# Integrated and sustainable energy concepts for urban neighbourhoods – a generic approach based on Austrian experiences

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## Abstract
Larger Austrian cities are confronted with the necessity to develop new districts and to revitalise existing neighbourhoods. This process includes the development of new energy supply systems. Conventional in Vienna usually are gas grids for decentralised use on the one hand and district heating systems on the other hand. But both systems remain unsatisfactory: The simple gas supply is not in line with sustainability and green house gas (GHG) emission reduction goals, whereas district heating (with combined heat and power (CHP) as one major source) is confronted with serious economic problems due to changes at the electricity markets and municipal utilities thus refuse to enlarge their district heating systems.

The paper describes the process for selecting alternative heat supply concept for a new urban settlement. The assessment of locally available renewable resources and infrastructures sets the basis for the identification of technically feasible options. After definition of specific heat supply ideas, concept design phase leads to dimensioning of elements of the heat supply concepts. Based on the technical description an environmental and economical assessment was carried out. The different technical and energy-economical energy concept options are assessed by means of a life-cycle cost analysis.

This generic approach was applied in the concept phase of the development of a new neighbourhood area in the City of Vienna called Donaufeld. In this feasibility study several technical options for heat supply were developed together with experts within the administration of the city and the municipal energy supplier.

Main outcome of the project are life-cycle costs for every heat supply concept. Alternative concepts with heat pumps and geothermal probes as main elements have similar life cycle costs than district heating. These concepts have a high share of locally produced renewable energy and can meet local 2000 Watt targets. However, higher investment costs have to be covered at the very beginning which is crucial for existing funding conditions for buildings.

## Background
Cities are facing the challenge of developing new districts and increasing the density of existing districts' due to constant urbanisation. In addition, the development of energy supply solutions for these city districts is part of this process. Conventional solutions are gas networks and decentralised use of gas boilers in buildings or district heat supply – but both systems are unsatisfactory with regard to new urban areas. The increasing need for sustainability and the targets of reducing the GHG emissions are not in line with simple gas supply. Owing to the changes in the electricity market, district heating (with cogeneration and gas as one of the main sources) is confronted with serious economic problems recently. Hence, urban energy suppliers avoid expanding the district heating plants. In addition, district heat supply reaches its limits of economic efficiency at lower energy density in the supply areas. Moreover, the question rises whether it makes a good economic sense to have two infrastructures for heating and energy at decreasing heat consumption.

The city of Vienna faces a particularly big challenge. There are 1.77 million people living in Vienna at the moment (as of 2013) [1]. Forecasts say that the city will have more than 2 million inhabitants by 2028 already. This means an average increase of more than 15,000 people per year [2]. Therefore, numerous new districts are built in the "green fields" to meet the housing demand.

The city sets great value on the sustainability of these development areas. In the course of the Smart City initiative [3], targets for living quality, conserving resources and innovation as well as the target values for $CO_2$ emissions and primary energy demand defined in accordance with the requirements of the Zurich 2000-watt society [4]. In order to achieve a sustainable and fair society, the city of Zurich has decided upon the 2000-watt model. According to this model, the known overall average primary energy usage of 2,000 Watt is sufficient for every human being, which equals a yearly energy demand of about 17,500 kWh electricity and heat per person. Thereby, about one fourth of this output (500 Watt primary energy) is available for housing purposes [5].

For the above reasons, the Municipal Department for Energy Planning (MA 20) of the city of Vienna commissioned a study to examine the technical energy supply solutions that are both environmental and economically viable for a concrete urban construction site while taking account of local renewable energy sources. The construction site is the city development area Donaufeld in the north of Vienna.

## City development area Donaufeld

The city development area Donaufeld has a size of about 60 hectares and is located in Floridsdorf, the 21$^{th}$ district of Vienna. According to the guiding principles [6], the target is to develop an energy strategy that leads to an environment and climate friendly district.

This area will be mostly used for residential buildings. There are plans to construct buildings on an area of 757,000 square metres gross floor area and 6,000 apartments. A very dense development is intended with buildings having 5–7 upper floors.

The area will be realised in three construction phases. The first construction site is located southeast of the Donaufeld; the second construction site is located in the northeast. Both are situated east of the grass strip and will be set up in the coming years. The third construction site is located in the west of the green area and will probably only be built in the mid-2020s.

## Methods

### DEVELOPMENT PROCESS

It was the target of the project to develop possible energy supply solutions for the new district Donaufeld in consideration of local renewable energy resources, the examination of the technical feasibility as well as the environmental and economical evaluation. Moreover, it was aimed at involving essential stakeholders of the city of Vienna for new heat supply solutions. For this reason, a project advisory board was announced that includes municipal stakeholders. However, the municipal energy supplier is the main addressee of the study: the energy supplier's next step should be the implementation of the newly developed heat supply solution in concrete development areas.

