A STRATEGY FOR REDUCING CARBON EMISSIONS IN A CITY USING A LOW-CARBON STRATEGY - A CASE STUDY

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Various environmental policies are created on the basis of scientific knowledge in the sectors of energy, climate and transport. An important role has the Paris Agreement with the aim of limiting the increase in global temperature. The commitments regarding climate neutrality within the framework of "Fit for 55" are important. One of the principles of how to approach the reduction of CO_2 emissions within the strategies of countries, regions, cities and municipalities is the use of low-carbon strategies. As part of the study, an analysis of the input data is carried out as part of the assessment of the energy demand and efficiency of public and residential buildings, buildings of the tertiary sector, energy consumption in the public lighting sector, or the use of renewable resources in the city. The aim of the article is to determine the potential of energy savings in individual sectors and propose measures to achieve a reduction in CO_2 emissions.

KEYWORDS

Low-carbon strategy, GHG, emissions, CO_2

1 INTRODUCTION

Carbon neutrality has become a focal point and climate action is key to achieving it. There are extensive scientific analyzes of the risks associated with climate change, especially in urban agglomerations. The role of cities and their stakeholders in creating a sustainable low-carbon society is becoming increasingly important and critical. Exposure to air pollution is one of the biggest environmental factors on a global scale. Greenhouse gas emissions not only contribute to climate change, but also negatively affect air quality and the water system. Urbanization is therefore one of the main factors affecting CO_2 emissions. Research also points to the fact that air quality can influence the desire of qualified people to live in cities. Settlements are therefore currently the core of air quality determination. Cities and their supply chains are responsible for almost 80% of global energy consumption and more than 60% of greenhouse gas emissions produced. CO_2 emissions from cities around the world represent 71% - 76% of all global CO_2 emissions. Cities around the world recognize their role in mitigating climate change and are responding with various activities that should lead to the goal of reducing carbon emissions [Harris 2020, Vianaa 2020, Croci 2021, Shahnazi 2021, Huovila 2022, Deroubaix 2023, Liu 2023, Salvia 2023, Ulpiani 2023, Wang 2023].

Buildings, as well as transport and industry, represent one of the largest sectors of energy consumption. According to the United Nations Environment, buildings are estimated to account for approximately 36% of global energy consumption and are responsible for approximately 37% of anthropogenic greenhouse gas emissions. According to data from the International Energy Agency (IEA), almost half of the energy demand in buildings was used for heating and hot water production in 2021. The result was the production of 2,450 million tons of direct CO_2 emissions. While the residential sector alone is responsible for 26.3% of final energy consumption in the European Union (EU) and causes 23.6% of greenhouse gas emissions. The evaluation and management of CO_2 emissions created by buildings is therefore crucial [Roh 2017, Huang 2019, Guo 2022, Fereidoni 2023, Yu 2023].

The assessment of all energy inputs is the first step towards achieving the goal of increasing the energy efficiency of buildings. Building envelope, i.e., the interface between the interior of the building and the external environment, serves as a thermal barrier and plays an important role in determining the demand for energy to ensure thermal comfort. Improving the thermal insulation properties of buildings plays a significant role in reducing their energy consumption. Subsequently, it is possible to implement measures to optimize the production of heat and hot water. An important role is played by the implementation of RES-based technology. The analysis showed that even with the increasing degree of urbanization, the increase of RES sources, will caused CO_2 emissions reduction over the years [Lee 2017, Zilberberg 2021, Grodzicki 2022, Guo 2022].

2 METHODOLOGY

A significant contribution to the reduction of pollutant emissions comes from different sets of policies in the sectors of energy, climate, transport and taxation. One such policy is the European Green Deal - EGD. The adopted EGD measures increase the ambition levels of the Paris Agreement. The signatories of the Paris Agreement (196 countries) from 2015 committed to reduce the effect of greenhouse gas emissions (GHG) in order to limit the increase in global temperature below 2°C. Such an ambitious goal requires the achievement of zero emissions (hereinafter referred to as carbon neutrality) by 2050. The commitments regarding climate neutrality within the framework of "Fit for 55" are significant. The "Fit for 55" package was presented in July 2021 to respond to the requirements set out in European climate legislation to reduce European's net greenhouse gas emissions by at least 55% by 2030. While individual states have set different target years for the fulfilment of obligations (e.g., 2045 for Germany; 2050 for France). Net zero targets are also gradually being presented by regional and local governments [Caravaggio 2019, EGD 2019, Huovila 2022, Deroubaix 2023, FF55 2023, Weng 2023, Salvia 2023].

