# THE INFLUENCE OF SEVERAL PARAMETERS ON THE PERFORMANCE OF EARTH TO AIR HEAT EXCHANGERS IN SOUTH-EASTERN EUROPEAN CLIMATES

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*Passive building concept was introduced in the early 1990s in Germany by W. Feist. A technical solution proposed to increase the energy performance of passive buildings is earth-to-air heat exchanger(EAHE). This paper analyzes for the first time the appropriateness of this solution in the climate of South-Eastern Europe. It studies the influence of several design parameters of a registry type system on its performance. The following parameters are taken into account: the length and diameter of the pipe, the depth where the exchanger is placed. The basic design solution used in this study is that existing at AMVIC building near Bucharest. The results prove that EAHEs are indeed effective for South-Eastern Europe.*

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**Keywords:** earth-to-air heat exchanger, South-Eastern Europe, design parameters, simulation

## 1. Introduction

Different configurations of earth-to-air heat exchangers (EAHEs) have been used in Central and Western Europe as heat suppliers during the cold season. EAHEs are seldom used in connection with passive buildings, a concept proposed and developed by W. Feist in Germany in 1990+. EAHEs performance, energy saving and efficiency can be predicted by simulation. In literature were also conducted simulations for EAHE such as for passive SD Worx office in Kortrijk, Belgium[1], for Pirmasens house in Germany[2], for Geoser system in Switzerland[3], for an italian building related at the climate of three Italian cities[4].

In this context, the following simulation aims to fill a gap, presenting for the first time results for South-Eastern Europe. This paper aims to develop a simulation of the EAHE system (the one from the AMVIC building, located in Bragadiru, a small town located 10 km south of Bucharest) for several cities from Romania, Bulgary, Hungary, Macedonia, Serbia. In this simulation are varied, one at a time, several parameters, such as pipe length, pipe diameter and pipe depth.

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The results, their variation, the obtained performance differences depending on the climate are the issues that we focus on. The turbulence effects are not included and are not touched in this study.

## 2. System description

The EAHE system (AMVIC passive building) is composed (Table 1) of eight polypropylene tubes placed horizontally and connected to a distributor and a collector (Figure 1). A detailed description of the system can be found in [5].

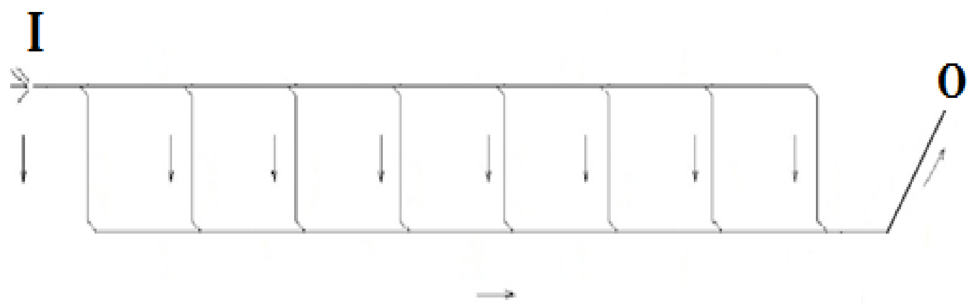


Fig. 1: Airflow from the air intake through the earth-to-air heat exchanger; I – fresh air intake, O – output from earth-to-air heat exchanger

Ground heat exchanger's tubes have an antimicrobial inner layer to ensure a fresh and hygienic air. Burial depth is 3.5 m, instead of the standard 1.5 m used by REHAU [5]. At a depth of 3.5 m, soil temperature can be considered stable in time, with negligible fluctuations. Also, at this depth, the considered constant temperature is higher (or/lower - depending on season) than the temperature at 1.5 m depth. This enables a more efficient exchange of energy between soil and air in all seasons. To achieve the user's need for yearly heating and cooling, EAHE system must be accompanied by an additional heating and cooling system.

