CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF CIVIL ENGINEERING

Department of Construction Management and Economics

MASTER´S THESIS

Cost for Cooling Systems in Buildings of Czech Republic and Peru

2019 Bc. Zuzana Musková

ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Musková** Jméno: **Zuzana** Osobní číslo: **438459**

Fakulta/ústav: **Fakulta stavební**

Zadávající katedra/ústav: **Katedra ekonomiky a řízení ve stavebnictví**

Studijní program: **Stavební inženýrství**

Studijní obor: **Projektový management a inženýring**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Náklady na systémy chlazení v budovách České republiky a Peru

Název diplomové práce anglicky:

Cost for Cooling Systems in Buildings of Czech Republic and Peru

Pokyny pro vypracování:

Téma chlazení v budovách
Porovnání přístupů v České republice a Peru
Náklady na chlazení
Případové studie RD a BD
Vyhodnocení

Seznam doporučené literatury:

ČSN 73 0540-2, 2011. Thermal protection of buildings – Part 2: Requirements. Czech technical standards.
ECOFYS, 2015. Assessment of cost optimal calculations in the context of the EPBD (ENER/C3/2013-414): Final report. [Online] Available at: https://ec.europa.eu/energy/sites/ener/files/documents/Assess-ment%20of%20cost%20optimal%20calculations%20in%20the%20cotext%20of%20the%20EPBD_Final.pdf
Tywoniak, J.; Matuška, T.; Staněk, K.; Novák, J.; Růžička, J.; Šenberger, T. Nízkoenergetické domy 3. nulové, pasivní a další, Praha: GRADA PUBLISHING, 2012. ISBN 978-80-247-3832-1.

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Datum zadání diplomové práce: **26.09.2019** Termín odevzdání diplomové práce: **05.01.2020**

Platnost zadání diplomové práce: __________

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III. PŘEVZETÍ ZADÁNÍ

Diplomantka bere na vědomí, že je povinna vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

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Statutory declaration

I hereby declare that the bachelor’s thesis entitled “Cost for cooling systems in buildings in the Czech Republic and Peru” submitted to Czech Technical University in Prague was written by myself under the guidance of Ing. Jiří Karásek, Ph.D. and Ing. Ramzy Francis Kahhat Abedrabbo Ph.D., I have stated all the resources used to elaborate this thesis in conformity with the Methodical guide for ethical development of university final thesis.

Prague, 5th January Zuzana Musková

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Acknowledgements

I would hereby like to express my sincere gratitude to my supervisors for their personal guidance, patience and inspiration during the work on this thesis. I would like to thank my family for their support and encouragement throughout the years.

Table of Contents

Symbols and Abbreviations in This Thesis

All symbols and indexes used in this work in Chapter 2 are in accordance with ČSN EN ISO 52016-1: Energy performance of building - Energy need for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures.

Other used Abbreviations

AC	Air conditioning
EER	Energy Efficiency Ratio
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
EED	Energy efficiency Directive
EU	European Union
Toe	Tonne of oil equivalent

Anotace

Diplomová práce se zabývá problematikou chlazení budov především kvůli klimatickým změnám a rostoucím požadavkům na kvalitu vnitřního prostředí v rodinných a bytových domech. Pro lepší pochopení problematiky tato studie vysvětluje tepelný komfort a představuje použité metody pro výpočet potřeby energie na chlazení budov. Představuje základní způsoby chlazení využívané v Peru a České republice a věnuje pozornost možným zlepšením chlazení v podmínkách České republiky.

Klíčová slova

Chlazení budov, potřeba energie, náklady na chlazení budov, rodinný dům, bytový dům.

Abstract

Due to the recent climate changes and increasing temperature on the Earth, the cooling of buildings became more important than ever. Because of the warmer weather, the demand for the cooling of the buildings and family houses is on the rise. This study explains the concept of thermal comfort and the methods used for the calculation of an energy required for the cooling of structures. In addition, types of cooling systems in the Czech Republic and Peru are introduced and suggestions for possible improvements in the Czech Republic are discussed.

Keywords

Building cooling, energy , costs of building cooling, family house, apartment building.

1. Introduction

The demand for good indoor environment quality is growing and it became one of the leading trends in construction industry over the last decade. Factors that most affect the indoor air quality are heating, ventilation and cooling. In the past, the cooling in the Czech Republic did not receive much attention as heating and ventilation, but recently things started to change. With climate changes and rising temperatures, this issue is discussed more frequently.

The thermal insulation of the building has many positive effects, such as a lower heat demand. However, it can also have some negative impacts. For example, because of an insulation a room overheats faster during the warm summer days. The cooling can increase the energy performance of a whole building, so it is necessary to think about its energy efficiency and cost.

The goal of this thesis is to analyse the cooling of a family house and apartment building from an energetic and economic point of view. The first chapters briefly sum up the theory of energy performance of buildings and describe the calculation of heat loss, heat gain and total energy need for cooling. Following sections summarise the types of the cooling systems in the buildings in the Czech Republic and Peru. Thanks to its long-term maximum temperatures and long-lasting summers, I expect Peru has more experience with building cooling than the Czech Republic. Therefore, a comparison between methods used in the Czech Republic and Peru can lead to an improvement in building cooling and it can inspire new ideas leading to innovation. Moreover, it may answer the question regarding the ideal building envelope that will consider not only heating and ventilation but also cooling.

2. Literature review

In order to understand the issue better, the following paragraphs explain the basic terms and approaches in both the Czech Republic and Peru. The sources are taken from Czech and foreign literature, mostly Peruvian and American.

2.1 Introduction of standards relating to building cooling in the Czech Republic and Peru

In the Czech Republic, reducing the energy performance of a building is no longer just a fashion fad, sense of environmental friendliness or economic sentiment. It is mandatory to reduce energy performance by the Act No. 406/2000 Coll. on Energy Management. Furthermore, the Regulation No. 78/2013 Coll. on Energy Performance of Buildings needs to be followed. This regulation strengthens the energy performance requirements and tightens the value for energy performance indicators: non-renewable primary energy and the average heat transfer coefficient of the building. It is based on The Energy Efficiency Directive 2012/27/EU (abbreviated EED), is a European Union directive which mandates energy efficiency improvements within the European Union. The recommendations for building cooling are described in Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads, a standard with code ČSN EN ISO 52016-1.

In Peru, the Reglamento Nacional de Edificaciones (RNE) is used as national norms. The norms are freely available on the website http://www.construccion.org/normas. Regarding the cooling of buildings, Peru follows a regulation named ESTÁNDAR EM.050 INSTALACIONES DE CLIMATIZACIÓN. This standard mainly deals with the air conditioning units and related equipment within buildings and other constructions. The regulation exists only in Spanish, but it is translated as an Appendix 1 as a part of this thesis.

When it comes to heating, ventilation and air conditioning (HVAC), the most used standards are from the global organisation ASHRAE. This is an abbreviation for The American Society of Heating Refrigerating and Air-Conditioning Engineers, which was founded in 1894 in New York. ASHRAE publishes a set of standards and guidelines in relation to the HVAC systems. These regulations are often referenced in building codes. For the purpose of this work, the most important publications are ASHRAE Handbook-Fundamentals, ASHRAE Cooling and Heating Load Calculation Manual and ASHRAE Handbook-HVAC Systems and Equipment, which are very similar to standards used in EU.

Following the standards is not mandatory, however they are often adopted in construction contracts in both countries.

2.2 Thermal comfort

The primary purpose of air conditioning (hereinafter referred to as AC) and ventilation systems is providing a thermal comfort. To understand the subject entirely, it is necessary to have a clear idea what does this term mean. ASHRAE describes it as: "*A condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation*." [1]

Setting up thermal comfort is a very complicated issue. There are many factors, which affect human well-being. For example, a preservation of body temperature, temperature of walls and surrounding objects and skin moisture need to be taken into consideration. Human behaviour, such as ventilation intensity, choice of clothing, intensity of body movement and time spent in the room also have impact on thermal comfort.

Surprisingly, despite the climate, living conditions and cultural differences throughout the world, people find similar temperatures comfortable. Under the identical conditions (including clothing, body movement, humidity and air flow) most people will feel pleasant around the same degree.

In Czech standards, internal calculation temperatures are established by Decree No 194/2007 Coll., which designates the rules for heating and supply of hot water, measurement indicators of consumption of heat energy for heating and for the preparation of hot water. The calculation temperature for permanently used residential buildings for living rooms and kitchens is 20°C and the highest daily air temperature for residential buildings in summer is 27°C by the ČSN EN 73 0540-2 named Thermal protection of buildings – Part 2: Requirements [2][3].

However, the temperature of 26°C is entered as the comfort temperature for cooling systems in the calculations [4].

The calculation temperature in Peru is defined by the ASHARE standard for human comfort, which can be seen in Figure 1.

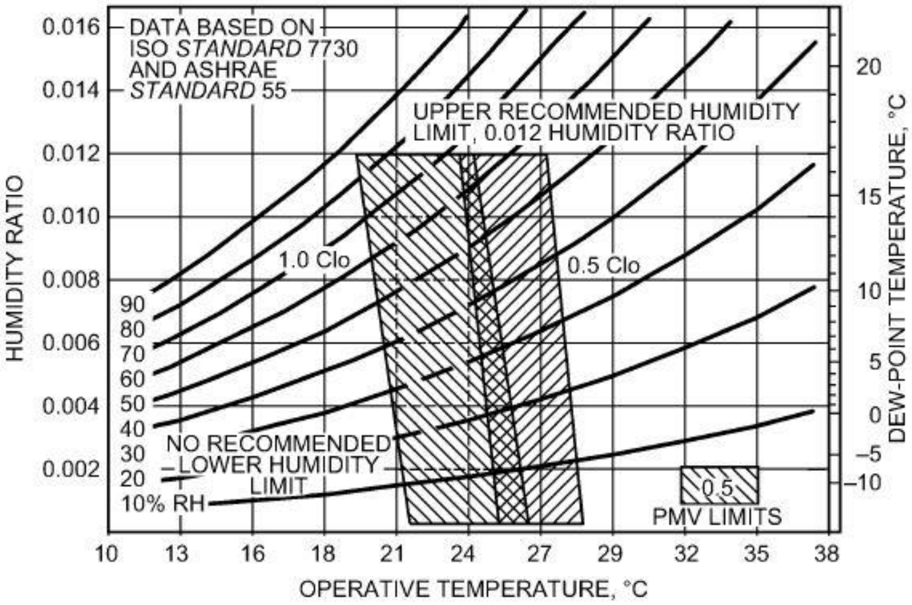

Figure 1 ASHRAE Summer and Winter Comfort Zone
Source: [1]

The temperature range for 50% humidity, in respect to the relative humidity and the clo-value[1], is similar, its range is between 20°C and 27°.

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[1] Clo-value corresponds to local clothing habits, for example: a type of shoes, shirts and headdress[1].

2.3 Building cooling

Due to different cultures and climatic conditions, approaches of both Peru and the Czech Republic to cooling are clarified in following paragraphs.

2.3.1 Comparison of approaches of the Czech Republic and Peru

The Czech Republic lies in Europe and it is considered a developed country while Peru is a developing country in Latin America. Developing countries are characterized by low energy consumption. Peru is about 16 times larger than Czech Republic. The Figure 2 shows the difference in size between the both countries. The area of Czech Republic is approximately 78,867 sq km, while Peru's is approximately 1,285,216 sq km. Meanwhile, the population of the Czech Republic is ~10.7 million people, however 20.4 million more people live in Peru.

Figure 2 Size difference between the Czech Republic and Peru
Source: [5]

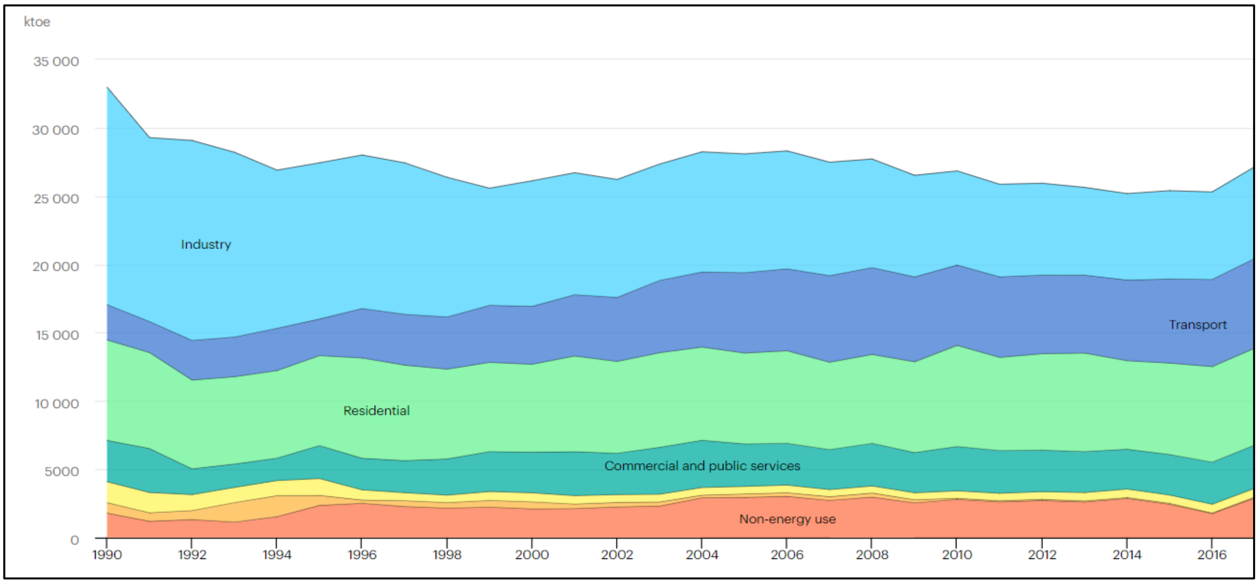


Figure 3 Total final consumption by sector, The Czech Republic, 1990-2017
Source: [6]

In focus on the residential sector (Figures 3 and 4), there is a big difference in energy consumption per person. For the Czech Republic, it is approximately 0,67 toe per person, and for Peru, it is 0,11 toe per person.

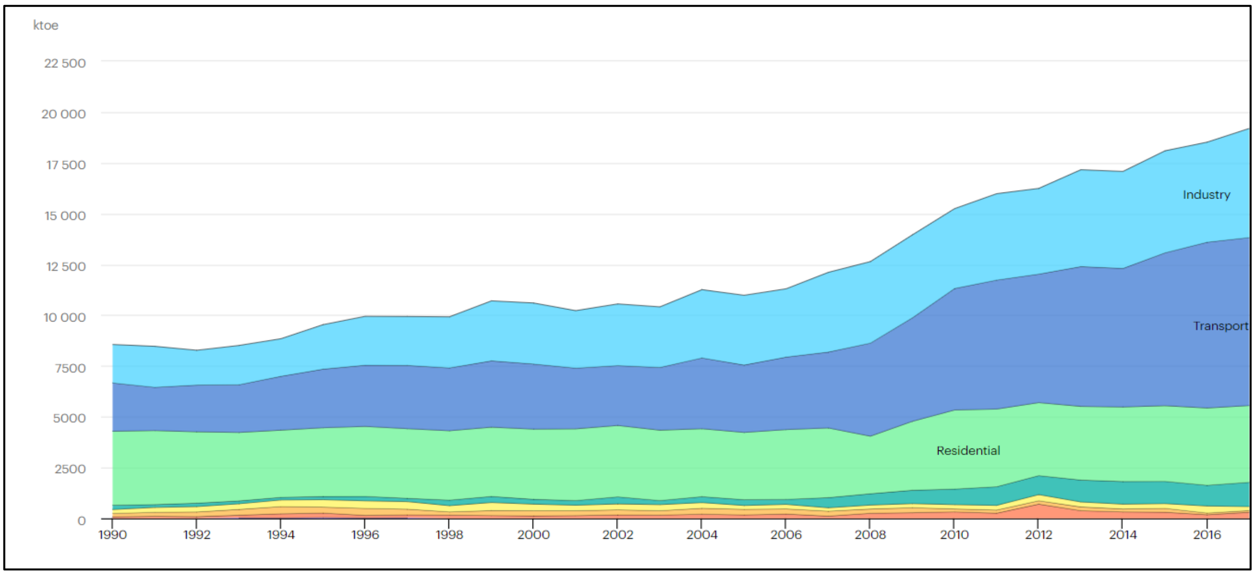


Figure 4 Total final consumption by sector, Peru, 1990-2017
Source: [6]

It is obvious that people in Peru use energy mainly to secure their basic needs, not for comfort. However, the thermal comfort is also important for Peruvians. Therefore, low-energy solutions and bioclimatic designs are used instead of conventional air-conditioning equipment designated for building cooling.

In the Czech Republic, the heating is still the number one priority. During winter, the difference between the indoor and outdoor temperatures can reach up to the 30°C, therefore the design of buildings is subjected to winter conditions.

The climate of Peru is very diverse, with a large variety of climates and microclimates, including 28 of the 32 world climates. Such a diversity is chiefly conditioned by the presence of the Andes mountains and the cold Humboldt Current. For this reason, one region of Peru is selected for the following research. Selection of part of Peru for comparison is done in Paragraph 4.2.

2.3.2 Typical cooling systems in the Czech Republic

As mentioned before, AC is used to improve the indoor environment by cooling the air inside a building. Therefore, it eliminates heat gains (loads) in the same way heating eliminates heat loss. There are several types of air conditioning systems that control the temperature, humidity and air quality. Each of them has its own characteristics and ways to control the parameters mentioned in the previous sentence. Cooling and heating systems can be categorized according to heat-transfer (cold-transfer) mediums. The heat is usually transported by air (then we talk about air-conditioning systems), water (water-conditioning) or a refrigerant (refrigerant systems). Cooling systems can be classified in terms of their use in residential areas as follows [7]:

Mobile air conditioners

This device is not considered a full-fledged air conditioning solution for larger spaces. As the name suggests, mobile air conditioners are compact devices, which are designed to be handled and moved around easily. Therefore, no special wiring or construction work is required to use them. The disadvantages of mobile air conditioners include a lower performance and a relatively high noise level, which may bring discomfort to the users [8].

"Single hose" (Figure 5) is the most widely used version of the mobile air conditioning system. Warm air is sucked from the room into the device, where part of the air is cooled and blown back into the room. The rest of the warm air is pushed outside through the hose and thus removes the heat from the room. The hose usually leads through a window. This process is similar with the vacuum ventilation of rooms. The exhaust of air from a room creates negative pressure, which makes warm air flow into the cooled room through slots and other leaks from other uncooled rooms. However, this unfortunately reduces the efficiency of the system. Another disadvantage is the presence of the compressor in the unit and in the cooled room. The quality of the indoor environment improves in terms of thermal comfort but decreases because of the noise [9].