One of the principles is the reduction of CO_2 emissions within the framework of low-carbon strategies of countries, regions, cities and municipalities. More than 5,000 European cities have introduced targets to address climate change and joined international initiatives such as the Convention of Mayors (CoM). The concept of a low-carbon strategy is also based on the methodology of the Convention of Mayors. CoM is the commitment of cities and municipalities in the area of reducing CO_2 emissions, through increasing energy efficiency and using clean technologies for energy production and consumption. The entire initiative is based on voluntary commitment. From a methodological point of view, the CoM Initiative allows local people to develop a Low Carbon Strategy in such a way that it reflects local conditions [GCM 2016, Croci 2021, Lopez 2021, Huovila 2022, Ulpiani 2023].

The methodology resulting from the CoM presents procedures with multiple options, while being strictly based on existing standards and methods:

- determination of the reference year,

- emissions inventory,
- included greenhouse gases,
- emission factors,
- definition of the reduction target.

The CoM methodology for creating a low-carbon strategy is flexible and adaptable to local conditions, while complying with international and European standards. The basis for processing is the Baseline Emissions Inventory (BEI), which must include at least three of the four key sectors [Croci 2021].

As part of the low-carbon strategy, measures are evaluated and proposed in the following parts:

A. Public buildings of local government
- administrative buildings
- cultural buildings
- school buildings
- sports facilities
- social facilities
- other objects

B. Buildings of the tertiary sector

C. Residential buildings
- family houses
- apartment houses

D. Public lighting

E. Transport

F. SMART Cities

G. Renewable energy sources

H. Climate change.

2.1 *Determination of the reference year*

The determination of the reference year for the implementation of the low-carbon strategy represents the starting year with which the goal of reducing emissions is compared. To determine the year, it is possible to choose the year for which the most comprehensive and reliable data can be obtained. The EU commitments regarding the reduction of greenhouse gas emissions by 20% by 2020 (Kyoto Protocol) and by 40% by 2030 (EU Nationally Determined Contribution, Paris Agreement) refer to the year 1990. Since problems may arise when determining the reference year 1990 and that due to obtaining sufficiently relevant data for the given period, it is possible to choose the next year for which sufficiently complex and relevant data are available. In exceptional cases, when a relevant amount of valid data cannot be collected for any of the years between 1990 and 2005, it is also possible to use a later starting year than 2005. Such a choice of reference year should be justified in the low-carbon strategy [GCM 2016].

2.2 *Base balance of CO_2 emissions*

Greenhouse gas emissions are quantified by multiplying the final energy consumption by the corresponding emission factor. To calculate these emissions, two methods can be used within the CoM [GCM 2016]:

- IPCC - emission factors for burning fuels – based on the carbon content of individual fuels,
- LCA - emission factors for the overall life cycle of individual energy carriers, i.e., not only the emissions of greenhouse gases that arise when burning fuel, but also the emissions of the entire energy supply chain.

Since CO_2 is the most common pollutant emitted by human activity, policy targets are usually expressed in CO_2e equivalent. [Caravaggio 2019].

3 BASELINE ANALYSIS

An analysis of the input data of the city of Nova Bana is carried out as part of the assessment of the energy demand and efficiency of public and residential buildings, buildings of the tertiary sector, energy consumption in the public lighting sector, or the use of renewable resources. Subsequently, the rate of possible CO_2 reduction is determined.

