and politics, as well as changes in market conditions such as high demand or supply, labor shortages, profit margins and so on [87] , [88].

Escalation also includes the effects of, but differs from, inflation, which is a general change in prices caused by debasement of the value of a currency. Therefore, escalation deals with specific goods and services, while inflation is concerned with a basket of goods and services and involves average change.

From an estimator's perspective, escalation it is a unique "risk" cost that must be estimated. Complicating the issue, price escalation varies for different capital project components such as office and field labor, bulk materials, fuel prices, and equipment; it also varies by region and procurement strategy. Just as forecast price indices can be used to estimate future escalation, historical price indices can be used to normalize past project estimated or actual cost to a current year basis. Escalation is what effects the actual costs and revenues that will be realized for a project, so escalation of costs and revenues is the consideration that must be accounted for in economic evaluation of investment [87] , [88].

2.2.5 Discount Rate

The discount rate is the rate at which future values in the financial analysis are discounted to the present. It is often difficult to determine accurately all inputs of the project. In addition, the discount rate is one of the crucial parameters in appraising the project and it is often that the decision of project accepting or rejecting depends on the value of the discount rate [89].

The discount rate reflects the opportunity cost of capital in the long term, defined as 'the expected return forgone by bypassing other potential investment activities for a given capital', but may also be referred to as the required rate of return, and the cost of capital. There are many theoretical and practical ways of estimating the reference rate to use for the discounting of the financial analysis [89].

Several techniques are presented for calculating the discount rate.

1) For normal-risk or average-risk projects, the appropriate discount rate is the company's cost of capital, k, which reflects the risk of the company. If the risk associated with the project differs from that of the company, managers should adjust the discount rate for the risk. In practice, managers cannot estimate future cash flows with absolute accuracy. A range of possible outcomes is likely for each cash flow. As a result, the payoffs associated with capital expenditures are risky. An important part of the project evaluation is measuring the risk associated with the cash flows and incorporating this risk into the evaluation process. Ignoring or improperly accounting the risk can result in improper investment decisions, which in turn can reduce the value of the company [89].

Any decision-making task includes the necessity of taking into account the problems of the risk. The risk is inherent in most decisions. The risk in finance is defined in terms of variability of actual returns on an investment around an expected return, even when those returns represent positive outcomes. Usually the more benefits are desired a riskier decision should be taken and it is visible when making investment choices. However, there is one more aspect of the risk and that is a connection of the risk with innovation. As it happens, the innovations are designed with the risk of denying. In most cases, the innovations are developed to exploit the risk for the higher returns. Thus, the risk taking decision is a part of a success [89].

In capital budgeting, the risk refers to the uncertainty of a project's future profitability. Financial theory typically views decision makers as being risk averse. The risk averse decision maker considers a risky investment only if it provides compensation for the risk through a risk premium. One of the main ideas of considering the project is to forecast both costs and benefits to calculate for example NPV, but it is rare to forecast all aspects with certainty. Analysts can sometimes base their risk analysis on historical data, but most of the time they cannot. Thus, risk analysis in business usually involves subjective judgments [89].

A capital budgeting project can be looked from different points of contribution to a company, to a shareholder's portfolio or it can be a stand-alone unit (see Figure 2.8).

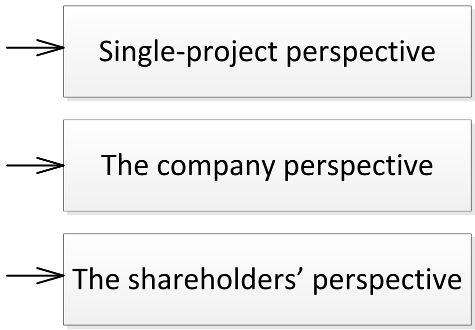

Figure 2.8 Different points of view of contribution to a company

Often managers focus on a single-project perspective because it is the easiest among the others perspectives. Because of the existence of a high correlation among all three perspectives, the stand-alone risk is a base for the others types of the risk [89].

a) Single-project Risk. The priority issue is to calculate a project's expected future cash flows or returns and it consists of three components: expected value, standard deviation and coefficient of variation. The input in calculating the standard deviation is the expected value, E(X), which is the probability-weighted average amount of all outcomes.

The expected value:

$$E(X) = \sum_{i=1}^{n} p_i X_i;$$

The standard deviation:

$$\sigma = \sqrt{\sum_{i=1}^{n} p_i [X_i - E(X)]^2}.$$

The small standard deviation gives little variability around the expected outcome and subsequently less risk and vice versa.

The coefficient of variation:

$$CV = \frac{\sigma}{E(X)},$$

Where CV is the measure of the relative risk or the risk per unit of return (expected value) [89].

Two popular approaches are used for making conclusion over the project: sensitivity analysis and scenario analysis. These techniques do not provide decision rules for making accept-reject decisions. The first one does the research on a change in any input variable that affects cash flows or a firm cost of capital will affect the net present value (NPV). It helps managers to find critical variables, which are useful for budgeting. The second technique is a variation of the first and it is a risk analysis technique used to examine what happens to profitability estimates such as NPV under several different sets of assumptions. Unlike sensitivity analysis, scenario analysis measures the impact on NPV of simultaneous changes in input variables and reflects a range of outcomes as reflected by a probability distribution. Three scenarios are usually considered: optimistic (when outcomes are better than the most likely), most likely and pessimistic. That provides managers with the ranges/boundaries of NPV [89].

b) Company Risk. Taking the project can considerably influence on the company, even though it can lead to bankruptcy. To make the risk less managers can diversify the company's portfolio by adding projects with low positive correlations (correlation coefficient). The risk measure for the portfolio is generally the standard deviation of the probability distribution of the expected returns.

c) Market Risk or the shareholder's perspective. The following equation is useful to understand the risk: Total risk = Systematic + Unsystematic risk. The systematic risk or market risk is the variability of investment returns caused by market fluctuations and it is undiversifiable. The second component is the risk connected with a particular company and it can be reduced by contribution of various shares in the portfolio [89].

For providing accept-reject decisions to managers or shareholders, the capital asset pricing model (CAPM) is used. The CAPM measures the relationship between the risk and the required rate of return for assets held in the well-diversified portfolios. The CAPM is an expectational model that contains predicted future values [89].

The CAPM equation:

$$k_i = R_f + \beta_i (R_m - R_f),$$

where k_i is the return on project i; R_f is the risk-free rate of return; R_m is the expected rate of return on the market; β_i is the beta coefficient of project i; and $(R_m - R_f)$ is the risk premium. The CAPM model has many assumptions: perfect capital markets, the ability of investors to borrow and lend unlimited amounts at the risk-free rate. The CAPM is applied for determining the required return for a company and hurdle rates for corporate investments. As the risk-free rate of return financial managers operate with yields on government securities with the same maturity as the project. The next part is the market return and there are two variants for how to estimate this value: 1) basing on historical data; 2) reading investment advisory surveys. A project's beta evaluates the sensitivity of changes in the project's returns to changes in the market's returns. The procedure for estimating beta, basically uses comparable companies' data (pure-play method). If the company uses debt in its capital structure, then beta should be adjusted by the following formula:

$$\beta_u = \frac{\beta_{pp}}{1+(1-T_{pp})\frac{D_{pp}}{E_{pp}}},$$

where β_u is the unlevered beta for a company or project; β_{pp} is the levered beta of the pure-play company; T_{pp} is the marginal tax rate of the pure-play company; and D_{pp} and E_{pp} are market values of the debt and common equity of the pure-play company [89].

The weighted average cost of capital (WACC) is the weighted average of the costs of debt and equity of the company. WACC is referred as an average risk of the company and can be used for a project in case if the project profile is similar to the company profile. If the company consists of various divisions, the divisional cost of capital is likely to differ from the company's WACC depending on the riskiness of the division. Since a firm uses debt and equity capital, WACC represents a mixture of the returns needed to compensate both creditors and stockholders.

$$WACC = \sum_{i=}^{n} w_i k_i = r_e \cdot \frac{E}{D+E} + r_d \cdot \frac{D}{D+E} \cdot (1-t),$$

Where w_i is the percentage of total permanent capital represented by capital source i; k_i is the after-tax cost of each new capital component and i is a type of new capital; r_e is the discount rate, r_d is the interest rate, E is own capital, D is the loan capital; t is corporate taxes [89].

The WACC can measured also by different ways and it depends what it would be as equity: book value weights, market value weights or target value weights. The book value weights are taken from firm's balance sheet, the market value weights method is calculated by multiplying price per share by the number of shares and the target weights represent the best estimate of how the firm, on average, will raise money in the future [89].

Because the risk was mentioned we can return to the NPV model. There are two approaches for adjustment of the NPV relatively to incorporating time and risk: risk-adjusted discount rate (RADR) method; and the certainty equivalent (CE) method. The RADR method is implemented when the project's risk increases exponentially during all time and the CE method is applicable when a project's risk varies over time [89].

1) The RADR method

Instead the simple value of discount rate the adjusted discount rate (k*) is used in this model.

$$NPV = \sum_{t=1}^{T} \frac{CF}{(1+k^*)^t} - I_0$$

All rules of accepting the project are the same as for the NPV without any adjustments. As for the usual discount rate the difficulties with determine the appropriate discount rate with adjustment are. Two risk-adjusted discount rates can be adopted: adjusted cost of capital, k, for risk and the CAPM.

a) Adjust k for risk:

$$k^* = R_f + R_1 + R_2$$

Where $k = R_f + R_1$ is the required rate of return or the company's cost of capital and R_2 is a project risk adjustment.

Usually the project risk adjustment is again chosen by manager's experience, subjective judgment and using historical data, of course, the manager can use sensitivity and scenario analyses, but they will not give the full picture. Moreover, the hypothetical risk adjustments for project risk classes can be applied. If it is a replacement project, then the risk is similar to the firm's current level of risk. If it is an expansion project with already existing or related products and markets, then to the company's risk 3÷5% of additional level of risk is come to. And the last kind of the risk class adjustment is about an expansion of a completely new project; in this case to the current firm's risk the risk premium of 6÷10% is added [89].

b) Using the CAPM allows us to represent coefficients R_1 and R_2 in the form of $\beta_i(R_m - R_f)$.

