Integrated System HVAC in Family House

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Zásady pro vypracování:

1. **Vypracujte studii řešení energeticky úsporných rodinných domů s téměř nulovou spotřebou vstupní energie z hlediska stavební fyziky, spotřeby energie, řešení tvorby mikroklimatu, osvětlení, akustických problémů a možnosti využití obnovitelných zdrojů energie.**
2. **Na základě výše uvedené analýzy popište požadavky na zařízení techniky prostředí, osvětlení včetně způsobu řízení, monitorování a komunikace.**
3. **Pro konkrétní budovu navrhněte vhodný systém techniky prostředí s možností využití obnovitelných zdrojů energie. Vytápěcí systém bude odpovídat parametrům rodinného domu se zdrojem ZP a využitím tepelného čerpadla a solárních panelů s možností chlazení vnitřních prostorů.**
4. **Navrhněte vhodný systém řízení, monitorování a komunikace navrženého systému techniky prostředí s vizualizací SCADA.**
5. **Zvažte možnost využití fotovoltaických panelů a proveďte jejich technicko-ekonomické hodnocení.**

Rozsah diplomové práce:

Rozsah příloh:

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ABSTRAKT

Cílem této práce je návrh integrovaného systému techniky prostředí v budově rodinného domu. Práce zpracovává studii řešení energeticky úsporných rodinných domů s téměř nulovou spotřebou vstupní energie z hlediska stavební fyziky, spotřeby energie, osvětlení, akustických problémů a možností využití obnovitelných zdrojů energie. Má za úkol popsat požadavky na zařízení techniky prostředí, monitorování a komunikaci na základě výše uvedené analýzy. V praktické části je navrhnut vhodný systém techniky prostředí pro konkrétní budovu. Je vybrán vhodný systém řízení, monitorování a komunikace navrženého systému techniky prostředí s vizualizací SCADA. Na závěr práce je provedeno technicko-ekonomické hodnocení fotovoltaických panelů a otopného systému.

Klíčová slova: integrovaný systém, stavební fyzika, spotřeba energie, obnovitelné zdroje energie, zařízení techniky prostředí, řízení, monitorování, komunikace, SCADA, technicko-ekonomické hodnocení, fotovoltaické panely

ABSTRACT

The aim of this work is to design an integrated system of HVAC in a family house. This thesis is a study of energy saving solutions of low-energy houses in terms of building physics, energy consumption, lighting, acoustic problems and possibilities of using renewable energy resources. Requirements for HVAC, monitoring and communication based on terms mentioned above will be described. In the analysis, the HVAC system design is specified. Monitoring and communication of the given system with SCADA visualisation will also be discussed. At the end of the work, an economic evaluation of photovoltaics and the heating system is calculated.

Keywords: HVAC system, low-energy house, building physics, renewable energy resources, monitoring, communication, SCADA, economic evaluation, photovoltaics

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I hereby declare that the print version of my Master's thesis and the electronic version of my thesis deposited in the IS/STAG system are identical.

CONTENTS

INTRODUCTION

An Intelligent Building can be understood as a building with embedded systems which can communicate with each other and work as one single unit. Automation of the building is used to increase the living ambient comfort and also to reduce operating costs. The aim of these systems is the limitation of human intervention to control and simplify operations. Controlled systems can be heating, hot water preparation, ventilation, security systems and others. Due to the constant evolution of technology, initial costs of intelligent systems are continuously reduced, which results in more widespread use of intelligent buildings.

The aim of this work is to study the concept of intelligent buildings and try to propose an appropriate combination of systems for a real building. However, the proposal of a low-energy or intelligent building is very broad term. This design starts with the proper orientation of the building in the terrain, continuing with the appropriate choice of structure materials, ending with installations of systems using renewable resources of energy.

In the first part of the thesis, the types of intelligent buildings and their properties will be described. The second part should serve as a basis for the design of a real intelligent building for a family.

I THEORY

1 ENERGY-EFFICIENT HOUSES

1.1 Definition of contemporary energy-efficient houses

Types of houses can be divided into different groups, depending on chosen criteria. Nowadays, it seems like heat consumption for heating the house is one of the most important one. Using this criterion, we could name type of houses as zero house, passive house, low-energy house and average contemporary house. Although, we should also mention old houses, which values seems now way obsolete. The most popular houses of today are low-energy houses.

The main objective of today's high demands on the construction is reaching a state where the new building is implemented as zero-energy house. Effective way is represented by building solution with greatly reduced heat demand. The next step is the choice of energy resources with low energy conversion factor producing energy from renewable resources in the building or in the close surroundings. [1]

Table 1: Types of houses divided according its heat consumption for heating

Category	**Heat consumption for heating** [kWh/m^2]
Zero house	0 - 5
Passive house	6 - 15
Low-energy house	16 – 50
Average house	51 – 150
Old house	Up to 250

1.2 Zero house

Zero houses, also known as a zero-energy houses or net-zero energy building, simply mean that a home produces as much energy as it consume. It minimizes energy use through efficiency and meets remaining needs through renewable energy systems. These buildings do not increase the amount of greenhouse gases in the atmosphere. Most zero houses get half or more of their energy from the grid, and return the same amount at other times. Building which consumes slightly more energy than its own production is called near-zero energy building. [2]

1.3 Passive house

These are buildings that meet certain criteria for energy savings. To achieve these criteria, it uses high quality thermal insulation and smart air-conditioning systems which heat up the air in the winter and cool it down in the summer. For the design and certification of such a house, it is required to meet certain conditions, as the annual heat consumption for heating may not exceed 15 kWh/m^2 of living space per year. [3]

1.4 Low-energy house

Low-energy houses have excellent insulating properties, and thus the low costs for heating compare to traditional house. In these constructions, the annual energy consumption for heating must be less than 50 kWh/m^2 per year. Achieving these values is realized primarily through optimized architectural design of the building envelope and using high quality thermal insulation. Proper function of insulating materials also ensures envelope airtightness. [4]

2 INDOOR ENVIRONMENTAL INPUT PARAMETERS

The energy consumption of buildings depends significantly on the criteria of the internal environment (temperature, ventilation and lighting) and design and operation of buildings. Indoor environment also affects health, productivity and user convenience. Recent studies have shown that good indoor environmental conditions can improve overall work and study performance. In addition, persons dissatisfied with the thermal state can take measures to make themselves feel comfortable, which can have negative energy consequences.

Even today, it is very difficult to create comfortable conditions for persons. Therefore, the parameters for proper environmental conditions are covered by standards ČSN EN 15251.

Indoor air quality in residential buildings depends on many parameters and sources of pollutants, which are the number of people (time availability), emissions from activities (smoking, humidity, intense cooking) emissions from facilities, hobbies, etc. Special attention requires moisture, since most of adverse health effects and construction defects (condensation, mold) are dealing with moisture. Some of these sources of pollutants cannot be influenced or controlled by the designer. [5]

Interior comfort is made up of several components, studying the interaction between them, and how they affect the building and people.

Therefore, interior comfort components are:

- Thermal comfort relative to temperature, humidity, air velocity;
- Acoustic comfort: noise from outside, inside, vibrations;
- Visual comfort and lighting quality: vision, lighting, indicator of brightness, reflection;
- The quality of indoor air pollution, odor, fresh air supply.

2.1 Thermal comfort

One of the most important components of interior comfort, based on a number of criteria and levels of performance established over time in order to obtain the users of the building to a state of satisfaction with the environment (definition on ASHRAE – American Society of Heating, Refrigeration and Air-Conditioning Engineers). Interior comfort also depends on the physical, psychological and sociological profile of each individual and is directly influenced by indoor and surface delimiters of the room temperature, humidity, air velocity and the air conditioning operation.

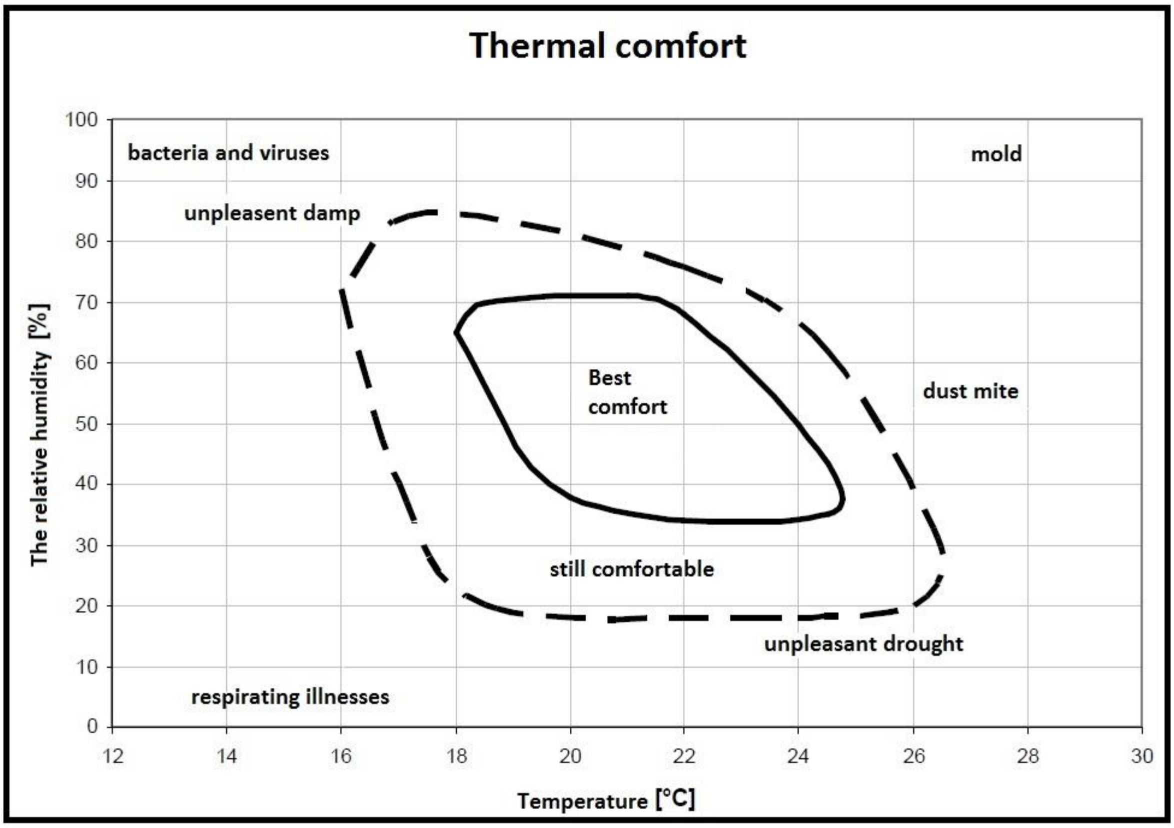


Figure 1: Graph of thermal comfort

2.2 The operative temperature

When considering thermal comfort, there are numbers of criteria. To simplify, we introduce a quantity called operative temperature. This temperature implies an influence of convective air exchange and the effect of heat transfer by radiation. [6]

To determine the operative temperature in a real environment on the measurement basis is needed to measure the mean radiant temperature, air temperature and air velocity. In most cases, the difference between the mean radiant temperature and air temperature is (< 4 °C) and air velocity (< 0.2 $m.s^{-1}$). In such cases, the operative temperature is set as arithmetic average of the meant radiant temperature and air temperature. Otherwise, the operative temperature is calculated according to Formula 1.

$$\Theta_o = A * \Theta_a + (1 - A) * \Theta_r \ [°C] \quad (1)$$

Where:

$\boldsymbol{\Theta_o}$ Operative temperature [°C];

A Coefficient of air velocity according table (Table 2) [-];

$\boldsymbol{\Theta_a}$ Air temperature [°C];

$\boldsymbol{\Theta_r}$ Mean radiant temperature [°C];

Table 2: Coefficient A dependent on the air velocity $\boldsymbol{w_a}$

w_a [m.s^{-1}]	0,2	0,3	0,4	0,6	0,8	1
***A* [-]**	0,5	0,53	0,6	0,65	0,7	0,75

2.3 Air velocity

Air velocity is caused by pressure differences at two places. These differences result in air migration from place with higher pressure to a place with a lower pressure. This migration is characterized by velocity and direction. [7]

2.4 Relative air humidity

Air humidity can be expressed as humidity relative or absolute. Absolute one is understood as a pressure of water vapor in the air, which influences a heat loss by evaporation of persons, which results in thermal equilibrium (entire thermal body comfort).

Relative humidity is indicating the ratio between the amount of water vapor in the air and the amount of vapor that the air would have about the same temperature and pressure at full saturation. In winter, there is usually a low relative humidity and drying out due to high temperature of radiators. If the relative humidity does not reach 20%, it can support dust increasing. On the other hand, combination of exceeding 70% and high temperature can cause a feeling of stuffiness and mold.

$$\varphi = \frac{\mathrm{m}}{\mathrm{M}} * 100 \quad [\%] \tag{2}$$

Where:

φ Relative humidity [%];

m Mount of water vapor in the air [g/m^3];

M Amount of water vapor in the state of saturation [g/m^3].

2.5 PMV

Predicted Mean Vote is a pointer corresponding to the mean thermal sensation based on feedback from a large group of people valuing their feelings using a seven-point scale, based on the thermal equilibrium of the human body. Thermal equilibrium occurs when the internal heat production of the body is equal to the heat loss in a given environment.

Table 3: PMV index

Thermal sensation	**Hot**	**Warm**	**Slightly warm**	**Neutral**	**Slightly cool**	**Cool**	**Cold**
PMV index	3	2	1	0	-1	-2	-3

$$PMV = (0.303 * e^{-0.036} * M + 0.028) * L \quad [-] \tag{3}$$

Where:

PMV PMV index [-];

M Human energy expenditure (metabolic rate) [W];

L Thermal load [W].

L = thermal load – defined as the difference between the internal heat production and the heat loss to the actual environment

PMV can be used to verify whether a given thermal environment meets the criteria of convenience and to establish requirements for different levels of acceptability. Placing PMV = 0 arises equation allowing the combination of weather activity, clothing, and environmental parameters cause thermal neutral feeling. [8]

PMV can be used only if values are in range -2 and +2 (cold – heat, see the table 3) and following 6 parameters are in the given range:

- Heat production (metabolic rate): $\boldsymbol{M}$ = 46 – 232 W/m$^{2;}$
- Clothing insulation: $\boldsymbol{I_d}$ = R_{cl} = 0 – 0.31 (m^2*K)/2;
- Air temperature: $\boldsymbol{t_a}$ = 10 – 30 °C;
- Mean radian temperature: $\boldsymbol{t_r}$ = 10 – 40 °C;
- Air velocity: $\boldsymbol{w_a}$ = 0 – 1 m/s;
- Water vapor partial pressure: $\boldsymbol{p_a}$ = 0 – 2700 Pa. [9]

2.6 PPD

Predicted Percentage Dissatisfied (PPD) – index is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment.

PPD can be calculated from PMV according to the Formula 4.

$$PPD = 100 - 95 * e^{(-0.03353*PMV^4+0.2179*PMV^2)} \quad [\%] \qquad (4)$$

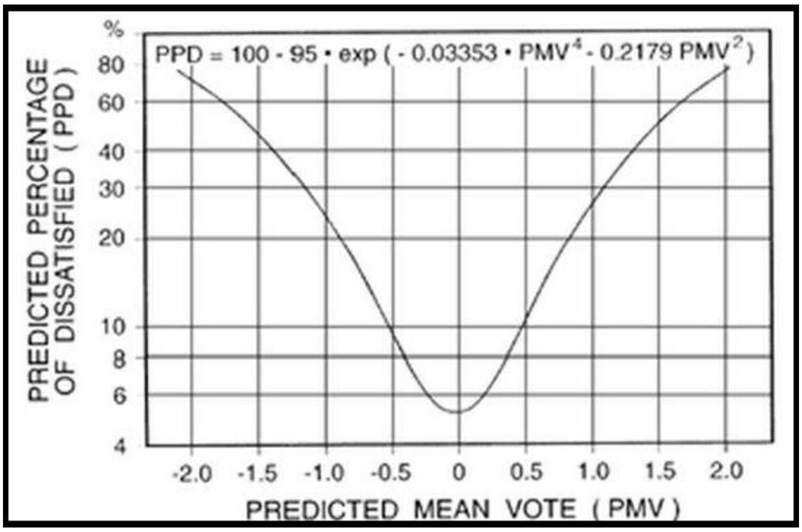


Figure 2: Graph of PMV [10]

2.7 Heat production (metabolic rate)

The metabolic rate, human body heat or power production is often measured in the unit "Met". The metabolic rate of a relaxed seated person is 1 Met, where

$$1\ Met = 58\frac{W}{m^2} \tag{5}$$

The mean surface area of the human body is approximately 1.8 m^2 (19.4 ft^2). The total metabolic heat for a mean body can be calculated by multiplying with the area. The total heat from a relaxed seated person with mean surface area would be

$$58\frac{W}{m^2} * 1.8m^2 = 104\ W \tag{6}$$

Metabolic rate varies on a specific person and its dispositions, on the conditions in which it occurs and the activities it performs. Typical values for some common activities are indicated in the Table 4. [11]

Table 4: Metabolic rates for common activities

Activity	**W/m^2**	**W**	**Met**
Sleeping	46	83	0.8
Seated relaxed	58	104	1
Standing at rest	70	126	1.2
Domestic work – shaving, dressing	100	180	1.7
Domestic work – raking leaves	170	306	2.9
Swimming	348	624	6.2
Running in 15 km/h	550	990	9.5

2.8 Lighting

To perform accurate and efficient visual tasks, people must be given enough light. It is recommended using a daylighting (natural illumination) in place of artificial lighting, which represents a major component of energy consumption in buildings. Proper lighting can enhance task performance, improve the appearance of an area, or have positive psychological effect on occupants. The required level of illumination is independent of the season and for selecting the appropriate type of lighting, we may use criteria as a normal period of use, time of availability and location of the building.

The outdoor light level is approximately 10.000 Lux on a clear day. In the building, in the area closest to windows, the light level may be reduced to approximately 1.000 Lux. In the middle area it may be as low as 25 – 50 Lux. Additional lighting equipment is often necessary to compensate the low levels. Earlier it was common with light levels in the range 100 – 300 Lux for normal activities. Today the light level is more common in the range 500 – 1000 Lux – depending on activity.

- Natural lighting: Illumination from the sun, using windows, light shelves;
- Artificial lighting: Accomplished by using electric devices;
- Hybrid lighting: Combination of natural and artificial illumination. [12]

Table 5: Guidance for recommended light level in different work spaces

Activity	**Illumination**
Public areas with dark surroundings	20 – 50
Working areas where visual task are only occasionally performed	100 – 150
Classes	250
Homes	500
Drawing Work, Detailed Mechanical Workshops	1000
Performance of very special visual tasks of extremely low contrast and small size	10000 – 20000

2.9 Acoustics

Acoustics conditions or noise criteria usually do not affect the building's energy performance. However, in naturally ventilated buildings, it may present a problem when the required amount of outdoor air cannot be supplied with openable widows, because the noise from the outside would be a violation of the criteria. Also in the case of forced ventilation and cooling. Providing required air flow may create unacceptable levels of noise from the fans.

The sound pressure level L_A is expressed in decibels [dB] or [dB (A)], which are decibels with filter applications, which is sensitive to the human ear. The noise is perceived subjectively. Someone hears better, someone worse. But there are certain limits, from the level of silence to the level of unpleasant noise. The standard ČSN EN 15 251 specifies values for residential buildings only for living room and bedroom. The living room has a standard design value L_A 32 dB and typical range from 25 – 40 dB. In the bedroom standard identifies 26 dB and a typical range of 20 – 35 dB. [13]

Table 6: Examples of noise levels effects

Psycho-physiological disorders	**Noise level, [dB (A)]**
Threshold of hearing	0
Quiet area	20 – 30
Inconvenience to the rest and physiological effects	40 – 50
Intellectual working capacity decrease	50 – 60
Routine work capacity decrease	60 – 70
Sleep and intellectual work failure	70 – 80
Unable to work, psychophysiological disorders	> 80

3 EXTERNAL CLIMATIC CONDITIONS

Among external climatic conditions, there are such quantities that depend on location, time of day and year and affect climatic conditions inside the building. It affects not only humans, but the lifetime of buildings and technical equipment as well.

3.1 External climatic temperature

It is a fundamental variable, which is considered in the design of HVAC systems. It is determined as the average of five coldest consecutive days in the winter. Those values are detected by long meteorological measurements. In the Czech Republic, the design temperatures are set between -12 °C and -18 °C.

3.2 Air Humidity

Humidity is influenced by geographical location, proximity of watercourses and water bodies, intensity of rainfall and annual and time of day. If the humidity is higher, there is increase of the moisture content within walls of the house, resulting in higher heat loss of the object.

3.3 The wind

The airflow is caused by pressure differences that determine the direction and airflow. In the Czech Republic, wind speed averages are about 4 to 10 m/s.

3.4 Air pressure

Pressure exerted by the weight of air in the atmosphere. In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point. The pressure decreases with increasing elevation.

3.5 Solar radiation

The intensity of solar radiation is measured as the solar constant, in range from 1340 W/m^2 to 1380 W/m^2. It is one of the main and important sources of light and heat. Solar energy gets into buildings and objects due to convection and radiation through structures and glass surfaces. The amount of solar radiation is dependent on the orientation of the house, the geographic location. In some areas, importance of sky pollution may be important as well, especially in areas of cities and industrial zones, where the pollution is higher than in the mountain areas.

4 REQUIREMENTS OF PHYSICAL CONSTRUCTION PARAMETERS

Ensuring heating technology provides mainly prevention of thermal technical defects and failures of buildings, thermal comfort, protection of health and healthy living conditions. For an economically reasonable working life of structures and buildings, it is required to comply with thermal technical standards working of commonly foreseeable actions.

4.1 Thermal conductivity

Thermal conductivity or heat transfer in the construction, are directly related to the issue of exploring certain parameters of the building, which are important for people living inside. This includes temperature of the inner surface, decrease of contact temperature or U value.

4.2 The lowest temperature of the inner surface

The inner surface temperature is appropriate to evaluate in a ratio of the inner surface temperature factor. The temperature factor is a pure design feature or relations structures in a given place, which is independent of the adjacent ambient temperatures.

$$f_{R_{si}} = 1 - U_x * R_{si} \tag{7}$$

Where:

f_{Rsi} Inner surface factor [-];

U_x Local U value at the point x in the inner surface [W/(m^2*K)];

R_{si} R value during heat transfer;

At the inner side of filling spaces R_{si} = 0.13 [(m^2*K)/W];

At the inner side of construction R_{si} = 0.25 [(m^2*K)/W].

During the winter period, the construction has to meet the condition $f_{Rsi} \geq f_{Rsi,N}$ at any point of the construction. $f_{Rsi,N}$ is the setpoint of the lowest inner surface factor. [14]

4.3 U value

It is a measure of heat loss in a building element such as a wall, floor or roof area of 1 m^2 at a temperature difference 1 K between the surfaces. It can also be referred to as an overall heat transfer coefficient and measure how well parts of a building transfer heat. This includes the exchange of heat between two spaced environments in a steady state. It includes the effect of thermal bridges, which are part of the structure. Heated objects have to have a relative humidity of indoor air up to 60% and U value less or equal to the desired value.

$$U \leq U_N \quad [W/(m^2*K)] \tag{8}$$

Where:

U	U value [W/(m^2*K)];
U_N	required value of U [W/(m^2*K)].