*Table 1*

**Components of ground heat exchanger (see Fig. 1)**

| Component | Inner diameter (mm) |
|---|---|
| Fresh Air intake | 400 |
| Air distributor | 400 |
| Air collector | 400 |
| 8 parallel tubes | 200 |

Fresh Air intake AI (Fig. 1) that absorbs air has an internal diameter of 0.4 m. The 8 parallel pipes are system AWADUKT Thermo DN 200 from Rehau - Germany. Their sizes are as follows: length of 5 m and 0.2 m inner diameter and outer diameter of 0.214 m (7.3 mm pipes wall thickness). The pipes are made of polypropylene PP SN10/SN16 RAUSITO (density ρ =920kg/m$^3$, specific heat c=1800 J/(kgK) and thermal conductivity λ =0.12 W/(mK)). The pipes are connected to a distributor and a collector. Both distributor and collector are system AWADUKT Thermo DN 400 type with the following sizes: 31m long, 0.4 m inner diameter and 0.429 m outer diameter (14.5 mm wall thickness). There is turbulence at inlet and outlet of the connecting pipes because of the cross section area difference between the distributor/collector and the 8 parallel pipes, as seen in Table 1. Heat transfer area is 103 m$^2$. [5]

### 3. Input and output parameters for simulation

GAEA is an easy-to-use software that supports the design of an EAHE in the early stage of planning a building. It is based on analytic calculations of heat exchange between soil, systems of parallel buried pipes and the air flow through the pipes. GAEA is based on the general models for heat and mass transfer [6, 7, 8, 9]. The model is described in detail in [10]. The calculation tool has been tested and validated in [11].

The software takes into account several parameters when performing a simulation. The tables 2, 3, 4 and 5 list the input data required to perform a simulation. Table 6 has been given just to have a better view about the economic parameters in Romania. The software offers results either for a certain time of day or annual results.

For each region was made a chart external temperature, with hourly values from a meteorological database - Meteonorm version 3.0 [12]. This database contains the typical climate of the region properties such as the average air temperature of the month or the maximum and minimum air temperatures.

*Table 2*

**EAHE location [5,13]**

| Name | units | Value |
|---|---|---|
| The distance between the building and the center of EAHE | m | 21.5 |
| Placing fan: EAHE input / output | | Output |
| Depth of groundwater | m | 8 |

*Table 3*

**Design parameters [13]**

| Name | units | Value |
|---|---|---|
| Number of parallel pipelines | buc | 8 |
| Length of parallel pipelines | m | 5 |
| Diameter of pipe | mm | 200 |
| Distance between parallel lines | m | 4.34 |
| Depth at which they are placed | m | 3.50 |

*Table 4*

**Operational parameters [5, 12, 14, 15, 16]**

| Name | units | Value |
|---|---|---|
| The weather data | Area | Bucharest |
| Building’s volume | $m^3$ | 9859 |
| Airflow | $m^3/h$ | 3060 |
| Air exchange rate | | 0.31 |
| Reference temperature (temperature desired inside) | ºC | 22 |
| The temperature at which the heating starts | ºC | 20 |
| The temperature at which cooling starts | ºC | 25 |
| Fall constant pressure | Pa | *50* |
| Fan’s efficiency | % | *85* |

*Table 5*

**Soil properties [17]**

| Name | units | Value |
|---|---|---|
| Soil density | kg/m3 | 1800 |
| Specific heat | J/ kgK | 2200 |
| Thermal conductivity | W/mK | 1.2 |
| Soil density | kg/ $m^3$ | 1800 |

*Table 6*

**Economic parameters [5, 13]**

| Name | units | Value |
|---|---|---|
| Cost for Pipeline | €/m | 7 |
| Cost for digging | €/m | 6.46 |
| fixed investment | € | 19900 |
| Cost for maintenance | % | 2 |
| Cost for maintenance | €/an | 100 |
| Date | ani | 30 |
| Heating Cost | €cent/kwh | 2.8 |
| Cost for cooling | €cent/kwh | 11 |
| Cost for electricity | €cent/kwh | 11.63 |
| Interest rate | % | 6.25 |
| Inflation | % | 5.8 |
| Inflation rate (energy) | % | 22.4 |

In the context of the simulation focuses primarily on South-Eastern Europe, it must be said that if we refer to the Balkan Peninsula so far results have been reported in Greece [18], and less in the rest of the region. Therefore, for the study were chosen following cities which can be seen in Figure 2: Bucharest (Romania), Sofia (Bulgaria), Skopje (Macedonia), Belgrade (Serbia), Budapest (Hungary).


Fig. 2: The five cities in South-Eastern Europe used in this study

Table 6 contains the geographical coordinates of cities considered in this chapter simulation. Data were collected from the website http://www.heavens-above.com. As can be seen from the table 7 the easternmost city is Bucharest and the highest (highest elevation) is Sofia.