To sum up, the RADR method is easy to use and interpreter the obtained results so it give the understandable decision about accepting or rejecting the project, but as usual there is a problem connected with finding an appropriate risk-adjusted discount rate and the method makes the discount rate be the same over the project's life [89].

2) The CE method

In comparison with the previous method the CE method adjusts not the discount rate, but it makes separate corrections for time (by using R_f as the discount rate) and risk (by converting risky cash flows into certain cash flows). Again, the question arises above the converting risky future cash flows to certainty equivalent cash flows. A certainty equivalent cash flow is a smaller cash flow that the decision maker would accept with certainty in exchange for a risky cash flow. The formula below describes the CE method.

$$NPV_{CE} = \sum_{t=1}^{n} \frac{\propto_t CF_t}{(1 + R_f)^t} - \propto_0$$

where CF_t is the expected net cash flow in period t; α_t is the certainty equivalent factor associated with the risky net cash flows in period t and it is equal to the ratio of a certain return to a risky return; α_0 is the certainty equivalent factor associated with the initial investment, I, in period 0; and R_f is the risk-free rate of return assumed to remain constant over the project's life. The certainty equivalent factor can vary in the range from 0 to 1 for the cash inflows, when the cash inflow is known certainly then α=1 therefore the factor is increasing when the risk is decreasing. But for the cash outflows it is greater than 1 [89].

In summary, the CE method includes time and risk in the model, it is not so complicated model, but the predicting the CE factors can be difficult and the CE method is more sophisticated than the RADR method [89].

From the point of view of the household, the benchmark of the discount rate is an opportunity cost. It means that the private person should think what he or she can do with the money, find all possible investment ways, and choose the best one. For instance, it can be purchasing government bonds or keeping the money in a bank account, but the household's opportunity costs are considerably different from the company's opportunity costs. In Figure 2.9 the Czech government bond yield curve is presented. The positive slope of the government bond yields decreased noticeably during one year. For example, ten-year government bonds were sold at an average yield of 1.2% in January [68].

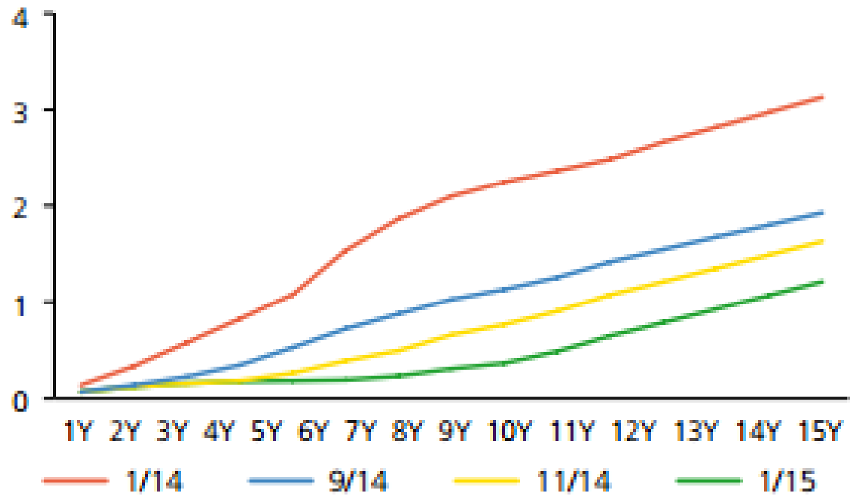

Figure 2.9 The Czech government bond yield curve [68]

In Russia, the yield of the government bonds depends on the duration considerably and varies from 9.81% up to 14.35% (Figure 2.10). For instance, in April the Russia Government Bond 10Y decreased to 11.03% from 12.12% in March of 2015 [90].

Figure 2.10 The yield curve of the Russian Government Bonds [91]

To sum up, the private person has limited opportunities to invest money in comparison with the business company. Typically, the discount rate for the private person can be derived from the government bonds, because they have an advantage of choosing the maturity of the bond, it can be from one month to decades. In our case, the appropriate discount rate for the apprising the project for the private investor is not more than 3% (in the Czech Republic). From the point of view of the business company, the appropriate discount rate is usually 6÷8%.

2.2.6 Tax Shield

The possible method of decreasing income tax is a tax shield. The tax shield is an allowable deduction and can be caused by applying bank interest, charitable donations, depreciation, and amortization. The tax shield is possible to use for households (mortgage) -

deduction of the interest paid from household's tax base (maximum of CZK 300,000 per year). Moreover, for companies usually tax shield is applied for the depreciation [92].

Depreciation

Tax depreciation is different for tangible and intangible assets; it depends on the investment value and depreciation period. The Czech Income Tax Act sets forth the definition of the tangible assets and the intangible assets. The tangible assets are any buildings/constructions and movable assets with an input price above CZK 40,000 whose useful life exceeds one year (moveable assets). Land is not depreciated for tax purposes. The tangible assets are divided into six depreciation categories with different depreciation periods (Table 2.1). The classification of the tangible assets by depreciation category is shown in following Table 2.2. The company can use either straight-line or accelerated tax depreciation for tangible assets. However, once a method of the tax depreciation is selected for a particular asset, this method may not be changed later. If a tangible asset is sold/liquidated during a tax period, half of the annual tax-depreciation charge can be claimed in such tax period (together with the tax residual value of the disposed asset). In case of partial liquidation of asset, special regulations are applied [92].

Table 2.1 Characterization of depreciation categories [92]

Depreciation category	Minimum depreciation period (in years)
1. computers and office equipment, measuring and control devices, etc.	3
2. cars, buses, machinery and equipment, lorries and tractors	5
3. metal structures, motors, metal products, machinery and equipment for the metals industry, ships, lifts, cranes, electric motors, ventilation and cooling units, etc.	10
4. electric mains, gas and oil pipelines, water mains, pillars, chimneys	20
5. buildings (factories), bridges, roads, tunnels, water works, cableways	30
6. buildings (hotels, administration/business/shopping centers)	50

Table 2.2 The straight-line and accelerated methods of depreciation [92]

	Straight-line depreciation			Accelerated depreciation		
	Annual depreciation rates (%)			Coefficients for accelerated depreciation		
Depreciation category	first year	subsequent years	for increased input price	first year	subsequent years	for increased input price
1	20	40	33.3	3	4	3
2	11	22.25	20	5	6	5
3	5.5	10.5	10	10	11	10
4	2.15	5.15	5.0	20	21	20
5	1.4	3.4	3.4	30	31	30
6	1.02	2.02	2	50	51	50

The relation between the depreciation and the inflation is important. The depreciation is a stable parameter and if inflation value is high, the depreciation significance is low.

Bank interest. Using the loan capital instead of equity capital gives the opportunity to deduct the value of the bank interest. The mortgage also provides an interest tax shield for a property buyer because interest on mortgages is generally deductible. The interest tax shield may encourage the company to finance the project through debt [93].

2.2.7 Electricity Prices

Next factor, which has influence on the cash flows, is prices on electricity. They are completely different in both countries. But they have the same tendency of climbing up every year.

Czech power prices are fully liberalized and it gives every consumer the legal right to choose electricity supplier [94]. The price of electricity consists of several parts: energy, supply, networks, taxes, and levies. As it is shown in Figure 2.11 the energy-supply cost component is declining and the network cost component is steadily rising. Nevertheless, the price of electricity in spite of declining cost of electricity generation is moderately going up for households (see Figure 2.12) [95], [96].

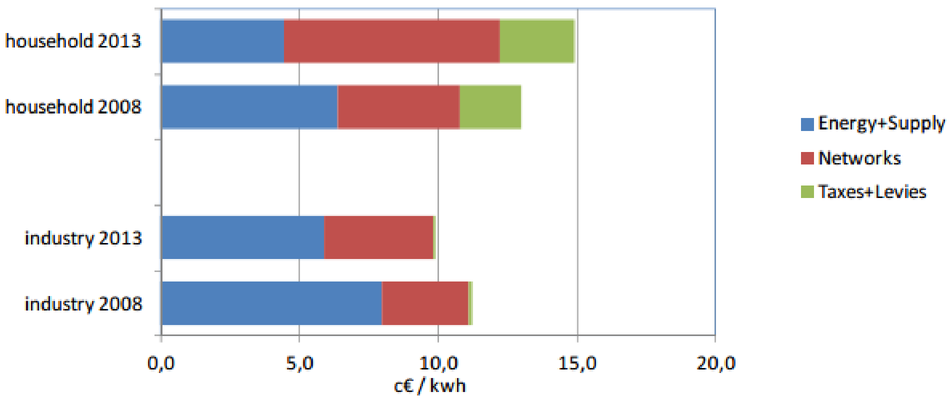

Figure 2.11 Electricity price change by component 2008 – 2013 (source: Eurostat, energy statistics) [95]

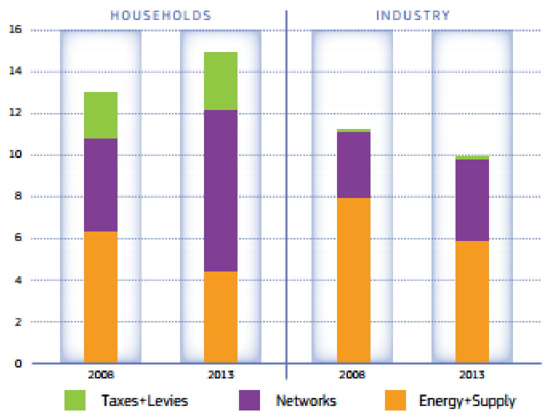

Figure 2.12 Retail prices of electricity in the Czech Republic (in €/kWh) [96]

A little another situation is in Russia. The share of electricity in Russia traded at free market prices was increased according to the liberalization schedule, what gives the consumers a competitive market. By 2011 all the electricity, except for households' consumption, which hovers around 10%, had been traded on liberalized wholesale electricity market. By 2014, electricity tariffs for households had been raised to economically justified level, assuming that operations related to production, transmission, sale, and dispatch are performed with a minimum rate of return. The electricity tariffs for households will remain regulated until 2015–2017, and by 2017 electricity supplies for all the consumers are planned to be liberalized [97].

The tariffs for households in Russia are considerably lower (in two times or more) than in the Czech Republic and they depend on Federal Districts (see Figure 2.13) [98].