U value is calculated using either of the thermal conductivity and thickness of the structure (Formula 9), or by R values (Formula 10).

$$U = \frac{1}{(\frac{1}{h_i}+\sum\frac{d}{\lambda}+\frac{1}{h_e})} \quad [W/(m^2*K)] \tag{9}$$

Where:

h_i	Internal surface coefficient of heat transfer, h_i = 8 [W/(m^2*K)];
d	Thickness of each structure layer [m];
λ	Thermal conductivity coefficient [W/(m^2*K)];
h_e	External surface coefficient of heat transfer, h_e = 23 [W/(m^2*K)].

$$U = \frac{1}{(R_i + \sum R_N + R_e)} \text{ [W/(m}^2\text{*K)]} \quad (10)$$

Where:

$\boldsymbol{R_i}$ ***R*** value at inner side [(m^2*K)/W];

$\boldsymbol{R_N}$ ***R*** value of each structure layer [(m^2*K)/W];

$\boldsymbol{R_e}$ ***R*** value of outdoor side [(m^2*K)/W].

4.4 The Average U value

U value of the building envelope is evaluated by using an average U value, which has to be less or equal to desired U value. Thus value expresses fundamental effect of building solution for heat consumption. Required and recommended values of the average U values are shown in the Table 7.

Table 7: Required and recommended U values [14]

Volumetric shape factor of the building ***A/V*** **[m²/m³]**	***$U_{em,N}$*** **[W/(m2*K)]**	
	Required values ***$U_{em,N,rq}$*** **[W/(m2*K)]**	**Recommended values** ***$U_{em,N,rc}$*** **[W/(m2*K)]**
≤0.2	1.05	0.79
0.3	0.8	0.6
0.4	0.68	0.51
0.5	0.6	0.45
0.6	0.55	0.41
0.7	0.51	0.39
0.8	0.49	0.37
0.9	0.47	0.35
≥1	0.45	0.34
Intermediate values	$0.3+\frac{0.15}{\frac{A}{V}}$	0.75* $\boldsymbol{U_{em,N,rq}}$

The average U value is calculated from:

$$U_{em} = \frac{H_T}{A} \text{ [W/(m2*K)]} \tag{11}$$

Where:

$\boldsymbol{U_{em}}$ The average ***U value*** [W/(m2*K)];

$\boldsymbol{H_T}$ The specific loss of heat transfer [W/K];

A Surface of building envelope [m²].

$$H_T = U * A * b \ \ [\text{W/K}] \quad (12)$$

Where:

b Coefficient of thermal reduction;

U U value.

Table 8: Designed values for coefficient of thermal reduction

Structure		**Coefficient of thermal reduction *b* [-]**	
		Fully heated	**Partially heated**
Windows, doors, etc.		1.15	0.52
Roofs and ceilings above the outdoor environment		1	0.71
Curtain wall		1	0.71
Attic, roof space	Uninsulated, roofless	0.83	0.54
	Uninsulated, sealed	0.74	0.46
	Insulated, sealed	0.57	0.29
Basement, technical floor	Completely under the terrain	0.43	0.14
	Partially under the terrain	0.49	0.2
	Ventilated	0.57	0.29
Adjacent garage above the ground, winter garden, etc.		0.49	0.2

4.5 Moisture characteristics of structures

The water vapor, formed by condensation, may occur inside the structure. This water steam directly affects the function of the structure, such as the lifetime, increasing weight and it may also lead to a mold formation. Thus, any such condensation shall be prevented.

For building structures where the condensation of water vapor inside the structure deteriorates its desired function of limiting the annual amount of condensed water.

$$M_C \leq M_{C,N} \text{ [kg/(m}^2\text{*year)]} \tag{13}$$

Where:

M_C Annual amount of condensed water steam [kg/(m^2*year)];

$M_{C,N}$ Maximal amount of condensed water steam [kg/(m^2*year)].

For single-roof structures, structures with integrated door elements, structures with external thermal insulation, or another peripheral structure with low diffusion permeable outer surface layers is the value of the maximal annual amount of condensed water according to the Formula 14 or 3% of the basis weight material, in which occurs condensation of water steam, if its density is higher than 100 kg/m^3. For materials with a density lower than 100 kg/m^3, it is recommended using 6% of its basis weight.

$$M_{C,N} = 0.1 \frac{kg}{(m^2 * a)} \tag{14}$$

For other structures, we assume 5% of its basis weight in cases of density higher than 100 kg/m^3. If the density is lower than 100 kg/m3, we consider 10% of its basis weight.

The average annual value of condensed water vapor inside the structure has to be lower than the average annual value of water vaporised inside the structure.

$$M_C \leq M_{ev} \text{ [kg/(m}^2\text{*year)]} \quad (15)$$

Where:

M_{ev} Average annual value of water vaporised inside the structure [kg/(m^2*year)].

4.6 Thermal stability of the room

It specifies a requirement, that the thermal state of the room was in a given temperature range for a given time period. We distinguish between the thermal stability during a winter and a summer season.

4.6.1 Thermal stability in winter season

At the end of the cool-down period, a critical room has to meet criteria of the Formula 16. In most cases, the critical room is situated in a corner of the house, under the roof and has the highest ***U value***.

$$\Delta\phi_V(t) = \Delta\phi_{V,N}(t) \text{ [°C]} \quad (16)$$

Where:

$\Delta\phi_V(t)$ Temperature's decrease during winter season [°C];

$\Delta\phi_{V,N}(t)$ Required temperature's decrease during winter season [°C].

Table 9: Required values of temperature's decrease during winter season

Type of room		**Temperature's decrease during winter season $\Delta\phi_{V,N}(t)$ [°C]**
Residence of people after heating	Heating by radiators, radiant panels and warm-air system	3
	Heating by hearth and floor heating	4
No people residence after heating	Massive building	6
	Slight building	8

4.6.2 Thermal stability in summer season

The critical room has to follow Formula 17.

$$\theta_{ai,max} \leq \theta_{ai,max,N} \ \ [°C] \tag{17}$$

Where:

$\theta_{ai,max}$ The highest daytime temperature in the room [°C];

$\theta_{ai,max,N}$ The required value of highest daytime temperature in the room [°C].

Table 10: The highest daytime temperature in the room

Type of building		The highest daytime temperature in the room [°C]
Nonindustrial		27
Others with internal heat source	Up to 25 W/m^3	29.5
	Over 25 W/m^3	31.5

In this case, a critical room is considered as the one with the largest area of sunlight on a transparent structure, relative to the floor surface. Most often, the critical room is oriented to the west, southwest, south, southeast, east.

We must remember that cooling-down will result to significantly higher energy consumption. Thus, it is advisable to design those systems only in cases, where the previous requirements cannot be met by building solutions. [15]

4.7 Heat loss

Knowledge of heat loss is very important for designing houses. It is well described in standard ČSN EN 12831.

The total design heat loss of heated area is calculated by using design heat loss through heat transfer and design heat loss through ventilation, as shown in Formula 18.

$$\Phi_i = \Phi_{T,i} + \Phi_{V,i} \ \text{[W]} \tag{18}$$

Where:

ϕ_i Total heat loss [W];

$\phi_{T,i}$ Total heat loss through heat transfer [W];

$\phi_{V,i}$ Total heat loss through ventilation [W].

4.7.1 Designed heat loss through heat transfer

This value is dependent on the surrounding structures and rooms, which are exchanging the thermal energy between each other. Furthermore, heat loss may increase due to heat transfer into the terrain.

$$\Phi_{T,i} = \left(H_{T,ie} + H_{T,iue} + H_{T,ig} + H_{T,ij}\right) * (\theta_{int,i} - \theta_e) \text{ [W]} \tag{19}$$

Where:

- $\boldsymbol{\phi_{T,i}}$ Total heat loss through heat transfer [W];
- $\boldsymbol{H_{T,ie}}$ Coefficient of heat loss through heat transfer from heated space to outdoor area through construction [W/K];
- $\boldsymbol{H_{T,iue}}$ Coefficient of heat loss through heat transfer from heated space to outdoor area through unheated space [W/K];
- $\boldsymbol{H_{T,ig}}$ Coefficient of heat loss through heat transfer from heated space into the terrain [W/K];
- $\boldsymbol{H_{T,ij}}$ Coefficient of heat loss through heat transfer from heated space to surrounding area heated at different temperature [W/K];
- $\boldsymbol{\theta_{int,i}}$ Calculated indoor temperature [°C];
- $\boldsymbol{\theta_e}$ Calculated outdoor temperature [°C].

4.7.2 Designed heat loss through ventilation

This value is very important for the thermal comfort and for hygienic criteria, too.

$$\Phi_{V,i} = H_{V,i} * (\theta_{int,i} - \theta_e) \text{ [W]} \tag{20}$$

Where:

- $\boldsymbol{\phi_{V,i}}$ Total heat loss through ventilation [W];
- $\boldsymbol{H_{V,i}}$ Coefficient of heat loss through ventilation, calculated from Formula (21) [W/K];
- $\boldsymbol{\theta_{int,i}}$ Calculated indoor temperature [°C];
- $\boldsymbol{\theta_e}$ Calculated outdoor temperature [°C].

$$H_{V,i} = V_i * \rho * c_p \ \text{[W/K]} \tag{21}$$

Where:

$\boldsymbol{H_{V,i}}$ Coefficient of heat loss through ventilation [W/K];

$\boldsymbol{V_{,i}}$ Air exchange of heated space [m^3/s];

$\boldsymbol{\rho}$ Air humidity at a particular temperature [kg/m^3];

$\boldsymbol{c_{,p}}$ Specific heat capacity of the air at a particular temperature [kJ/kg*K].

4.8 Heat gains

Heat gains can be divided into two basic groups. The first one is an internal heat gain, created inside the building. The second one is an external heat gain, located outside the building.

4.8.1 Internal heat gains

Those gains may be caused by animate and inanimate objects that produce thermal energy. The total value of internal heat gains is the sum of all internal thermal sources.

Heat gains from animate objects are dependent on the activity and the size of the object. In most cases, these gains are provided by a person or a pet.

Inanimate sources of internal heat gains are mainly electrical appliances. The biggest role is played by lighting, computers, televisions or housework such as laundry, washing dishes, etc.

4.8.2 External heat gains

The most important component is a solar radiation. It is not permanent and depends on the season. The solar radiation consists of heat gain by convection (Formula 22) and radiation (Formula 23).

$$Q_{CON} = U_W * A_W * (\theta_e * \theta_i) \ \ [\text{W}] \qquad (22)$$

Where:

$\boldsymbol{Q_{CON}}$ Heat gain by convection [W];

$\boldsymbol{U_O}$ U value of window [W/(m^2*K)];

$\boldsymbol{A_O}$ Surface of the window, with frame [m^2];

$\boldsymbol{\theta_e}$ Computation surface of exterior [°C];

$\boldsymbol{\theta_i}$ Computation surface of interior [°C].

$$Q_{RAD} = [A_{WS} * I_W * c_a + (A_W - A_{WS}) * I_{DIF}] * \tau \ \ [\text{W}] \qquad (23)$$

Where:

$\boldsymbol{Q_{RAD}}$ Heat gain by radiation [W];

$\boldsymbol{A_{WS}}$ Surface of window under the sunlight [m^2];

$\boldsymbol{I_W}$ Intensity of solar radiation through single glaze [W/m^2];

$\boldsymbol{c_a}$ Index of atmospheric purity [-];

$\boldsymbol{A_W}$ Surface of window with frame [m^2];

$\boldsymbol{I_{DIF}}$ Intensity of solar radiation obtained by diffusion through a single glazing [W/m^2];

$\boldsymbol{\tau}$ Shading coefficient [-].

Table 11: Shading coefficient for various versions of windows and blinds [16]

Material	**τ**
Window with a single glazing	1
Window with a double glazing	0.9
Window with a triple glazing	0.7
Inner blinds 45°, bright colour	0.56
Inner blinds, 45°, dark colour	0.75
Reflective curtain, bright colour	0.6
Reflective curtain, dark colour	0.7

4.8.3 Location of a building in the terrain

The most important requirement for the location of a building in the terrain is the orientation of the building. The biggest amount of thermal energy from sunlight is penetrated into buildings through transparent structures. Therefore, it is important to design the location and orientation of the house so, that the side with biggest concentration of transparent structures is oriented to the south side and at the same time, these transparent structures are not shielded by nearby objects. With large areas of transparent structures we can gain not only a lot of heat, but there may be several troubles too, such as privacy breach, overheating of the object during hot summer months or enormous heat loss in winter months.

Problem with overheating of the object in hot summer months can be resolved by installing shading systems, such as shading blinds and roller blinds. In the case of high heat losses, we must ensure application of suitable insulation between transparent structures and walls of the house, where the highest heat loss is. [16]

4.8.4 Structures and walls of the house

Nowadays, modern houses are based on low energy consumption, which is related to perfect thermal insulation. Such insulation can be 50 cm wide. Insulation is not important only between structures connecting outdoor and indoor environment, but also in case of internal structures between heated and unheated space (garage, basement, etc.).

The ideal design of a modern house and its construction cannot be based on any versatile model. It is necessary to proceed with the project individually and carefully examine its specifications and design a particular solution. The final design should be thermal bridge free and airtight.

It seems, that smaller diameter of bearing brickwork, subsequently supplemented by an insulating material is rather chosen. Also, a sandwich structure is popular, where the insulation is situated between two layers of the wall. [17]

4.8.5 Glass surfaces and windows

Low-energy houses widely use glass surfaces and windows for heat extract. It is important that these areas have higher thermal solar gains than heat losses. Roughly, more energy has to fall into the room than it escapes out. The most important element in the design of such surfaces is the quality. The ideal solution is offered by triple low-e glazing windows or systems where the middle glass pane is replaced by a reflecting film or a selective layer, which acts as a semipermeable membrane. It lets the solar radiation in, which is in the object converted into heat, and the membrane stops and reflects the heat inside the room.

Another frequently used element used for glass surfaces is a layer between glass panes. It rules here, that the thicker the layer is, the better it isolates. On the market, triple glazing windows with a gap 16 – 44 mm are common. These gaps are filled with argon or another noble gas with good insulating properties.

Frames of glazed surfaces are important as well. Unfortunately, they have less thermal insulation than glass surface itself. Various materials are used for the frames, such as wood or plastic. These frames are usually insulated with a polyurethane insulation.

There is always an option of supplementing the household of air-conditioning. In this case, unopenable windows, whose price is lower, can be used. However, for safety reasons (in case of power failure), in every room has to be at least one openable window. [17]

5 ENERGY CONSUMPTION IN THE BUILDING

Assessing the energy performance of the building relates to builders, owners and operators of buildings. These demands are placed on the energy performance of the building during its construction, renewals and enhancements of the building, energy rating in the sale or rental or duty to process the energy performance certificate for government departments.

5.1 Energy Performance Certificate

The energy performance of buildings (EPC) is a hot topic of nowadays. In Czech Republic, from January 1st, 2013 came into a force a duty of energy performance certificate. This is an output of the energy audit, which can be done only by a certified person, who classifies the building into one of seven categories of energy according to its energy demands. The most important parameter, which is observed for all building's structures, is the U value. This coefficient is expressed in watts and it indicates the heat loss of the structure under thermodynamic temperature of 1 K relative to the 1 m^2 area.

An energy performance certificate tells you how energy efficient a home is on a scale of A – G. The most efficient homes, which should have the lowest fuel bills, are in band A. The certificate is valid for 10 years.

The EPC in Czech Republic displays parameters such as:

- Total primary energy per year;
- Non-renewable primary energy per year;
- The total energy delivered per year;
- Sub-supplied energy for HVAC systems;
- The average U value;
- U value for each structures at system limit;
- The efficiency of HVAC.

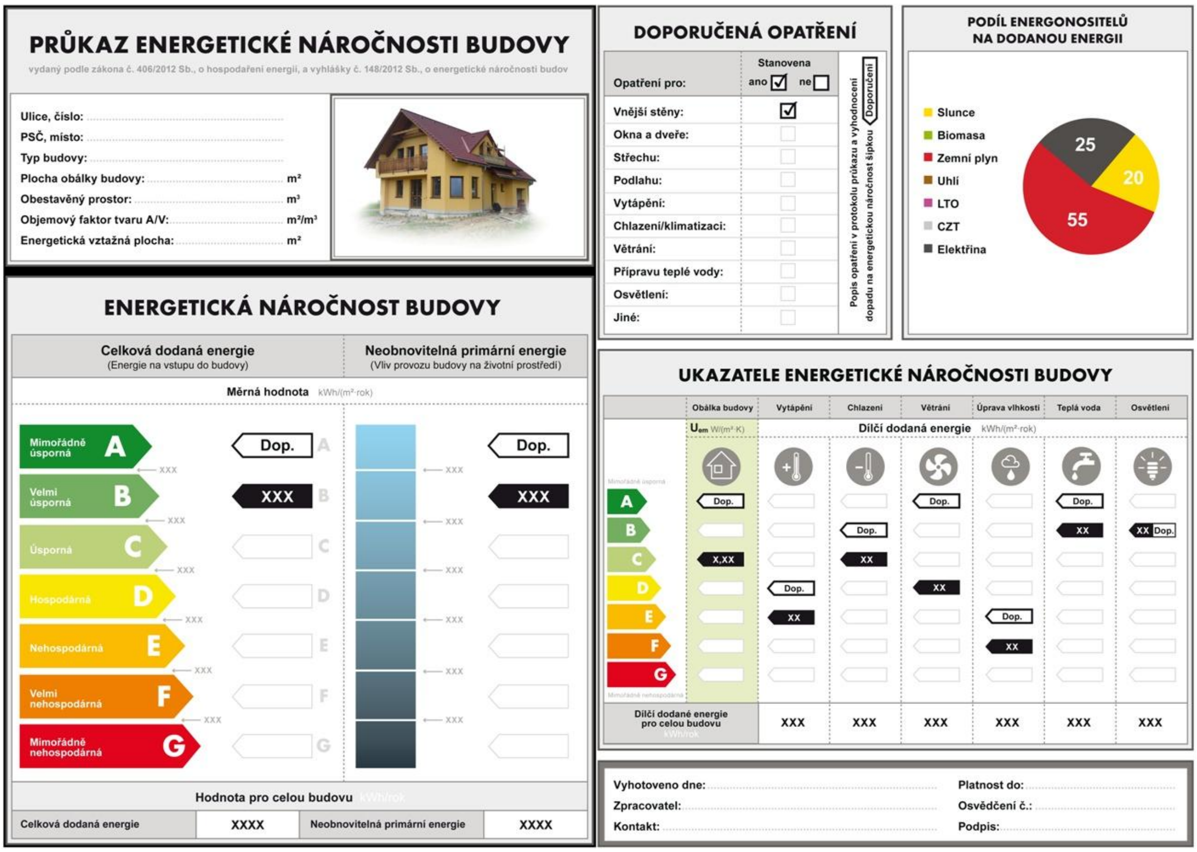
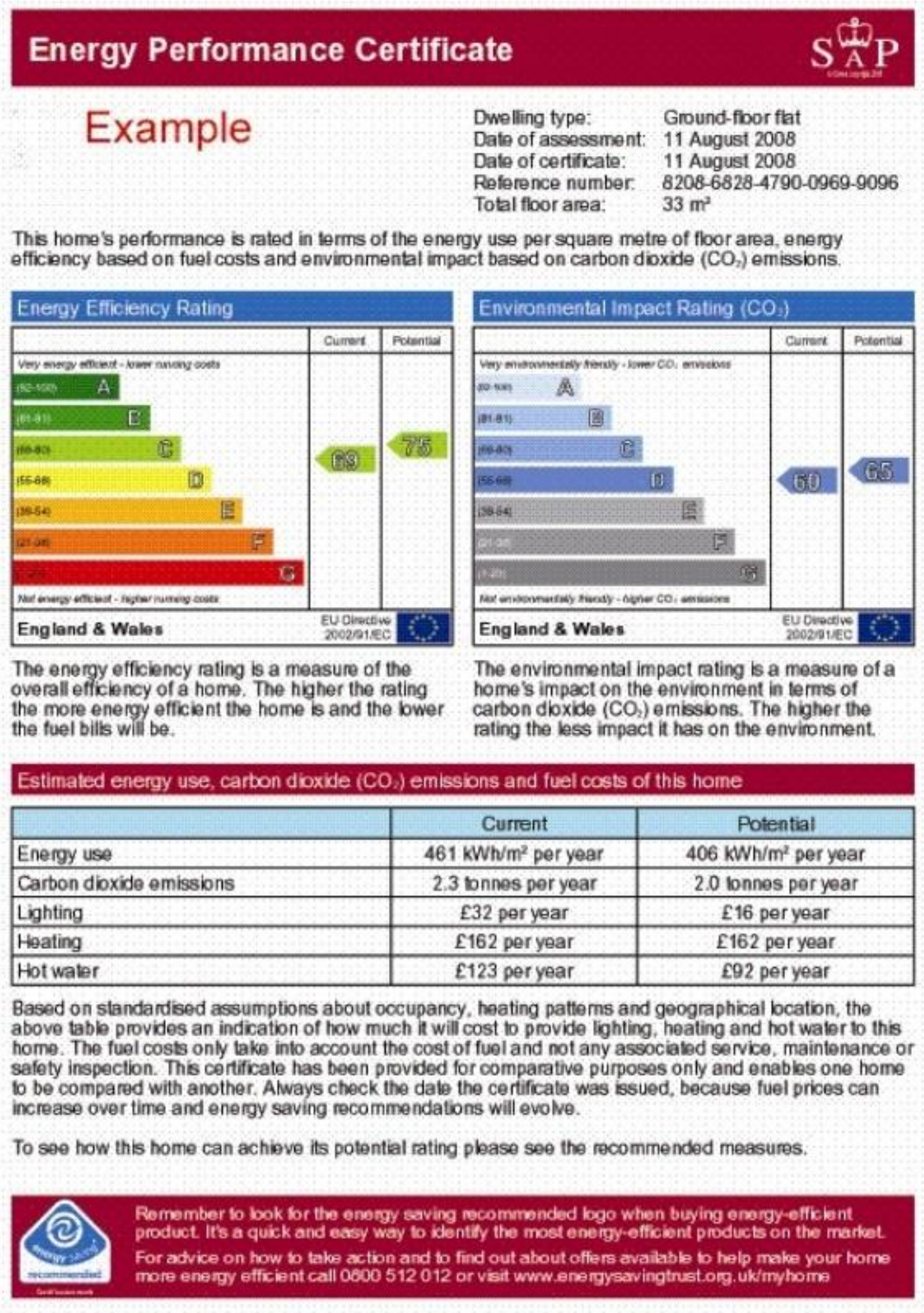


Figure 3: Example of EPC in Czech Republic



Energy Performance Certificate

SAP

Example

Dwelling type:	Ground-floor flat
Date of assessment:	11 August 2008
Date of certificate:	11 August 2008
Reference number:	8208-6828-4790-0969-9096
Total floor area:	33 m²

This home's performance is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO_2) emissions.

