# GEOTHERMAL DISTRICT HEATING MODELLING FOR TYPICAL HUNGARIAN RESIDENTIAL BUILDINGS IN DEBRECEN

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## ABSTRACT

The most important aim of this paper is to examine the technical possibilities to replace natural gas fired district heating system in Debrecen, E-Hungary, with geothermal energy. In order to present these challenges in a comparable way, the existing common residential buildings were grouped into seven subcategories and linked together theoretically, representing a system with diverse conditions. It has been established that hot geothermal water is able to replace a natural gas boiler in the range of 97-98% of the energy consumption, saving 91,000-111,000 $m^3$ of natural gas yearly. The calculation identified, that the radiator system and the heat loss parameters of the residential buildings are the most crucial elements of the system. According to the presented scenario-B, which assumes only radiator replacement in more than half of the heat market, representing 325,000 net $m^2$, a decrease in total energy consumption is experienced in the range of 8-10%. On the other hand, scenario-C, which is assuming complex reconstructions for out-dated buildings, results in a significant 17-19% energy consumption savings, compared to Scenario-A (original case). In this regard, it is worth considering improvement to out-dated buildings within the heat market before starting geothermal energy development, to get an efficient, well-constructed system.

## 1. INTRODUCTION

The main aim of this paper is to investigate the replacement of the existing natural gas fired district heating system for geothermal energy in Debrecen city. This paper works out a mathematical model to design a purposeful project, linking together residential buildings from seven defined subcategories which describe well the building structure in Debrecen and also Hungary. To demonstrate the differences between these residential buildings in a comparable way, each major building category (1-family houses, 2-prefabricated concrete panel block buildings and 3-new apartment buildings) was balanced to consume roughly the same quantity of heat in design condition. It was essential to analyse the current heat market and explore what are the technical barriers and bottlenecks of a similar geothermal district heating project in Hungary. The theoretical model shows the importance of energy efficiency and also heating system refurbishment, before deciding on any geothermal district heating development. The final results of the report, aiming at replacing the natural gas boiler, were drawn up as three different proposals (scenario-A: "Status quo"; scenario-B: "radiator replacement"; scenario-C:

"complex refurbishment") to optimize the energy consumption of this theoretical system. During the design progress, it should be considered that the temperature level of the geothermal water is limited in Hungary, in order to get a realistic, reliable result about the possibilities.

## 2. THE ENERGY SECTOR IN HUNGARY

### 2.1 Energy overview for Hungary

Hungary is a relatively poor country in conventional energy sources, therefore most of the time in the past, energy import had a significant role. Regarding the production side, in 2013 the most dominant energy source was nuclear, with a 50.83% gross electricity production share, solid fuels had 20.79% share (mostly coal), and natural gas had 18.48% share (European Commission, 2015). Heating production is less diverse than electricity production, because natural gas plays the main role in several forms of cogeneration and also direct heat supply by gas boilers, furthermore individual gas boilers are also very prevalent. Statistical data suggests that natural gas has the biggest influence within the Hungarian energy sector, adding that it is mainly imported. In 2011, the heat consumption of the building sector had a 38.6% share of the Hungarian primary energy consumption, representing 403 PJ (ÉMI Non-Profit Llc., 2015).

Hungary has a long tradition of low-temperature geothermal utilisation. In 2014, there were 672 active thermal wells, producing almost 80 million $m^3$ hot water per year. Almost the half of the utilization was used for balneology purposes (Tóth, 2015). Also in 2014, the country had the fifth largest annual geothermal use in the world with 9573 TJ (excluding heat pumps) (Lund and Boyd, 2015). The main fields of direct utilization are the greenhouse sector, more specifically plastic-tent heating. The biggest agricultural producers are in Szentes, Szeged, Csongrád and Szegvár. The estimated geothermal use of agriculture was around 2800 TJ in 2011. Space heating is also an important part of the utilization; in 2013 more than 2000 TJ was consumed for this purpose. There are 23 geothermal district heating systems in Hungary, located mainly close to the Great Hungarian Plain (Nádor et al., 2013). The country has still no geothermal power generation, however the implementation of the first 2.7 MW unit just started in the town of Tura in June of 2016. This project was a unexpected result of an exploration, finding unusual geothermal conditions in that area.

### 2.2 Geological details

Hungary is situated in the Carpathian Basin bordered with Alpine, Carpathian and Dinaric mountains with mostly sedimentary formations, which are derived from the Miocene through Quaternary in age (Horváth et al., 2013). Regarding the characteristic geologic formation, Hungary does not have any active volcanic areas, most of the reservoirs been considered relatively low-temperature fields (excepting some unusual geologic anomalies). For instance, in the southeast part of the country, the Békés basin has a 90–100°C temperature reservoir conditions (Hotváth et al., 2013) in average at 2000 m depth, which is one of the most promising geothermal areas in Hungary. It is also notable that the maximum depth of thermal water yield allowed by the sedimentary formations is around 3000 m (Kozák and Mikó, 2004). For geothermal district heating, it is crucial to find not only high enough temperature, but as well sufficient yield. For summary, the possibilities of finding geothermal water above 90°C below 2000-2500 m with sufficient mass flow is better than average condition. Tura example suggests that very often the role of luck is very important, even more than strongly established geological exploration.

## 2.3 Basic details of Hungarian district heating sector

The history of the Hungarian district heating application started in the early 1950s and 1960s. Initially this began with industrial consumers, however, since that time residential space heating has played the main role, as shown in Figure 1. Considering the energy policy aspects and the most easily exploitable resources with the available technologies for each time, all of the district heating system were designed for natural gas and coal. These district heating systems are a kind of heritage for Hungary, as well as for other ex-communist countries of the Eastern Bloc. District heating systems had a spectacular improvement until 1989 (GKI - Energy Research and Consulting Ltd., 2005) but at that time the political system changed significantly; Hungary escaped from the Eastern Bloc, which has had a



FIGURE 1: Estimated reservoir temperature data in East-Hungary (Kozák and Mikó, 2004)

serious impact on the energy policy framework. The expanding role of district heating systems was closely related with the residential block house building strategy implementation, which was discontinued at that time, which also hindered the district heating improvement. Therefore, these, often old, thermal power stations were overdesigned to account for a planned higher heat market. This has led to the thermal power stations (or cogeneration power plants) still having a surplus of heat generation. The industrial district heating demand decreased significantly between 1985 and 1999, or more than fifty per cent.
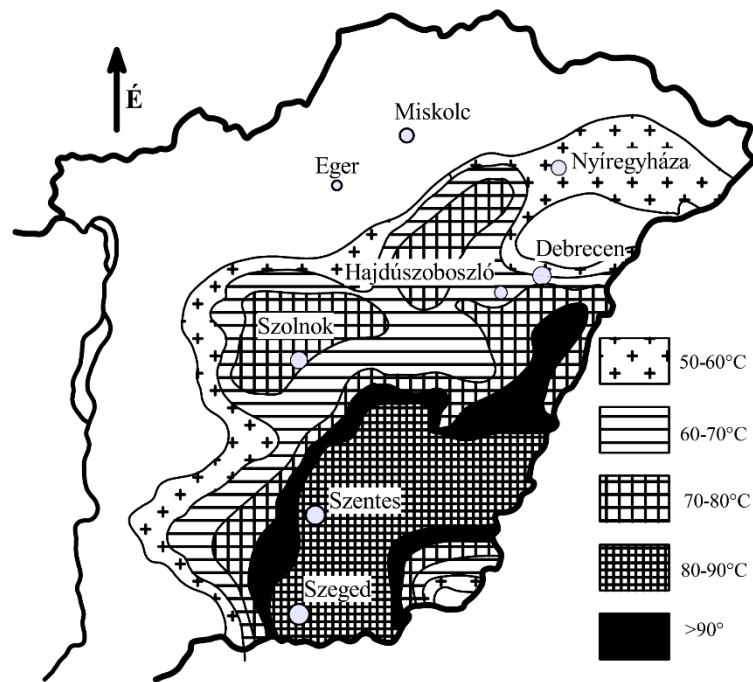
In 2014, district heating facilities are available in 94 settlement, comprising 219 district heating systems. Most of the consumption or 76.4% is from households, which consist of space heating and hot water. There are no significant changes in the number of flats supplied with district heating; in 2014 the total was 648,329, almost the same number as in 1990, shown in Figure 2. More than 90% of those are also supplied with heat for hot tap water (MEKH, 2014). There are 168 power plant units in operation in Hungary, with more than 8000 MW installed capacity, providing district heating facilities. Thirty units are operating as a cogeneration power plant (with gas engine generator set
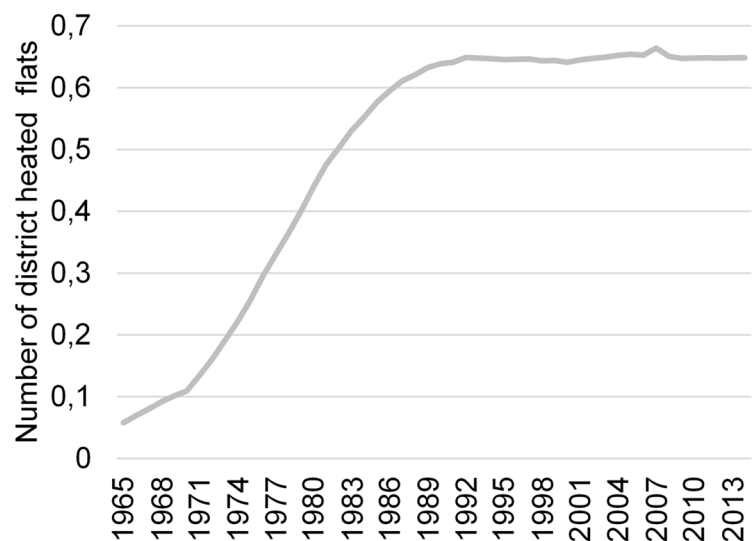


FIGURE 2: Number of district heated flats in Hungary between 1965 and 2014
(Hegedűs, 2005; MEKH, 2014)

and boiler to supply direct heat, representing more than 1800 MW installed capacity), producing electricity and using heat for district heating, however 62 power plants (representing 1371 MW) produce only hot water for direct heat supply by boilers. This paper focuses on the most common power plants, having the highest number. Besides there are, however, many different systems existing which are less common.