At the beginning of the project, the members of the project advisory board were asked to submit proposals on how to create a sustainable heat supply for Donaufeld. After that, agreement on a shortlist of possible heat supply options was reached. During the following meetings of the project advisory board, the current status and the interim results were presented and discussed in order to keep the participants informed and give them the possibility to actively contribute their experience and know-how. Thus, the heat supply options could be adjusted to the Viennese general conditions and can expect a higher acceptance.

### CALCULATING AND DIMENSIONING METHODS

The development of heat supply solutions is built on determining the level and density of energy demand as well as analysing the local energy resources. On the basis of the values found, the performance values for space heating and hot water were calculated. The size and the operating mode of the plant were defined according to the heat supply solution.

On the one hand, the energy demand definition is based on determining the maximum permissible value of the heating demand and the expectable building compactness in the construction site; on the other hand, it relies on internal surveys and measurements of buildings that are similar in size and built

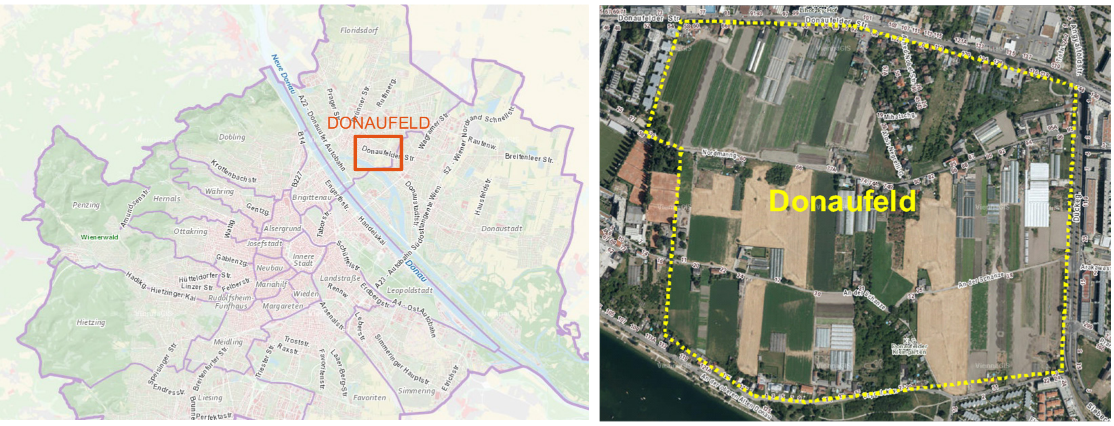


*Figure 1. Overview and site plan of the city development area Donaufeld (Source: Guiding principles of Donaufeld, own additions).*

with a construction standard of about 2010 conducted by the municipal energy supplier. In order to determine the hot water demand [7, 8, 9] and energy demand of households [10, 11, 12] further studies were taken into account.

The heat amount necessary to satisfy the demand for heating and hot water as well as the upstream losses up to the building's technical centre is the relevant factor to determine the heat demand. The system boundary of the value is comparable to the $Q^*_H$ of room heating as well as the $Q^*_{TW}$ of hot water according to the Austrian Standard (ÖNORM) H 5056 [13]. The level for these indicators for room heating is 35 kWh/m²year and 28 kWh/m²year for hot water (referring to the conditioned gross floor area). These values are measured values and are based on a study of similar buildings by the municipal energy supplier. In comparison to the calculated heat demand of a passive house (about 10 kWh/m²year per gross floor area), these values seem to be relatively high. The differences to heat demand calculations according to the requirements for energy performance certificates are additional losses because of heat emission and distribution and higher indoor temperature than used in heat demand calculations. The assessment of the differences to energy consumption is calculated by using the monthly energy balance method for issuing the energy performance certificate in Austria [14]. The design values for the building envelope are as followed: U-value for wall = 0.12 W/m²K, U-value for windows (total) = 0.90 W/m²K, U-values for roof = 0.10 W/m²K. The ratio between surface and building volume = 0.35 1/m and indoor temperature was set to 22 °C in contrast to 20 °C based to the requirements of the energy performance certificate.

The construction site and the surrounding exploitations were examined to define the local renewable energy resources. A first limitation was done by the study "Options for designing the Viennese energy systems in the future" (Ger. "Optionen für die Gestaltung des Wiener Energiesystems der Zukunft") [15] of the Vienna University of Technology (TU Wien). This study gives an overview of plausible options for renewable energy sources within the city of Vienna. With respect to the energy resources mentioned in the study, the local circumstances were examined regarding renewable energy resources as a second limitation. The use of ground-source heat pump and solar energy is regarded as promising.

This city development area consists almost entirely of residential buildings. There is no remarkable amount of waste heat within the construction site (e.g. due to cooling systems of commercial areas) that could be included in the concept. Unfortunately, big potential for waste heat lies outside of the construction site, e.g. in buildings such as the indoor sporting arena "Albert-Schulz-Halle" or the shopping mall "Donauzentrum". These objects were not taken into consideration, because their distance to the border of the construction site is bigger than 500 metres and other city development areas are planned that are closer to those objects.

