



HAL
open science

Systematic approach to natural gas usage for domestic heating in urban areas

Dejan Brkić, Toma I. Tanasković

► **To cite this version:**

Dejan Brkić, Toma I. Tanasković. Systematic approach to natural gas usage for domestic heating in urban areas. *Energy*, 2008, 33 (12), pp.1738-1753. 10.1016/j.energy.2008.08.009 . hal-01586554

HAL Id: hal-01586554

<https://hal.science/hal-01586554>

Submitted on 13 Sep 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Elsevier Editorial System(tm) for Energy
Manuscript Draft

Manuscript Number: EGY-D-08-00110R2

Title: Systematic Approach to Natural Gas Usage for Domestic Heating in Urban Areas

Article Type: Full Length Article

Keywords: Natural Gas; Settlement; Gas Distribution; District Heating; Urbanism

Corresponding Author: Mr Dejan Brkic, Master of Sc. in petroleum eng. PhD stud

Corresponding Author's Institution: Ministry of Science

First Author: Dejan Brkic, Master of Sc. in petroleum eng. PhD stud

Order of Authors: Dejan Brkic, Master of Sc. in petroleum eng. PhD stud; Toma I Tanaskovic, PhD in mining engineering

SUBMISSION CHECKLIST

Please read this list and answer the questions only after you have examined them carefully. Do not submit the paper unless you can truthfully answer 'yes' to questions 1-14 (or 'not applicable' for question 8 if your paper does not include computation or experiments) for new papers, and 'yes' also to question 15 for revised papers.

Make sure you check each item carefully before submitting your manuscript.

1. yes

2. yes

3. yes

4. yes

5. yes

6. yes

7. yes

8. yes

9. yes

10. yes

11. yes

12. yes

13. yes

14. yes

15. If this is a **REVISED** version of a previously-reviewed paper, have you included all of the materials requested by the Editor, including:

yes

yes

yes

Dear Prof. Lior,

We are grateful to referees for their suggestions. According to referees' comments, we have modified our paper "Systematic Approach to Natural Gas Usage for Domestic Heating in Urban Areas"- EGY-D-08-00110R1. We are returning our rewritten manuscript. This paper has not been published previously, it is not under consideration for publication elsewhere, and if accepted it will not be published elsewhere in substantially the same form, in English or in any other language, without the written consent of the Publisher. Also, don't forget we want to attach Electronic annex refer to our work - MS Excel file (annex DB ver3). We hope that English expression in our paper is now improved.

Beograd, 11.08.2008.

Yours Sincerely,

Dejan Brkic

Toma Tanaskovic

Systematic Approach to Natural Gas Usage for Domestic Heating in Urban Areas

Dejan Brkić^{a*}, Toma I. Tanasković^b

^aMinistry of Science and Technological Development, Đušina 7, 11000 Beograd, Serbia,

^bFaculty of Mining and Geology, University of Belgrade, Đušina 7, 11000 Beograd, Serbia

Received: 22 February 2008; received in revised form:

Abstract: Natural gas can be used for satisfying population needs for heating, either directly by bringing the gas to the dwellings through the gas distribution system and combusting it in the domestic boiler (gas distribution system-G), or indirectly by combusting the natural gas in the heating plant and distributing the heat energy to the dwellings through the district heating system (district heating system-DH). The selection of a certain type of heating system is made according to the disposition of buildings in the area, their number, size, insulation quality, etc. Based on these characteristics, calculations of investments and exploitation costs have been made for both heating systems and a comparison has been made for all of the 96 presented cases. Almost each type of real settlement can be represented by one of the types of the conditional urban area which are introduced in the paper. The main goal of this paper is to establish a general model to achieve coordinated development of centralized energy supply systems fueled by natural gas, based on defined and accepted criteria. A structure analysis of centralized systems for energy supply has been done with accent on their pipelines.

Keywords: Natural Gas, Settlement, Gas Distribution, District Heating, Urbanism

*Corresponding author, Tel./fax: +381113243457, e-mail: dejanrgf@tesla.rcub.bg.ac.yu, (D. Brkić)

Nomenclature

y – number of “Conditional Dwellings” per building [-]

N - number of buildings per “Conditional Urban Area” [-]

x - Peak load densities or “Heat Load” [MW/km²]

DH – costs of district heating system [€]

G - costs of local gas heating system (domestic boiler in each dwelling) [€]

DHN - costs of district heating network, i.e. costs of building/civil works, costs of materials (insulated pipes, pumps, accessories, etc.) and telemetry systems, etc [€]

HE - costs of heat exchanger stations located in buildings [€]

HP –investment in new heating plant [€]

DHOC - annual costs of maintenance calculated as percentage of investment, network, heat exchanger station, annual natural gas consumption and annual electricity consumption for pumps drive [€]

MPRS - costs include costs of main pressure reduction stations [€]

PRS - costs of pressure reduction stations [€]

DN - costs of natural gas distribution network [€]

DS - costs of domestic measurement sets [€]

B - costs of domestic boilers [€]

GOC - annual costs of maintenance calculated as percentage of investment; in gas distribution network, in pressure reduction station, in measurement set, domestic boiler and annual natural gas consumption [€]

dr - “Discount Rate” [%]

NPV - “Net Present Value of Costs” [€]

t – Time [years]

1. Introduction

If a gas based system in a settlement is planned, the decision can be done among two conflicted options:

1. Indirect system; natural gas is being combusted in a heating plant and household heat supply is provided by a District Heating System (DH),
2. Direct system; dwellings are being heated by natural gas brought through a gas distribution system and then combusted in domestic gas boilers in each dwelling, individually (G).

The initial decision on choosing one of two systems is based on the number and size of buildings in a settlement, the size of the settlement itself and the heating insulation of buildings [1]. In boundary cases, if it is possible to achieve both options it is also possible to introduce a sort of hybrid system which is not considered in this paper. The economic analysis of the renovation of small-scale district heating systems in Lithuania is available [2]. District heating systems using cogeneration, as well as the local fuel-based and electric heating systems for detached houses, are analyzed by L. Gustavsson and A. Karlsson [3]. Their analysis includes the whole energy system, from the natural resource to the end user, with respect to the primary energy use, emission and cost. They found that natural gas based systems are less expensive than the corresponding wood-fuel based systems, except the matter of ecology. In the future, green energy sources or fossil energy sources such as oil and natural gas will be more used in industrial

processes in order to decrease the ratio of greenhouse gases released from the coal-based local and industrial processes [4].

The goal of the model introduced in this paper is to determine the connections among urban and energy characteristics of settlements in cities and to be benefit from more rational usage of natural gas as non-renewable fossil fuel. Energy demands for heating are shown for the Canadian case [5], from the economical point of view. The introduction of natural gas in the Greek energy market has broadened the options in the field of space heating [6]. The paper by C. Dinca, A. Badea, P. Rousseaux, and T. Apostol [7] aims to select the optimal energetic scenario applied to a consumer with 100 000 inhabitants from the residential–tertiary sector in Romania (series of seven scenarios based on natural gas have been analyzed). The natural gas in optimized bivalent heating systems is shown in the paper of SI. Gustafsson and BG. Karlsson [8]. The study of MS. Torekov, N. Bahnsen, and B. Qvale [9] is in correlation with this paper and strives to clarify to what extent the improved insulation of new buildings affects the economically rational choice of heating supply. District heating should be advocated only for areas with a strong heat demand, primarily for areas with apartment buildings [9]. R. Lazzarin and M. Noro [10] have done analyses of local or district natural gas heating from energetic, environmental and economic points of view. The legal and policy aspects of the utilization of different energy supply systems in households sector can also be found in the available literature [11]. Some German studies with subject relevant for development of district heating systems in urban environment are also useful and highly evaluated, but this literature is available only in German language [12-14], with related papers presented in scientific journals [15]. The main achievement of these German researches is the establishing of interaction between heating systems, settlement structure and

urban planning at the local level. The study analyses options for heat supply in up to 10 types of built up areas [12] – from densely populated urban areas to villages. A new German study 20 years later refers to this work [13], with projection to 2020 [14].

Considering the selection of heating systems and the utilization of the existing capacities in the systems for centralized energy supply, the present practice in many cities is that every single case must be considered separately and, very often, the selection is done without clear criterions. The proposed model could be useful to urban planners, municipal officials, public utility companies, etc., as a first step in system selection (see Electronic Annex in the online version of this article).

The most suitable option for satisfying heating demands in urban areas is by using a centralized system. The centralized energy supply from heating plants has many advantages: saves primary energy (due to the modern construction of boilers in heating plants as well as the utilization of modern energetic and ecological ways of combustion, the primary energy sources are better used during the transformation of primary energy into heat energy), the distribution of hot water consumption (the centralized hot water distribution is the way to avoid the transformation of primary energy, mostly from heat to electric energy, and then again, from electric to heat energy), the possible utilization of low quality fuel, the possible utilization of some alternative kind of fuel, the centralized storage for fuel, less expenses for the standard discontinuous transportation of fuel (saving motor vehicles' fuel), due to the centralized and highly controlled heating, there is less danger from fire. There is also a well organized, professional fire protection. There are also some negative aspects of the heating systems from heating plants: high investments during the initial phase of building of heating sources and pipeline structure,

possible quitting with heat energy supply caused by the damage in heating plant or distribution network, in some cases, heating expenses are measured by squaring, not by consumption. The advantages of the systems for the individual consumption of gas in households by using the gas distribution network are the following: the gas consumption is being measured separately for each apartment and the paying of costs depends on consumption (which is not always the case when DH systems are being used), gas saving for hot water supply and cooking (these demands are being satisfied directly by the transformation of chemical energy of natural gas into heat energy, that is how the gas used for transformations of primary energy into electric energy is saved), there is no need for storehouses in households, less costs for the standard fuel distribution (the fuel is saved for motor vehicles), relatively small investments in the construction of distribution network in relation to thermal network, less possibility for quitting of supply. The disadvantages of the centralized natural gas supply systems are: an increased fire danger, explosions, or possibility of suffocation caused by damaged installations for different reasons, the combustion is taking place in the apartment, the possible lack of gas or an interrupted distribution pipeline, etc.

Life comfort [16] is the same in both options; every individual dwelling has the same network of conduits and radiators. The main intention of this model approach is to find a way to distribute heat energy in each dwelling using the existing capacities (not to make strategy for a city planning, but to exploit most possible rationally existing capacities). The primary goal of this paper is not to investigate district heating or gas distributive infrastructure, but to compare investments in both systems with their specific details (pipelines with included costs of domestic boilers for the G system or costs of heat exchanger for the DH system, investment in new

capacities in heating plant, etc.). The main subject of the examination is in the “Conditional Urban Areas”. The comparison of investments in pipelines for both systems is the most important parameter of this analysis. In the most detailed heating analyses in one town, the other types of fuel for heating plants, the alternatives for heating in the cases of the lack of natural gas, etc. must also be taken into consideration.

The model which is presented here is developed as a tool for solving some of the misunderstandings in the strategy of urbanism correlated to natural gas heating in Serbian towns. This project has been supported by the Ministry of Science of Serbia. All the values in this paper refer to conditions in Serbia, but readers also have an access to the relevant file (see Electronic Annex 1 in the online version of this article), and can change all the values (green tones in excel file can be changed). According to that possibility, this model can be applied for conditions anywhere in the world.

The strategy for heating of dwellings in urban areas of Serbia, since the communist period, had been made to favor district heating systems in towns. The consumer area of Belgrade is being supplied with thermal energy by district heating system consisting of 15 heating plants which use gas ($83\% = 265 \cdot 10^6 \text{ m}^3/\text{year}$ [1]) and crude oil as basic fuel. Statistical data show that 38% of the buildings are connected to the district heating system, which represents 240000 flats and 7500 business offices heated in that way. The construction projects of thermal network and gas distribution network in downtown areas take an important place in the scope of the Belgrade environmental protection program, so approximately 800 individual solid fuel boilers have been shut down so far. Nowadays, most of these plants are being fueled by natural gas, but in the past

they were fueled by liquid fuels or by coal (in some smaller and obsolete plants). All of these mini plants have to be closed. According to the new strategy, the heat supply for relevant dwellings will be provided by some sort of natural gas heating. The government has the strategy to connect almost all dwellings to some form of natural gas heating system. The goal is not to use solid fuel heating, especially not electric energy. They should be used only in some rare cases. There are 42 city heating plants in Serbia with heat energy capacity of 5.5GW. However, Serbia does not have sufficient energy production or funds for their procurement. The main characteristics of Serbia's heating plants are low operating readiness due to insufficient maintenance and outdated equipment, financial exhaustion and an inability to perform urgent intervention on sources and grids. Heating is poor and there is a need for additional capacity, mostly fueled by natural gas. Serbia doesn't have enough gas production reserves from its own fields or to satisfy the demands (the annual peak of the production was $600 \cdot 10^6 \text{ m}^3$ and now it is several times lower ($285 \cdot 10^6 \text{ m}^3$) [1]). The imported gas is available for Serbia since 1979. from one direction (from north, through Hungary). Serbia also has the EU perspective [17, 18], and the Government's strategy is to make Serbia a transient country for the export of Russian gas to the western countries of EU countries (from the second direction, through Bulgaria). Due to the European obligation to reduce greenhouse gas emissions in the framework of the Kyoto Protocol, the trend towards the use of natural gas is expected to continue in the future. The increased consumption and comparably low indigenous gas resources within Europe are expected to increase the Europe's dependency on gas imports from abroad in the future. In addition to the existing supply sources from Russia [19] and Algeria, gas resources from the Middle East and the Caspian and Central Asian regions could be the possible supply options to cover Europe's gas demand in the future. Today, natural gas heating in Serbia has a great perspective [20-23].

A hypothetical equivalent within a model has been made for every type of settlement. The investment costs were calculated and the comparison has been made for each (of a limited number) of hypothetical settlements. The system with the smallest investments (including exploitation and the maintenance in the next 25 years), depending on the city planning parameters, is more cost effective and adopted. This creates a direct link between the city planning parameters and the choice of one of the systems.

2. The concept of conditional urban areas

The model upon which the decision on choosing one of two systems is made (DH vs. G) is based on the introduction of hypothetical urban settlements. By introducing this practice, it is not necessary to perform the entire calculation for both systems and after which the choice of a heating system in the settlement is made. The application of this model makes easier the job for energy and city planners. People with higher living standard often do not take economic parameters into consideration when deciding between gas or district heating system. The decision is based on a personal affinity (and often, prejudice) [24].

The parts of a city with residential and other buildings within real settlements are called „Real Urban Area“. They can be divided into several zones based on the same or similar urban characteristics. The zones divided like this, for the model purposes, need to have an area of 0.05 km² - “Basic segment” (Fig. 1.). Further on, real urban parameters of a real settlement can be copied onto the selected “Basic segment” (Fig. 2.). “Basic segment” with rectangular size with

dimension approximately $160\text{ m} \cdot 315\text{ m} = 0.05\text{ km}^2$ is adopted for this purpose [1]. Based on the spatial disposition within the model, there are 6 different versions of “Basic segments”: 4, 8, 16, 32, 64 and 128 buildings per “Basic segments”: (Fig. 1). “Examination segment” (Fig. 3.) consists of ten “Basic segments” with an added pipeline (gas and district heating). Only one type of “Basic segment” can exist in one “Examination segment”. Real zone formed like this can be joined with one of the 96 „Conditional Urban Areas“(Fig. 4. and Table 1.). Each particular “Conditional Urban Area” consists of ten “Basic segments” (all the ten belong to one of the six types shown in fig 1.), buildings (all the buildings are the same in one regarded segment) and pipeline (district heating pipeline or gas distribution pipeline) – Table 2. Every real situation in town has to be joined to one of the best fitted „Conditional Urban Areas”. A different heat load (peak load density) can be given to each one of these basic types of “Examination segment”, which is based on the size of buildings. There are 8 different heat loads in this model: 10 MW/km², 20 MW/km², 30 MW/km², 40 MW/km², 50 MW/km², 75 MW/km², 100 MW/km² or 125 MW/km² (Fig. 2). These values are chosen for the analysis in order to include a wide range of possible real urban situations.

Every settlement, found in reality, corresponds to one of the 96 hypothetical settlements included in the model (Table 1). They are called “Conditional Urban Area” (six “Basic segment” multiply by eight “Heat Loads” multiply by two types of insulation) [1]. According to a variety of possible settlements (in density, size and layout of buildings) a model which has the ability to represent their different characteristics is formed. With six types of “Basic segments” (Fig. 1) all the possible densities of built up areas in settlements can be described. Different sizes of buildings can be found in each particular urban area from small houses to skyscrapers, i.e. with

eight types of buildings graduated by size all situations can be described (eight different “Heat Loads”). Each of the 96 proposed hypothetical settlements can be joined with different city planning parameters such as: the number of buildings reduced to the unit value of surface, the size of buildings, the number of dwellings within the buildings, the number of floors within buildings, the spatial disposition of buildings within the settlement, the quality of heat insulation of dwellings etc [25-27]. If there are several types of buildings or density of built up areas within the settlement, settlements need to be divided into several „Conditional Urban Areas“. Every single type of building can be very good or poor insulated (older buildings versus newer buildings) [28]. Numbers of “Conditional Dwellings” per building are shown in Table 1.

For every “Conditional Urban Area“, it is possible to calculate the entire investment costs for the implementation of gas distribution and district heating systems (Table 3). The investment’s calculations are based on the detailed estimate of distribution network for both systems with all the equipment included as well as the labor expenses and the spare parts for replacement in the first 25 years. Thus, the investments for all the 96 cases can be calculated (one of these cases is shown in Table 4). After that, the values of gas distribution costs are being subtracted from the investment costs of the district heating system (Table 5) and then they are being discounted (Table 6). For cases with positive values the option of gas distribution is more favorable than the district heating system (negative values).