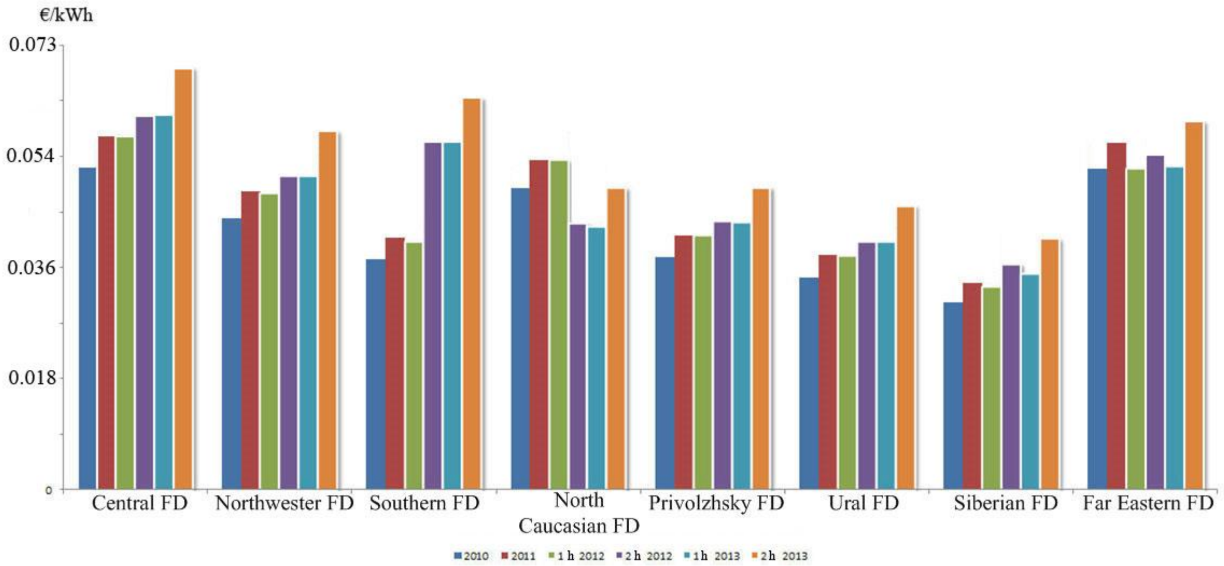

Figure 2.13 Retail prices of electricity in the Russian Federation depending on Federal Districts (VAT is included) [98]

The rising electricity price in both countries stimulates the households to decrease consumption and one of possible way of that is to implement modern technologies.

2.2.8 Exchange Rate

Exchange rate can cause the uncertainty in the decision-making process and price drift by exchange rate volatility. Accordingly, monetary value will affect investment expenditures and revenues. Therefore, the threshold at which exchange rate the investment is undesirable and influence of exchange rate on investment (if it is only misalignments or cancelling) should be determined [99]. The project can be very dependent on exchange rate due to imported equipment or foreign investments. If currency depreciates, then its value goes down relatively to the value of another currency and these movements have effects on the project [100]. Overall, the standpoint of the investor should be identified and from where equipment for the project will be acquired.

For example, the Czech currency reflects slightly to euro changes (Figure 2.14).

Figure 2.14 Exchange rate EUR/CZK

In the case of Russia, the ruble value sharply declined (even reached 67% drop) relatively to the value of euro in 2014 (Figure 2.15). The reasons for that were a slowdown of Russia's GDP growth rate since 2012, record numbers of the capital outflow from Russia, drop in oil prices, policy etc. [101].

Figure 2.15 Exchange rate EUR/RUB

The depreciation of the currency usually leads to declining of the purchasing power of people. If a person consumes more imported goods, then his or her purchasing power decreased considerably. On the other hand, it can be a positive sign for the company, which exports goods to other countries, because it can get more money due to fluctuating rate. Therefore, the project with imported goods is always depending on the exchange rate of the currencies.

2.3 Apprising Methods for Estimating the Project

2.3.1 The NPV Approach

The process of analyzing the long-term decision-making includes myriad impacts. That process is called investment appraisal and refers to objective function (present value) [102].

Present value is the current worth of a future sum of money or stream of cash flows given a specified rate of return [103]:

$$PV = \sum_{t=1}^{T} \frac{NCF_t}{(1+k)^t} + \frac{TV_t}{(1+k)^t}$$

Where NCF is net cash flow (it is the difference between a company's cash inflows and outflows in a given period), k is the discount rate and TV is the terminal value (it is the value of an asset at a specified, future valuation date), T is the time of the project.

Using the present value gives us an opportunity to calculate the following appraising methods for the investors: a net present value (NPV), this approach is a superior in comparison with the rest of them such as a profitability index (PI), an internal rate of return (IRR), a modified internal rate of return (MIRR), and a discounted payback function (DPP) [103].

The correct method of evaluation of economic effectiveness of the project is the NPV method. The NPV method considers how much it will cost to launch and run the project and how much money the project will generate. It is a crucial component of the process to determine the monetary advantages and disadvantages of undertaking the project [104]. This method simply calculates the sum of the discounted cash flows associated with the project including initial cost of the project I_0:

$$NPV = \sum_{t=1}^{T} \frac{CF_t}{(1+k)^t} - I_0$$

The NPV is an absolute and the most obvious investment appraisal technique for assessing an investment and measures the increase of value due to the investment. There are three types of results based on which the investor can make a conclusion of undertaking the task or not:

1. The project has a positive NPV. The investor could accept the project. And that means that the value of the company will increase by the amount of the NPV. Even the project with the NPV of CZK 1 will be acceptable if all calculation procedures are accurate. The result of the NPV>0 means that the investor gets the rate of return higher than in cases of the alternative investments.
2. The NPV is equal to zero. The investor should be technically indifferent to the project. Of course, the investor will return all money spent or in other words the project will earn its required rate of return; the risk will be taken into account and therefore everything will be compensated, but it will add nothing to the wealth of the investor.
3. The NPV is less than zero. A rational decision maker will reject the project because it causes decreasing the wealth of the investor [89].

Obviously, getting the positive NPV is not only a casual event; it is usually a consequence of a competitive advantage of a technology or a product. Moreover, in reality mistakes and forecasting biases may happen, for instance overtaking or undertaking cash inflows, and in such cases the decision maker should adjust or correct all mistakes made [89].

Five main advantages of the NPV approach are presented:

1. The NPV approach helps to derive the full picture of project's expected benefits or contribution and maximize the investor wealth.
2. The NPV method takes into account the time value of money.

3. Profitability and risk of the project are given high priority. The NPV implicitly assumes that the firm can reinvest all of a project's cash inflows at the project's required rate of return throughout the life of the project.
4. The approach offers theoretically correct accept-reject conclusions for projects based on their effect on the investor wealth.
5. The method includes the opportunity cost, thus all real options are considered within the investment [89].

There are also some disadvantages of the NPV approach:

1. It does not show the relative profitability. Therefore, investors cannot see the difference between NPV=100 CZK attained from the project with CZK 200 initial investment and CZK 20,000 respectively [89].
2. There is the sensitivity of the NPV value to the discount rate [105].

The other three approaches are considered briefly as the supplementary methods.

2.3.2 The PI Approach

The next approach that is based on CF simulations is the PI. The PI shows the ratio of the present value (PV) of the cash flows to the value of the initial investments. It means that the investor can estimate the relative profitability of the project. This approach is the same as the NPV approach, because it uses the same data. The equation of the PI approach can be determined as:

$$PI = \frac{PV\ of\ cash\ flows}{initial\ investments}$$

The obtained ratio says about how many present CZK in present value is generated by the invested amount of money. Sometimes managers use this ratio as a project's margin of error and risk indicator. The result of the calculations is compared with 1; the project is acceptable if the ratio is greater than 1 and vice versa. The relationship among PI and the required rate of return can be presented as following statements: if PI<1, then the required rate of return is less than it needs to be and the investor does not recover the invested cost; if PI=1, then the required rate of return is equal to what the investor expects; if PI>1, then the required rate of return is greater than it needs to be [89].

2.3.3 The IRR Approach

The third approach is the IRR. The IRR is the rate of return that equates the present value of all cash flows to zero and it gives expected rate of return. The IRR cannot be straightly related to changes of the investor wealth. The IRR can be found as:

$$\sum_{t=0}^{T} \frac{CF_t}{(1 + IRR)^t} = 0$$

Figure 2.16 graphically shows a) the relation between the NPV and the IRR for a single project and b) the relation between the NPV and the IRR for two projects. In Figure 2.16 b) the crossover rate is presented and it is called as Fisher's intersection. The Fisher's intersection is the discount rate at which the NPV profiles intersect and the NPVs of the two projects are equal. The conflict in ranking occurs because the first project has higher the NPV than the second one when the discount rate is below the crossover rate, but at the same time, the first project has lower the IRR in comparison with the second project. At discount rates above the crossover rate, the NPV and IRR yield the same ranking and no conflict in ranking exists [106].

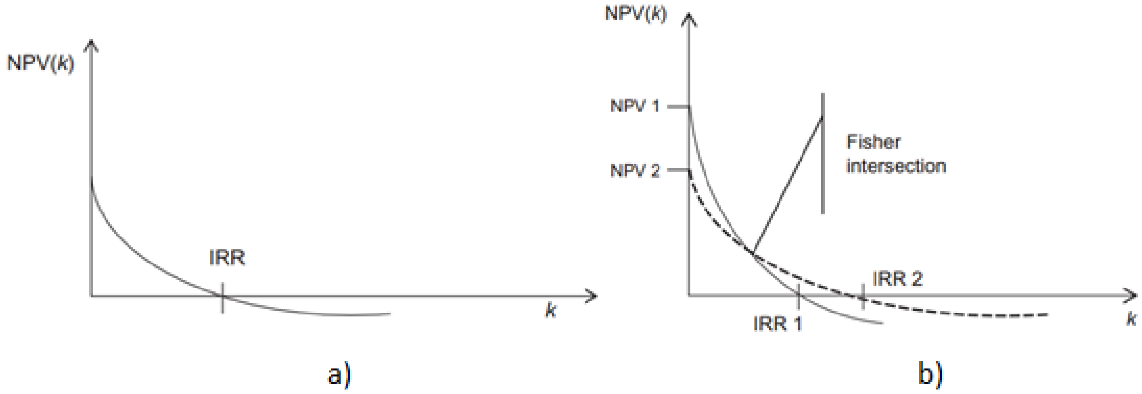

Figure 2.16 a) The representation of NPV and IRR relation for the single investments; b) The representation of NPV and IRR relation for two projects with the Fisher intersection [89]

This approach need not determine the appropriate discount rate, but on the other hand the investor should establish the required rate of return to compare with obtained results and if it is greater than the required rate of return, the project is applicable. Thus, the IRR shows the profitability (in percent points) and demonstrates the return on each CZK contributed; this gives an opportunity to get a "margin of profit." However, the method has a considerable drawback; the investor can receive several numbers of the IRR if there are non-conventional cash flows, it leads to problems with understanding which value is correct. In addition, this method cannot be applied for the projects without revenues [89].