## Results

### LIST OF ENERGY SUPPLY SOLUTIONS THAT HAVE BEEN EXAMINED IN DETAIL (SHORTLIST)

The selection of energy supply options is divided into reference options, options with heat network (with/without district heating) and an option without heat network (see Figure 2).

Reference options are those options that are normally used at the moment in Vienna. On the one hand, there is the op-

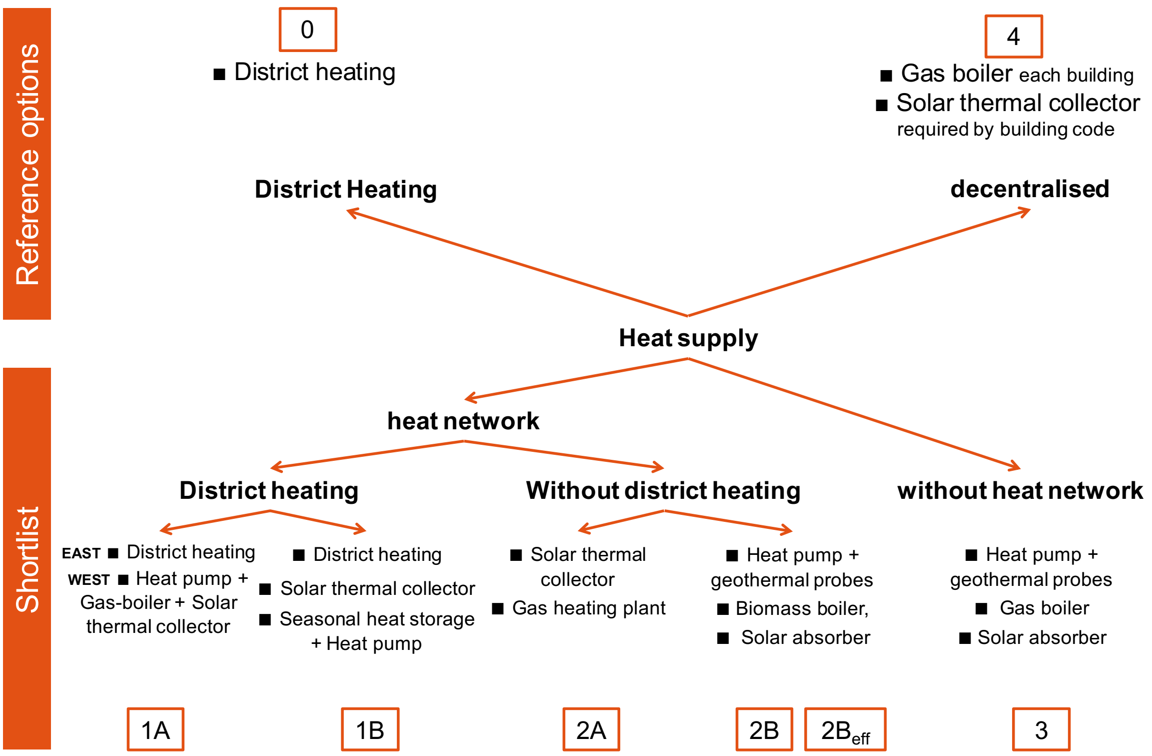


*Figure 2. Shortlist of energy supply options (Source: own depiction).*

tion of district heating connected to the building (**option 0**); on the other hand, there is the option of a gas boiler in every building (**option 4**). According to the requirements of the Viennese building regulations, however, heat supply must not be provided by a gas boiler only. In order to reduce the $CO_2$ emissions, solar thermal energy of one square meter collector surface per 100 square meters living area of the building has to be considered when using gas boilers as main heat generation system.

Options including a heat network and district heating are divided as follows:

- Option 1A: Construction phase 1 and 2 (east of the green area) will be supplied with district heating. The supply of construction phase 3 (west of the green area) will be ensured with a heat pump on the building site and a central gas boiler to cover peak loads as well as solar thermal energy on the roof of the building.
- Option 1B: This option tries to reach a maximum coverage with solar thermal energy. The solar heat will be saved in seasonal storages. One heat pump per seasonal storage as well as district heating is available to cover the additional heat demand. The seasonal storage should be a concrete container filled with water for thermal storage. There are two additional heat systems as heat pump is used for base load and district heating just for peak load.

Options including a heat network without district heating are divided as follows:

- Option 2A: Solar thermal energy is intended on about 30 % of the roof surface. The remaining heat demand will be supplied with central gas heating plants per construction phase.
- Option 2B: Option 2B consists of a small micro heat networks for around 4–7 buildings. This covers an area without street crossings. Heat is provided by heat pumps and geothermal probes. An exhaust air heat pump for buildings will be used for hot water. The electricity yield of the photovoltaic system on the roof will be directly utilised for the pump. Solar absorbers and heat pumps are used for regeneration of geothermal probes.
- Option 2Beff: Option 2Beff complies with option 2B, but has a reduced energy demand and thermal load by integrated ventilation systems with heat recovery.