The territory of the city cadastre is one climatic area, while the average monthly temperature ranges from -2.4 to 18.1°C. The highest temperature reached is in the month of July, with a long-term average value of 18.1°C. The maximum air temperature rises to 25 °C or more (summer day) in an average of 60 days and to 30 °C or more (tropical day) in an average of 12 days. In hot summers, absolute maximum air temperatures reach up to 38 °C. The warm period, defined by an average daily air temperature of 15 °C and above, lasts an average of 100 days, from the beginning of June to the end of the second decade of September. The lowest temperature is in the month of January with an average monthly air temperature of -2.4°C and a drop in the minimum air temperature to -25°C. The frost period defined by the average daily air temperature of 0 °C and below lasts an average of 70 days, from mid-December to the beginning of the second decade of February. The minimum air temperature falls below 0 °C (frost day) on average on 118 days and the maximum air temperature (cold day) on average on 20 days.

The following graph (Fig. 1) shows the degree-days for the period 2015–2020. The average value in the monitored period is 3395 daily degrees.

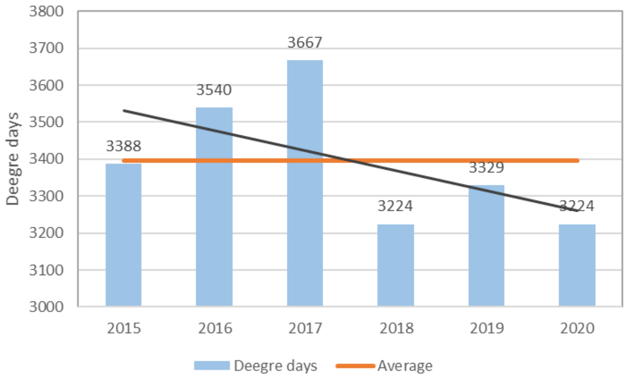


Figure 1. Nova Bana degree-days for the period 2015–2020

3.1 *Analysis of the existing state of thermal equipment*

On the territory of the city, current heating devices are located in relation to the structure of the building and the concentration of heat consumers. The city of Nova Bana has a low degree of centralized heat supply. The high percentage of gasification of the city caused the dominant position of the use of natural gas for local heating of family houses. The analysis shows that 22 boilers are installed in the monitored boiler facilities, of which the most numerous are boilers up to 100 kW, or 45.45%. The second most numerous group are installed boilers with an output of 0.1-0.5 MW, namely 31.82%. Currently, 2 boilers with outputs up to 100 kW have been shut down due to uneconomical operation and disconnection of customers, thus reducing the number of installed boilers to 20. Installed boiler output is 6062 kW (5766 kW in 2021). Number of district boiler rooms is 4, as well as number of domestic boiler rooms.

3.2 *Analysis of energy consumption in the building sector*

Objects that are the subject of an energy assessment within local government buildings are owned or managed by the city. In total, 29 buildings are owned and managed by the city. In the city of Nova Bana, in 2020 the total consumption of natural gas (ZP) and electricity (EE) was dominated by social facilities, which accounted for up to 38.66% share (1,432 MWh ZP; 139 MWh EE), the second highest energy consumption was shown by schools buildings, which made up a 36.39% share (1,270 MWh ZP; 126 MWh EE; 82 MWh biomass), buildings for culture showed consumption with a 12.84% share (408 MWh ZP; 83 MWh EE), administrative buildings had 12.12% (394 MWh ZP; 98 MWh EE) share of total consumption.

Buildings of the tertiary sphere are divided in the city according to the subject of activities and form of use. In the city, in 2020 energy consumption in the analysed tertiary sphere was dominated by shops and services, which accounted for up to 34.81% share (300 MWh ZP; 129 MWh EE), the second highest energy consumption was shown by accommodation facilities with 23.21% (200 MWh ZP; 86 MWh EE). This was followed by catering and restaurant services, which consumed 17.42% (150 MWh ZP; 65 MWh EE) of the total energy consumption of the tertiary sector of buildings. Health services accounted for 9% (82 MWh ZP; 29 MWh EE) of consumption. Financial services and intermediation accounted for 8.7% (75 MWh ZP; 32 MWh EE) of the share, the provision of transport services within the operation of the railway station took part in the energy consumption of 5.62% (52 MWh ZP; 17MWh EE) and Slovak Post offices 1.24% (11 MWh ZP; 4MWh EE).