The disposition of networks for all cases is shown in figure 3 (“Examination segment”). The disposition designates the pipeline length, but not structure of diameters of conduits in the pipeline composition. The determination of structure of diameters of conduits the pipeline

composition can be done only after the “Conditional Urban Area” is formed. A structure of pipes diameters depends on building size. The “Examination segment” has ten times bigger area surface than the “Basic segment” because of the network sensitivity exploration. Note that in fig. 3 (“Examination segment”) pipeline network exists, while in Fig. 1 or in Fig. 2 it doesn’t (“Basic segment”).

So, the similarity between “Conditional Urban Area” and “Real Urban Area” can be determined by two different independent quantities [1].

- 1) Number of buildings in an urban area (the number of buildings on 0.05 km^2 – 5 hectares); (Fig. 1),
- 2) A heat demand [29] of an urban area (“Heat Load” or peak load densities of all buildings heated in a zone divided by the size of an area), MW/km^2 ; (Fig. 2),

The term “building” is used here for family houses also, as well as for the similar smaller constructions with the same meaning as e.g. skyscrapers. In all analyses, “Conditional Residential Unit” [1], i.e. “Conditional Dwelling” [1] with net heating surface area of 60 m^2 is observed. “Conditional Dwelling” has, for the purpose of the model approach, a heat demand of $142 \text{ W}/\text{m}^2$ (heat peak load for lower insulated dwelling) in case of a low (bad) insulation, and in case of better (good) insulation it has a heat demand of $95 \text{ W}/\text{m}^2$ (heat peak load for better insulated dwelling). Each combination of a defined number of buildings and peak load density corresponds to a different number of average dwellings in the building (Table 1). An average dwelling (60 m^2) is practically “Conditional Dwelling”.

The concept of the “Examination segment” is regarded only for the purpose of exploration on realistic values of diameters in the pipeline structure, but values of N-number of buildings presented in this paper are nominally per “Basic segment”. “Heat load” is expressed in MW/km² (not in MW/0.05 km² or in MW/0.5 km²) and it is nominally equal for both “Examination segment” and “Basic segment”.

3. The model of rational natural gas usage based on city planning parameters

Based on the introduced “Conditional Urban Area“, a techno-economical model of rational natural gas usage has been made. For each of the 96 cases investment, a calculation has been made in both of the proposed heating systems (Gas Distribution [30] vs. District Heating [31]) including the exploitation in the next 25 years (investments). For each case, a comparison of costs has been made so that the heating system with the smallest cost has an advantage in the implementation. The number of dwellings per buildings, i.e. the identification of all the 96 cases shown here is shown in Table 1.

Both of the heating types in the model have special costs since both of them have special elements; e.g. the district heating system is made of steel conduits, pumps and heat exchangers, on the contrary, the gas distribution system is made of cheaper polyethylene conduits and has stations for measuring and regulation with internal gas equipment (each dwelling has domestic gas boiler etc). The investment in new capacities for heating plant is included in the model in a directly i.e. by increasing the price of natural gas for district heating, or can be added by

including the new cost indirectly. The investments in a new heating plant fueled by natural gas are: 80000 €/MW (for heat plant capacity <50MW), 65000 €/MW (for heat plant capacity 50-100 MW) and 52000 €/MW (for heat plant capacity 100-200 MW) [1]. That means additional costs of 450-680 € per “Conditional dwelling”. It implies that this kind of additional costs is not essential for this kind of analyses (Fig 5.). The changes in the slope of borderline in the model diagram² are caused the discount rate changes (Fig 5.) or by differentiation in the structure of diameters of conduits in the pipeline³. Same conclusion can be made with price variations of domestic boiler (see Table 5 and Fig 5). L. Gustavsson and A. Karlsson [3] estimated the DH investment and maintenance costs. An increasing price of domestic gas boilers simultaneously with the introduction of the same amount of investments in a heating plant are to be annulled (Fig 5.) (for detailed analyses consult electronic annex 1).

A relative amount of investments (per “Conditional Dwelling” included annual costs) in district heating – DH and in local gas heating system – G (each “Conditional Dwelling” is equipped with domestic boiler fueled by natural gas) can be calculated after following eqs. (1 and 2).

$$DH = \frac{DHN + HE + HP + DHOC}{y} \quad (1)$$

Where there are: DH – costs of District Heating System [€], DHN - costs of District Heating Network, i.e. costs of building/civil works, costs of materials (insulated pipes, pumps, accessories, etc.) and telemetry systems, etc [€], HE - costs of Heat Exchanger stations located in buildings [€], HP –investment in new heating plant[€], DHOC - annual costs of maintenance

² See also Fig 11.

³ See also Fig 12 in case study

calculated as a percentage of investment, in network, heat exchanger station, annual natural gas consumption and annual electricity consumption for pumps drive [€] and y – number of “Conditional Dwellings” per building [-].

The annual maintenance costs calculated as a percentage of investment (eq. 1), in network (2,5%); lifetime of 25 years, heat exchanger station (1,5%); lifetime 12 years, annual natural gas consumption - 10% more than in the system with domestic boiler in each “Conditional Dwelling”) (942,7 m³ per “Conditional Dwelling” - 0.12 €/m³) and the annual electricity consumption for pumps drive (250 kWh – 0,035 €/kWh²). The estimated heat losses in the district-heating network are 10%.

$$G = \frac{\text{MPRS} + \text{PRS} + \text{DN} + \text{DS} + \text{B} + \text{GOC}}{y} \quad (2)$$

Where there are: G - costs of Local Gas Heating System (domestic boiler in each dwelling) [€], MPRS - costs include costs of Main Pressure Reduction Stations [€], PRS - costs Pressure Reduction Stations [€], DN - costs of natural gas Distribution Network [€], DS - costs of Domestic measurement sets [€], B - costs of domestic boilers [€], GOC - annual costs of maintenance calculated as a percentage of investment; in gas distribution network, in pressure reduction station, in measurement set, domestic boiler and annual natural gas consumption [€] and y – number of “Conditional Dwellings” per building [-].

The annual maintenance costs calculated as a percentage of investment (eq. 2); in gas distribution network (2,25%); lifetime of 25 years, in pressure reduction station (2,25%); lifetime of 25 years, in measurement set (2,25%), lifetime of 12 years, domestic boiler (2,25%), lifetime

of 12 years and the annual natural gas consumption (857 m³ per “Conditional Dwelling” - 0.12 €/m³).

The efficiency of the NG boiler is the best during winter when space heating is needed. During summer, when only hot water is required the boiler is often operated at a very low load and the average efficiency is reduced. For examination in this paper, on-line database SEDBUK⁴ (Seasonal Efficiency of Domestic Boilers in United Kingdom) [32] is very useful (Fig. 6 and 7). District heating is often less efficient with respect to modern heating technologies using natural gas. Condensing boilers guarantee higher efficiencies with respect to “traditional” district heating.

An investment in a new heating plant or the increasing domestic gas boiler’s price is included in the calculation, with the introduction of such costs or investments on both G and DH sides simultaneously, caused the equal impact in all of the six “examination segments” (does not change slope of borderline in Fig. 5⁵).

In the equations above, the common costs for both systems are not shown. Different investments in these two opposite systems can be compared for the purpose of a model (Fig 8).

All the previous investments are considered for the present conditions in Serbian energy sector. Of course, this model is applicable for conditions and particular cases all over the world, but

⁴ available from www.sedbuk.com

⁵ or in case study in Fig 11

diagrams (figures in this paper) are generated for prices ratio in Serbia. Detail calculation for one case of 96 is shown in table 4.

Values of initial costs (shown in Table 3) for DH subtracted by initial costs of G are shown in table 5.

Generally, each project task has a time component. Every particular element of the two systems shown here has a lifetime, and it has a price on the market (expressed in €). If one of the elements has reached the end of its lifetime (e.g. 26 years), it has to be replaced. Thus, in a project, during the first and the next several years, costs for provision, maintenance and replacement of elements exist (e.g., some elements must be replaced after 14 years and some after 25 years). A sum of costs calculated for each year (t) for gas distribution system is labeled here as G, and for district heating system as DH. "Present Value of Costs" is one of the most useful criterions for project analyses for a whole lifetime of every particular system element. In that way, discount flows reduced on "Present Value of Costs" can be evaluated. "Present Value of Costs" is, by default, cumulative cost for all the elements of the system in present and in future expanded for discount rate. "Future Value of Costs" has to be reduced to present value and to be added to real present costs. Thus, the generated value is called "Present Value of Costs". For the reduction of "Future Value of Costs", an appropriate "Discount Rate" (dr) has to be adopted. In the case of possible risks for the safety of investments, higher value of "Discount Rate" is being calculated. "Discount Rate" could be equalized with "Interest" on the market or for realized credit.

In our case, an economical evaluation is realized during the comparison of two “Present Values of Costs”, for gas distribution system (G) and for district heating system (DH) [33]. “Net Present Value of Costs” (NPV) (eq. 3) is the result of subtraction of the “Present Value of Costs” calculated for district heating system (DH) and the “Present Value of Costs” calculated for gas distribution system (G).

$$NPV = \sum_{t=1}^n \frac{DH - G}{(1 + D_r)^t} \quad (3)$$

The value of “Discount Rate” or capital cost rate in this case is rated and adopted as $dr=10\%$.

The value of discount rate has great impact on the optimal choice of quantitative conclusions (Fig. 5). The changes of calculated values for $dr=5\%$ and $dr=7\%$ are shown in Table 6. Annual gas consumption calculated for one “Conditional Dwelling” is 857 m^3 for heating only, and this amount is 10% higher for district heating system. Besides, a statistical approach based on nonlinear regression principles can be made to natural gas consumption estimation of individual residential and small commercial customers [34]. The annual costs of electrical energy for running the pumps for district heating system are estimated to 250 kWh per “Conditional Dwelling”.

Analyses are done for all the 96 cases (six “Conditional Urban Area” multiplied by eight “Heat Loads” and by two conditions of insulation – bad or good insulation) for the period of $t=26$ years. In table 6, case with a bad insulation is shown.

The values in certain cases in table 6 vary more or less from zero. For example, for “Conditional Urban Area” with 16 buildings and with “Heat Loads” 50 MW/km², the calculated “Net Present Value of Costs” (NPV) is only -5 per “Conditional Dwelling” for a period of 26 years. Therefore, the realization of gas distribution system for that “Conditional Dwelling” is only 5 € for 26 years in advantage versus district heating system. This case and the other similar cases are in the “gray zone” (Fig. 9). In the “gray zone”, both systems are payable, especially for a period of 26 years.

If a considered value for a certain housing block exceeds the recommended limiting value, more or less, the decision to recommend a particular centralized heating system is more reasonable. Changing the structure and the price ratio (i.e. the state political decision to subsidize the gas price in a system or to issue a price, which would disturb the current price ratio of gas used for district heating system and individual consumers), the conception and manner of a construction of certain system and its elements may cause these parameters to vary. Currently, plastic-polyethylene conduits (cheep) are used for distribution to individual consumers while steel conduits (expensive) had been used before. It led to the considerable cuts in network construction prices, while maintaining the same level of safety and endurance.

For the same “Heat Loads”, when there are many smaller family houses located on a “Conditional Urban Area” e.g. N=32, sometimes only with one “Conditional Dwelling”, gas distribution system is more reasonable. On the contrary, when there is a smaller number of skyscrapers located on “Conditional Urban Area” e.g. N=4, it is more reasonable to use district heating system (Fig. 9).

By means of techno – economic analysis for a certain area, it is possible to determine the advantages of one system over the other (district heating over gas). However, considering the situation on the ground, it may turn out that the system is inaccessible in that part of the city (heating plant does not have enough capacity or, in the first stage, the areas closest to the plant could have a priority in system installation). In that case, if the installation costs of the other available system are not too high, it is rational to install that type of heating system (thus saving the consumption costs of electric energy and reducing the amount of pollution if the object is coal).

If, after the analysis, it turns out that one system has more significant economic advantages than the others, but it is unavailable, some form of hybrid system should be considered. For instance, if the installation of district heating system has a lot of economic advantages but it is not available, it is possible to build a local boiler room which would be gas operated. This hybrid solution would demand additional economic and ecologic analyses [35] and estimations of which good features of district heating system would be kept and which would be discarded.

4. Case study; Application under real conditions

The characteristics of the “Real Urban Area”: number of buildings, disposition and size of buildings, construction type, etc. are the factors of influence. The adoption of a type of centralized heating system can be done according to the conclusion established by the model shown. That is possible only if both systems are available near the settlement.

Today, social help habitants have a discount for district heating price of up to 50%. For the gas consumers who use gas distribution systems directly, such discounts are not available. Besides, the payment for the DH is per m^2 of heated surface area (proportional to the size of the house), and in the G system payment is per m^3 of used gas, in Serbia. In the DH bills are fixed, and any sort of economizing in that way is discouraged.

In that case (Belgrade's settlement Karaburma is taken here into consideration), a type of the chosen system depends on urban characteristic of the settlement only. Because of that, the demonstrative settlements are parceled (divided) into eight "Real Urban Areas" with similar buildings on each particular parcel; (Fig. 10). That way, the determined "Real Urban Area" can be associated with the "Conditional Urban Area". The characteristic points for each of the eight parcels (intersection of number of buildings and heat load of parcel) can be plotted into the characteristic model diagram; (Fig. 10). The types of insulation of buildings in the settlement are mixed; old buildings have bad and new buildings have good insulation. Both old and new buildings have heterogeneous spatial disposal.

Two boundary cases have been treated, because of heterogeneity of insulation quality of buildings [27, 28, 36-38]; (Fig. 11):

- Maximal "Heat Load", all buildings have bad insulation (142 W/m^2),
- Minimal "Heat Load", all buildings have good insulation (95 W/m^2),

The value of fuel consumption depends on heating insulation of the building. Energy consumption in the residential sector can be determined according to various methods shown in an available literature [39]. Therefore, the “Heat Load” depends on heating insulation of the building. The number of buildings on each particular parcel is constant. “Gray zone” is the zone where decision on the type of the system depends, in a great deal, on the type of insulation of the building; (Fig. 9. and 10). In the “Gray zone”, the costs for both systems (gas distribution system and district heating system) are very similar. Characteristic points for each of eight particular also depend on the quality of insulation. Small change in slope of borderline for good insulation ($K_1=tg\theta_1$) and for bad insulation ($K_2=tg\theta_2$) in Fig 11 is generated only because of differentiation in structure of diameters of conduits in pipeline (Fig 12).

“Real Urban Area” No 8 includes types of small buildings or family houses which can contain only one “Conditional Dwelling”. Only for that “Real Urban Area” the gas distribution system has very payable advantages versus district heating system. “Real Urban Area” No 3 includes school, kindergarten, local office, shops. These kinds of buildings can contain twenty or more “Conditional Dwellings”. Only for that “Real Urban Area” the district heating system has great advantages. All the other zones are in the “gray zone”. In the “gray zone”, one system is more payable in comparison with the other, no more than 200 € per “Conditional Dwellings”. This amount cannot be crucial for decision. Some illustrations of investigation of price changes (natural gas price, or domestic boilers price) are shown in figure 13.

If large areas are covered by agricultural terrain, by excluding it, the above-mentioned parameters obtain unrealistic values.

Note that pipeline is one of the most important parameters of the analyses shown in this paper. Every particular type of the “examination segment” has a different length of a pipeline route. The length of a pipeline route is fixed by choosing of one six “examination segments”. This selection has to be done to present density of built up areas. Further, for detailed examination, when certain type of “examination segment” is chosen, the length of the route is determined, at the same time. Now, the next factor to be varied is the heat load. The heat load is directly correlated with the size of buildings, i.e. diameters can vary for the fixed length of a pipeline and its structure. Larger diameters of conduits in pipeline structure are correlated to larger buildings. So, the length of a pipeline route depends on the density of built up areas, and structure of the pipe diameters in a pipeline depends on the size of buildings. Therefore, in city conditions, the diameters of pipes are more sensitive (have a greater impact) in some cases, apropos to the length of a pipeline for decision between heating systems. In the conditions of densely populated urban areas, when one type of the “examination segment” is considered, the decision for implementation of certain heating system has to be done according to the above mentioned criterions. The lengths of pipelines and the structures of diameters of conduits are the main factors for establishing these criterions. Accordingly, in villages, the distances between houses are larger, so the length of the dwelling’s pipeline has greater impact then the pipeline diameters. The analysis of the distribution of district heat in sparse areas by C. Reidhav and S. Werner [40, 41] shows that such distribution can be profitable for Swedish district heating companies, if wisely implemented. Sparse district heating is a label for district-heating systems located in the areas of low heat densities. However, a profitable sparse district heating presupposes a favorable combination of certain factors. The boundaries of two such factors have been identified for

Swedish conditions; linear heat density and annual use of district heat/house. An annual use of district heat higher than 50 GJ/house and a linear heat density greater than 2 GJ/m are required for profitability. In Sweden, the general competitiveness of sparse district heating is facilitated by the high consumption taxes for fuel oil, natural gas, and electricity. Hence, it should be more difficult to introduce sparse district heating in other countries with low energy taxes. Such areas are unfavorable, since revenues from heat sold are low compared with the investment costs for the local distribution network. This situation results in high distribution costs. Distribution heat-losses are also higher at low heat-densities.

All the previous values of limiting parameters are calculated for the present gas prices for heating plants, for households, for domestic gas boilers' price, the costs of pipes, labor, etc. Regarding the variation of all parameters, readers can consult electronic annex (Microsoft Excel file). Valuable information for the energetic situation in the city of Belgrade is shown in the paper of M. Jovanović, N. Afgan, P. Radovanović and, V. Stevanović [42] (Belgrade's settlement Karaburma is shown in Fig. 10).