Energy Efficiency Rating

	Current	Potential
Very energy efficient - lower running costs		
(92-100) A		
(81-91) B		
(69-80) C	69	75
(55-68) D		
(39-54) E		
(21-38) F		
(1-20) G		
Not energy efficient - higher running costs		
England & Wales	EU Directive 2002/91/EC	

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills will be.

Environmental Impact Rating (CO_2)

	Current	Potential
Very environmentally friendly - lower CO_2 emissions		
(92-100) A		
(81-91) B		
(69-80) C		
(55-68) D	60	65
(39-54) E		
(21-38) F		
(1-20) G		
Not environmentally friendly - higher CO_2 emissions		
England & Wales	EU Directive 2002/91/EC	

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating the less impact it has on the environment.

Estimated energy use, carbon dioxide (CO_2) emissions and fuel costs of this home

	Current	Potential
Energy use	461 kWh/m² per year	406 kWh/m² per year
Carbon dioxide emissions	2.3 tonnes per year	2.0 tonnes per year
Lighting	£32 per year	£16 per year
Heating	£162 per year	£162 per year
Hot water	£123 per year	£92 per year

Based on standardised assumptions about occupancy, heating patterns and geographical location, the above table provides an indication of how much it will cost to provide lighting, heating and hot water to this home. The fuel costs only take into account the cost of fuel and not any associated service, maintenance or safety inspection. This certificate has been provided for comparative purposes only and enables one home to be compared with another. Always check the date the certificate was issued, because fuel prices can increase over time and energy saving recommendations will evolve.

To see how this home can achieve its potential rating please see the recommended measures.

energy saving recommended

Remember to look for the energy saving recommended logo when buying energy-efficient product. It's a quick and easy way to identify the most energy-efficient products on the market.

For advice on how to take action and to find out about offers available to help make your home more energy efficient call 0800 512 012 or visit www.energysavingtrust.org.uk/myhome

Figure 4: Example of EPC in UK

6 HVAC SYSTEMS

Selection of appropriate HVAC systems depends on the availability of resources and on parameters of the building. The most efficient way is to use resources which are available close to the building. For a regular family house, it is mostly a presence of gas connection. Low-energy and passive houses are equipped with extra systems based on renewable and alternative energy sources, such as heat pumps, solar collectors or photovoltaic panels.

Before I will start describing particular HVAC systems, I would like to mention two main categories of energy resources.

Non-renewable resource

A finite resource which does not renew itself at a sufficient rate for sustainable economic extraction in a meaningful human time-frame. Non-renewable resources can be separated into two main categories, fossil (gas, coal) and nuclear fuels (uranium).

Renewable resource

These resources are an important aspect of sustainability. Renewable resource is an organic natural resource which can be regenerated or replenished. The most frequently used resources are biomass, water, wind, solar and geothermal.

6.1 Heat pump

A heat pump is a device that is able to transfer heat from one fluid at a lower temperature to another at a higher temperature. Heat pumps owe their name to the fact that they allow heat to be carried from a lower to a higher temperature level, inverting natural heat flow, which in nature tends to be from a higher to a lower temperature. The function of the heat pump may therefore be compared to that of a water pump positioned between two water basins that are connected to each other but which are located at different altitudes. The water will naturally flow from the higher to the lower basin. It is, however, possible to return water to the higher basing by using a pump, which draws water from the lower one.

A heat pump consists of a closed circuit through which a special fluid (refrigerant) flows. This fluid takes on a liquid or gaseous state according to temperature and pressure conditions.

This closed circuit consists of a compressor, a condenser, an expansion valve and an evaporator. The condenser and the evaporator consist of heat exchangers, i.e. special tubes placed in contact with service fluids (which may be water or air) in which the refrigerant flows. The latter transfers heat to the condenser (the high temperature side) and take it away from the evaporator (the low temperature side). [18]

During operation, the refrigerant, inside the circuit, undergoes the following transformations:

- **Condensation:** refrigerant flowing from the compressor passes from a gaseous to liquid state, giving of heat to the outside;

- **Expansion:** passing through the expansion valve, the liquid refrigerant cools and is partially transformed into vapour;

- **Evaporation:** the refrigerant absorbs heat and evaporates completely;

- **Compression:** the refrigerant, in a gaseous state and at low pressure, coming from the evaporator, is taken to a high pressure. During compression it is heated, absorbing a certain amount of heat.

All of these transformations together make up the electric heat pump's cycle. The compressor provides the refrigerant with energy. The refrigerant absorbs heat in the evaporator from the surrounding medium, and through the condenser, transfers it to the medium to be heated.

During its operation, a heat pump:

- Consumes electrical energy for the compressor;
- Absorbs heat in the evaporator from the surrounding medium, which may be air or water;
- Gives off heat to the medium to be heated in the condenser (air or water). [18]

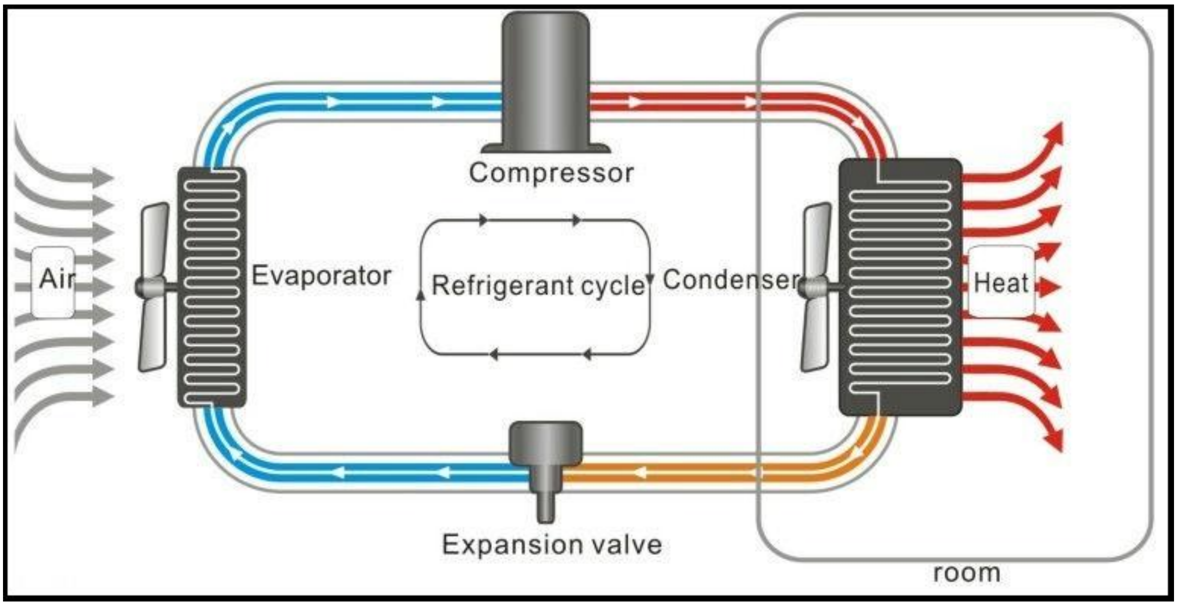


Figure 5: Heat pump working principle [19]

Heat pumps can be categorised on the basis of cold source and hot source that they use. According to the fluid used for the transfer of heat from the cold source to the heat pump, and from the heat pump to the hot source, there may be four types.

Types of heat pumps:

- Air – water;
- Air – air;
- Water – water;
- Water – air. [20]

The efficiency of an electric heat pump is measured by its ***COP***, coefficient of performance, which is the ratio of the energy it supplies (heat transferred to the medium to be heated), to the electrical energy it consumes. The ***COP*** varies according to the type of heat pump and operating conditions. If the heat pump has a ***COP*** 2,5 it means, that for each kWh of electrical energy consumed, it will supply about 2,5 kWh of heat energy to the medium to be heated. [21]

$$COP = k * \frac{\theta_s}{\theta_s - \theta_z} \tag{24}$$

Where:

- $\boldsymbol{k}$ Correlation coefficient respecting the actual circulation ($\boldsymbol{k}$ = 0,4 to 0,6) [-];
- $\boldsymbol{\theta_s}$ The absolute temperature of the heat appliance [K];
- $\boldsymbol{\theta_z}$ The absolute temperature of the heat source [K].

From September 26th, 2015, all heat pumps with power rating until 70 kW, must be equipped with energy labels. In parallel, to this data, they also have to meet the minimum seasonal energy efficiency of heating.

6.2 Solar Collectors

A solar collector transforms solar radiation into heat and transfers that heat to a medium (water, solar fluid, or air). Solar heat can be used for heating water, to back up heating systems or for heating swimming pools.

The heart of a solar collector is the absorber, which is usually composed of several narrow metal strips. The carrier fluid for heat transfer flows through a heat-carrying pipe, which is connected to the absorber strip. In plate-type absorbers, two sheets are sandwiched together allowing the medium to flow between the two sheets. Absorbers are typically made of copper or aluminium. On the other hand, swimming pool absorbers are usually made of plastic, as the lower temperatures involved do not require greater heat capacity. [22]

Heating and storage are united in reservoir collector. Arrays of reservoir collectors do not need circulating pumps or regulating mechanisms, as the drinking water is warmed and stored right in the collector.

Absorbers are usually black, as dark surfaces demonstrate a particularly high degree of light absorption. The level of absorption indicates the amount of short-wave solar radiation being absorbed. As the absorber warms up to a temperature higher than the ambient temperature, it gives off a great part of the accumulated solar energy in form of long-wave heat rays. The ratio of absorbed energy to emitted heat is indicated by the degree of emission.

In order to reduce energy loss through heat emission, the most efficient absorbers have a selective surface coating. This coating enables the conversion of a high proportion of the solar radiation into heat, simultaneously reducing the emission of heat. The usual coatings provide a degree of absorption of over 90%. [22]

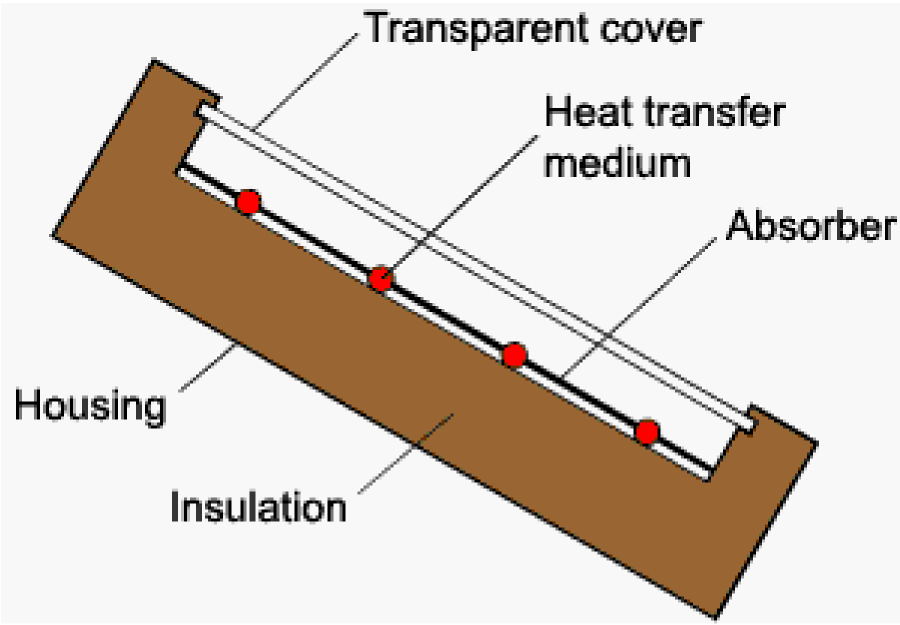


Figure 6: Flat-plate collectors [22]

6.3 Photovoltaics

This method is converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. Photovoltaics are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons. The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current.

Solar cells are composed of various semiconducting materials. Semiconductors are materials, which become electrically conductive when supplied with light or heat, but which operate as insulators at low temperatures. Over 95% of all solar cells produced worldwide are composed of the semiconductor material silicon. [23]

One can distinguish three cell types according to the type of crystal:

- **Monocrystalline**: monocrystalline rods are extracted from melted silicon and then sawed into thin plates. This production process guarantees a relatively high level of efficiency;
- **Polycrystalline**: production of polycrystalline cell is more cost-efficient. In this process, liquid silicon is poured into blocks that are subsequently sawed into plates;
- **Amorphous**: if a silicon film is deposited on glass or another substrate material, this is so-called amorphous or thin layer cell. The layer thickness amounts to less than 1μm (human hair = 50 – 100μm), so the production costs are lower due to the low material costs. Because of lower efficiency, they are primarily used in low power equipment such as watches, pocket calculators, etc.

Table 12: Efficiency of silicon cell types [24]

Material	**Efficiency in lab [%]**	**Efficiency [%]**
Monocrystalline	Approx. 24	14 – 17
Polycrystalline	Approx. 18	13 – 15
Amorphous	Approx. 13	5 – 7

6.3.1 Design of photovoltaics

First of all, it is necessary to determine the size of area where the photovoltaics can be used. After that, the approximate performance can be calculated according to Formula 25.

$$P_{PP} = A * \eta \ \text{[kW]} \tag{25}$$

Where:

P_{PP} Capacity factor of photovoltaics [kW];

A Available area [m^2];

η Efficiency of photovoltaics [%].

The capacity factor will help us to calculate an annual photovoltaics yield. For this calculation, we need to know an annual solar energy, energy gain in the given inclination of photovoltaics and performance ratio, whose value is shown in the Table 12.

$$E_{EL} = H_{SOLAR} * f_{INCLIN} * P_{PP} * PR \ \text{[kWh/year]} \tag{26}$$

Where:

E_{EL} Yeild of photovoltaics [kWh/year];

H_{SOLAR} Annual solar energy, Czech Republic usually 1000 [kWh/m^2];

f_{INCLIN} Energy gain in the given inclination [-];

P_{PP} Capacity factor of photovoltaics [kW];

PR Performance ratio [-] (table 13).

Table 13: Performance ratio

Characteristic of the system	**Performance ratio**
Excellent system, ventilated, unshadowed, small pollution	0.85
Good system, ventilated, unshadowed	0.8
The average level of system	0.75
The average level of system, due to bad ventilation and shading	0.7
Poor level of system, high loss caused by shading, pollution	0.6
Very bad system with major shading and malfunctions	0.5

6.4 Hot water preparation

Hot water preparation should be designed so that the temperature of hot water is in range 50 – 55°C. This final temperature may differ in special cases. The basic need for hot water is described in ČSN 06 0320. It indicates that the need for hot water is 82 litres per person and heating of this amount of water consumes 4.3 kWh. [25]

$$Q_{TP} = n * 4{,}3 \ \text{[kWh]} \tag{27}$$

Where:

$\boldsymbol{Q_{TP}}$ Total need of heat [kWh];

$\boldsymbol{n}$ Number of residents.

Heat loss during a preparation and distribution:

$$Q_{ZP} = 0{,}5 * Q_{TP} \text{ [kWh]} \quad (28)$$

Where:

Q_{ZP} Heat loss during a preparation and distribution [kWh];

Q_{TP} Total need of heat [kWh].

Total need of heat supplied by heater:

$$Q_P = Q_{TP} + Q_{ZP} \text{ [kWh]} \quad (29)$$

Where:

Q_P Heat supplied by heater [kWh];

Q_{TP} Total need of heat [kWh];

Q_{ZP} Heat loss during a preparation and distribution [kWh].

The entire amount of water that we use is not the same throughout the day, it is consumed unevenly. Therefore, it is necessary to divide a period of warming on daily sections and its heat consumptions. Individual parts determine how much heat is consumed in each section. This sections are determined according the claims of the house and are evaluated as a proportional sampling curve. [25]

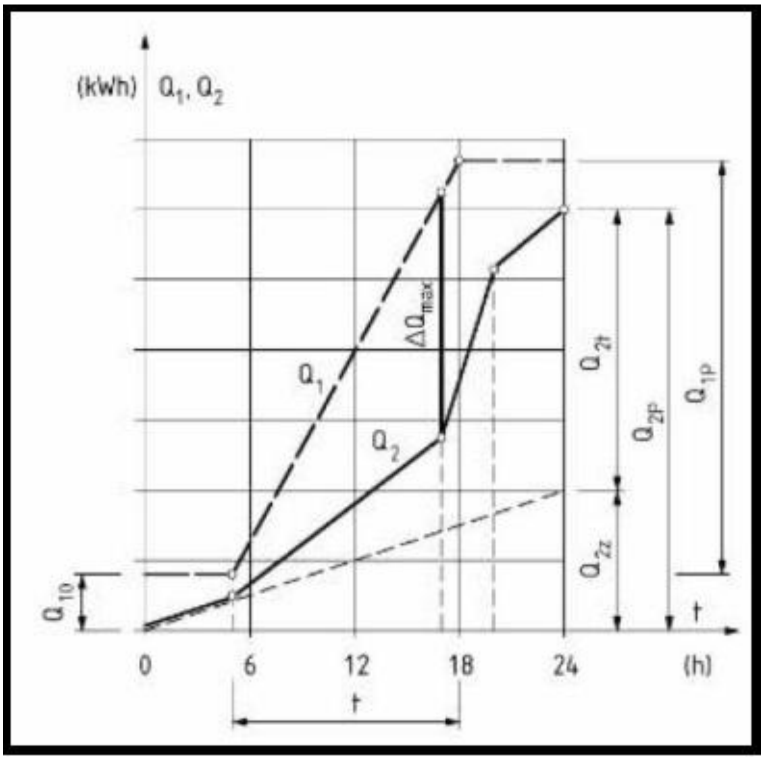


Figure 7: Proportion sampling curve of hot water

From this curve we can determine the greatest difference of taken heat from which we set size of the water tank and nominal heat output of hot water heater.

$$V_Z = \frac{\Delta Q_{max}}{c_p * \Delta\theta} \text{ [l]} \tag{30}$$

Where:

Vz	Size of water tank [l];
ΔQmax	The biggest difference of heat removed in daily sections [kWh];
cp	Specific heat capacity of water [J/(kg*K)];
Δθ	Temperature difference of inputted and hot water [°C].

$$\phi = \frac{Q_p}{t_p} \text{ [kW]} \quad (31)$$

Where:

$\boldsymbol{\phi}$ Nominal heat output [kW];

$\boldsymbol{Q_p}$ Heat supplied by heater [kWh];

$\boldsymbol{T_p}$ Time period, 24 [h]. [25]

6.5 Heating system – underfloor heating

Underfloor heating brings residents ensuring of heating and thermal comfort as well. Due to constantly improving the insulating properties of objects, underfloor heating is being an increasingly used. This system is very efficient especially for low temperature heating, temperature of heating water to 50 °C, and for buildings where the heat loss is less than 20 W/m^3.

Modern underfloor heating systems use either electrical resistance elements or fluid flowing in pipes to heat the floor. Either type can be installed as localized floor heating for thermal comfort or as the primary, whole-building heating system. Electrical resistance can be used only for heating. On the other hand, hydronic system offers a cooling as well.

Electric heating elements or hydronic piping can be cast in a concrete floor slab, sometimes called as a poured floor, or wet system. They can also be placed under the floor covering, called dry system, or attached directly to wood sub floor, called sub floor system. [26]

Floor heating can be divided according to:

- To a heating medium:
    - Electrical;
    - Hot water;
    - Air;
- To a installation:
    - Dry system;
    - Wet system;

- To a modelling pattern:
    - Serpentine;
    - Counter flow;
    - Meander;
    - Double meander.

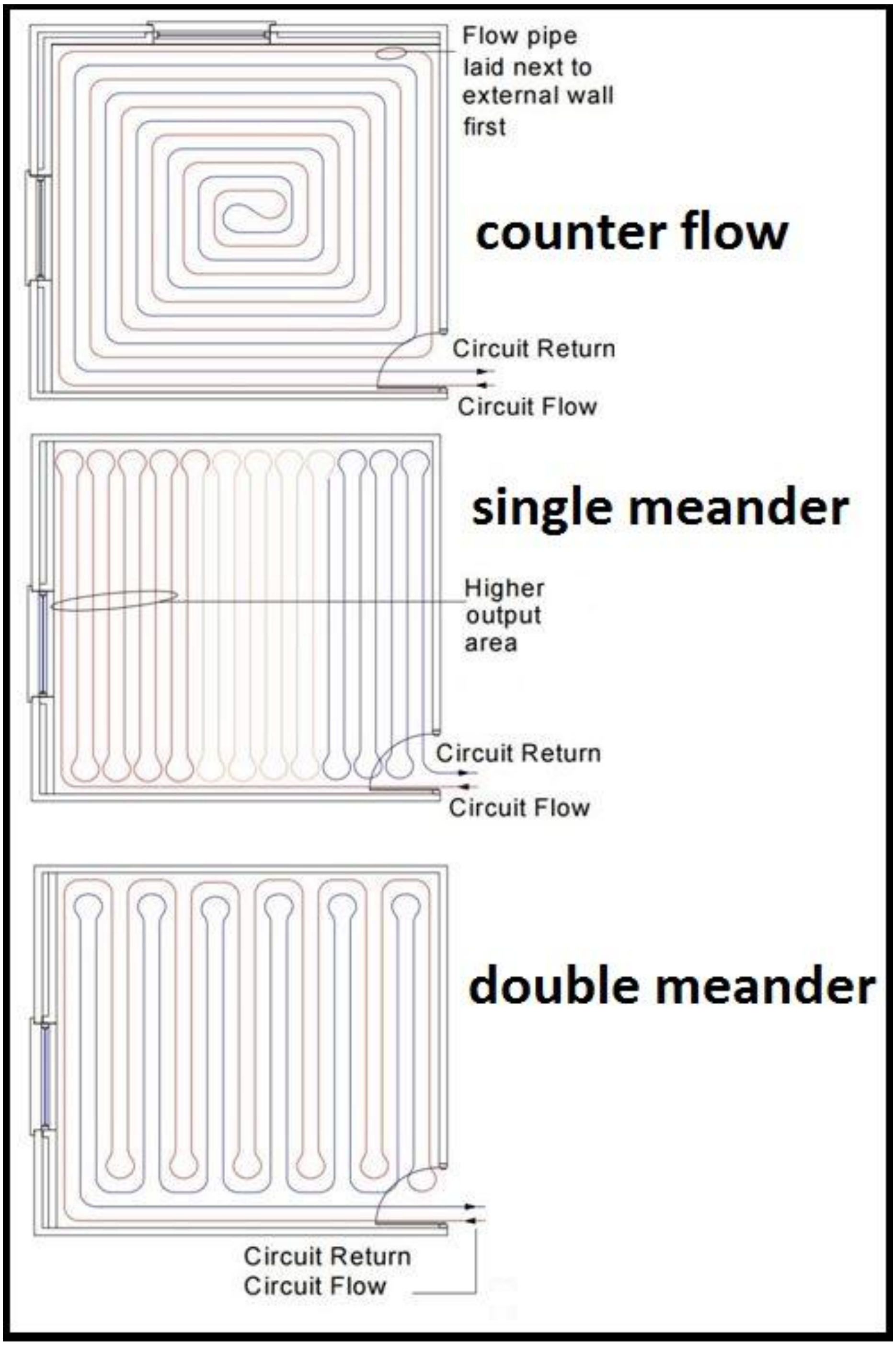


Figure 8: Modelling pattern of underfloor heating [27]

6.5.1 Calculation of underfloor heating

Calculation of undefloor heating verifies the applicability of the system in a given room in terms of performance in compliance with the maximum required floor temperature.