For the housing and public sector, the city's heat supplier is the municipal housing company (MsBP Nova Bana) and a private company (MAGNA TEPLO, a.s.). In 2020, the company's heat sources supplied heat for heating and preparation of domestic hot water for 22 apartment buildings with a total number of 986 apartments, in which 2128 people lived in 2020. The supply of heat to the central heating system was 3,664.98 MWh and the domestic hot water was 22,417.13 m^3 with a heat content of 2208.873 MWh.

3.3 *Characteristics of building systems of residential buildings*

The analysed residential buildings in the city of Nova Bana were built between 1974 and 2019. The thermal and technical properties of the building structures of individual building systems reflect the technical level at the time of their design and implementation.

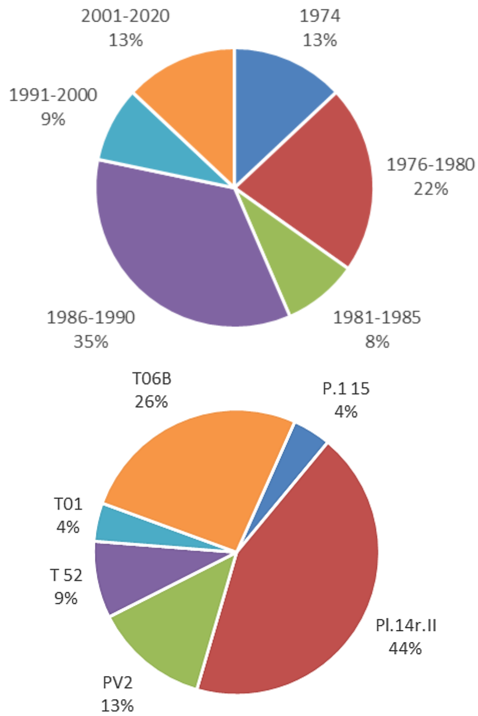


Figure 2. The structure of residential buildings in the city of Nova Bana according to the year they were put into use and according to the implemented building systems

Among the dominant building systems is Pl.14r.II with 44% representation (Fig. 2).

The difference in the energy intensity of building systems is up to 37%, while the lowest energy intensity is in building systems that were built after 1995. Normative indicators of heat consumption for heating determined by the Decree of the Office for the Regulation of Network Industries no. 328/2005 Col. The average normative indicator of heat consumption for heating residential buildings according to building systems is shown in Fig. 3.

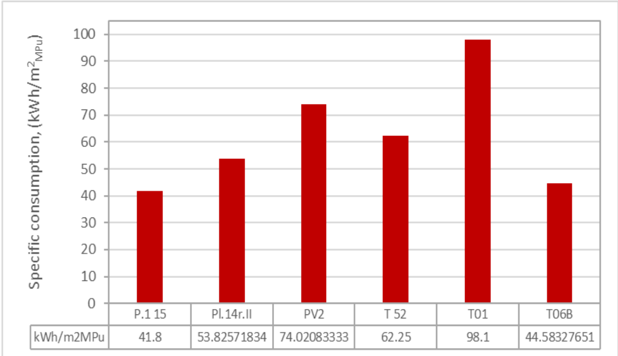


Figure 3. Average normative indicator of heat consumption for heating residential buildings according to building systems

4 ENERGY BALANCE AND CO_2 ELIMINATION MEASURES

An energy balance is processed for individual systems of thermal equipment and individual thermal circuits with determination of potential savings from production, heat distribution and consumption of heat and hot water in relation to the LCS methodology.