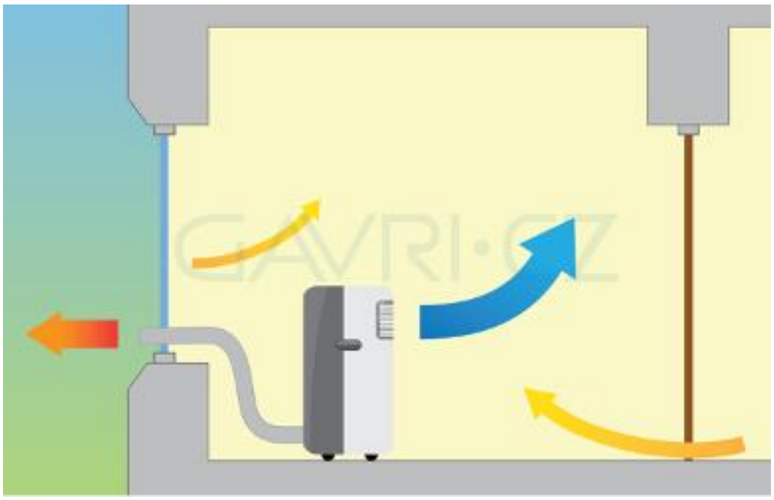


Figure 5 Single hose
Source: [9]

Another type of mobile air conditioner is the "Dual hose". This version uses the first hose as a hot air outlet in the same way as the single hose system and the second hose drains air from the outside. Then, the air is directly cooled by the unit. This type of AC cools the room faster and more effectively.

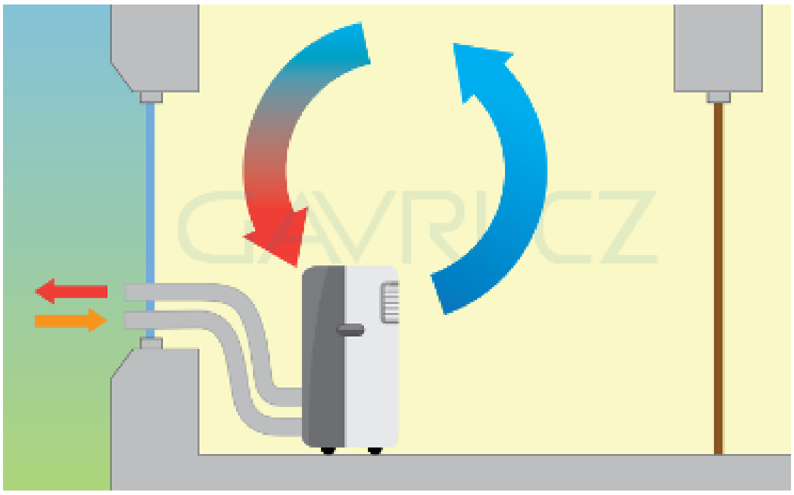


Figure 6 Dual hose
Source: [9]

Split system

This system consists of two parts, an indoor and an outdoor unit. The indoor unit contains an evaporator and a fan. It is installed directly in a room, mostly on a wall under a ceiling or under a window. The outdoor unit (condensing unit), which consists of a condenser and a compressor, is located outside a building. The advantage is that various indoor units can be connected to the one condensing unit outside. Therefore, there is no need to install outdoor units with condensers and compressors for each unit separately and it is quite easy to cool large number of rooms at once. This is called a multi-split. Placing the compressor in the outdoor unit reduces noise in the cooled room. Nevertheless, the noise can be undesirable and disturbing outdoors. The location of the external condensation unit must also be selected with care. This type of air conditioner works by circulating the refrigerant in the duct between the indoor unit with the evaporator, which receives heat from the air in the room and the outdoor unit, which takes the heat away from the cooled space. The unit consists of two parts - an internal and an external part, which are connected by a pipeline. The installation of the device needs to be performed by a specialized company [8].

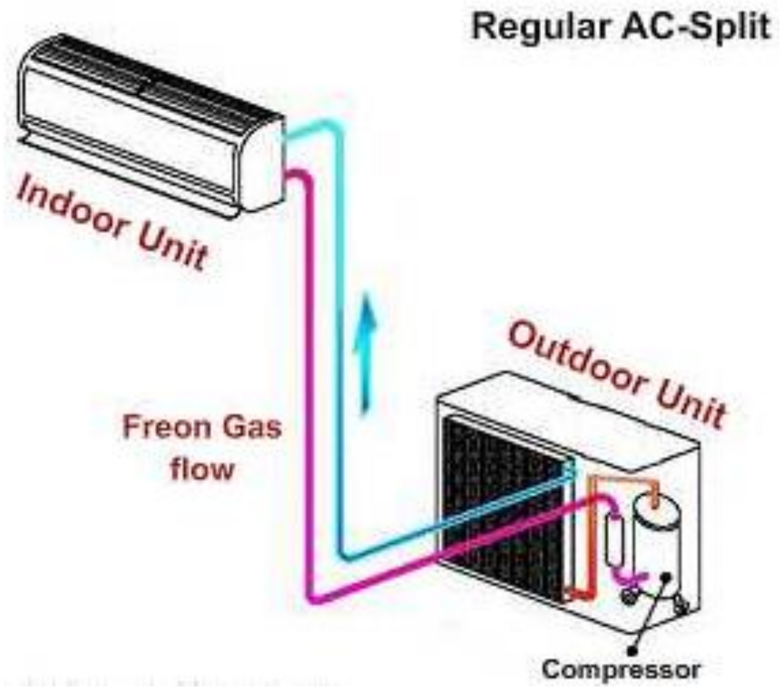


Figure 7 Split system
Source: [10]

Fan-coil

In addition to the split (or multisplit) system with a refrigerant circuit, cooling by water is also often used. The specific value for water coolers is the temperature gradient, which indicates temperatures of the heat transfer medium (water) at the outlet, respectively inlet into a cooler. The characteristic temperature gradient for water coolers is 6/12 °C but different temperatures can also be observed. Water cooling is provided by the chiller, which uses the refrigerant circuit and works on the principle of the reversed Carnot cycle. A reversible heat pump can be used as an alternative. A typical fan-coil unit is shown in Figure 8. The heat exchanger is supplied with water (heated or cold) and the fan transfers air through the heat exchanger, where the gas is cooled or heated to the desired temperature. Finally, the heated/cooled air is distributed from the device into the room [7].

For cooling, the condensate drainpipe must be connected to the fan coil. The fan coil units can be built-in, freestanding or pendant, which are classified by the method of the installation - on the wall, windowsill, channel or cassette. The cooling/heating intensity can be controlled by reducing the flow of cooling/heating medium or changing the fan speed. The control panel can be located in the room where the fan coil is installed or in the central room, where several fan coil units are connected [7][11].

The fan coil is used in single-family homes with heat pump systems, in office buildings or in hotels, where not only heating needed. The most significant advantages of using fan coils include lower operating costs, reduced CO2 production, an energy-efficient system, heating and cooling supply and quiet device operation [11].

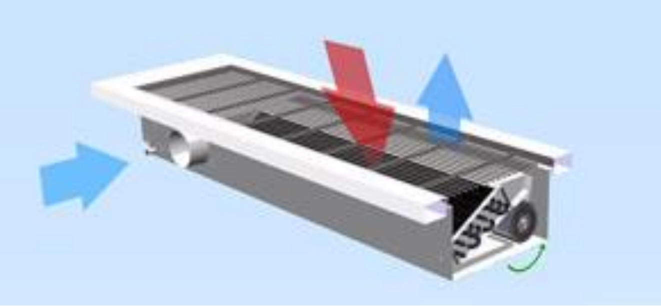


Figure 8 Fan-coil unit floor installation
Source:[12]

Cooling ceiling system

Cooling ceilings radiate cold from the ceiling surface (or a suspended ceiling) in order to cool a space. The system works on the same principle as underfloor heating and, in theory, it is possible to use one system for heating and cooling. The problem with the combination of this cooling/heating system is that instead of cooling the surface of the ceiling below, it cools the surface of the floor above. The piping through which the heat transfer fluid circulates needs to be installed as close as possible to the floor surface. It also must be made of a suitable material, to ensure the best heat transfer through the floor surface and further into the room. Therefore, if the same pipeline is used for cooling, the floor of the heated room becomes cold rather than the ceiling of the room below. Consequently, a separate cooling system is used. It is usually installed in suspended ceilings or directly under the ceiling of a room [13].

Design-wise, the cooling ceilings can be divided into massive (slab cooling) and light (cooled ceilings). Massive cooling ceilings consist of a pipe system embedded in a concrete ceiling structure. Light cooling ceilings are usually hung under a concrete slab in a suspended ceiling or independently [13].

The primary distribution of light cooling ceilings is divided into two categories - open (convective) and closed (radiant) systems. Open cooling ceilings allow air to flow from the floor of the room to the ceiling of the room, thanks to their construction (using holes and gaps) as opposed to closed ceilings. However, this method can dampen the surface and increase humidity of the indoor environment. The cooling water temperature should be appropriately set to minimize this phenomenon [13].

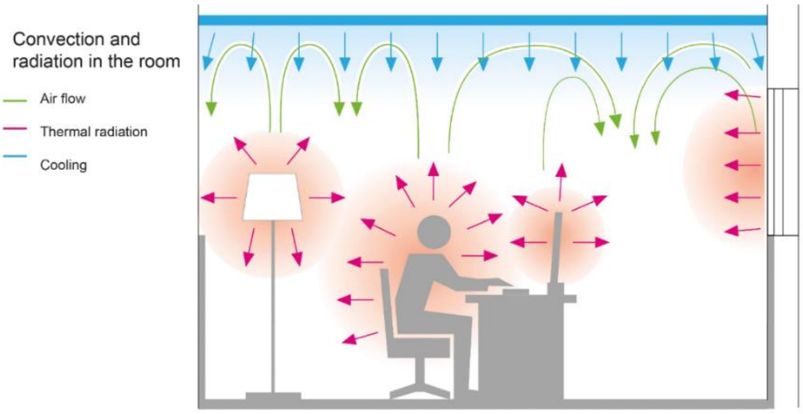


Figure 9 Principle of cooling ceiling
Source: [14]

2.3.3 Typical cooling systems in Peru

As mentioned above, the bioclimatic design is the main method for cooling buildings. Most often seen solutions are shaded patio, window shading, added vegetation and adjustment of ventilation (such as a use of night ventilation).

Bioclimatic housing

Many problems are associated with AC systems. For example, the rising cost of energy, the cost of AC systems and a high energy consumption. Furthermore, many other problems such as the decreasing amount of fossil fuels and greenhouse gas emissions, which are generated during the production of these systems are related to this topic. Therefore, a housing designed to follow the bioclimatic principles, is becoming an important part of the sustainable development [15]. The term “development” means "*to expand or realize the potentialities of; bring gradually to a fuller, greater, or better state*"[16].

Sustainable development satisfies the needs of the present without adversely affecting the conditions for future generations. The term "bioclimatic" is used to describe the connection between living organisms (especially human beings) and the climate. The bioclimatic design is an approach that uses the unique characteristics of the local climate and combines them with appropriate technology, form and fabric of the building to control the heat transfer process. Therefore, this approach promotes energy saving as well as ensures thermal comfort. A bioclimatic house is a house designed to take full advantage of the natural benefits of its surroundings [17].

Passive cooling

Bioclimatic design is essential in Peru. Both passive and active heating/cooling systems are used. The suitable system for the designated location is selected in response to climatic conditions and diversity of the landscape.

Energy management is an economic approach, which strives to reach the desired thermal comfort while minimalizing costs and pollutants. This can only be achieved by using renewable energy. The alternative and renewable energy allows us to reduce the pollution and save money on fossil fuels. This savings will increase significantly in the future, when oil reservoirs in Middle East will be depleted and costs of fuels derived from oil and gas will rise. A lower energy consumption can be also acquired by a suitable design of a building. An appropriate choice of lighting, ventilation, heating or air conditioning can reduce the energy costs considerably.

Insulation by ground

There are several ways to insulate the buildings in hot climates; one way is to use the earth as insulation material. In hot climate, the ground keeps a constant temperature of 13 ºC, which is usually lower than the air temperature. If the building was located underground while surrounded by land, it would behave as if the house lied in a climate of 13 ºC. If the terrain is dry and 1,50 to 2,50 meters deep, the indoor temperature will not exceed 21°C at the exterior temperature of 38°C. A good example of a structure insulated by ground is a troglodyte building [18]. However, this system is applicable only in hot dry climate. Otherwise, the humid air would cause a lot of condensation on the interior walls of the building.

Building envelope insulation

Passive design of a house also must include an insulation of building envelope. Thermal insulation reduces the heat loss or gain by the transmission and acts as a barrier to the heat flow. In winter, it keeps the house warm and in summer helps the house to remain cool. Insulation is used in walls, ceiling and floors [18].

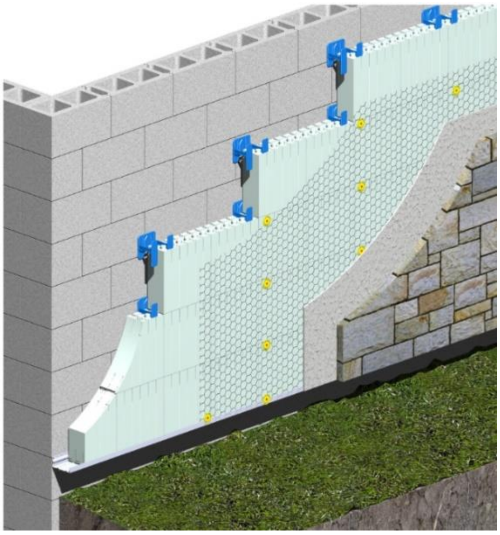


Figure 10 Building insulation
Source: [19]

Double-skin construction

The cooling of a building by two skins is done the air cavity. The air in the cavity is rises out of the building. Then, the heat is taken away by a process known as the chimney effect. The differences in air density create a circular movement, which causes warmer air to rise and escape the cavity [20].

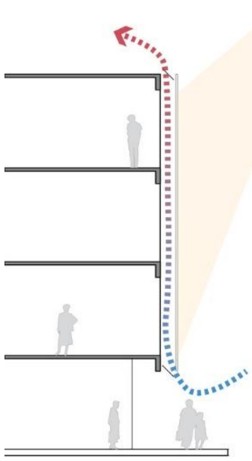


Figure 11 Double skin construction
Source: [20]

Lightweight construction

It is important to consider the thermal comfort during sleeping hours in warm climates. Lightweight construction reacts quickly to cooling winds. On the other hand, a heavy structure slowly re-releases the heat absorbed during the day, which is not desirable at night [21].

Vegetation and shading

Vegetation also affects the air entering the building. The Figure 12 shows an example of how the vegetation can be used to lower temperature of a structure. The tree, thanks to its shadow and evaporation processes cools down the surroundings, therefore the air entering the building is less warmer [18].

Shading by temporary or permanent elements can significantly reduce heat gains. When designing the building, it is important to know the position of the sun in summer and winter. [18].

Figure 12 Shading by overhangs and vegetation, Peru
Source: Author

Shaded Patios

A patio is a roofless inner courtyard, as shown in the figure. It is often used in Peru. The shaded patio is an effective way of cooling; it can be covered on hot days by light lattices, which interfere with the entering sun rays [18].

Figure 13 Shaded patio
Source: Author

Night natural ventilation and thermal chimney

A building can be also cooled by natural ventilation. This is mostly done by ventilation openings, which need to have a right size and must be set into a right position. At night, the room's heated air is removed by natural ventilation. This cools the solid concrete ceilings, which act as cold storage batteries and prevent the internal temperature from rising strongly during next day. The driving force behind the night ventilation is thermal buoyancy: air flows through windows and doors into rooms and leaves again at the highest point of the building.

This phenomenon is complex and depends on the external and internal layout of the building and its openings. This effect is explained in more detail in Chapter 3.2.

Solar chimney uses air convection to create ventilation. The air trapped in the chimney overheats and goes up. To fill up the empty space freed by raising warm air, the fresh and cold air from inside is sucked into the chimney, where it is heated. Then it flows to the top and the process repeats [18].

3. Methods used

For purpose of this thesis a monthly calculation method is used to calculate heating and cooling needs. In this method, the heat balance of a building (or a building thermal zone) is restored at monthly intervals. Dynamic effects are considered by correction and adjustment factors.

Conditions and requirements may vary for cooling and heating. Therefore, two calculations are performed for each month. The calculation period is the whole year. The monthly calculation method can determine:

- basic energy needs
- special needs

Specific characteristics and specific regulations of technical systems are used to compute special needs. The lengths of the heating and cooling seasons are defined by the operating hours corresponding to the technical systems.

Required data for further calculation include:

- basic energy needs
- months without a prolonged vacancy period

3.1 Energy need for heating and cooling

Energy need is calculated for heated and cooled building. To calculate the energy needed for both heating and cooling, boundary conditions must be set. The calculation of the energy need in a building or zone in a building is done by the envelope method and according to the ČSN EN ISO 52016-1 [22].

Annual energy needs for heating

Equation (1) describes annual energy need for heating $Q_{H,nd,an}[kWh]$. It is a sum of energy need for each month:

$$Q_{H,nd,an} = \sum_{m=1}^{12} Q_{H,nd,m} \qquad (1)$$

where

$Q_{H,nd,m}$	monthly energy needs for heating determined by (2), in kWh.

Monthly energy needs for heating are defined as (2):

$$Q_{H,nd,m}=Q_{H,ht,m}-Q_{H,gn,m}\cdot\eta_{H,gn,m} \qquad (2)$$

where

$Q_{H,ht,m}$	monthly heat transfer (heating mode), in kWh;
$Q_{H,gn,m}$	monthly heat gains (heating mode), in kWh;
$\eta_{G,H}$	gain utilization factor for heating, dimensionless.

Dynamic effects must be considered by the gain utilization factor for heating $\eta_{G,H}$, which is determined by equations (3),(4),(5). It is a function dependent on the ratio of heat balance $\gamma_{H,m}$ and numerical parameter a_H.

If $\gamma_{H,m} \neq 1$ $$\eta_{H,gn,m} = \frac{1-{\gamma_{H,m}}^{a_H}}{1-{\gamma_{H,m}}^{a_H+1}} \qquad (3)$$

If $\gamma_{H,m} = 1$ $$\eta_{H,gn,m} = \frac{a_H}{a_H+1} \qquad (4)$$

If $\gamma_{H,m} < 0$ $$\eta_{H,gn,m} = \frac{1}{\gamma_{H,m}} \qquad (5)$$

The heat-balance ratio is the ration of monthly heat gains and monthly heat transfer(6):

$$\gamma_{H,m} = \frac{Q_{H,gn,m}}{Q_{H,ht,m}} \qquad (6)$$

where

$\gamma_{H,m}$	heat balance ratio for heating, dimensionless;
$Q_{H,ht,m}$	monthly heat transfer, in kWh;

$Q_{H,gn,m}$	monthly heat gains, in kWh;
a_H	numerical parameter, dimensionless.