There are three power plant units in Debrecen, situated next to each other roughly in the central part of the city. The three power plant units are owned by three different companies: Tiszántúli Hőtermelő Kft., E.ON Energiatermelő Kft. and Debreceni Kombinált Ciklusú Erőmű Kft. The first unit is a gas engine generator set combined with a natural gas boiler (29 MW), the second unit is the same as the first unit, but includes a back-pressure steam turbine generator set (349 MW), and the third unit is a combined cycle power plant unit (90 MW). The available thermal capacity of these units, all together, is 468 MW. These units operate together for the district heating supply. They are, however, also able to run separately, which will be very important according to the final goal of this theoretical project.
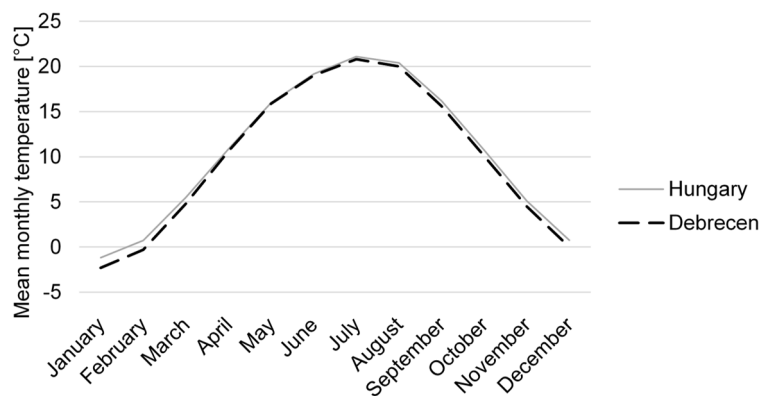
## 2.4 Meteorological conditions



FIGURE 3: Mean monthly temperature in Debrecen and Hungary (data sample 1900-2010) (OMSZ, 2016)

Hungary is located between the 45°45' and 48°35' latitude in the middle of Central Europe in the Pannonian Basin. The country has basically a continental climate, however, different surrounding climates have modification effects. In this regard, the temperature and general weather conditions are changeable during the whole year. The Hungarian annual mean temperature is around 9.5-11°C, calculated data from 1900-2010 (OMSZ, 2016), (Figure 3). Temperature conditions in winter and summer can be very far from this average value, which is important for heating system design. During the heating system design, it is essential to take into account the coldest (possible) temperature conditions of the analysed location. Before the heating system design, the most crucial task is to analyse all of the available meteorological data about the measured mean daily outdoor temperature history. Outdoor design temperature is one of the most important chosen elements of the model, which serves as a basis to estimate the volume of the necessary heat consumption of the heat market.

Hungarian Meteorological Service (OMSZ) has reported temperature and other essential meteorological data for five Hungarian cities; Budapest, Debrecen, Pécs, Szeged and Szombathely from 1900 to 2010, shown in Table 1. Between 1901 and 1965 the daily mean temperature was calculated with the measured 7 am, 2 pm and 9 pm average, where the 9 pm measurement was weighted twice. Since 1965, the calculation method of the daily temperature consists of the 7 am, 1 pm, 7 pm and 1 am recordings with a simple arithmetic average in equal weight for each measurement (Baumann, 2012). On the other hand, according to the Hungarian Standard (MSZ-04-140/3-87, see Appendix I) which defines the required design outdoor temperature in the function of the location (Zsebik, 2004), the minimum designed temperature is:

1) Southwest Hungary:                                    -11°C;
2) Northeast Hungary:                                    -15°C;
3) Central Hungary (lies between 1 and 2):               -13°C.

TABLE 1: Used flats in the function of building material and floor area
(Hungarian Central Statistical Office, 2013)

| Building material | ≤ 49 [m²] | 50–99 [m²] | ≥ 100 [m²] | Total | Average floor area [m²] |
|---|---|---|---|---|---|
| Brick, stone | 363,670 | 1,342,978 | 777,359 | **2,484,007** | 84 |
| Prefabricated concrete panel block building | 196,446 | 539,491 | 41,326 | **777,263** | 62 |
| Adobe, slob | 53,986 | 422,126 | 107,377 | **583,489** | 77 |
| Wooden, other | 7,874 | 37,575 | 22,221 | **67,670** | 84 |
| Total | 621,976 | 2,342,170 | 948,283 | **3,912,429** | 78 |

This is a relatively old standard (28 years old) however it is still in use. Experience has shown, that the heating activity is necessary if the mean daily temperature is below 12°C (this is the marginal heating temperature). In case it happens more than three times continuously, the district heating companies should have to start the system operation, regardless of the date. Officially, the heating season in Hungary is between 15th of October and 15th of April. Furthermore, if the temperature conditions require; the customers also have the right to ask the heating service to operate outside of the heating season (Zsebik, 2004).

## 2.5 Temperatures records

Considering the long-term history temperatures, the north-eastern part of the country is the coldest. This study will relate to the coldest part of Hungary and will focus on the town of Debrecen. The measurement history of Debrecen in the last half-century (1960-2010) is shown in Figure 4. There were only 16 cooling days (Hungarian Meteorology Service, 2016), when the mean daily temperature was lower than the commonly used -15°C design temperature (Hungarian Standard, MSZ-04-140/3-87 – Appendix I). This statistical sample of about 51 years consisting of 18,627 days (altogether with leap years), shown in Figure 4 (see also table in Appendix II), with only 16 extremely cold days below this designed temperature, means that, on average, there is only one cold day in every three years; which is an acceptable rate (OMSZ, 2016).
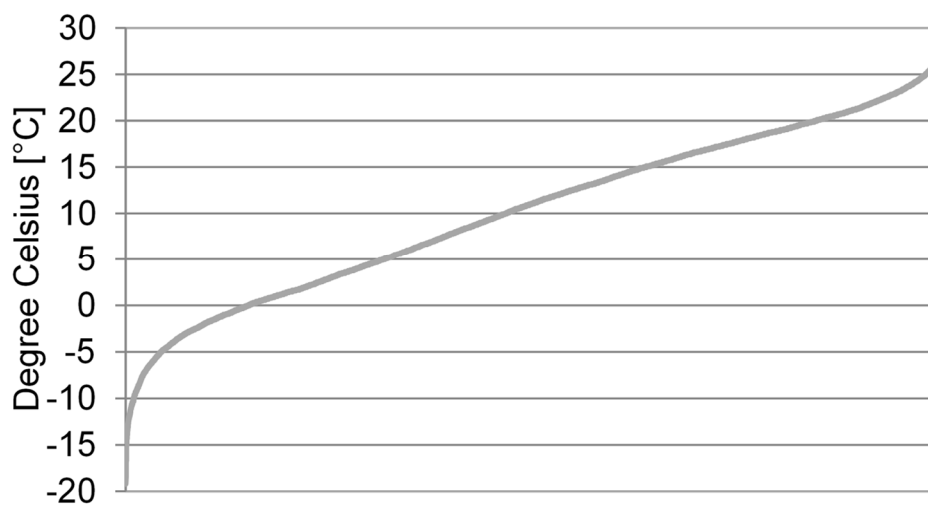


FIGURE 4: Outdoor temperature duration curve for Debrecen (1961-2010) (OMSZ, 2016)

For a heating engine, it is necessary to calculate the number of degree days, it is therefore the first element of the calculation to estimate the length of the heating season. Within this statistic sample, there were 9917 days when the outdoor mean temperature was lower than 12°C ($N_T$ days), and 8710 when it

was higher. Dividing with 365.25 (considering leap years as well) gives the average number of heating season within a year as 194.4 days. This result is very close to the widely used heating design practice; with district heating companies usually expecting to cope with 190-200 days long heating seasons. Also necessary to know, is the average mean outdoor temperature for $N_T$ days ($N_{mT}$), which is 3.14°C in this case (Karlsson, 1982). Degree days for "T" period are given by Equation 1:

$$DD_{(T)} = N_T(T - N_{mT}) \qquad (1)$$

where $DD_{(T)}$ = Annual degree days, for the desired indoor temperature (T);
$N_T$ = Number of days when the outdoor temperature is below T, through the whole year;
$N_{mT}$ = The mean outdoor temperature for $N_T$ days (°C).

Regarding the calculation above, the average degree days in Debrecen are around 3280. The same formula is used to calculate degree hours depending on what is the exactness requirement. This result bears out the degree days map (see Baumann, 2012 – Appendix III).

Meteorological calculation basis is a very important element of the district heating design progress, to avoid under or overdesign. If the system is under-designed it will not be able to keep the desired indoor temperature, therefore cannot fulfil the heating requirements. Also, if the system is overdesigned it will cause unnecessary thermal capacity, increasing the investment and operational costs which makes the system economically ineffective. Furthermore, heat loss parameters about the building structure are also a crucial part of the designing progress.

## 2.6 Building structure details

The following section will provide an overall summary and detailed information about Hungarian private apartments. The most important data source is the population census from 2011 (Hungarian Central Statistical Office, 2013). The total number of the counted flat units was 4,381,976 in 2011. This paper takes into account only the dwellings, which was 3,904,103. Brick is the most common building material in Hungary (shown in Table 2), with almost 2.5 million dwellings. Also, an important condition is that more than 2.2 million buildings are detached houses, which are mostly built from brick according to the general experiences. Houses which are made from adobe or slob also have a significant share with almost 0.6 million detached houses. Almost 80% of these houses are located in the eastern part of the country and surrounding Budapest. Also, a significant segment are the panel and concrete buildings; 95% of which are located in cites of various size. Wood and other building materials have a very low share within dwellings, and are negligible.

## 2.7 Heating system details

In most cases the building material and the location of the building determines the applicable heating resource and also the type of heating system. Natural gas is the main energy resource in Hungary (see Section 2.1), and is widely used for district heating, for individual convector heating, for circulating hot water heating, and also for central gas boiler heating. More than 2.4 million dwellings have central heating system and almost 1.5 million flats heating have individual heating systems (shown in Table 2). The share and role of individual heating is reducing year by year. Between 2001 and 2011 the number of individually heated flats decreased by -12%. The share of district heating has also decreased in this period, however less than individual heating, or by -3%. The most commonly used heating system in Hungary is the central heating solutions, including the newly built apartment buildings as well. District heating applications are mostly used for heating prefabricated concrete panel block buildings (for the further text it will called: "block building) in Hungary, and almost nowhere used for family house heating. These block buildings were constructed without extra insulation, with relatively small radiators designed for 90/70 systems. The lack of heating control possibility is also a serious problem. These facts were evaluated and district heating got a very negative image, however, this is not evidence.

TABLE 2: The share of different kind of heating systems in Hungary
(Hungarian Central Statistical Office, 2013)

| Type of heating system | | 2001 | 2011 | Change compared to 2001 |
|---|---|---|---|---|
| District heating (incl. pipeline from heating-station) | Central heating | 625,333 | 607,578 | 97.16% |
| One or more flat heated w. central heating (house central heating, circulating hot water heating/individual central heating) boiler, or other equipment | Central heating | 1,395,917 | 1,829,459 | 131.06% |
| Individual room heating | Individual heating | 1,669,523 | 1,475,392 | 88.37% |
| **Total** | | **3,690,773** | **3,912,429** | **106.01%** |