4.1 *CO_2 energy saving through insulation*

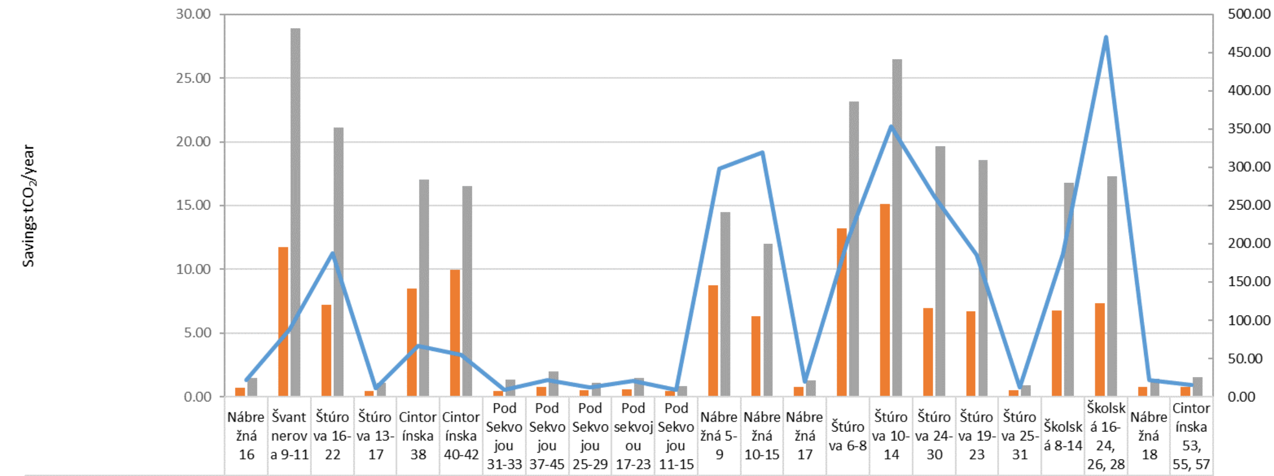
To comprehensively insulate an apartment building, it is necessary to reduce heat leakage by insulating the floors on the ground, or the ceiling above the basement, by insulating the roof, but also the entrance doors, windows on the stairs or basements. Along with insulation, it is necessary to deal with the removal of thermal bridges and system defects of building structures.

The insulation of an apartment building requires a change in the supply of heat, at the same time an adequate reduction in the amount of supplied heat must be ensured by changing the heating curve of the heat source and changing the hydraulic ratios in the heat distribution.

The analysis of the insulation of buildings, the status as of the evaluation year is as follows:

- number of evaluated apartment buildings: 50
- number of apartment buildings with cladding insulation 13 (26%)
- number of apartment buildings with roof structure insulation 16 (32%)
- number of buildings with insulation of the cladding and roof structure 12 (24%).

The proposed implementation measure represents a saving of 22.35% on the energy consumption of central heating of all apartment buildings. The total saving in emissions is approximately 171.2 tCO_2/year. In the case of the implementation of the measure as a whole until 2025, the subsequent saving of emissions in the five-year horizon represents 855.98 tCO_2, and in the horizon of 2050 the amount of saved CO_2 emissions is 5,135.87 tCO_2 (Fig. 4).