A city is considered to be sustainable if it establishes the balance between economic and socio-cultural development, on one side, and the progress in environmental protection with active participation of its citizens, on the other side. When using one of the power resources (in this case natural gas) in various systems, the difference in the amount of pollution is very small. Big differences cannot occur in the overall effect on the city level, but in certain areas they can. While heating plant is a concentrated pollutant which disperses harmful combustion products evenly on a wide area depending on the wind, gas lined consumption disperses locally (consumer

pollutes his nearest neighborhood) [43]. Globally, the biggest gas consumer is the biggest city polluter. For including environmental impacts of different centralized energy supply systems in a model, it is necessary to estimate the annual environmental costs for both systems and include them in related equations. Compared to all of the fossil fuels, natural gas is a minor pollutant. It burns without a solid residue and has the least coefficient of CO₂ emission of about 56 kg/GJ (which is significant considering the limitations imposed by The Kyoto Protocol) [44-47]. M.S. Torekov, N. Bahnsen and B. Qvale [9] found that DH system realized 78-93 kg/MWh CO₂, 0.1 kg/MWh NO_x and 0.06 kg/MWh SO₂, G system with individual furnace realize 205 kg/MWh CO₂, 0.07 kg/MWh NO_x and 0.001 kg/MWh SO₂, and electrical heating system 559 kg/MWh CO₂, 88 kg/MWh NO_x and 44 kg/MWh SO₂. 1 MWh of delivered energy is 61% cheaper in natural gas in comparison with electrical energy [46]. The comparison of environmental impacts of two residential heating systems in Canada is shown in paper of L. Yang, Zmeureanu R., and Rivard H. [48].

The key advantage of installing gas or district heating system is not in their mutual differences, but in the substitution of by the far more expensive (in terms of energy and ecology [49]) and the highest quality form of energy – the electric energy, whose usage for heating is by far less rational; (Fig. 14). The introduction of competition to electricity generation and commercialization has been the main focus of many restructuring experiences around the world. The open accesses to the transmission network and a fair regulated tariff have been the keystones for the development of the electricity market [50]. Parallel to the electricity industry, the natural gas business has great interaction with the electricity market in terms of fuel consumption and energy conversion. Given that the transmission and distribution monopolistic activities are very

similar to the natural gas transportation through pipelines, economic regulation related to the natural gas network should be coherent with the transmission counterpart [51]. Electricity and natural gas use for residential space heating in USA is shown in paper by D. Bodansky [52]. Today, discussions about district heating systems are not rare in scientific literature [53-63].

5. Conclusions

The latest increase in gas prices turned all eyes once again to the space heating problem in Europe. However, economic concern is not the only factor pushing the authorities to rethink about the suitability of the currently existing sources. Cities are the biggest consumers of the country's energy production. The increase in annual consumption of total primary energy is 3% and its largest part is used for lighting, cooking, heating, cooling, and transport of freights and passengers. The importance of reducing the energy consumption level, by changing the forms of consumption and making improvements in technology and lifestyle, should be noted. Sustainable forms of energy production, distribution and usage represent the goals of a sustainable development. A city is considered to be sustainable if it establishes the balance between economic and socio-cultural development, on one side and the progress in environmental protection with active participation of citizens. On the other side, the economics of the G and the DH systems very much depend on the specific circumstances [64, 65]. If installed in an area with only scattered buildings, the length of the pipes which are necessary to supply households will be higher, relative to the number of buildings. Installation costs will be shared by fewer consumers. The DH system is the capital intensive; in particular due to the distribution system of insulated pipes. The G system is another form of energy which is being distributed for domestic heating

purposes. The dimensions of pipes are small compared to the DH pipes and no insulation is needed, thus the distribution system is less capital intensive.

District heating is often less efficient with respect to modern heating technologies using natural gas [66-68]. Condensing boilers guarantee higher efficiencies with respect to the “traditional” district heating. In this study, a noncondensing boiler with average efficiency has been chosen from following database: “Seasonal Efficiency of Domestic Boilers in United Kingdom“ [32]. The efficiency of domestic boiler and heating plant has equalized by efficiency in this model. The typical efficiencies of plants fueled by natural gas are reported in paper of R. Lazzarin and M. Noro [10].

Figure 5 is essential for the full understanding of the model presented here. All dwellings in the option of gas distribution system are equipped with one type of an average boiler. The linear price increase moves the borderline in the model diagram in advantage of the district heating (Fig. 10. and Fig. 11.). The same conclusion is made for the investments in new capacities in heating plant, but it moves borderline in direction of the gas distribution system. On the contrary, changes in value of discount rate have a great impact (Fig 5.). Changes in the price of domestic boilers or investment in new capacities in heating plant has the equal impact in all of the six “examination segments”, changes of discount rate does not.

The conducted analyses confirm literature and empirical information:

- District heating system is a better option in areas with small built up density, but with skyscrapers.
- Gas system is a better option in areas with high density of individual houses (in this case gas distribution system is significantly in advance).

These two boundary cases are illustrative. But in the case with small density of built up areas with individual houses, the G system is a cheaper option (but not necessary according to some Swedish studies [40, 41]). With high density of built up areas with skyscrapers, the G system is also a cheaper solution. But, safety regulation is a limiting factor for the implementation of gas system directly in such a high building. Anyway, in this case the G system has a slight advantage, and by the increasing price of domestic gas boilers, the DH system became the cheaper option (Fig 8. and Table 5).

In more details, if a certain number of objects N exist in a “Conditional Urban Area”, it can be concluded that (Fig. 8.):

1. $N = 4$, district heating system has an advantage over gas if an average building has over 29 “Conditional Dwellings” (i.e. if the overall heating surface is over 1740 m^2 or if the length of pipeline route is below 8m)
2. $N = 8$, district heating system has an advantage over gas if an average building has over 22 “Conditional Dwellings” (i.e. if the overall heating surface is over 1320 m^2 or if the length pipeline route is below 7,6m)

3. $N = 16$, district heating system has an advantage over gas if an average building has over 18 “Conditional Dwellings” (i.e. if the overall heating surface is over 1080 m^2 or if the length of pipeline route is below 7m)
4. $N = 32$, district heating system has an advantage over gas if an average building has over 15 “Conditional Dwellings” (i.e. if the overall heating surface is over 900 m^2 or if the length of pipeline route is below 6,4m)
5. $N = 64$, district heating system has an advantage over gas or if an average building has over 12 “Conditional Dwellings” (i.e. if the overall heating surface is over 720 m^2 or if the length of pipeline route is below 5,8m)
6. $N = 128$, gas system is practically always advantageous (for a high density of small individual house equal as for high density of skyscrapers). Note that case with 128 skyscrapers on 0.05 km^2 rarely appears in practice. The gas distribution system is advantageous because all 128 buildings must be equipped with expensive heat exchangers. That is highly unpractical and expensive for individual houses. For skyscrapers, gas system, theoretically, has a slight advantage, but with an increased price of domestic gas boilers, district heating system can be applied in larger buildings. Besides, the implementation of the gas system in skyscrapers is forbidden according to safety regulations.

6. Acknowledgment

This paper is a part of the research done within the project of Ministry of Science NP EE 34-406A, Serbia, Belgrade and the authors would like to thank for financial support.

7. Appendix

The algorithm for initial decision for selection of a natural gas heating system in settlements is shown in figure 15:

8. References

- [1]. Brkić D. Natural gas as heating fuel (Природни гас као гориво за грејање). Beograd: Andrejevic Foundation (Задужбина Андрејевић), 2006. (in Serbian)
- [2] Dzenajviciene EF., Kveselis V., McNaught C., Tamonis M. Economic analysis of the renovation of small-scale district heating systems—4 Lithuanian case studies. *Energy Policy* 2007; 35 (4): 2569–2578.
- [3]. Gustavsson L., Karlsson A. Heating detached houses in urban areas. *Energy* 2003; 28 (8): 851–875.
- [4] Riva A., D’Angelosante S., Trebeschi C. Natural gas and the environmental results of life cycle assessment. *Energy* 2006; 31 (1): 138–148.
- [5]. Douthitt RA. An economic analysis of the demand for residential space heating fuel in Canada. *Energy* 1989; 14 (4): 187–197.
- [6] Papadopoulos AM., Oxizidis S., Papandritsas G. Energy, economic and environmental performance of heating systems in Greek buildings. *Energy and Buildings* 2008; 40 (3): 224–230.
- [7] Dinca C., Badea A., Rousseaux P., Apostol T. A multi-criteria approach to evaluate the natural gas energy systems. *Energy Policy* 2007; 35 (11): 5754–5765.

- [8] Gustafsson SI., Karlsson BG. Natural gas in optimized bivalent heating systems. *Energy* 1990; 15 (11): 993-999.
- [9]. Torekov M S., Bahnsen N., Qvale B. The relative competitive positions of the alternative means for domestic heating. *Energy* 2007; 32 (5): 627-633.
- [10]. Lazzarin R., Noro M. Local or district heating by natural gas: which is better from energetic, environmental and economic point of views?. *Applied Thermal Engineering* 2006; 26 (2-3): 244-250.
- [11]. Grohnheit PE., Mortensen BOG. Competition in the market for space heating. district heating as the infrastructure for competition among fuels and technologies. *Energy Policy* 2003; 31 (9): 817-826.
- [12]. Roth U., Häubi F., Albrecht J. Interaction between urban infrastructure and district heating system (Wechselwirkungen zwischen des Siedlungsstruktur und Wärmeversorgungssystemen). Bonn: Bundesminister für Raumordnung, Bauwesen und Städtebau, 1980. (in German)
- [13]. AGFW-Arbeitsgemeinschaft Fernwärme. Pluralistische Wärmeversorgung - Zeithorizont 2005 (Vorstudie). See also: <http://www.agfw.de/86.0.html> (in German)
- [14]. AGFW-Arbeitsgemeinschaft Fernwärme. Pluralistische Wärmeversorgung - Zeithorizont 2020. Hauptstudie See also: <http://www.agfw.de/86.0.html> (in German)
- [15]. Ter Brugge R. Spatial structure in relation to energy production and consumption. *Journal of Economic and Social Geography-Tijdschrift voor Economische en Sociale Geografie* 1984; 75 (3): 214-222.
- [16]. Bojić M., Despotović M. Influence of duration of thermal comfort provision on heating behavior buildings. *Energy Conversion and Management* 2007; 48 (8): 2416-2423.

- [17] Holz F., von Hirschhausen C., Kemfert C. A strategic model of European gas supply (GASMOD). *Energy Economics* 2008; 30 (3): 766–788.
- [18] Afgan NH., Carvalho MG., Pilavachi PA., Martins N. Evaluation of natural gas supply options for south east and central Europe. Part 1: Indicator definitions and single indicator analysis. *Energy Conversion and Management* 2007; 48 (9): 2517–2524.
- [19] Lund Sagen E., Tsygankova M., Russian natural gas exports—Will Russian gas price reforms improve the European security of supply?. *Energy Policy* 2008; 36 (2): 867–880.
- [20] Remme U., Blesl M., Fahl U. Future European gas supply in the resource triangle of the Former Soviet Union, the Middle East and Northern Africa. *Energy Policy* 2008; 36 (5): 1622–1641.
- [21] Lise W., Hobbs W. Future evolution of the liberalised European gas market: Simulation results with a dynamic model. *Energy* 2008; 33 (7): 989-1004.
- [22] Herbert JH., Berg J. Soviet natural gas exports and the European energy balance. *Energy* 1990; 15 (10): 833-840.
- [23] Kabirian A., Reza Hemmati M. A strategic planning model for natural gas transmission networks. *Energy Policy* 2007; 35 (11): 5656–5670.
- [24]. Santamouris M., Kapsis K., Korres D., Livada I., Pavlou C., Assimakopoulos M.N. On the relation between the energy and social characteristics of the residential sector. *Energy and Buildings* 2007; 39 (8): 893–905.
- [25]. Stanislaw S. The measurement of demand for natural gas. *Energy* 1985; 10 (2): 165–180.
- [26]. Hartshorn JE. Introduction: Natural gas development begins at home. *Energy* 1985; 10 (2): 111–118.

- [27]. Mihalakakou G., Santamouris M., Tsagrassoulis A. On the energy consumption in residential buildings. *Energy and Buildings*, 2002; 34 (7): 727–736.
- [28]. Olesen BW., Parsons KC. Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730. *Energy and Buildings* 2002; 34 (6): 537–548.
- [29]. Huei-Chu L., Tsai-Feng C. Space-heating and water-heating energy demands of the aged in the US. *Energy Economics* 2002; 24 (3): 267-284.
- [30]. Corfield G., Hunt BE., Ott RJ., Binder GP., Vandaveer F. E. Distribution Design for Increased Demand. In: Segeler CG, editor. *Gas Engineers Handbook*. New York: Industrial Press. p. 9/63-9/83.
- [31]. Recknagel H., Sprenger E., Honmann W. Heating (Грејање). In: Višnjić M., editor. *Heating and Air Condition (Грејање и климатизација)*. Beograd: Gradjevinska knjiga. p. 293-835. (in Serbian)
- [32]. SEDBUK-Seasonal Efficiency of Domestic Boilers in United Kingdom. See also: <http://www.sedbuk.com>
- [33]. Papadopoulos AM., Theodosiou T., Karatzas K. Feasibility of energy saving renovation measures in urban buildings: the impact of energy prices and the acceptable pay back time criterion. *Energy and Buildings* 2002; 34 (5): 455–466.
- [34]. Vondraček J., Pelikan E., Konar O., Čermakova J., Eben K., Maly M., Brabec M. A statistical model for the estimation of natural gas consumption. *Applied Energy* 2008; 85 (5): 362–370.
- [35]. Braniš M., Domasova M., Rezačova P. Particulate air pollution in a small settlement: the effect of local heating. *Applied Geochemistry* 2007; 22 (6): 1255–1264.

- [36]. Gustafsson SI., Bojić M. Optimal heating-system retrofits in residential buildings. *Energy* 1997; 22 (9): 867-874.
- [37]. Torchio MF., Genon G., Poggio A., Poggio M. Merging of energy and environmental analyses for district heating systems. *Energy* 2008; doi:10.1016/j.energy.2008.01.012
- [38]. Ossebaard ME., van Wijk AJM., van Wees MT. Heat supply in the Netherlands: a systems analysis of costs, exergy efficiency, CO₂ and NO_x emissions. *Energy* 1997; 22 (11): 1087-1098.
- [39]. Aydinalp-Koksal M., Ismet Ugursal V. Comparison of neural network, conditional demand analysis, and engineering approaches for modeling end-use energy consumption in the residential sector. *Applied Energy* 2008; 85 (4): 271–296.
- [40]. Reidhav C., Werner S. Profitability of sparse district heating. *Applied Energy* 2008; 85 (9): 867–877.
- [41]. Forsaeus Nilsson S., Reidhav C., Lygnerud K. Werner S. Sparse district-heating in Sweden. *Applied Energy* 2008; 85 (7): 555–564.
- [42]. Jovanović M., Afgan N., Radovanović P., Stevanović V. Sustainable development of the Belgrade energy system. *Energy* 2008; doi:10.1016/j.energy.2008.01.013
- [43]. Strachan N., Farrell A. Emissions from distributed vs. centralized generation: The importance of system performance. *Energy Policy* 2006; 34 (17): 2677-2689.
- [44]. Haberl H., Adensam H., Geissler S. Optimal climate protection strategies for space heating; the case of Austria. *Energy Policy* 1998; 26 (15): 1125-1135.
- [45]. Cowie AL., Kirschbaumb MUF., Ward M. Options for including all lands in a future greenhouse gas accounting framework. *Environmental Science & Policy* 2007; 10 (4): 306–321.
- [46]. Karlssona A., Gustavsson L. External costs and taxes in heat supply systems. *Energy Policy* 2003; 31 (14): 1541–1560.

- [47]. Holmgren K., Amiri S. Internalising external costs of electricity and heat production in a municipal energy system. *Energy Policy* 2007; 35 (10): 5242–5253.
- [48] Yang L., Zmeureanu R., Rivard H. Comparison of environmental impacts of two residential heating systems. *Building and Environment* 2008; 43 (6): 1072–1081.
- [49] Ford A. Simulation scenarios for rapid reduction in carbon dioxide emissions in the western electricity system. *Energy Policy* 2008; 36 (1): 443–455.
- [50] Jednak S, Kragulj D, Bulajić M, Pittman R. Electricity reform in Serbia. *Utilities Policy* 2008; doi:10.1016/j.jup.2008.02.002
- [51] Morais MS., Marangon JW. Lima Combined natural gas and electricity network pricing. *Electric Power Systems Research* 2007; 77 (5-6): 712–719.
- [52]. Bodansky D. Electricity and natural gas use for residential space heating: U.S. experience, 1976–1980. *Energy* 1984; 9 (4): 303-313.
- [53]. Lunda H., Hvelplunda F., Kassb I., Dukalskis E., Blumberga D. District heating and market economy in Latvia. *Energy* 1999; 24 (7): 549–559.
- [54]. de Almeida AT., Lopes AC., Carvalho A., Mariano J., Jahn A., Broege M. Examining the potential of natural gas demand-side measures to benefit customers, the distribution utility, and the environment: two case studies from Europe. *Energy* 2004; 29 (7): 979–1000.
- [55]. Knutsson D., Sahlin J., Werner S., Ekvall T., Ahlgren EO. HEATSPOT—a simulation tool for national district heating analyses. *Energy* 2006; 31 (2-3): 278–293.
- [56]. Dotzauer E. Experiences in mid-term planning of district heating systems. *Energy* 2003; 28 (15): 1545–1555.
- [57]. Sundberg G., Karlsson BG. Interaction effects in optimising a municipal energy system. *Energy* 2000; 25 (9): 877–891.