Single pipe free-flow system (Figure 5A) is a serial connected secondary circle, which was widely used mostly between 1970 and 1980. According to the Hungarian architectural policy of that time, this was the obligatory applied heating system. The difficulties of this system is that there is no possibility to control the indoor temperature, it is only balanced from the heat source which takes a long time, furthermore inhabitants usually "control" the temperature by opening windows. Accordingly, over- or under heating is very common in the system, and therefore the system is not able to work efficiently and sufficiently. Today, the opinion is that this is not a development that people want to continue. Single-cross pipe system with individual valve (Figure 5B) is a developed single-pipe flow system, inserting an individual valve. However, these heating systems development of (Figure 5A and B) are not the best option, but became a very commonly used practise as it requires low investment costs. Double pipe systems (Figure 5C) are the latest version of secondary heating circles which provide the best option (of these common types) to control heating system individually (MIHŐ, Ltd., 2016).
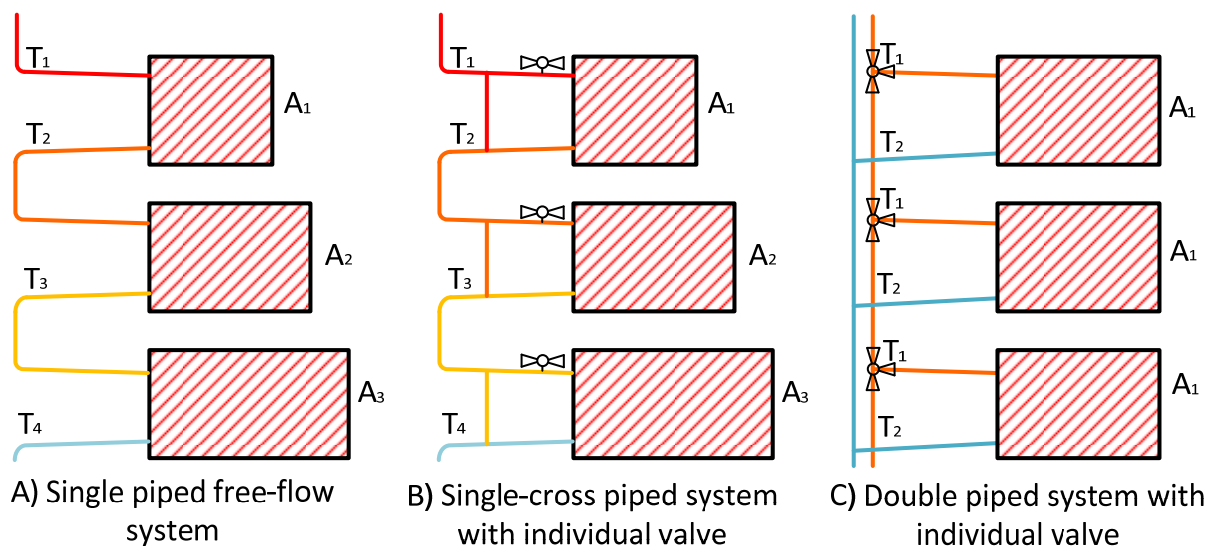


A) Single piped free-flow system

B) Single-cross piped system with individual valve

C) Double piped system with individual valve

FIGURE 5: Different types of radiator heating circles in Hungary
(drawing based on MIHŐ, Ltd., 2016)

## 3. HEAT MARKET ANALYSIS

### 3.1 Debrecen city

To explain the challenges of the design process of a geothermal district heating system, this study will present a mathematical model for an invented development project. In this regard, it is necessary to choose a concrete location for this purpose. The main focus of this study will be in Debrecen city, which is situated in the eastern part of Hungary, one of the major cities of the Great Hungarian Plain. Debrecen is the second most populated city in Hungary with around 200,000 inhabitants (Hungarian Central Statistical Office, 2013). The following important aspects were taken into account on the selected settlement. It should:

- Consist of several types of residential buildings (located close to each other);
- Already have an existing fossil fuel fired district heating system;
- Be located relatively close to the explored geothermal fields (Hajdúszoboszló, Nagyvárad);
- Be one of the coldest parts of the country;
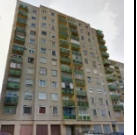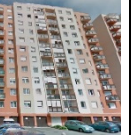- Have significant agricultural production for further cascaded use.

In 2011 there were 94,708 dwelling units in Debrecen, which increased to 95,772 in 2014. The number of unoccupied dwellings in Debrecen was 9,458 (Hungarian Central Statistical Office, 2013), but it is important to emphasise that this phenomenon is not common in the central area of the city where the examined heat market is located. In this regard, the model will not account for it. To get a realistic and applicable result of the study, it is also necessary to set out typical building groups, for simplification.

### 3.2 Building groups

It is important to emphasize, that this study is not an already planned project. This is only a simulation, based on mainly the available geothermal utilization experiences of Miskolc, regarding the geothermal wells. The main goal of the model is to represent proportionally and properly the existing building structure, which is typical in Debrecen, and also for Hungary. It is suitable to represent the conditions and parameters of the different types of buildings in one system. The floor area and the shape of the buildings give only an example for the calculation. The mathematical model is also applicable for other settlements. To demonstrate these differences in a comparable way; each major building category (1-family houses, 2-block buildings, 3-new apartment buildings - Appendix IV) will require roughly the same quantity of heat in the design conditions, around 10 MW. In this regard, the heat market will represent around 30 MW heat consumption in design condition. This quantity, however, does not include the system losses such as distribution heat loss. The full size of the heat market was estimated with the help of calculated heat loss data for the different building types, based on the already district heated block buildings.

According to the aim of the theoretical project, the system will mostly be based on the geothermal energy resource, considering that the temperature of the geothermal water is usually the bottleneck within the implementation. The temperature and the yield of the geothermal water in this area is able to provide a constant base load, but above that level gas boiler is necessary to provide enough heat supply in the peak periods. Each of the selected building categories are relatively widespread in Debrecen, but this limited geothermal heat supply allows only smaller parts to link to the theoretical system. To use a realistic heat loss coefficient (U) value (shown in Table 3) for each building of the model, calculations were based on a very detailed literature, National Typology of Residential Buildings in Hungary (Csoknyai et al., 2014).

TABLE 3: Heat loss coefficient values of the defined building groups

| Building element | Group-1: Family house | | Group-2: Prefabricated concrete panel block buildings | | | | Group 3: New apartm. houses |
|---|---|---|---|---|---|---|---|
| | Building type 1 | Building type 2 | Building type 3 | Building type 4 | Building type 5 | Building type 6 | Building type 7 |
| All parameters in $\left[\dfrac{W}{m^2\,K}\right]$ |  |  |  |  |  |  |  |
| Wall + insulation | 1.50 | 0.17 | 0.8 | 0.19 | 0.8 | 0.19 | 0.21 |
| Roof | 1.50 | 0.14 | 0.91 | 0.14 | 0.91 | 0.14 | 0.17 |
| Slab | 1.30 | 0.14 | - | - | - | - | - |
| Floor above ground | 0.98 | 0.98 | 0.55 | 0.15 | 0.55 | 0.15 | 0.26 |
| Windows | 3.00 | 1.30 | 1.15/3.30 | 1.00 | 1.15/3.30 | 1.00 | 1.15 |
| Doors | 3.00 | 1.30 | 1.15/3.30 | 1.00 | 1.15/3.30 | 1.00 | 1.15 |

Furthermore, it is also important to estimate the typical number of inhabitants for each sort of building type. The available statistics from the population census (2011) provide a good basis to estimate these values. Accordingly, the average number of inhabitants in Debrecen from the mentioned statistics are:

- $\leq 79$ m$^2$: 2-3 inhabitants / unit;
- $\geq 80$ m$^2$: 3-4 inhabitants / unit (regardless of the building material of the building).

79-80 m$^2$ is the border value between the categories, because most block building flats are smaller than 79 m$^2$, and most family houses are bigger than 80 m$^2$. Block buildings have a very complex structure regarding flat sizes. Appendix V shows the copy of ground plans for type P100 of prefabricated concrete block building (Csoknyai et al., 2014), while Appendix VI represents the original ground plans for type MOT I. 58-264/76-K C-1. Therefore, all net floor sizes are known, allowing estimation of the number of inhabitants based on the building types (Appendix IV).

### 3.2.1 Family houses

The first category consists of family houses. There are almost 2.5 million family houses in Hungary, most of them (1.8 million) were built earlier than 1979. The bigger part of them have never been reconstructed, therefore these houses have already become out-dated. More than 50% of the existing buildings in Debrecen were built earlier than 1979, representing 53,929 flats altogether; mostly family houses. Obviously there were built several different sort of dwellings during that time, but to simplify this group, two commonly built subcategories will be taken into account: 1) *"Old Hungarian cube house"* (or also called "Kádár cube house") and 2) *"Refurbished family house"*.

Old Hungarian cube houses were commonly built between 1945 and 1979 (Csoknyai et al., 2014), and even nowadays are quite widespread. These houses were built from solid brick, without any additional insulation, with only a plaster layer added for both sides. Typical U values (shown in Table 3) of the walls are between 1.36 and 1.77 W/m$^2$K, depending on thickness. In the mathematical model an average will be considered, using 1.5 W/m$^2$K as the heat transmission coefficient value. The average floor area

of these houses is approximately 90-110 m$^2$. Generally, the roof does not serve as a dwelling area, as it is only used for storage during the year. These houses were built without cellar, with one floor, including 2 or 3 bedrooms. The most common heating system is (constant temperature non-condensing) gas boilers or firewood stoves. The wooden windows and doors are not well insulated, and most of these houses are poorly maintained, out-dated, and do not satisfy the basic thermoeconomic requirements. These are the most wasteful type of residential buildings in Hungary; heat consumption is two times higher than for the reconstructed, well insulated family houses. Almost all family houses are heated with individual gas boilers or firewood stoves in Hungary (Hungarian Central Statistical Office, 2013). Most of these houses are situated at the borders of the central area or outside them, in poor districts and usually owned by poor people and/or senior citizens. Commonly, full reconstruction would be more expensive than the value of the house and the site itself.

The second category was mainly built later, and until around 2000. These houses were refurbished and/or extended to nearly 200 m$^2$. The most important difference between the two categories, is that the second type of houses were developed with a 10-20 cm thick insulation and new plastic made insulated windows, resulting in significantly lower heat loss parameters. The most frequent heating system is constant temperature non-condensing gas boilers, but in ambitious refurbishments, condensing gas boilers are used (Csoknyai et al., 2014). Full renovation generally requires large amounts of money; therefore, very often it is implemented in more affluent areas then the first category. As a result of these developments, the heat loss values have decreased significantly.

### 3.2.2 Prefabricated concrete panel block buildings

This building category represents a very common type of building in Debrecen and also in Hungary. Roughly 7-8% of the Hungarian population are living in this type of buildings, representing 777,263 inhabitants (Hungarian Central Statistical Office, 2013). Also in Debrecen, a significant part of the population is living in block buildings, with several thousands of flats being built between 1957 and 1990. It is known that the number of district heated flats was 30,895 in Debrecen in 2011 (Hungarian Central Statistical Office, 2013), and also known that 99% (ÉMI Non-Profit, Llc., 2015) of the district heated flats are prefabricated concrete block buildings, meaning that this number is very close to the total number of block buildings in Debrecen. In the last decade, the Hungarian Government through financial programmes, started to support the refurbishment of these buildings, resulting in the number of refurbished block buildings starting to increase. These refurbishments generally result in significantly lower heat loss parameters. This was also considered, as well as windows and balcony doors being also replaced in buildings, which are still in original condition. The ratio between the "*new*" and "*old*" window/balcony equipped flats was estimated by Google Maps.

### 3.2.3 New buildings

This category includes all the buildings which were recently built (or will be potentially built in the future) and have low heat loss parameters (Table 3). In fact, these houses are generally operating with house central heating based on a gas boiler. In the model, it was assumed that these buildings are constructed with district heating systems. An example of a floor map of a newly planned building is shown in Appendix VII (from Hatvan street 62, Debrecen).

### 3.2.4 Tap water

It is difficult to estimate the tap water consumption with accuracy. The number of inhabitants is estimated according to the statistics; however, the estimate is highly dependent on personal behaviours, the standard of living, the average staying time at home and so on. Consequently, the estimate of the tap water heat consumption was calculated based on the type-7 building radiator heat consumption divided by the number of inhabitants. This methodology gives a 0.147 kW / inhabitant value as a constant which is very close to widely used estimation; which predict tap water heat consumption as 8-10% of the building radiator heat consumption (Zsebik, 2004).

### 3.3 Exact location of the theoretical project

The model will be using three different types of building groups and seven subcategories described in detail in Appendix IV. Considering the concrete location of these typical Hungarian buildings the selected location is in the northern part of the city, located at a 2-3 km distance from the main square of Debrecen (Appendix VII). This is an ideal place for this analysis because all of the building categories can be found next to each other (except type-7, which is not existing).