Option 3 is planned without a heat network. Instead, one heat pump per construction site will be installed. The heating resources are geothermal probes. Solar absorbers and heat pumps are used for regeneration of geothermal probes in summer.

In the course of this study, the examination of a high number of technologies and supply systems was intended. Figure 3 provides an overview about the different possibilities to design the single options. It depicts the determinations for heat supply, heat networks, the temperature level of heat networks, ways of storage, hot water supply as well as the way of solar energy usage.

With regard to the option using geothermal probes, heat supply for the building as well as the regeneration of the geother-

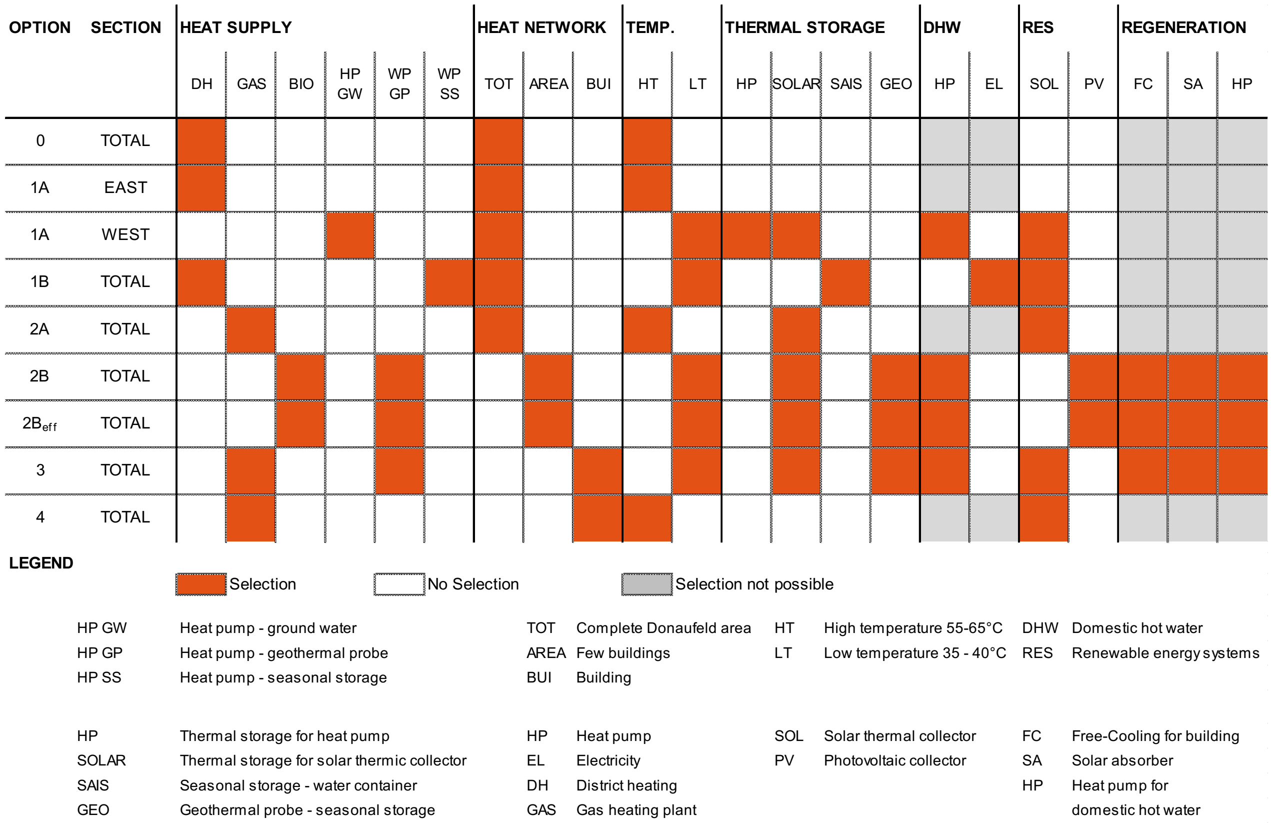


*Figure 3. Overview about the different technologies of energy supply options.*

mal probes have to be considered. According to the concepts of option 2B, 2Beff and 3, which include fields of geothermal probes, it is necessary to balance the heat exchange in geothermal probes equally. That means that the energy amount used for room heating and hot water in winter has to be reproduced in summer. Otherwise, there is the threat of the soil cooling down in the long-term (up to the freezing of probes) and a decrease in the efficiency of the energy supply solutions [16].

