Building’s heat potential on resources in respect to CO₂ emissions and primary energy reduction (Case study)

Frantisek Vranay¹, Zuzana Vranayova¹, Anna Lis²

¹Institute of Architectural Engineering, Department of HVAC, Faculty of Civil Engineering, Technical University of Košice, Vysokoškolská 4, 042 00, Košice, Slovakia
²Czestochowa University of Technology, Faculty of Civil Engineering, Akademicka 3, 42-200 Częstochowa, Poland

zuzana.vranayova@tuke.sk

Abstract. An increased utilization of renewable energy sources for heating and electricity generation is one of the main tasks of the Slovak Republic. The main hypothesis is that heat pumps are very energy-efficient, and therefore environmentally benign, while providing heating and cooling in many applications. Within good conditions, the energy from low-positional heat, in other way unusable, is used to supply the energy for heat pumps. The paper confirms the applicability of such systems for long term (about 25 years). A building in Košice was used as the model of the transformation of a common office object into the character of a green and energy active one with the target programme being a sustainable building with zero balance of the energy from the network. From the comparison of the past and present operation data of the building, it is possible to show the big advantage of the usage of the heat pump water-water to the energy supply system. At favourable technical conditions in a heat supply system, it becomes the most advantageous solution in achieving today’s targets - minimum emission production combined with investment, low operating costs and achieving necessary human thermal comfort. The convenience of the system increases as it can switch between the cooling and heating process according to conditions. For the whole observed period, the energy consumption is reduced by 70%, the primary energy decrease by 69% compared to 1996 and CO₂ emissions were reduced by 98%. The simulations of the object were performed and verified based on the measured data.

1. Introduction
An increased utilization of renewable energy sources in the heat and electricity generation is one of priority tasks of the Slovak Republic. This can be realized by boosting the use of domestic energy potential and thus decreasing our dependency on imported fossil fuels. The European Commission would like to see less coal mines and more renewable energy resources harnessed in the whole Europe. The target is 27% of the final energy consumption from renewable sources by 2030. Slovakia is using wood biomass in heat production, but the ministry sees a large so-far unused potential in geothermal energy. [1-3]

The renewable energy is proved to be commercially viable for a growing list of consumers and purposes. The renewable energy technologies provide many benefits that go well beyond the energy alone. More and more, the renewable energies contribute to the three pillars of the sustainable
development in the economy, the environment, and the society. Several renewable energy technologies are established in world markets. Other renewables become competitive in growing markets, and some are widely recognized as the lowest cost option for stand-alone and off grid applications [4].

Heat pumps offer the most energy-efficient way to provide heating and cooling in many applications, as they can use renewable heat sources in their surroundings. It is argued that heat pumps are very energy-efficient, and therefore environmentally friendly. Within good conditions the energy from low-positional heat, in other way unusable, is used for the price of supplied energy for heat pump performance as is stated in many studies, e.g. [5-7].

Climate changes have brought summer thermal waves that can cause heat strokes. If the daily temperature rises above 30 °C, especially older or ill people are in danger. The number of collapses on a day like this can reach about 100 people in Slovakia. The scorching heats cause the risk of the organism collapse rise up to 33% if a person is exposed to the heat for 48 hours. The organism suffers the thermal stress. [4]

2. Material and methods
The measurements in the laboratories and corresponding energy models only rarely describe the reality in a building accurately. It is the result of the fact that buildings are characterized by a huge amount of mass and a system of variable parameters connected to the building. Without the correction of the models on the basis on measured parameters, the literature points to the fact that the laboratory measurements and the models often reach the accuracy of only about 50%. The behaviour of an operator and users is individual and can significantly influence implemented conditions and therefore the values of calculated parameters. A qualitatively different problem is that while the technology is used for the first time in a case study, it is possible to gradually eliminate the identified problems from implemented solution only by detailed measurements and analysis of gained data. Two or three-year verification in practical operation represents the standard time for the achievement of necessary knowledge and their projection into project documentation. [4]

The experimental building is an older office building in the centre of Košice. The idea to use the energy potential of low-temperature water originated in 2006. The heat pump as an energy source has been in operation since November 2007. The technology is projected for 40 years, although the energy potential contained even in low-temperature water is inexhaustible.