The maximal floor temperature is 33 °C for bathroom and 29 °C for living rooms. The maximal required performance is 100 W/m^2.

The desired heat flux density

$$q_{des} = \frac{Q_{N,f}}{A_f} \text{ W/m}^2 \tag{32}$$

Where:

q_{des} Desired heat flux density of the underfloor heating [W/m^2];

$Q_{N,f}$ Heat loss of the room [W/m^2];

A_f Surface of the heating area [m^2].

The mean temperature of the floor surface

$$\theta_{F,m} = \left(\frac{q}{8{,}92}\right)^{\frac{1}{1{,}1}} + \theta_i \text{ [°C]} \tag{33}$$

Where:

$\theta_{F,m}$ The mean temperature of the floor surface [°C];

q Heat flux density [W/m^2];

θ_i Indoor air temperature [°C].

Power of the floor heating

$$Q_H = A_F * q * \left(1 + \frac{R_o}{R_u} + \frac{\theta_i - \theta_u}{q * R_u}\right) \text{ W} \tag{34}$$

Where:

Q_H Required power output of heating system [W];

A_F Surface of the heating area [m^2];

q Heat flux density [W/m^2];

R_o Floor thermal resistance from heating pipes upwards [(m^3*K)/W];

R_u Floor thermal resistance from heating pipes downwards [(m^3*K)/W];

θ_i Indoor air temperature [°C];

θ_u Air temperature of environment under the floor [°C]. [28]

Characteristic coefficient of the floor

$$m = \sqrt{\frac{2 * (\frac{1}{R_o} + \frac{1}{R_u})}{\pi^2 * \lambda_d * d}} \; [m^{-1}] \tag{35}$$

Where:

m Characteristic coefficient of the floor [m^{-1}];

R_o Floor thermal resistance from heating pipes upwards [(m^3*K)/W];

R_u Floor thermal resistance from heating pipes downwards [(m^3*K)/W];

λ_d Thermal conductivity coefficient of material in which pipes are embedded [W/(m*K)];

d External diameter of pipes [m].

The mean temperature of the circulating water

$$\theta_m = (\theta_{F,m} - \theta_i) * R_o * \alpha_P * \frac{m * \frac{T}{2}}{tgh(m * \frac{T}{2})} + \theta_i \quad [°C] \tag{36}$$

Where:

- $\boldsymbol{\theta_m}$ The mean temperature of circulating water [°C];
- $\boldsymbol{\theta_{F,m}}$ The mean temperature of the floor surface [°C];
- $\boldsymbol{\theta_i}$ Indoor air temperature [°C];
- $\boldsymbol{R_o}$ Floor thermal resistance from heating pipes upwards [$(m^3*K)/W$];
- $\boldsymbol{\alpha_p}$ The U value on the floor surface [$W/(m^2*K)$];
- $\boldsymbol{m}$ Characteristic coefficient of the floor [m^{-1}];
- $\boldsymbol{T}$ The pitch of pipes [m]. [28]

Water flow rate

$$\dot{m} = \frac{Q_H}{\Delta\theta * c_p} \quad kg/s \tag{37}$$

Where:

- $\boldsymbol{\dot{m}}$ Water flow rate [kg/s];
- $\boldsymbol{Q_H}$ Required power output of heating system [W];
- $\boldsymbol{\Delta\theta}$ Temperature gradient of heating fluid [K];
- $\boldsymbol{c_p}$ Specific heat capacity of the heating fluid, water $\boldsymbol{c_p}$ = 4190 [J/(kg*K)].

Flow velocity of the heating fluid

$$w = \frac{\dot{m}}{\frac{\pi * d^2}{4} * p} \text{ m/s} \tag{38}$$

Where:

w Flow velocity of heating fluid [kg/s];

$\dot{m}$ Water flow rate [kg/s];

d External diameter of pipes [m];

$\Delta\theta$ Temperature gradient of heating fluid [K];

ρ Water density, ρ = 1000 [kg/m^3].

Duct length

$$l = \frac{A}{T} \text{ m} \tag{39}$$

Where:

l Length of the pipe [m];

A Surface of the heating area [m^2];

T The pitch of pipes [m].

The pressure loss

$$\Delta p_z = \lambda * \frac{l}{d} * \frac{w^2}{2} * \rho \text{ Pa} \tag{40}$$

Where:

Δp_z Total friction loss in the pipe [Pa];

λ Thermal conductivity coefficient [-];

l Length of the pipe [m];

d External diameter of pipes [m];

w Flow velocity of heating fluid [kg/s];

ρ Water density, ρ = 1000 [kg/m^3]. [28]

7 ELECTRONIC SYSTEMS

To increase the comfort of living and the protection of property, using electronic security systems is highly recommended. First system is called fire alarm system and it is used for early warning of smoke or fire presence. Second system is I&HAS (Intruder & Hold Up Alarm System) and its purpose is to detect unauthorized entry into a protected premises. Last electronic system is KNX. Its aim is to connect all electrical installations, making them able to exchange information and control used technologies, such as lighting, heating, ventilation, or already mentioned fire system and I&HAS).

7.1 I&HAS

Alarm systems are a worthwhile investment in the protection of our home and family. Studies reveal that it is far less likely that you will become the victim of a burglary at home if you have a correctly fitted and well maintained burglar alarm. However, they should be regarded only as one element within a complete security package.

The main task of I&HAS is intrusion detection and early warning of intrusion by unauthorized persons into the building. Sensors can be divided into three main groups, according to the zone their cover. [29]

Scope of sensors:

- Sensors of perimeter protection:
    - Watching the trespass of object such as fences, gates, perimeter;
- Sensors of building protection:
    - Watching the shell of building like walls, windows and doors;
- Sensors of indoor protection:
    - Watching the movement inside the building.

Basic elements of I&HAS systems:

- Alarm control panel:
  - The brain of the system. It decides about the states, arm/disarm and alarm or not
- Keypads:
  - The human-machine interface. Usually features a small multi-character display. Mostly wall-mounted;
- Sensors:
  - Devices for intrusion detection;
  - Variety of methods of monitoring:
    - Monitoring of doors and windows opening;
    - Monitoring of unoccupied areas for motions, sounds, vibration, etc.;
- Alerting devices:
  - Indicators of an alarm;
  - Warning occupants of intrusion, scaring off burglars;
- Interconnections:
  - Hard-wired;
  - Wire-free;
  - Hybrid.

Alarms that utilize audio, video, or combination of both verification technologies give more reliable data to assess the threat level of a triggered alarm. Audio and video verification techniques use microphones and cameras to record audio frequencies, video signals, or image snapshots. The resources of audio and video streams are sent over a communication link, usually an Internet protocol network, to the central station. An example of this system could be a motion detector which takes and transmits a number of snapshots before an alarm is triggered.

7.2 Fire alarm

Not all fires are the same, they vary in their progression and spreading velocity. These depend on ambient material and on the environment as well. Fires could be detected on a various factors, such as smoke, heat or gas. Usually, a fire alarm system is part of a total security system. Several studies have concluded that when working smoke alarms are present, the chance of dying from the fire is cut in half. A fire alarm system is an active fire protection system detecting fire or effects of fire. While doing it, it provides one or more of the following services. It notifies the occupants, notifies persons in the surrounding area, summons the fire service, and controls all the fire alarm components in a building. [30]

Parts of fire alarm:

- Fire alarm control panel:
    - The brain of the system. It monitors and evaluates data from fire sensors. Triggers an alarm;
- System sensors:
    - Based on the method of fire detection (flame, ionization, smoke, gas, temperature, etc.);
    - Combination of detection methods (smoke and temperature, etc.);
- Initiating devices:
    - Manually actuated devices, sometimes called fire alarm boxes;
- Notification appliances:
    - Its purpose is to alert the occupants of the need of evacuation;
    - Usually combined and connected to alarm of security system;
- Additional equipment:
    - In case of alarm, enables to control fire alarm system and other systems as well (e.g. system can open doors, windows, etc.).

7.3 KNX

KNX is a standard for applications in home and building control. It ranges from lighting control, HVAC, audio and video distribution, energy management to a various security systems. On the top of that you can access to the system via LAN or mobile phone networks for having a control of the system via PC and Smartphone. KNX is the worldwide standard for home and building control with a single, manufacturer independent design and commissioning tool (ETS), with a complete set of supported communication media (TP, PL, RF and IP). KNX is approved as an European (CENELEC EN 50090 and CEN EN 13321-1) and an International standard (ISO/IEC 14543-3). [31]

All the devices for a KNX installation are connected together by a two wire bus (the most common form of installation), thus allowing them the data exchange. The function of the individual bus devices is determined by their project planning, which can be adapted and changed at any time. [32]

KNX has its own certification process, which ensures that any product, from various manufacturers, which has a KNX label, will communicate and cooperate with others. On one side, certification causes and extra costs, but on the other side it ensures a high degree of flexibility while expanding or altering the installation.

7.3.1 KNX topology

KNX allows tree, line and star topologies, which can be mixed as needed. It is a fully distributed network, accommodating up to 65 536 devices in a 16 bit individual address space. The logical topology or sub network structure allows 156 devices on one line. Up to 15 lines can be connected to a main line via line coupler for a total of 16 lines. One line consists of a maximum of 4 line segments, each with a maximum of 64 bus devices. Each segment requires an appropriate power supply. Maximum segment length is 1000 m. For segments may be connected with the line repeaters to establish a network length of 4000 m and 256 devices. The actual number of devices is dependent on the selected power supply and on the power input of the individual devices. [32]

Each device on the bus is assigned an unique address, called an individual address. This address may be, e.g. 1.1.1. The first digit stands for the area, the second for the line and the third for a device itself. It is also used for determination of a location on the bus. The participants exchange information between each other by using the data telegram. The data telegram contains a multicast address that is assigned to each group of objects on the device. Each device may have several groups of objects, such as group object for dimming lights, heat or ventilation control, etc.

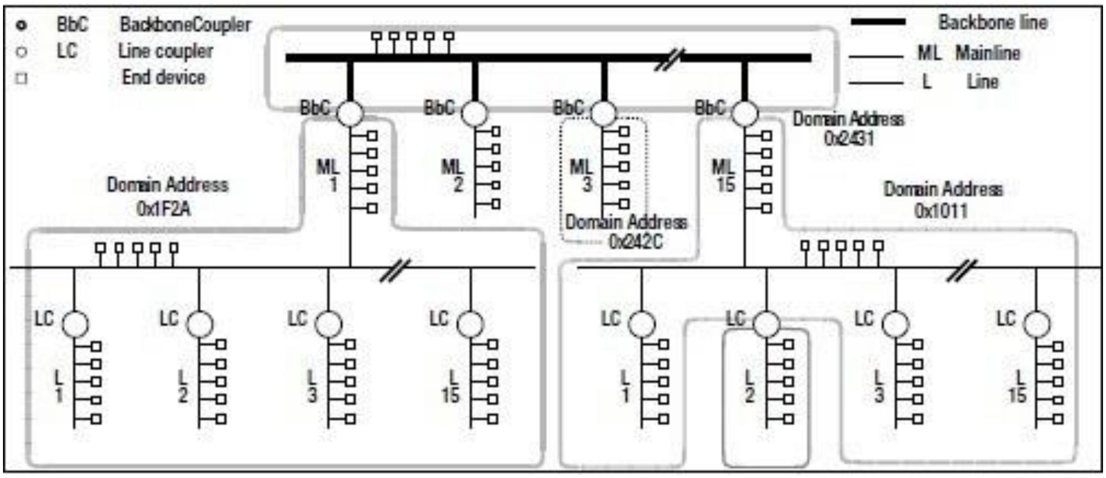


Figure 9: KNX topology [33]

KNX physical communication media:

- Twisted pair;
- Powerline;
- Radio;
- Infrared;
- Ethernet.

7.4 SCADA

SCADA (Supervisory Control and Data Acquisition) is a system operating over communication channels to provide control of remote equipment. In basic SCADA architectures, information from sensors or manual inputs are sent to PLCs (programmable logic controllers) or RTUs (remote terminal units), which then send that information to computers with SCADA software. Software analyses and displays the data in order to help operators and other workers to improve efficiency in the process.

Effective SCADA systems can result in significant savings of time and money. [34]

II ANALYSIS

8 DESCRIPTION OF THE PROPOSED BUILDING

This is a new family house, which is situated in a new urban area, in a quiet village Kudlov, close to Zlín. The building has a partial basement floor and this floor is fitted in the ground from the west. The building consists of 2 units – the building itself and garage, which creates a single object with two flat roofs. Basement floor and Ground floor are detached from each other and they create a completely separate residential unit. The new building is connected to a local service road and is connected to the technical infrastructure.

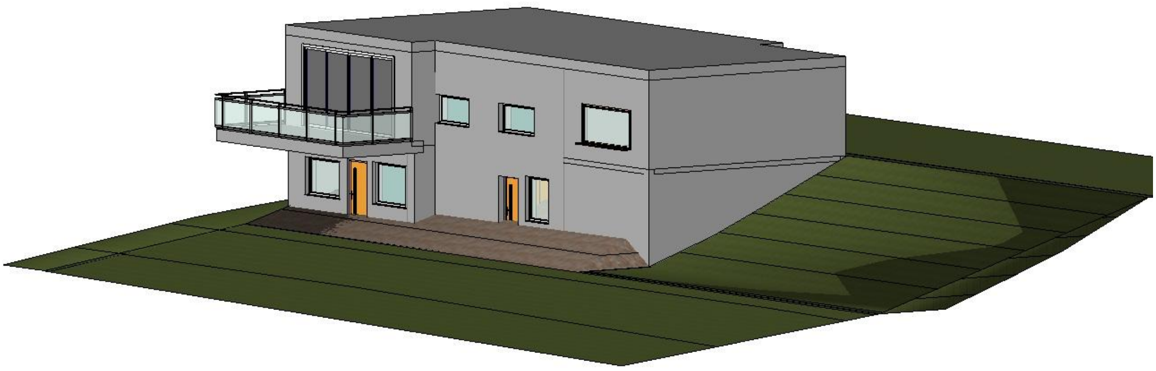


Figure 10: Southwest view (created in Revit 2014 software)

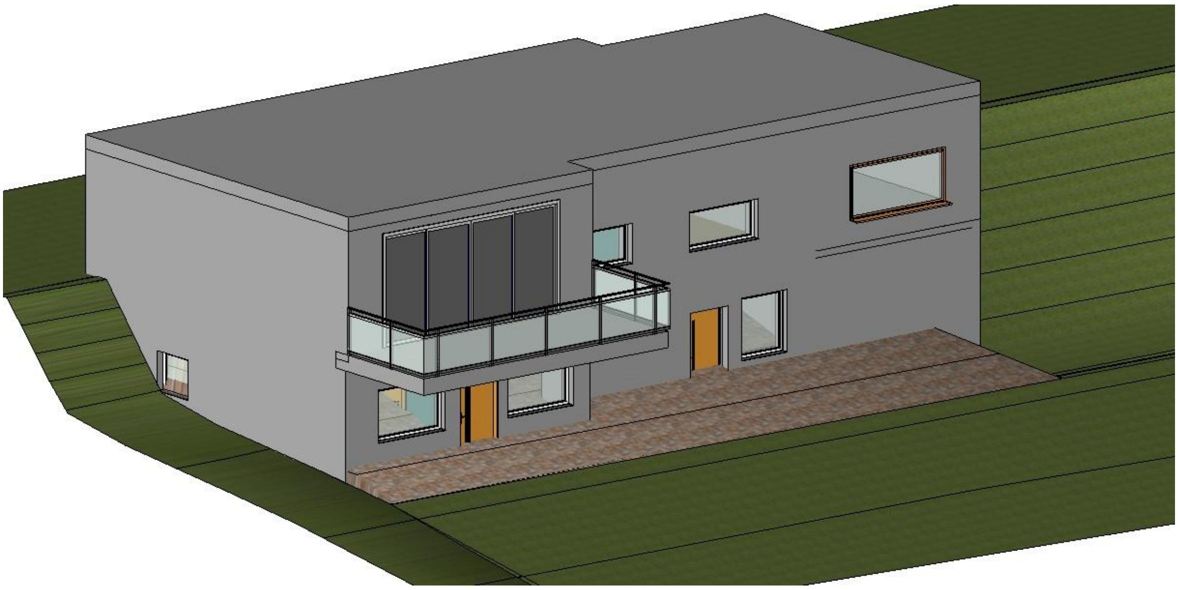


Figure 11: Northwest view (created in Revit 2014 software)

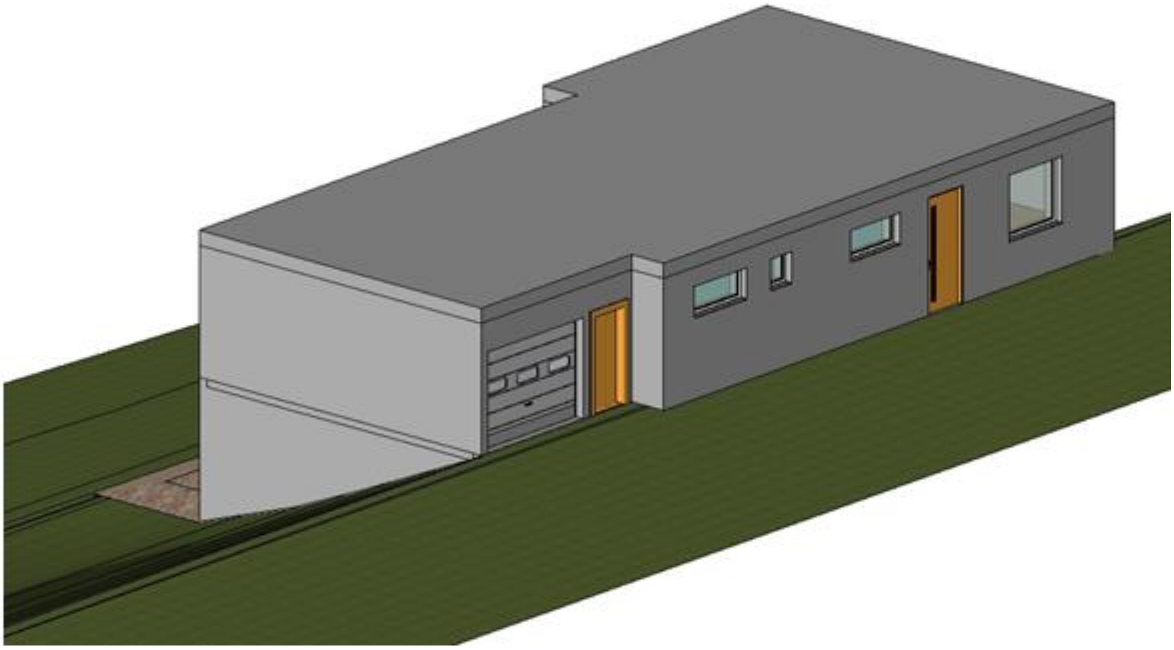


Figure 12: Northeast view (created in Revit 2014 software)

8.1 Parameters of the object

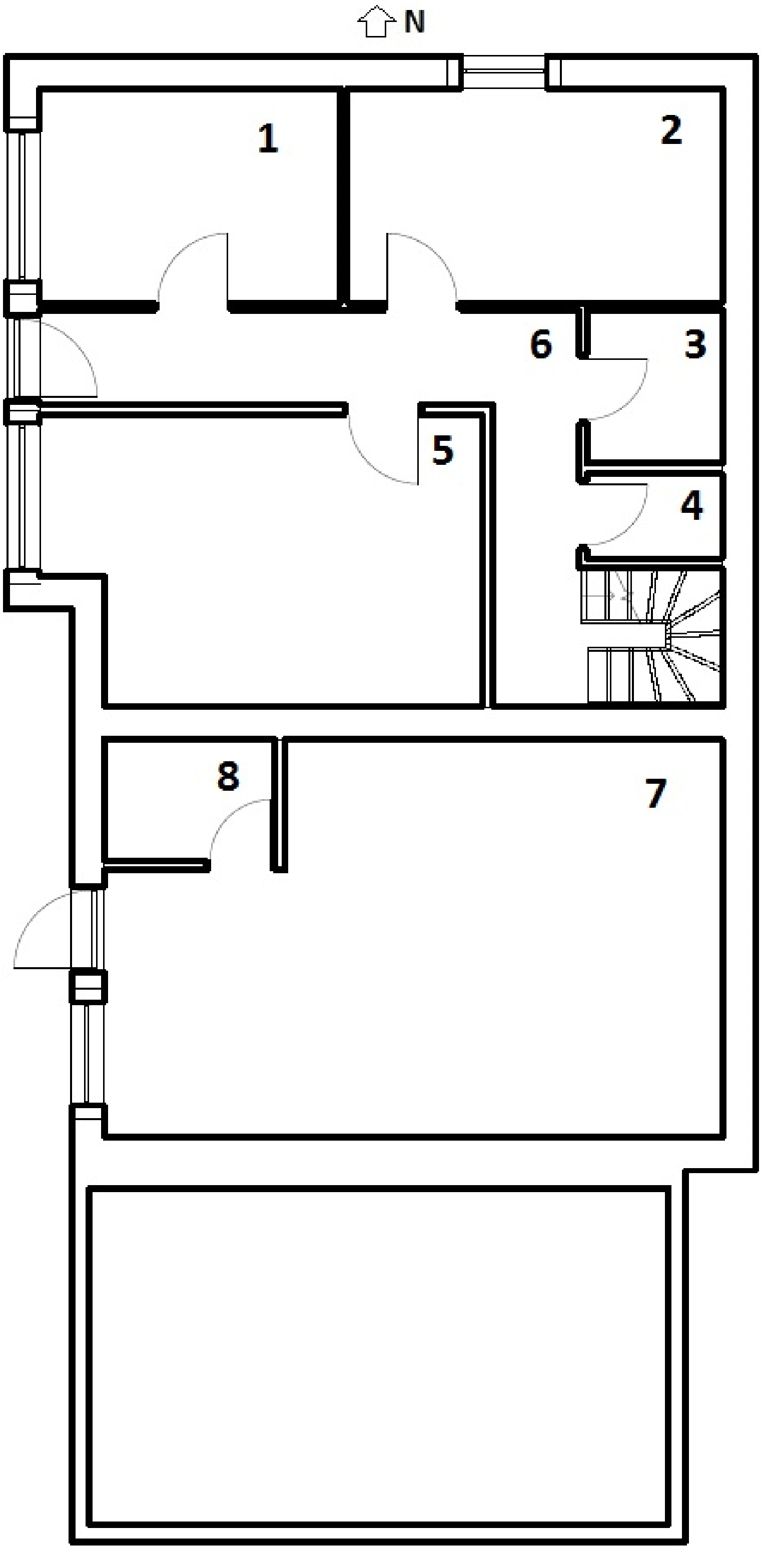


Figure 13: Lower ground floor (Basement floor)