*Table 7*

**Geographical coordinates for cities in South-Eastern Europe**

| City | longitude°E | latitude°N | altitude (m) |
|---|---|---|---|
| Bucharest | 26.100 | 44.433 | 76 |
| Sofia | 23.317 | 42.683 | 569 |
| Skopje | 21.434 | 42.001 | 259 |
| Belgrade | 20.500 | 44.833 | 59 |
| Budapest | 19.083 | 47.500 | 103 |

## 4. Results

### 4.1. The influence of pipe length

We performed a simulation in which the geometry of EAHE from AMVIC building was preserved. The pipe length was varied in three cases: 5m, 10m and 17m.

In [17] there is a study on the design of the EAHE from passive office building AMVIC. There were studied two types of air circulation (i.e. flow configurations in Z and Pi) and 4 geometric configurations that differed in the number of pipeline and pipe length. Configuration chosen according to economic considerations and calculations and was one of 8 parallel pipelines and a colector/distributor of 31m long and 5m length parallel pipelines. It should be noted that the size of the garden - available for EAHE was 31 x 17 m$^2$ [17], therefore in this study we chose the maximum pipe length 17 m.

The study was made for cities in eastern Europe: Bucharest, Belgrade, Skopije and Sofia. The software GAEA offers results hourly, so for one day there are 24 results (output temperature). It was made a daily average and monthly average temperatures for the outlet of EAHE.

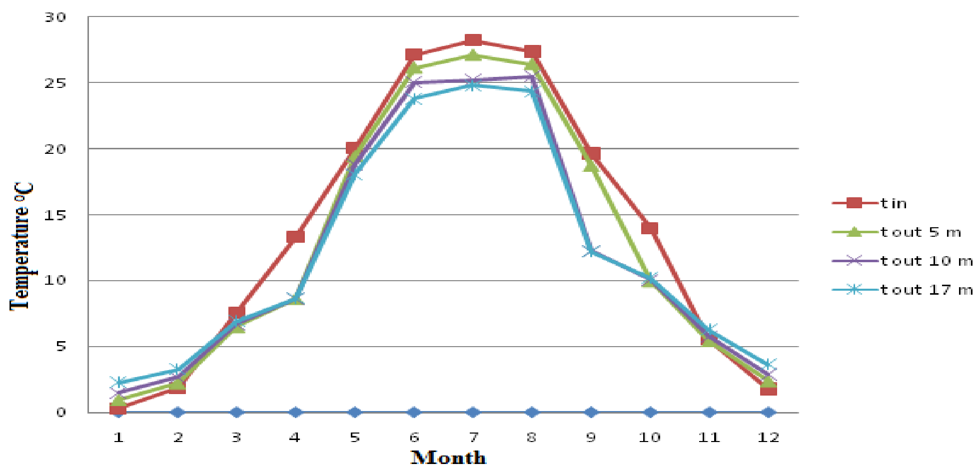


Fig. 3: Air temperature at the exit from EAHE at Bucharest; annual values for different values of pipeline length: 5; 10; 17m

In Bucharest, the highest temperatures were recorded in July, with an average inlet temperature of 28.2 °C and, when output air temperature t out for 5m pipe was 27.13 ºC and if the pipe was 17m long then t out was 24.8 ºC. It is easy to see that the air is always cooled in the summer by the system and DT maximum(i.e., the maximum difference of temperature between T in and T out) was 3.4 °C. As it can be seen in Figure 3, the lowest temperatures were recorded in January, with an monthly average for inlet temperature of 0.29. In the case for pipe length of 5m, t output was 0.95 ° C, while for the largest length was 2.26 °C, maximum DT was 1.97 °C. The system is preheating the air in the winter.