The agreement for the cooperation of the project realisation was signed by the Civil Engineering Faculty of the Technical University of Košice (TUKE) and Honours Company that financed the project. It is a known technology, as seen in articles e.g. [8-10], however our contribution is that the solutions proposed are not only feasible but good for the return of the investment as well as environmentally friendly. [4]

2.1. Study area - Locality
Košice city lies at an altitude of 206 meter above sea level and covers an area of 242.77 km². It is located in eastern Slovakia, about 20 kilometers from the Hungarian, 80 kilometers from the Ukrainian, and 90 kilometers from the Polish borders. It is about 400 kilometers east of Slovakia's capital Bratislava and a chain of villages connects it to Prešov which is about 36 kilometers to the north. Košice is on the Hornád River in the Košice Basin. [11]

This city has a humid continental climate, as it lies in the North Temperate Zone. The city has four distinct seasons. Precipitation varies little throughout the year with abundance precipitation that falls during summer and only few during winter. The coldest month is January, with an average
temperature of −2.6 °C and the hottest month is July, with an average temperature of 19.3 °C (Figure 1).

The months May, June, July, August and September have a nice average temperature. The average annual maximum temperature is: 13.0°C and the average annual minimum temperature is: 3.0°C. For this project it is necessary to know the data during the heating season (Table 1).

![Figure 1. Average minimum and maximum temperature over the year [11]](image)

Table 1. Košice climate table for heating period [11]

| Climatic conditions          | Košice          |
|-----------------------------|-----------------|
| Place                       | Košice          |
| Average external temperature in heating period: | +3.0 °C       |
| Regional design temperature: | -12 °C         |
| Altitude:                   | 220 m asl.      |
| The number of days in heating period: | 225 days       |

2.2. Experimental building
The observed object is built in the centre of Košice in 1980 and an extension was constructed in 1985 (Figure 2). The building is a non-residential building designed for administration and management. It has a concrete frame construction that allows to structurally adjust the interior according to the required needs.

Parameters of the building:
- Floor area: 4,500 m²
- Heated area: 4,000 m²
- Number of floors: 6 above-ground floors + 1 underground floor
- Number of heated floors: 6 above-ground floors + extension of 2 floors

2.3. Gradual transformation of building
The building needs to be gradually transformed to meet several criteria. The first is to achieve a state of an energy-efficient building, then a green building and the final target is zero/positive energy balance. This transformation started in 1996 as a long-term case study (more than 25 years).
The period from 1996 to 2007 involved the development of energy-saving technologies. In 2008, fossil energy was replaced by selected renewable technologies. To achieve economic performance and the return of the investment period of 4 to 12 years, a very precise timing is needed for the introduction of the selected technologies in practice.

Following measures were implemented on the observed building:
- The reconstruction of the discharge station of the central heating system in 1996
- The exchange of the heating system for hot water for the building from a central type to a local type in 1996
- The replacement of windows in the period of 2000-2005
- The insulation of the building from 2000 to 2005
- The installation of internal window aluminium blinds from 2000 to 2005
- The hydraulic regulation of the heating in the building in 2005
- The installation of a local energy source - a heat pump in 2008
- The realisation of radiant ceiling heating and cooling system from 2012
- The improvement of the quality of internal environment and expansion of the services by cooling.

The main incentives for the transformation of a building were [4, 8-10]:
- the reduction of operational costs of buildings by the means of energy-efficiency
- the reduction of the CO₂ emissions production related to the energy supply consumed
- the reduction of future costs connected to the fees for CO₂ emissions released into the atmosphere reflected in the energy prices
- the elimination of increased risk related to the price rise of energy from the fossil fuels because of their decreasing amount
- the change of the conventional heating to the radiant system - the solution with a higher quality of internal climate, which reduces morbidity, headaches, allergies, etc.
- the installation of a new service, cooling, and providing the required temperature of internal climate with the positive impact on the worker’s performance.

Our final solution is based on the system of micro-capillaries placed in a ceiling and water from a well as heat pump devices. The scheme of the connection of a heat pump water-water in the system of the transformation for the supply of the office building is described in the Figure 3. The technical parameters of the selected heat pump can be seen in the Table 2.