- [58]. Gustavsson L. District heating systems and energy conservation-part I. *Energy* 1994; 19 (1): 81-91.
- [59]. Gustavsson L. District heating systems and energy conservation-part II. *Energy* 1994; 19 (1): 93-102.
- [60]. Benonysson A., Bohm B., Ravn HF. Operational optimization in a district heating system. *Energy Conversion and Management* 1995; 36 (5): 297–314.
- [61]. Gebremedhin A., Moshfegh B. Modelling and optimization of district heating and industrial energy system - an approach to a locally deregulated heat market. *International Journal of Energy Research* 2004; 28 (5): 411–422.
- [62]. Barelli L., Bidini G., Pinchi EM. Implementation of a cogenerative district heating: Optimization of a simulation model for the thermal power demand. *Energy and Buildings* 2006; 38 (12): 1434–1442.
- [63]. Larsen HV., Paison H., Bohm B., Ravn H.F. Aggregated dynamic simulation model of district heating networks, *Energy Conversion and Management* 2001; 43 (8): 995–1019.
- [64]. Bouvy C., L.Klaus. Multicriterial optimisation of communal energy supply concepts. *Energy Conversion and Management* 2007; 48 (11): 2827-2835.
- [65]. Söderman J., Pettersson F. Structural and operational optimisation of distributed energy systems. *Applied Thermal Engineering* 2006; 26 (13): 1400-1408.
- [66]. Rosa L., Tosato R. Experimental evaluation of seasonal efficiency of condensing boilers. *Energy and Buildings* 1990; 14 (3): 237-241.
- [67]. Lazzarin RM., Schibuola L. Performance analysis of heating plants equipped with condensing boilers. *Journal of Heat Recovery Systems* 1986; 6 (4): 269-276.

[68]. Agrell J., Bogetoft P. Economic and environmental efficiency of district heating plants.
Energy Policy 2005; 33 (10): 1351–1362.

Figure 1. “Real Urban Area” associates with several types of “Basic segments” according to the spatial disposition of buildings

Figure 2. Examples of different “Heat Loads” for the same “Basic segments” (two cases)

Figure 3. Standard length of networks for all the six types of “Examination segments” (0,5 km²)

Figure 4. “Conditional Urban Areas” – two examples

Figure 5. Effects of price and discount rate changes, example of factors with linear influence and nonlinear influence (costs for one average dwelling)

Figure 6. Brand new domestic boilers in the UK market sorted according to efficiency class (SEDBUK)

Figure 7. Diagram for selection of appropriate domestic boiler for the examination condition

Figure 8. Comparisons of investments in district heating and gas distribution system

Figure 9. Identification of some characteristic cases in model diagram

Figure 10. Diagram for adoption of optimal system for observed settlement

Figure 11. Displacement of borders and characteristic points calculated for different quality of building insulation

Figure 12. Length of conduits sort by diameters for DH pipeline for good and poor insulated buildings in the Karaburma settlement – case study

Figure 13. Price changing sensitivity, sample for few factors of influence

Figure 14. Consumption of electrical energy in the observed settlement

Figure 15. Algorithm for centralized energy supply system selection fueled by natural gas

Table 1: Identification of all of the 96 considered case (number of average dwelling per building)

Table 2: Structure of pipe diameters for one of the cases (example)

Table 3: Investments in both systems per dwelling; G and DH [€]

Table 4: Costs for gas distribution system and district heating system (example)

Table 5: Initial costs^a - € per “Conditional Dwelling”

Table 6: “Net Present Value of Costs” (NPV)^a - € per “Conditional Dwelling”

1 Deleted from old version

2 Added in new version

3 **Systematic Approach to Natural Gas Usage for Domestic Heating in Urban Areas**

4 **Dejan Brkić^{a*}, Toma I. Tanasković^b**

5 ^aMinistry of Science and Technological Development, Đušina 7, 11000 Beograd, Serbia,

6 ^bFaculty of Mining and Geology, University of Belgrade, Đušina 7, 11000 Beograd, Serbia

7 Received: 22 February 2008; received in revised form:

8

9 **Abstract:** ~~Establishing of proper criteria for economical and energy efficient operation of district~~
10 ~~heating i.e. natural gas supply system for fulfilling low temperature heat demands in domestic~~
11 ~~use, is necessary condition for optimal and mutual persuasive operation of these systems. The~~
12 ~~main goal of this paper is to establish general model to achieve coordinated development of~~
13 ~~centralized energy supply systems, based on defined and accepted criteria. An analysis of~~
14 ~~structure for centralized systems for energy supply has been done with accent on their pipelines.~~
15 ~~Investment and exploitation costs are evaluated considering specified area of town as a function~~
16 ~~of systems' technical characteristics. Model for evaluation of economy for different solutions is~~
17 ~~established, backed up by computer spreadsheet. This model for different heat loads and number~~
18 ~~of objects on conditional urban area (as parameters of real energy and urban situation) with~~
19 ~~defined prices and costs, suggests one of systems as optimal for the area. General model for~~
20 ~~harmonization and optimal development of district heating and natural gas supply systems~~
21 ~~represents analytical approach in considering development of centralized energy supply systems~~
22 ~~in towns. The goal function of this model besides component that considers costs, involves~~

* Corresponding author. Tel./fax: +381113243457, e-mail: dejanrgf@tesla.rcub.bg.ac.yu, (D. Brkić)

23 energetic, techno-economic, social, ecological and safety constraints. Natural gas can be used for
24 satisfying population needs for heating, either directly by bringing the gas to the dwellings
25 through the gas distribution system and combusting it in the domestic boiler (gas distribution
26 system-G), or indirectly by combusting the natural gas in the heating plant and distributing the
27 heat energy to the dwellings through the district heating system (district heating system-DH).
28 The selection of a certain type of heating system is made according to the disposition of
29 buildings in the area, their number, size, insulation quality, etc. Based on these characteristics,
30 calculations of investments and exploitation costs have been made for both heating systems and a
31 comparison has been made for all of the 96 presented cases. Almost each type of real settlement
32 can be represented by one of the types of the conditional urban area which are introduced in the
33 paper. The main goal of this paper is to establish a general model to achieve coordinated
34 development of centralized energy supply systems fueled by natural gas, based on defined and
35 accepted criteria. A structure analysis of centralized systems for energy supply has been done
36 with accent on their pipelines.

37 **Keywords:** Natural Gas, Settlement, Gas Distribution, District Heating, Urbanism

38

39 **Nomenclature**

40 y – number of “Conditional Dwellings” per building [-]

41 N - number of buildings per “Conditional Urban Area” [-]

42 x - Peak load densities or “Heat Load” [MW/km²]

43 DH – costs of district heating system [€]

44 G - costs of local gas heating system (domestic boiler in each dwelling) [€]

45 DHN - costs of district heating network, i.e. costs of building/civil works, costs of materials
46 (insulated pipes, pumps, accessories, etc.) and telemetry systems, etc [€]
47 HE - costs of heat exchanger stations located in buildings [€]
48 HP –investment in new heating plant [€]
49 DHOC - annual costs of maintenance calculated as percentage of investment, in network, heat
50 exchanger station, annual natural gas consumption and annual electricity consumption for pumps
51 drive [€]
52 MPRS - costs includes costs of main pressure reduction stations [€]
53 PRS - costs of pressure reduction stations [€]
54 DN - costs of natural gas distribution network [€]
55 DS - costs of domestic measurement sets [€]
56 B - costs of domestic boilers [€]
57 GOC - annual costs of maintenance calculated as percentage of investment; in gas distribution
58 network, in pressure reduction station, in measurement set, domestic boiler and annual natural
59 gas consumption [€]
60 dr - “Discount Rate” [%]
61 NPV - “Net Present Value of Costs” [€]
62 t – Time [years]
63
64 **1. Introduction**
65
66 If a gas based system in a settlement is planned, the decision can be done among two conflicted
67 options:

68 1. Indirect system; natural gas is being combusted in a heating plant and household heat supply is
69 provided by a District Heating System (DH),

70 2. Direct system; dwellings are being heated by natural gas brought through a gas distribution
71 system and then combusted in domestic gas boilers in each dwelling, individually (G).

72

73 The initial decision on choosing one of two systems is based on the number and size of buildings
74 in a settlement, the size of the settlement itself and the heating insulation of buildings [1]. In

75 boundary cases, if it is possible to achieve both options it is also possible to introduce a sort of
76 hybrid system which is not considered in this paper. The economic analysis of the renovation of

77 small-scale district heating systems in Lithuania is available [2]. District heating systems using

78 cogeneration, as well as the local fuel-based and electric heating systems for detached houses,

79 are analyzed by L. Gustavsson and A. Karlsson [3]. Their analysis includes the whole energy

80 system, from the natural resource to the end user, with respect to the primary energy use,

81 emission and cost. They found that natural gas based systems are less expensive than the

82 corresponding wood-fuel based systems, except the matter of ecology. In the future, green

83 energy sources or fossil energy sources such as oil and natural gas will be more used in industrial

84 processes in order to decrease the ratio of greenhouse gases released from the coal-based local

85 and industrial processes [4].

86

87 The goal of the model introduced in this paper is to determine the connections among urban and

88 energy characteristics of settlements in cities and to be benefit from more rational usage of

89 natural gas as non-renewable fossil fuel. Energy demands for heating are shown for the Canadian

90 case [5], from the economical point of view. The introduction of natural gas in the Greek energy

91 market have broadened the options in the field of space heating [6]. The paper by C. Dinca, A.
92 Badea, P. Rousseaux, and T. Apostol [7] aims to select the optimal energetic scenario applied to
93 a consumer with 100 000 inhabitants from the residential–tertiary sector in Romania (series of
94 seven scenarios based on natural gas have been analyzed). The natural gas in optimized bivalent
95 heating systems is shown in the paper of SI. Gustafsson and BG. Karlsson [8]. The study of MS.
96 Torekov, N. Bahnsen, and B. Qvale [9] is in correlation with this paper and strives to clarify to
97 what extent the improved insulation of new buildings affects the economically rational choice of
98 heating supply. District heating should be advocated only for areas with a strong heat demand,
99 primarily for areas with apartment buildings [9]. R. Lazzarin and M. Noro [10] have done
100 analyses of local or district natural gas heating from energetic, environmental and economic
101 points of view. The legal and policy aspects of the utilization of different energy supply systems
102 in households sector can also be found in the available literature [11]. Some German studies with
103 subject relevant for development of district heating systems in urban environment are also useful
104 and highly evaluated, but this literature is available only in German language [12-14], with
105 related papers presented in scientific journals [15]. The main achievement of these German
106 researches is the establishing of interaction between heating systems, settlement structure and
107 urban planning at the local level. The study analyses options for heat supply in up to 10 types of
108 built up areas [12] – from densely populated urban areas to villages. A new German study 20
109 years later refers to this work [13], with projection to 2020 [14].

110

111 ~~The present practice in many cities, for heating systems selection and utilization of existing~~
112 ~~capacities in systems for centralized energy supply, includes separate consideration of every~~
113 ~~single case or very often selection without clear criterions. Proposed~~ Considering the selection of

114 heating systems and the utilization of the existing capacities in the systems for centralized energy
115 supply, the present practice in many cities is that every single case must be considered separately
116 and, very often, the selection is done without clear criterions. The proposed model could be
117 useful to urban planners, municipal officials, public utility companies, etc., as a first step in
118 system selection (see Electronic Annex in the online version of this article).

119

120 ~~In urban areas, the most suitable option for satisfying the heating demands is by using a~~
121 ~~centralized system.~~ The most suitable option for satisfying heating demands in urban areas is by
122 using a centralized system. The centralised energy supply from heating plants has many
123 advantages: saves primary energy (due to the modern construction of boilers in heating plants as
124 well as the utilisation of modern energetic and ecological ways of combustion, the primar energy
125 sources are better used during the transformation of primar energy into heat energy), the
126 distribution of hot water consumption (the centralised hot water distribution is the way to avoid
127 the transformation of primary energy, mostly from heat to electric energy, and then again, from
128 electric to heat energy), the possible utilisation of low quality fuel, the possible utilisation of
129 some alternative kind of fuel, the centralised storage for fuel, less expenses for the standard
130 discontinuous transportation of fuel (saving motor vehicles' fuel), due to the centralised and
131 highly controled heating, there is less danger from fire. There is also a well organised,
132 professional fire protection. There are also some negative aspects of the heating systems from
133 heating plants: high investments during the initial phase of building of heating sources and
134 pipeline structure, possible quitting with heat energy supply caused by the damage in heating
135 plant or distribution network, in some cases, heating expenses are measured by squaring, not by
136 consumption. The advantages of the systems for the individual consumption of gas in households

137 by using the gas distribution network are the following: the gas consumption is being measured
138 separately for each apartment and the paying of costs depends on consumption (which is not
139 always the case when DH systems are being used), gas saving for hot water supply and cooking
140 (these demands are being satisfied directly by the transformation of chemical energy of natural
141 gas into heat energy, that is how the gas used for transformations of primary energy into electric
142 energy is saved), there is no need for storehouses in households, less costs for the standard fuel
143 distribution (the fuel is saved for motor vehicles), relatively small investments in the construction
144 of distribution network in relation to thermal network, less possibility for quitting of supply. The
145 disadvantages of the centralised natural gas supply systems are: an increased fire danger,
146 explosions, or possibility of suffocation caused by damaged installations for different reasons, the
147 combustion is taking place in the apartment, the possible lack of gas or an interrupted
148 distribution pipeline, etc.

149

150 ~~If a gas based system in a settlement is planned, decision can be done among two conflicted~~
151 ~~options:~~

152 ~~1. Indirect system; natural gas is being combusted in a heating plant and households heat supply~~
153 ~~is provided by a District Heating System (DH);~~

154 ~~2. Direct system; dwellings are being heated by natural gas brought through a gas distribution~~
155 ~~system and then combusted in domestic gas boilers in each dwelling individually (G).~~

156

157 Life comfort [16] is the same in both options; every individual dwelling has the same network of
158 conduits and radiators. ~~Main~~ **The main** intention of this model approach is to find a way ~~how~~ to
159 ~~deliver~~ **distribute** heat energy in each dwelling using **the** existing capacities (not to make strategy

160 for a city planning, but to exploit most possible rationally existing capacities). ~~Primarily~~ The
161 ~~primary~~ goal of this paper is not to investigate ~~whole~~ district heating or gas distributive
162 infrastructure, but to compare investments in both systems with their specific details (pipelines
163 with included costs of domestic boilers for ~~the G system~~ or costs of heat exchanger for ~~the DH~~
164 ~~system~~, investment in new capacities in heating plant, etc.). ~~Main~~ The main subject of ~~the~~
165 examination is in the “Conditional Urban Areas”. ~~Comparisons~~ The comparison of investments
166 in pipelines for both systems ~~are~~ is the most important parameter ~~in~~ of this analysis. ~~The most~~
167 ~~detailed analyses of the heating in one town must take into consideration other types of fuel for~~
168 ~~heating plant, alternatives for heating in the cases of the lack of natural gas, etc.~~ In the most
169 detailed heating analyses in one town, the other types of fuel for heating plants, the alternatives
170 for heating in the cases of the lack of natural gas, etc. must also be taken into consideration.

171
172 ~~Model~~ The model which is presented here is developed as a tool for solving some of the
173 misunderstandings in ~~the~~ strategy of urbanism correlated to natural gas heating in Serbian towns.
174 This project has been supported by ~~the~~ Ministry of Science of Serbia. All ~~the~~ values in this paper
175 refer to conditions in Serbia, but readers ~~also~~ have ~~an~~ access to the relevant file (see Electronic
176 Annex 1 in the online version of this article), and can change all the values (green tones in excel
177 file can be changed). According to that ~~possibility~~, this model can be applied for conditions
178 anywhere in the world.