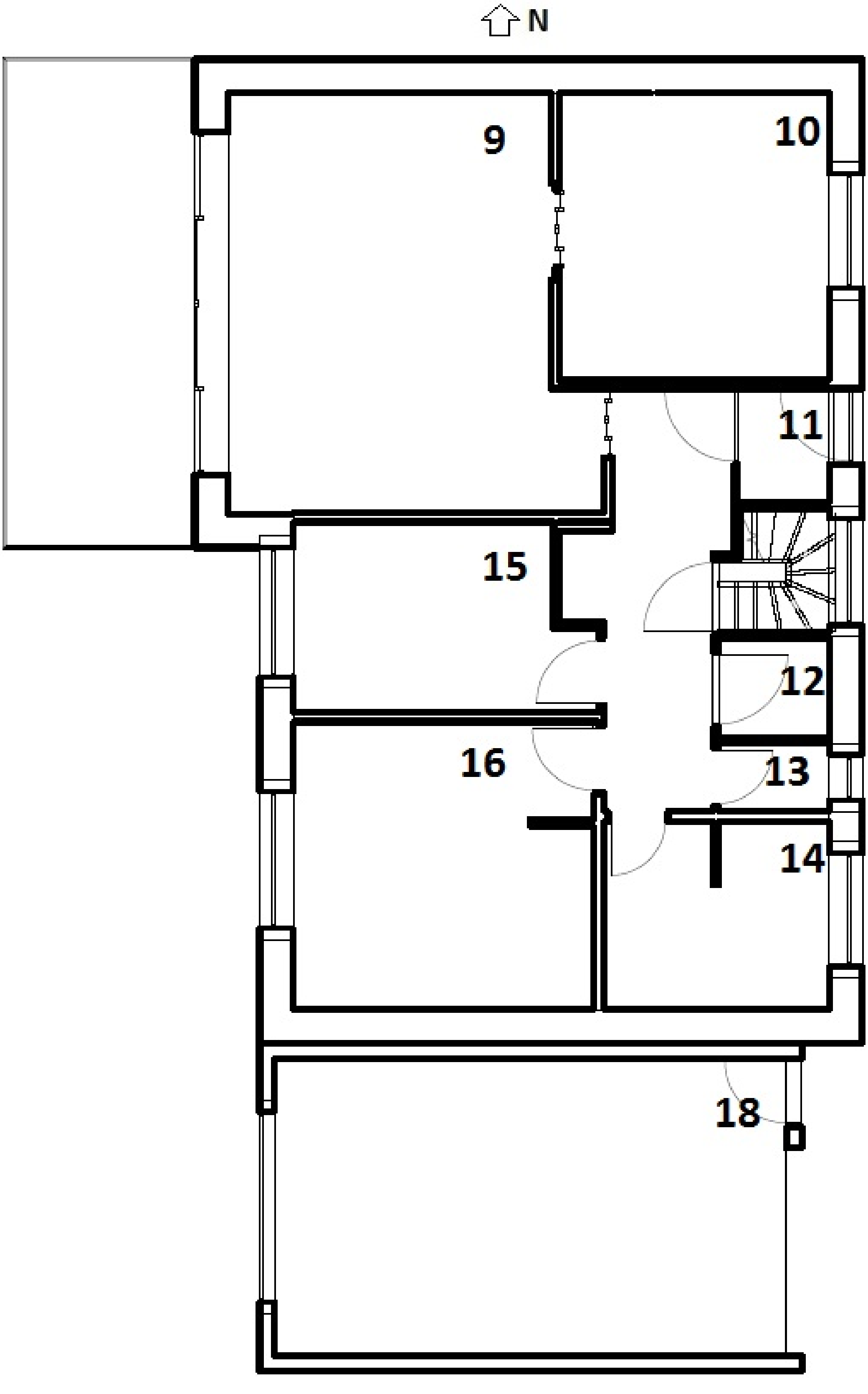


Figure 14: Ground floor

Table 14: Marginal conditions

Altitude *h* [m]	405.0
Enclosed space of building's heated parts *V*[m^3]	384.8
Heated space [m^2]	137.8
Total builded area A_z [m^2]	196.5
Total area of structure *A* [m^2]	264.3
Length of heating period *d* [day]	234.0
Designed outdoor temperature Θ_e [°C]	-13.0
Average annual temperature in the heating season $\Theta_{e,m}$ [°C]	5.7

Table 15: The list of rooms with design parameters

Floor	**Number of the room**	**Room**	**Surface** A **[m²]**	**Volume of the room** V **[m³]**
Lower ground floor	1	Living room	8.63	19.75
	2	Bedroom	10.74	24.57
	3	Bathroom	2.79	6.40
	4	WC	1.54	3.52
	5	Kitchen	16.17	37.01
	6	Corridor	12.99	29.72
	7	Cellar	29.76	68.10
	8	WC	2.76	6.31
Ground floor	9	Living room	24.49	56.04
	10	Kitchen	13.25	30.33
	11	Entrance corridor	1.79	4.10
	12	Utility room	1.86	4.27
	13	WC	1.29	2.94
	14	Bathroom	7.18	16.43
	15	Office	9.19	21.02
	16	Bedroom	14.79	33.84
	17	Corridor	8.97	20.52
	18	Garage	26.13	57.18
	19	Stairs	2.20	4.90

8.2 Parameters of the house

8.2.1 The Assessment of U value

Determination of the heat transfer coefficient is an important criterion for assessing buildings. It is the basic indicator for evaluating the construction quality in terms of thermal parameters and related economic aspect of heating and operation of the house.

8.2.2 The Assessment of the building envelope

For the proper function, the building envelope must meet the criteria according to ČSN 73 0540 in terms of water vapour condensation within the building's walls. The annual amount of condensed water must be less than the annual amount of water vapour inside the structure.

To assess the condition of the building envelope, I used the Teplo 2014 software, which evaluates and processes necessary factors.

In total, we consider 5 building perimeter structures. The first one is for basement floor in contact with the terrain, the second one is in contact with the unheated rooms, the third one is for a ground, the fourth one is in contact with environment and the last one is a roof.

Table 16: The basement floor in contact with the terrain (from interior)

Construction	***D* [m]**	***Lambda* [W/m*K)]**
Stucco plaster	0.0200	0.4900
Porotherm 44 Profi	0.4400	0.1300
Hydro insulation	0.0051	0.2100
Extruded polystyrene	0.0200	0.0340
Asphalt coating	0.0150	0.2100

Protocol from program Teplo 2014 software:

- R value: 3.296 m^2K/W;
- U value: 0.289 W/m^2K;
- Amount of condensed vapor per year: 0.339 kg/(m^2*year);
- Amount of vaporised water vapor: 0.485 kg/(m^2*year).

Table 17: The basement floor in contact with unheated rooms

Construction	***D* [m]**	***Lambda* [W/m*K)]**
Stucco plaster	0.02	0.49
Porotherm 36.5 Profi	0.44	0.13
Stucco plaster	0.02	0.49

Protocol from program Teplo 2014 software:

- R value: 2.653 m^2K/W;
- U value: 0.354 W/m^2K;
- Amount of condensed vapor per year: 0.0356 kg/(m^2*year);
- Amount of vaporised water vapor: 3.444 kg/(m^2*year).

Table 18: Construction in contact with ground

Construction	***D* [m]**	***Lambda* [W/m*K)]**
Linoleum floor	0.002	0.170
Anhydrite floor	0.050	1.200
PVC board	0.020	0.160
Foam polystyrene	0.080	0.038
Concrete	0.200	1.230

Protocol from program Teplo 2014 software:

- R value: 2.609 m^2K/W;
- U value: 0.360 W/m^2K;
- There is no condensation of water vapor in the structure.

Table 19: Construction in contact with environment

Construction	***D* [m]**	***Lambda* [W/m*K)]**
Stucco plaster	0.020	0.490
Porotherm 44 Profi	0.440	0.130
Foam polystyrene	0.100	0.038
Stucco plaster	0.020	0.490

Protocol from program Teplo 2014 software:

- R value: 6.021 m^2K/W;
- U value: 0.162 W/m^2K;
- Amount of condensed vapor per year: 0.0119 kg/(m^2*year);
- Amount of vaporised water vapor: 1.0943 kg/(m^2*year).

Table 20: Roof (from interior)

Construction	***D* [m]**	***Lambda* [W/m*K)]**
Stucco plaster	0.0200	0.4900
Cavity roof panel	0.2500	1.2000
Hydro insulation	0.0051	0.2100
Foam polystyrene	0.3000	0.0380
Fatrafol roofing	0.0100	0.3500

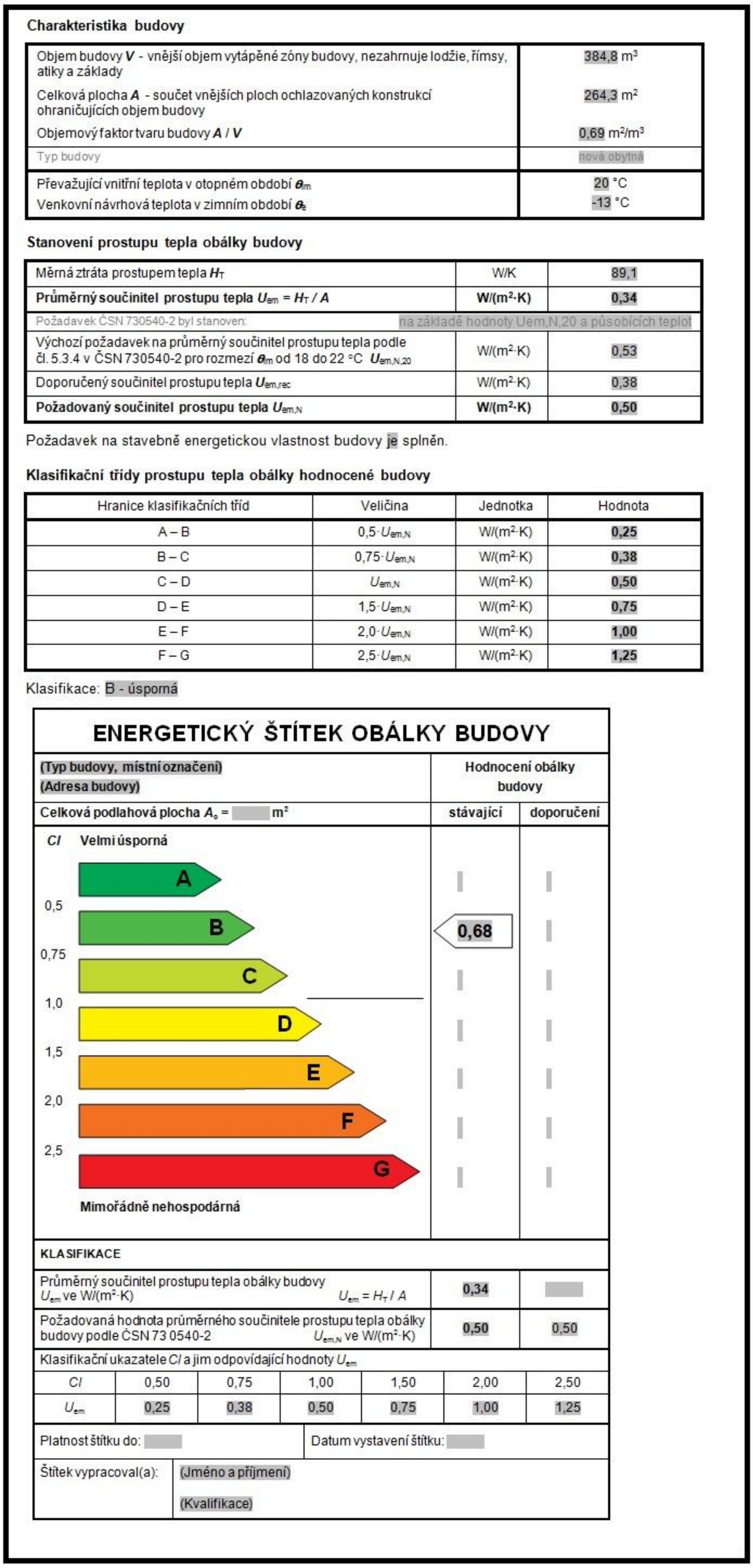
Protocol from program Teplo 2014 software:

- R value: 8.197 m^2K/W;
- U value: 0.120 W/m^2K;
- Amount of condensed vapor per year: 0.0146 kg/(m^2*year);
- Amount of vaporised water vapor: 0.0182 kg/(m^2*year).

8.2.3 Energy performance certificate of the building

While we are analysing individual building structures of the house, we have to put emphasis on building openings such as ceilings, floors, doors, windows and any other adjacent structures. After finding all the required values, energy performance certificate can be evaluated. More details about energy performance certificate are mentioned in chapter 5.1.

According to the standard, today's designed buildings have to meet class C or better. Energy performance certificate is shown in Figure 15.



Charakteristika budovy

Objem budovy V - vnější objem vytápěné zóny budovy, nezahrnuje lodžie, římsy, atiky a základy	384,8 m³
Celková plocha A - součet vnějších ploch ochlazovaných konstrukcí ohraničujících objem budovy	264,3 m²
Objemový faktor tvaru budovy A / V	0,69 m²/m³
Typ budovy	nová obytná
Převažující vnitřní teplota v otopném období θ_{im}	20 °C
Venkovní návrhová teplota v zimním období θ_e	-13 °C

Stanovení prostupu tepla obálky budovy

Měrná ztráta prostupem tepla H_T	W/K	89,1
Průměrný součinitel prostupu tepla $U_{em} = H_T / A$	**W/(m²·K)**	**0,34**
Požadavek ČSN 730540-2 byl stanoven:	na základě hodnoty Uem,N,20 a působících teplot	
Výchozí požadavek na průměrný součinitel prostupu tepla podle čl. 5.3.4 v ČSN 730540-2 pro rozmezí θ_{im} od 18 do 22 °C $U_{em,N,20}$	W/(m²·K)	0,53
Doporučený součinitel prostupu tepla $U_{em,rec}$	W/(m²·K)	0,38
Požadovaný součinitel prostupu tepla $U_{em,N}$	**W/(m²·K)**	**0,50**

Požadavek na stavebně energetickou vlastnost budovy je splněn.

Klasifikační třídy prostupu tepla obálky hodnocené budovy

Hranice klasifikačních tříd	Veličina	Jednotka	Hodnota
A – B	$0,5 \cdot U_{em,N}$	W/(m²·K)	**0,25**
B – C	$0,75 \cdot U_{em,N}$	W/(m²·K)	**0,38**
C – D	$U_{em,N}$	W/(m²·K)	**0,50**
D – E	$1,5 \cdot U_{em,N}$	W/(m²·K)	**0,75**
E – F	$2,0 \cdot U_{em,N}$	W/(m²·K)	**1,00**
F – G	$2,5 \cdot U_{em,N}$	W/(m²·K)	**1,25**

Klasifikace: B - úsporná

ENERGETICKÝ ŠTÍTEK OBÁLKY BUDOVY

(Typ budovy, místní označení)
(Adresa budovy)

Celková podlahová plocha A_c = m²

Hodnocení obálky budovy — **stávající** | **doporučení**

CI **Velmi úsporná**

A
0,5 B 0,68
0,75 C
1,0 D
1,5 E
2,0 F
2,5 G

Mimořádně nehospodárná

KLASIFIKACE

	stávající	doporučení
Průměrný součinitel prostupu tepla obálky budovy U_{em} ve W/(m²·K) $U_{em} = H_T / A$	0,34	
Požadovaná hodnota průměrného součinitele prostupu tepla obálky budovy podle ČSN 73 0540-2 $U_{em,N}$ ve W/(m²·K)	0,50	0,50

Klasifikační ukazatele *CI* a jim odpovídající hodnoty U_{em}

CI	0,50	0,75	1,00	1,50	2,00	2,50
U_{em}	0,25	0,38	0,50	0,75	1,00	1,25

Platnost štítku do: Datum vystavení štítku:

Štítek vypracoval(a): (Jméno a příjmení)
(Kvalifikace)

Figure 15: Energy performance certificate

Building classification:

- $\boldsymbol{U_{em,N}}$ 0.53 W/m2K;
- $\boldsymbol{U_{em}}$ 0.34 W/m2K;
- B energy efficient.

8.2.4 The assessment of heat loss of the house

Knowledge of heat loss is fundamental for appropriate heating design. The standard ČSN EN 12831 specifies procedures for calculation of heat loss of the building and the proposed thermal power. For following procedures and calculations, Ztráty 2014 software was used.

$$\Phi_i = \sum \Phi_{T,i} + \sum \Phi_{V,i} = 2690 + 2947 = 5636\ kW \tag{41}$$

Heating source must cover this heat loss together with the planned hot water preparation.

Table 21: Heat loss

Floor	Number of the room	Room	Heat loss though heat transfer $\phi_{T,I}$ [W]	Heat loss though ven-tilation $\phi_{V,I}$ [W]	Total heat loss ϕ_i [W]
Lower ground floor	1	Living room	193	111	304
	2	Bedroom	221	138	359
	3	Bathroom	179	134	313
	4	WC	3	59	62
	5	Kitchen	218	623	841
	6	Corridor	137	167	303
Ground floor	9	Living room	494	314	809
	10	Kitchen	666	510	1177
	11	Entrance corridor	85	23	108
	12	Utility room	19	24	43
	13	WC	1	49	50
	14	Bathroom	234	344	577
	15	Office	98	118	215
	16	Bedroom	116	190	306
	17	Corridor	23	115	92
	19	Stairs	49	28	77
TOTAL			**2690**	**2947**	**5636**

8.2.5 The assessment of heat gains of the house

Determination of heat gains is important especially during summer months, when an interior overheating may occur. In case, that indoor temperature exceeds 27 °C, it is necessary to consider a cooling system. As a critical room, home office (number 15) was chosen. It is situated southwest, on the ground floor. According the Simulace 2014 software, maximal temperature of the indoor air is 26.91 °C, therefore, there is no need to design a cooling system.

9 DESIGN OF HVAC

The following chapters describe proposed solutions for HVAC systems, for creating a microclimate conditions for living inside the house. The heart of the system is a heat pump (ALEZIO AWHP 8 MR), supported by electric boiler for ensuring a bivalent operation in case of any malfunction or extremely low temperatures.

These sources are used primarily for heating and preparation of hot water. The heat pump may be also used for cooling during a summer. In the scheme, there is also a room for additional solar collector, which may be installed in the future.

9.1 Design of the heating system

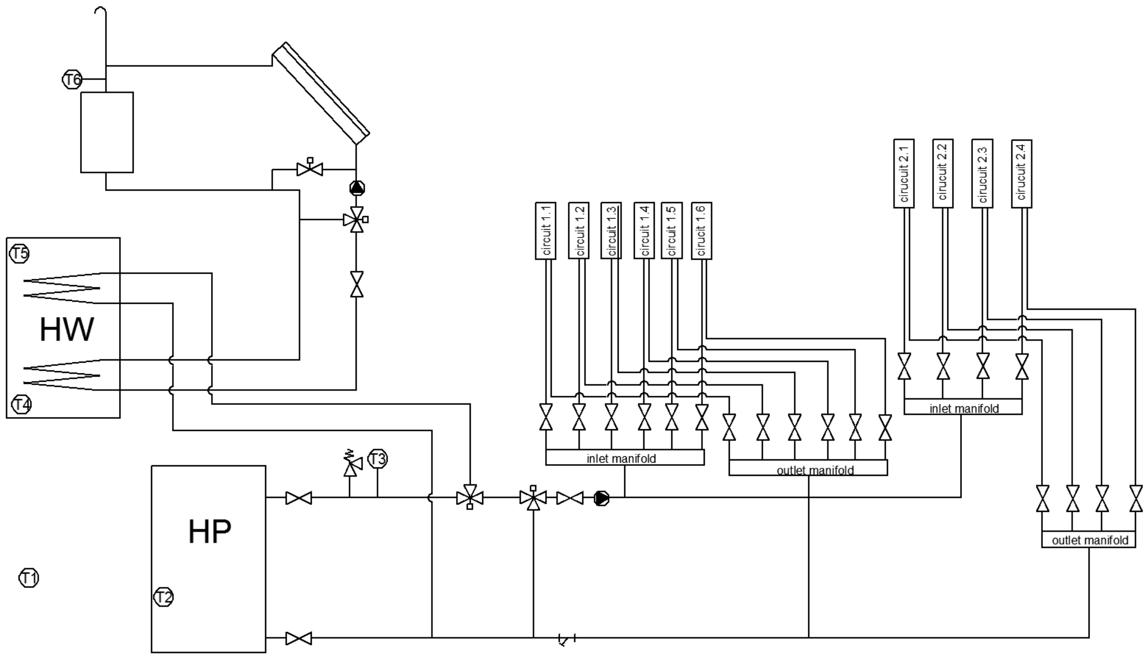


Figure 16: Design of heating system (AutoCad)

9.2 The proposal of heat pump air/water

The coefficient of performance, sometimes only ***COP***, is a ratio between heating or cooling provided to electrical energy consumed. As higher the ***COP*** is, as lower the operating costs. ***COP*** is highly dependent on operating conditions as absolute temperature and relative temperature between system and sink.

$$COP = k * \frac{\theta_s}{\theta_s - \theta_z} = 0{,}5 * \frac{50+273.15}{(50+273.15)+(0+273.15)} = 3.23 \tag{42}$$

Parameters of the chosen heat pump at +7 °C/ +35 °C (air temperature/hot water temperature):

COP:	4.40
Heating power:	8 kW
Electric energy consumption:	1.82 kW
The level of acoustic pressure:	43.2 dB

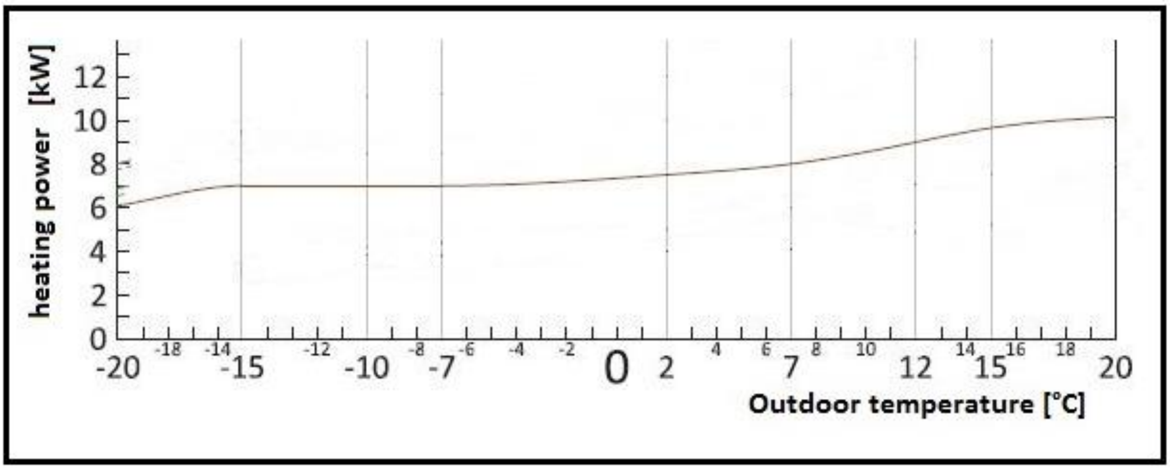


Figure 17: Graph of heating power (ALEZIO AWHP 8 MR)

The heat pump has been designed with a built-in bivalent electric boiler. Selection of boiler was adapted in order to cover the total power required for heating and hot water preparation in case of heat pump failure.