The left side of the map (Appendix VIII) is basically an area covered with family houses, shown with a red rectangular. The exact location of the area shows that it borders with the Szabó Lőrinc - József Attila - Böszörményi and Akademia streets. It is around 0.25 km$^2$, mostly covered with buildings of type-1 and type-2. It should be emphasized that district heating access is not provided here, as these houses are usually running with individual gas boilers. In model calculation, it is assumed that new district heating connection and refurbished radiator heating facilities will already be provided for these houses. The new pipeline thermal efficiency is considered to be 96% (0.96) (Appendix IV). The model will assume that 280 type-1 and 440 type-2 buildings will be linked to the system. It is also assumed according to the statistical data (Hungarian Central Statistical Office, 2013) that three people live in building type-1 and four people live in building type-2 on average. This is altogether 720 family houses representing 116,000 m$^2$ net heated floor area, with 2600 inhabitants. This part of the heat market needs 9.97 MW thermal capacity based on design conditions.

The biggest housing estate area is situated in the central part of Debrecen, only 2-3 km distance from the city centre, shown with yellow rectangular in the right side of the location map (Appendix VIII). The Újkert housing estate area was built in 1970, representing around 20,000 inhabitants. These buildings are heated by the local district heating system, hence the distribution system and radiator heating facilities are already arranged. This fact was the major reason to select this area for the theoretical model. The location of this area shows that its borders are along Doberdó – Böszörményi – Füredi – Nádor -Thomas Mann – Mikszáth - Békessy and Kartács streets. The area is around 0.78 km$^2$, mostly covered with buildings of type-3, type-4, type-5 and type-6. The supply pipeline was built more than 40 years ago, therefore it is assumed that some part of it has been reconstructed since that time, so the existing pipeline is considered with an estimated 92% (0.92) thermal efficiency value. There are several types of block buildings in this area, but the most common types in the examined area are the fifteen-storey (type P-100) and a ten-storey (MOT I. 58-260/76-K C-1) block buildings (Appendices V and VI). From the bordered area, nine P-100 buildings and 29 refurbished block buildings will be linked to the theoretical model. Of the P-100 buildings there are two buildings already refurbished, but seven buildings are in the original state without complex development. From the C-1 block buildings, 29 buildings will be linked to the system theoretically (24 refurbished, five in out-dated conditions). This is altogether 38 block buildings, representing 209,329 m$^2$ net heated floor area, with 8388 inhabitants. This part of the heat market needs 10.35 MW thermal capacity in design condition.

The selection of newly built apartment buildings is more flexible than the two previously mentioned categories, because currently it does not exist. At two streets in a north direction from the family houses and also next to block buildings there is a 0.26 km$^3$ green field, shown with blue rectangular in Appendix VIII, which is theoretically suitable for building type-7. This is, however, only an example for the location. The exact location of this area is bordered by Károli Gáspár - Tessedik Sámuel - Böszörményi and Vezér streets. As a result of this, it is assumed that for new houses with a new district heating pipeline, the thermal efficiency is considered to be 98% (0.98). This means that theoretically, additional 130 new buildings will be linked to the system, representing 214,760 m$^2$ net heated floor area, with 7280 inhabitants. This part of the heat market needs 10.03 MW thermal capacity in design condition.

## 4. DESCRIPTION OF THE THEORETICAL MODELLING

One of the main goal of this project to design a geothermal district heating system which uses as much geothermal energy as possible (respecting sustainability aspects) to reduce natural gas boiler usage. Regarding to the 51 years statistical sample of weather measurements, and also considering the related Hungarian standard (Appendix I), the minimum outdoor design temperature of the systems in Debrecen is -15°C. This is one of the most important fixed parameter of the district heat system; each further step of the design process will be based on this value. The second important parameter is the designed (desired) indoor temperature. This parameter depends on the individual expectations, and is a strict parameter with large influence on the installed thermal capacity of the power plant. For indoor design temperature, 20°C is the widely used value in Hungary. Therefore, this value will be used for the current modelling (during the heating season). This project assumes that a significant part of the heat consumption could be provided by the geothermal resource for the assigned building groups, therefore the gas boilers will only be used for back-up.
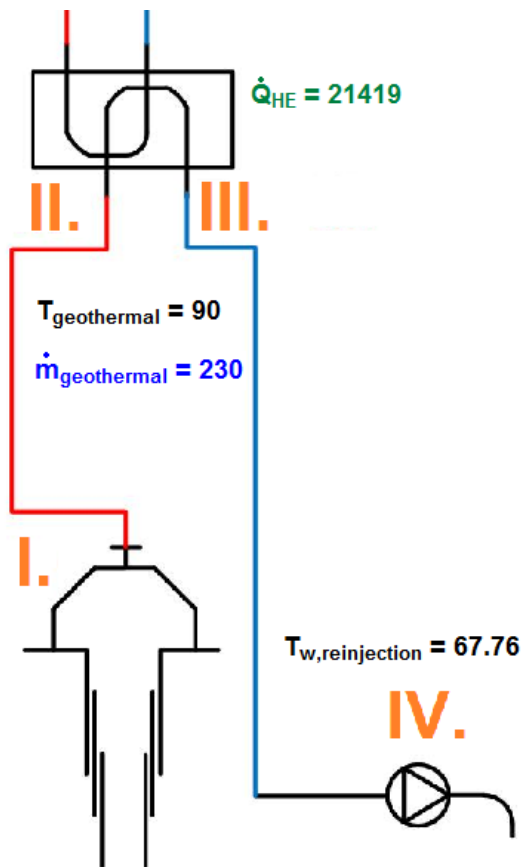
### 4.1 Primary circle

The most important role of the primary circle is to heat up the return water using the geothermal energy, transferring heat to the secondary circle through a heat exchanger and keep the desired temperature conditions of the system, shown in Figure 6. The theoretical model assumes only one heat exchanger between the primary circle and the heat market which is not common in the existing Hungarian district heating systems. Therefore, this requires a modification, mainly regarding the existing block buildings. The primary circle consists of the geothermal well(s), the heat exchanger (between the primary and secondary circle) and the reinjection well(s). The theoretical project assumes two geothermal production wells and two reinjection wells with the technical parameters of the system found in the table in Appendix IV. This estimate is based on the technical parameters of a similar existing geothermal project implemented in Miskolc, which is around 85-90 km from Debrecen. It is also assumed, that the heat exchanger is operating 4.5°C pinch (on the return side) and 5°C pinch (in the intermediate side) during the energy transfer. According to Table 4, the geothermal fluid mass flow is expected to be 230 l/s with a 90°C constant temperature.



FIGURE 6: Schematic drawing of the primary circle of the designed district heating system

TABLE 4: The most important parameters of the assumed geothermal wells for the theoretical project (based on Miskolc-Mályi geothermal system conditions)

| Type of well | Mass flow of geothermal water [l/s] | Temperature of geothermal water [°C] | Depth [m] |
|---|---|---|---|
| I. Production well | 100 | 90 | 1500-2500 |
| II. Production well | 130 | 90 | 1500-2500 |
| I. Reinjection well | 90 | - | 800-1800 |
| II. Reinjection well | 100 | - | 800-1800 |

One of the biggest problems for geothermal utilization in Hungary is that the heating season length is around 200 days and the heat markets do not need any space heating during the remaining 165 days. Because of this, geothermal wells are commonly closed out of the heating season. Consequently, the model has to follow this practise.

## 4.2 Secondary circle

The most important role of the secondary circle to heat up the intermediate water temperature using the natural gas boiler, if the temperature is not high enough to cover the heat market needs. Therefore, it is important to emphasize that the gas boiler is not used at all most of the time, unless it is necessary. Nevertheless, the gas boiler is also able to replace geothermal wells if the geothermal system requires unexpected maintenance work or when the daily mean temperature is below the outdoor design temperature, $t_{od\ des}$. The intermediate water temperature is 81.035°C in design condition and considering the size and conditions of the heat market, the necessary system supply temperature should be 95°C. This is the "worth" case, when the outdoor temperature is -15 °C. It means that considering the examined system parameters, the maximum $\Delta t$ required with gas boiler is 95-81.035 = 13.965 °C, as shown in Figure 7. The system is operating with mass flow control according to the actual heat consumption of the system. In this regard, the mass flow and intermediate water temperature are the two important variables of the designed system to satisfy the heat market needs. The water circulation is provided by circulation pumps.
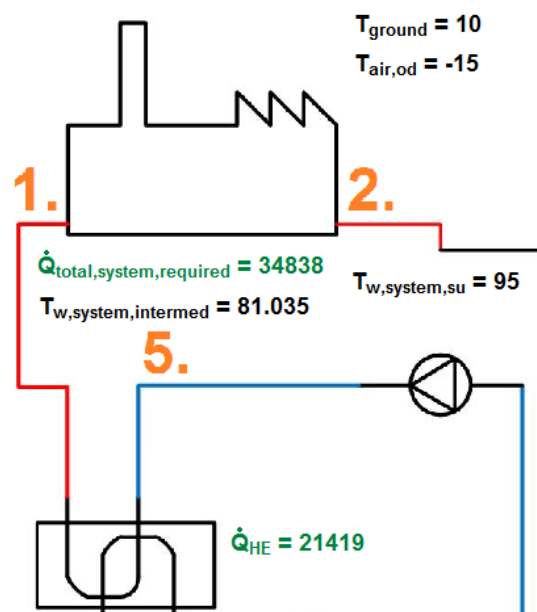


FIGURE 7: Schematic drawing of the boiler station and intermediate stage of the designed district heating system

## 4.3 The mathematical model for district heating

### 4.3.1 Tap water heat consumption

The level of hot water consumption is roughly the same during the whole year for residential consumers. Actually, the consumed heat is higher during the heating season and usually lower in summer time, but this difference is not significant. To simplify this factor, the model will assume that the heat consumption is constant during the year. This simplification means that the result of the boiler load in design condition could be a little higher in real conditions. Slovakian experience has shown that the supplied heat quantity used for hot water heating (per capita) is roughly equal with the heat loss of a modern building in 13°C outdoor temperature (per capita). According to the heat loss calculation for tap water heat, a constant 0.147 kW/inhabitant value will be used for all types of building. It is also very important to estimate realistically the number of inhabitants/m$^2$ (Hungarian Central Statistical Office, 2013), because tap water consumption is highly dependent on the number of users.

### 4.3.2 Space heating – heat loss calculation

The necessary heat consumption should always be a bigger value than the total heat losses, because of the several forms of heat losses (pinch in the heat exchange, heat loss of the distribution system, heat loss from the houses, etc.). The major task is to provide sufficient quantity of heat for the heat market. Considering that, the first important task is to calculate the total heat loss of the building. There are

several elements in a building, which are able to modify the volume of the total heat loss considerably. The most crucial elements are the windows, doors, and the quality of the additional insulation. To avoid the over-, or under-design, the first task is to calculate the heat loss value ($Q_T$) for the heated unit (building/house) using a fixed design temperature. From the respect of the building, there are three values to consider in calculating the heat balance, 1) heat loss, 2) heat equity and 3) heat surplus. Heat loss is the usual heat transfer during the heating season caused by transmission and filtration. To simplify the heat loss calculation; the transmission ($Q_{tr}$) and filtration heat loss ($Q_{fr}$) will be considered almost as 100% of the building heat loss, other sort of heat losses are negligible (such as other complex energy transfers within the building, wind cooling effect etc.), as demonstrated in Figure 8. For the current purpose, it is not necessary to calculate in more detailed heat losses. Equation 2 defines the total heat loss for a building:



FIGURE 8: Calculation methodology of different types of transmission heat losses

$$Q_T = Q_{tr} + Q_{fr} \tag{2}$$

where $Q_T$ = Total heat loss of the building [kW];
$Q_{tr}$ = Transmission heat loss [kW]; and
$Q_{fr}$ = Filtration heat loss (caused by infiltration and ventilation) [kW].