2.3.4 The MIRR Approach

The MIRR method is the improved version of the IRR approach. The MIRR assumes that all cash flows are reinvested at the company's cost of capital and therefore it more accurately reflects the profitability of the project [107]. The method also does not have any problems with multiple-rate result from non-conventional cash flows.

The formulas for calculating MIRR are:

$$\sum_{t=0}^{n} \frac{COF_t}{(1+k)^t} = \frac{\sum_{t=0}^{n} CIF_t (1+k)^{n-t}}{(1+MIRR)^n}; PV\ cash\ outflows = \frac{TV}{(1+MIRR)^n}$$

Where CIF_t and COF_t are the expected cash inflows and cash outflows.

As for the IRR method the MIRR is compared with required rate of return and if there are several projects, then the highest MIRR gives better result for the project. The MIRR has an advantage over the IRR that MIRR incorporates a better reinvestment rate assumption than the IRR technique and does not have undefined values [89].

2.3.5 The PP and DPP Approaches

The Payback Period (PP) is the length of time needed for the cash flows to equal the amount of the investment. The PP can be expressed as:

$$0 = \sum_{t=1}^{PP} CF_t - I_0$$

But there is the advanced technique of the payback period and it is the discounted payback period (DPP) [89]. The DPP is the number of years required for getting cumulative discounted cash flows equal to zero. It is more realistic in comparison with the usual payback period due to using discounted cash flows. The DPP can be found by the following formula:

$$0 = \sum_{t=1}^{DPP} \frac{CF_t}{(1+r)^t} - I_0$$

Figure 2.17 presents the situation when two projects have contrariety in the NPV and the DPP approaches. As it can be seen that the first project has higher NPV value, but the payback period is longer than the payback period of the second project [89].

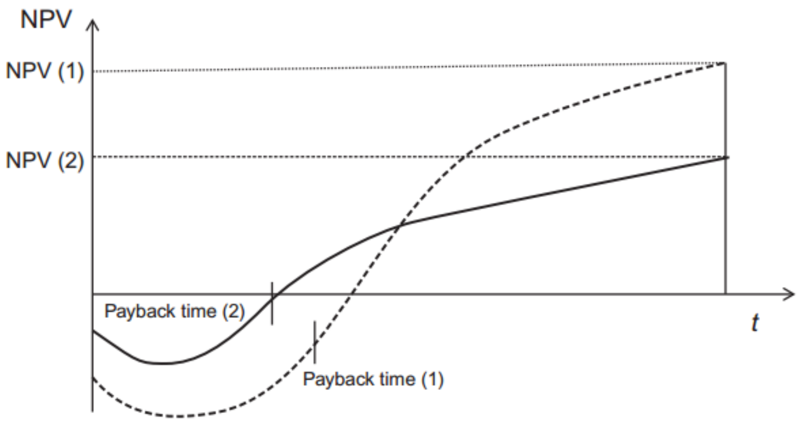

Figure 2.17 The contrariety in the NPV and DPP approaches for two different projects [89]

The criteria for choosing the best project is to select the project with the DPP which is less or equal to the maximum discounted payback period. If different projects are analyzed, the project with the shortest DPP is preferable. To sum up, the DPP is the period of time after that the investor will return all expenses; it shows liquidity and risk for the project. The DPP neglects the further cash flows beyond the DPP and does not give any information about contribution of the project to the investor's wealth [89].

In conclusion, the NPV approach is the primary decision criterion, but the other criteria help to understand and consider the question project more deeply [89].

2.3.6 Calculating Project with Different Lifetime of Devices

The difficulties with the differences in lifetime of devices can easily occur during the project appraising. There are several procedures for solving this problem, which will be described below [89].

- **Replacement chain**

The approach is based on the series of replacements of each asset by other assets having similar or the same characteristics until the lives of the investments are equal. Consequently, a common ending period (when the projects end at the same time) is required to be found. After the extension of the cash flows, the NPV should be calculated. The NPV rules of decision-making are the same. This method is appropriate when the activity served by the investment continues over time. The main disadvantage is that the approach can be sometimes unrealistic and tedious (because of founding the lowest common denominator) [89].

- **Equivalent annual annuity (annualized NPV)**

The method indicates how much NPV per year the project will generate for as long as the company maintains the project. The equivalent annual annuity approach (EAA) is a way to develop NPV ranking for projects/devices with different lives. The equation for the EAA is presented below:

$$EAA = \frac{NPV}{PVIFA_{n,k}}, PVIFA_{n,k} = \frac{1 - \frac{1}{(1+k)^n}}{k},$$

Where PVIFA is the present value interest factor of an annuity for n periods at an interest rate of k per period. This method allows repeating investments and as the result the higher value of the EAA is more preferable. But in case when the projects do not generate cash flows and involve only costs, then the equivalent annual charge (EAC) is an appropriate technique for ranking. The rule of accepting the project is to choose the project with the lowest EAC [89].

For the both approaches, the decision maker should be attentive and punctual because assumptions for the projects sometimes are unrealistic [89].

2.4 Cash Flow Computations

The cash flow statement collects all operating activities from sales, cash operating expenses, cash interest expense, and cash tax payments. Moreover, the cash flows of the project are used for all above mentioned appraisal methods and it emphasizes the necessity of the calculation. The cash flow statement can be estimated by means of two ways: the indirect method and the direct method [108], [109].

The direct method is a direct difference between inflow and outflow money. It means that the company has to determine all types of operating activities and their components such as cash receipts from customers, cash paid to suppliers, cash paid for salaries, etc. After that, the result is derived by summing up all figures using the beginning and ending balances of accounts [110], [111]. The formula can be written as follows:

Add (+):	**Subtract (-):**	**= Net Cash**
• net sales; • ending accounts receivable; • ending assets (prepaid rent, inventory, etc.); • ending payables (tax, interest, salaries, accounts payable, etc.)	• beginning accounts receivable; • beginning assets (prepaid rent, inventory, etc.); • ending payables (tax, interest, salaries, accounts payable, etc.)	

The indirect method starts from the earnings after taxation for the certain period and then subtracts gains or adds losses that result from financing or investment cash flows. The next step is to add back any non-cash charges as depreciation and amortization. The last step is to account for changes in all current assets and liabilities except notes payable and dividends payable [108]. In general, the formula for the indirect method can be presented as follows [111]:

Net Income +/-	**Adjustments**	**= Net Cash Provided/ Used by Operating Activities**
	• **Add back noncash expenses**, such as depreciation expense, amortization, or depletion. • **Deduct gains and add losses** that resulted from investing and financing activities. • **Analyze changes** to noncash current asset and current liability accounts.	

In some cases, the project does not have revenue or two projects have the same revenue. Then we have a question: Why should we take care about revenues if they are the same? In this case we do evaluation or decision-making on discounted sum of expenditures including a tax shield. Such projects are called the project with the same production effect. It leads us to calculating the cash flow statement and all components of the statement. In the further calculations the direct method is used from the household's point of view.

To sum up, the list of the different economic factors considered in the project estimating is presented below:

- Financing of the project;
- VAT;
- Income tax;
- Discount rate;
- Inflation;
- Tax shield;
- Electricity prices etc.

Despite economic influences, one more time the list of non-economic effects should be also mentioned, because from the point of view of the household the main reason for building the smart house is getting non-economic benefits:

- Comfort and convenience (easiness of use);
- Safety and security [57];
- Avoiding fuse problems [55];
- Usefulness and individuality;
- Easiness of load management and supervision;
- Increased independency of energy supply;
- Increased competition in energy markets;
- Higher reliability and longer lifetime of equipment and the system in general;
- Combination of separate functions in a single system;
- Flexibility of technologies and possibility of introducing new functions;
- Large variety of design and decoration components;
- Time-saving etc. [58].

For choosing the right decision, which mixes all factors (non-economic and economic) of constructing or reconstructing either the smart house or ordinary house, the multiple criteria decision making techniques can be applied, because they refer to making decisions in the presence of multiple, usually conflicting, criteria. Examples of these methods include Agrepref method, weighted-sum method and so on.

3 Case Study

In the case study, an old house (it was completely renovated in the period of 2008-2009) in Czech with a big history was considered. Having taken the old house could be explained by several reasons. Firstly, a large old housing stock exists in the Czech Republic, what was discussed previously. Subsequently, it is a big area for smart house companies, which develops technologies and systems for making life of residents easier. Secondly, the interest in improving the house was strong, because as it is shown after, there were some inconveniences in the house. Finally, it should have been discovered how difficult it is to modernize the house partly, because it had already had a lot of its advantages, disadvantages, and restrictions. Furthermore, the interest in a perspective of savings was great.

3.1 Background

Description of the House

For different buildings such as flats, houses, schools etc. the smart house system can be applied. It depends only on size, characteristics, typology of users based on their level of purchasing power, which also affects the type of devices and diversity.

In this work the evaluation of the implementation of some particular and desirable smart systems are applied for the single-family house located outside Prague and oriented to the north (Figure 3.1). It is two-story building with ground and the first floors. The house is intended for a young family (two workers). Therefore, the family lives in the house all the time (during all seasons except holidays and some weekends).

Figure 3.1 Family house

The size of the footprint at ground level is 85 square meters and the total area is approximately 170 square meters. The plan of the first floor is presented in Figure 3.2. The first floor includes four living rooms, toilet, corridor, and chamber.