![Diagram](image1)

**Figure 3.** The adjustment of the machine room of the energy source for the application of the radiant system of A) the heating operation, B) the cooling operation [11]
Table 2. Technical parameters of applied heat pump [4, 11]

| Parameter                                      | Specification                                                                 |
|-----------------------------------------------|-------------------------------------------------------------------------------|
| Power W10 / W35                               | 135.5 kW                                                                      |
| Power consumption W10 / 35                    | 28.1 kW                                                                       |
| Heat pump control                             | START - STOP                                                                  |
| Digging well diameter                         | 1.5 m, depth 8 m water column approx. 4 m                                     |
| Yield of the well usable                      | 10 l/s maximum 12 l/s (above 10 l/s sand leaching)                           |
| Infiltration tanks 2 pieces                   | capacity 2 x 5 l/s = 10 l/s                                                   |
| Storage tank                                  | 2,000 liters                                                                  |
| Well pump                                     | 4.0 kW without frequency converter                                           |
| Other pumps                                   | with frequency converter                                                     |

3. Results and discussions

Several analyses have shown that the largest energy consumer buildings, reaching as much as 41% of all energy used, could be transformed. Article 9 of the EPBD requires that Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy. To achieve this, cost-effective economy-driven innovation principles are used to save as much fossil energy as possible. As a second step remaining energy will be obtained from alternative renewable sources. [12 - 16]

The course of the heat consumption in our case study from 2002 to 2006 shows the necessity to perform the hydraulic regulation that would eliminate the human factor on the side of heat supplier (Figure 4).

With the introduction of the capillary heating/cooling system, the building reached a virtual zero energy status (Figure 4). The gradual adjustments of the building along with the energy management shows the energy savings of 71%.
In such a case the primary energy in the form of electricity that is necessary for the drive of the heat pump is not included in the energy balance because the supplied energy for the heat pump drive does not pass the envelope structure in the form of heat, although the economic part of system boundary of the building passes. Consumed energy for the heat pump drive does not contribute to the heating of the building. The heat is calculated using the legislative in effect as standardized consumption by the means of day degrees. (Table 3, Figure 5) [11, 17-21]

**Table 3.** The course of heat consumption, and recalculated primary energies and CO2 production

|                      | DH     | RES     | EE       |
|----------------------|--------|---------|----------|
| Heat consumption Wh/yr | 478    | 332     | 282      |
| RES                  | 427    | 292     | 272      |
| DH                   | 33     | 218     | 218      |
| EE                   | 34     | 222     | 222      |
| DH                   | 46     | 265     | 264      |
| EE                   | 42     | 244     | 244      |
| Primary energy Wh/yr  | 1056   | 716     | 695      |
| EE                   | 111    | 76      | 65       |
| Production CO2 ton/yr | 670    | 485     | 381      |

![Figure 5. The course of primary energy for heating during the transformation of the building from 1996 to 2019](image)

At present, the system produces only 2% of the original emissions for the heat production calculated for 1996 as seen in Figure 6. In the case of a heat pump, emissions are calculated only from the electricity consumption to drive the heat pump and other auxiliary electrical equipment. Renewable heat source (energy from the well) is not included in production. [4, 11, 17]
Figure 6. The courses of the CO₂ emissions production during the transformation of the building from 1996 to 2019

In addition to the economic effects, the quality of the internal climate is improved, which causes lower morbidity, higher labour productivity and reduction of the risk related to the heat strokes as the consequence of climate changes that can be seen from the Figure 7 with the temperature gradient in the hot summer day. [4, 22-28]

Figure 7. The vertical temperature course in the offices cooled by radiant ceiling system at external temperature 34°C

4. Conclusions
The case study indicates an applicability of selected system for the chosen administrative building in Košice. From the comparison of the past and present operation data of the building, it is possible to confirm the advantage of the application of the heat pump water-water to the energy supply system. Under favourable technical conditions in a heat supply system and suitable application, it becomes the
most advantageous solution in achieving the minimal emission production, combined with investment, low operating costs, and achieving human thermal comfort. The convenience of the system increases as it can switch between the cooling and heating process according to conditions.

For the whole observed period, the energy consumption is reduced by 70% compared to 1996. We must consider that after the installation of the heat pump, the heat consumption consists of energy to drive the compressor, support equipment and a renewable heat source (well). The biggest benefit is in the additional insulation + thermostatization of the building, which was 32%. The primary energy decreased by 69% and the CO2 emissions were reduced by 98% compared to 1996. The simulations of the object were performed and verified based on the measured data and could be used for future work.

Acknowledgment(s)

This work is supported by the project of Slovak Research and Development Agency APVV-18-0360

Active hybrid infrastructure towards to sponge city.

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