*Transmission heat loss (*$Q_{tr}$*)*

To quantify transmission and filtration heat losses, it is necessary to know the geometrical data for all types of buildings. For this purpose, floor maps could provide sufficient information (Appendices V, VI and VII) about the shape of buildings, surface and building material of the walls and windows/doors, etc. This simple modelling simulation used a contracted U value for doors and windows, including a thermal bridge coefficient as well. Transmission heat loss was calculated from Equation 3 used for all type of buildings:

$$Q_{tr} = \left( \sum A_{w,d} * U_{w,d} + \sum A_w * U_w + \sum (l_{tb} * U_{tb}) * (t_{id} - t_{od}) \right) \tag{3}$$

where $A_{w,d}$ = Surface covered by windows or doors [m²];
$U_{w,d}$ = Coefficient of heat transmission for windows or doors [W/m²K];
$A_w$ = Wall surface [m²];
$U_w$ = Coefficient of heat transmission for walls [W/m²K];
$l_{tb}$ = Length of thermal bridge [m²];
$U_{tb}$ = Coefficient of heat transmission for thermal bridge [W/m²K];
$t_{id}$ = Indoor temperature [°C];
$t_{od}$ = Outdoor temperature [°C].

For calculation, it is sufficient and important to take into account the exact shape of the buildings, not only the value of floor area, because it does not determinate the surface area of the borders (which is highly related to the heat loss). To set the usual number of windows for each building category, Google Street View software was used for building types 1, 2, 3 and 4 as a sufficient estimation, considering these buildings are not completely similar. For the rest of the building types (5, 6 and 7) floor maps were available, which provided more exact basis for estimation (Appendices V, VI and VII). For the calculation of the buildings volumetric data it is important to divide the gross floor area and net floor in the case of complex buildings. This was considered in all types of buildings except building of type 1 and 2, because in these cases, gross and net floor areas are equal. For instance, garages, staircases and caloric centres do not need any heat or only a lower quantity. This is a significant difference, as calculated in Appendix VIII, meaning that the net floor is only 75-85% of the total floor area depending on the building type.

Transmission heat loss would be the only significant heat loss if the heated unit would be perfectly isolated all the time and all of the windows/doors would be closed constantly (without causing any air leaks), but in real life it is not true at all. Obviously air exchange is essential for everyday life and so in this respect it is necessary to take into account the filtration heat loss (z) (consists of infiltration and ventilation factor) caused by opening doors, windows, operating ventilation system, air condition, etc. Evidently, this factor is highly based on the number of inhabitants/dwellings, from other individual habits, and also from the quality of doors and windows. In order to get a proper value, it is possible to estimate this factor according to the heat engine experiences and also from usually applied standards. Filtration heat loss ($Q_{fr}$) given by Equation 4:

$$Q_{fr} = z * c_a * \rho_a * (t_{id} - t_{od}) \tag{4}$$

where   z        = Infiltration and ventilation factor [1/h];
        $c_a$        = Specific heat of the air [kJ/kg K].

The difference between infiltration and ventilation is that ventilation is a purposeful, human controlled air exchange process but infiltration cannot be controlled directly, as it is caused by air leakages and other faults of the building. Infiltration and ventilation factor has a crucial role in filtration heat loss, because this factor determinates the value of the final heat consumption, especially in large buildings (types 3, 4, 5 and 6). To quantify this factor, it is usually given in estimated values, which are based on several measurements and experiences. Considering that 0.75 1/h value will be considered for building types 1, 3 and 5; 0.6 1/h for building types 2, 4 and 6,m and 0.5 1/h for building type 7, according to the quality of the building materials (Soltész, 2008). The results of the heat loss calculations give significant differences between the examined buildings types. It is remarkable, that the refurbished block buildings had the best results regarding the heat consumption per inhabitant and also the heat consumption per square metre, shown in Figure 9. Newly built apartment buildings have a similar good value, however these buildings usually consist of larger flats in which case the number of inhabitants is lower and the specific energy consumption is larger.
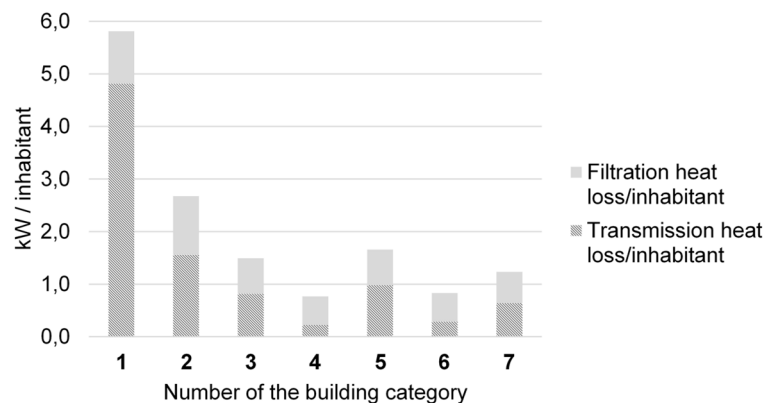
FIGURE 9: Heat consumption values per inhabitant, weighted with the net floor area for 7 different types of examined building

After the heat loss calculation, all data is known to calculate how much thermal energy is needed for the whole system in design condition. Before, it was explained how many buildings will be linked together in the theoretical model to keep the balanced ratio between the different types of buildings within the system.

According to the previously calculated heat loss values, all the parameters are known to calculate the overall heat transfer coefficient number for all type of buildings (Kl value) for design condition, shown in Appendix IV. This parameter is a specific value to describe the building heat loss conditions, representing how much heat is consumed by the building while the outdoor temperature decreases by 1°C:

$$Kl = \frac{Q_{T\_des}}{(t_{id\_des} - t_{od\_des})} \tag{5}$$

where   K l        = Overall heat transfer coefficient [kW/°C].

According to the parameters above, for the next step it is necessary to calculate the heat consumption of the building for each case of varying outdoor temperature by:

$$Q = Kl * (t_{id} - t_{od}) \qquad (6)$$

where   Q       = Heat consumption [W].

All of the Kl values related to each building type are listed in Appendix IV.

**4.3.3 Heat consumption by the radiator**

Most of the district heating systems are using hot water in order to provide heat transfer from the power plant to the heated area. Evidently, total heat loss of the building has to be equal with maximum heat load of the radiators. One of the most important parameters of the system is to calculate the return water temperature from the radiators in design condition. This result describes the quality of the heat market, and determines how much energy is required to keep the heating system circulation. It is also necessary to estimate the volume of the mass flow required for the system. The surface temperature of the radiator is different in each point, as shown in the thermal photo in Figure 10, but for the quantification, it is necessary to assume a fixed value to for further calculations. Equation 7 is used for calculating logarithmic temperature difference on the radiator surface:
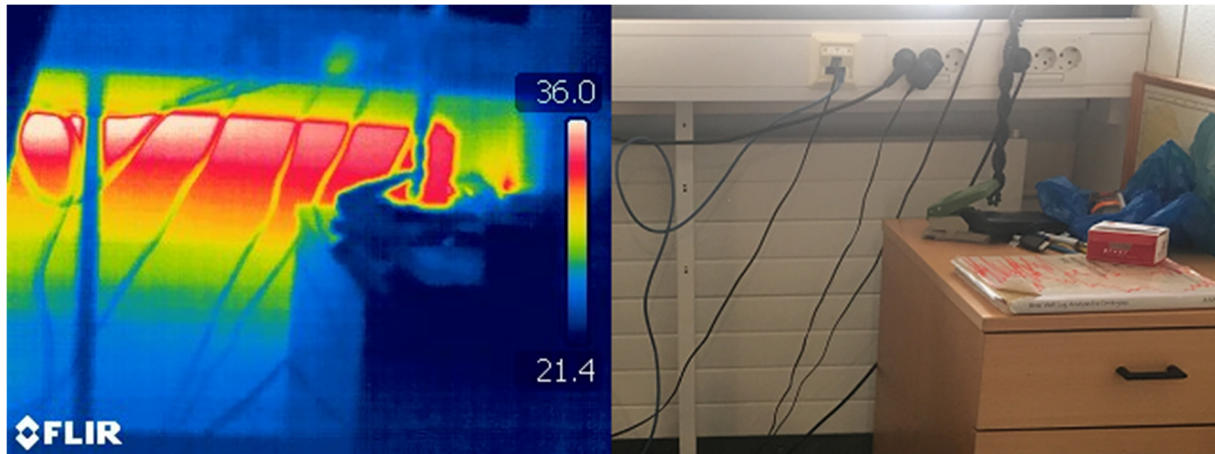


FIGURE 10: Heat consumption values per inhabitant, weighted with the net
floor area for 7 different types of examined building (photo taken by
Gunnlaugur M. Einarsson, 29/09/2016, ÍSOR, Iceland)

$$\log \left( \Delta t_{rad\_des} \right) = \frac{(t_{w\_su\_des} - t_{w\_re\_des})}{\ln \left[ \frac{(t_{w\_su\_des} - t_{id})}{(t_{w\_re\_des} - t_{id})} \right]} \qquad (7)$$

Total heat consumption consists of not only heat consumed by radiators, tap water heating is also considered as a part of the heat consumption. With the help of Equation 7, radiator heat consumption is known for design conditions for the whole system for each building type (Valdimarsson and Tryggvason, 2005).