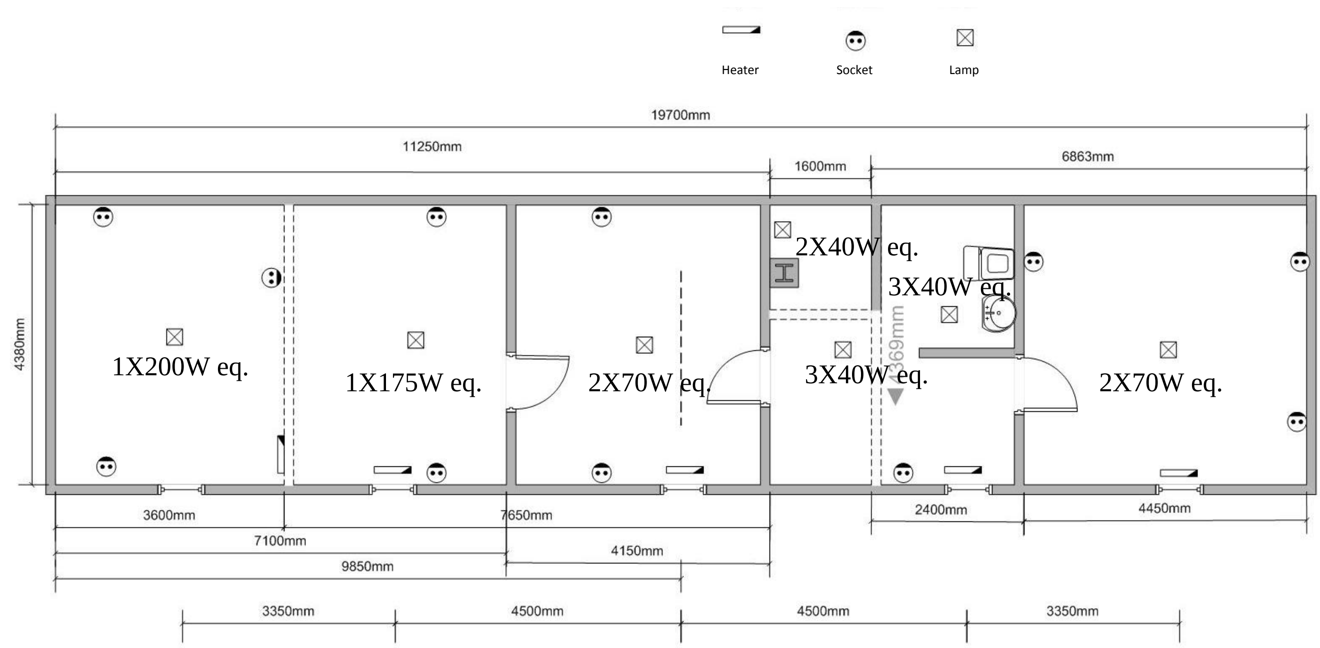

Figure 3.2 Plan of the first floor

The ground floor has similar planning as the first floor and includes a wine room, living room, bedroom, corridor, toilet, bathroom, kitchen with dining area, and storage place for wood.

The house had been under reconstruction until September 2008. Therefore, some of the most important and applicable variants of improvements were performed. All old windows were changed to new double-glazed windows; it means that they have a high insulating value and it has been checked by infrared thermography (Figure 3.3).

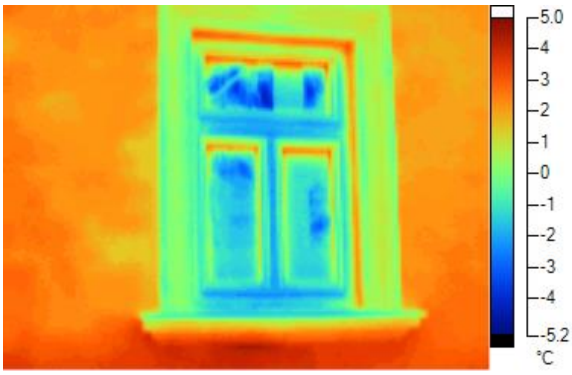

Figure 3.3 Thermogram of a new window

Nevertheless, there is a problem with a wide temperature difference between the ground floor and the first floor, and between individual rooms. It happens because the temperature measurement point is located on the first floor of the house. Therefore, when it gets cool enough or warm enough in there, then the heating system is turned off or on; it means that the temperature downstairs is not taken into account.

Devices installed

The house is heated by a hybrid system, which consists of a wood stove (with heat exchanger), and electric boiler. Two pumps perform the circulation of heated water. Installed power of one pump is 70W. Batteries represent safety system for the electric heating system.

The wood stove uses 12-13 m^3 of fire wood each year (average for the period of 2009-2014) and it is relatively constant (independent on temperature profile of a given year). It should be noticed that the price of 1 m^3 is approximately equal to CZK 1000 (VAT and transport expanses are included). The electric boiler is used for heating water when the wood stove is off. Installed power of the entire heating system is 14 kW.

New energy-efficient bulbs (Compact Fluorescent Lights) are used in all rooms. Lighting in the corridors is presented as ceiling spots. The chart below shows the equivalent amount of Watts which is required by CFL bulbs (Table 3.1) [112].

Table 3.1 Comparison chart of incandescent bulbs vs. CFL bulbs

Incandescent bulb, Watts	CFL bulb, Watts
40	8-12
60	13-18
75-100	18-22
100	23-30
150	30-55

Permanent network connection to the Internet is provided via Wi-Fi router.

The annual number of hours that an average device spends is one of the most difficult aspects of the unit electricity consumption calculation, because the behavior of people is unpredictable and there are some uncertainties in unit usage. Ideally, the usage estimates would be based on a recording the time that all units spend, but it is beyond the scope of this study and we know some habits of residents' life. All devices and appliances with their nominal power are presented in Table 3.2

Table 3.2 List of devices, their nominal power and time of using

Appliances/devices	Energy consumption, W	Quantity
Ground floor		
Fridge	40	1
Freezer	33	1
Mini refrigerator for vine, baumatic	17	1
Wi-Fi router	6	1
pumps	70	2
TV panel (LED) 22"	35	1
Electric range:		
Cooktops	1800	1
Oven	3400	1
Microwave	1000	1
Kettle	1500	1
Mixer	500	1
Washing machine kWh/year		1
Water Heater 100l, 15^0C-45^0C	2000	1
Lightening/ Energy savings bulbs		
Wine room	15	3
Bedroom	15	1
Living room	15	3
Corridor	15	3
Toilet	15	1
Bathroom	15	2
Outside	15	1
Dependent on sun		
Kitchen	15	3
The first floor		
TV plasma 42"	200	2
Lightening/ Energy savings bulbs		
Chamber	10	1
Toilet	10	2
Stairs	10	2
Corridor	10	3
1st living room	50	1
2d living room	40	1
3d living room	18	2
4th living room	18	2

Electricity Tariff

Because of the installed electrical heating system in the house, the best variant is a two tariffs plan. Such plan is based on the high tariff, which is implemented during peak hours and is mostly for standard electricity usage, and the low tariff, which is used at off-times and generally applies to electrical heating. The home´s accumulator or storage heater is set to automatically store up heat energy at night when the tariff is low. By encouraging consumers to use more energy at off-hours, the electrical company can curb heavy electricity consumption during times of high demand [113]. The tariff (D35d) with 16 hours of low tariff has been chosen for the house. For 16 hours every day, the entire home is fed by low-tariff electricity [114], [115].

Final electricity bill

Annual energy consumption of the house during 6 years is presented in Table 3.3 and the sum of money spent is calculated.

Table 3.3 Electricity bill for 6 years

	High tariff	Low tariff	High tariff	Low tariff	Total
Period	MWh	MWh	CZK/kWh	CZK /kWh	CZK
2008-2009	1,23	7,505	2,006	1,361	23032
2009-2010	1,098	7,742	1,987	1,295	23523
2010-2011	1,284	7,481	1,868	1,278	24422
2011-2012	1,006	5,86	2,014	1,389	20080
2012-2013	0,882	6,765	2,014	1,389	23981
2013-2014	0,812	5,55	1,618	1,141	19390

3.2 Possibilities for Improving the House

After the consultation with a representative from EKIS (Energy Consulting and Innovation Center) at EkoWatt, s.r.o., two possible alternatives of home improvements were proposed based on data available:

1) Equithermal regulation + regulation system for lights;
2) Equithermal regulation + heat accumulation of hot water + regulation system for lights.

The equithermal control is suitable for buildings where it is not possible to determine the reference room. Principle of the equithermal control is the optimization of the water temperature of heating system depending on the outside temperature. This dependence is expressed by the equithermal curves (for the required room temperature), according to which the contro device selects the required temperature of the heating system water (Figure 3.4). The thermostat will calculate the heating water temperature according to the selected equithermal curve, which it sends subsequently to the boiler. The boiler warms water to the required temperature value. It is necessary to select the curve steepness according to the heating system that there would be no permanent overheating or insufficient heating of the building. Selection of the right curve for the given system is a long-term matter and it is necessary to test the system at different outside temperatures. It is advisable to set the internal temperature in rooms for example by control with thermostatic heads. Water temperature of the heating system is limited by minimum and maximum borders. During this control an outside sensor has to be always connected at the boiler [116].

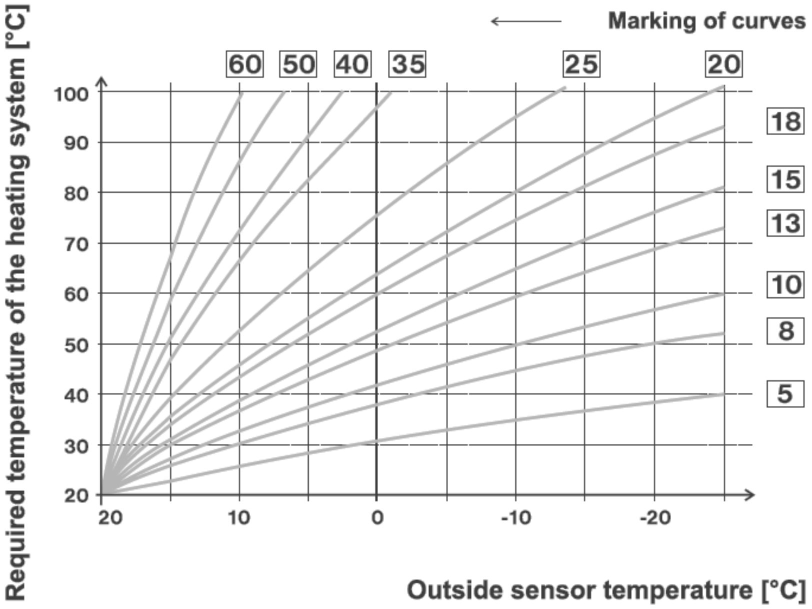

Figure 3.4 Equithermal curves [116]

Additionally, the new heating system allows habitants to remotely control their house from wherever they are and to guarantee the constant temperature within the house. For example, it makes easy to prepare the house before arriving. Therefore, the equithermal system brings undoubted benefits of flexibility, simple and easy control of the home heating. Moreover, it provides the residents with the comfort and enhanced quality of life [116].