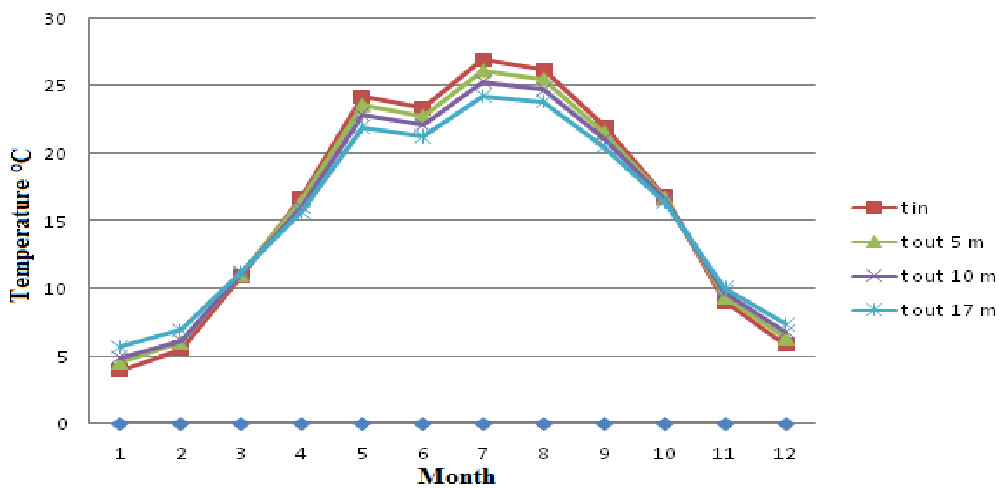


Fig. 4: Air temperature at the exit from EAHE at Belgrad; annual values for different values of pipeline length: 5; 10; 17m

Figure 4 shows that in Belgrade, the highest temperatures were recorded in July, with an average inlet temperature of 26.96 °C and, when t out for 5m pipe was 26.15 ºC and if the pipe was 17m long then t out was 24.29 ºC. So maximum cooling value was 1.86 °C. The lowest temperatures were recorded in January, with an monthly average for inlet temperature of 3.98. The system is preheating the air and in case for pipe length of 5m, t output was 4.57 °C, while for the largest length was 5.73 °C, maximum DT was 1.16 °C.

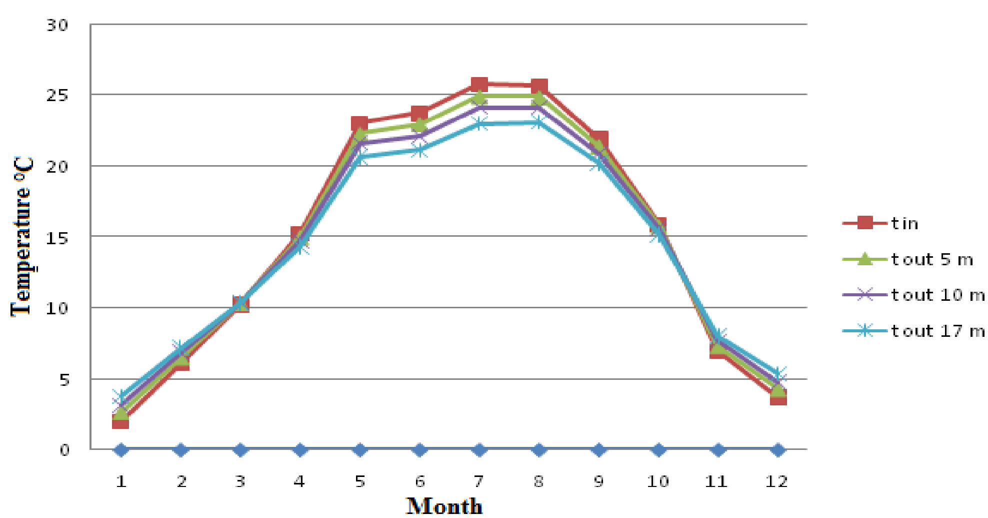


Fig. 5.: Air temperature at the exit from EAHE at Skopje; annual values for different values of pipeline length: 5; 10; 17m

At Skopije (Fig. 5), the highest temperatures were recorded in July, with an average inlet temperature of 25.79 °C and, when t out for 5m pipe was 24.96 ºC and if the pipe was 17m long then t out was 23.01 ºC. So DT maximum was 1.95 °C. As the figure 5 shows, the lowest temperatures were recorded in January, with an monthly average for inlet temperature of 2.03. In case for pipe length of 5m, t output was 2.64 °C, while for the largest length was 3.85 °C, maximum DT was 1.21 °C. Again both functions (cooling and heating the air) are met.

At Sofia, it is clear from Figure 6 the fact that the highest temperatures were recorded in August, with an average inlet temperature of 22.54 °C and, when t out for 5m pipe was 21.84 ºC and if the pipe was 17m long then t out was 20.19 ºC. So DT maximum for precooling the air was 1.65 °C. The lowest temperatures were recorded in January, with an monthly average for inlet temperature of -0.09 °C . In case for pipe length of 5m, t output was 0.38 °C, while for the largest length was 1.77 °C, maximum DT for heating was 1.39 °C.