179
180 ~~Strategy~~ The strategy for heating of dwellings in urban areas of Serbia, ~~since from~~ the
181 communist period, had been made to favor district heating systems in towns. ~~Consumer~~ The
182 ~~consumer~~ area of Belgrade is ~~being~~ supplied with thermal energy by district heating system

183 consisting of 15 heating plants which use gas ($83\%=265\cdot 10^6\text{ m}^3/\text{year}$ [1]) and crude oil as basic
184 fuel. Statistical data show that 38% of the buildings are connected to the district heating system,
185 that is, which represents 240000 flats and 7500 business offices are heated in that way. In the
186 scope of the Belgrade environmental protection program, construction of thermal network and
187 gas distribution network in downtown area takes an important place. The construction projects of
188 thermal network and gas distribution network in downtown areas take an important place in the
189 scope of the Belgrade environmental protection program, so approximately 800 individual solid
190 fuel boilers have been shut down so far. Most of these plants nowadays are fueled by natural gas,
191 but in the past they were fueled by liquid fuels or some smaller and obsolete by coal. All of these
192 mini plants have to be closed, and heating for relevant dwellings, according to new strategy, will
193 be provided by some sort of natural gas heating. Nowadays, most of these plants are being fueled
194 by natural gas, but in the past they were fueled by liquid fuels or by coal (in some smaller and
195 obsolete plants). All of these mini plants have to be closed. According to the new strategy, the
196 heat supply for relevant dwellings will be provided by some sort of natural gas heating.
197 Government strategy is The government has the strategy to connect almost all dwelling
198 dwellings to some form of natural gas heating system. Goal The goal is not to use solid fuel
199 heating, and especially not electrical electric energy. They should be used only in some rare
200 cases. There are 42 city heating plants in Serbia with heat energy capacity of 5.5GW. However,
201 Serbia does not have sufficient energy production or funds for their procurement. The main
202 characteristics of Serbia's heating plants are low operating readiness due to insufficient
203 maintenance and outdated equipment, financial exhaustion and an inability to perform urgent
204 intervention on sources and grids. Heating is poor and there is a need for additional capacity,
205 mostly fueled by natural gas. Serbia doesn't have enough gas production reserves from its own

206 fields or to satisfy the demands (the annual peak of the production was $600 \cdot 10^6 \text{ m}^3$ and now it's
207 several times lower ($285 \cdot 10^6 \text{ m}^3$) [1]). ~~Note, that~~ The imported gas ~~from import~~ is available for
208 Serbia since 1979. from one direction (from north, through Hungary). ~~Also, Serbia~~ Serbia also
209 has the EU perspective [2, 3 17, 18], and ~~government~~ the Government's strategy is to ~~be make~~
210 Serbia a transient country for the export of Russian gas to the western countries of EU countries
211 (from the second direction, through Bulgaria). Due to the European obligation to reduce
212 greenhouse gas emissions in the framework of the Kyoto Protocol, the trend towards the use of
213 natural gas is expected to continue in the future. The increased consumption is ~~faceed with~~ and
214 comparably low indigenous gas resources within Europe, ~~so that the dependency of Europe on~~
215 ~~gas imports from abroad will rise in the future~~ are expected to increase the Europe's dependency
216 on gas imports from abroad in the future. In addition to the existing supply sources from Russia
217 [4 19] and Algeria, gas resources from the Middle East and the Caspian and the Central Asian
218 regions ~~may be~~ could be the possible supply options to cover Europe's gas demand in the future.
219 Today, natural gas heating in Serbia has a great perspective [5-8 20-23].

220

221 ~~For every type of settlement a hypothetical equivalent within a model was made.~~ A hypothetical
222 equivalent within a model has been made for every type of settlement. ~~For each (of limited~~
223 ~~number) of hypothetical settlements investments were calculated and comparison was made.~~ The
224 investment costs were calculated and the comparison has been made for each (of a limited
225 number) of hypothetical settlements. The system with the least smallest investments (including
226 exploitation and the maintenance in the next 25 years), depending on the city planning
227 parameters, is more cost effective and it is adopted. This creates a direct link between the city
228 planning parameters and the choice of one of the systems.

229

230 The initial decision on choosing one of two systems is based on the number and the size of
231 buildings in a settlement, its size and heating insulation of the buildings [1]. In boundary cases,
232 if it is possible to achieve both options it is also possible to introduce a sort of hybrid system, not
233 considered in this paper. Economic analysis of the renovation of small scale district heating
234 systems in Lithuania is available [9]. District heating systems using cogeneration, as well as local
235 fuel based and electric heating systems for detached houses, are analyzed by L. Gustavsson and
236 A. Karlsson [10]. Their analysis includes the whole energy system, from the natural resource to
237 the end user, with respect to primary energy use, emission and cost. They found that systems
238 based on natural gas are less expensive than the corresponding wood fuel based systems, except
239 the matter of ecology. In the future, green energy sources or fossil energy sources such as oil and
240 natural gas will be more greatly used in industrial processes in order to decrease the ratio of
241 greenhouse gases released from coal based local and industrial processes [11].

242

243 Goal of model introduced in this paper is to determine the connections among urban and energy
244 characteristics of settlements in cities, and to be of benefit for more rational usage of natural gas
245 as non-renewable fossil fuel. Energy demands for heating are shown for Canadian case [12] from
246 the economical point of view. The introduction of natural gas in the Greek energy market
247 broadened the options in the field of space heating [13]. Paper by C. Dinca, A. Badea, P.
248 Rousseaux, and T. Apostol [14] aims to select the optimal energetic scenario applied to a
249 consumer with 100 000 inhabitants from the residential tertiary sector in Romania (series of
250 seven scenarios based on natural gas has been analyzed). Natural gas in optimized bivalent
251 heating systems is shown in paper of SI. Gustafsson and BG. Karlsson [15]. Study of MS.

252 Torekov, N. Bahnsen, and B. Qvale [16] is in correlation with this paper and strives to clarify to
253 what extent the improved insulation of new buildings affects the economically rational choice of
254 heating supply. District heating should be advocated only for areas with a high concentration of
255 heat demand, primarily areas with apartment buildings [16]. R. Lazzarin and M. Noro [17] have
256 done analyses of local or district heating by natural gas from energetic, environmental and
257 economic point of views. Legal and policy aspects of different energy supply systems utilization
258 in households sector can also be found in available literature [18].

259

260 **2. Concept** The concept of conditional urban areas

261

262 The model upon which the decision on choosing one of two systems is made (DH vs. G), is
263 based on the introduction of hypothetical urban settlements. By introducing this practice,
264 performing it is not necessary to perform the entire calculation for both systems is avoided and
265 after which the choice on of a heating system in a the settlement is made. Application The
266 application of this model makes easier the job for energy planners and city planners. People with
267 higher living standard; often do not take economic parameters into consideration economic
268 parameters when deciding between gas or district heating system. The decision is based on a
269 personal affinity (and often, prejudice) [19 24].

270

271 Parts The parts of a city with residential and other buildings within real settlements are called
272 „Real Urban Area“. They can be divided into several zones based on the same or similar urban
273 characteristics. Zones The zones divided like this, for the model purpose purposes, need to have
274 an area of 0.05 km² - “Basic segment” (Fig. 1.). Further on, real urban parameters of a real

275 settlement can be copied onto the selected “Basic segment” (Fig. 2.). “Basic segment” with
276 rectangular size with dimension approximately $160\text{ m}\cdot 315\text{ m}=0.05\text{ km}^2$ is adopted for this
277 purpose [1]. Based on the spatial disposition within the model, there are 6 different versions of
278 “Basic segments”: 4, 8, 16, 32, 64 and 128 buildings per “Basic segments”: (Fig. 1).
279 “Examination segment” (Fig. 3.) ~~consist~~ consists of ten “Basic segment segments” with an added
280 pipeline (gas and district heating). Only one type of “Basic segment” can exist ~~into~~ in one
281 “Examination segment”. Real zone formed like this can be joined with one of the 96
282 „Conditional ~~urban~~ Urban Areas“(Fig. 4. and Table 1.). Each particular “Conditional ~~urban~~
283 Urban Area” ~~consist~~ consists of ten “Basic segment segments” (all the ten belong to one of the
284 six types shown in fig 1.), buildings (all the buildings ~~is~~ are the same in one regarded segment)
285 and, pipeline (district heating pipeline or gas distribution pipeline) – Table 2. Every real situation
286 in town has to be joined to one of the best fitted „Conditional ~~urban Area~~ Urban Areas”. ~~To each~~
287 ~~one of these basic types of “Examination segment” a~~ A different heat load (peak load density)
288 can be given to each one of these basic types of “Examination segment”, which is based on the
289 size of buildings. ~~In this model there~~ There are 8 different heat loads in this model: $10\text{ MW}/\text{km}^2$,
290 $20\text{ MW}/\text{km}^2$, $30\text{ MW}/\text{km}^2$, $40\text{ MW}/\text{km}^2$, $50\text{ MW}/\text{km}^2$, $75\text{ MW}/\text{km}^2$, $100\text{ MW}/\text{km}^2$ or 125
291 MW/km^2 (Fig. 2). These values are chosen for the analysis in order to include a wide range of
292 possible real urban situations.

293

294 Every settlement, found in reality, corresponds to one of the 96 hypothetical settlements included
295 in the model (Table 1). They are called “Conditional Urban Area” (six “Basic segment” multiply
296 by eight “Heat Loads” multiply by two ~~type~~ types of insulation) [1]. According to a variety of
297 possible settlements (in density, size and layout of buildings) a model which has the ability to

298 represent their different characteristics is formed. With six types of “Basic segment segments”
299 (Fig. 1) all the possible densities of built up areas in settlements can be described. In each
300 particular urban area, buildings with different sizes can be found; Different sizes of buildings can
301 be found in each particular urban area from small houses to skyscrapers, i.e. with eight types of
302 buildings graduated by size all situations can be described (eight different “Heat Loads”). Each
303 of the 96 proposed hypothetical settlements can be joined with different city planning parameters
304 such as: the number of buildings reduced to the unit value of surface, the size of buildings, the
305 number of dwellings within the buildings, the number of floors within buildings, the spatial
306 disposition of buildings within the settlement, the quality of heat insulation of dwellings etc [20-
307 22-25-27]. If within the settlement there are several types of buildings or density of built up
308 areas, If there are several types of buildings or density of built up areas within the settlement,
309 settlements need to be divided into several „Conditional Urban Areas“. Every single type of
310 building can be very good or poor insulated (older buildings versus newer buildings) [23 28].
311 Numbers of “Conditional Dwellings” per building are shown in Table 1.

312
313 For every „Conditional Urban Area“, it is possible to calculate the entire investment cost of costs
314 for the implementation of gas distribution and district heating system systems (Table 3).
315 Investments are calculated The investment’s calculations are based on the detailed estimate of
316 distribution network for both systems with all of the equipment included, as well as the labor
317 expenses and the spare parts for replacement in the first 25 years. Thus, the investments for all
318 the 96 cases can be calculated (one of these cases is shown in Table 2 4). After that, the values of
319 gas distribution costs are being subtracted from the investment cost costs of the district heating

320 system (Table 3 5) and then they are being discounted (Table 4 6). For cases with positive values
321 the option of gas distribution is more favorable than the district heating system (negative values).

322

323 ~~Disposition~~ The disposition of networks for all cases is shown in figure 3 (“Examination
324 ~~segment~~”). ~~Disposition means length of pipeline~~ The disposition designates the pipeline length,
325 but not structure of diameters of conduits in ~~composition of pipeline~~ the pipeline composition.
326 ~~Determination~~ The determination of structure of diameters of conduits in ~~composition of pipeline~~
327 the pipeline composition can be done only after the “Conditional Urban Area” is formed. A
328 structure of pipes diameters depends on building size. The “Examination segment” has ten
329 times bigger area surface than the “Basic segment” because of the network sensitivity
330 exploration. Note that in fig. 3 (“Examination segment”) ~~exist pipeline network~~ pipeline network
331 exists, while in Fig. 1 or in Fig. 2 ~~don't it doesn't~~ (“Basic segment”).

332

333 So, the similarity between “Conditional Urban Area” and “Real Urban Area” can be determined
334 by two different independent quantities [1].

335

336 1) Number of buildings in an urban area (the number of buildings on 0.05 km^2 – 5 hectares);

337 (Fig. 1),

338 2) Heat A heat demand [24 29] of an urban area (“Heat Load” or peak load densities of all

339 buildings heated in a zone divided by the size of an area), MW/km^2 ; (Fig. 2),

340

341 ~~Term~~ The term “building” is used here also for family houses also, as well as for the and similar
342 smaller constructions with the same meaning as e.g. skyscrapers. In all analyses, “Conditional

343 Residential Unit” [1], i.e. “Conditional Dwelling” [1] with net heating surface area of 60 m^2 is
344 observed. “Conditional Dwelling” has, for the purpose of the model approach, a heat demand of
345 142 W/m^2 (heat peak load for lower insulated dwelling) in case of lower a low (bad) insulation,
346 and in case of better (good) insulation it has a heat demand of 95 W/m^2 (heat peak load for better
347 insulated dwelling). Each combination of a defined number of buildings and peak load density
348 corresponds to a different number of average dwellings in the building (Table 1). Average An
349 average dwelling (60 m^2) is practically “Conditional Dwelling”.

350

351 ~~Concept~~ The concept of the “Examination segment” is regarded only for the purpose of
352 exploration on realistic values of diameters in structure of pipeline the pipeline structure, but
353 values of N-number of buildings presented in this paper are nominally per “Basic segment”.
354 “Heat load” is expressed in MW/km^2 (not in $\text{MW}/0.05 \text{ km}^2$ or in $\text{MW}/0.5 \text{ km}^2$) and accordingly
355 it is nominally equal for for both “Examination segment” as for and “Basic segment”.

356

357 **3. Model The model of rational natural gas usage based on city planning parameters**

358

359 Based on the introduced “Conditional Urban Area“, a techno-economical model of rational
360 natural gas usage was has been made. For each of the 96 cases investment investment, a
361 calculation was has been made in both of the proposed heating systems (Gas Distribution [25 30]
362 vs. District Heating [26 31]) including the exploitation in the next 25 years (investments). For
363 each case, a comparison of costs was has been made so that the heating system with the least
364 smallest cost has an advantage in the implementation. Number . The number of dwelling

365 dwellings per buildings, i.e. the identification of all here shown 96 cases the 96 cases shown here
366 is shown in Table 1.

367

368 ~~In the model, both types of heating~~ Both of the heating types in the model have special costs
369 since both of them have special elements; e.g. ~~the district heating system is built with~~ made of
370 steel conduits, pumps and heat exchangers, on the contrary, ~~the~~ gas distribution system is ~~built~~
371 ~~with~~ made of cheaper polyethylene conduits and has stations for measuring and regulation with
372 internal gas equipment (each dwelling has domestic gas boiler etc). ~~Investment~~ The investment
373 in new capacities ~~in for~~ heating plant ~~are~~ is included in ~~the~~ model in a ~~direct way~~ directly i.e. by
374 increasing the price of natural gas for district heating, or can be added by including the new cost
375 indirectly. ~~Investments~~ The investments in a new heating plant ~~fuel~~ fueled by natural gas are:
376 80000 €/MW (for heat plant capacity <50MW), 65000 €/MW (for heat plant capacity 50-100
377 MW) and 52000 €/MW (for heat plant capacity 100-200 MW) [1]. That means additional ~~cost~~
378 ~~costs~~ of 450-680 € per “Conditional dwelling”. ~~That~~ It implies that this kind of additional ~~cost~~
379 ~~costs~~ is not essential for this kind of analyses (Fig 5.). ~~Changes~~ The changes in ~~the~~ slope of
380 borderline in ~~the~~ model diagram¹ are caused by ~~changes in discount rate~~ the discount rate
381 ~~changes~~ (Fig 5.) or by differentiation in ~~the~~ structure of diameters of conduits in ~~the~~ pipeline².
382 Same conclusion can be made with ~~variation in price~~ price variations of domestic boiler (see
383 Table 3 5 and Fig 5). L. Gustavsson and A. Karlsson [40 3] estimated ~~DH investment costs and~~
384 ~~DH maintenance costs~~ the DH investment and maintenance costs. ~~Increasing of price of domestic~~
385 ~~gas boiler simultaneously with introducing of investments in heating plant in the same amount~~
386 ~~are to be annulled~~ An increasing price of domestic gas boilers simultaneously with the

¹ See also Fig 11.

² See also Fig 12 in case study

387 introduction of the same amount of investments in a heating plant are to be annulled (Fig 5.) (for
388 detailed analyses consult electronic annex 1).

389

390 **Relative** A relative amount of investments (per “Conditional Dwelling” included annual costs) in
391 district heating – DH and in local gas heating system – G (each “Conditional Dwelling” is
392 equipped with domestic boiler fueled by natural gas) can be calculated after following eqs. (1
393 and 2).

394

$$395 \quad DH = \frac{DHN + HE + HP + DHOC}{y} \quad (1)$$

396 Where there are: DH – costs of District Heating System [€], DHN - costs of District Heating
397 Network, i.e. costs of building/civil works, costs of materials (insulated pipes, pumps,
398 accessories, etc.) and telemetry systems, etc [€], HE - costs of Heat Exchanger stations located in
399 buildings [€], HP –investment in new heating plant[€], DHOC - annual costs of maintenance
400 calculated as a percentage of investment, in network, heat exchanger station, annual natural gas
401 consumption and annual electricity consumption for pumps drive [€] and y – number of
402 “Conditional Dwellings” per building [-].

403

404 ~~Annual costs of maintenance~~ The annual maintenance costs calculated as a percentage of
405 investment (eq. 1), in network (2,5%); lifetime of 25 years, heat exchanger station (1,5%);
406 lifetime 12 years, annual natural gas consumption - 10% more than in the system with domestic
407 boiler in each “Conditional Dwelling”) (942,7 m³ per “Conditional Dwelling” - 0.12 €/m³) and
408 the annual electricity consumption for pumps drive (250 kWh – 0,035 €/kWh²). ~~Assumption of~~
409 ~~the~~ The estimated heat losses in the district-heating network is are 10%.

410

$$411 \quad G = \frac{\text{MPRS} + \text{PRS} + \text{DN} + \text{DS} + \text{B} + \text{GOC}}{y} \quad (2)$$

412 Where there are: G - costs of Local Gas Heating System (domestic boiler in each dwelling) [€],
413 MPRS - costs include costs of Main Pressure Reduction Stations [€], PRS - costs Pressure
414 Reduction Stations [€], DN - costs of natural gas Distribution Network [€], DS - costs of
415 Domestic measurement sets [€], B - costs of domestic boilers [€], GOC - annual costs of
416 maintenance calculated as a percentage of investment; in gas distribution network, in pressure
417 reduction station, in measurement set, domestic boiler and annual natural gas consumption [€]
418 and and y – number of “Conditional Dwellings” per building [-].

419

420 Annual costs of maintenance The annual maintenance costs calculated as a percentage of
421 investment (eq. 2); in gas distribution network (2,25%); lifetime of 25 years, in pressure
422 reduction station (2,25%); lifetime of 25 years, in measurement set (2,25%), lifetime of 12 years,
423 domestic boiler (2,25%), lifetime of 12 years and the annual natural gas consumption (857 m³
424 per “Conditional Dwelling” - 0.12 €/m³).