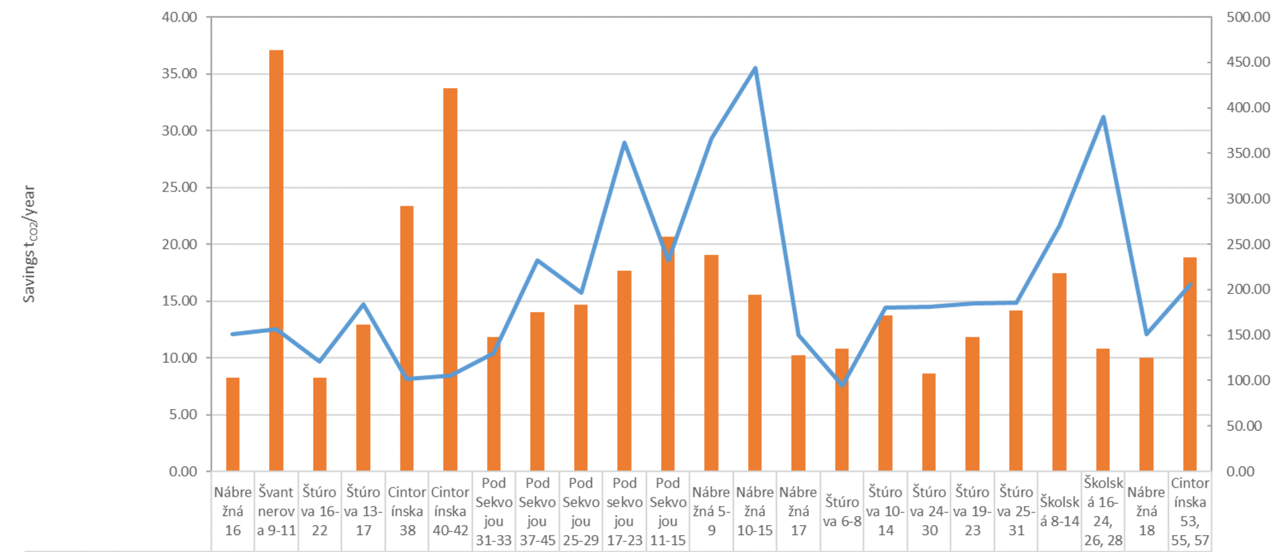
	Nábrežná 16	Švantnerova 9-11	Štúrova 16-22	Štúrova 13-17	Cintorínska 38	Cintorínska 40-42	Pod Sekvojou 31-33	Pod Sekvojou 37-45	Pod Sekvojou 25-29	Pod sekvojou 17-23	Pod Sekvojou 11-15	Nábrežná 5-9	Nábrežná 10-15	Nábrežná 17	Štúrova 6-8	Štúrova 10-14	Štúrova 24-30	Štúrova 19-23	Štúrova 25-31	Školská 8-14	Školská 16-24, 26, 28	Nábrežná 18	Cintorínska 53, 55, 57
kgCO2/year per person	11.31	196.11	119.70	7.27	141.83	165.47	7.74	12.49	8.40	9.65	7.52	145.32	104.92	12.63	220.55	252.18	116.40	111.44	8.74	112.87	122.18	13.17	13.22
kgCO2/ yearper residence	24.07	481.37	351.63	18.39	283.66	275.79	22.56	33.09	18.51	24.30	13.89	241.55	200.01	21.59	385.97	441.32	327.37	309.55	15.29	279.35	288.00	23.23	25.71
Savings tCO2	1.32	5.30	11.25	0.66	3.97	3.31	0.54	1.32	0.72	1.26	0.54	17.87	19.20	1.19	12.35	21.18	15.71	11.14	0.73	11.17	28.22	1.28	0.93

Figure 4. Assumption of the development of the tCO_2 savings rate for individual residential buildings

4.2 Possibilities of energy and CO_2 saving in the preparation of DHW

A significant amount of energy savings in the preparation of DHW is represented by solar systems. The proposal consists in determining CO_2 emission savings based on energy savings, assuming the gradual installation of solar systems over a five-year horizon. Determining the potential for heat savings from the preparation, distribution and consumption of DHW was determined for individual apartment buildings in which DHW supply is provided, taking into account the method of preparation and place of DHW consumption. The calculation includes the period of operation in summer mode. The energy produced in the winter mode of operation is not included in the balance sheets, and it can therefore be concluded that the rate of savings from the point of view of the whole year should reach higher values.

The PVGIS database was used to analyse the amount of incident energy, on the basis of which the various options for the inclination of the panels were evaluated. Considering the course of the amount of incident energy per m2/day for the given area, it is advisable to use a slope of 30°. These conditions are suitable for the summer type of system operation, where 62.5% of the radiation in the year falls on the chosen slope of the panels for the period from April to September. With the chosen year-round operation (angle of inclination of the panels 45°) it is 58.71%. Based on these results, summer operation with an optimized angle of 34° is chosen, where the most suitable distribution of energy intake for the given period is achieved. Optimization leads to the elimination of maximum energy gains in the months with the highest energy potential and an increase in energy production in marginal months.



	Nábrežná 16	Švantnerova 9-11	Štúrova 16-22	Štúrova 13-17	Cintorínska 38	Cintorínska 40-42	Pod Sekvojou 31-33	Pod Sekvojou 37-45	Pod Sekvojou 25-29	Pod sekvojou 17-23	Pod Sekvojou 11-15	Nábrežná 5-9	Nábrežná 10-15	Nábrežná 17	Štúrova 6-8	Štúrova 10-14	Štúrova 24-30	Štúrova 19-23	Štúrova 25-31	Školská 8-14	Školská 16-24, 26, 28	Nábrežná 18	Cintorínska 53, 55, 57
kgCO2/year per person	103.06	463.87	102.90	161.57	291.72	421.87	148.18	175.16	183.02	221.10	257.87	238.23	193.99	128.00	135.21	171.33	107.37	147.55	176.89	218.45	135.04	124.57	235.23
Savings tCO2	12.06	12.52	9.67	14.70	8.17	8.44	10.37	18.57	15.74	28.96	18.57	29.30	35.50	12.03	7.57	14.39	14.50	14.75	14.86	21.63	31.19	12.08	16.47