The numerical parameter is defined by time constants as (7):

$$a_H = a_{H,0} + \frac{\tau_{H,m}}{\tau_{H,0}} \tag{7}$$

where

$a_{H,0}$	numerical parameter, dimensionless, Table 1;
$\tau_{H,m}$	time constant, in h;
$\tau_{H,0}$	reference building time constant, in h, Table 1.

Table 1 Numerical parameter and reference building time constant

$a_{H,0}$	$\tau_{H,0}$
1,0	15

Source: [22]

The dimensionless time constant characterizes the internal heat capacity. Values may vary for heating and cooling (8):

$$\tau_H = \frac{\frac{C_{m,eff}}{3600}}{H_{H,tr,m}+H_{H,gr,m}+H_{H,ve,m}} \tag{8}$$

where

$C_{m,eff}$	Specific heat capacity defined by Table 2 as a simplified method, in kJ/K;
$H_{H,tr,m}$	Heat transfer coefficient for heating for every building element, except the elements, which are connected to the ground, in W/K;
$H_{H,gr,m}$	Heat transfer coefficient for heating for elements, which are connected to the ground, in W/K;
$H_{H,ve,m}$	Total heat transfer coefficient by ventilation for heating and cooling, in W/K.

Annual energy needs for cooling

Annual energy needs for cooling $Q_{C,nd,an} [kWh]$ are calculated by the same method as annual energy needs for heating. The sum of energy needed for cooling for every month is defined as (9):

$$Q_{C,nd,an} = \sum_{m=1}^{12} Q_{C,nd,m} \tag{9}$$

Monthly energy needs for cooling (10), in kWh, are defined as (10):

$$Q_{C,nd,m} = Q_{C,gn,m} - Q_{C,ht,m} \cdot \eta_{C,ht,m} \tag{10}$$

where

$Q_{C,ht,m}$	monthly heat transfer (cooling mode), in kWh;
$Q_{H,gn,m}$	monthly heat gains (cooling mode), in kWh;
$\eta_{G,C}$	gain utilization factor for cooling, dimensionless.

Dynamic effects must be considered by the gain utilization factor for heating $\eta_{G,H}$, which is determined by equations (11),(12),(13). It is a function dependent on the ratio of heat balance $\gamma_{C,m}$ and numerical parameter a_C.

If $\gamma_{C,m} \neq 1$ $\quad \eta_{C,ht,m} = \frac{1-\gamma_{C,m}^{-a_C}}{1-\gamma_C^{-(a_C+1)}}$ (11)

If $\gamma_{c,m} = 1$ $\quad \eta_{C,ht,m} = \frac{a_C}{a_C+1}$ (12)

If $\gamma_{c,m} < 0$ $\quad \eta_{C,ht,m} = 1$ (13)

Heat balance ratio is determined as (14):

$$\gamma_H = \frac{Q_{H,gn}}{Q_{H,ls}} \tag{14}$$

where

$\gamma_{C,m}$	Heat balance ratio for cooling, dimensionless;
$Q_{C,ht,m}$	Total heat transfer, in kWh;
$Q_{C,gn,m}$	Total heat gains, in kWh;
a_C	Numerical parameter, dimensionless.

Numerical parameter is determined as (15):

$$a_C = a_{C,0} + \frac{\tau_C}{\tau_{C,0}} \tag{15}$$

where

$a_{C,0}$	Numerical parameter, dimensionless, Table 2;
$\tau_{C,m}$	Time constant, in h;
$\tau_{C,0}$	Reference building time constant, in h, Table 2.

Time constant is defined as (16):

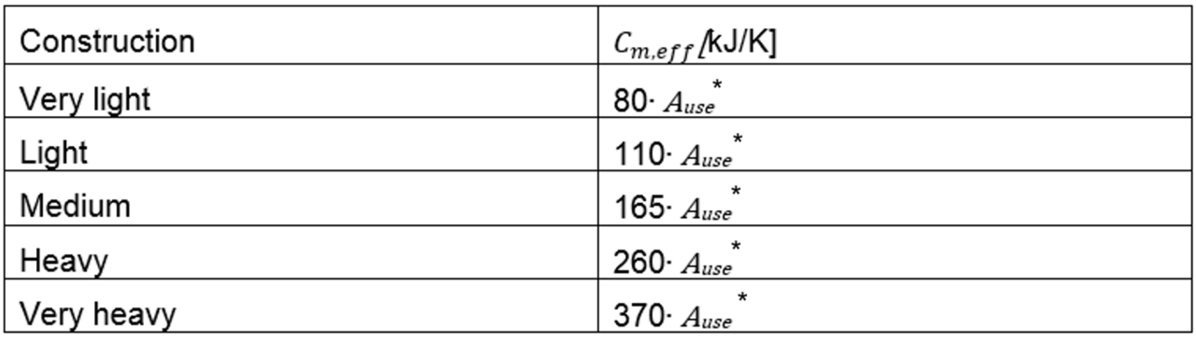
$$\tau_{C,m} = \frac{\frac{C_{m,eff}}{3600}}{H_{C,tr,m}+H_{C,gr,m}+H_{C,ve,m}} \tag{16}$$

The dimensionless time constant characterizes the internal heat capacity. Values may vary for heating and cooling (16),

where

$C_{m,eff}$	Specific heat capacity defined by Table 2 as a simplified method, in kJ/K;
$H_{C,tr,m}$	Heat transfer coefficient for heating for every building element except the elements, which are connected to the ground, in W/K;
$H_{C,gr,m}$	Heat transfer coefficient for heating for elements, which are connected to the ground, in W/K;
$\mathrm{H_{C,ve,m}}$	Total heat transfer coefficient by ventilation for heating and cooling, in W/K.

Table 2 Heat capacity $C_{m,eff}$ of the building for basic types of structures



Construction	$C_{m,eff}$ [kJ/K]
Very light	$80 \cdot A_{use}{}^{*}$
Light	$110 \cdot A_{use}{}^{*}$
Medium	$165 \cdot A_{use}{}^{*}$
Heavy	$260 \cdot A_{use}{}^{*}$
Very heavy	$370 \cdot A_{use}{}^{*}$

Source: [22]

*A_{use} is a useful floor area.

Total heat transfer and heat gains

The calculation of heat gains and heat transfers is simplified. Therefore, only the most relevant heat gains and heat transfers are considered.

Total heat transfer

The procedure specified in the standard to calculate heat losses by transmission and ventilation is similar; it is necessary to determine the transmission heat transfer coefficients for each element and the ventilation heat transfer coefficient. Then the heat transfer is the summation of the product of: the coefficients, the temperature difference and the duration of the period (month).

For every month and every zone, total heat transfer is calculated as (17)(18):

- For heating: $Q_{H,ht,m}=Q_{H,tr,m}+Q_{H,ve,m}$ (17)
- For cooling: $Q_{C,ht,m}=Q_{C,tr,m}+Q_{C,ve,m}$ (18)

where

$Q_{H,tr,m}$	Total heat transfer by transmission for heating, in kWh;
$Q_{H,ve,m}$	Total heat transfer by ventilation for heating, in kWh;
$Q_{C,tr,m}$	Total heat transfer by transmission for cooling, in kWh;
$Q_{C,ve,m}$	Total heat transfer by ventilation for cooling, in kWh;

Total heat gains

The calculation of total heat gains involves internal heat gains and solar gains. Internal heat gains calculations are simplified to include only the most relevant internal heat sources.

For every month and every zone, total heat gains are calculated as:

- For heating: $Q_{H,gn,m}=Q_{H,int,m}+Q_{H,sol,m}$ (19)
- For cooling: $Q_{C,gnm}=Q_{C,int,m}+Q_{C,sol,m}$ (20)

where

$Q_{H,int,m}$	Total internal heat gains for heating, in kWh;
$Q_{H,sol,m}$	Total solar heat gains for heating, in kWh;
$Q_{C,int,m}$	Total internal heat gains for cooling, in kWh;
$Q_{C,sol,m}$	Total internal heat gains for cooling, in kWh.

Heat transfer by transmission

- For heating

$$Q_{H,tr,m}=(H_{H,tr,m}\cdot(\theta_{int,calc,H,m}-\theta_{e,a,m})+H_{gr,an,m}\cdot(\theta_{int,calc,H,m}-\theta_{e,a,an}))\cdot 0,001\cdot\Delta t_m \quad (21)$$

- For cooling

$$Q_{C,tr,m}=(H_{C,tr,m}\cdot(\theta_{int,calc,C,m}-\theta_{e,a,m})+H_{gr,an,m}\cdot(\theta_{int,calc,C,m}-\theta_{e,a,an}))\cdot 0,001\cdot\Delta t_m \quad (22)$$

where

$H_{H/C,,tr,m}$	Heat transfer coefficient for heating for every building element, except the elements connected to the ground, in W/K;
$\theta_{int,calc,H,m}$	Internal calculation temperature for heating/cooling zone, in C°;
$\theta_{e,a,an}$	External mean monthly air temperature, in C°;
$H_{gr,an,m}$	Heat transfer coefficient for heating for elements, which are connected to the ground, in W/K;

Δt_m	Duration of month, dimensionless.

Total heat transfer coefficient for heating and cooling for every building element except the elements, which are connected to the ground $H_{H/C,tr,m}$ (23):

$$H_{H/C,tr,m} = \sum_K (H_{H/C,el,k,m}) + H_{tr,tb} \tag{23}$$

where

$H_{H/C,el,k,m}$	Total heat transfer coefficient for heating and cooling for k element, in W/K;
$H_{tr,tb}$	Total heat transfer coefficient by thermal bridge, in W/K;

Total heat transfer coefficient for heating and cooling for building element is defined $H_{H/C,el,k,m}$(24):

$$H_{H/C,el,k,m}=b_{ztu,k,m} \cdot U_{H/C,k,m} \cdot A_{el,k} \tag{24}$$

where

$U_{H/C,k,m}$	Thermal transmittance, in (W/m^2·K);
$A_{el,k}$	Area of the building envelope element, in m2;
$b_{ztu,k,m}$	Temperature reduction factor in case of thermally unconditioned zone, dimensionless.

Thermal bridges

Total heat transfer coefficient of thermal bridge $H_{tr,tb}$ is calculated by the following formula (25):

$$H_{tr,br} = \sum_k (I_{tb,k} \cdot \Psi_{tb,k}) \tag{25}$$

where

$I_{tb,k}$	Length of thermal bridge k, in m;
$\Psi_{tb,k}$	linear thermal transmittance of thermal bridge k, in (W/m·K).

Total quantity of heat transfers by ventilation $Q_{H,tr,m}$ (26):

$$Q_{H/C,ve,m}=H_{H/C,ve,m}\cdot\theta_{int,calc,H/C,m}-\theta_{e,a,m}\cdot\Delta t_m \tag{26}$$

where

$H_{H/C,ve,m}$	Total heat transfer coefficient by ventilation for heating and cooling, in W/K;
$\theta_{int,calc,H/C,m}$	internal calculation temperature for heating/cooling zone, in C°;
$\theta_{e,a,m}$	external mean monthly air temperature, in C°;
Δt_m	duration of month, dimensionless.

Total heat transfer coefficient from ventilation for heating and cooling is calculated by the following formula (27):

$$H_{\mathrm{H/C},ve,m}=\rho_a\cdot c_a\cdot\sum_k b_{ve,k,\frac{H}{C},m}\cdot q_{V,k,\frac{H}{C},m}\cdot f_{ve,dyn,k,m} \tag{27}$$

where

ρ_a	Density of air, in kg/m3;
c_a	Specific heat capacity of air, in J/(kg·K);
$b_{ve,k,\frac{H}{C},m}$	Monthly temperature reduction factor for heating and cooling, dimensionless;
$q_{V,k,H/C,m}$	Monthly air volume flow rate for heating and cooling, in W/m2;
$f_{ve,dyn,k,m}$	Dynamic ventilation factor, dimensionless;
$Index\ k$	Identification of individual relevant air components, dimensionless.

Total heat gains

Total internal heat gains are defined as (28):

$$Q_{H/C,int,dir,m} = (Q_{H/C,spec,int,oc,m} + Q_{H/C,spec,int,A,m} + Q_{H/C,spec,int,L,m} + Q_{H/C,spec,int,WA,m} + Q_{H/C,spec,int,HVAC,m} + Q_{H/C,spec,int,proc,m}) \cdot A_{use} \quad (28)$$

where

$Q_{H,spec,int,oc,m}$	Internal specific heat gain when influenced by occupants for heating/cooling, in kWh;
$Q_{H,spec,int,A,m}$	Internal specific heat gain when influenced by appliances for heating/cooling, in kWh;
$Q_{H,spec,int,L,m}$	Internal specific heat gain under the influence of lightening for heating/cooling, in kWh;
$Q_{H,spec,int,WA,m}$	internal specific heat gain under the influence of hot water distribution for heating/cooling, in kWh;
$Q_{H,spec,int,HVAC,m}$	internal specific heat gain under the influence of heating, ventilation, air conditioning for heating/cooling, in kWh;
$Q_{H,spec,int,proc,m}$	internal specific heat gain under the influence of processes for heating/cooling, in kWh;
A_{use}	useful floor area, in m^2.

Total solar heat gains

Total solar heat gains are defined as (29):

$$Q_{H,sol,dir,m} = \sum_{k=1} Q_{H/C,sol,wi,k} + \sum_{k=1} Q_{H/C,sol,op,k} \quad (29)$$

where

$Q_{H/C,sol,wi,k}$	Monthly solar heat gains through translucent element wi,k (window) , in kWh;
$Q_{H/C,sol,op,k}$	Monthly solar heat gains through opaque element, in kWh.

Monthly solar heat gains through a window are defined as (30):

$$Q_{H/C,sol,wi} = g_{gl,wi,H/C,m} \cdot A_{wi} \cdot \left(1 - F_{fr,wi}\right) \cdot F_{sh,obst,wi,m} \cdot H_{sol,wi,m} - Q_{sky,wi,m} \tag{30}$$

where

A_{wi}	Area of a window, m^2;
$g_{gl,wi,H/C,m}$	Total solar energy transmittance for heating/cooling, dimensionless;
$F_{fr,wi}$	Fraction of a frame and window area, dimensionless;
$F_{sh,obst,wi,m}$	Factor of s shading by external obstacles and a window, dimensionless;
$H_{sol,wi,m}$	Monthly solar irradiation according to inclination and orientation of window, in W/K;
$Q_{sky,wi,m}$	Quantity of heat under the influence of radiation to the sky, in kWh.

Total solar energy transmittance for heating/cooling is defined as (31):

$$g_{gl,wi,H/C,m} = F_w \cdot g_{gl,n,wi} \tag{31}$$

where parameters Fw and $g_{,gl,n,wi}$ are added in Appendix 3.

Fraction of a frame and window area are defined as (32):

$$F_{fr,wi} = 1 - \frac{A_{gl,wi}}{A_{wi}} \tag{32}$$

where

$A_{gl,wi}$	Glazing area of the window element, m^2;
A_{wi}	Area of a window element, m2.

Factor of s shading by external obstacles and a window by method of direct radiation (33):

$$F_{sh,obst,wi,m} = F_{sh,dir,k,m} \cdot f_{sol,dir,m} \tag{33}$$

$F_{sh,dir,k,m}$	Shading factor of a direct irradiation, dimensionless;
$f_{sol,dir,m}$	Fraction of a direct irradiation, dimensionless, added in Appendix 2.

3.2 Simulation – software DesignBuilder

The energy needs (for cooling and heating) are calculated with a software for a more accurate calculation with the inclusion of night cooling, which is a complex calculation requiring a software.

The software DesignBuilder is used for dynamic simulation, calculation of thermal comfort and energy needs for building cooling. This software is available in version DesignBuilder 6.1.3.008 , 2019 on the official website designbuilder.co.uk. The DesignBuilder software is an advanced graphical user interface that has been specially developed to run EnergyPlus simulations. DesignBuilder, as a software created in the United Kingdom, is based on the European directives. Climatological data are necessary for proper simulation. The software works with a large amount of data; for the solved objects, the data from the meteorological station Prague-Libuš and Lima-Callao are suitable, and the programme contains these data by default.

The heat transfer coefficients of the individual building structures were assigned according to the values determined by the Czech standard named ČSN

EN ISO 73 0540 - 2: Thermal protection of buildings – Part 2: Requirements in Table 3.

Table 3 Heat transfer coefficients

The heat transfer coefficients	**Recommended values [W/m2.K]**
External wall	0,25
Roof (flat and sloping to 45 degrees)	0,16
Floor of heated space adjacent to the ground	0,3

Source: [3]

Natural ventilation

The software calculates all the essential characteristics (such as heat gains, losses, thermal bridges, etc.) to obtain the energy needed for cooling of the building. However, the main advantage of this calculation is that software also considers the airflow through the exact geometry of the building.

Two forces drive natural ventilation in buildings. The first is stack effect. The warm air is lighter than the cooler air, therefore it tends to rise. The second is wind, which affects air movement.

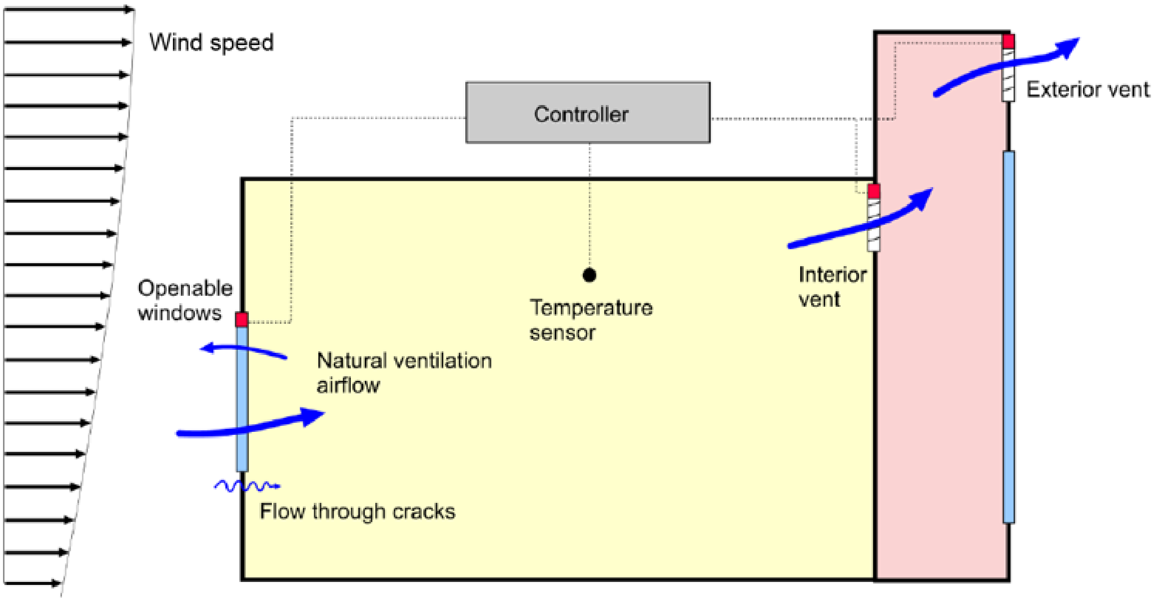


Figure 14 Natural ventilation flow and control
Source: [23]

The main characteristics affecting the natural ventilation in a real building are: the size, the shape, the position and the orientation of openings and cracks in the fabric of the building, as well as the meteorological conditions, such as wind-speed and outside temperatures.