425

426 The efficiency of the NG boiler is the best during the winter when space heating is needed. In
427 During summer, when only hot water is required the boiler is often operated at a very low load
428 and the average efficiency is reduced. For examination in this paper, on-line database SEDBUK³
429 (Seasonal Efficiency of Domestic Boilers in United Kingdom) [32] is very useful (Fig. 6 and 7).
430 District heating is often less efficient with respect to modern heating technologies using natural

³ available from www.sedbuk.com

431 gas. Condensing boilers guarantee higher efficiencies with respect to “traditional” district
432 heating.

433

434 ~~Investment~~ An investment in a new heating plant or the increasing of price of domestic gas boiler
435 boiler’s price is included in the calculation, with the introduction of such costs or investments on
436 both G and DH sides simultaneously, caused the equal impact in all of the six “examination
437 segments” (does not change slope of borderline in Fig. 5⁴).

438

439 In the equations ~~above costs common~~ above, the common costs for both systems are not shown.

440 Different investments in these two opposite systems can be compared for the purpose of a model
441 (Fig 6 8).

442

443 All the previous investments are considered for the present conditions in Serbian energy sector.

444 Of course, this model is applicable for conditions and particular cases all over the world, but
445 diagrams (figures in this paper) are generated for prices ratio in Serbia. Detail calculation for one
446 case of 96 is shown in table 2 4.

447

448 Values of initial costs (shown in Table 3) for DH subtracted by initial costs of G are shown in
449 table 3 5.

450

451 Generally, each project task has a time component. Every particular element of the two systems
452 shown here has a lifetime, and it has a price on the market (expressed in €). If one of the

⁴ or in case study in Fig 11

453 elements has reached the end of its lifetime (e.g. 26 years), it has to be replaced. Thus, in a
454 project, during the first and the next several years, costs for provision, maintenance and
455 replacement of elements exist (e.g., some elements must be replaced after 14 years and some
456 after 25 years). A sum of costs calculated for each year (t) for gas distribution system is labeled
457 here as G, and for district heating system as DH. “Present Value of Costs” is one of the most
458 useful criterions for project analyses for a whole lifetime of every particular system element. In
459 that way, discount flows reduced on “Present Value of Costs” can be evaluated. “Present Value
460 of Costs” is, by default, cumulative cost for all the elements of the system in present and in
461 future expanded for discount rate. “Future Value of Costs” has to be reduced to present value and
462 to be added to real present costs. Thus, the generated value is called “Present Value of Costs”.
463 For the reduction of “Future Value of Costs”, an appropriate “Discount Rate” (dr) has to be
464 adopted. Higher value of “Discount Rate” is calculated when risks for the safety of investments
465 exist. In the case of possible risks for the safety of investments, higher value of “Discount Rate”
466 is being calculated. “Discount Rate” could be equalized with “Interest” on the market or for
467 realized credit.

468

469 In our case, an economical evaluation is realized during the comparison of two “Present Values
470 of Costs”, for gas distribution system (G) and for district heating system (DH) [27-33]. “Net
471 Present Value of Costs” (NPV) (eq. 3) is the result of subtraction of the “Present Value of Costs”
472 calculated for district heating system (DH) and the “Present Value of Costs” calculated for gas
473 distribution system (G).

474

$$475 \quad NPV = \sum_{t=1}^n \frac{DH - G}{(1 + D_r)^t} \quad (3)$$

476

477 ~~Value~~ The value of “Discount Rate” or capital cost rate in this case is rated and adopted as
478 $dr=10\%$. The value of discount rate has great impact on the optimal choice of quantitative
479 conclusions (Fig. 5). ~~Changes~~ The changes of calculated values for $dr=5\%$ and $dr=7\%$ are shown
480 in Table 4 6. ~~Annual~~ An annual gas consumption calculated for one “Conditional Dwelling” is
481 857 m^3 for heating only, ~~and for district heating system, this amount is 10% higher~~ and this
482 ~~amount is 10% higher for district heating system.~~ Also, Besides, a statistical approach based on
483 nonlinear regression principles can be made to natural gas consumption estimation of individual
484 residential and small commercial customers [28 34]. ~~Annual~~ The annual costs of electrical
485 energy for running the pumps for district heating system are estimated to 250 kWh per
486 “Conditional Dwelling”.

487

488 Analyses are done for all the 96 cases (six “Conditional Urban Area” multiplied by eight “Heat
489 Loads” and by two conditions of insulation – bad or good insulation) for the period of $t=26$
490 years. In table 4 6, case with a bad insulation is shown.

491

492 The values in certain cases in table 4 6 vary more or less from zero. For example, for
493 “Conditional Urban Area” with 16 buildings and with “Heat Loads” 50 MW/km^2 , the calculated
494 “Net Present Value of Costs” (NPV) is only -5 per “Conditional Dwelling” for a period of 26
495 years. Therefore, ~~in this case,~~ the realization of gas distribution system for that “Conditional
496 Dwelling” is only 5 € for 26 years in advantage versus district heating system. This case and the
497 other similar cases are in the “gray zone” (Fig. 7 9). In the “gray zone”, both systems are
498 payable, especially for a period of 26 years.

499

500 If a considered value for a certain housing block exceeds, ~~more or less, the recommended~~
501 ~~limiting value~~ the recommended limiting value, more or less, the decision to recommend a
502 particular centralized heating system is more reasonable. Changing the structure and the price
503 ratio (i.e. the state political decision to subsidize the ~~price of gas~~ gas price in a system or to issue
504 a price, which would disturb the current price ratio of gas used for district heating system and
505 individual consumers), the conception and manner of a construction of certain system and its
506 elements, may cause these parameters to vary. Currently, plastic-polyethylene conduits (cheap)
507 are used for distribution to individual consumers while steel conduits (expensive) had been used
508 before. It led to the considerable cuts in network construction prices, while maintaining the same
509 level of safety and endurance.

510

511 For the same “Heat Loads”, when there are many smaller family houses located on a
512 “Conditional Urban Area” e.g. N=32, sometimes only with one “Conditional Dwelling”, gas
513 distribution system is more reasonable. On the contrary, when there is a smaller number of
514 skyscrapers located on “Conditional Urban Area” e.g. N=4, it is more reasonable to use district
515 heating system (Fig. 7 9).

516

517 By means of techno – economic analysis for a certain area, it is possible to determine the
518 advantages of one system over the other (district heating over gas). However, considering the
519 situation on the ground, it may turn out that the system is inaccessible in that part of the city
520 (heating plant does not have enough capacity or, in the first stage, the areas closest to the plant
521 could have a priority in system installation). In that case, if the installation costs of the other

522 available system are not too high, it is rational to install that type of heating system (thus saving
523 the consumption costs of electric energy and reducing the amount of pollution if the object is
524 coal).

525

526 If, after the analysis, it turns out that one system has more significant economic advantages than
527 the others ~~do~~, but it is unavailable, some form of hybrid system should be considered. For
528 instance, if the installation of district heating system has a lot of economic advantages but it is
529 not available, it is possible to build a local boiler room which would be gas operated. This hybrid
530 solution would demand additional economic and ecologic analyses [29 35] and estimations of
531 which good features of district heating system would be kept and which would be discarded.

532

533 **4. Case study; Application under real conditions**

534

535 ~~Characteristics~~ The characteristics of the “Real Urban Area”: number of buildings, disposition
536 and size of buildings, construction type, etc. are the factors of influence. ~~Adoption~~ The adoption
537 of a type of centralized heating system can be done according to the conclusion established by
538 the model shown. That is possible only if both systems are available near the settlement.

539

540 Today, social help habitants have a discount for district heating price of up to 50%. For
541 ~~consumers of gas~~ the gas consumers who use gas distribution systems directly, such discounts
542 are not available. ~~Also, in Serbia,~~ Besides, the payment for the DH is per m² of heated surface
543 area (proportional to the size of the house), and in the G system payment is per m³ of used gas, in
544 Serbia. In the DH bills are fixed, and any sort of economizing in that way is discouraged.

545

546 In that case (Belgrade's settlement Karaburma is taken here into consideration), a type of the
547 chosen system depends ~~only on urban characteristic of the settlement~~ on urban characteristic of
548 ~~the settlement only~~. Because of that, the demonstrative settlements are parceled (divided) into
549 eight "Real Urban Areas" with similar buildings on each particular parcel; (Fig. 8 10). That way,
550 the determined "Real Urban Area" can be associated with the "Conditional Urban Area".

551 ~~Characteristic~~ The characteristic points for each of the eight parcels (intersection of number of
552 buildings and heat load of parcel) can be plotted into the characteristic model diagram; (Fig. 8
553 10). The types of insulation of the buildings in the settlement are mixed; old buildings have bad
554 and new buildings have good insulation. Both old and new buildings have heterogeneous spatial
555 disposal.

556

557 Two ~~border~~ boundary cases have been treated, because of heterogeneity of insulation quality of
558 buildings [22, 23, 30-32 27, 28, 36-38]; (Fig. 9 11):

559

560 -Maximal "Heat Load", all buildings have bad insulation (142 W/m^2),

561 -Minimal "Heat Load", all buildings have good insulation (95 W/m^2),

562

563 The value of fuel consumption depends on heating insulation of the building. Energy
564 consumption in the residential sector can be determined according to various methods shown in
565 an available literature [33 39]. Therefore, the "Heat Load" depends on heating insulation of the
566 building. The number of buildings on each particular parcel is constant. "Gray zone" is the zone
567 where decision on the type of the system ~~depends in great deal~~ depends, in a great deal, on the

568 type of insulation of the building; (Fig. 7-9. and 8 10). In the “Gray zone”, the costs for both
569 systems (gas distribution system and district heating system) are very similar. Characteristic
570 points for each of eight particular also depend on the quality of insulation. Small change in slope
571 of borderline for good insulation ($K_1=tg\theta_1$) and for bad insulation ($K_2=tg\theta_2$) in Fig 9 11 is
572 generated only because of differentiation in structure of diameters of conduits in pipeline (Fig 10
573 12).

574

575 “Real Urban Area” No 8 includes types of small buildings or family houses which can contain
576 only one “Conditional Dwelling”. Only for that “Real Urban Area” the gas distribution system
577 has very payable advantages versus district heating system. “Real Urban Area” No 3 includes
578 school, kindergarten, local office, shops. These kinds of buildings can contain twenty or more
579 “Conditional Dwellings”. Only for that “Real Urban Area” the district heating system has great
580 advantages. All the other zones are in the “gray zone”. In a the “gray zone”, one system is more
581 payable in comparison with the other, no more than 200 € per “Conditional Dwellings”. This
582 amount cannot be crucial for decision. Some illustrations of investigation of price changes
583 (natural gas price, or domestic boilers price) are shown in figure 11 13.

584

585 If large areas are covered by agricultural terrain, by excluding it, the above-mentioned
586 parameters obtain unrealistic values.

587

588 Note that pipeline is one of the most important parameters of the analyses shown in this paper.

589 Every particular type of the “examination segment” has a different length of a pipeline route. The
590 length of a pipeline route is fixed by choosing of one six “examination segments”. This selection

591 has to be done to present density of built up areas. Further, for detailed examination, when
592 certain type of “examination segment” is chosen, the length of the route is determined, at the
593 same time. Now, the next factor to be varied is the heat load. The heat load is directly correlated
594 with the size of buildings, i.e. diameters can vary for the fixed length of a pipeline and it's
595 structure. Larger diameters of conduits in pipeline structure are correlated to larger buildings. So,
596 the length of a pipeline route depends on the density of built up areas, and structure of the pipe
597 diameters in a pipeline depends on the size of buildings. Therefore, in city conditions, the
598 diameters of pipes are more sensitive (have a greater impact) in some cases, apropos to the
599 length of a pipeline for decision between heating systems. In the conditions of densely populated
600 urban areas, when one type of the “examination segment” is considered, the decision for
601 implementation of certain heating system has to be done according to the above mentioned
602 criterions. The lengths of pipelines and the structures of diameters of conduits are the main
603 factors for establishing these criterions. Accordingly, in villages, the distances between houses
604 are larger, so the lenth of the dwelling’s pipeline has greater impact then the pipeline diameters.
605 The analysis of the distribution of district heat in sparse areas by C. Reidhav and S. Werner [40,
606 41] shows that such distribution can be profitable for Swedish district heating companies, if
607 wisely implemented. Sparse district heating is a label for district-heating systems located in the
608 areas of low heat densities. However, a profitable sparse district heating presupposes a favorable
609 combination of certain factors. The boundaries of two such factors have been identified for
610 Swedish conditions; linear heat density and annual use of district heat/house. An annual use of
611 district heat higher than 50 GJ/house and a linear heat density greater than 2 GJ/m are required
612 for profitability. In Sweden, the general competitiveness of sparse district heating is facilitated
613 by the high consumption taxes for fuel oil, natural gas, and electricity. Hence, it should be more

614 difficult to introduce sparse district heating in other countries with low energy taxes. Such areas
615 are unfavorable, since revenues from heat sold are low compared with the investment costs for
616 the local distribution network. This situation results in high distribution costs. Distribution heat-
617 losses are also higher at low heat-densities.

618

619 All the previous values of limiting parameters are calculated for the present gas prices for
620 heating plants, for households, for domestic gas boilers' price, the costs of pipes, labor, etc.
621 Regarding the variation of all parameters, readers can consult electronic annex (Microsoft Excel
622 file). Valuable information for the energetic situation in the city of Belgrade is shown in the
623 paper of M. Jovanović, N. Afgan, P. Radovanović and, V. Stevanović [42] (Belgrade's
624 settlement Karaburma is shown in Fig. 10).

625

626 A city is considered to be sustainable if it establishes the balance between economic and socio-
627 cultural development, on one side, and the progress in environmental protection with active
628 participation of its citizens, on the other side. Using When using one of the power resource
629 resources (in this case natural gas) in various systems, the difference in the amount of pollution
630 is very little small. Big differences cannot occur in the overall effect on the city level, but in
631 certain areas they can. While heating plant is a concentrated pollutant which disperses harmful
632 combustion products evenly on a wide area depending on the wind, gas lined consumption
633 disperses locally (consumer pollutes his nearest neighborhood) [43]. Globally, the biggest gas
634 consumer is the biggest city polluter. For including environmental impacts of different
635 centralized energy supply systems in a model, it is necessary to estimate the annual
636 environmental costs for both systems and to include them in related equations. Compared to all

637 of the fossil fuels, natural gas is a minor pollutant. It burns without a solid residue and has the
638 least coefficient of CO₂ emission of about 56 kg/GJ (which is significant considering the
639 limitations imposed by The Kyoto Protocol) [34-37 44-47] . M.S. Torekov, N. Bahnsen and B.
640 Qvale [46-9] found that DH system realized 78-93 kg/MWh CO₂, 0.1 kg/MWh NO_x and 0.06
641 kg/MWh SO₂, G system with individual furnace realize 205 kg/MWh CO₂, 0.07 kg/MWh NO_x
642 and 0.001 kg/MWh SO₂, and electrical heating system 559 kg/MWh CO₂, 88 kg/MWh NO_x and
643 44 kg/MWh SO₂. 1 MWh of delivered energy is 61% cheaper in natural gas in comparison with
644 electrical energy [36 46]. ~~Comparison~~ **The comparison** of environmental impacts of two
645 residential heating systems in Canada is shown in paper of L. Yang, Zmeureanu R., and Rivard
646 H. [38 48].

647
648 The key advantage of installing gas or district heating system is not in their mutual differences,
649 but in **the** substitution of **by** the far more expensive (in terms of energy and ecology [39 49]) and
650 the highest quality form of energy – the electric energy, whose usage for heating is by far less
651 rational; (Fig. 42 14). The introduction of competition to electricity generation and
652 commercialization has been the main focus of many restructuring experiences around the world.
653 The open accesses to the transmission network and a fair regulated tariff have been the keystones
654 for the development of the electricity market [50]. Parallel to the electricity industry, the natural
655 gas business has great interaction with the electricity market in terms of fuel consumption and
656 energy conversion. Given that the transmission and distribution monopolistic activities are very
657 similar to the natural gas transportation through pipelines, economic regulation related to the
658 natural gas network should be coherent with the transmission counterpart [40 51]. Electricity and

659 natural gas use for residential space heating in USA is shown in paper by D. Bodansky [41 52].
660 Today, discussions about district heating systems are not rare in scientific literature [53-63].

661

662 5. Conclusions

663

664 The latest increase in gas prices turned all eyes once again to the space heating problem in
665 Europe. However, economic concern is not the only factor pushing the authorities to rethink
666 about the suitability of the currently existing sources. Cities are the biggest consumers of the
667 country's energy production. The increase in annual consumption of total primary energy is 3%
668 and its largest part is used for lighting, cooking, heating, cooling, and transport of freights and
669 passengers. ~~It should be noted how important it is to reduce the energy consumption level, by~~
670 ~~changing the forms of consumption and making improvements in technology and lifestyle~~ The
671 importance of reducing the energy consumption level, by changing the forms of consumption
672 and making improvements in technology and lifestyle, should be noted. Sustainable forms of
673 energy production, distribution and use usage represent the goals of a sustainable development.
674 A city is considered to be sustainable if it establishes the balance between economic and socio-
675 cultural development, on one side and the progress in environmental protection with active
676 participation of citizens. On the other side, the economics of G and DH very much depends
677 depend on the specific circumstances [64, 65]. If installed in an area with only scattered
678 buildings, the length of the pipes which are necessary to supply households will be higher,
679 relative to the number of buildings. Installation costs will be shared by fewer consumers. The
680 DH system is the capital intensive; in particular due to the distribution system of insulated pipes.
681 The G system is another form of energy which is being distributed for domestic heating

682 purposes. The dimensions of ~~the~~ pipes are small compared to the DH pipes and no insulation is
683 needed, thus the distribution system is less capital intensive.