Figure 5. tCO_2/year saving rate for individual apartment buildings (columns) and $kgCO_2$/year saving rate calculated per person (line)

The preparation of DHW in family houses is subject to the same trend of decreasing water consumption as in apartment buildings, where the current average for the evaluated period is only 7.41 m^3 per person. The inclusion of minimum consumption values and hygiene indicators allows us to consider an average consumption of 17.5 m^3 per person per year. The considered temperature of the prepared water is 60°C, cold water temperature 10°C. The energy required to heat water for 1 person per day under defined conditions is 2.07 kWh.

Theoretically, the amount of energy saved for a period of 1 year per person is 269kWh (130 sunny days between April and September). Theoretically, the saving amount of CO_2 emissions for a period of 1 year per person is 54.06 kg CO_2/year. In the evaluation of the period until 2030, this value is 540 kg CO_2/person. By 2050, there will be a theoretical saving of 1621.8 kg of CO_2/person.

The number of households with 1 member is approximately 15%, households with 2 to 4 members make up approximately 60% of the total number of households, therefore it is possible to extend this methodology also for these numbers of household members. Subsequently, the average three-person household saves 162.18 kg of CO_2/year over a period of one year. In the evaluation of the period until 2030, this value is 1621.8 kg CO_2/household. By 2050, there will be a theoretical saving of 4865.4 kg of CO_2/household.

4.3 Reducing heat consumption in buildings - domestic boiler rooms, the education sector and other public administration entities and entities of public interest

Significant savings potential in heat production can be achieved by installing heat aggregates with a high degree of efficiency. A suitable type of equipment in terms of increasing efficiency is the use of gas heat pumps. The design of the solution consists in the installation of a power equivalent, i.e., of heat pumps with a considered efficiency of gas heating units of 152% to 164%. The rate of CO_2 savings is shown in Fig. 6.

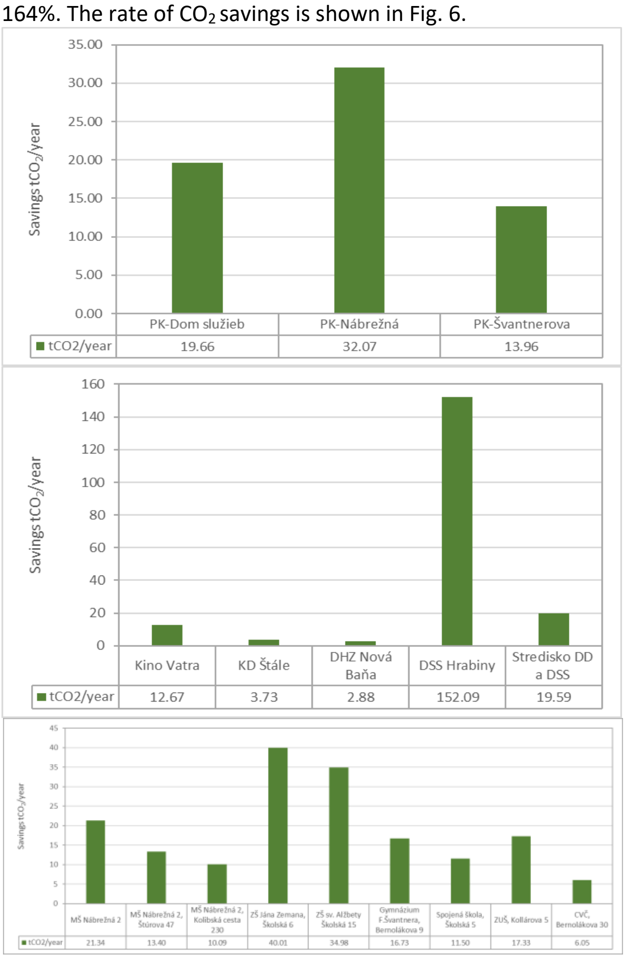


Figure 6. The rate of CO_2 savings by installing a more efficient power equivalent, i.e., heat pumps

4.4 Public lighting

The lighting system in the city is predominantly one-sided. The geometry of the lighting system is implemented on separate support points, or on the low-voltage network, and in that case it depends on the existing distribution of the network. The municipality underwent a comprehensive modernization of public lighting in 2015 - 2016. As part of the modernization, road lamps were replaced with new LED lamps, including the addition of lamps so that they met Slovak technical standards (STN) for road lighting.