Relative heat load of the radiator is calculated according to Equation 8:

$$\frac{\dot{Q}_R}{\dot{Q}_{R-0}} = \left( \frac{\log(\Delta T_{RAD})}{\log(\Delta T_{RAD-0})} \right)^{\frac{4}{3}} \qquad (8)$$

where   $\Delta t_{RAD-0}$ = Radiator temperature difference between the supply and return water

Figure 11 shows the temperature of the return water in the function of different building types. The supply temperature was assumed with a constant level for each building (see Figure 14 later). However, building types 2 and 7 have a modern 80/40 and 75/32 heating system, which provides the possibility to utilize better available heat to a lower level. The existing Hungarian district heating systems has a 90°C supply and 70°C return temperature radiators in design conditions, which requires a higher temperature. In that case, the return water is warmer than 60°C in design condition, which makes the system inefficient, furthermore reinjection temperature is also very high, 67.76 °C.
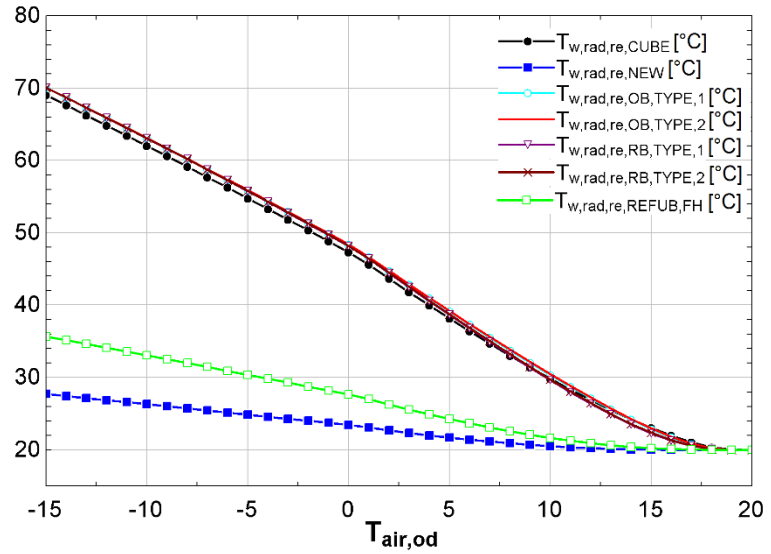


FIGURE 11: Return water temperature from the radiators as a function of different building types in the designed district heating system

In Figure 7, it was shown that the system intermediate, is the temperature, which is available from the geothermal field, considering the heat exchanger, while the system supply is the temperature, which is required by the heat market. The fact of the higher requirement, shown in Figure 12, is simply caused by out-dated buildings and secondary circles. To decrease the system supply temperature, two possible scenarios are considered in the further part of this study.
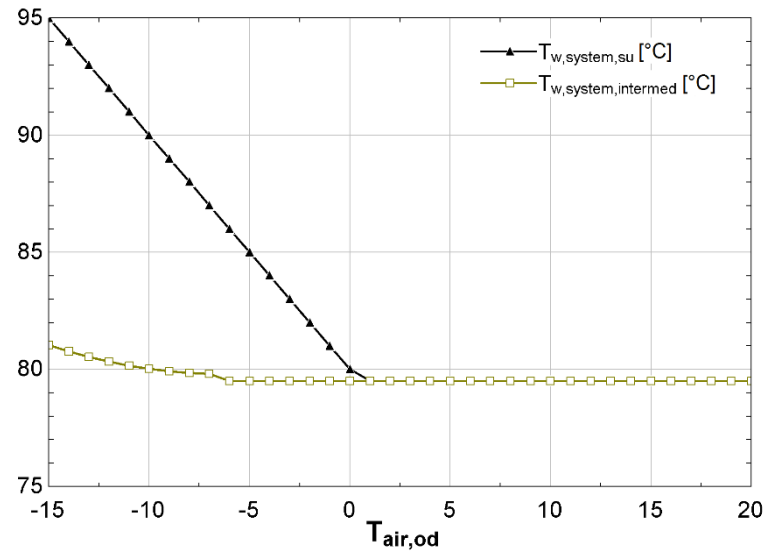
**4.3.4 Mass flow calculation**

Mass flow in the primary circle coming from the geothermal well is assumed at a constant level with 230



FIGURE 12: Supply and intermediate water temperature of the designed district heating system

l/s, as shown in Figure 13. In the secondary circle, mass flow is depending on the heat requirements due to the outdoor temperature. Eventually mass flow in the secondary side is also related with conditions of the radiator system. The mass flow is given by Equation 9.

$$\dot{m}_{des} = \frac{\frac{Q\_rad\_des}{cp\_w}}{(t_{w\_su\_des} - t_{w\_re\_des})} \qquad (9)$$

where  $\dot{m}_{rad\_des}$ = Radiator mass flow (secondary circle) in design condition [kg/s];

$Q\_rad\_des$ = Heat consumption in design condition [kW];

$cp\_w$ = Specific heat of the water [kJ/kg K];

$t_{w\_su\_des}$ = Supply water temperature of the secondary system in design condition[°C];

$t_{w\_re\_des}$ = Return water temperature of the secondary system in design condition [°C].
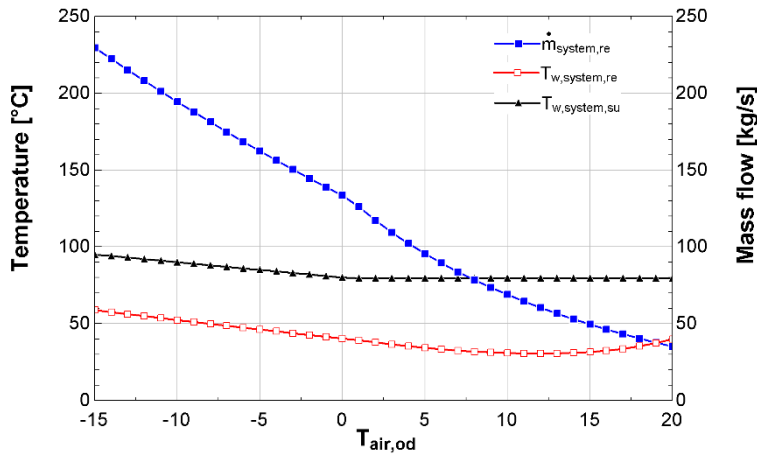
FIGURE 13: Return and supply water temperature as a function of mass flow for designed district heating system

It is also important to take into account the heat loss caused by transmission pipelines. To describe this quality of pipeline, the tau value ($\tau_{des}$) gives a proper value between 0-1, where 1 means a totally insulated pipeline and 0 is a pipe which loses all the heat content of the heating fluid. This parameter of the pipeline bears on the supply and return temperature of the system. If the pipeline heat losses are too high, the system requires higher and higher heat consumption (Valdimarsson and Tryggvason, 2005), as shown through Equation 10:

$$\tau = \tau_{des} \left( \frac{\dot{m}_{rad\_des} + \dot{m}_{tap\_des}}{\dot{m}_{rad} + \dot{m}_{tap}} \right)^{\frac{4}{3}} \tag{10}$$

where  $\tau$  = Heat loss coefficient for a district heating pipeline [%];
$\tau_{des}$ = Heat loss coefficient for district heating pipeline in design condition [%];
$\dot{m}_{rad}$ = Radiator mass flow (in secondary circle) [kg/s];
$\dot{m}_{tap}$ = Mass flow for tap water heat (in secondary circle) [kg/S].

Figure 14 shows a schematic drawing of the designed district heating system. Pipeline heat loss was considered only between points 2 and 3/b in Figure 14. The pipeline between the power plant and block building exists, therefore it was assumed with 0.94 pipeline coefficient value (Appendix VIII). In the cases for the rest of the building connections, it was assumed that the existing pipeline has to be extended to link together family houses and new buildings (Appendix VIII) with a 0.96 pipeline coefficient value considering that this is a newly built pipeline, for only a few hundred metres' distance.
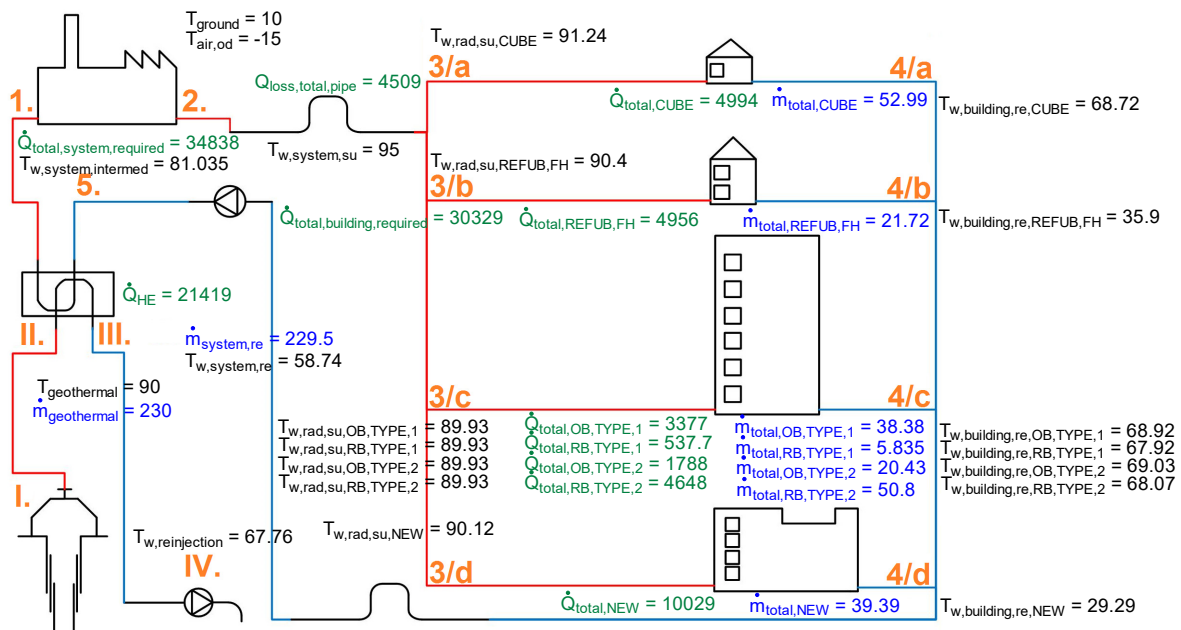


FIGURE 14: Schematic drawing about the designed district heating system

## 5. RESULTS

The most important result of the examination is that the natural gas boiler could be replaced most of the time within the heating season and it is possible to reduce the total heat consumption of the boiler to 12854 GJ/year. In Figures 15-17, an orange colour triangle shows the necessary heat consumption provided by the boiler within a year. Obviously, tap water heat consumption is considered as a base load during the whole year, according to the usage 0.147 kW/inhabitant, therefore out of the heating season this is the only heat need for the buildings. Return water temperature is 58.74°C and reinjection temperature is also high; 67.76°C. Considering this result, it is possible to design a more efficient system.

*Scenario A: "Status quo"*

A significant part of the heat market (building types 1, 3 and 5) is badly equipped with high temperature radiators (90/70), which have a relatively small surface. The only assumed modification here is the radiator system work up in building types 1 and 2 because these buildings are not connected to the district heating system now and are usually equipped with a firewood stove. The calculations find that the gas boiler can be replaced in a range of 127-139 days within the heating season, when the outdoor temperature is colder than 0 or -1°C. It means that the geothermal water reduced the usage of the natural gas boiler on average to 55-67 day a year. The system requires a 435.6 TJ thermal output, however, the gas boiler has to run for two months, but 97.05 % of the thermal output provided by geothermal. The utilization provided by the gas boiler is marked with an orange colour triangle (shown in Figure 15). This scenario is mainly a theoretical solution (Figure 15), because the significant number of out-dated buildings (such as types 1, 3 and 5) makes the system inefficient.
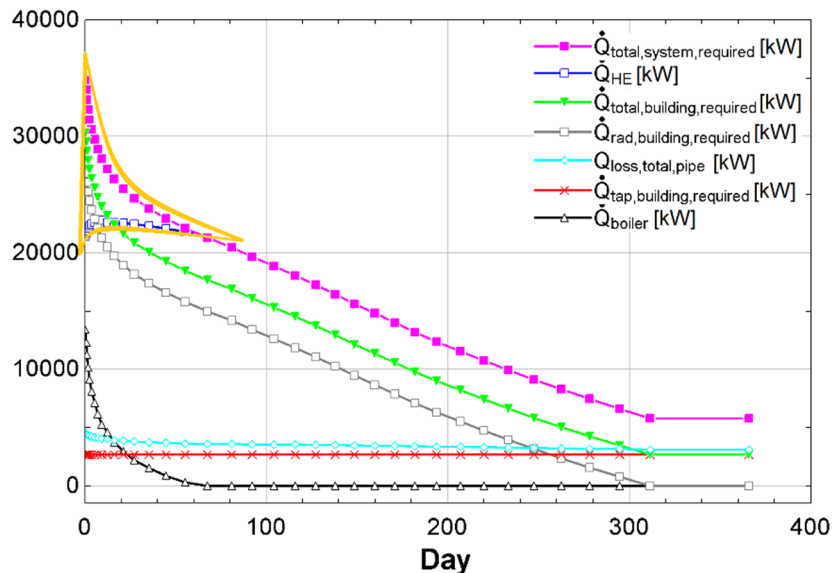


FIGURE 15: The most important heat consumption results of the designed district heating system in case of Scenario A

*Scenario B: "Radiator replacement"*

According to previous calculations, it was seen that the size of the radiator is the crucial element of the system. In the second case it is assumed that only the radiators will be replaced in out-dated buildings (building types 1, 3, and 5), and also in refurbished block buildings (building types 4 and 6) by installing 80/40 radiators with a bigger surface. In that case, the system requires only 391.2 TJ thermal output, with a very similar renewable/fossil fuel ratio as Scenario A assumes, or 97.98% geothermal and 2.02% natural gas usage. Gas boiler usage is marked with orange colour triangle (see Figure 16.), representing a lower area than in the case of Scenario A. This case assumes that the natural gas boiler is necessary for only 44 days in a year. This reconstruction requires a relatively low expenditure and manpower, considering that the recorded total energy consumption it saves is around 8-10%.