684

685 District heating is often less efficient with respect to modern heating technologies using natural
686 gas [66-68]. Condensing boilers guarantee higher efficiencies with respect to ~~the~~ “traditional”
687 district heating. In this study, a noncondensing boiler with average efficiency ~~was~~ ~~has been~~
688 chosen from ~~following~~ database: “Seasonal Efficiency of Domestic Boilers in United Kingdom”
689 [42-32]. ~~Efficiency~~ ~~The efficiency~~ of domestic boiler and ~~efficiency of heating plant on that way~~
690 has equalized by efficiency in this model. ~~Typical~~ ~~The typical~~ efficiencies of plants fueled by
691 natural gas are reported in paper of R. Lazzarin and M. Noro [47-10].

692

693 Figure 5 is essential for ~~fully~~ ~~the full~~ understanding of the model presented here. All dwellings in
694 the option of gas distribution system are equipped with one type of ~~an~~ average boiler. ~~Increasing~~
695 ~~the prize linearly~~ ~~The linear price increase~~ moves the borderline in the model diagram in
696 advantage of ~~the~~ district heating (Fig. 8 10. and Fig. 9 11.). The same conclusion is made for the
697 investments in new capacities in heating plant, but ~~that~~ ~~it~~ moves borderline in direction of ~~the~~ gas
698 distribution system. On the contrary, changes in value of discount rate have a great impact (Fig
699 5.). Changes in ~~the~~ price of domestic ~~boiler~~ ~~boilers~~ or ~~investments~~ ~~investment~~ in new capacities
700 in heating plant has the equal impact in all of ~~the~~ six “examination segments”, changes of
701 discount rate does not.

702

703 The conducted analyses confirm literature and empirical information:

704

705 - District heating system is a better option in areas with small built up density, but with
706 skyscrapers.

707 -Gas system is a better option in areas with high density of individual houses (in this case gas
708 distribution system is significantly in advance).

709

710 These two boundary cases are illustrative. But in the case with small density of built up areas
711 with individual houses, the G system is a cheaper option (but not necessary according to some
712 Swedish studies [43, 44 40, 41]). ~~On the contrary, with~~ With high density of built up areas with
713 skyscrapers, the G system is also a cheaper solution. But, safety regulation is a limiting factor for
714 the implementation of gas system directly in a building so high such a high building. Anyway, in
715 this case the G system has a slight advantage, and by the increasing the price of domestic gas
716 boiler boilers, the DH system became the cheaper option (Fig 6 8. and Table 3 5).

717

718 In more detail details, if a certain number of objects N exist in a “Conditional Urban Area”, it
719 can be concluded that (Fig. 6 8.):

720

721 1. N = 4, district heating system has an advantage over gas if an average building has over 29
722 “Conditional Dwellings” (i.e. if the overall heating surface is over 1740 m² or if the length of
723 pipeline route is below 8m)

724 2. N = 8, district heating system has an advantage over gas if an average building has over 22
725 “Conditional Dwellings” (i.e. if the overall heating surface is over 1320 m² or if the length
726 pipeline route is below 7,6m)

727 3. $N = 16$, district heating system has an advantage over gas if an average building has over 18
728 “Conditional Dwellings” (i.e. if the overall heating surface is over 1080 m^2 or if the length of
729 pipeline route is below 7m)

730 4. $N = 32$, district heating system has an advantage over gas if an average building has over 15
731 “Conditional Dwellings” (i.e. if the overall heating surface is over 900 m^2 or if the length of
732 pipeline route is below 6,4m)

733 5. $N = 64$, district heating system has an advantage over gas or if an average building has over 12
734 “Conditional Dwellings” (i.e. if the overall heating surface is over 720 m^2 or if the length of
735 pipeline route is below 5,8m)

736 6. $N = 128$, gas system is practically always advantageous (for a high density of small individual
737 house equal as for high density of skyscrapers). Note that case with 128 skyscrapers on 0.05 km^2
738 is appeared rare rarely appears in practice. Gas The gas distribution system is advantageous
739 because all 128 buildings must be equipped with expensive heat exchanger exchangers. That is
740 highly unpractical and expensive for individual houses. For skyscrapers, gas system,
741 theoretically, has a slightly slight advantage, but with an increased prize price of domestic gas
742 boiler boilers, district heating system can be applied in larger buildings. Also, Besides, the
743 implementation of the gas system in skyscrapers is forbidden during according to safety
744 regulations.

745

746 ~~If large areas are covered by agricultural terrain, by excluding it, the above mentioned~~
747 ~~parameters obtain unrealistic values.~~

748

749 The above mentioned limiting values for use of gas are consistent in case of an average heat-
750 insulated apartment of 60m^2 . In other cases, additional corrections should be made, or different
751 input values must be entered in the model.

752

753 Note that, pipeline is one of the most important parameters in the analyses shown in this paper.
754 Every particular type of “examination segment” has a different length of pipeline route. Length
755 of pipeline route is fixed by choosing of one six “examination segments”. This selection has to
756 be done to present density of built up areas. Further, for detailed examination, when certain type
757 of “examination segment” is chosen, in the same time length of route is determined. Now, next
758 factor to be varied is heat load. Heat load is directly correlated with the size of buildings, i.e. for
759 fixed length of pipeline, structure of pipeline diameters can vary. Larger diameters of conduits in
760 pipeline structure are correlated to larger buildings. So, length of pipeline route depends on the
761 density of built up areas, and structure of pipe diameters in pipeline depend on the size of
762 buildings. Therefore, in city condition diameters of pipes are more sensitive in some cases (has
763 greater impact) apropos to length of pipeline for decision of heating system. In the conditions of
764 densely populated urban areas, when one type of “examination segment” is considered, decision
765 for implementation of certain heating system has to be done according to above mention
766 criterions. Lengths of pipeline and structures of diameters of conduits are main factor for
767 establishing of these criterions. Accordingly, in villages, distances between the houses are larger,
768 so dwelling’s length of pipeline has greater impact then the pipeline diameters. The analysis of
769 the distribution of district heat in sparse areas by C. Reidhav and S. Werner [43, 44] shows that
770 such distribution can be profitable for Swedish district heating companies, if wisely
771 implemented. Sparse district heating is a label for district heating systems located in areas of low

772 heat densities. However, profitable sparse district heating presupposes a favorable combination
773 of certain factors. The boundaries of two such factors have been identified for Swedish
774 conditions; linear heat density and annual use of district heat/house. An annual use of district
775 heat higher than 50 GJ/house and a linear heat density greater than 2 GJ/m are required for
776 profitability. In Sweden, the general competitiveness of sparse district heating is facilitated by
777 the high consumption taxes for fuel oil, natural gas, and electricity. Hence, it should be more
778 difficult to introduce sparse district heating in other countries with low energy taxes. Such areas
779 are unfavorable, since revenues from heat sold are low compared with the investment cost for the
780 local distribution network. This situation results in high distribution costs. Distribution heat-
781 losses are also higher at low heat densities.

782

783 All previous values of limiting parameters is done for present prices of gas in for heating plants,
784 for households, for price of domestic gas boilers, costs of pipes, labor, etc. But for variation of all
785 parameters, readers can consult electronic annex (Microsoft Excel file).

786

787 Some German studies with subject relevant for development of district heating systems in urban
788 environment are also useful and highly evaluated, but this literature is available only in German
789 language [45-47], with related papers presented in scientific journals [48]. Main achievement of
790 these German researches is in establishing of interaction between heating systems, settlement
791 structure and urban planning at the local level. The study analyses options for heat supply in up
792 to 10 types of built up areas [45]—from densely populated urban areas to villages. A new
793 German study 20 years later refers to this work [46], with projection to 2020 [47]. Valuable
794 information for the energetic situation in city of Belgrade is shown in the paper of M. Jovanović,

795 ~~N. Afgan, P. Radovanović and, V. Stevanović [49] (Belgrade's settlement Karaburma is shown~~
796 ~~in Fig. 8.)~~.

797

798 ~~Today, discussions about district heating systems are not rare in scientific literature [50-56].~~

799

800 **6. Acknowledgment**

801

802 The **This** paper is a part of the research done within the project of Ministry of Science NP EE 34-
803 406A, Serbia, Belgrade and the authors would like to thank for financial support.

804

805 **7. Appendix**

806

807 ~~Algorithm~~ **The algorithm** for initial decision for selection of **a** natural gas heating system in
808 settlements is shown in figure ~~13~~ **15**:

809

810 **8. References**

811

812 [1]. Brkić D. Natural gas as heating fuel (Природни гас као гориво за грејање). Beograd:
813 Andrejevic Foundation (Задужбина Андрејевић), 2006. (in Serbian)

814 [2] Holz F., von Hirschhausen C., Kemfert C. A strategic model of European gas supply
815 (GASMOD). ~~Energy Economics 2008; 30 (3): 766-788.~~

816 [~~3] Afgan NH., Carvalho MG., Pilavachi PA., Martins N. Evaluation of natural gas supply
817 options for south east and central Europe. Part 1: Indicator definitions and single indicator
818 analysis. *Energy Conversion and Management* 2007; 48 (9): 2517–2524.~~

819 [~~4] Lund Sagen E., Tsygankova M., Russian natural gas exports—Will Russian gas price reforms
820 improve the European security of supply?. *Energy Policy* 2008; 36 (2): 867–880.~~

821 [~~5] Remme U., Blesl M., Fahl U. Future European gas supply in the resource triangle of the
822 Former Soviet Union, the Middle East and Northern Africa. *Energy Policy* 2008; 36 (5): 1622–
823 1641.~~

824 [~~6] Lise W., Hobbs W. Future evolution of the liberalised European gas market: Simulation
825 results with a dynamic model. *Energy* 2008; 33 (7): 989–1004.~~

826 [~~7] Herbert JH., Berg J. Soviet natural gas exports and the European energy balance. *Energy*
827 1990; 15 (10): 833–840.~~

828 [~~8] Kabirian A., Reza Hemmati M. A strategic planning model for natural gas transmission
829 networks. *Energy Policy* 2007; 35 (11): 5656–5670.~~

830 [~~9] Dzenajaviciene EF., Kveselis V., McNaught C., Tamonis M. Economic analysis of the
831 renovation of small-scale district heating systems—4 Lithuanian case studies. *Energy Policy*
832 2007; 35 (4): 2569–2578.~~

833 [~~10]. Gustavsson L., Karlsson A. Heating detached houses in urban areas. *Energy* 2003; 28 (8):
834 851–875.~~

835 [~~11] Riva A., D'Angelosante S., Trebeschi C. Natural gas and the environmental results of life
836 cycle assessment. *Energy* 2006; 31 (1): 138–148.~~

837 [~~12]. Douthitt RA. An economic analysis of the demand for residential space heating fuel in
838 Canada. *Energy* 1989; 14 (4): 187–197.~~

839 [13] Papadopoulos AM., Oxizidis S., Papandritsas G. Energy, economic and environmental
840 performance of heating systems in Greek buildings. *Energy and Buildings* 2008; 40 (3): 224–
841 230.

842 [14] Dinea C., Badea A., Rousseaux P., Apostol T. A multi-criteria approach to evaluate the
843 natural gas energy systems. *Energy Policy* 2007; 35 (11): 5754–5765.

844 [15] Gustafsson SI., Karlsson BG. Natural gas in optimized bivalent heating systems. *Energy*
845 1990; 15 (11): 993–999.

846 [16]. Torekov M.S., Bahnsen N., Qvale B. The relative competitive positions of the alternative
847 means for domestic heating. *Energy* 2007; 32 (5): 627–633.

848 [17]. Lazzarin R., Noro M. Local or district heating by natural gas: which is better from
849 energetic, environmental and economic point of views?. *Applied Thermal Engineering* 2006; 26
850 (2–3): 244–250.

851 [18]. Grohnheit PE., Mortensen BOG. Competition in the market for space heating, district
852 heating as the infrastructure for competition among fuels and technologies. *Energy Policy* 2003;
853 31 (9): 817–826.

854 [19]. Santamouris M., Kapsis K., Korres D., Livada I., Pavlou C., Assimakopoulos M.N. On the
855 relation between the energy and social characteristics of the residential sector. *Energy and*
856 *Buildings* 2007; 39 (8): 893–905.

857 [20]. Stanislaw S. The measurement of demand for natural gas. *Energy* 1985; 10 (2): 165–180.

858 [21]. Hartshorn JE. Introduction: Natural gas development begins at home. *Energy* 1985; 10 (2):
859 111–118.

860 [22]. Mihalakakou G., Santamouris M., Tsagrassoulis A. On the energy consumption in
861 residential buildings. *Energy and Buildings*, 2002; 34 (7): 727–736.

862 [23]. Olesen BW., Parsons KC. Introduction to thermal comfort standards and to the proposed
863 new version of EN ISO 7730. *Energy and Buildings* 2002; 34 (6): 537–548.

864 [24]. Hwei-Chu L., Tsai Feng C. Space heating and water heating energy demands of the aged in
865 the US. *Energy Economics* 2002; 24 (3): 267–284.

866 [25]. Corfield G., Hunt BE., Ott RJ., Binder GP., Vandaveer F. E. Distribution Design for
867 Increased Demand. In: Segeler CG, editor. *Gas Engineers Handbook*. New York: Industrial
868 Press. p. 9/63–9/83.

869 [26]. Recknagel H., Sprenger E., Honmann W. Heating (Грејање). In: Višnjić M., editor.
870 Heating and Air Condition (Грејање и климатизација). Beograd: Gradjevinska knjiga. p. 293–
871 835. (in Serbian)

872 [27]. Papadopoulos AM., Theodosiou T., Karatzas K. Feasibility of energy saving renovation
873 measures in urban buildings: the impact of energy prices and the acceptable pay back time
874 criterion. *Energy and Buildings* 2002; 34 (5): 455–466.

875 [28]. Vondraček J., Pelikan E., Konar O., Čermakova J., Eben K., Maly M., Brabec M. A
876 statistical model for the estimation of natural gas consumption. *Applied Energy* 2008; 85 (5):
877 362–370.

878 [29]. Braniš M., Domasova M., Rezačova P. Particulate air pollution in a small settlement: the
879 effect of local heating. *Applied Geochemistry* 2007; 22 (6): 1255–1264.

880 [30]. Gustafsson SI., Bojić M. Optimal heating system retrofits in residential buildings. *Energy*
881 1997; 22 (9): 867–874.

882 [31]. Torchio MF., Genon G., Poggio A., Poggio M. Merging of energy and environmental
883 analyses for district heating systems. *Energy* 2008; doi:10.1016/j.energy.2008.01.012

884 [32]. Ossebaard ME., van Wijk AJM., van Wees MT. Heat supply in the Netherlands: a systems
885 analysis of costs, exergy efficiency, CO₂ and NO_x emissions. *Energy* 1997; 22 (11): 1087-1098.

886 [33]. Aydinalp Koksak M., Ismet Ugursal V. Comparison of neural network, conditional demand
887 analysis, and engineering approaches for modeling end-use energy consumption in the residential
888 sector. *Applied Energy* 2008; 85 (4): 271-296.

889 [34]. Haberl H., Adensam H., Geissler S. Optimal climate protection strategies for space heating;
890 the case of Austria. *Energy Policy* 1998; 26 (15): 1125-1135.

891 [35]. Cowie AL., Kirschbaum MUF., Ward M. Options for including all lands in a future
892 greenhouse gas accounting framework. *Environmental Science & Policy*, 2007; 10 (4): 306-321.

893 [36]. Karlsson A., Gustavsson L. External costs and taxes in heat supply systems. *Energy Policy*
894 2003; 31 (14): 1541-1560.

895 [37]. Holmgren K., Amiri S. Internalising external costs of electricity and heat production in a
896 municipal energy system. *Energy Policy* 2007; 35 (10): 5242-5253.

897 [38]. Yang L., Zmeureanu R., Rivard H. Comparison of environmental impacts of two residential
898 heating systems. *Building and Environment* 2008; 43 (6): 1072-1081.

899 [39] Ford A. Simulation scenarios for rapid reduction in carbon dioxide emissions in the western
900 electricity system. *Energy Policy* 2008; 36 (1): 443-455.

901 [40] Morais MS., Marangon JW. Lima Combined natural gas and electricity network pricing.
902 *Electric Power Systems Research* 2007; 77 (5-6): 712-719.

903 [41]. Bodansky D. Electricity and natural gas use for residential space heating: U.S. experience,
904 1976-1980. *Energy* 1984; 9 (4): 303-313.

905 [42]. SEDBUK-Seasonal Efficiency of Domestic Boilers. See also: <http://www.sedbuk.com>

906 [43]. Reidhav C., Werner S. Profitability of sparse district heating. *Applied Energy* 2008; 85 (9):
907 867–877.

908 [44]. Forsaeus Nilsson S., Reidhav C., Lygnerud K., Werner S. Sparse district heating in Sweden.
909 *Applied Energy* 2008; 85 (7): 555–564.

910 [45]. Roth U., Häubi F., Albrecht J. Interaction between urban infrastructure and district heating
911 system (Wechselwirkungen zwischen der Siedlungsstruktur und Wärmeversorgungssystemen).
912 Bonn: Bundesminister für Raumordnung, Bauwesen und Städtebau, 1980. (in German)

913 [46]. AGFW Arbeitsgemeinschaft Fernwärme. Pluralistische Wärmeversorgung—Zeithorizont
914 2005 (Vorstudie). See also: <http://www.agfw.de/86.0.html> (in German)

915 [47]. AGFW Arbeitsgemeinschaft Fernwärme. Pluralistische Wärmeversorgung—Zeithorizont
916 2020. Hauptstudie See also: <http://www.agfw.de/86.0.html> (in German)

917 [48]. Ter Brugge R. Spatial structure in relation to energy production and consumption. *Journal*
918 *of Economic and Social Geography Tijdschrift voor Economische en Sociale Geografie* 1984; 75
919 (3): 214–222.