The ventilation rate (34) through each opening and crack is calculated based on the pressure difference, using wind and stack pressure effects:

$$q = C \cdot \delta \cdot P \cdot n \qquad (33)$$

where:

q the volumetric flow through the opening/crack.

δP the pressure difference across the opening/crack.

n the flow exponent varying between 0.5 for fully turbulent flow and 1.0 for fully laminar flow.

C the flow coefficient, related to the size of the opening/crack.

3.3 Costs of cooling

This work discusses the costs of AC equipment, AC supply and costs of energy consumption.

The costs of air-conditioning equipment and supply are compiled based on consultations and offers from experts from air-conditioning companies in the Czech Republic.

The energy price is calculated per kilowatt hour (kWh) in Czech crowns (CZK) according to the hourly energy need calculation in the program DesignBuilder. The price per kWh is determined by an Internet survey.

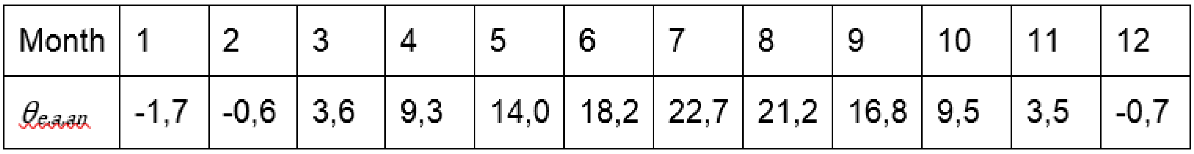
4. Case of study

This case of study focuses on the cost of cooling in buildings, in a family house and in an apartment building. At first, the study sites are described, because the parameters influencing cooling needs depend mainly on climatic conditions.

4.1 Climate of the Czech Republic

The climate of the Czech Republic can be described as typical European continental climate influenced with warm, dry summers and cold winters. The external temperature is one of the basic inputs for the calculations described in Chapter 2, especially external mean monthly air temperature. In the Czech Republic, the standard named *Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads* with code ČSN EN ISO 52016-1 defines external mean monthly air temperature. The temperatures specified in the standard are stated in Table 4.

Table 4 External mean monthly temperature



Month	1	2	3	4	5	6	7	8	9	10	11	12
$\theta_{e,a,an}$	-1,7	-0,6	3,6	9,3	14,0	18,2	22,7	21,2	16,8	9,5	3,5	-0,7

Source: [22]

According to the standard named *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics* with code ČSN EN 15251 [24], the internal calculation temperature for a cooling zone is 26°C.

It is obvious that the external mean monthly air temperatures are lower than the internal calculation temperature for cooling. It would mean there is no energy need for cooling.

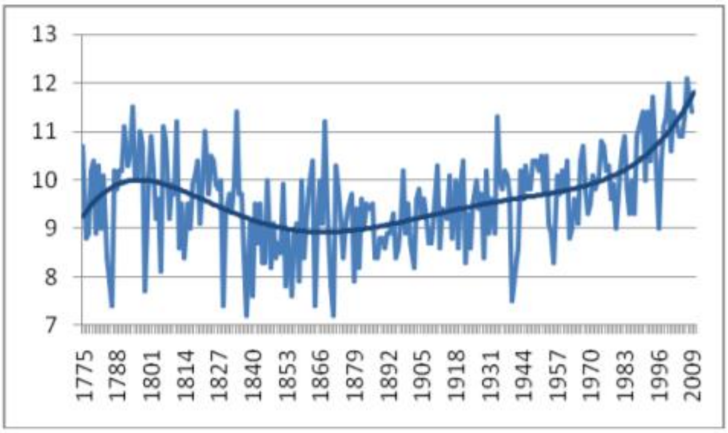


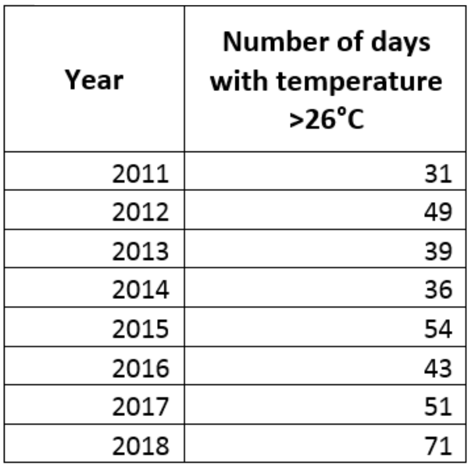
Figure 15 Mean annual temperatures, 1775-2010, meteorology station Prague-Klementinum
Source: [25]

The chart above shows an upward trend of mean annual temperatures through the years.

Global warming is to blame for increasing temperatures in the Czech Republic, which is the reason why it is becoming a big problem. In order to maintain thermal comfort in buildings, cooling is a common measure to solve the microclimate in buildings.

Over the past 8 years, the number of days with external temperature bigger than 26°C is shown in the Table 5 and the maximum temperature month values are shown in the Appendix 3.

Table 5 External temperature bigger than 26°C, the Czech Republic



Year	Number of days with temperature >26°C
2011	31
2012	49
2013	39
2014	36
2015	54
2016	43
2017	51
2018	71

Source: [25]

4.2 Selection of a part of Peru for comparison

The climate of Peru is very diverse, with a large variety of climates and microclimates, including 28 of the 32 world climates. Such a diversity is chiefly conditioned by the presence of the Andes mountains and the cold Humboldt Current. For this reason, one region of Peru is selected for the following research. The climate on the coast is arid and semi-arid with high temperatures and very little rainfall. The Andes mountains observe a cool-to-cold climate with rainy summers and very dry winter. The eastern lowlands present an Equatorial climate with hot weather and rain distributed all year long.

In the Table 16 below are simply described the main Peruvian types of climates [18].

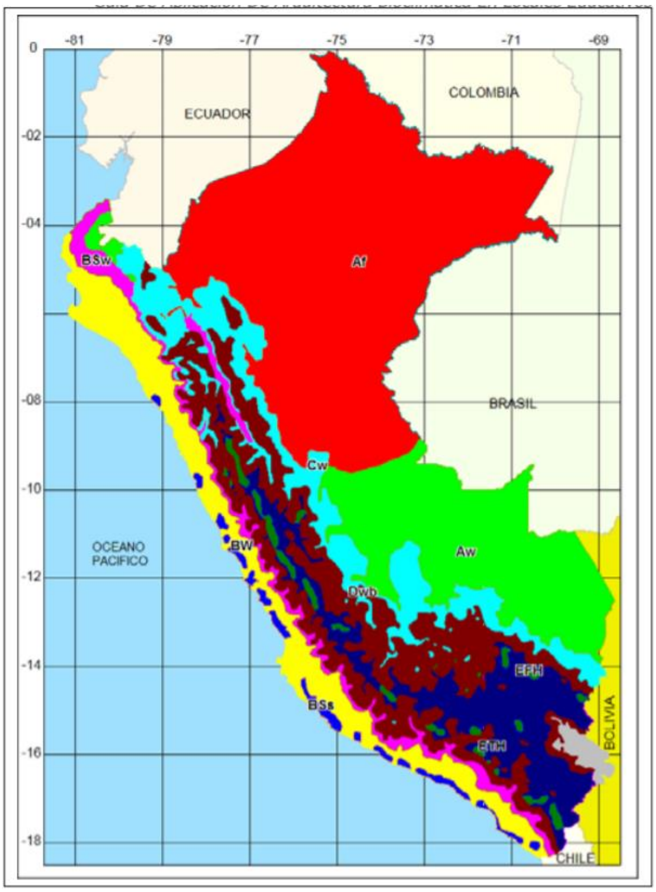
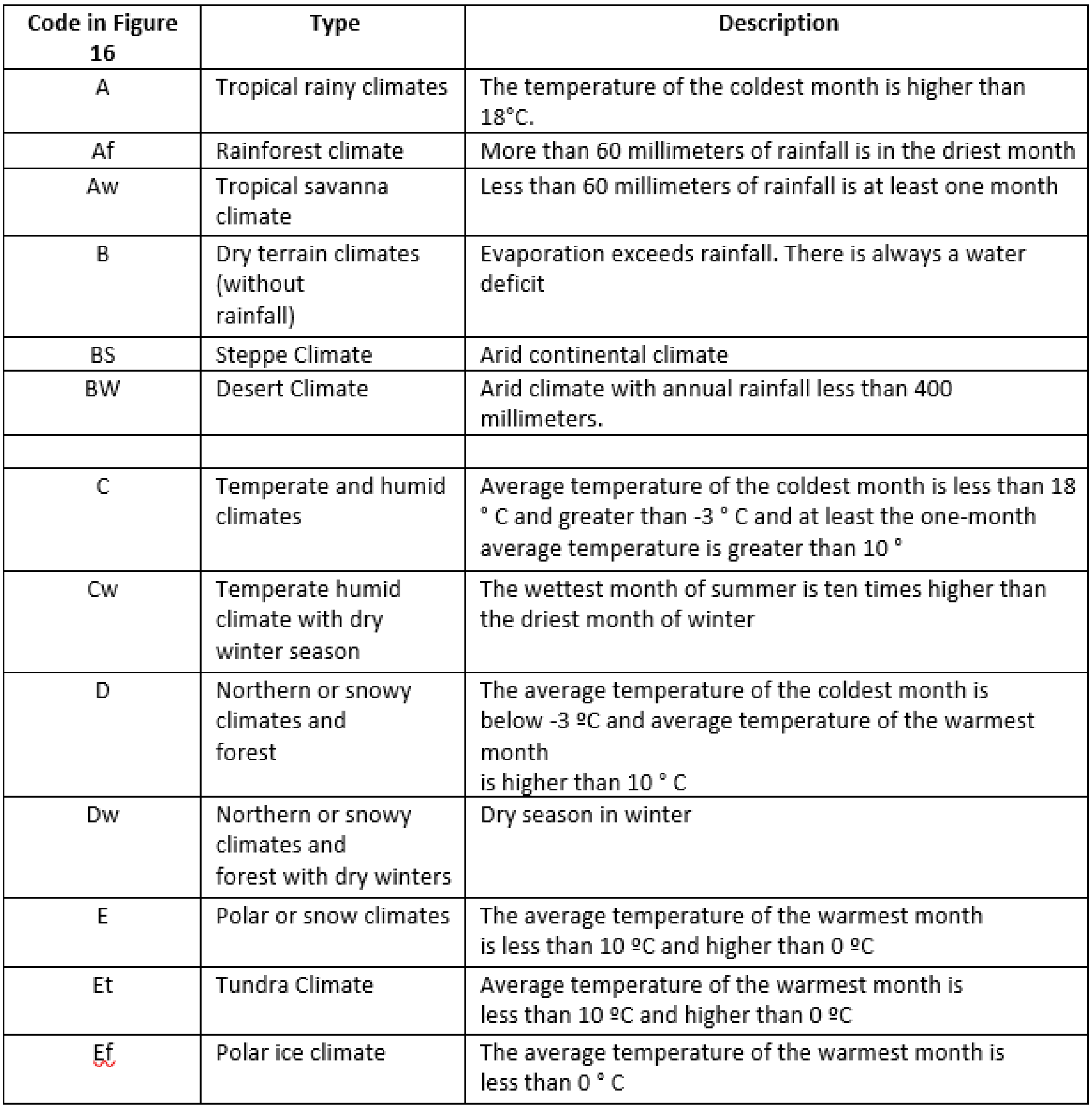


Figure 16 Climas en el Perú según Köppen
Source: [18]

Table 6 Description of Figure 16



Code in Figure 16	Type	Description
A	Tropical rainy climates	The temperature of the coldest month is higher than 18°C.
Af	Rainforest climate	More than 60 millimeters of rainfall is in the driest month
Aw	Tropical savanna climate	Less than 60 millimeters of rainfall is at least one month
B	Dry terrain climates (without rainfall)	Evaporation exceeds rainfall. There is always a water deficit
BS	Steppe Climate	Arid continental climate
BW	Desert Climate	Arid climate with annual rainfall less than 400 millimeters.
C	Temperate and humid climates	Average temperature of the coldest month is less than 18 ° C and greater than -3 ° C and at least the one-month average temperature is greater than 10 °
Cw	Temperate humid climate with dry winter season	The wettest month of summer is ten times higher than the driest month of winter
D	Northern or snowy climates and forest	The average temperature of the coldest month is below -3 ºC and average temperature of the warmest month is higher than 10 ° C
Dw	Northern or snowy climates and forest with dry winters	Dry season in winter
E	Polar or snow climates	The average temperature of the warmest month is less than 10 ºC and higher than 0 ºC
Et	Tundra Climate	Average temperature of the warmest month is less than 10 ºC and higher than 0 ºC
Ef	Polar ice climate	The average temperature of the warmest month is less than 0 ° C

Source: [18]

For the following research is chosen arid continental climate in Lima to imitate cooling days in the Czech Republic.

4.3 Family house

Selected house is a storeyed family house with ground floor and residential attic without basement named Aktual 421, visualization can be seen in Figure 17,18 and 19. This family house with a useful floor area 88.44 m^2 meets the requirements for housing a family of 3-4 members. The advantage of this family house is a small built-up area (floor plan dimensions are 7.5m x 8m = 60 m^2). On the first floor, there is a corridor, bathroom + toilet, kitchen and living room. On the second floor, there is a hall, bedroom, two rooms, bathroom + WC.

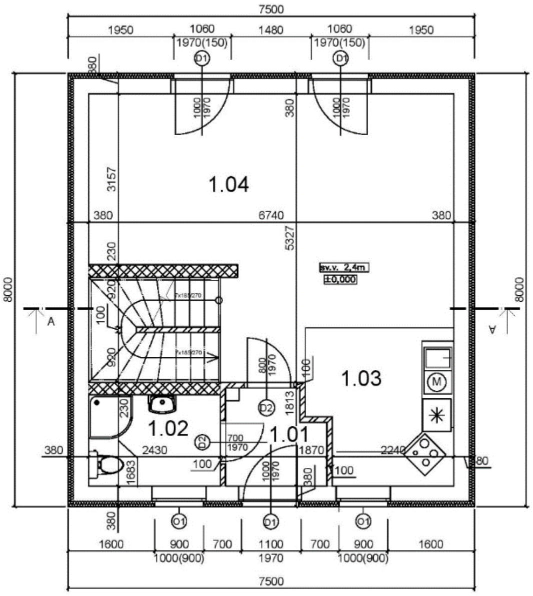


Figure 17 ground floor plan
Source: Author

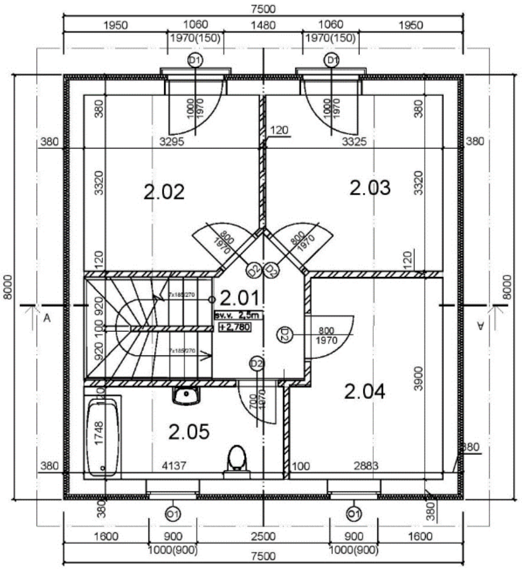


Figure 18 first floor plan
Source: Author

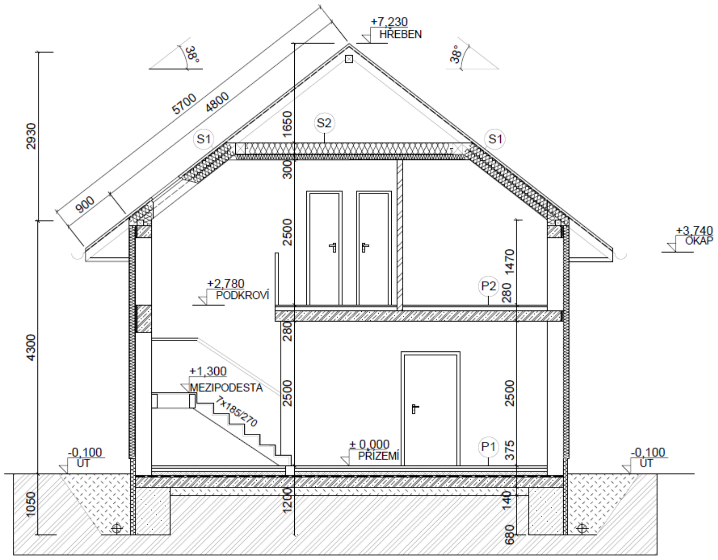


Figure 19 model family house
Source: Author

Apartment building

The apartment building was chosen as a classic apartment building used in the Czech Republic. In Prague, there are a lot of public housing estates. It is a four-storey building and on each floor there are 3 housing units. The useful floor of each unit is 60m^2. Visualization can be seen in Figure 21 and 22.