Characteristics and further information of the heat pump are shown in catalogue in appendic.

9.3 Design of hot water preparation

According the standard ČSN 06 0320, for the hot water calculation, we may use formulas below (Formula 43 – 45).

Total need for 3 residents:

$$Q_{TP} = n * 4.3 = 12.9\ kWh \tag{43}$$

Loss during a preparation and distribution:

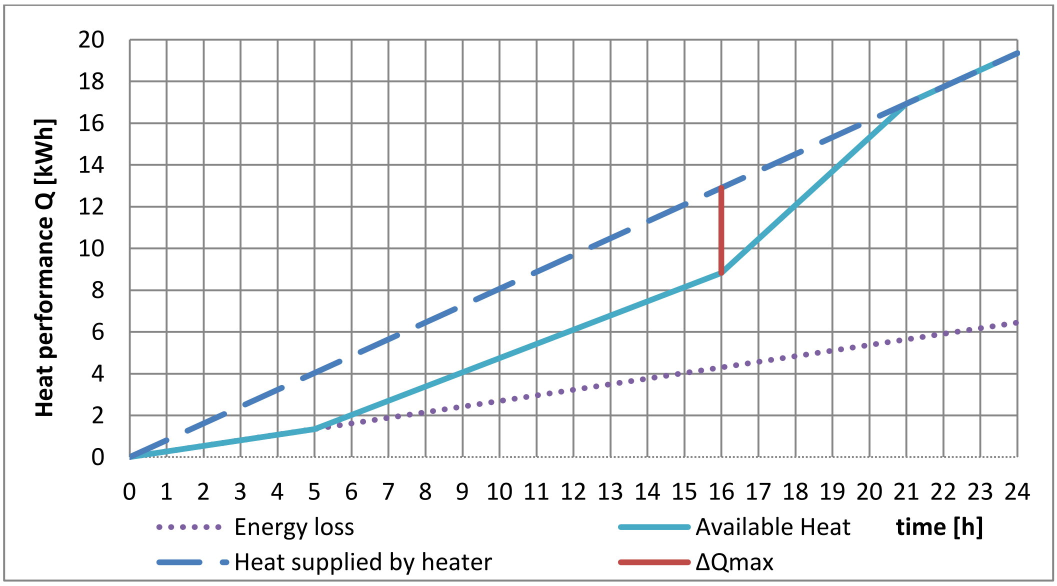
$$Q_{ZP} = 0.5 * Q_{TP} = 6.45\ kWh \tag{44}$$

Total heat supplied by heater:

$$Q_P = Q_{TP} + Q_{ZP} = 19.35\ kWh \tag{45}$$

Table 22: Hot water consumption in time periods

Time [hours]	Water usage [%]	Heat [kWh]
5 - 16	35	4,52
16 - 21	50	6,45
21 - 24	15	1,94



Graph 1: Hot water consumption

9.4 Design of underfloor heating

Since a building is a newly built, and the investor has demanded a thermal comfort, the underfloor heating was designed. Underfloor heating is installed as the main heat source in all heated rooms, except the bathroom (ground floor, room 14), which is complemented by a heating ladder.

Design and calculation are performed according to Heating system – underfloor heating (Chapter 6.5) and formulas below (Formula 32 – 40).

Example calculation for kitchen (ground floor, room 10):

Heat loss = 1177 W $\boldsymbol{A}$ = 13.25 m^2 $\boldsymbol{R_o}$ = 0.151 $\boldsymbol{R_u}$ = 0.408

The desired heat flux density

$$q_{des} = \frac{Q_{N,f}}{A_f} = \frac{1177}{13.25} = 88.83\ W/m^2 \tag{46}$$

The mean temperature of the floor surface

$$\theta_{F,m} = (\frac{q}{8.92})^{\frac{1}{1.1}} + \theta_i = (\frac{1177}{8.92})^{\frac{1}{1.1}} + 20 = 28.08\ °C < 29\ °C \tag{47}$$

Power of the floor heating

$$Q_H = A_F * q * \left(1 + \frac{R_o}{R_u} + \frac{\theta_i - \theta_u}{q * R_u}\right) = 13.25 * 88.83 * \left(1 + \frac{0.151}{0.408} + 0\right) = 1612.61\ W \tag{48}$$

Characteristic coefficient of the floor

$$m = \sqrt{\frac{2*(\frac{1}{R_O}+\frac{1}{R_U})}{\pi^2 * \lambda_d * d}} = \sqrt{\frac{2*(\frac{1}{0.151}+\frac{1}{0.408})}{\pi^2 * 1.1 * 0.02}} = 9.14\ m^{-1} \tag{49}$$

The mean temperature of the circulating water

$$\theta_m = (\theta_{F,m} - \theta_i) * R_o * \alpha_P * \frac{m*\frac{T}{2}}{tgh(m*\frac{T}{2})} + \theta_i = (28.08 - 20) * 0.151 * 11 * \frac{9.14*\frac{0.15}{2}}{tgh(m*\frac{0.15}{2})} + 20 = 34.44 \quad (50)$$

Water flow rate

$$\dot{m} = \frac{Q_H}{\Delta\theta * c_p} = \frac{1612.61}{5*4190} = 0.08\ kg/s \quad (51)$$

Flow velocity of the heating fluid

$$w = \frac{\dot{m}}{\frac{\pi*d^2}{4}*p} = \frac{0.08}{\frac{\pi*0.02^2}{4}*1000} = 0.25\ m/s \quad (52)$$

Duct length

$$l = \frac{A}{T} = \frac{13.25}{0.2} = 66.25\ m \quad (53)$$

The pressure loss

$$\Delta p_z = \lambda * \frac{l}{d} * \frac{w^2}{2} * \rho = 0.047 * \frac{66.25}{0.02} * \frac{0.25^2}{2} * 1000 = 4673.18\ Pa \quad (54)$$

These calculations were used for other heated rooms as well. Results are shown in tables below (Table 23 and Table 24).

Table 23: Parameters of designed floor heating (Lower ground floor)

	Lower ground floor			
Room	**Living Room (1)**	**Bedroom (2, LGF)**	**Bathroom + WC (3 + 4)**	**Kitchen (5)**
Floor surface [m^2]	8.63	10.74	4.29	16.17
Heat loss [W/m^2]	304.00	359.00	375.00	841.00
Heat flux density [W/m^2]	35.23	33.43	84.41	52.01
The mean temperature of the floor surface [°C]	23.49	23.32	27.96	24.97
Power of the floor heating [W]	471.47	557.31	575.22	1296.59
Characteristic coefficient of the floor [m^{-1}]	9.64	9.64	9.64	9.64
The mean temperature of circulating water [°C]	32.14	32.00	33.41	33.47
Water flow rate [kg/s]	0.08	0.10	0.10	0.22
Duct length [m]	69.15	71.70	28.45	98.85
Water flow rate [m/d]	0.02	0.03	0.03	0.06
Flow velocity of the heating fluid [m/s]	0.07	0.08	0.09	0.2
The pressure loss [kg/s]	416.93	604.07	255.34	4507.64

Table 24: Parameters of designed floor heating (Ground floor)

	Ground floor					
Room	**Living room N (9N)**	**Living room S (9S)**	**Kitchen (10)**	**Bath-room + WC (14+13)**	**Office (15)**	**Bedroom (16)**
Floor surface [m^2]	12.50	12.50	13.25	8.47	9.19	14.79
Heat loss [W/m^2]	404.500	404.50	1177	627	215	306
Heat flux density [W/m^2]	33.03	33.03	88.83	74.03	23.39	20.69
The mean temperature of the floor surface [°C]	23.29	23.29	28.08	26.85	22.40	22.15
Power of the floor heat-ing [W]	554.20	554.20	1612.61	859.05	399.44	583.29
Characteristic coeffi-cient of the floor [m^{-1}]	9.14	9.14	9.14	9.14	9.14	9.14
The mean temperature of circulating water [°C]	32.96	32.96	34.44	33.10	30.66	29.53
Water flow rate [kg/s]	0.10	0.10	0.28	0.15	0.07	0.1
Duct length [m]	86.63	86.63	66.25	42.35	54.95	73.95
Water flow rate [m/d]	0.03	0.03	0.08	0.04	0.02	0.03
Flow velocity of heating fluid [m/s]	0.08	0.08	0.25	0.13	0.06	0.09
The pressure loss [kg/s]	721.76	721.76	4673.18	847.74	198.86	710.15

9.5 Security devices of the system

For proper and safe operation of the system, particular security devices have to be designed. These devices include especially a pressure relief valve and expansion tank, which provide protection from exceeding the maximum values of under/ overpressure. The design of the system was made regard to the standard ČSN 06 8030. [35]

9.5.1 The pressure relief valve design

$$S_{rv} = \frac{2*\Phi_p}{\alpha*\sqrt{p_{OP}}} = \frac{2*8}{0.444*\sqrt{250}} = 2.279 \text{ mm}^2 \quad (55)$$

Where:

S_{rv} Relief valve seat cross section [mm2];

ϕ_p Desired power output [kW];

α Relief valve discharge coefficient, given by manufacturer [-];

p_{OP} Opening pressure of relief valve [kPa];

d_{sv} Minimum diameter of the safety valve [mm]. [36]

$$d_{sv} = 10 + 0.6 * \sqrt{\Phi_p} = 10 + 0.6 * \sqrt{8} = 11.697 \text{ mm} \quad (56)$$

Where:

d_{sv} Minimum diameter of the safety valve [mm];

ϕ_p Desired power output [kW].

9.5.2 The expansion tank design

Before we determine the total volume of the expansion tank, partial calculations must be done.

The degree of expansion tank utilisation:

$$P_{D,dov} = 1.1 * h * \rho * g * 10^{-3} = 1.1 * 3 * 1000 * 9.81 * 10^{-3} = 32.37 \text{ kPa} \quad (57)$$

$$p_{H,dov} = 250 \text{ kPa} \tag{58}$$

$$\eta = \frac{P_{H,dov,abs} - P_{D,dov,abs}}{P_{H,dov,abs}} = \frac{(P_{H,dov}+100)-(P_{D,dov}+100)}{(P_{D,dov}+100)} = 0.62 \tag{59}$$

Where:

$\boldsymbol{P_{D,dov}}$ Initial overpressure [kPa];

$\boldsymbol{h}$ Maximum height of heating element [m];

$\boldsymbol{\rho}$ Density [kg/m^3];

$\boldsymbol{g}$ Gravity acceleration constant [m/s^2];

$\boldsymbol{P_{H,dov}}$ Terminal overpressure [kPa];

$\boldsymbol{\eta}$ The degree of expansion tank utilisation [-].

$$V_{et} = \frac{1.3 * V * n}{\eta} = \frac{1.3 * 330 * 0.0118}{0.62} = 8.16 \text{ l} \tag{60}$$

Where:

$\boldsymbol{V_{et}}$ Total volume of expansion tank [l];

$\boldsymbol{V}$ Volume of water in the system [l];

$\boldsymbol{n}$ The coefficient of volume increase [-], $\boldsymbol{n}$ = 0.0118 for (50 °C – 10 °C);

$\boldsymbol{\eta}$ The degree of expansion tank utilisation [-]. [36]

According the standard ČSN EN 12828 is necessary to increase the volume of expansion tank by 20% in case that the volume of expansion tank is less than 15 litres.

The size of chosen expansion tank is 12 litres and it is embedded in heating pump.

9.6 Design of solar collectors for hot water

Solar collectors are considered as an auxiliary power for hot water preparation. For the design of solar collectors, solar collector Suntime 2.1 (Propuls solar s.r.o) was chosen. Collector dimensions are 1895 x 1063 mm, it weights 38 kg and absorption surface is 1.83 m^2.

The design and calculation of solar collectors was performed by using Suntiware 13.2 software, which is available for free. By entering specific information about the object, the software calculates the optimum values of the solar system with financial calculations.

Ideal values according to Suntiware 13.2 software:

- Surface of solar collectors: 4 m^2,
- Volume of water tank: 200 litres,
- Inclination of collectors: 45 °,
- Azimuth: 0 °.

Table 25: Calculations from Suntiware 13.2 software

	Hot water
Energy consumption [kWh/year]	2700.0
Use of solar energy [kWh/year]	1818.0
Solar cover [%]	67.4

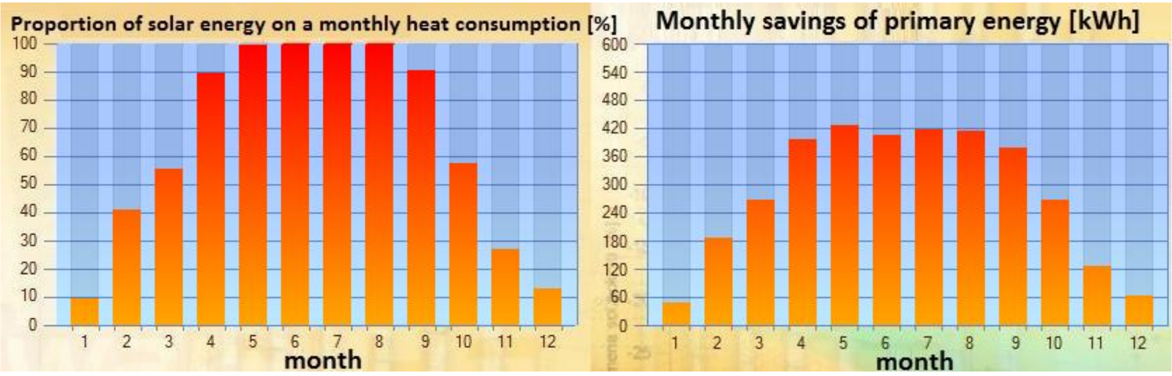


Figure 18: Graphs from software Suntiware 13.2

To verify results from the Suntiware software, calculations below were used (Formula 61, Formula 62 and Formula 63).

Suppose that one person consumes 40 litres of water, which corresponds to 2.1 kWh/day.

Sizing of the storage tank:

$$V_{ST} = 2 * V_{PER} * n = 2 * 40 * 3 = 240 \ \text{l} \tag{61}$$

Where:

V	Size of water storage tank [l];
$\boldsymbol{V_{PER}}$	Water consumption by 1 resident, $\boldsymbol{V_{PER}}$ = 40 [l];
n	Number of residents [-].

The power consumption for water heating per year:

$$Q_{HW} = 365 * 2.1 * 3 = 2299.5 \ \text{kWh} \tag{62}$$

Solar collector sizing:

$$S_{COL} = \frac{0.6}{0.3} * \frac{Q_{HW}}{H_{SOLAR} * f_{INCLIN}} = \frac{0.6}{0.3} * \frac{2299.5}{1000 * 1.022} = 3.8325 \ \text{m}^2 \tag{63}$$

Where:

$\boldsymbol{H_{SOLAR}}$	Annual solar radiation [W/m^2], $\boldsymbol{H_{SOLAR}}$= 1000 [W/m^2];
$\boldsymbol{f_{INCLIN}}$	Solar gain for particular collector inclination [kWh/year],
	$\boldsymbol{f_{INCLIN\ (45°)}}$= 1022 kWh/year.

Due to calculations above, I suggest using 2 solar collectors Suntime 2.1 with following parameters:

- Dimensions: 1895 x 2110 mm,
- Absorption surface: 1.84 m^2,
- Solar gain for 45° inclination: 1022 kWh/year,
- Volume of water: 1.1 l,
- Weight: 38 kg.

Calculations show that between values from the Suntiware software and my own calculations are no major differences.

9.7 Design of photovoltaics

The first step in the design of photovoltaic panels is to establish an area of the roof where the panels can be installed. If we subtract the area for potential solar panels, chimney and antenna, we get an area up to 80 square meters. Although, due to the high initial cost, we will consider only a half of the area while calculating

Process design and calculation is performed according to Design of photovoltaics (Chapter 6.3.1) and formulas (Formula 25, Formula 26). Assuming an average efficiency of photovoltaic panels to 15.4% and annual solar energy in Zlín 1100 [kWh/m^2], we can calculate the total installed capacity and electricity profits.

$$P_{PP} = A * \eta = 36 * 0.15 = 5.54 \text{ kW} \tag{64}$$

$$E_{EL} = H_{SOLAR} * f_{INCLIN} * P_{PP} * PR = 1100 * 1.1 * 5.54 * 0.8 = 5363 \text{ kWh/year} \tag{65}$$

Average value of photovoltaics installed on family houses is around 5 kW of installed capacity.

Parameters of the selected photovoltaics:

- Installed capacity: 5.04 kWp;
- Solar panels: 21 pieces 240 Wp;
- Solar panels efficiency: 15.4%;
- Surface: 36 m^2;
- System lifetime: 30+ years;
- Warranty on the performance +80%: 25 years.

10 ELECTRICAL INSTALLATION

The house is connected to the electric meter cabinet, which binds to the house's main distribution board. Distribution board is located on the ground floor, in the entrance corridor (room number 11). Furthermore, wiring is fed into the secondary distribution boards, such as distribution board in lower ground floor, in the utility room, in the garage and in the cellar. Individual distribution boards are divided into lighting and socket circuits into various rooms. Each floor wiring is drawn in the figures below (Figure 20 – 23).

Using electrical equipment in bath or shower rooms has always needed care to ensure safety. 3 particular zones within the bathroom are indentified to indicate what type of electrical equipment can be installed.

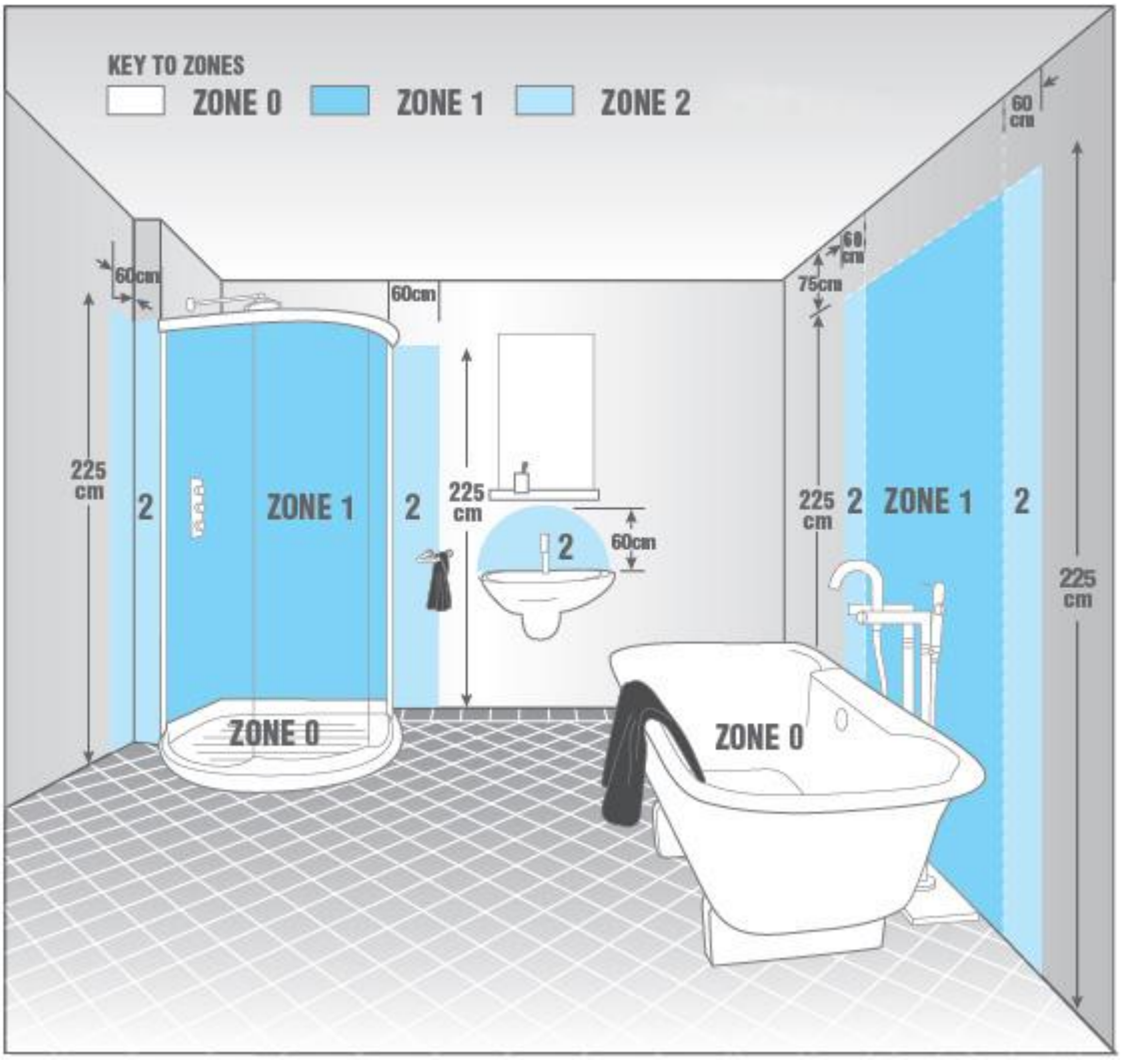


Figure 19: Bathroom zones [37]

Zone 0: Inside the bath or shower. Any fitting used here must be SELV (maximum of 12 V) and minimum of IPX7 (protected against immersion in water);

Zone 1: Above the bath and shower to a height of 2.25 m. A minimum rating of IPX4 is required* (see Note 1);

Zone 2: The area stretching to 0.6 m outside the bath or shower and above the bath or shower. An IP rating of at least IPX4 is required (see note 1);

Note 1: In zones 1 & 2, if there is likelihood of water jets being used for cleaning purposes, a minimum of IPX5 is required. [37]

All electrical installation situated in bathroom must be equipped with residual-current device (RCD), which is an electrical wiring device that disconnect an electrical circuit whenever it detects difference between the energized and the return conductor (small leakage currents, typically 5 – 30 mA). RCD is designed to disconnect the conducting wires quickly enough (less than 300 ms).

10.1.1 Lighting circuit and blinds opening

Lighting circuits are designed to cover the required values of light intensity, which is defined in standard ČSN 12464-1 and it is also described in chapter 2.8. Switches are usually placed at the front door, on the handle side, but it is not mandatory. [38]

Buttons for blinds control are situated in every room, beside the light switches.