In order to regenerate the geothermal probes, free cooling of the apartments as well as the storage of heat from heat supply systems is intended. The following methods are examined to be used as heat supply systems: solar absorbers, reverse cycle heat exchangers (used as recovered heat), photovoltaic-thermal collectors (PVT), thermal solar plants and hot water heat pumps. The decisive factors are their possible application in summer and low production costs for the heat. For this project, solar absorbers and heat pumps are selected for thermal regeneration purposes.

### ENVIRONMENTAL EVALUATION OF ENERGY SUPPLY SOLUTIONS

For environmental assessment, the indicators primary energy and $CO_2$ emissions are used. The energy consumption per supply option is calculated by means of an annual balance based on the calculation methods according to the Austrian Standard (ÖNORM) H 5056. This is a monthly energy balance taking into account energy losses for heat emission, distribution, storage and generation. The heat demand for room heating and hot water has already been defined (see chapter "Method"). Based on these values, the losses outside of the building due to heat distribution, heat storage as well as heat supply were calculated.

The results are annual balanced final energy parameters of every energy supply option. In order to identify the $CO_2$ emissions and primary energy parameters, the final energy was multiplied by the conversion factors in Table 1.

The values for specific primary energy demand per square meter gross floor area of the options are between 21 and 75 kWh/m²year. The lowest primary energy demand (about 21 kWh/m²year) is caused by district heat supply (option 0). This value is enabled by a low primary energy factor of 0.33 for district heating in Vienna caused by the allocation between electricity and heat for CHP plants. By contrast, the values for gas heating are the highest (option 4 and 2A). The options with heat pumps (2B, 2Beff and 3) have a specific primary energy demand between 40 and 50 kWh/m²year. Primary energy factor for electricity is 1,91 and is based on a the mix of electricity production in Austria. This value is stated in the OIB G 6 which defines minimum energy performance requirements for buildings and primary energy factor for the Energy Performance Certificate.

Efficient heat pumps lay good foundations for a low primary energy value, whereas peak load boilers increase this value. The options that use a mixture of district heating and heat pumps (option 1A and 1B) require around 30 kWh/m²year.

A similar picture can be seen when evaluating the $CO_2$ emissions (see Figure 5). In terms of this indicator, options with gas supply are responsible for the highest $CO_2$ emissions; whereas options with district heating cause only very low emissions. In comparison to primary energy, options with biomass boilers (option 2B and 2Beff) achieve better value due to a low $CO_2$ factor of 4 g/kWh.

In Figure 6, the energy supply options were measured by the primary energy performance target of 500 W/person (based on the non-renewable primary energy factor). This value is related to the 2,000 Watt model of Zurich. The value 500 W is the share for residential buildings. The figure shows that the options using mainly gas supply cannot keep the 2,000 watt targets, as they already shortly fall below or even exceed the targets regarding the energy demand of room heating and hot water. The values for the use of electricity in apartments (248 Watt/person) have not been considered here. The options using district heating as well as those using heat pumps, are significantly below the value of 500 W/person and can meet the target also when taking the electricity use of the apartments into account.

### ECONOMICAL EVALUATION OF ENERGY SUPPLY SOLUTIONS

The economic evaluation is separated into investment costs for the construction of heat supply and life cycle costs over a period of 40 years. The life-cycle costs contain investment costs, operational costs and the residual value of the energy supply systems. The operational costs include energy, maintenance, renewal at the end of its service life, management and a profit margin for energy supply companies. The nominal discount rate is 3 %/a. The life-cycle costs shown in Figure 7 present bandwidths of net present value taking into account following sensitivity analysis: with/without consideration of residual value, energy price increases of 2 %/a and 4 %/a.

The assumptions for the cost calculation were chosen cautiously, so as not to imply too many expectations, for example by high energy price increases.

The results in Figure 7 show advantages for gas boiler solutions (variant 4). The heat pump solution without heating networks (variant 3) as well as with micro-heat network (variant 2B) come to similar cost levels as district heating (variant 0). Additional energy efficiency measures in variant 2Beff are not cost optimal. The variant with maximum amount of thermal solar collectors on buildings (1B) shows that this

**Table 1. Conversion factors for primary energy and $CO_2$ (source: OIB Richtlinie 6, edition 2015; Wien Energie).**

| Source of energy | Primary energy factor | Primary energy factor renewable | Unit | $CO_2$ emission parameter | Unit |
|---|---|---|---|---|---|
| Electricity | 1.91 | 0.59 | – | 276 | g/kWh |
| Gas | 1.17 | 0.00 | – | 236 | g/kWh |
| District heating in Vienna | 0.33 | 0.06 | – | 20 | g/kWh |
| Biomass | 1.08 | 1.02 | – | 4 | g/kWh |