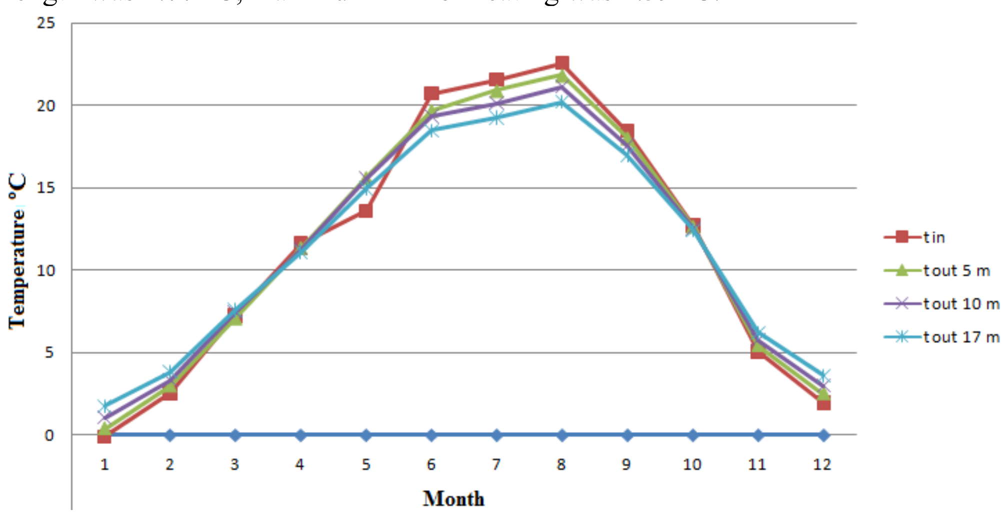


Fig. 6: Air temperature at the exit from EAHE at Sofia; annual values for different values of pipeline length: 5; 10; 17m

According to the results and graphs we may conclude: in that year the hottest summer was in Bucharest and the coldest winter was in Sofia. The EAHE systems haves similar performance in all four cities from South-East of Europe.

For the longest pipeline (17 m) was recorded the best performance throughout the year - the highest temperatures in winter and the lowest temperatures along the summer. Also for 10m pipe length were recorded better performance for both cooling and heating than 5m long pipe. These results are in good agreement with those presented in [19] which says that higher efficiency can be achieved with the price of increasing the length of the tube.

## 4.2. The influence of pipe depth

Another parameter that can influence the performance EAHE is the depth at which the pipe is burried in the ground. According to [20] the minimum depth at wich an EAHE can be installed is 1.5 m. Regarding the AMVIC building the depth is 3.5 m. Also, according to [21], to studied that tubes should be buried at a minimal depth of 1.5m, but rarely justify their burial at a depth greater than 3.5 m. These values were chosen for simulation and besides them was considered a third value, an intermediate one, of 2.5 m.

*Table 8*

**Heat gain and heat loss values for East European cities; annual values for pipe depth variation**

| City | Depth (m) | T in EAHE (max) °C | T out EAHE (max) °C | T in EAHE (min) °C | T out EAHE (min) °C | heat gain (kWh) | heat loss (kWh) |
|---|---|---|---|---|---|---|---|
| Bucharest | 1.5 | 35.9 | 34.4 | -16.3 | -14.8 | 2393.9 | 710.7 |
| Sofia | | 34.2 | 32.9 | -14.3 | -13.1 | 2223.7 | 420.9 |
| Skopje | | 34.7 | 33.4 | -14.3 | -12.9 | 2246.7 | 865.1 |
| Belgrade | | 37.8 | 36.3 | -16.2 | -14.6 | 2347.4 | 939.9 |
| Budapest | | 34.3 | 33 | -16.2 | -14.7 | 2210.3 | 526.8 |
| Bucharest | 2.5 | 35.9 | 34.4 | -16.3 | -14.8 | **2544.4** | 751.3 |
| Sofia | | 34.2 | 32.8 | -14.3 | -13 | 2350 | 446.9 |
| Skopje | | 34.7 | 33.3 | -14.3 | -12.9 | 2359.9 | 923.2 |
| Belgrade | | 37.8 | 36.3 | -16.2 | -14.6 | 2460.3 | 987 |
| Budapest | | 34.3 | 32.9 | -16.2 | -14.7 | 2337.4 | 557.9 |
| Bucharest | 3.5 | 35.9 | 34.4 | -16.3 | -14.8 | 2530.3 | 739.7 |
| Sofia | | 34.2 | 32.8 | -14.3 | -13 | 2313 | 442.6 |
| Skopje | | 34.7 | 33.3 | -14.3 | -12.9 | 2323.6 | 913.9 |
| Belgrade | | 37.8 | 36.3 | -16.2 | -14.6 | 2431.6 | **973.5** |
| Budapest | | 34.3 | 32.9 | -16.2 | -14.7 | 2322.3 | 551.4 |

According to the conducted simulation, in most cases, the depth at which we obtained the best performance for heat input was 2.5 m. Table 8 shows that the highest values for heating gain were recorded for Bucharest, 2544.4 kWh, where the lowest inlet temperatures throughout the winter were reported.