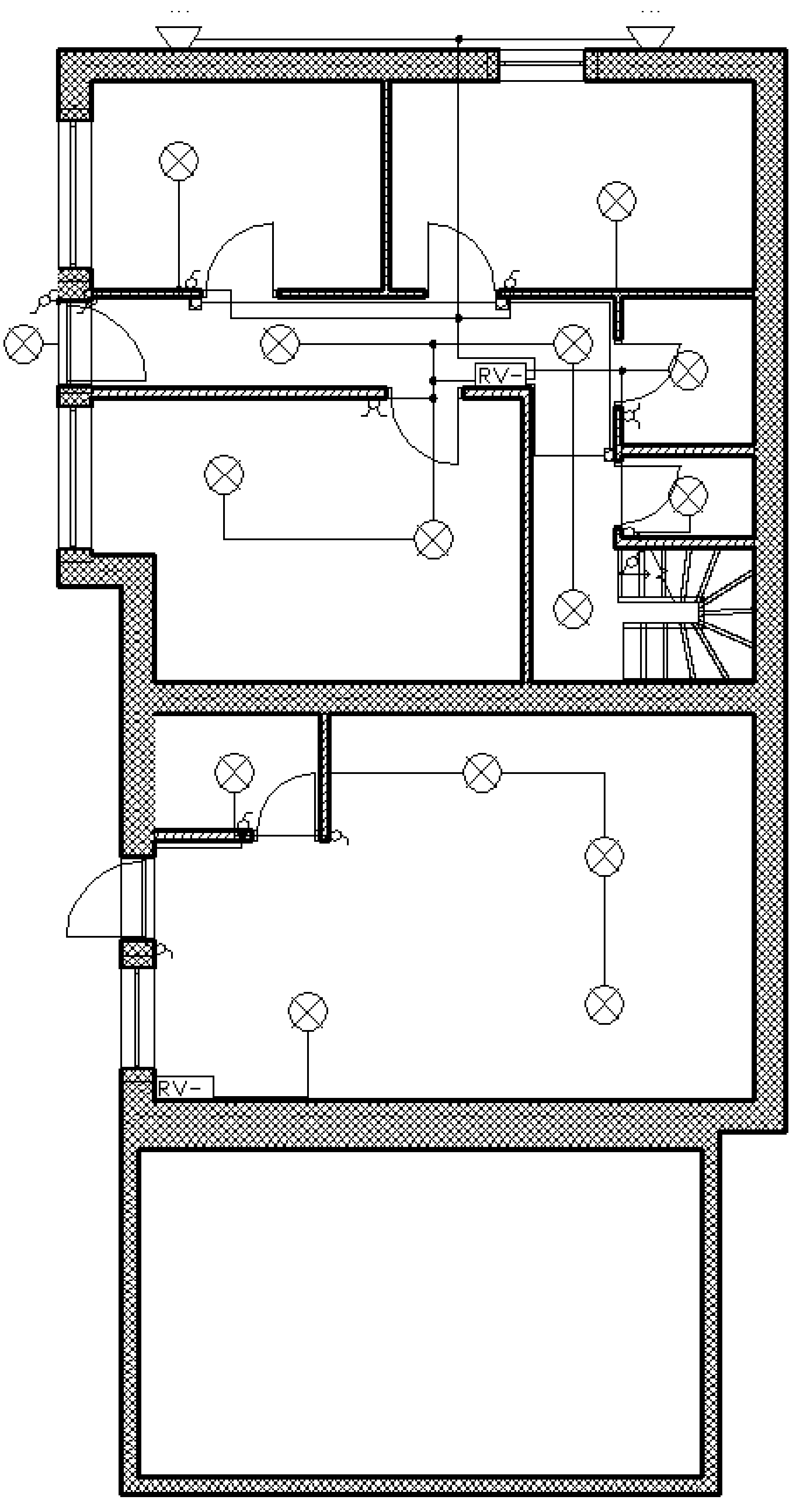


Figure 20: Lower ground floor lighting circuit

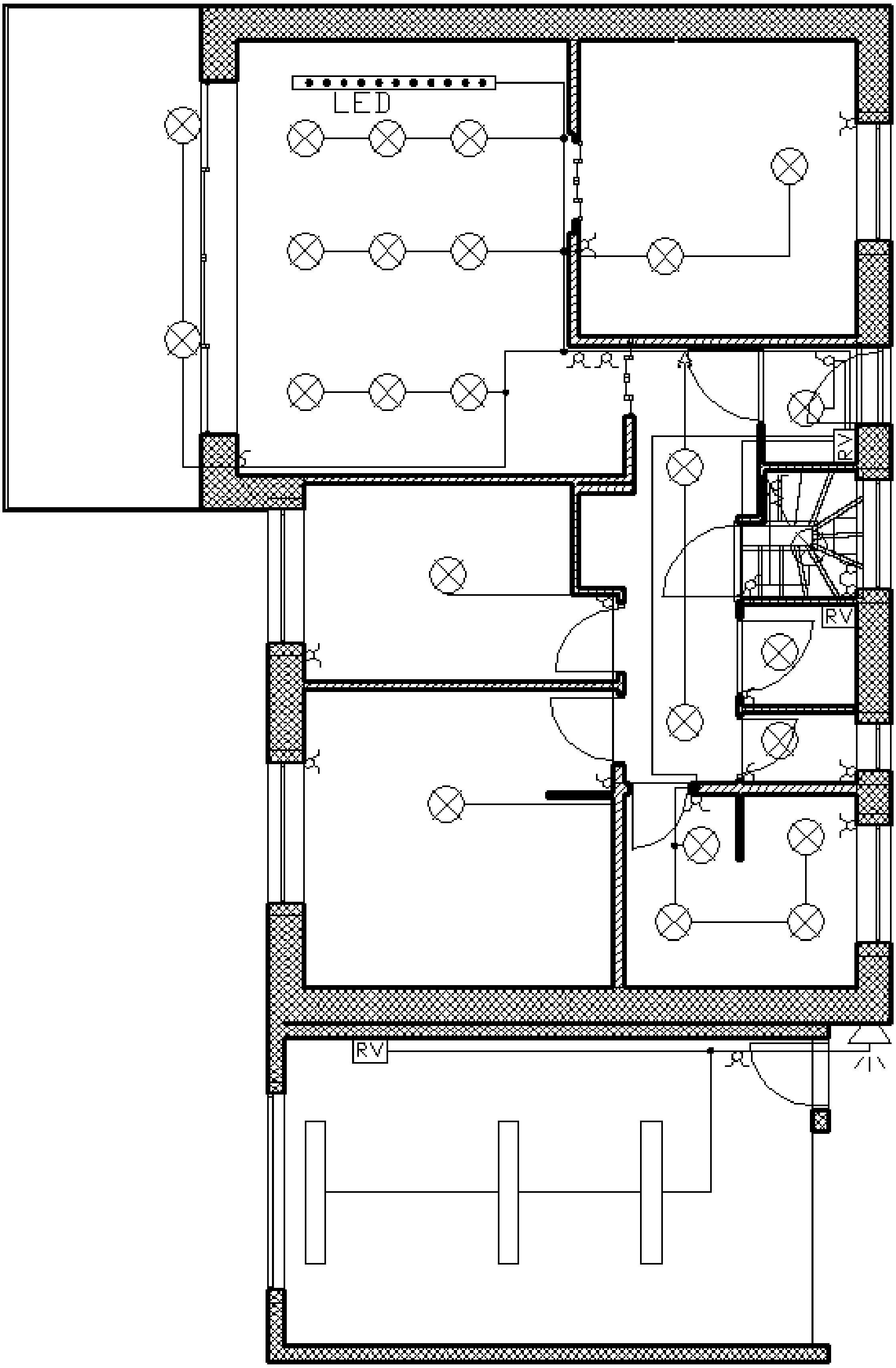


Figure 21: Ground floor lighting circuits

Lighting circuits according to distribution board placement:

- Lower ground floor:
    - RCD bathroom (3);
    - Living room (1), bedroom (2), outdoor lights;
    - Rest of floor;
- Ground floor:
    - RCD bathroom (14);
    - Bedroom (16), office (15), WC (13), entrance corridor (11);
    - Living room (9), balcony, kitchen (10), corridor (17);
- Utility room:
    - Utility room (12);
- Garage:
    - Garage (18);
- Cellar:
    - Cellar (7+8).

10.1.2 Socket circuit

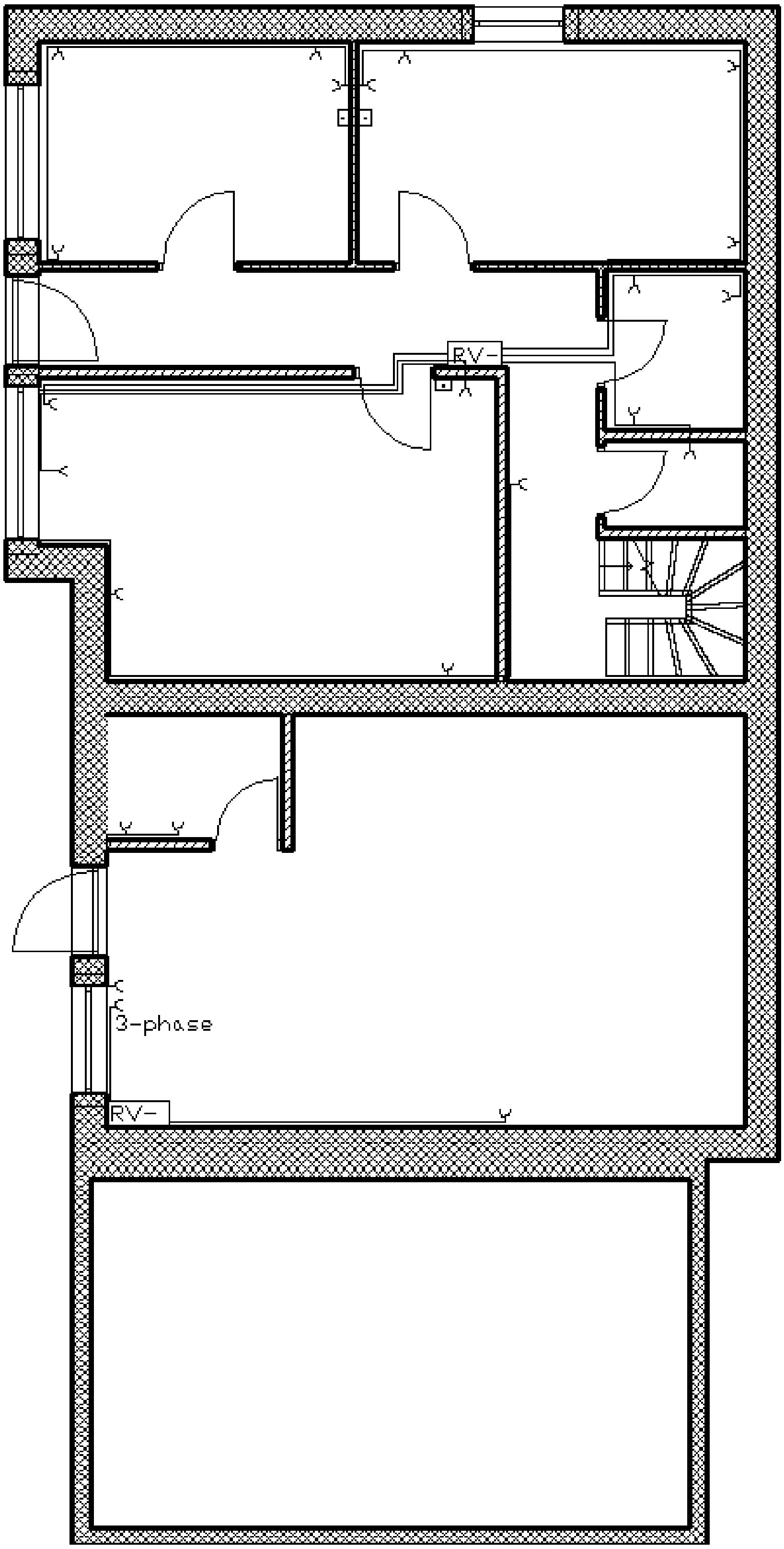


Figure 22: Lower ground floor socket circuit

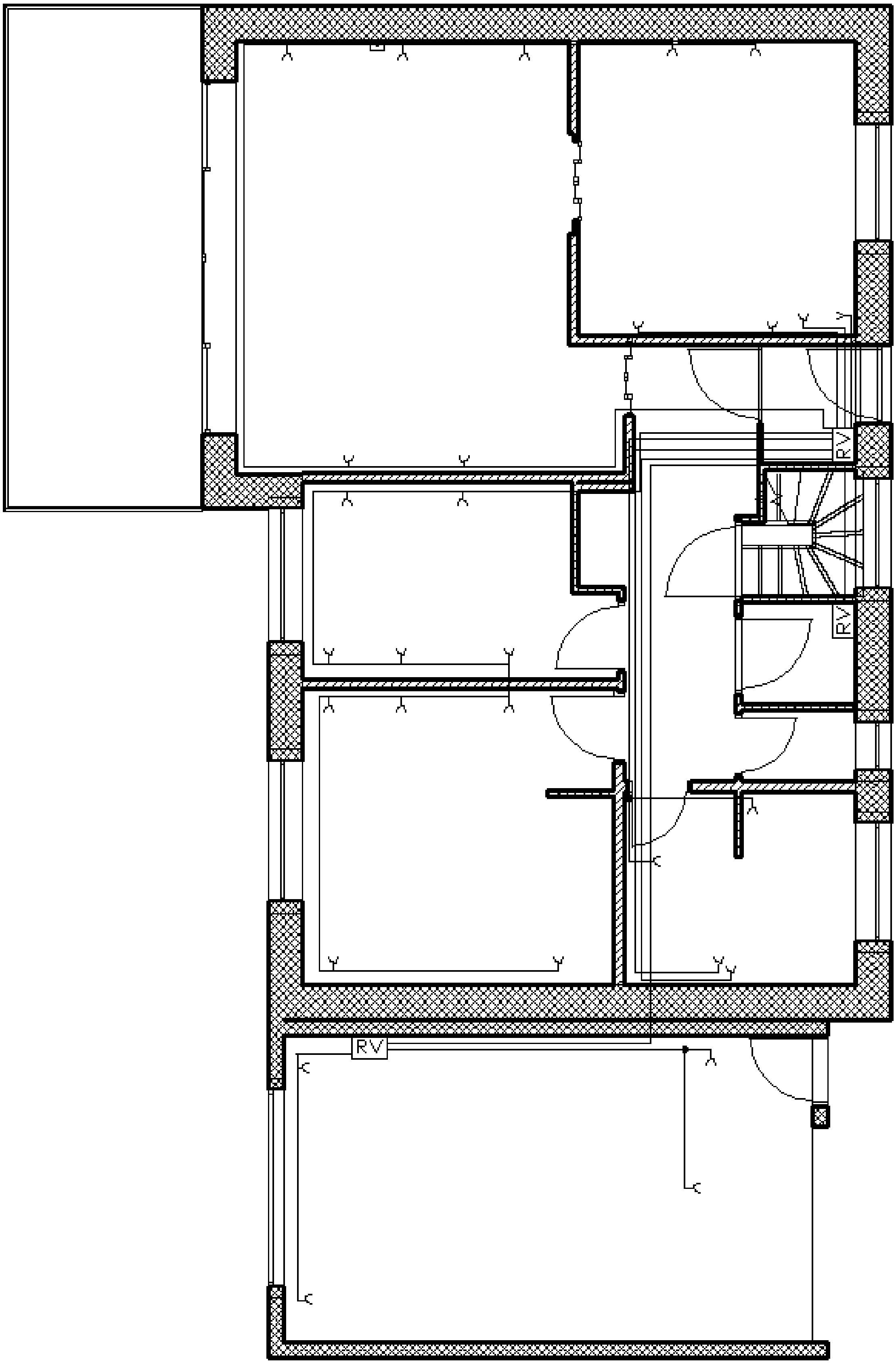


Figure 23: Ground floor socket circuit

Socket circuits according to distribution board placement:

- Lower ground floor:
    - RCD bathroom (3);
    - Dishwasher;
    - Cooker;
    - Electric kettle, living room (1), bedroom (2);
- Ground floor:
    - 3 circuits of RCD in bathroom (14): dryer, washing machine, sockets;
    - 3 circuits of RCD in kitchen (10): dishwasher, cooker, rest of sockets;
- Utility room:
    - Utility room (12);
- Garage:
    - Garage (18);
- Cellar:
    - Cellar (7+8);
    - 3-phase circuit.

10.1.3 Fire alarm system and I&HAS

The security system has been designed in a wired version. The main components of the system are magnetic contacts (security of windows and doors) and PIR detectors (to prevent unauthorized movement inside the building). Other devices are PBX of the security system (platform), fire detector, outdoor siren and 2 keyboards to control the whole system.

11 CONTROL AND COMMUNICATION

Designed KNX system is far away from dimensions it could reach. It is caused by the financial limitations from the investor, who expressed the wish not to propose large and expensive system. For this reason, installation for control 3 circuits was designed. These circuits include the control circuit of solar collectors, control circuit of hot water and heating system. Wiring is conducted under plasters and lower ceilings and intertwines the requested areas. Main components of the system are thermometers, shutoff valve, 2-way valve, 3-way mixing valve, 3-way thermostatic mixing valve and water pump.

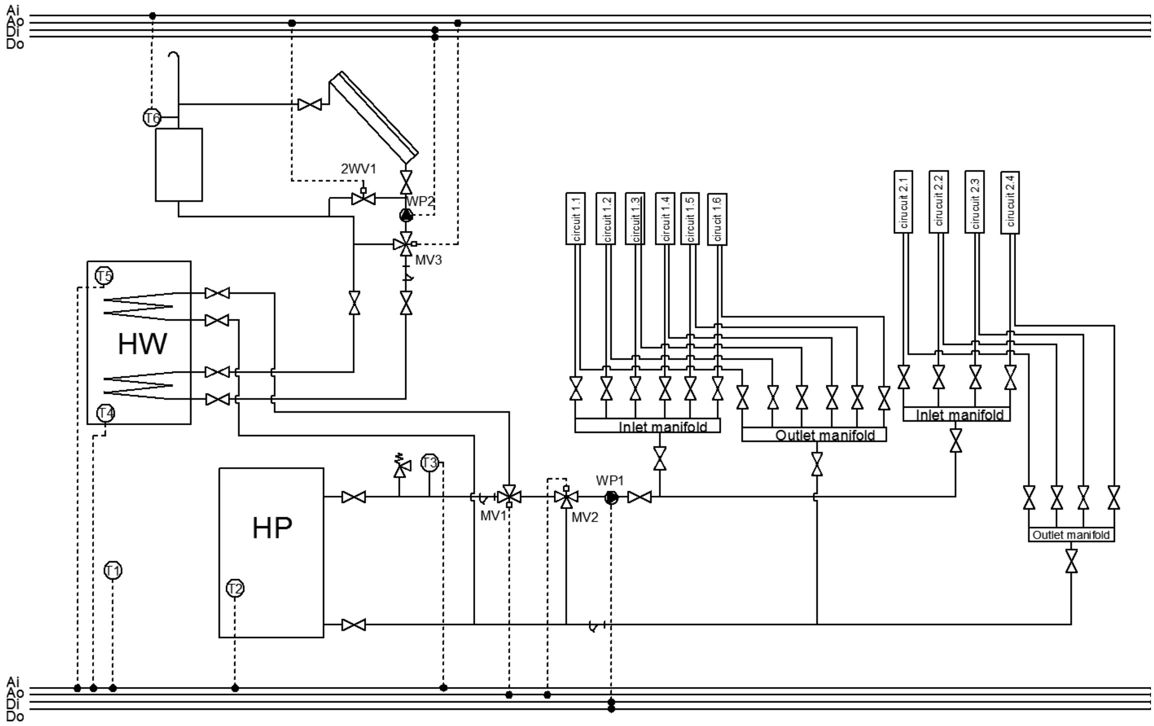


Figure 24: Scheme of heating and hot water preparation

11.1 Description of the heating system control

Hot water preparation' circuit.

The desired temperature of hot water is set to 50 °C. If the temperature T5 < 50 °C, MV1 (3-way mixing valve no. 1) is closed in the way to heating circuits and all hot water is directed to HW tank.

When the temperature T5 ≥ 50 °C, MV1 is opened in the way to heating circuits and system is heating.

Solar collectors' circuit.

If T6 > T4, MV3 (3-way mixing valve no. 3) is opened, which leads to filling HW tank with water from solar collectors.

If T6 < T4, MV3 is closed. This condition means, that water from solar collector is colder than the water inside HW tank and their mixing would cause cooling of the water inside the HW tank and it would be highly disadvantageous and uneconomic.

If T6 < T4 lasts longer than one hour, it means there are not ideal conditions and WP2 (water pump no. 2) will be closed and 2VW1 (2-way valve no. 1) opened. Same mode will be held in the period between 8 pm to 7 am and in the winter.

Conditions of the system.

MV2 is a 3-way thermostatic valve and its temperature is set to the same temperature as the temperature of heating circuit. If the MV2 is opened, WP1 must be turned on. If MV2 is closed, WP1 must be turned off, otherwise the destruction of water pump is being risked.

According to sanitary regulations, water inside HW must be heated to more than 80 °C once in a certain period of time.

11.2 SCADA visualisation

The basic element of the system is the central touch panel, which contents the visualisation control. The panel is connected to the bus and communicates with other elements of intelligent systems, thereby allows systems control as well. As it was mentioned earlier, due to financial limitations, the system visualisation offers only the heating system and temperature data. The touch panel is divided into 4 main categories. General conditions, heating system and the remaining two are for individual floors.

Pictures of SCADA visualisation are shown below (Figure 25, Figure 26 and Figure 27).