The heat accumulation system can be presented by accumulation tanks. Storage tanks for heating systems are usually containers, which keep spare heat in the form of warm water and used for the short- or long- storage of heat. They are mainly designed for optimization of heat energy economy using solid fuel boilers, pyrolytic boilers, solar systems and other low-potential or contrarily heat sources regulated with difficulty [117]. Thus, the main function of the accumulation tank is to save excessive unconsumed heat from the boiler or fireplace inserts. As economic benefit from the system with the accumulation is money savings. It was said that the economy of energy consumption might reach 10-15%.

The available method of advancing the lightening system is to replace wire lightening system by a wireless one. The new system allows creating lighting ambience and mood scenes in the house and providing a complete control of units. The system works by sending wireless signals from controllers to wired receiver units. These receiver units in turn control any light fittings that connected to them. The controllers are battery operated and wireless. They communicate with the receivers via radio waves. It gives opportunities to place controllers anywhere; moreover, emphasizing the benefit of the system, they can be moved elsewhere at any time without any unpleasant changes [118]. The economic benefit of such system can be received in the case of remodeling of the house that will save money on wires.

As additional improvement, the safety system has been suggested. Regarding to the absence of continuous security control the variant of installation a safety control system has been considered. It means that the house will be provided by safety devices and cameras (indoor/outdoor sensors). The opportunity of online access to the house in this case is available.

Moreover, the security system can be monitored by a central station of the security company, for example D.I. Seven. Help will be sent in the event of a burglary, fire or other emergency. Prices of such service can vary from CZK 500 to CZK 700 per month (without installation) [119].

Undoubtedly, a zero alternative always exists, when the decision is to change nothing (i.e. remain everything as it is).

3.3 The Decision Proposed and Evaluation

The mentioned variants of the improving the house heating system are reviewed further.

1. <u>Equithermal regulation</u>

Equithermal regulation consists of several devices and all heat sources (radiators) are controlled individually. Additionally, the temperature outside, in the boiler and in the rooms is monitored continuously. The list of the heating system devices is presented below.

Central unit with GSM module – PH-CJ37-GST (Figure 3.5) [116]

It is a brain of the system, which ensures the operation of all elements and has saved all the data and programs. It can be placed anywhere in the building (within the range), it is the so-called coordinator between the heat source and particular elements. Main advantage is the ability to operate the connected heat source and that enables to control the heating system depending on outside temperature [116].

Figure 3.5 Central unit with GSM module (PH-CJ37-GST) [116]

Wireless receiver for boiler - PH-PK55 (Figure 3.6) [116]

PH-PK55 is used as the boiler receiver that has extended functions for setting of equithermal regulation. The wireless receiver for the boiler switches on and off the boiler in accordance with the information from the central unit. PH-CJ37 works in according set program and in achieving the required temperature sent signal to the PH-PK55 for turn off the hot water for heating. PH-PK55 always reconfirms the receipt of the information from PH-CJ37. If PH-CJ37 does not receive answer then it indicates on the LCD “Error.” After that, the householders are immediately informed of the problems with communication. All operating states are indicated using LEDs [116].

Figure 3.6 Wireless receiver for boiler (PH-PK55) [116]

Wireless digital radiator head - PH-HD20 (Figure 3.7) [116]

On the basis of information received from the central unit it controls the position of the radiator valve. Even though, it can have the right to ask for the boiler switching-on. It can work also in autonomous mode, independently of the central unit. Head senses the current internal temperature and by difference in required temperature closes or opens the valve. Information about the position of the valve, the temperature, and battery power status transfers to the central unit [116].

Figure 3.7 Wireless digital radiator head (PH-HD20) [116]

Application for Smartphones and Software PocketHome for PC

The entire system can be controlled via the Internet or smartphone. The residents only have to download the application of PocketHome (Figure 3.8). This application allows convenient operation of the central unit PocketHome through your mobile device.

Application simplifies configuration and management features of your heating system:

- Adding a pair of elements with the central unit;
- An overview of elements in the home, the possibility of sorting and filtering;
- Monitoring of actual values (e.g. actual temperature) on each device;
- Rapid heating management programs, setting the required waveforms using only touch and gestures [116].

Figure 3.8 PocketHome application for smartphones [116]

2. <u>Implementation of the storage tank</u>

The available range of the storage tanks is plentiful and depends on the shape, functions (only storage, direct heating or pre-heating), thermal isolation (with or without) and volumes [120].

Source of heat for the storage tank can be:

- central heating with solid fuel
- solar system
- stoves with heat exchangers
- heat pump system etc.

Some storage tanks enable combining more sources of energy [120].

It has been decided that the storage tank of type NAD of the Czech company Dražice is the most suitable for the house. The tank serves only to storage spare heat in the heating system and it does not allow direct heating of hot water or its pre-heating for another water heater. The direct heating and pre-heating is usually necessary for solar or heat pump system which cannot provide a desired temperature of the hot water. The storage tanks types NAD combined with a boiler with solid fuel assure optimal operation of the boiler at ideal temperature [120].

Because the main obstacle of the storage tank implementation in the house is place available, thus, the storage tank type NAD 500v8 has been chosen (Figure 3.9). The tank is the most appropriate tank from the range, it is equipped with a top-quality reinforced insulation and has a parallelepiped shape. Therefore, it can be placed outside the house or in the cellar next to the boiler, wood stove, and pumps [120]. If the accumulation device is placed in the cellar, it will decrease expenses on cables, tubes and other connecting devices. The characteristics of the tank are presented in Table 3.4.

Table 3.4 General parameters of tank NAD 500v8 [120]

Dimensions of insulation [mm]	980x940x2065
Tank diameter [mm]	600
Capacity [l] 500	500
Max. operating pressure [MPa]	0.3
Maximum heating water temperature [°C]	80

Figure 3.9 NAD 500 v8 [120]

The scheme of the connection of the heating system and the accumulating tank is shown in Figure 3.10.

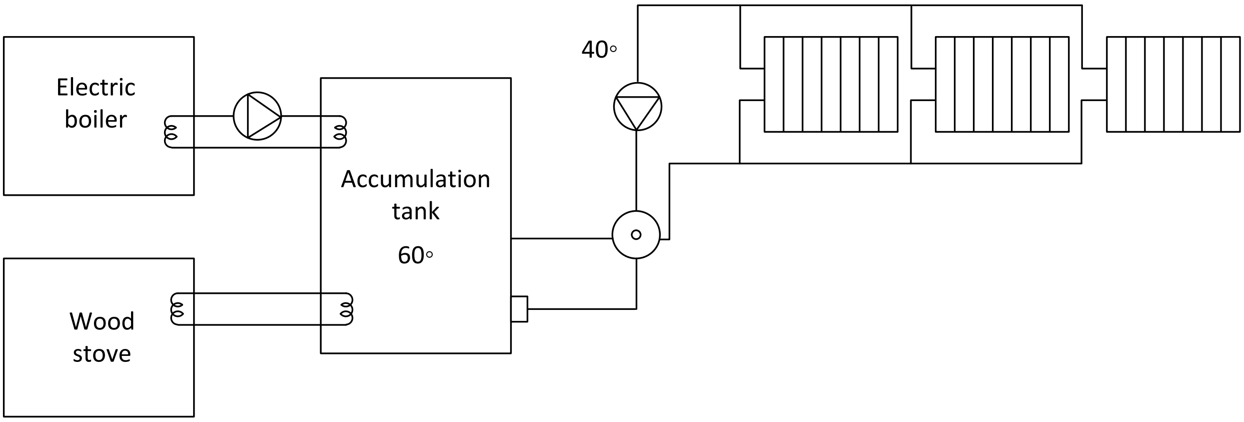

Figure 3.10 The heating system scheme with accumulating device/storage tank

3. **Lightening**

The decision on the lightening control was to implement several lighting controllers (DR3-SD, Figure 3.11) of the company Elektrobock in the kitchen, two living rooms and corridor, because these places are the most occupied by the residents. They enable to switch on, switch off and change the illumination level by mere touch (on the cap) or by remote control of TV, video and HiFi tower. The reduction of the illumination level results in savings of electric energy but also the conservation of eyes. It is quickly and easily to install [116].

Table 3.5 is a list of devices, which can be installed according to the first variant, but if we add the storage tank, it is the second variant of improvements.

Figure 3.11 DR3-SD - Touch and remote lighting controllers

Table 3.5 The list of devices chosen

Name	Price, CZK	Lifetime, years
Central unit with GSM module – PH-CJ37-GST	5 808	10
Wireless receivers for boiler PH-PK55	1 498	10
Wireless digital radiator head PH-HD20	1724	10
Accumulation tank NAD 500v8	21 384	15
DR3-SD	799	10

Calculations

To calculate the electric expenses on space heating (because it is a major part of electricity consumption where money may be saved), residential power consumption of all electrical devices on average per year had to be determined. If we look at the electricity bill then we can see that the family has almost the same power consumption during the measured period, of course, there are some fluctuations, but they are not so significant. It allowed us to calculate only one year in general (power consumption of all electrical devices).

The following assumptions were taken in order to calculate correctly. Winter period is from the middle of September until the middle of May (15.09-15.05, 243 days). Number of days per year when people are at home was approximately equal to 281 days (the whole year without holidays and some weekends). In Czech townhouses, per-capita hot water consumption was found to be 50 liters per day [121].