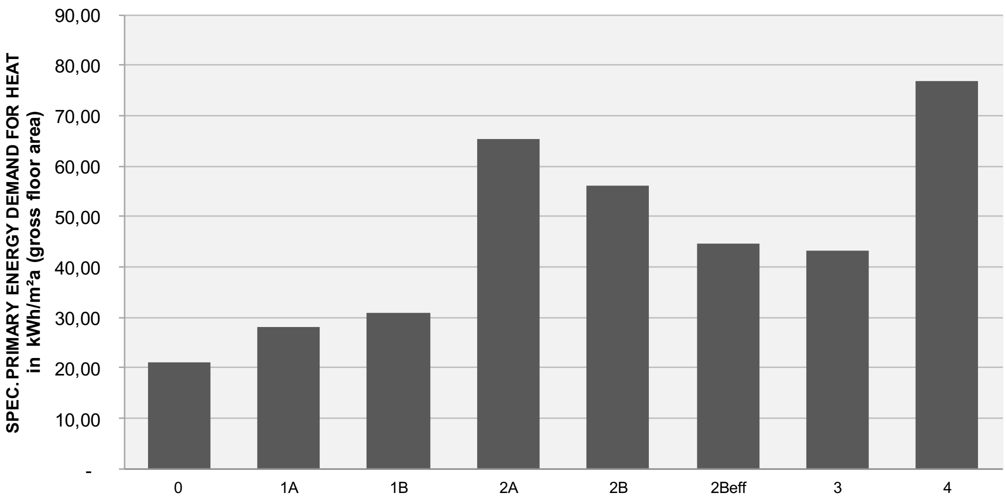


*Figure 4. Area specific primary energy of the energy supply options.*

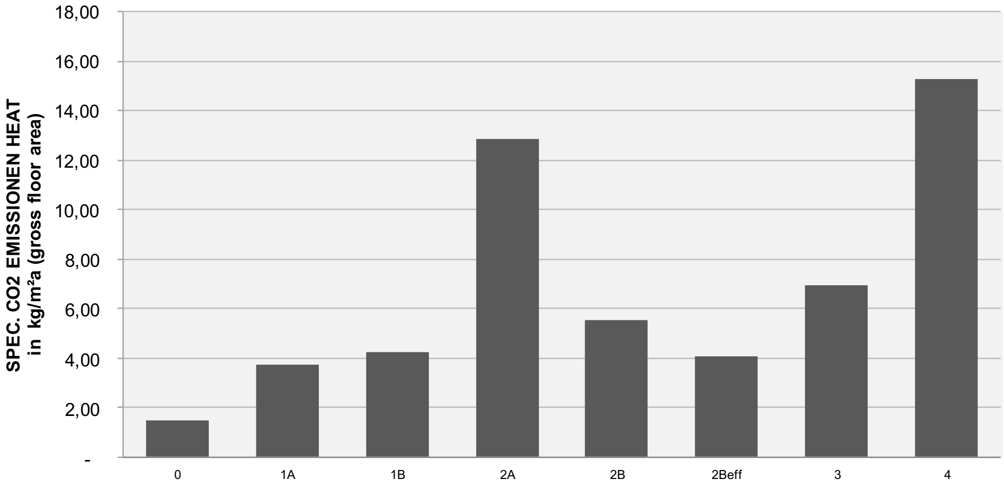


*Figure 5. Area specific $CO_2$ emissions of the energy supply options (source: own depiction).*

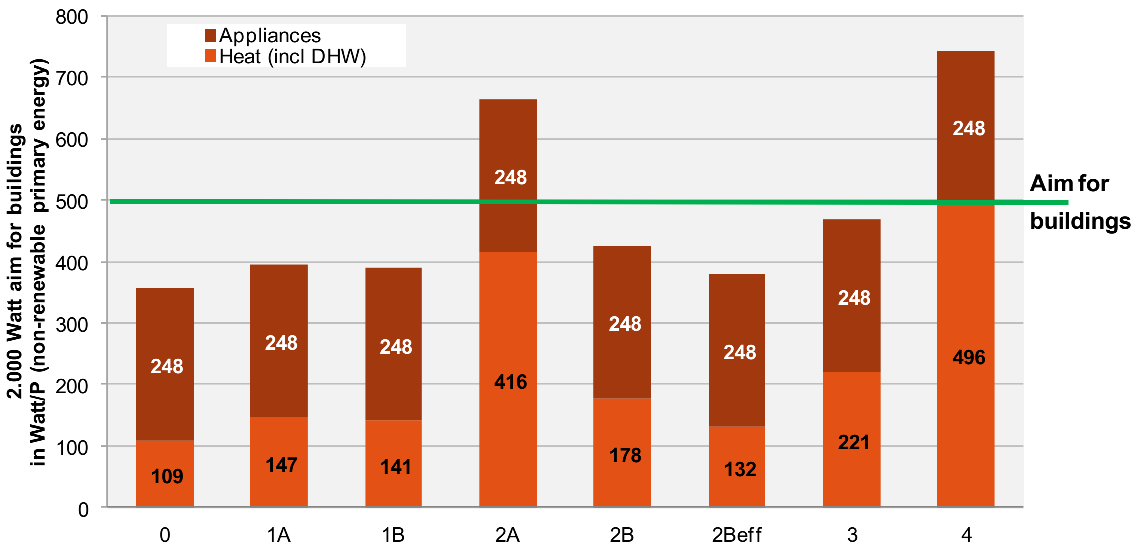


*Figure 6. Orientation towards 500 Watt non-renewable primary energy performance per person for living (source: own depiction).*

concept is not economically feasible for the framework conditions of this area.