*Scenario C: "Complex refurbishment"*

This alternative assumes full refurbishment, including additional insulation, replacement of the windows, doors, radiators and reconstruction of the roof area. More specifically; building type 1 is developed similarly to type 2, building type 3 is developed similarly to type 4, and type 5 is developed similarly to type 6. It requires refurbishing 280 houses from building type 1, seven buildings from type 3 and five buildings from type 5, which represents almost the half of the heat market (104,087 net m$^2$) in floor area. In this case (Figure 17), the system requires only 345.8 TJ thermal output, which is significant 17-19% savings compared with Scenario A (in system level). The ratio between renewable and fossil fuel is very similar to the previous two cases; 97.93% geothermal and 2.07% natural gas usage.

According to the final results (shown in Table 5) in my opinion, Scenario-C is the most perspective way to design an efficient geothermal district heating system in Debrecen with the existing block buildings to replace a significant part from the currently used natural gas resource.
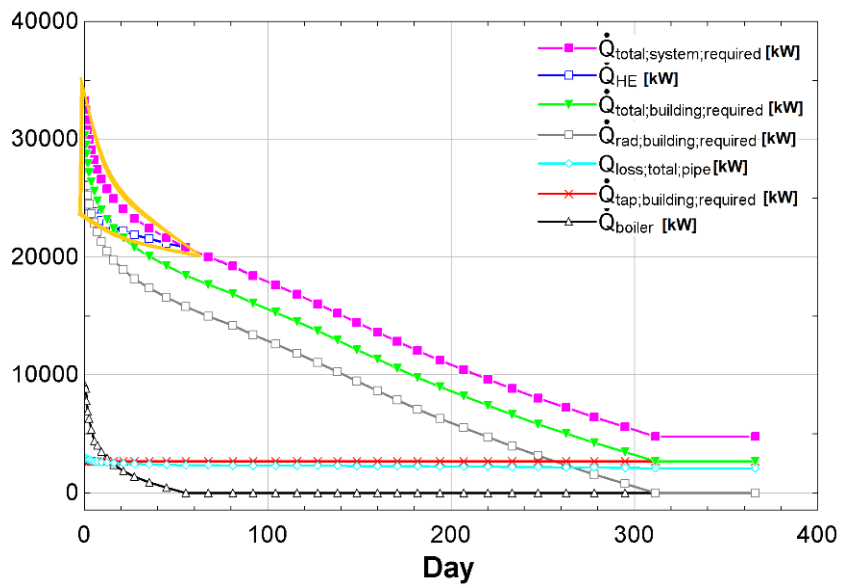


FIGURE 16: The most important heat consumption results of the designed district heating system in case of Scenario-B
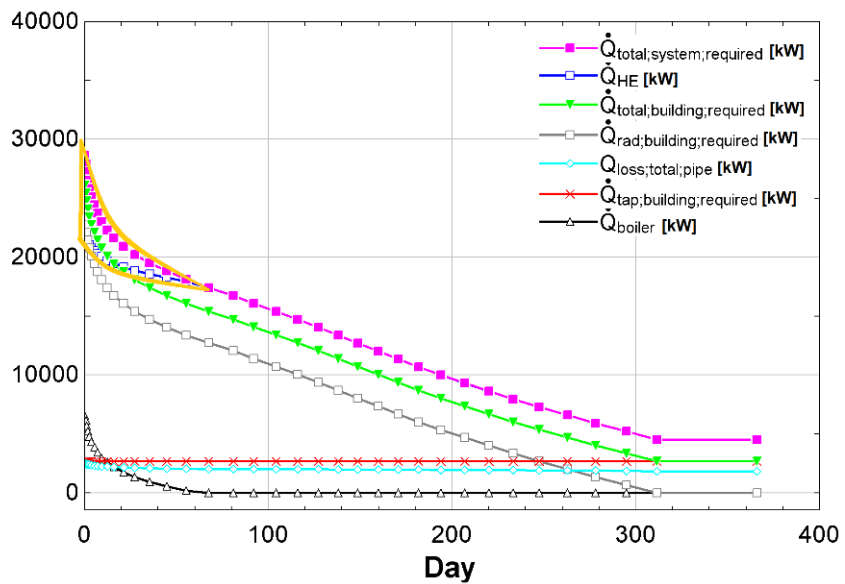


FIGURE 17: The most important heat consumption results of the designed district heating system in case of Scenario-C

TABLE 5: Comparison of the final results for the possible contribution of geothermal energy

| | Geothermal energy | | | Gas boiler | | Total system consumption |
|---|---|---|---|---|---|---|
| | **[TJ]** | **[%]** | **Saved natural gas [m$^3$]** | **[TJ]** | **[%]** | **[TJ]** |
| Scenario A | 422.8 | 97.05 | 111,252 | 12.854 | 2.95 | **435.6** |
| Scenario B | 391.2 | 97.98 | 102,957 | 8.068 | 2.02 | **399.3** |
| Scenario C | 345.8 | 97.93 | 91,007 | 7.324 | 2.07 | **353.1** |

## 6. CONCLUSION

1. It has been established that the potentially available, relatively low-temperature geothermal water is more than enough to replace a significant part of the installed thermal capacity of the natural gas fired district heating power plant.
2. The limited possibilities of using geothermal water with high temperatures require paying special attention to the heat market facilities to organise an effective system.
3. Only the replacement of the old radiators could decrease the system heat consumption itself. Larger radiators do not require a high supply water temperature, which is not common in Hungary.
4. Complex building rehabilitation is the best way to combine with geothermal energy, which causes significantly lower heat consumption and a lower radiator supply temperature.
5. Considering the current energy production running with natural gas cogeneration in Debrecen, the replacement of the thermal capacity could cause a significantly lower efficiency of natural gas based electricity production. It is worth considering to replace all the fossil fuel based energy production (thermal and electricity production as well), not only the thermal output part.

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**APPENDIX I: Hungarian standard on regional required outdoor design temperature**
**(Standard Number: MSZ-04-140/3-87)**
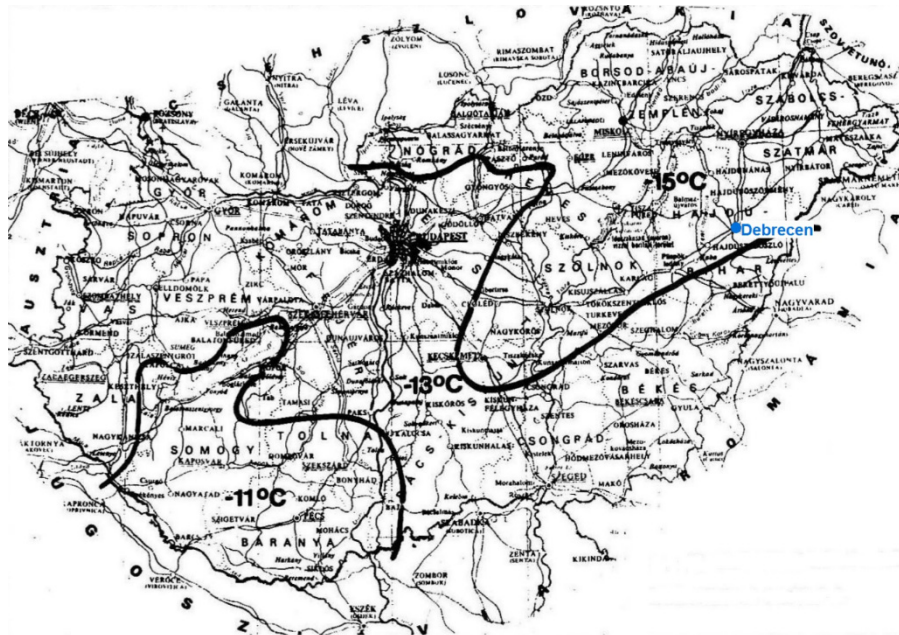


**APPENDIX II: Lowest mean daily temperature records of Debrecen (1960-2010)**
(OMSZ, 2016)

| Mean daily temperature [°C] | Date | | | Mean daily temperature [°C] | Date | | |
|---|---|---|---|---|---|---|---|
| -15.1 | 17 | January | 1964 | -17.0 | 19 | January | 1964 |
| -15.2 | 8 | January | 1985 | -17.1 | 22 | January | 1964 |
| -15.4 | 10 | February | 2005 | -17.2 | 19 | January | 1982 |
| -15.5 | 12 | February | 1985 | -17.5 | 13 | January | 1987 |
| -15.8 | 17 | January | 1982 | -17.5 | 21 | January | 1964 |
| -16.4 | 24 | January | 1963 | -17.9 | 17 | January | 1963 |
| -16.7 | 18 | January | 1982 | -18.4 | 18 | January | 1963 |
| -16.8 | 14 | January | 1982 | -19.2 | 13 | January | 1964 |