According to Table 8, regarding the heat loss, in most cases, the depth at which the best performance obtained for the cooling intake was 2.5 m. The highest values for cooling energy intake were recorded for Belgrade, 987 kWh, which hass also the highest summer temperature input (maximum temperature recorded in that year was 37.8 °C).

From Table 8 and figures 3, 4 and 6 one sees that the EAHE system has a low economical performance. Indeed, consider the case of Romania. The yearly heating supply by the EAHE system is 2544 kWh. The highest specific cost of the electrical energy is about 0.125 Euro/kWh, VAT included. Therefore, the payback period is about 60 years. In some countries, building passive houses receives financial support from various government and European funding programs. If this applied for Romania, a shorter payback period will result.

In conclusion, it is generally better performance at greater burial depths (2.5m and 3.5m instead of 1.5m), as is also specified in [22]. In that paper, increasing the depth from 1m to 2m resulted in an increase by 24.31% of heat gain and 47.57% of heat loss. As it can be seen from table 8, always the output temperature is lower then the input temperature in the summer and higher in the winter.

### 4.3. The influence of pipe diameter

Another parameter that can influence the performance of the EAHE is the pipe diameter. In the case of the EAHE system from AMVIC building the diameter of the 8 parallel pipelines is 200 mm [17]. De Paepe and Janssens in [19] notes that generally decreasing the tube diameter increases effectiveness. It is better to have multiple smaller diameter tubes. In [23] it is specified that the heat transfer is negatively influenced by large diameter pipe (350 mm). In the same paper it is mentioned that the diameter is an important factor for thermal efficiency.

*Table 9*

**Heat gain and heat loss values for South-East European cities; annual values for different values of pipe diameter**

| City | Diameter (mm) | heat gain (kWh) | heat loss (kWh) |
|---|---|---|---|
| Bucharest | 100 | **3459.5** | 557.8 |
| Sofia | | 3235.5 | 338.3 |
| Skopje | | 3290 | 684 |
| Belgrade | | 3438.7 | 707.7 |
| Budapest | | 3295.4 | 419.7 |
| Bucharest | 200 | 2530.3 | 739.7 |
| Sofia | | 2313 | 442.6 |
| Skopje | | 2323.6 | 913.9 |
| Belgrade | | 2431.6 | **973.5** |
| Budapest | | 2322.3 | 551.4 |

| | | | |
|---|---|---|---|
| Bucharest | 300 | 2447.4 | 727.6 |
| Sofia | | 2235.5 | 435.2 |
| Skopje | | 2243.8 | 899.1 |
| Belgrade | | 2346.7 | 958.3 |
| Budapest | | 2242.5 | 542.3 |

Table 9 shows that the largest heating contribution for one of the cities in South-Eastern Europe was in Bucharest and was 3459.5 kWh/year. This may be due to the fact that in Bucharest were very low temperatures in winter. For all 5 cities the diameter of 100mm is most beneficial for heat gain, as it ca be seen from table 9. In [24] it was observed something similar. In that paper, the heat capacity of the system was reduced when the pipe diameter was increased from 100 to 150mm. This is due to a reduction in convective heat transfer coefficient and increased pipe surface, thus resulting in lower air temperature at the exit.

According to the values in the table 9 the greatest value for heat loss of one of the cities in Eastern Europe was recorded in Belgrade and it was 973.5 kWh/year. This may be due to the fact that in Belgrade were the highest temperatures during summer. For all the 5 cities the diameter of 200mm is most beneficialfor cooling case.. Whether cooling or heating values are different, the EAHE is useful and fulfills both functions – cooling and heating the air.

## 5. Conclusion

For the first time, cities like Sofia, Skopije or Belgrade were considered in performing a simulation of an EAHE system. The hottest summer was in Bucharest and the coldest winter was in Sofia. The EAHE system has a similar performance in all 5 cities from East of Europe. Design parameters like pipe length, pipe depth and pipe diameter influences the performance of the system. The system can provide heating in winter and cooling in summer. In specific situations, the EAHE of passive buildings should be complemented with additional sources of heating or cooling.

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