Regarding investment costs in Figure 8, those variants with a low share of local, renewable energy sources have lower investment costs (variants 0 and 4). Variants with a high share of local renewables, in particularly those with large areas of thermal solar systems (variant 1B), have the highest investment costs. Combined solutions of heat pump and peak load boilers in variants 2B and 3 have slightly higher investment costs than district heating.

## Conclusions

The conclusions focus on the following three supply concepts: gas (options 2A and 4), district heating (option 0) and heat pump (options 2B, $2B_{eff}$ and 3). Cost for option 1B are too high because the technical concept does not fit to the framework conditions of the planned buildings. Option 1A is divided into two options: one with district heating (construction phase 1 and 2) and another one with heat pump and heat network (construction phase 3). Both solutions are also addressed in other options.

### CONCLUSIONS OF ENVIRONMENTAL EVALUATION

In environmental terms, the decisive indicators are non-renewable primary energy demand and $CO_2$ emissions. The options with gas supply (option 2A and 4) have the highest values of primary energy and $CO_2$. The gas supply options do not meet the 2,000 Watt targets of the city of Vienna and can thus be excluded from a future-oriented heat supply model.

The district heat supply (option 0) reaches the lowest values for both indicators. Hence, district heating plays a leading role at the environmental level. In order to maintain the good