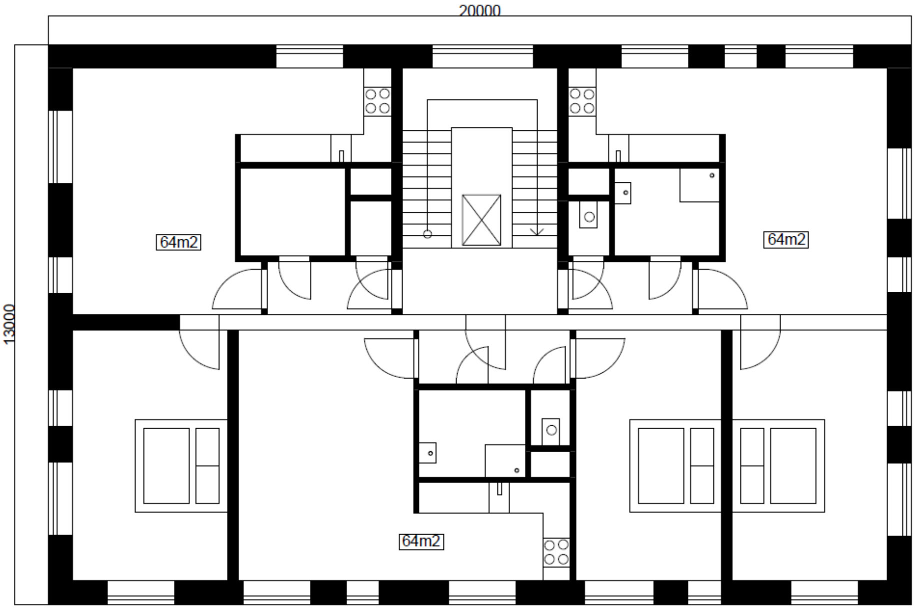


Figure 21 Apartment building floor plan
Source: Author

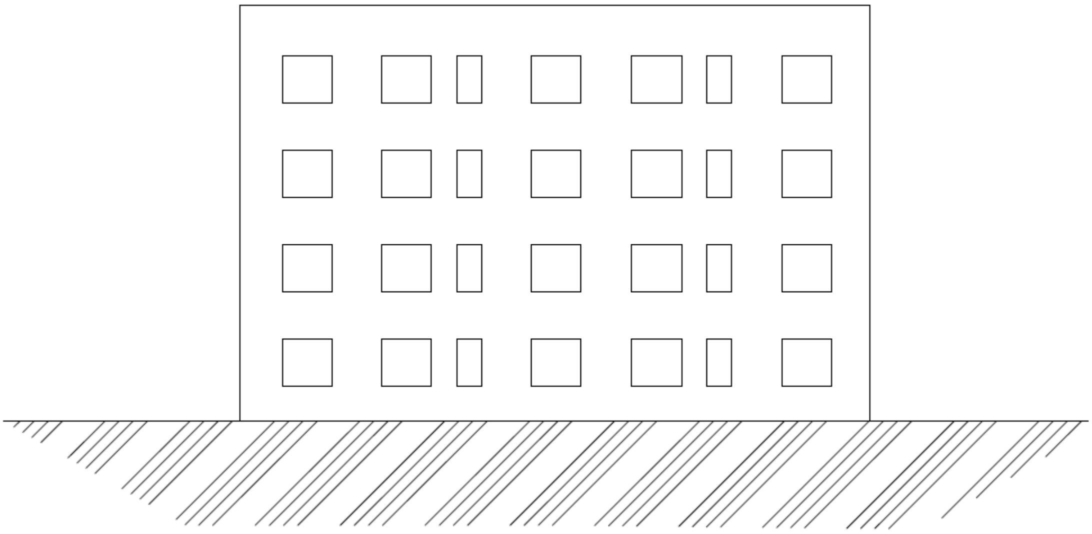


Figure 20 Apartment building northern view
Source: Author

4.4 Cost of cooling

The following chapter contains the costs of AC equipment, AC supply and costs of energy consumption.

4.4.1 Cost of air conditioner

After consulting with Czech air-conditioning experts, 4 offers were prepared for each of the buildings. Supply includes the cost of installation and AC equipment. The resulting cost amount is shown in the Table 6.

Table 7 Costs of the air conditioners

	Cooled area[m2]	**Offer 1**	**Offer 2**	**Offer 3**	**Offer 4**	**Average**
Family house	66,64	133 280 CZK	112 595 CZK	153 000 CZK	58 000 CZK	114 219 CZK
Apartment	51	102 000 CZK	65 202 CZK	77 710 CZK	70 702 CZK	78 903 CZK
Apartment building	612	1 224 000 CZK	782 420 CZK	932 520 CZK	848 424 CZK	946 841 CZK

Source: Air conditioning companies

Air conditioning multi-split system was chosen as the best solution for this concrete type of family house and apartment building.

4.4.2 Cost of energy needs for cooling

The average electricity rate is 4,6 CZK per kilowatt hour (kWh). In the Appendix 4, the real prices of electricity per kWh in the Czech Republic in 2019 are shown. The price of electricity 4,6 CZK was calculated as an average of these prices.

Energy needs

The simulation in DesignBuilder was created to calculate energy needs for cooling. The visualization of the simulated family house and apartment building is seen in Figures 22 and 23 below.

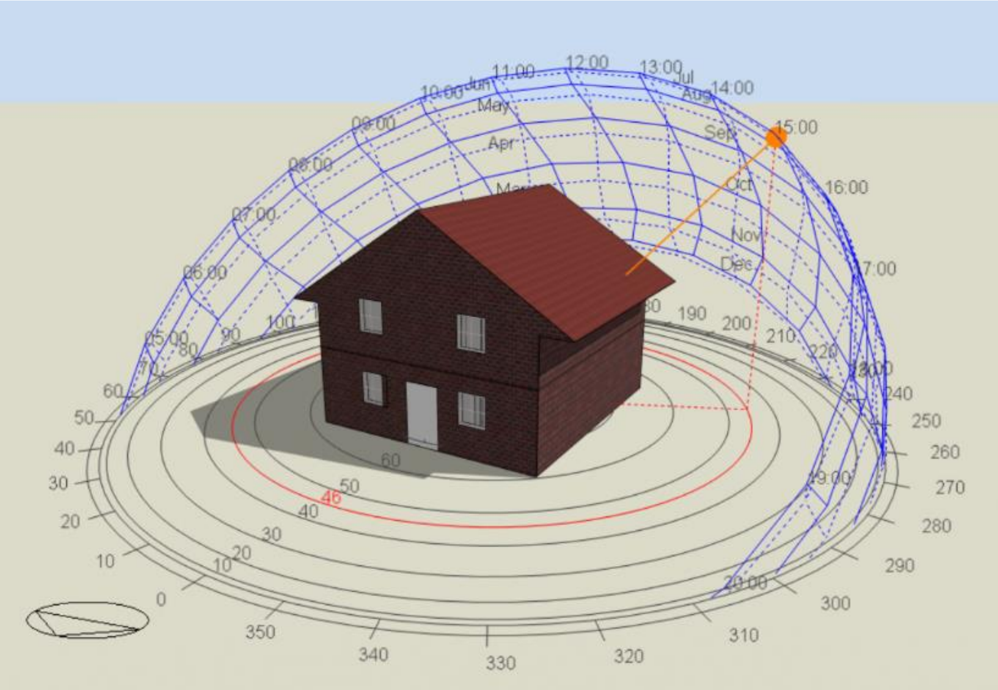


Figure 22 Family house
Source: Author

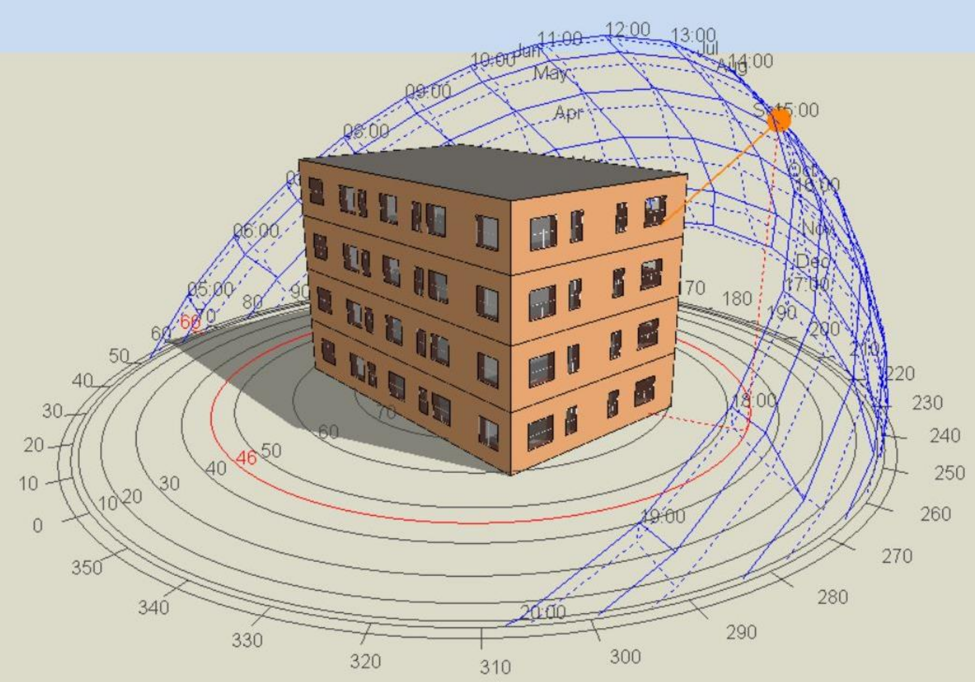


Figure 23 Apartment building
Source: Author

Energy consumption

The ratio EER (energy efficiency of cooling performance) is determined by the amount of cooling generated by the air conditioner. For example, to have EER of 2,5 means that an air conditioner generates 2,5 kW of cooling energy when using 1 kW of electricity. Below the energy classification table is seen [26]:

- Class A, EER 3,2
- Class B, EER 3,2-3,0
- Class C, EER 3,0-2,8
- Class D, EER 2,8-2,6
- Class E, EER 2,6-2,4

5. Evaluation

The same buildings were simulated in the conditions of Lima and Prague. As can be seen from the temperature profile in Figure 26 and 27, the temperatures in Lima are higher than temperatures in Prague, so the results in the Table 7 also show a higher energy need for cooling in Lima.

Table 8 Total cooling energy need

Total cooling energy need	Family house [kWh]	Apartment building [kWh]
Prague	762,4	19922,4
Lima	4248,0	74018,9

Source: Author

The energy need for cooling is almost 6 times bigger in case of the family house and almost 4 times bigger in case of the apartment building.

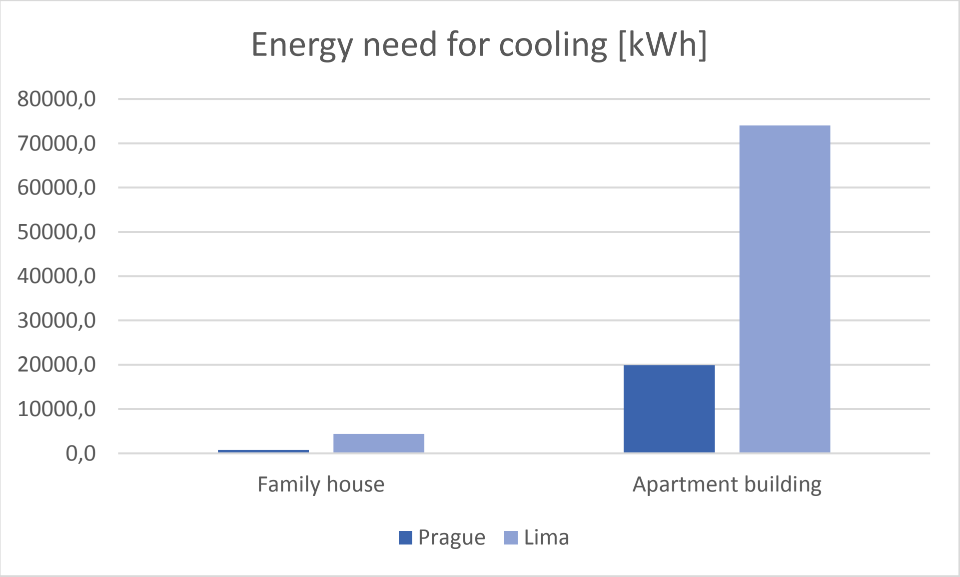


Figure 24 Graph of energy need for cooling
Source: Author

The graph in Figure 24 shows the energy need differences between Prague and Lima for the both types of buildings.

Cooling costs vary depending on the energy needs and its values are shown in the Table 8 and Figure 25.

Table 9 Total energy costs of cooling

Total energy costs of cooling [CZK]	**Family house**	**Apartment building**
Prague	1 131 CZK	29 562 CZK
Lima	6 454 CZK	109 834 CZK

Source: Author

The graph shows that cooling costs in Prague are much lower compared to Lima.

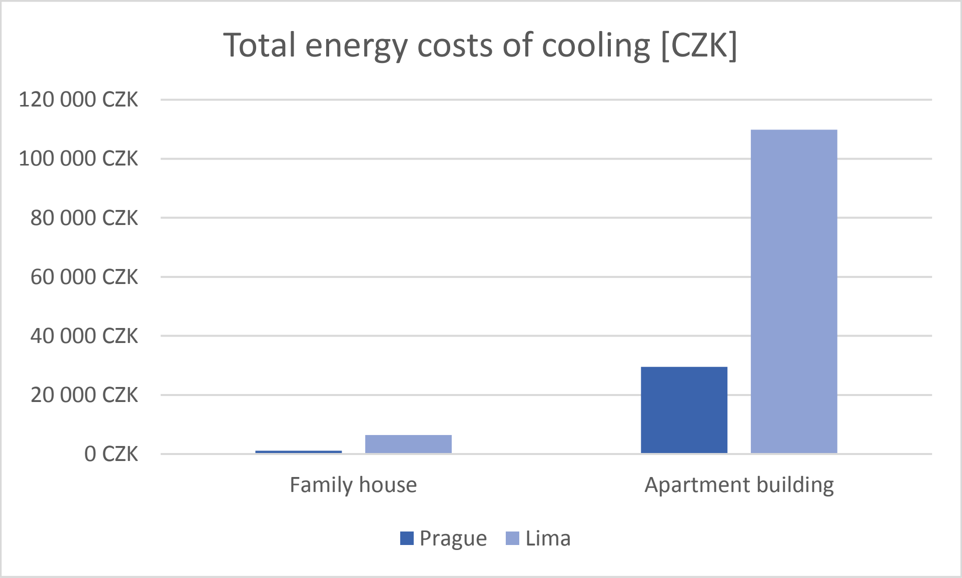


Figure 25 Total energy costs of cooling
Source: Author

The outside temperature profile differences in Lima and Prague

The Figures 27 and 28 display different temperature profiles of Lima and Prague. The temperature range in Lima is not as extensive as in Prague.

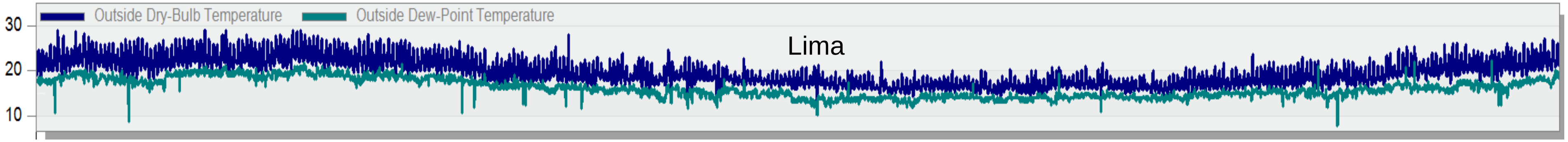


Figure 26 Temperature profile in Lima
Source: Design builder

The maximal temperatures in Lima are up to 30°C and minimal temperatures in Lima do not usually fall below 10°C.

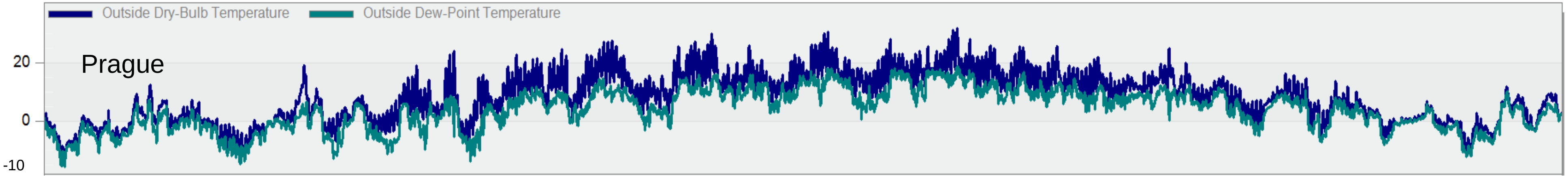


Figure 27 Temperature profile in Prague
Source: Design builder

On the other hand, the maximal temperatures in Prague are also around 30 ° C but minimal temperatures fall often below 0 °C and the temperatures in the summer are very changeable.

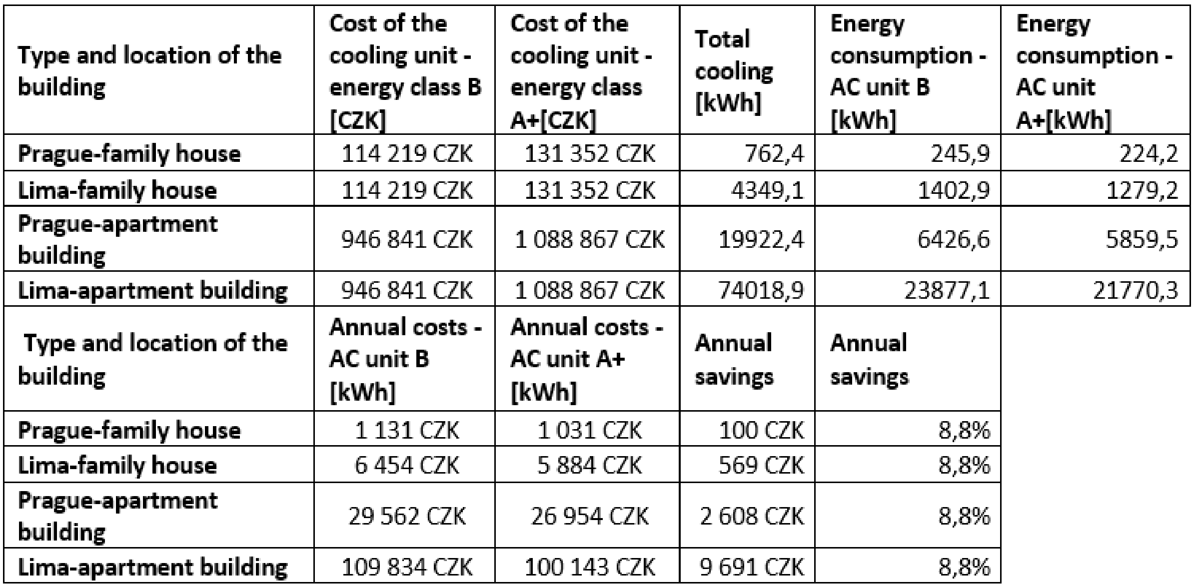
5.1 Proposals to reduce cooling costs

In order to reduce cooling costs, four proposals were simulated. It was recommended to change of energy class of the AC device and to take advantage of the bioclimatic design, which is widely used in Peru.

5.1.1 Change of the energy class of the air conditioning device

The energy classes are described in Chapter 2. The difference on price in energy classes B and A+ is approximately 15%.

Table 10 Change of the energy class of the AC device



Type and location of the building	**Cost of the cooling unit - energy class B [CZK]**	**Cost of the cooling unit - energy class A+[CZK]**	**Total cooling [kWh]**	**Energy consumption - AC unit B [kWh]**	**Energy consumption - AC unit A+[kWh]**
Prague-family house	114 219 CZK	131 352 CZK	762,4	245,9	224,2
Lima-family house	114 219 CZK	131 352 CZK	4349,1	1402,9	1279,2
Prague-apartment building	946 841 CZK	1 088 867 CZK	19922,4	6426,6	5859,5
Lima-apartment building	946 841 CZK	1 088 867 CZK	74018,9	23877,1	21770,3

Type and location of the building	**Annual costs - AC unit B [kWh]**	**Annual costs - AC unit A+ [kWh]**	**Annual savings**	**Annual savings**
Prague-family house	1 131 CZK	1 031 CZK	100 CZK	8,8%
Lima-family house	6 454 CZK	5 884 CZK	569 CZK	8,8%
Prague-apartment building	29 562 CZK	26 954 CZK	2 608 CZK	8,8%
Lima-apartment building	109 834 CZK	100 143 CZK	9 691 CZK	8,8%

Source: Author

The simulation and calculation show that the return on this investment is minimal. A graphical representation of energy consumption and annual energy cost can be seen in Figures 29 and 30.