The time usage of the lightening in the kitchen was calculated in according to daylight (sunrise and sunset) (Figure 3.12) with assumptions that the kitchen is used from 7:30 a.m. to 8:00 a.m. and from 6:00 p.m. to 9:00 p.m.

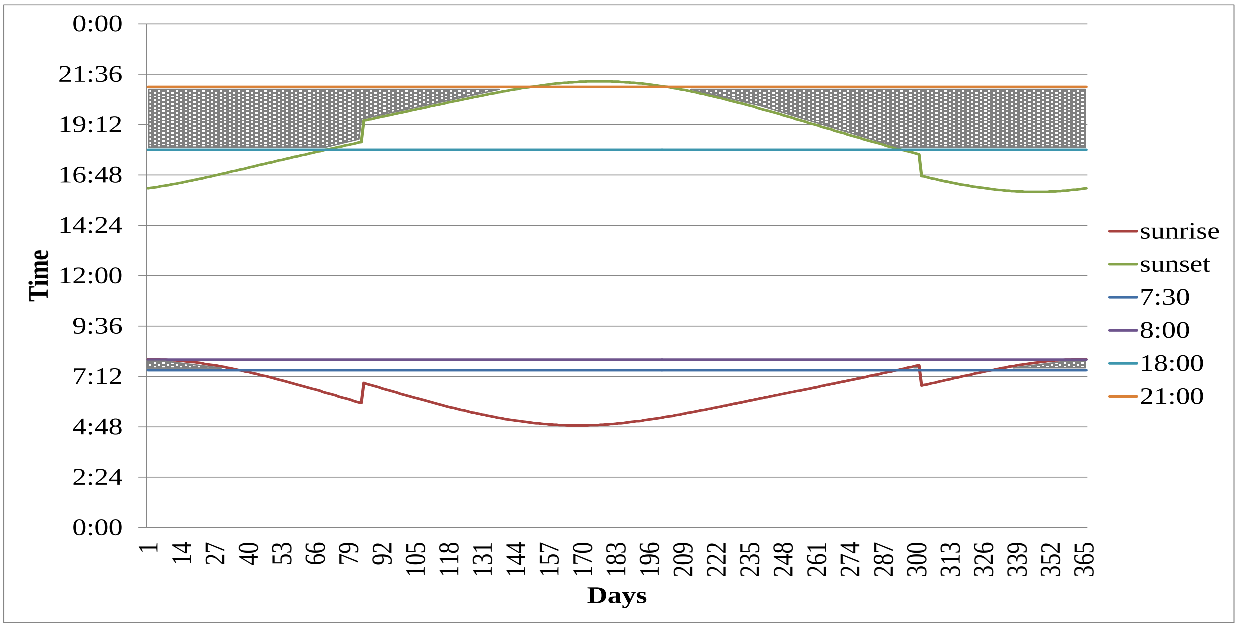

Figure 3.12 Kitchen lightening usage during a year

For each device estimates for the annual average usage (in hours) were developed and they were multiplied by the estimated average power draw (in Watts) to calculate the unit electricity consumption. The power consumption difference during different tariffs was also taken into account. The sum of the power consumption during two tariffs equaled the annual electricity consumption. All devices and appliances with their nominal power and annual energy consumption are presented in Appendix 1. As you can see in Appendix 1, the calculated numbers of the electricity consumption during the high tariff period (1.14 MWh/year) are roundly equal to the numbers in the electricity bill (1.2 MWh/year). It means that the energy consumption estimations are correct. Thus, the space heating consumption is equal to the difference between the total consumption in the low tariff and estimated consumption of the devices (7.5 MWh/year – 2.25 MWh/year = 5.25 MWh/year).

After that, the model for apprising the project was developed. Firstly, the NPV model was calculated. As it was mentioned before, the NPV is a discounted sum of the expected net cash flows. In our case, there was no any cash inflows, but the expected savings in electric power consumption were taken as potential revenues from the project. The initial investments were included as negative amount of the money spent on the chosen equipment and installation costs.
The calculations were based on the assumptions that expected annual savings from the equithermal regulation were up to 10%, savings from the storage tank implementation were up to 15% and savings from the lightening control were up to 5% of electricity spending. The wood consumption was expected to remain the value of 12-13 m^3. The electricity price in first-year (2016) terms was expected to be equal to current tariffs CZK 1.96 per kWh and CZK 1.38 per kWh for the high and low tariffs respectively. As it was discussed above in the second chapter, the discount rate was equal to 1.5% and the escalation rate of electricity prices was assumed 1% per annum (it could be explained by increase/expected increase in fuel costs, labor, exchange rate, bulk materials, commodities etc.) Table 3.6 is a list of all costs of the project. Table 3.7 and Table 3.8 are present value tables of the expected savings.

Table 3.6 List of costs

Costs	
Appliances	Price, CZK
Accumulation tank	21384
Delivery	1000
Installation	1500
Explotational and revision costs	500
Lifetime, years	15
Sum	23884
PocketHome, Equithermal system	
Central unit with GSM module – PH-CJ37-GST	5808
Wireless receivers for boiler PH-PK55	1498
Wireless digital radiator head PH-HD20	5172
Other costs	1500
Lifetime, years	10
Sum	13978
Lightening	
DR3-SD	3196
Lifetime, years	10

Table 3.7 Present values of the expected savings and expenditures 2016/2023

	Present value							
Year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Savings from accumulation tank, CZK	1 087	1 082	1 076	1 071	1 066	1 060	1 055	1 050
Explotational and revision costs for accumulation tank, CZK	-500	-505	-510	-515	-520	-525	-530	-536
Savings from equithermal regulation, CZK	725	721	717	714	710	707	703	700
Savings from lightening, CZK	2	0	0	0	0	0	0	0

Table 3.8 Present values of the expected savings and expenditures 2024/2030

	Present value						
Year	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Savings from accumulation tank, CZK	1 045	1 040	1 034	1 029	1 024	1 019	1 014
Explotational and revision costs for accumulation tank, CZK	-541	-546	-552	-557	-562	-568	-574
Savings from equithermal regulation, CZK	697	693	0	0	0	0	0
Savings from lightening, CZK	0	0	0	0	0	0	0

With all mentioned assumptions, the NPV values of the proposed improvements were negative. The corresponding values of the NPV calculations were CZK -16172, CZK -6891 and CZK -3196 for the accumulation tank, equithermal system and lightening respectively. However, the conclusions had to be adjusted for the timing issue; because the devices were with unequal lives (the accumulation tank had longer lifespan). In that case, to adjust evaluation and reach right results the EAA approach was used. The values of EAA for the accumulation tank, equithermal system and lightening were equal to CZK -1212, CZK -747 and CZK -346 respectively.

Hence, from the economic point of view the investments should not have been accepted. The next step of the calculations was a scenario analysis. The scenario analysis was carried out in order to understand the boundary conditions of the positive NPV. Critical values of the savings, electricity prices, periods of lifetime etc. were varied to see the results of changing the NPV (to reach at least zero value). All results of scenario analysis are shown in Appendix 2. Ten cases were developed for the accumulation tank and equithermal system; the cells, which are highlighted, were changed. The lightening control system was not considered, because it has small savings and the increase in energy use in four rooms could not be raised significantly. The major findings are discussed further.

For the first scenario nothing was changed, it is the first calculations of the NPV and EAA. The second scenario was aimed at reaching zero value of the NPV of the hot water accumulation tank by increasing heating energy consumption. Thus, when the energy consumption of heating was increased by 103% the NPV of the device was zero. In the third case, the NPV of the equithermal system was set to be zero and energy consumption of heating reached 97%.

Scenarios number 4 and 5 show that the EAAs of the accumulation tank and equithermal system were zero on conditions that the low tariff was raised in 2 times. To demonstrate the influence of the maintenance expenditures on the NPV of the accumulation tank the 6th case was conducted and the NPV increased almost in 2 times. As the other variant, the lifespan of 21 years was applied for the equithermal regulation system to reach positive value of the NPV. The most realistic scenarios were recieved when savings from the accumulation tank and equithermal regulation system were 30% and 20% respectively. Hence, the analysis shows how changes in one variable, while holding others constant, affect the project's profitability.

After that, what-if analyses were performed. Table 3.9 shows the EAAs and includes two variables – increase in consumption/discount rate in the case of the accumulation tank. The best case in this analysis is when discount rate is approximately equal to zero and the value of the increase in consumption is the highest. Table 3.10 presents the dependence of the EAA on the increase in consumption and savings from the accumulation tank. The positive value of the EAA exist on the condition that savings and increase in consumption are 25% for each.

The same dependences were analyzed for the equithermal regulation. The best case in the analysis of dependence the EAA on the increase in consumption and discount rate is when discount rate is approximately equal to zero and the value of the increase in consumption is the highest (Table 3.11). Moreover, having increased percent of savings from the device or increase in consumption, it is visible how the EAA rises, but in the case of equithermal regulation, the positive values appear on condition that savings are 20% and increase in consumption is 0% or more (Table 3.12).