The system therefore evaluated the comparison with 2010 and the rate of energy saving and CO_2 production. The total energy saving as well as the reduction of CO_2 emission production in the city after the reconstruction represents 81,546 MWh of electricity and 19.51 tons of CO_2, which is a 28% reduction in electricity consumption compared to 2010.

5 SUMMARIZING THE POTENTIAL OF ENERGY AND CO_2 EMISSIONS SAVINGS IN THE CITY NOVA BANA

The decrease in emissions as well as energy consumption is also represented by measures designed for individual living in family houses, namely in the area of reducing primary energy consumption by installing hot water heaters in the area of central heating and solar systems in the area of DHW preparation.

- The comprehensive implementation of the insulation measure represents a saving of 22.35% on the energy consumption of the central heating of all apartment buildings, which amounts to approximately 853.54MWh/year. The total saving in emissions is approximately 171.2 tCO_2/year.
- The comprehensive implementation of the measure of replacement of domestic boiler room sources represents a saving of approx. 327.63 MWh/year, while the CO_2 emission savings is 65.69 tCO_2/year.
- The comprehensive implementation of the measure installation of solar systems for the preparation of hot water in apartment buildings represents a saving of 1,904.8MWh/year, while the saving of CO_2 emissions amounts to 382.05 tCO_2/year.
- Implementing measures in the education sector by installing an equivalent, i.e., of heat pumps with the considered gas heating efficiency of 152% to 164%, will lead to an energy saving of 854.71 MWh/year, while the saving of CO_2 emissions amounts to 171.43 tCO_2/year.
- Implementing measures in the public administration sector by installing an equivalent, i.e., of heat pumps with the considered efficiency of gas boilers of 152% to 164%, will lead to an energy saving of 852.07MWh/year, while the saving of CO_2 emissions amounts to 190.96 tCO_2/year.

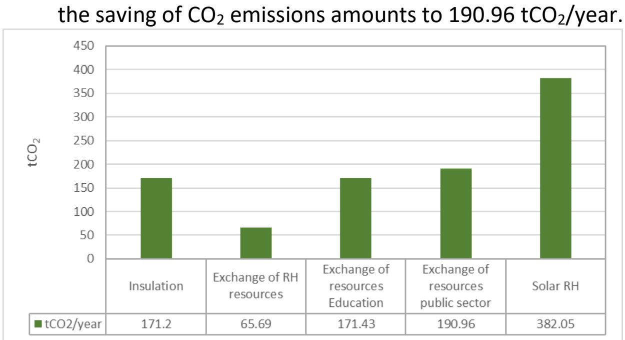


Figure 7. Assumption of tCO_2 saving rate

CONCLUSION

The analysis carried out of individual district boiler houses, domestic boiler houses, individual apartment buildings, family houses, objects of school facilities, medical facilities and other subjects of public administration and subjects of public interest, points to their percentage representation in savings through the implementation of measures. The results show a wide range of energy savings rates as well as total CO_2 savings. The result shows that an important role is played not only by the structure of resources, residential buildings, etc., but also by the behaviour of customers.

Although on the basis of the performed technical analysis and the energy balance of the existing systems, the total potential of savings in the production of pollutants was determined, the total real potential of savings is largely limited by the actual implementation of technical measures.

The summation of potential savings from heat consumption, heat production and DHW was converted into CO_2 emission savings. A significant measure in the housing sector is represented by the installation of solar systems and insulation. However, these measures are characterized by significant economic as well as technical complexity. The installation of heat pumps without changing the fuel base represents a suitable technology characterized by a significant degree of energy saving.

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