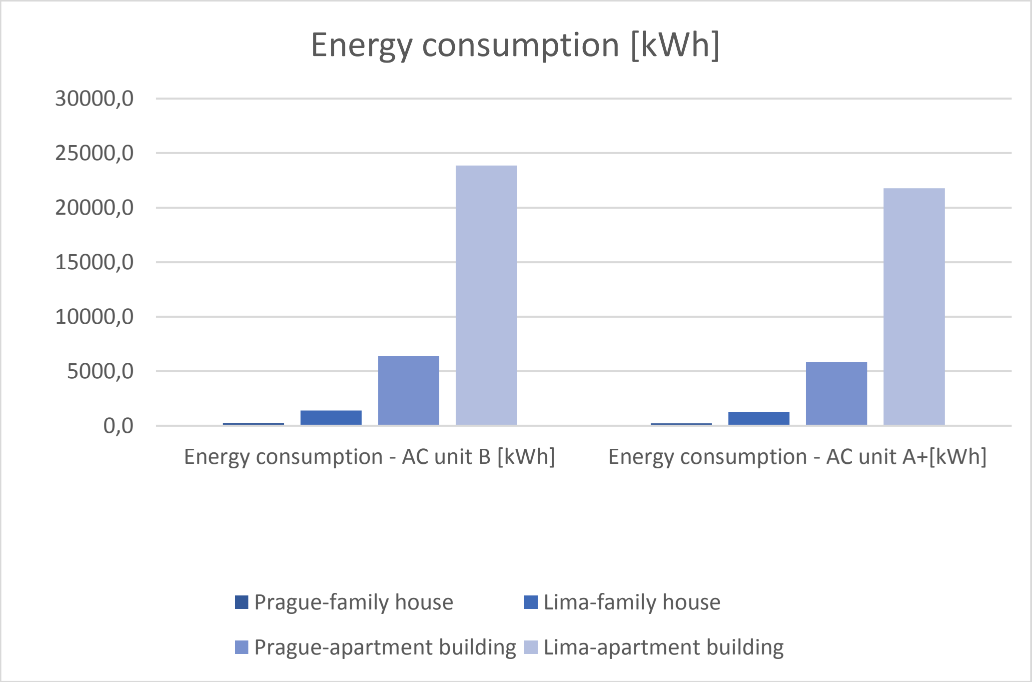


Figure 28 Energy consumption
Source: Author

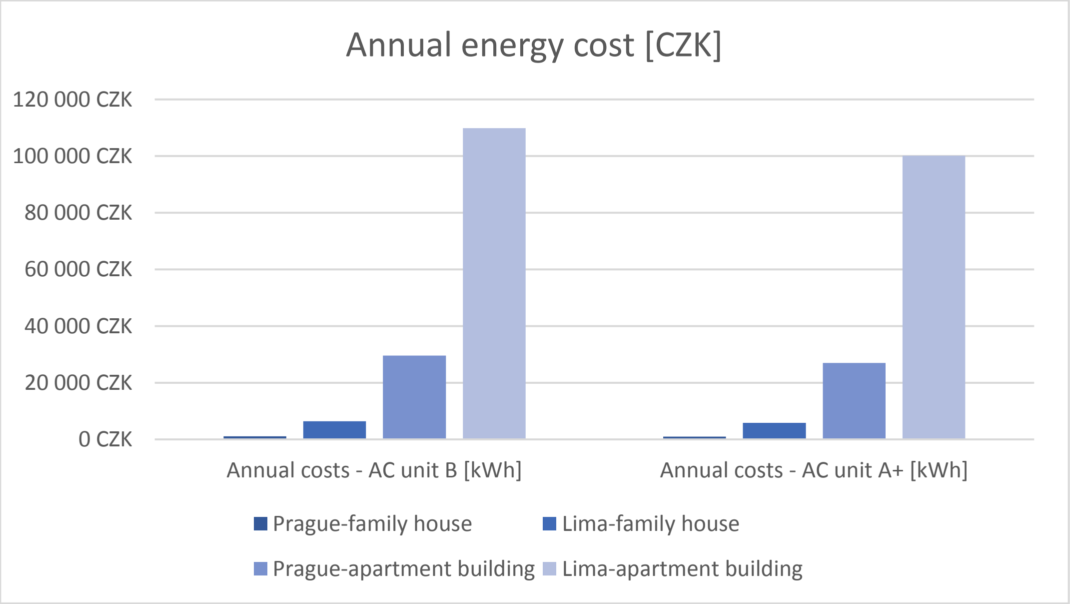
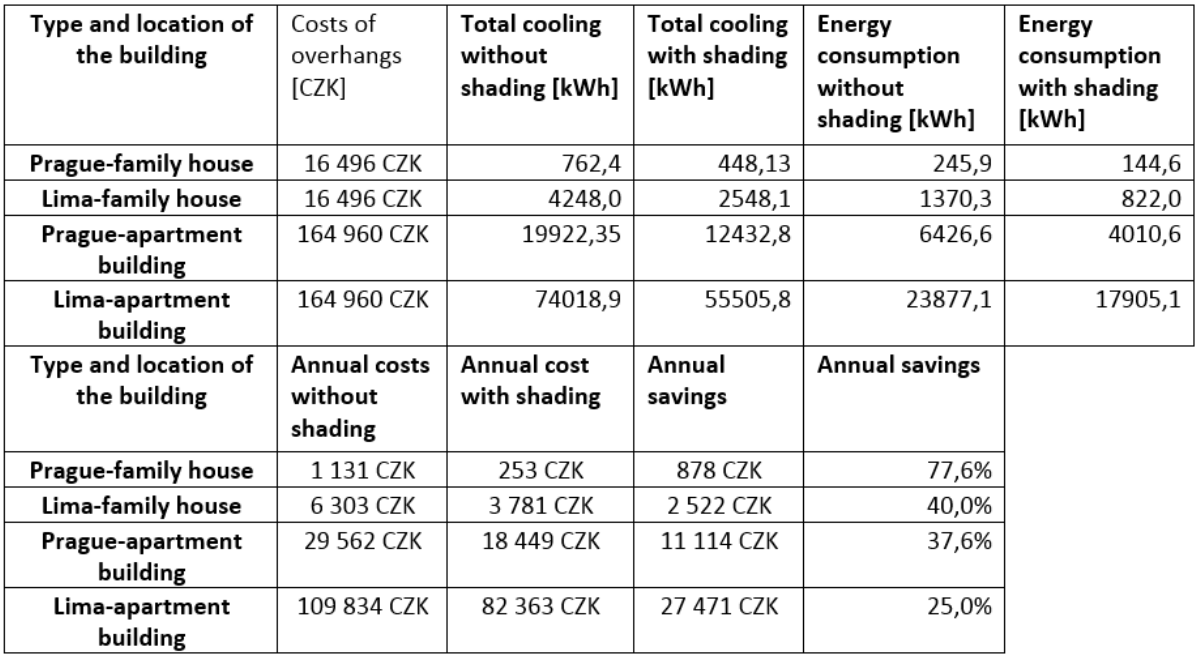


Figure 29 Annual energy cost
Source: Author

5.1.2 Shading by overhangs

Overhangs of 1 meter depth meter were added to the model. The price of the overhangs was designed based on an internet survey.

Table 11 Shading by overhangs



Type and location of the building	Costs of overhangs [CZK]	**Total cooling without shading [kWh]**	**Total cooling with shading [kWh]**	**Energy consumption without shading [kWh]**	**Energy consumption with shading [kWh]**
Prague-family house	16 496 CZK	762,4	448,13	245,9	144,6
Lima-family house	16 496 CZK	4248,0	2548,1	1370,3	822,0
Prague-apartment building	164 960 CZK	19922,35	12432,8	6426,6	4010,6
Lima-apartment building	164 960 CZK	74018,9	55505,8	23877,1	17905,1

Type and location of the building	**Annual costs without shading**	**Annual cost with shading**	**Annual savings**	**Annual savings**
Prague-family house	1 131 CZK	253 CZK	878 CZK	77,6%
Lima-family house	6 303 CZK	3 781 CZK	2 522 CZK	40,0%
Prague-apartment building	29 562 CZK	18 449 CZK	11 114 CZK	37,6%
Lima-apartment building	109 834 CZK	82 363 CZK	27 471 CZK	25,0%

Source: Author

The results show that the window shadings are most effective in Prague. This is mainly due to higher cloudiness and humidity in Lima when compared to Prague.

A graphical representation of energy consumption and annual energy cost can be seen in the Figures 31 and 32.

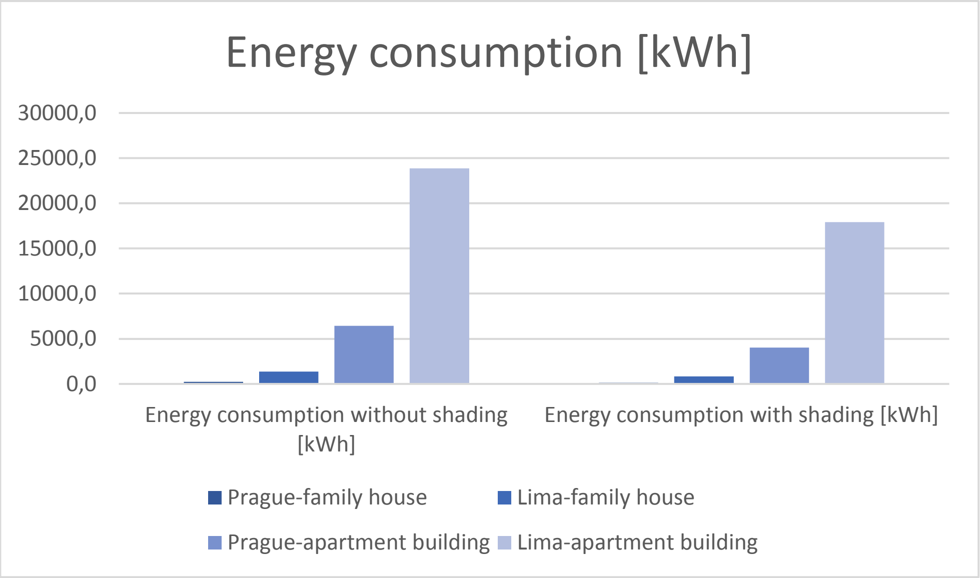


Figure 30 Energy consumption
Source: Author

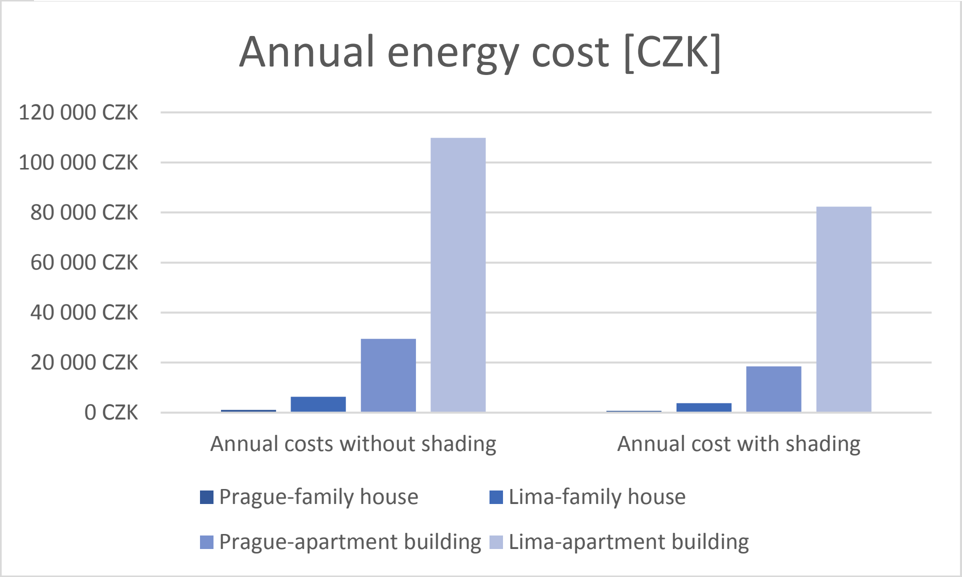
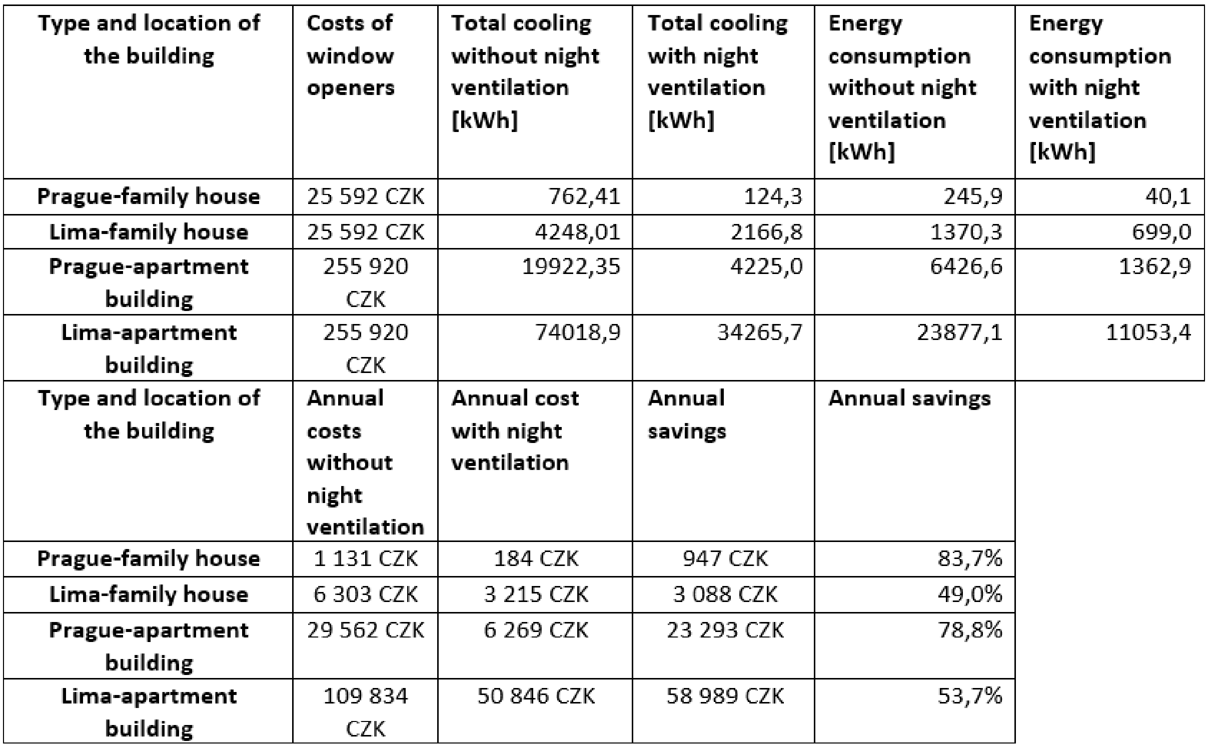


Figure 32 Annual energy cost
Source: Author

5.1.3 Night cooling

The temperature differences (Figure 27 and 28) during the day and night are very helpful for cooling. Overnight, the mass of the building is cooled through open windows and the building stays cool during the day.

Table 12 Night cooling



Type and location of the building	Costs of window openers	Total cooling without night ventilation [kWh]	Total cooling with night ventilation [kWh]	Energy consumption without night ventilation [kWh]	Energy consumption with night ventilation [kWh]
Prague-family house	25 592 CZK	762,41	124,3	245,9	40,1
Lima-family house	25 592 CZK	4248,01	2166,8	1370,3	699,0
Prague-apartment building	255 920 CZK	19922,35	4225,0	6426,6	1362,9
Lima-apartment building	255 920 CZK	74018,9	34265,7	23877,1	11053,4
Type and location of the building	**Annual costs without night ventilation**	**Annual cost with night ventilation**	**Annual savings**	**Annual savings**	
Prague-family house	1 131 CZK	184 CZK	947 CZK	83,7%	
Lima-family house	6 303 CZK	3 215 CZK	3 088 CZK	49,0%	
Prague-apartment building	29 562 CZK	6 269 CZK	23 293 CZK	78,8%	
Lima-apartment building	109 834 CZK	50 846 CZK	58 989 CZK	53,7%	

Source: Author

Night ventilation works better for family houses. The mass of air is not so large, and in the simulation, all interior doors can be opened for better airflow.

A graphical representation of energy consumption and annual energy cost can be seen in Figures 33 and 34.