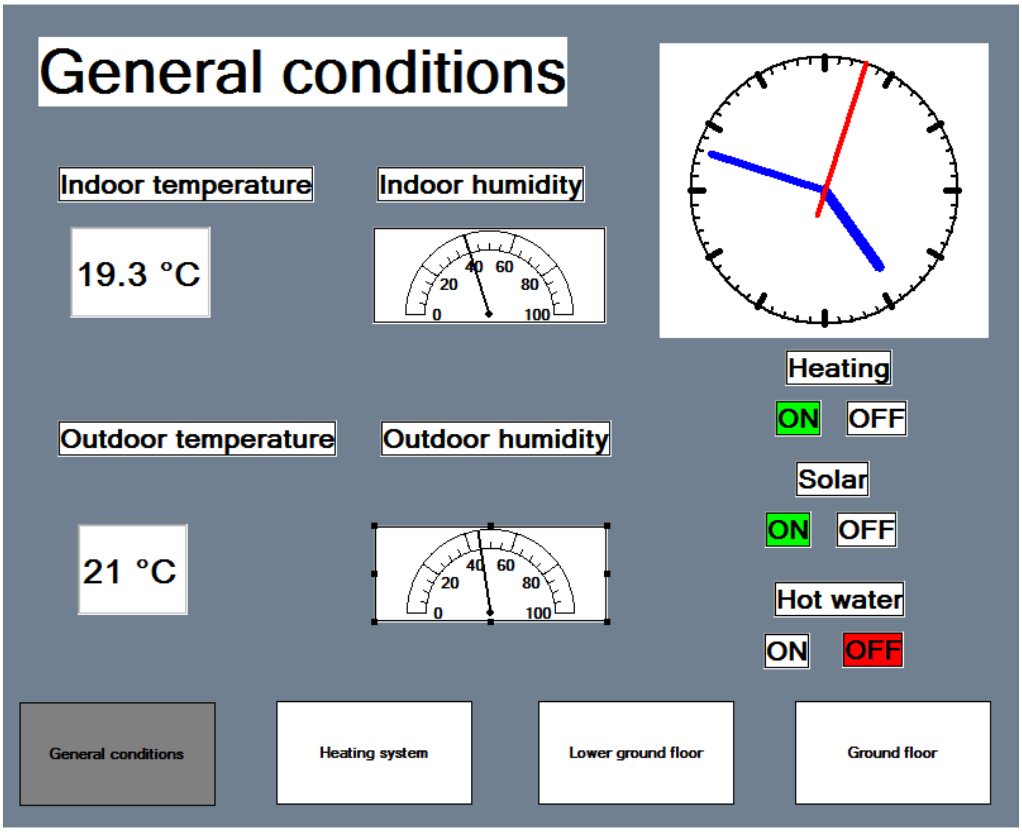


Figure 25: SCADA visualisation, general conditions

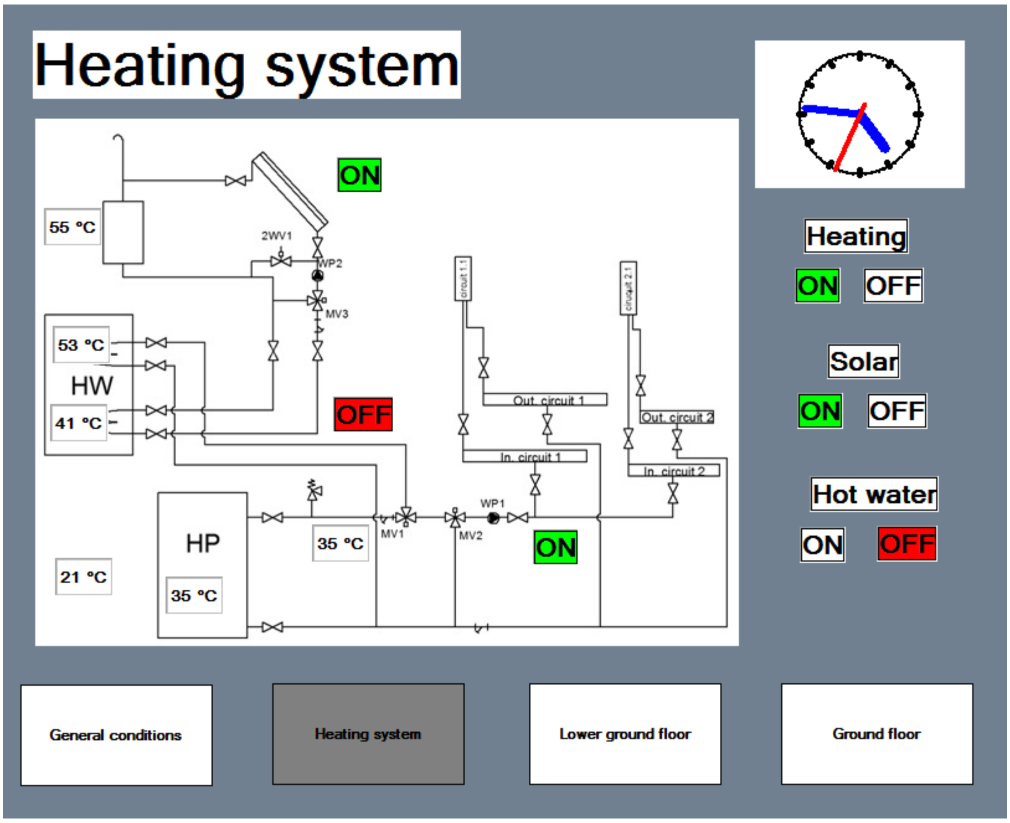


Figure 26: SCADA visualisation, heating system

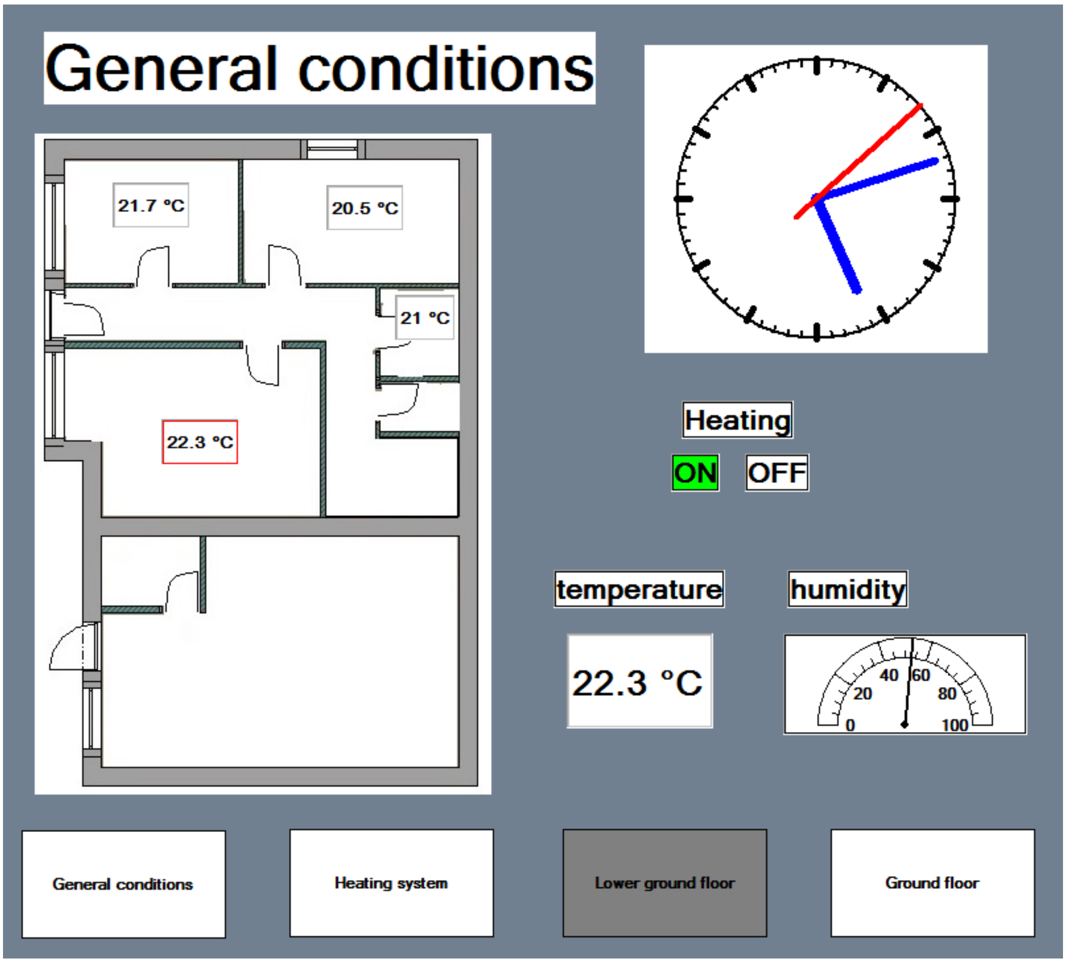


Figure 27: SCADA visualisation, lower ground floor

Red rectangle around the temperature in the room indicates which room values are displayed.

Figure for the category Ground floor has the same appearance as Figure 27.

12 ECONOMIC EVALUATION

Economic evaluation serves as the basis for an investor, who due to financial calculations can decide what technologies will be installed. The proposed technology can be divided into two groups. In the first group, I would place a heating system, solar collectors and photovoltaics. On the basis of financial calculations of acquisition and operating costs, the investor can easily verify which system is convenient for him and which not. On the other hand, this type of decision is no longer usable for the second group of systems, such as fire alarm system, I&HAS and intelligent systems. These systems do not guarantee financial savings but they do increase living comfort and ensures piece of mind.

12.1 Economic evaluation of photovoltaics

For exact determination of the financial evaluation is needed to know the cost of acquisition and operation of photovoltaics and the amount of savings brought by the system. Since it is uneconomical to supply the generated electricity into the grid, the savings rate will be considered only by the amount of energy that we use to operate the house.

The proposed photovoltaics is a turnkey solution, total cost is 219577 CZK and it includes all necessary components.

Additional parameters for calculations:

- Price per kWh: 2.2 CZK;
- Discount: ***r*** = 5%;
- Inflation: ***α*** = 2%;
- Average annual return: ***CF*** = 11880 CZK;
- Initial costs: 219577 CZK;
- Lifetime of project: ***t*** = 25 years.

Simple payback ***T*** calculation.

$$T = \frac{IN}{CV} = \frac{219577}{11800} = 18.48 \text{ years} \tag{66}$$

However, this calculation does not include cash flow over the time. Therefore, we consider more accurate discounted payback period ***Td***.

$$T_d = \frac{\ln\left[1+\frac{IN}{CF}*(\alpha-r)\right]}{\ln\frac{1+\alpha}{1+r}} = \frac{\ln\left[1+\frac{219577}{11880}*(0.02-0.05)\right]}{\ln\frac{1+0.02}{1+0.05}} = 27.89 \text{ years} \quad (67)$$

Next calculation is a net present value (***NVP***). It is defined as the sum of the present values of incoming and outgoing cash flows over a period of time. It is a useful tool to determine whether a project will result in a net profit or a loss. A positive ***NPV*** results in profit while a negative ***NVP*** results in a loss.

$$NPV = CF * \frac{(1+r-\alpha)^t-1}{(r-\alpha)*(1+r-\alpha)^t} - IN = 11880 * \frac{(1+0.05-0.02)^{25}-1}{(0.05-0.02)*(1+0.05-0.02)^{25}} - 219577 = -12708.81 \text{ CZK} \quad (68)$$

Considering formulas above (Formula 66, Formula 67, Formula 68) I do not recommend installation of photovoltaics in this project. Photovoltaic panels are not profitable due to low annual return, which is caused by heat pump and related low price per kWh.

12.2 Economic evaluation of solar system

Table 26: Economic evaluation of solar system

	Solar collectors
Investment cost [CZK]	82391.00
Average annual return [CZK/year]	4871.00
Discount [-]	0.05
Inflation [-]	0.02
Lifetime of the project [year]	25.00
Simple payback *T* [year]	16.91
Discounted payback time [year]	24.40
Net present value [CZK]	13083.00
Internal rate of return (IRR) [%]	6.18

Internal rate of return (***IRR***) is represented by function:

$$CF * \frac{(1+IRR)^t - 1}{IRR * (1+IRR)^t} = 0 \qquad (69)$$

IRR = 6.18%

Result 6.18% means, that investment will return during the lifetime and will bring a further 6.18% of the initial costs. Thus, installation of solar collectors is recommended.

Although discounted payback time is on the edge of system lifetime, the solar collectors are recommended. The main reason for this decision is the fact that the project is calculated for 3 persons and it is likely that this number will be increased in the future, which will result in more hot water consumption and therefore a higher system return.

There is also a possibility to participate in the Czech subsidy program Zelená úsporám. The company installing the solar collectors apply itself into the subsidy handling. If so, the initial cost would be reduced by 34000 CZK. Final calculations of the system are shown in table 27.

Table 27: Economic evaluation of solar system

	Solar collectors
Investment cost [CZK]	48391.00
Average annual return [CZK/year]	4871.00
Discount [-]	0.05
Inflation [-]	0.02
Lifetime of the project [year]	25.00
Simple payback *T* [year]	9.93
Discounted payback time [year]	12.21
Net present value [CZK]	47083.00
Internal rate of return (*IRR*) [%]	11.40

12.3 The cost of intelligent wiring

The cost of intelligent wiring is not included in the calculation of economic return, as they do not offer the option of financial savings. The main reason for installing these systems is the piece of mind knowledge and the increase of the comfort and safety of the house.

For design and price of KNX elements were used Schneider electric website and overall calculation was determined to 76178 CZK.

Since it is a newly built house and there is no problem to perform wiring for the security systems (Fire alarm system and I&HAS), wired version of the system was designed with the final price 22093 CZK.

Table 28: Calculation of security systems

	Prize per unit [CZK]	**Lower ground floor No. of units**	**Ground floor No. of units**
Magnetic contact	70	6	11
PIR	630	4	8
Fire detector	617	1	1
Outdoor siren	1254	0	1
Central panel	4050	0	1
Keyboard	1594	1	1
Prize of cables	2500		
Total	**22093**	**5151**	**16942**

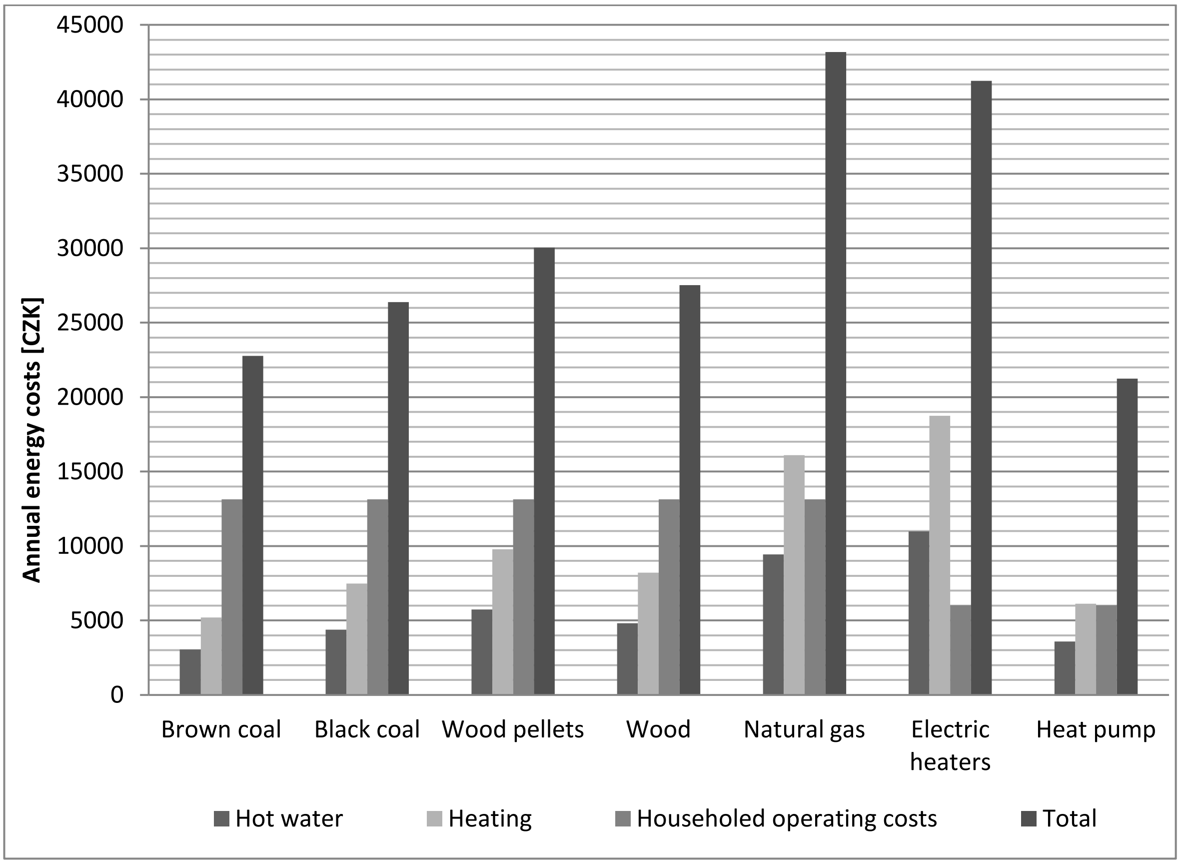
If we want to take into account the wireless version of security systems, the total costs would be doubled.

12.4 Economic evaluation of heating system and hot water preparation

Before we can estimate an overall evaluation, we have to determine the total costs of heating system.

- The energy consumption for heating: 8800 kWh/year;
- The energy consumption for HW: 4871 kWh/year;
- Total energy consumption: 13671 kWh/year.

Graph 2: Annual energy costs for individual heat sources



For an accurate understanding of the Graph 2, it is important to explain used values. In the total, operation costs of the household (cooking, lighting, TV, etc.) are counted as well. If we choose electric heaters or a heat pump, cheaper electricity rate could be set. Thus, operation costs would be 6006 CZK instead of 13138 CZK per year. On the other hand, it is necessary to mention the fee for this cheaper rate, which is 5532 CZK instead of 1380 CZK. The final calculation of mentioned information shows, that running the cheap rate is 2980 CZK more profitable.

As we can read from Graph 2, the cheapest fuel appears to be a heat pump (21244 CZK/year), followed by brown coal (22760 CZK/year) and black coal (26386 CZK/year). This final evaluation still does not perfectly reflect the ratio between mentioned heating systems. Moreover, each system has a different acquisition value and specific performance requirements. Heat pump has more expensive initial costs, but these costs are at least returned back due to the cheaper operations. Another big advantage of the heat pump is the operating comfort. There is no need for resources obtaining, its storage, or loading the boiler.

CONCLUSION

The aim of this thesis was a study of energy saving solutions of family houses. The thesis is divided into two parts. The first part is called Theory and describes houses with nearly zero energy consumption in terms of building physics, energy consumption, creation of microclimate, lighting, acoustic problems and possibilities of using renewable energy resources. Based on analysis of the factors above, the equipment requirements of the environment have been described.

The study also analyses the possibility of using renewable energy resources, such as heat pumps, solar collectors and photovoltaic panels. The HVAC chapter deals with hot water preparation and undefloor heating. A great emphasis has been placed upon on last issue, because in the second part of the thesis, there is a practical calculation of it. At the end of the Theory, electronic systems are mentioned. Electronic systems, such as security systems I&HAS, fire alarm systems and communication of intelligent system KNX with SCADA.

The second part is called Analysis. In this part, the practical application of the concepts described in the previous section is discussed.. Firstly, the particular object is described. For enhanced illustration of these concepts, images from software Revit software are used. Pictures of the 3D model of the object are followed by plans of floors, either lower ground floor, or ground floor. There is also a table of marginal conditions, whose values are needed for calculations of building characteristics. For each room U values of the building, heat loss and heat gains are identified. The calculations were verified by using suitable software, which helped to ensure that the most appropriate systems, materials and technology were used. Results of previous calculations are shown in the energy performance certificate, at the end of this chapter.

Another section is devoted to HVAC design, which describes a system for hot water preparation and heating, which will be used in the building. The design of appropriate underfloor heating is very important, thus, underfloor heating was proposed for each room exactly as it was described in the Theory. The HVAC chapter also contains a calculation of the expansion tank of the heating system and the design of systems using renewable energy resources, namely the proposal of a heat pump, solar collectors and photovoltaics. The last point contains a draft of the electrical wiring, which is divided into high and low voltage circuits, including lighting and socket circuits. The conclusion of this chapter refers to

I&HAS and fire alarm systems. All these points are supplemented by drawings from AutoCad software.

The penultimate chapter of this thesis investigates the design and analysis of intelligent KNX systems, its components and SCADA visualisation. The last pages describe the economic evaluation of afore-mentioned systems. Economic evaluation is vastly important to a potential investor, because they can easily verify the financial profitability of the systems. The evaluation is divided into particular systems and it is complemented by transparent calculations and graphs.

The result of this thesis is the design of an intelligent building with low operating costs, meeting the criteria for modern living comfort, while the technology of today is being used.

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LIST OF VARIABLES

$\boldsymbol{A}$	Surface [m^2]
$\boldsymbol{b}$	Coefficient of thermal reduction [-]
$\boldsymbol{c}$	Specific heat capacity [kJ/(kg*K)]
$\boldsymbol{d}$	External diameter [m]
$\boldsymbol{E_{EL}}$	Yeild of photovoltaics [kWh/year]
$\boldsymbol{f_{INCLIN}}$	Solar gain for particular collector inclination [kWh/year]
$\boldsymbol{g}$	Gravity acceleration constant [m/s^2]
$\boldsymbol{h}$	Height [m]
$\boldsymbol{H_{SOLAR}}$	Annual solar radiation [W/m^2]
$\boldsymbol{H_T}$	The specific loss of heat transfer [W/K]
$\boldsymbol{I_W}$	Intensity of solar radiation through single glaze [W/m^2]
$\boldsymbol{l}$	Length [m]
$\boldsymbol{L}$	Thermal load [W]
$\boldsymbol{M}$	Amount of water vapor in the state of saturation [g/m^3]
$\boldsymbol{m}$	Characteristic coefficient of the floor [m^{-1}]
$\boldsymbol{\dot{m}}$	Water flow rate [kg/s]
$\boldsymbol{n}$	Number [-]
$\boldsymbol{\phi_i}$	Total heat loss [W]
$\boldsymbol{\phi_p}$	Desired power output [kW]
$\boldsymbol{P_{PP}}$	Capacity factor of photovoltaics [kW]
$\boldsymbol{PR}$	Performance ratio [-]
$\boldsymbol{\phi_{T,i}}$	Total heat loss through heat transfer [W]
$\boldsymbol{\phi_{V,i}}$	Total heat loss through ventilation [W]
$\boldsymbol{q}$	Heat flux density [W/m^2]
$\boldsymbol{Q_{CON}}$	Heat gain by convection [W]

Q_H	Required power output of heating system [W]
$Q_{N,f}$	Heat loss of the room [W/m^2]
Q_P	Heat supplied by heater [kWh]
Q_{TP}	Total need of heat [kWh]
Q_{ZP}	Heat loss during a preparation and distribution [kWh]
R_{si}	R value during heat transfer
S_{rv}	Relief valve seat cross section [mm^2]
T	The pitch of pipes [m]
U_{em}	The average U value [W/(m^2*K)]
V	Volume [m^3]
w	Flow velocity [kg/s]
Δp_z	Total friction loss in the pipe [Pa]
$\Delta\theta$	Temperature difference [°C]
θ_i	Indoor air temperature [°C]
$\theta_{int,i}$	Calculated indoor temperature [°C]
θ_m	The mean temperature of circulating water [°C]
θ_s	The absolute temperature of the heat appliance [K]
θ_{si}	Inner surface temperature [K]
θ_u	Air temperature of environment under the floor [°C]
θ_z	The absolute temperature of the heat source [K]
λ	Thermal conductivity coefficient [-]
ρ	Density [kg/m^3]
τ	Shading coefficient [-]
φ	Relative humidity [%]

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
CENELEC	Comité Européen de Normalisation Electrotechnique
ČSN	Czech State Norm
CZK	Czech Koruna
E.g.	Abbreviation of for example
EPC	Energy Performance Certificate
Etc	Abbreviation of expressions such as, and so forth, and so on
HVAC	Heating, Ventilation, Air-Conditioning
I&HAS	Intruder & Hold Up Alarm System
IP	Internet Protocol
IRR	Internal Rate of Return
ISO	International Organization of Standardization
KNX	Konnex – OSI based network communications protocol
LAN	Local Area network
PBX	Private Branch Exchange
PC	Personal Computer
PDD	Predicted Percentage Dissatisfied
PIR	Passive InfraRed sensor
PL	Poweline
PLC	Programmable Logic Controler
PVM	Predicted Mean Vote
RTU	Remote Terminal Units
TP	Twisted pair
UK	United Kingdom

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APPENDIC

CD with an electronic version of the work and appendices is attached.