**APPENDIX III: Degree days curves of Hungary** (Baumann, 2012)
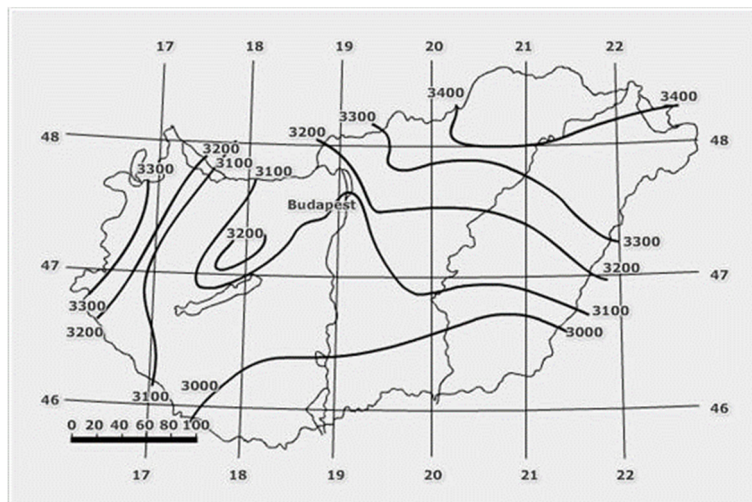
**APPENDIX IV: Summary table for the most important parameters and results for different building types**

| | Parameter | 1. Old Hungarian "Cube" house | 2. Refurbished family house | 3. Old block building type P100 | 4. Refur. block build. type P100 | 5. Old block building, type C-1 | 6. Refur. block building, type C-1 | 7. New appartment house |
|---|---|---|---|---|---|---|---|---|
| 0 | Pipeline heatloss coefficient | 0.96 | 0.96 | 0.94 | 0.94 | 0.94 | 0.94 | 0.96 |
| 1 | Gross area [m2] | 100 | 200 | 9750 | 9750 | 6366 | 6366 | 1928 |
| 2 | Net area [m2] | 100 | 200 | 7341 | 7341 | 4940 | 4940 | 1652 |
| 3 | Inhabitant/unit | 3 | 4 | 294 | 294 | 198 | 198 | 56 |
| 4 | Kl value [kW] | 0.4978 | 0.3055 | 12.547 | 6.446 | 9.384 | 4.702 | 1.969 |
| 5 | Transmission heat loss/unit | 14.461 | 6.234 | 240.153 | 66.435 | 194.61 | 57.518 | 35.693 |
| 6 | Transmission heat loss/inhabitant | 4.820 | 1.559 | 0.817 | 0.226 | 0.983 | 0.290 | 0.637 |
| 7 | Filtration heat loss/unit | 2.964 | 4.458 | 198.982 | 159.185 | 133.836 | 107.068 | 33.21 |
| 8 | Filtration heat loss/inhabitant | 0.988 | 1.115 | 0.677 | 0.541 | 0.676 | 0.541 | 0.593 |
| 9 | Radiator design consumption/unit [kW] | 17.425 | 10.692 | 439.135 | 225.62 | 328.446 | 164.586 | 68.903 |
| 10 | Tap water consumption/ unit [kW] | 0.441 | 0.588 | 43.218 | 43.218 | 29.106 | 29.106 | 8.232 |
| 11 | Tap water constant/inhabitant [kW] | 0.147 | 0.147 | 0.147 | 0.147 | 0.147 | 0.147 | 0.147 |
| 12 | 10+11 [kW] | 17.87 | 11.28 | 482.35 | 268.84 | 357.55 | 193.69 | 77.14 |
| 13 | Heating system design parameters [°C] | 90/70 | 80/40 | 90/70 | 90/70 | 90/70 | 90/70 | 75/32 |
| 14 | Heat consumption in design condition/ person [kW] | 5.96 | 2.82 | 1.64 | 0.91 | 1.81 | 0.98 | 1.38 |
| 15 | Heat consumption in design condition/square metre [kW] | 0.179 | 0.056 | 0.066 | 0.037 | 0.072 | 0.039 | 0.047 |
| 16 | Number of inhabitants in the system | 840 | 1760 | 2058 | 588 | 990 | 4752 | 7280 |
| 17 | Heat consumption of the building group in design consumption [MW] | 5.002 | 4.963 | 3.376 | 0.538 | 1.788 | 4.649 | 10.028 |
| 18 | Number of buildings in linked to the system | 280 | 440 | 7 | 2 | 5 | 24 | 130 |
| 19 | K 1 value / m$^2$ | 4.98 | 1.53 | 1.71 | 0.88 | 1.90 | 0.95 | 1.19 |
| 20 | Size of system [MW] | 9.97 | | 10.35 | | | | 10.03 |
| 21 | Heated floor area [m2] | 116000 | | 209329 | | | | 214760 |
| 22 | Number of inhabitants | 2600 | | 8388 | | | | 7280 |

**APPENDIX V: Floor map of type P100 prefabricated concrete panel block building**
(Hrabovszky-Horváth, 2015)
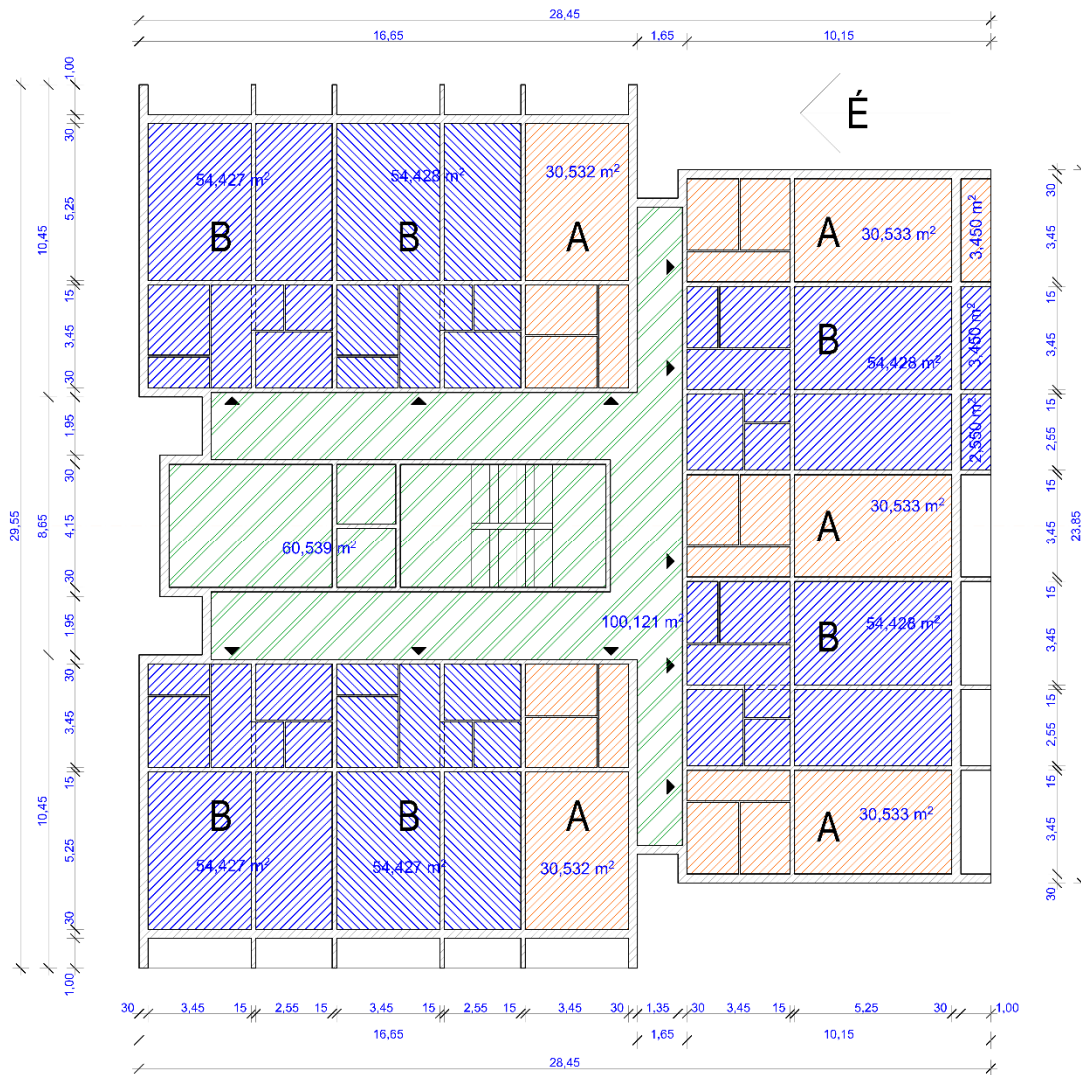
**APPENDIX VI: Floor map of type MOT I. 58-264/76-K C-1 prefabricated concrete panel block building** (Szirmai, 1976)
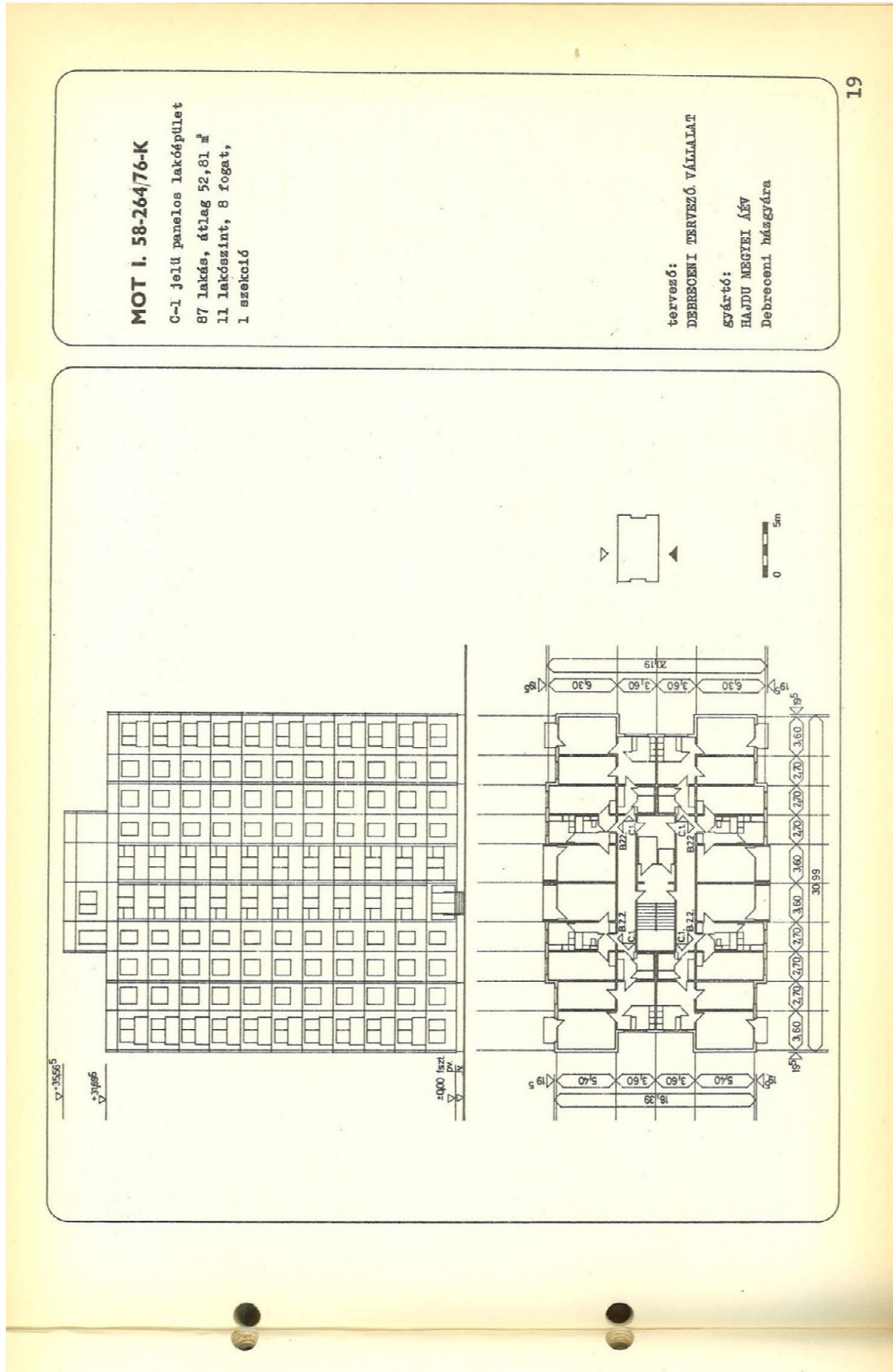
**APPENDIX VII: Floor map of newly designed apartment building in Hatvan street 62, Debrecen** (Új Lakás Debrecen, 2016)

**APPENDIX VIII: Location map for the examined area in Debrecen**
drawn with background from Google Earth (2016)