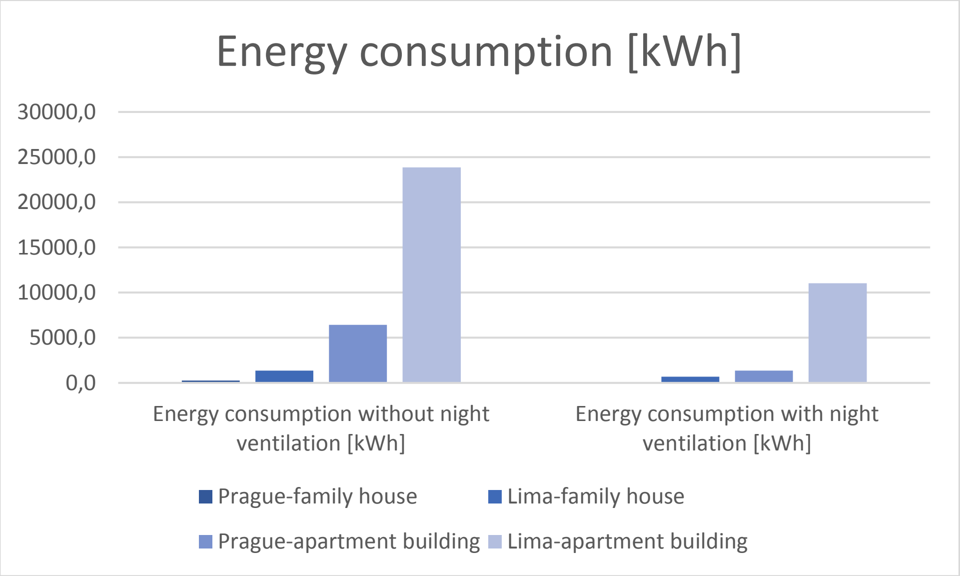


Figure 31 Energy consumption
Source: Author

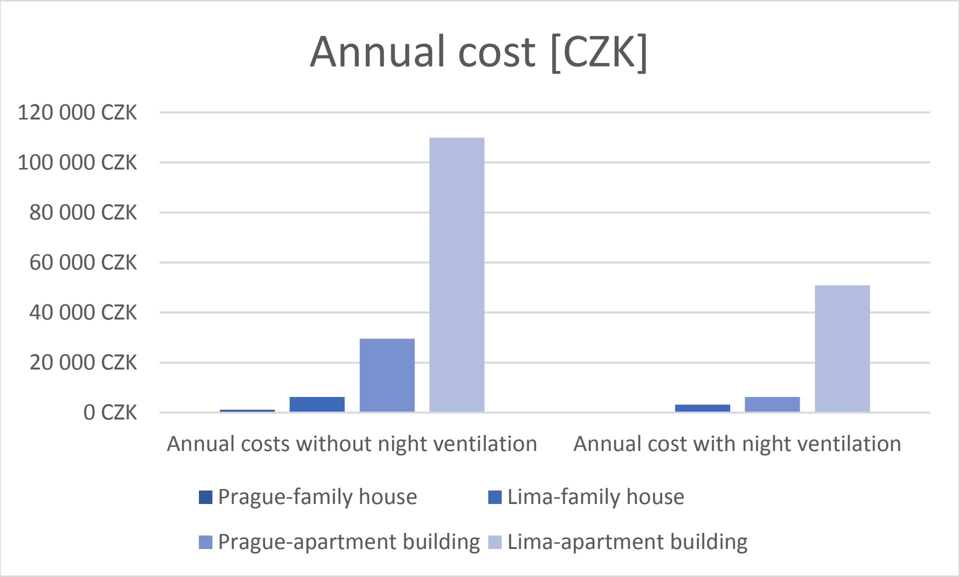
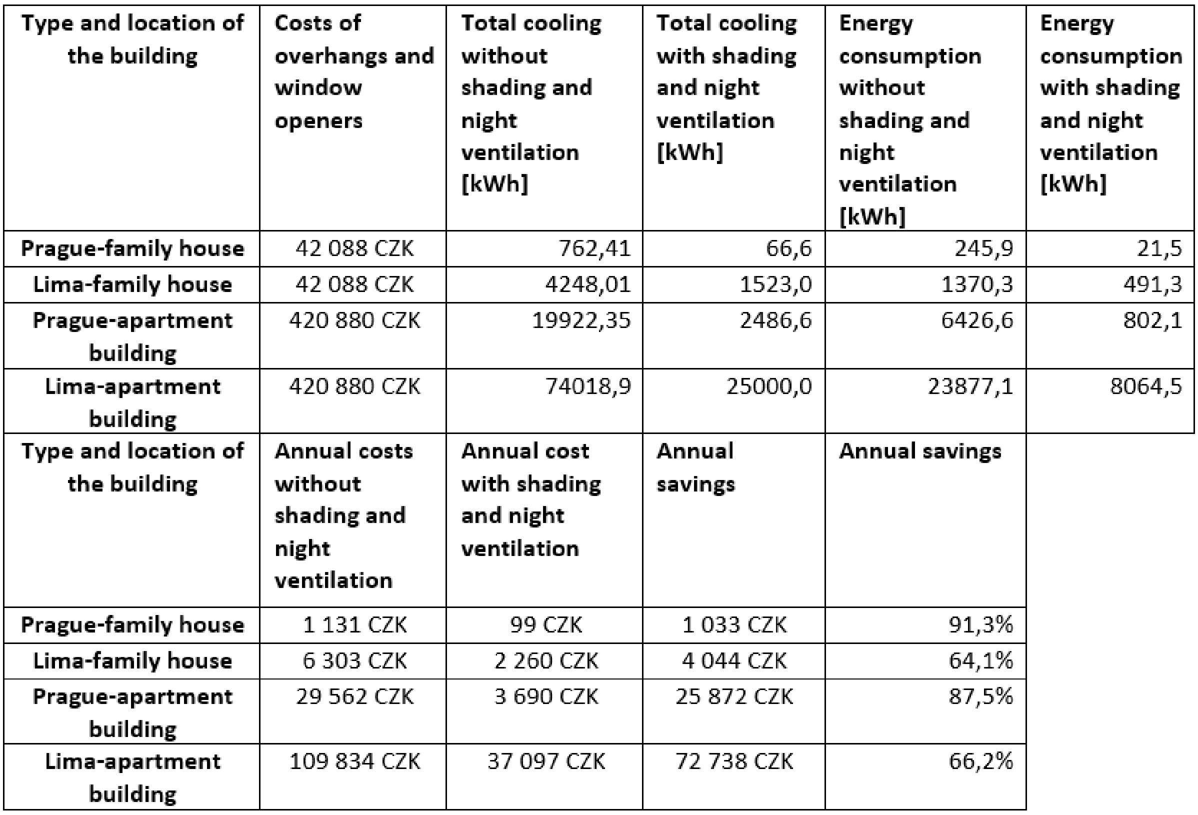


Figure 32 Annual energy cost
Source: Author

5.1.4 Combination of night cooling and shading by overhangs

The combination of these two variants has been modelled in an effort to reduce energy consumption as much as possible.

Table 13 Combination of night cooling and shading by overhangs



Type and location of the building	**Costs of overhangs and window openers**	**Total cooling without shading and night ventilation [kWh]**	**Total cooling with shading and night ventilation [kWh]**	**Energy consumption without shading and night ventilation [kWh]**	**Energy consumption with shading and night ventilation [kWh]**
Prague-family house	42 088 CZK	762,41	66,6	245,9	21,5
Lima-family house	42 088 CZK	4248,01	1523,0	1370,3	491,3
Prague-apartment building	420 880 CZK	19922,35	2486,6	6426,6	802,1
Lima-apartment building	420 880 CZK	74018,9	25000,0	23877,1	8064,5

Type and location of the building	**Annual costs without shading and night ventilation**	**Annual cost with shading and night ventilation**	**Annual savings**	**Annual savings**
Prague-family house	1 131 CZK	99 CZK	1 033 CZK	91,3%
Lima-family house	6 303 CZK	2 260 CZK	4 044 CZK	64,1%
Prague-apartment building	29 562 CZK	3 690 CZK	25 872 CZK	87,5%
Lima-apartment building	109 834 CZK	37 097 CZK	72 738 CZK	66,2%

Source: Author

A graphical representation of energy consumption and annual energy cost can be seen in Figures 35 and 36.

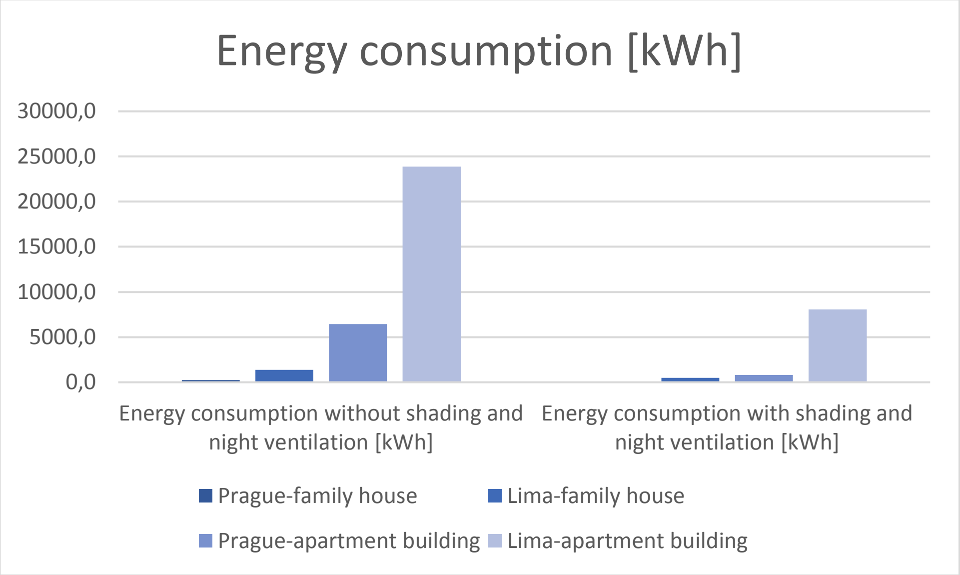


Figure 33 Energy consumption
Source: Author

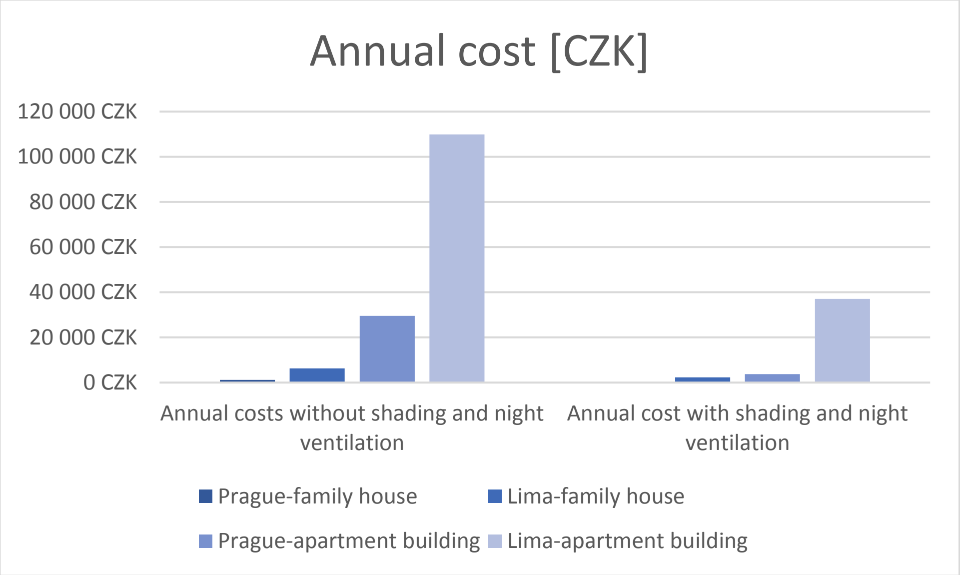


Figure 34 Annual energy cost
Source: Author

6. Conclusions

The approaches to building cooling in the Czech Republic and Peru are quite different. As an advanced European country, the Czech Republic uses energy-intensive cooling methods. On the other hand, developing country such as Peru takes advantage of bioclimatic housing. In this work, both variants are combined, and cost-effective solutions are sought. In European countries, the situation of high temperatures during summers is not threatening; it is all about thermal comfort. Due to cold winters, it is not so easy in the Czech Republic to make full use of bioclimatic design, because to save on heating costs we build our houses primarily to satisfy the heating demand. For this reason, the model buildings were chosen to meet winter conditions. The family house and apartment building were modelled and simulated in software DesignBuilder.

The same buildings were used in a simulation created in the climate conditions of Lima and Prague. For the climate of Lima, there was a bigger need for cooling due to warmer summer. In any real modification applied was not the need for cooling completely eliminated while considering the comfort temperature of 26°C. The next step was to reduce cooling needs. The most effective solution to reduce energy needs is the use of shading and night ventilation. For a family house in Prague, the cost of cooling decreased by approximately 90%. Night ventilation worked for both countries, especially for the family houses because of the small amount of mass of the air and the possibility to open all interior doors. The solution to shading windows in Lima was not as successful as in Prague due to higher cloudiness and higher temperatures. Without the use of air conditioning with proper shielding and night ventilation, the number of days when the temperature exceeds 26°C is approximately 15 days a year for the conditions of the Czech Republic, so it is up to each person how important thermal comfort is to them.

List of Tables

List of Figures

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Appendix 1 - ESTÁNDAR EM.050 INSTALACIONES DE CLIMATIZACIÓN

In a case of residential buildings, commercial buildings and buildings for other types of recreation, there can be assumed needs for air conditioners

The air conditioning installations must be able to automatically provide conditions of temperature, humidity, movement and purity of the air in a particular room or space within the prescribed values, according to the needs of ventilation and control the entry of air pollutants.

The air conditioning installations must be equipped with elements for heating, cooling, humidifying, dehumidifying and cleaning the supply air, as well as with the temperature and relative humidity regulating components of the premises.

This standard establishes the general construction specifications for air conditioning installations in order to obtain the construction and supervision of the work. It specifics elements to know the system and the correct installation.

Due to the emergence of new materials and technologies applied to air conditioning installations, it is necessary to continuously update these specifications, which specify the requirements, materials and rules that need to be met for the execution of the works.

According to the standard, the climatization facilities are defined as the ones that can automatically maintain the maximum and minimum values of the temperature and humidity of the air throughout the year.

The table below shows the classification of climatization facilities.

Type of facility	Constant Climate of Building	Suitable for variable building climate		
		for premises	for group of premises	for zonas
One channel low pressure AC	X			
One channel high pressure AC	X			
Two channel AC			X	X
AC with primary air and post heaters			X	
AC with primary air and mixing register				X
AC with primary air and post ventilation				X
AC with primary air and induction systems -two pipelines -three pipelines -four piprlines	X			

The standard describes general considerations of installations. The works for the air conditioning installations must run according to the following considerations:

1. In the installation project, the equipment and materials of all the air conditioning systems must be described, as well as the catalogue with all the concepts and quantities of materials which is necessary for the work

2. Complete electrical installations, necessary for the correct start-up of the equipment, as well as the circuit diagrams of the control systems.

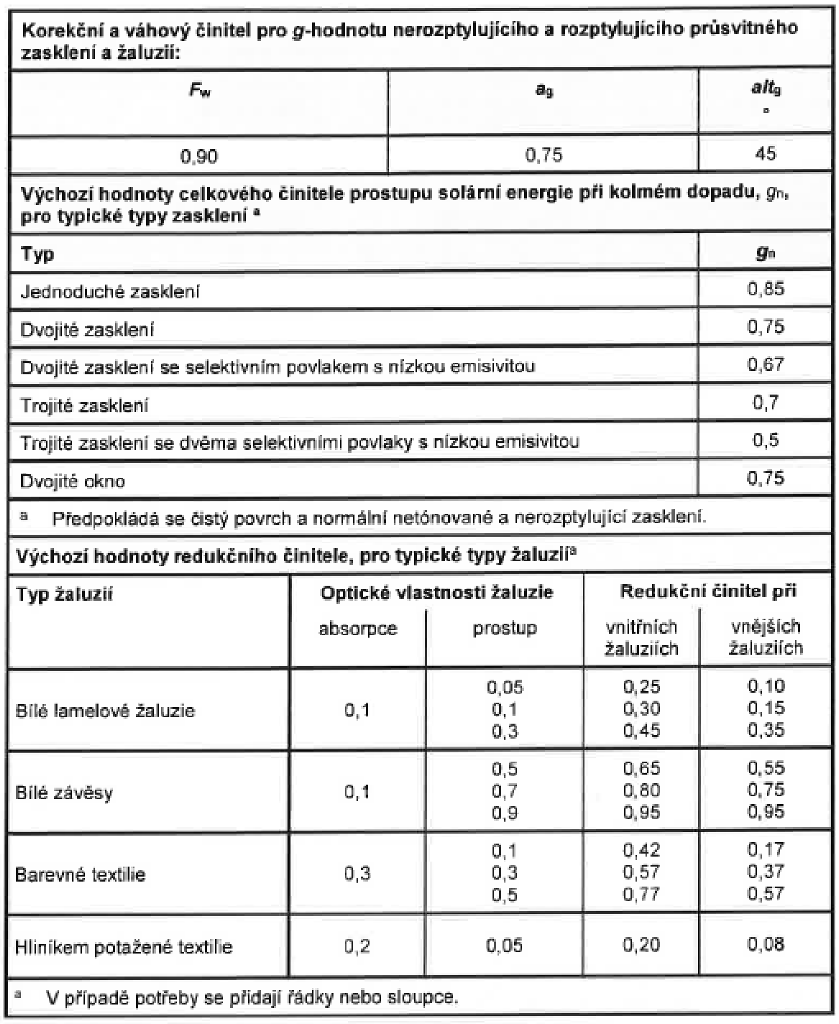
3. The final connections of water supply and drainage, from the preparations left in the machine rooms for the corresponding installation, continuing the work with the same quality of materials indicated in the specifications of hydraulic and sanitary installations.

4. Carry out all the masonry and painting work, which are required for the total completion of the above, including, among others grooves, perforations, resins, construction of bases and supports for the different equipment. These works must conform to indications of supervision and general civil works specifications.

5. Preparation of the completed construction plans using the updated architectural plans for this requirement is essential to consider the work of the work executor and the complete installation delivery.

Appendix 2 – Factors related to solar energy transmission

Table 14 Factors related to solar energy transmission



Korekční a váhový činitel pro *g*-hodnotu nerozptylujícího a rozptylujícího průsvitného zasklení a žaluzií:

F_w	a_g	alt_g °
0,90	0,75	45

Výchozí hodnoty celkového činitele prostupu solární energie při kolmém dopadu, g_n, pro typické typy zasklení [a]

Typ	g_n
Jednoduché zasklení	0,85
Dvojité zasklení	0,75
Dvojité zasklení se selektivním povlakem s nízkou emisivitou	0,67
Trojité zasklení	0,7
Trojité zasklení se dvěma selektivními povlaky s nízkou emisivitou	0,5
Dvojité okno	0,75

[a] Předpokládá se čistý povrch a normální netónované a nerozptylující zasklení.