Table 3.9 Two-variable data table (increase in consumption/discount rate for accumulation tank)

Accumulation tank	Discount rate						
Increase in consumption	0,01%	0,50%	1,00%	1,50%	2,00%	2,50%	3,00%
0%	-1 025	-1 085	-1 148	-1 212	-1 278	-1 345	-1 413
5%	-967	-1 026	-1 089	-1 153	-1 218	-1 285	-1 354
10%	-908	-968	-1 030	-1 094	-1 159	-1 226	-1 294
15%	-850	-909	-971	-1 035	-1 100	-1 166	-1 234
20%	-792	-851	-913	-976	-1 041	-1 107	-1 174
25%	**-733**	-792	-854	-917	-981	-1 047	-1 115

Table 3.10 Two-variable data table (increase in consumption/savings for accumulation tank)

Accumulation tank	Savings						
Increase in consumption	15%	20%	25%	30%	35%	40%	45%
0%	-1 212	-818	-425	-31	362	756	1 149
5%	-1 153	-740	-327	87	500	913	1 326
10%	-1 094	-661	-228	205	638	1 070	1 503
15%	-1 035	-582	-130	323	775	1 228	1 680
20%	-976	-504	-31	441	913	1 385	1 858
25%	-917	-425	67	559	1 051	1 543	2 035

Table 3.11 Two-variable data table (increase in consumption/ discount rate for equithermal regulation)

Equithermal regulation	Discount rate						
Increase in consumption	0,01%	0,50%	1,00%	1,50%	2,00%	2,50%	3,00%
0%	-640	-675	-711	-747	-784	-822	-860
5%	-603	-637	-673	-709	-746	-783	-821
10%	-565	-599	-634	-670	-707	-744	-782
15%	-527	-561	-596	-632	-668	-705	-743
20%	-489	-523	-558	-593	-630	-667	-704
25%	**-451**	-485	-520	-555	-591	-628	-665

Table 3.12 Two-variable data table (increase in consumption/savings for equithermal regulation)

Equithermal regulation	Savings						
Increase in consumption	15%	20%	25%	30%	35%	40%	45%
0%	-363	21	406	790	1 174	1 558	1 943
5%	-305	98	502	905	1 309	1 712	2 115
10%	-248	175	598	1 020	1 443	1 866	2 288
15%	-190	252	694	1 136	1 578	2 019	2 461
20%	-132	329	790	1 251	1 712	2 173	2 634
25%	-75	406	886	1 366	1 846	2 327	2 807

In according to all results, the project should have been rejected financially, because the NPVs in all cases were less than zero. In order to get the positive values of the NPV, specific input variables like the lifetime periods of the equipment, electricity prices, savings etc. had to be significantly changed. These changes are more likely not to occur.

To sum up, the economic benefits of the smart technology investments are easily to find and as the calculations shown the investments in advanced technologies were unprofitable.

Nevertheless, the problems exist in finding a single, widely accepted methodology to value noneconomic benefits in monetary terms, because they are also should be taken into account during the decision making process. As a consequence, it is suggested to consider such problems as multiple criteria decision making tasks. They allow decision makers to take into account a range of non-economic criteria in different areas, such as safety, comfort, quality of life, flexibility, etc. [122].

Conclusion

The first theoretical part of the work was devoted to the smart house concept, to find out the reasons of implementation, attitudes of people, interconnection with the smart grids and benefits. After dealing with the range of different literature, the smart house concept was defined as a complex system, which requires specific knowledge about the integration and installation of the technologies to meet all requirements. The smart house concept supports technological development and innovations in daily life of people. Today the smart house concept can cover all kinds of homes such as single-family houses, residential housing and institutional living, e.g. for older persons and for people subject to rehabilitation.

Primarily, the smart house concept was developed to create a system, which allows residents to feel better at home and shrink utility bills. For those purposes the smart technologies, structures and algorithms were developed such as prediction of behavior, location estimation and smart environments. All of these achievements are used to create the house which will be a part of your life creating perfect atmosphere.

The concept of the passive house was also considered in the first part of the work as a kind of the smart house, because it has complicated automated systems that allow incorporating. It is possible to build the passive house from the scratch and in all climates. As it was discussed, the passive house can achieve fantastically low energy use and provide people with comfort, heath and general wellbeing.

The next step of studies was pointed at the market analyses, the wide range of the smart appliances exists on the market of technologies. The customer only needs to define his or her wishes and desires. They can be both to be designed for entertainment or comfort life of residents. Moreover, the market surveys in Western Europe showed the positive trends of people motivation to purchase new technologies especially to increase security and safety confidence.

After literature review, the non-economic and economic benefits of the implementation of the smart technologies were investigated and discussed. It was found out that there is a considerable amount especially of non-economic benefits for people. The list of non-economic benefits includes comfort and convenience, safety and security, individuality, flexibility, timesaving etc. All these benefits were considered from the different points of view such as the energy systems, residents, society etc.

The second chapter of the thesis was focused on the methodology of evaluation. Different types of possible investors were emphasized. But primarily, the chapter was dedicated to considering two types of investors – households and business companies. Because the decision to acquire the smart systems for the house also is based on the situation in a particular country, availability of financial support from the government and a variety of economic factors such as inflation, exchange rate, taxes etc. were mentioned and compared in cases of two countries – the Czech Republic and Russia. In addition, it was observed that the construction rates in these countries were relatively high, it means that the possibilities of the smart system implementation were strong, because it is much easier to penetrate the smart technologies into a building under construction, than to an old one.

The aim of the third part of the work was to conduct the research of the opportunity to improve the family house and analyze the profitability of the proposed variants. The improvements in reducing the temperature differences, savings of the spare heat, remote control of the heating and lightening systems in the house were suggested by the representative of EKIS (Energy Consulting and Innovation Center) at EkoWatt, s.r.o. Therefore, it was supposed to calculate the profitability of the installation of the accumulation tank NAD 500v8, PocketHome system for the equithermal regulation and remote lightening control. The results of the calculations did not support the expectations that it would be profitable investments for the residents (all NPVs were negative). On the other hand, these systems could provide the residents with more comfortable life, because they would not have any problems with the cold house after arriving from holidays and weekends, the temperatures in different rooms would be the same and it was important in perspective of expanding the family. Moreover, these systems have user-friendly interface it means that there will not be any difficulties in controlling the systems. Therefore, the other techniques (not only economic) which include all criteria of the decision-making process should be used.

What is more, two consultations were held with the representatives Prucha Jan from InsightHome company and Radko Mach from AMX company. They emphasized that companies built or equipped houses with smart systems mostly for well-off people, who wanted to control everything in home by one click or remotely. Moreover, they got living in harmony with the house, comfort and safety, combining it with increasing productivity, memory, and mental functions. The minimum price for such smart systems begins from CZK 700,000; obviously, it is high price for ordinary people.

To summarize, the smart house concept has a hopeful outlook on the one hand, because the markets of the technologies and buildings are being developed and expanded, attitude of people is positive and smart systems are quite useful in the certain circumstances. On the other hand, the smart home has some obstacles such as a large old housing stock, lack of a common protocol between different producers and the most important obstacle is high initial investments from the consumers which cannot be covered by the expected savings in many cases. Nowadays the home automation technologies are built into luxury dwellings, but the situation is being changed due to decreasing prices of the technologies.

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Appendix 1. List of home appliances and devices with their annual energy consumption

Appliances/devices	Energy consumption, W	Quantity	Hours per day, h	Hours per year, h	Energy consumption, kWh/year	Energy consumption, high tariff, kWh/year	Energy consumption, low tariff, kWh/year
Ground floor							
Fridge	40	1	24	8760	350,00	116,67	233,33
Freezer	33	1	24	8760	290,00	96,67	193,33
Mini refrigerator for vine, baumatic	17	1	24	2928	49,78	16,59	33,18
Wi-Fi router	6	1	24	6744	40,46	13,49	26,98
pumps	70	2	24	5832	408,24		408,24
TV panel (LED) 22"	35	1	2	562	19,67	16,03	3,64
Electric range:							
Cooktops	1800	1	1	281	505,80	412,20	93,60
Oven	3400	1	0,29	80,29	272,97	222,46	50,51
Microwave	1000	1	0,08	23,42	23,42	19,08	4,33
Kettle	1500	1	0,17	46,83	70,25	57,25	13,00
Mixer	500	1	0,04	10,04	5,02	4,09	0,93
Washing machine kWh/year		1			200,00	0,00	200,00
Water Heater 100l, 45C-15C	2000	1	2	562	983,50	0,00	983,50
Lightening/ Energy savings bulbs							
Wine room	15	3	0,02	4,68	0,07	0,06	0,01
Bedroom	15	1	0,50	140,50	2,11	1,72	0,39
Living room	15	3	1,00	281,00	4,22	3,44	0,78
Corridor	15	3	1,00	281,00	4,22	3,44	0,78
Toilet	15	1	0,25	70,25	1,05	0,86	0,20
Bathroom	15	2	0,67	187,33	2,81	2,29	0,52
Outside	15	1	0,02	4,68	0,07	0,06	0,01
Dependent on sun							
Kitchen	15	3	3,00	671,48	10,07	8,21	1,86
The first floor							
TV plasma 42"	200	2	2	562	112,40	112,40	

Lightening/ Energy savings bulbs							
Chamber	10	1	0,08	23,42	0,23	0,19	0,04
Toilet	10	2	0,25	70,25	0,70	0,57	0,13
Stairs	10	2	0,08	23,42	0,23	0,19	0,04
Corridor	10	3	0,25	70,25	0,70	0,57	0,13
1st living room	50	1	0,86	240,86	12,04	9,81	2,23
2d living room	40	1	0,86	240,86	9,63	7,85	1,78
3d living room	18	2	0,50	140,50	2,53	2,06	0,47
4th living room	18	2	3,00	843,00	15,17	12,37	2,81
Total consumption					**3397,37**	**1140,60**	**2256,77**

Appendix 2. Results of the scenario analysis

Variables	Scenario									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Increase in energy consumption	0%	103%	97%	0%	0%	0%	0%	0%	0%	0%
Energy consumption of place heating (increased)), MWh/year	5,25	10,64	10,35	5,25	5,25	5,25	5,25	5,25	5,25	5,25
Electricity price (low tariff) with DPH, CZK	1,38	1,38	1,38	2,80	2,72	2,72	2,72	2,72	2,72	2,72
Operational and revision costs, CZK	500	500	500	500	500	0	500	500	500	500
Equithermal system lifetime, years	10	10	10	10	10	10	21	10	10	10
Savings from accumulation tank	15%	15%	15%	15%	15%	15%	15%	30%	15%	15%
Savings from equithermal regulation	10%	10%	10%	10%	10%	10%	10%	10%	20%	10%
Savings from lightening	3%	3%	3%	3%	3%	3%	3%	3%	3%	5127%
NPV										
Accumulation tank, CZK	-16 172	-0	-856	-0	-856	-8 132	-16 172	-0	-16 172	-16 172
Equithermal regulation, CZK	-6 891	385	-0	385	0	-6 891	511	-6 891	0	-6 891
Lightening, CZK	-3 194	-3 192	-3 192	-3 194	-3 194	-3 194	-3 194	-3 194	-3 194	0
EAA										
Accumulation tank, CZK	-1 212	-0	-64	-0	-64	-609	-1 212	-0	-1 212	-1 212
Equithermal regulation, CZK	-747	42	-0	42	0	-747	29	-747	0	-747
Lightening, CZK	-346	-346	-346	-346	-346	-346	-346	-346	-346	0