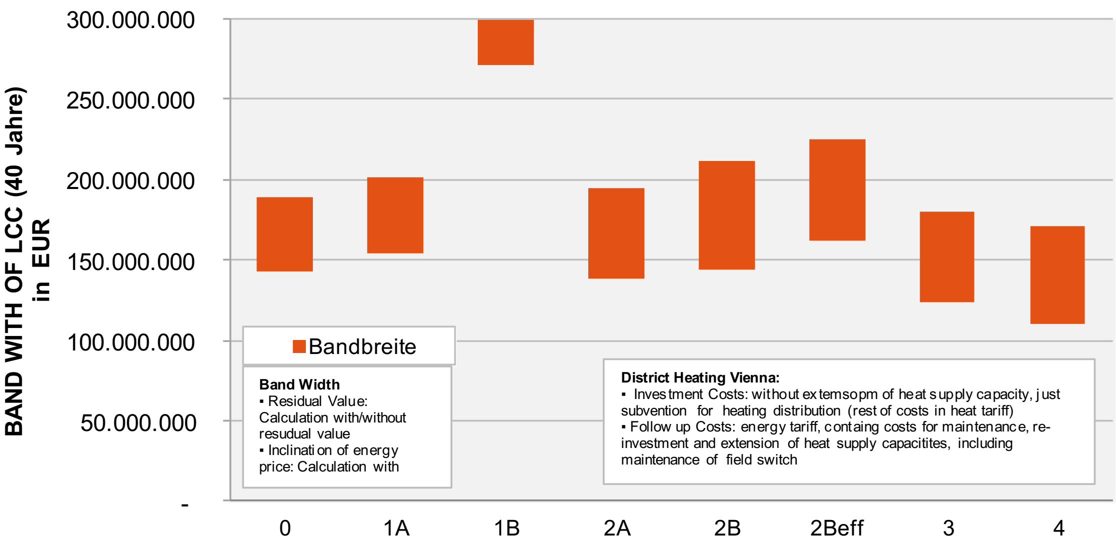


*Figure 7. Bandwidths of life-cycle costs for heat supply options.*

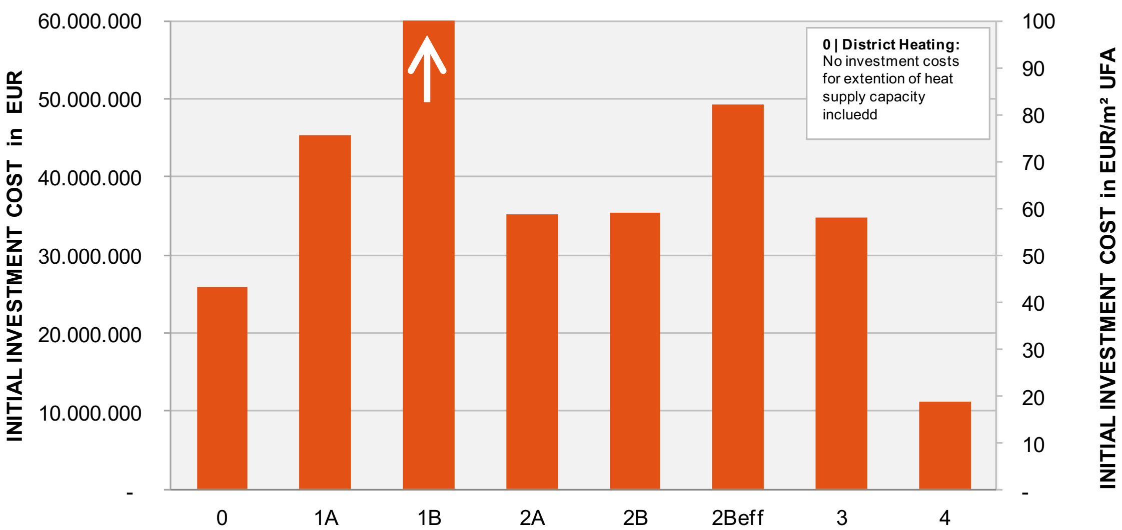


*Figure 8. Initial investment costs for heat supply options.*

environmental evaluation, the low conversion factors for primary energy and $CO_2$ for district heating must be continuously achieved in the future.

For heat pumps with geothermal probes, the level of primary energy and $CO_2$ emission are higher than district heating. However, the 2,000 watt targets can be fulfilled easily. For technical reasons, it is necessary to produce regeneration heat when using geothermal probes to have a seasonal balance between heat extraction and heat storage. This leads to an additional energy demand that is taken into account in the environmental evaluation. From the environmental point of view, heat pump concepts are a meaningful way of heat supply.

#### CONCLUSIONS OF ECONOMICAL EVALUATION

The option with gas supply (option 4) has the lowest value for construction costs, followed by the district heating option (option 0). For district heating different system boundaries are applied: investment costs for district heating do not consider the costs for heat generation, because investments in new heat plans for district heating is included in the energy tariff.

Regarding the heat pump options (options 2B and 3) it is crucial whether the peak load is covered by heat pumps and geothermal probes or by boilers. Peak load boilers can significantly reduce the construction costs. At this point, it is important to consider the disadvantages in environmental evaluation of gas or biomass boilers ($CO_2$ emission, fine dust). Moreover, the supply of regenerated heat in summer does burden the construction costs.

The gas option (option 4) is the most economic option concerning the life-cycle costs. High investment costs and lower operation costs of the option with heat pumps and geothermal probes lead to the same level of life-cycle costs in comparison with district heating.

#### GENERAL CONCLUSIONS

Heat supply by means of heat pumps and geothermal probes has higher construction costs than district heating and gas supply. These additional costs have to be covered during the construction phase of the building. However, there are difficulties to cover additional costs as there are upper limits for construction costs in the residential housing funding program in Vienna. This upper limit is already hard to meet at the moment.

Higher initial investment costs of alternative heat concepts lead to the consideration of new business models regarding the abovementioned cases in order to enable the financing of initial investment. After all, options featuring heat pump solutions can also be used in smaller development areas and independent of district heating. Hence, it is possible to realise the presented plans without a “traditional” energy supplier.

From a technical point of view, the option with heat pumps is far more complex than a district heat supply solution. A heat supply concept with heat pumps considers several heat pumps, numerous geothermal probes that are distributed in the supply area, heating storages in the buildings and systems to regenerate the geothermal probes. The technologies for heat supply in the supply area are arranged in a decentralised way and demand higher management, maintenance and repair efforts.

At the same time, this means a higher degree of local added value. The financial resources for heat supply will be spent for the acquisition of energy sources (e.g. gas or oil) to a smaller share and be used to build and operate heat supply plants instead. In comparison to heat supply concepts such as district heating, the expenses for energy are significantly lower.

For now, heat supply in the City of Vienna is mainly covered by district heating and gas boilers in the buildings. In areas where district heating is economically feasible, it is still meaningful to use district heating. However, there are many areas without district heat supply. This can apply to existing buildings and city districts as well as newly build supply areas. For environmental reasons, the new construction of a heat supply system based on gas supply does not contribute to the reduction of $CO_2$ emissions and the primary energy demand in a sustainable way. At this point, it is expedient to provide alternative solution concepts. The option of heat supply by means of heat pumps and geothermal probes offers a meaningful concept for urban heat supply.

Last but not least, an additional benefit of the heat pump solutions is the gain in comfort for the apartments: The first measure to generate regenerated heat in summer is free cooling of apartments. Thereby, the heat is extracted from the apartments and made available for the geothermal probes. In view of the hot summers in the last years, this solution offers a great benefit to the apartments. The “costless” temperature conditioning of apartments in summer provides a high level of comfort for the residents. This benefit should be considered in the overall evaluation of heat supply solutions.

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