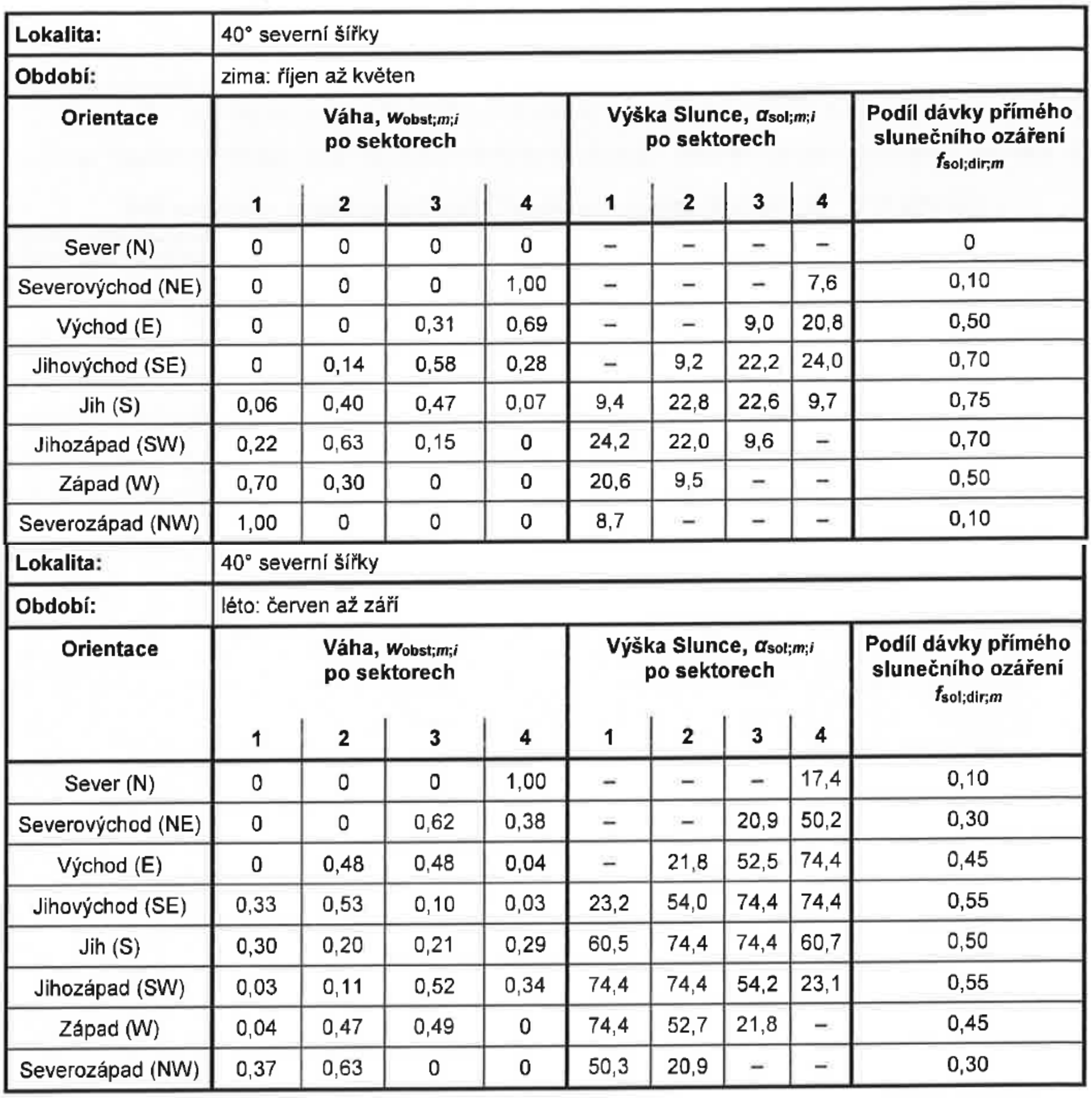
Výchozí hodnoty redukčního činitele, pro typické typy žaluzií[a]

Typ žaluzií	**Optické vlastnosti žaluzie**		**Redukční činitel při**	
	absorpce	prostup	vnitřních žaluziích	vnějších žaluziích
Bílé lamelové žaluzie	0,1	0,05 0,1 0,3	0,25 0,30 0,45	0,10 0,15 0,35
Bílé závěsy	0,1	0,5 0,7 0,9	0,65 0,80 0,95	0,55 0,75 0,95
Barevné textilie	0,3	0,1 0,3 0,5	0,42 0,57 0,77	0,17 0,37 0,57
Hliníkem potažené textilie	0,2	0,05	0,20	0,08

[a] V případě potřeby se přidají řádky nebo sloupce.

Source: [22]

Table 15 Parameters for monthly sunshade values



Lokalita:	40° severní šířky								
Období:	zima: říjen až květen								
Orientace	**Váha, $w_{obst;m;i}$ po sektorech**				**Výška Slunce, $\alpha_{sol;m;i}$ po sektorech**				**Podíl dávky přímého slunečního ozáření $f_{sol;dir;m}$**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	
Sever (N)	0	0	0	0	–	–	–	–	0
Severovýchod (NE)	0	0	0	1,00	–	–	–	7,6	0,10
Východ (E)	0	0	0,31	0,69	–	–	9,0	20,8	0,50
Jihovýchod (SE)	0	0,14	0,58	0,28	–	9,2	22,2	24,0	0,70
Jih (S)	0,06	0,40	0,47	0,07	9,4	22,8	22,6	9,7	0,75
Jihozápad (SW)	0,22	0,63	0,15	0	24,2	22,0	9,6	–	0,70
Západ (W)	0,70	0,30	0	0	20,6	9,5	–	–	0,50
Severozápad (NW)	1,00	0	0	0	8,7	–	–	–	0,10

Lokalita:	40° severní šířky								
Období:	léto: červen až září								
Orientace	**Váha, $w_{obst;m;i}$ po sektorech**				**Výška Slunce, $\alpha_{sol;m;i}$ po sektorech**				**Podíl dávky přímého slunečního ozáření $f_{sol;dir;m}$**
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	
Sever (N)	0	0	0	1,00	–	–	–	17,4	0,10
Severovýchod (NE)	0	0	0,62	0,38	–	–	20,9	50,2	0,30
Východ (E)	0	0,48	0,48	0,04	–	21,8	52,5	74,4	0,45
Jihovýchod (SE)	0,33	0,53	0,10	0,03	23,2	54,0	74,4	74,4	0,55
Jih (S)	0,30	0,20	0,21	0,29	60,5	74,4	74,4	60,7	0,50
Jihozápad (SW)	0,03	0,11	0,52	0,34	74,4	74,4	54,2	23,1	0,55
Západ (W)	0,04	0,47	0,49	0	74,4	52,7	21,8	–	0,45
Severozápad (NW)	0,37	0,63	0	0	50,3	20,9	–	–	0,30

Source: [22]

Appendix 3 – Monthly maximal temperatures

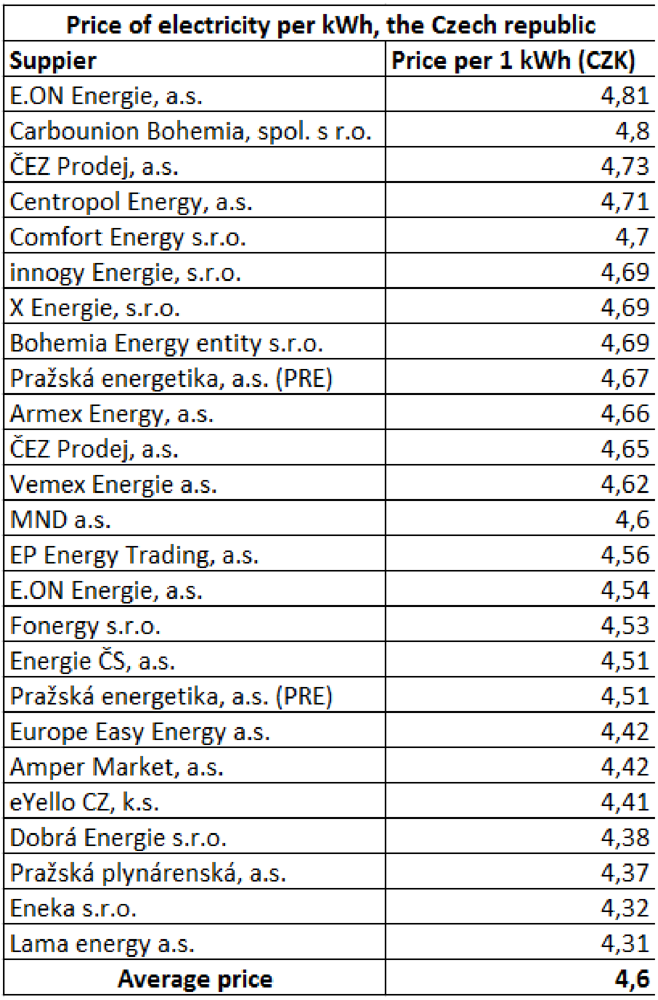
Table 16 Monthly maximal temperature

Monthly maximal temperatures measured by the Czech Hydrometeorological Institute in station P1PLIB01, Prague. [°C]																																Number of days with temperature >26°C
years	months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
2011	**05**	12,3	9,5	2,8	5,3	8,0	11,8	14,2	12,8	15,6	16,7	19,0	15,6	13,7	14,5	9,6	12,1	15,8	18,4	20,3	18,5	19,3	20,4	18,0	18,8	15,1	21,5	13,6	12,6	17,8	20,8	21,8	**0**
2011	**06**	20,3	20,0	26,8	28,1	29,5	28,4	27,9	26,2	19,3	21,8	23,5	20,0	23,9	24,2	26,7	28,5	24,3	19,4	17,6	21,1	24,3	30,5	23,3	20,6	19,0	21,5	25,7	26,4	29,1	23,2		**11**
2011	**07**	18,6	17,2	13,9	20,2	23,4	27,7	29	24,7	30,9	28,2	23,6	26,5	27,8	20,7	22,6	25,1	30,7	22,1	25,0	21,2	15,9	17,5	20,7	19,5	20,9	21,4	24,1	23,9	22,5	17,5	15,7	**7**
2011	**08**	21,0	25,5	28	26,2	25,8	27	22,2	24,1	20,2	16,9	23,6	25,6	24,0	27,8	20,2	23,0	27	30,8	26,7	25,2	29,5	31,3	31,2	31,6	28,4	32,6	26,0	21,9	22,9	19,5	21,3	**13**
2012	**05**	28,9	30,4	21,9	22,4	24,4	15,3	16,4	20,9	24,6	26,8	30,7	23,2	10,0	14,9	17,6	12,0	12,7	17,0	23,6	26,1	26,1	27,3	28,7	24,4	22,4	22,6	22,9	21,8	25,1	23,8	23,3	**8**
2012	**06**	17,4	17,8	23,0	20,2	15,4	19,2	25,6	26,8	23,4	16,3	21,1	20,5	18,1	15,6	25,0	31,8	27,9	32,6	25,7	29,1	27,4	26,0	25,6	28,7	23,0	21,4	26,2	28	32,4	33,5		**11**
2012	**07**	28,9	25,8	23,7	25,6	31,7	30,2	25,1	29,5	25,9	28,1	26,0	22,1	20,3	24,4	23,0	17,8	20,4	25,0	26,2	20,9	19,8	19,0	24,2	29,3	24,3	30,6	32,6	34,3	27,1	25,3	26,1	**12**
2012	**08**	28,9	33,3	27,7	28,5	31,8	30,1	23,9	23,1	23,2	20,8	18,5	22,7	22,3	24,9	27,1	25,4	25,1	29,3	34,4	39,6	32	30,1	28,9	29,2	29,4	24,3	23,1	27,7	28,1	29,5	20,5	**18**
2013	**05**	14,3	16,8	12,6	18,8	18,9	18,6	22,3	24,7	24,5	18,1	13,5	19,1	14,9	19,6	23,3	24,0	24,4	20,4	24,8	19,8	19,9	17,4	12,3	12,3	11,9	8,9	12,7	19,9	18,3	11,9	15,8	**0**
2013	**06**	14,4	14,4	9,9	15,6	19,3	19,4	22,7	25,9	26,2	16,5	21,4	24,1	27,1	21,6	26,2	26,7	29,9	35,7	33,3	34,1	27,6	26,9	25,2	20,1	12,8	13,3	17,7	20,3	20,8	18,2		**10**
2013	**07**	25,1	27,9	26,3	24,8	24,1	23,9	25,9	25,3	27,3	27	20,8	21,6	23,7	24,6	22,0	27,2	28,4	28,5	28,4	26,4	27,8	30,6	31,3	31,8	28,4	32,8	36,2	37,4	30,4	25,8	26,3	**19**
2013	**08**	30,4	34,2	37,9	30,1	28,4	33,4	29,9	29,4	23,4	24,8	23,3	25,5	22,1	21,8	23,4	25,8	29,4	31,6	23,9	19,0	21,9	22,7	22,5	23,7	18,7	17,2	16,4	19,6	23,9	24,8	25,1	**10**
2014	**05**	22,1	20,1	7,7	11,8	15,1	21,8	16,2	18,4	21,9	19,6	17,0	16,3	15,2	13,4	13,3	13,5	11,5	12,2	22,7	25,1	26,6	29	27,5	23,0	23,3	24,8	21,6	18,8	13,4	16,7	20,2	**3**
2014	**06**	19,9	19,6	20,7	23,6	21,6	24,4	28,8	32,5	32,4	33,4	33,4	24,9	22,8	19,7	20,0	21,8	22,3	25,3	24,4	17,4	17,6	19,6	22,1	22,3	18,2	19,4	24,9	28,7	21,5	18,7		**6**
2014	**07**	21,5	22,9	27,3	31	28,9	30,4	32,1	28	20,2	16,4	24,8	23,6	25,3	27,3	28,3	28,2	29	30,5	31,7	33,8	29,1	28,4	27,9	23,2	28,3	29,4	30,8	27,7	26,5	27,1	23,7	**22**
2014	**08**	23,6	30,5	30	23,0	22,9	24,7	25,7	28	28,8	31,1	24,0	23,6	20,4	21,7	22,2	19,9	22,0	21,8	22,6	20,4	20,4	22,7	22,3	17,3	21,0	15,6	19,4	22,2	23,1	24,0	18,4	**5**
2015	**05**	13,2	16,8	18,0	23,9	26,7	20,7	18,8	21,8	21,0	19,1	20,6	26,9	21,6	16,5	19,0	22,7	17,5	23,3	19,1	14,8	14,9	18,2	19,0	18,6	21,3	15,6	12,4	19,9	23,1	17,9	22,0	**2**
2015	**06**	26,9	27	30,3	23,9	27,7	32,5	26,2	19,6	13,6	19,6	22,6	30,3	30,1	27,4	20,0	19,2	19,4	19,0	16,4	16,7	18,2	20,9	16,6	18,4	22,2	25,0	20,6	22,7	24,8	27,8		**10**
2015	**07**	29,1	30	32,6	34,7	36,6	28,4	36	29	20,4	21,1	27	29,6	22,4	23,8	25,3	31,1	34,3	34,8	34,6	27,3	34,6	37,6	30,2	29,8	29,3	23,4	23,5	24,3	23,7	22,8	23,0	**20**
2015	**08**	28,8	25,9	30,3	35	31,3	36,1	38,4	38,2	33,6	36,8	36,8	35,7	34,9	37,3	31,1	28,1	18,7	16,0	17,7	21,9	25,0	24,8	24,3	27,3	23,5	27,4	31,6	29,8	29,6	33,1	34,1	**22**
2016	**05**	18,6	18,9	19,2	12,9	18,3	21,9	22,3	20,9	22,6	22,3	22,2	19,2	22,5	18,0	12,3	12,8	12,7	17,9	20,2	23,3	24,1	29,5	25,2	21,3	18,6	22,3	23,8	26,2	25,7	25,4	23,3	**2**
2016	**06**	23,9	22,5	20,9	24,7	26,0	24,5	23,5	27,5	23,0	22,6	20,7	22,0	22,9	23,3	21,9	27,2	19,1	24,1	23,8	21,0	23,3	27,8	31,4	33	34,4	23,6	23,2	25,4	27,3	26,1		**8**
2016	**07**	29,2	29,8	22,0	23,8	28,1	21,9	24,3	29,3	26,2	31,2	34,5	25,4	26,2	16,0	18,3	23,1	22,4	26,2	27,8	28,9	27,6	29,6	31	26,2	29,5	30,9	28,7	26,9	26,8	29,4	24,4	**21**
2016	**08**	23,7	21,9	25,0	31,2	25,1	23,8	26,6	29,6	24,1	18,2	19,4	18,0	25,8	26,7	25,1	21,9	21,9	25,9	28,1	30,2	23,3	22,2	26,6	27,3	29,5	31	30,6	33,5	25,6	22,6	25,3	**12**
2017	**05**	16,1	15,4	18,5	16,3	12,7	18,8	17,3	16,9	8,7	14,6	21,4	22,1	21,3	22,9	21,4	22,5	23,7	27,6	27,7	20,8	20,4	21,2	24,7	18,0	19,3	23,5	24,9	28,4	32,2	32,8	24,7	**5**
2017	**06**	24,5	26,5	29	23,0	22,7	25,8	18,6	23,5	28	23,1	27,6	29,3	23,2	24,6	29,1	23,7	20,5	25,2	29,6	33,3	29,4	35,8	27,3	30,7	27,1	26,2	23,2	29,5	22,3	23,6		**15**
2017	**07**	22,1	24,4	24,2	23,2	28,5	27,5	30,8	28,2	28,8	29,9	24,1	25,1	20,3	21,8	20,4	24,2	25,0	27,2	32,1	31,1	29,3	29,1	25,6	21,1	20,2	21,8	23,9	24,1	28,8	33,2	32,3	**14**
2017	**08**	36,4	30	28,1	29,4	32	24,6	25,2	27,3	26,8	29,3	20,0	20,1	24,6	25,2	30	23,3	27	31	25,7	22,0	20,9	20,9	22,1	28,8	28,4	28,4	26,0	24,0	27,1	30,4	27,8	**17**
2018	**05**	20,3	23,3	19,6	21,0	21,7	21,4	23,6	23,9	24,8	26,9	21,7	24,8	25,7	24,7	20,8	15,8	16,9	20,5	21,3	21,6	23,0	25,2	26,4	24,6	25,0	26,8	28,5	30,3	30,9	28,3	30,3	**8**
2018	**06**	26,9	26,9	26,3	27,9	25,7	28	29	29	32,2	29,4	26,6	23,2	19,4	18,9	23,6	26,5	28,4	25,0	23,7	28	31,2	15,9	16,4	18,3	21,4	23,3	21,9	18,6	28,2	23,9		**15**
2018	**07**	20,2	23,5	26,8	31,1	33,2	24,5	25,7	25,7	27,4	25,3	21,2	19,6	27,2	28,2	29,4	28,1	28,2	27,3	27,9	29,2	31	27,7	29	31,1	31,5	31	31,5	33,8	32,1	33,4	34,6	**23**
2018	**08**	35,2	35,3	34,4	35,3	28,7	29,5	34,8	34,4	35,5	28,6	27,2	28,7	35,1	27,4	25,7	29,2	30,8	29,7	32,7	33,2	28	32	33,6	26,7	19,9	20,0	26,1	24,3	29,8	24,2	20,0	**25**

Source: [25]

Appendix 4 – Price of electricity

Table 17 Price of electricity, the Czech Republic, 2019



Price of electricity per kWh, the Czech republic	
Suppier	**Price per 1 kWh (CZK)**
E.ON Energie, a.s.	4,81
Carbounion Bohemia, spol. s r.o.	4,8
ČEZ Prodej, a.s.	4,73
Centropol Energy, a.s.	4,71
Comfort Energy s.r.o.	4,7
innogy Energie, s.r.o.	4,69
X Energie, s.r.o.	4,69
Bohemia Energy entity s.r.o.	4,69
Pražská energetika, a.s. (PRE)	4,67
Armex Energy, a.s.	4,66
ČEZ Prodej, a.s.	4,65
Vemex Energie a.s.	4,62
MND a.s.	4,6
EP Energy Trading, a.s.	4,56
E.ON Energie, a.s.	4,54
Fonergy s.r.o.	4,53
Energie ČS, a.s.	4,51
Pražská energetika, a.s. (PRE)	4,51
Europe Easy Energy a.s.	4,42
Amper Market, a.s.	4,42
eYello CZ, k.s.	4,41
Dobrá Energie s.r.o.	4,38
Pražská plynárenská, a.s.	4,37
Eneka s.r.o.	4,32
Lama energy a.s.	4,31
Average price	**4,6**

Source: [27]