920 [49]. Jovanović M., Afgan N., Radovanović P., Stevanović V. Sustainable development of the
921 Belgrade energy system. *Energy* 2008; doi:10.1016/j.energy.2008.01.013

922 [50]. Lunda H., Hvelplunda F., Kassb I., Dukalskis E., Blumberga D. District heating and
923 market economy in Latvia. *Energy* 1999; 24 (7): 549–559.

924 [51]. de Almeida AT., Lopes AC., Carvalho A., Mariano J., Jahn A., Broege M. Examining the
925 potential of natural gas demand side measures to benefit customers, the distribution utility, and
926 the environment: two case studies from Europe. *Energy* 2004; 29 (7): 979–1000.

927 [52]. Knutsson D., Sahlin J., Werner S., Ekvall T., Ahlgren EO. HEATSPOT—a simulation tool
928 for national district heating analyses. *Energy* 2006; 31 (2–3): 278–293.

929 [53]. Dotzauer E. Experiences in mid-term planning of district heating systems. Energy 2003; 28
930 (15): 1545–1555.

931 [54]. Sundberg G., Karlsson BG. Interaction effects in optimising a municipal energy system.
932 Energy 2000; 25 (9): 877–891.

933 [55]. Gustavsson L. District heating systems and energy conservation part I. Energy 1994; 19
934 (1): 81–91.

935 [56]. Gustavsson L. District heating systems and energy conservation part II. Energy 1994; 19
936 (1): 93–102.

937 [2] Dzenajaviciene EF., Kveselis V., McNaught C., Tamonis M. Economic analysis of the
938 renovation of small-scale district heating systems—4 Lithuanian case studies. Energy Policy
939 2007; 35 (4): 2569–2578.

940 [3]. Gustavsson L., Karlsson A. Heating detached houses in urban areas. Energy 2003; 28 (8):
941 851–875.

942 [4] Riva A., D’Angelosante S., Trebeschi C. Natural gas and the environmental results of life
943 cycle assessment. Energy 2006; 31 (1): 138–148.

944 [5]. Douthitt RA. An economic analysis of the demand for residential space heating fuel in
945 Canada. Energy 1989; 14 (4): 187–197.

946 [6] Papadopoulos AM., Oxizidis S., Papandritsas G. Energy, economic and environmental
947 performance of heating systems in Greek buildings. Energy and Buildings 2008; 40 (3): 224–
948 230.

949 [7] Dinca C., Badea A., Rousseaux P., Apostol T. A multi-criteria approach to evaluate the
950 natural gas energy systems. Energy Policy 2007; 35 (11): 5754–5765.

951 [8] Gustafsson SI., Karlsson BG. Natural gas in optimized bivalent heating systems. Energy
952 1990; 15 (11): 993-999.

953 [9]. Torekov M S., Bahnsen N., Qvale B. The relative competitive positions of the alternative
954 means for domestic heating. Energy 2007; 32 (5): 627-633.

955 [10]. Lazzarin R., Noro M. Local or district heating by natural gas: which is better from
956 energetic, environmental and economic point of views?. Applied Thermal Engineering 2006; 26
957 (2-3): 244-250.

958 [11]. Grohnheit PE., Mortensen BOG. Competition in the market for space heating. district
959 heating as the infrastructure for competition among fuels and technologies. Energy Policy 2003;
960 31 (9): 817-826.

961 [12]. Roth U., Häubi F., Albrecht J. Interaction between urban infrastructure and district heating
962 system (Wechselwirkungen zwischen des Siedlungsstruktur und Wärmeversorgungssystemen).
963 Bonn: Bundesminister für Raumordnung, Bauwesen und Städtebau, 1980. (in German)

964 [13]. AGFW-Arbeitsgemeinschaft Fernwärme. Pluralistische Wärmeversorgung - Zeithorizont
965 2005 (Vorstudie). See also: <http://www.agfw.de/86.0.html> (in German)

966 [14]. AGFW-Arbeitsgemeinschaft Fernwärme. Pluralistische Wärmeversorgung - Zeithorizont
967 2020. Hauptstudie See also: <http://www.agfw.de/86.0.html> (in German)

968 [15]. Ter Brugge R. Spatial structure in relation to energy production and consumption. Journal
969 of Economic and Social Geography-Tijdschrift voor Economische en Sociale Geografie 1984; 75
970 (3): 214-222.

971 [16]. Bojić M., Despotović M. Influence of duration of thermal comfort provision on heating
972 behavior buildings. Energy Conversion and Management 2007; 48 (8): 2416-2423.

973 [17] Holz F., von Hirschhausen C., Kemfert C. A strategic model of European gas supply
974 (GASMOD). *Energy Economics* 2008; 30 (3): 766–788.

975 [18] Afgan NH., Carvalho MG., Pilavachi PA., Martins N. Evaluation of natural gas supply
976 options for south east and central Europe. Part 1: Indicator definitions and single indicator
977 analysis. *Energy Conversion and Management* 2007; 48 (9): 2517–2524.

978 [19] Lund Sagen E., Tsygankova M., Russian natural gas exports—Will Russian gas price
979 reforms improve the European security of supply?. *Energy Policy* 2008; 36 (2): 867–880.

980 [20] Remme U., Blesl M., Fahl U. Future European gas supply in the resource triangle of the
981 Former Soviet Union, the Middle East and Northern Africa. *Energy Policy* 2008; 36 (5): 1622–
982 1641.

983 [21] Lise W., Hobbs W. Future evolution of the liberalised European gas market: Simulation
984 results with a dynamic model. *Energy* 2008; 33 (7): 989-1004.

985 [22] Herbert JH., Berg J. Soviet natural gas exports and the European energy balance. *Energy*
986 1990; 15 (10): 833-840.

987 [23] Kabirian A., Reza Hemmati M. A strategic planning model for natural gas transmission
988 networks. *Energy Policy* 2007; 35 (11): 5656–5670.

989 [24]. Santamouris M., Kapsis K., Korres D., Livada I., Pavlou C., Assimakopoulos M.N. On the
990 relation between the energy and social characteristics of the residential sector. *Energy and*
991 *Buildings* 2007; 39 (8): 893–905.

992 [25]. Stanislaw S. The measurement of demand for natural gas. *Energy* 1985; 10 (2): 165–180.

993 [26]. Hartshorn JE. Introduction: Natural gas development begins at home. *Energy* 1985; 10 (2):
994 111–118.

995 [27]. Mihalakakou G., Santamouris M., Tsagrassoulis A. On the energy consumption in
996 residential buildings. *Energy and Buildings*, 2002; 34 (7): 727–736.

997 [28]. Olesen BW., Parsons KC. Introduction to thermal comfort standards and to the proposed
998 new version of EN ISO 7730. *Energy and Buildings* 2002; 34 (6): 537–548.

999 [29]. Huei-Chu L., Tsai-Feng C. Space-heating and water-heating energy demands of the aged in
1000 the US. *Energy Economics* 2002; 24 (3): 267-284.

1001 [30]. Corfield G., Hunt BE., Ott RJ., Binder GP., Vandaveer F. E. Distribution Design for
1002 Increased Demand. In: Segeler CG, editor. *Gas Engineers Handbook*. New York: Industrial
1003 Press. p. 9/63-9/83.

1004 [31]. Recknagel H., Sprenger E., Honmann W. Heating (Грејање). In: Višnjić M., editor.
1005 Heating and Air Condition (Грејање и климатизација). Beograd: Gradjevinska knjiga. p. 293-
1006 835. (in Serbian)

1007 [32]. SEDBUK-Seasonal Efficiency of Domestic Boilers in United Kingdom. See also:
1008 <http://www.sedbuk.com>

1009 [33]. Papadopoulos AM., Theodosiou T., Karatzas K. Feasibility of energy saving renovation
1010 measures in urban buildings: the impact of energy prices and the acceptable pay back time
1011 criterion. *Energy and Buildings* 2002; 34 (5): 455–466.

1012 [34]. Vondraček J., Pelikan E., Konar O., Čermakova J., Eben K., Maly M., Brabec M. A
1013 statistical model for the estimation of natural gas consumption. *Applied Energy* 2008; 85 (5):
1014 362–370.

1015 [35]. Braniš M., Domasova M., Rezačova P. Particulate air pollution in a small settlement: the
1016 effect of local heating. *Applied Geochemistry* 2007; 22 (6): 1255–1264.

1017 [36]. Gustafsson SI., Bojić M. Optimal heating-system retrofits in residential buildings. Energy
1018 1997; 22 (9): 867-874.

1019 [37]. Torchio MF., Genon G., Poggio A., Poggio M. Merging of energy and environmental
1020 analyses for district heating systems. Energy 2008; doi:10.1016/j.energy.2008.01.012

1021 [38]. Ossebaard ME., van Wijk AJM., van Wees MT. Heat supply in the Netherlands: a systems
1022 analysis of costs, exergy efficiency, CO₂ and NO_x emissions. Energy 1997; 22 (11): 1087-1098.

1023 [39]. Aydinalp-Koksal M., Ismet Ugursal V. Comparison of neural network, conditional demand
1024 analysis, and engineering approaches for modeling end-use energy consumption in the residential
1025 sector. Applied Energy 2008; 85 (4): 271–296.

1026 [40]. Reidhav C., Werner S. Profitability of sparse district heating. Applied Energy 2008; 85 (9):
1027 867–877.

1028 [41]. Forsaeus Nilsson S., Reidhav C., Lygnerud K. Werner S. Sparse district-heating in Sweden.
1029 Applied Energy 2008; 85 (7): 555–564.

1030 [42]. Jovanović M., Afgan N., Radovanović P., Stevanović V. Sustainable development of the
1031 Belgrade energy system. Energy 2008; doi:10.1016/j.energy.2008.01.013

1032 [43]. Strachan N., Farrell A. Emissions from distributed vs. centralized generation: The
1033 importance of system performance. Energy Policy 2006; 34 (17): 2677-2689.

1034 [44]. Haberl H., Adensam H., Geissler S. Optimal climate protection strategies for space heating;
1035 the case of Austria. Energy Policy 1998; 26 (15): 1125-1135.

1036 [45]. Cowie AL., Kirschbaumb MUF., Ward M. Options for including all lands in a future
1037 greenhouse gas accounting framework. Environmental Science & Policy 2007; 10 (4): 306–321.

1038 [46]. Karlssona A., Gustavsson L. External costs and taxes in heat supply systems. Energy Policy
1039 2003; 31 (14): 1541–1560.

1040 [47]. Holmgren K., Amiri S. Internalising external costs of electricity and heat production in a
1041 municipal energy system. *Energy Policy* 2007; 35 (10): 5242–5253.

1042 [48] Yang L., Zmeureanu R., Rivard H. Comparison of environmental impacts of two residential
1043 heating systems. *Building and Environment* 2008; 43 (6): 1072–1081.

1044 [49] Ford A. Simulation scenarios for rapid reduction in carbon dioxide emissions in the western
1045 electricity system. *Energy Policy* 2008; 36 (1): 443–455.

1046 [50] Jednak S, Kragulj D, Bulajić M, Pittman R. Electricity reform in Serbia. *Utilities Policy*
1047 2008; doi:10.1016/j.jup.2008.02.002

1048 [51] Morais MS., Marangon JW. Lima Combined natural gas and electricity network pricing.
1049 *Electric Power Systems Research* 2007; 77 (5-6): 712–719.

1050 [52]. Bodansky D. Electricity and natural gas use for residential space heating: U.S. experience,
1051 1976–1980. *Energy* 1984; 9 (4): 303-313.

1052 [53]. Lunda H., Hvelplunda F., Kassb I., Dukalskisb E., Blumberga D. District heating and
1053 market economy in Latvia. *Energy* 1999; 24 (7): 549–559.

1054 [54]. de Almeida AT., Lopes AC., Carvalho A., Mariano J., Jahn A., Broege M. Examining the
1055 potential of natural gas demand-side measures to benefit customers, the distribution utility, and
1056 the environment: two case studies from Europe. *Energy* 2004; 29 (7): 979–1000.

1057 [55]. Knutsson D., Sahlin J., Werner S., Ekvall T., Ahlgren EO. HEATSPOT—a simulation tool
1058 for national district heating analyses. *Energy* 2006; 31 (2-3): 278–293.

1059 [56]. Dotzauer E. Experiences in mid-term planning of district heating systems. *Energy* 2003; 28
1060 (15): 1545–1555.

1061 [57]. Sundberg G., Karlsson BG. Interaction effects in optimising a municipal energy system.
1062 *Energy* 2000; 25 (9): 877–891.

1063 [58]. Gustavsson L. District heating systems and energy conservation-part I. Energy 1994; 19
1064 (1): 81-91.

1065 [59]. Gustavsson L. District heating systems and energy conservation-part II. Energy 1994; 19
1066 (1): 93-102.

1067 [60]. Benonysson A., Bohm B., Ravn HF. Operational optimization in a district heating system.
1068 Energy Conversion and Management 1995; 36 (5): 297–314.

1069 [61]. Gebremedhin A., Moshfegh B. Modelling and optimization of district heating and industrial
1070 energy system - an approach to a locally deregulated heat market. International Journal of
1071 Energy Research 2004; 28 (5): 411–422.

1072 [62]. Barelli L., Bidini G., Pinchi EM. Implementation of a cogenerative district heating:
1073 Optimization of a simulation model for the thermal power demand. Energy and Buildings 2006;
1074 38 (12): 1434–1442.

1075 [63]. Larsen HV., Paison H., Bohm B., Ravn H.F. Aggregated dynamic simulation model of
1076 district heating networks, Energy Conversion and Management 2001; 43 (8): 995–1019.

1077 [64]. Bouvy C., L.Klaus. Multicriterial optimisation of communal energy supply concepts.
1078 Energy Conversion and Management 2007; 48 (11): 2827-2835.

1079 [65]. Söderman J., Pettersson F. Structural and operational optimisation of distributed energy
1080 systems. Applied Thermal Engineering 2006; 26 (13): 1400-1408.

1081

1082 [66]. Rosa L., Tosato R. Experimental evaluation of seasonal efficiency of condensing boilers.
1083 Energy and Buildings 1990; 14 (3): 237-241.

1084 [67]. Lazzarin RM., Schibuola L. Performance analysis of heating plants equipped with
1085 condensing boilers. Journal of Heat Recovery Systems 1986; 6 (4): 269-276.

- 1086 [68]. Agrell J., Bogetoft P. Economic and environmental efficiency of district heating plants.
1087 *Energy Policy* 2005; 33 (10): 1351–1362.

1088 **Figure 1.** “Real Urban Area” associates with several types of “Basic segments” according to the
1089 spatial disposition of buildings

1090 **Figure 2.** Examples of different “Heat Loads” for the same “Basic segments” (two cases)

1091 **Figure 3.** Standard length of networks for all the six types of “Examination segments” (0,5 km²)

1092 **Figure 4.** “Conditional Urban Areas” – two examples

1093 **Figure 5.** Effects of price and discount rate changes, example of factors with linear influence and
1094 nonlinear influence (costs for one average dwelling)

1095 **Figure 6.** Brand new domestic boilers in the UK market sorted according to efficiency class
1096 (SEDBUK)

1097 **Figure 7.** Diagram for selection of appropriate domestic boiler for the examination condition

1098 **Figure 6. Figure 8.** Comparisons of investments in district heating and gas distribution system

1099 **Figure 7. Figure 9.** Identification of some characteristic cases in model diagram

1100 **Figure 9. Figure 10.** Diagram for adoption of optimal system for observed settlement

1101 **Figure 10. Figure 11.** Displacement of borders and characteristic points calculated for different
1102 quality of building insulation

1103 **Figure 11. Figure 12.** Length of conduits sort by diameters for DH pipeline for good and poor
1104 insulated buildings in the Karaburma settlement – case study

1105 **Figure 12. Figure 13.** Price changing sensitivity, sample for few factors of influence

1106 **Figure 14.** Consumption of electrical energy in the observed settlement

1107 **Figure 15.** Algorithm for centralized energy supply system selection fueled by natural gas

1108 **Table 1:** Identification of all of the 96 considered case (number of average dwelling per
1109 building)

1110 **Table 2:** Costs for gas distribution system and district heating system Structure of pipe diameters
1111 for one of the cases (example)

1112 **Table 3:** Initial costs^a – € per “Conditional Dwelling” Investments in both systems per dwelling;
1113 G and DH [€]

1114 **Table 4:** “Net Present Value of Costs” (NPV)^a – € per “Conditional Dwelling” Costs for gas
1115 distribution system and district heating system (example)

1116 **Table 5:** Initial costs^a - € per “Conditional Dwelling”

1117 **Table 6:** “Net Present Value of Costs” (NPV)^a - € per “Conditional Dwelling”

Reviewer 1:

1. New abstract is in the paper.
2. The introduction is reorganized as requested (first literature review and after basic assumption and main objectives of our paper).
3. Explanation is added in lines 121-148; alternative option is to delete sentence 'The most suitable option for satisfying heating demands in urban areas is by using a centralized system.' to avoid further explanations
4. In our opinion text is now reorganized to explain basic assumption in better way (this request maybe we have not understood clear and we will be grateful for further explanations).
5. We hope that English expression in our paper is now improved.
6. Fig 6 and 7 with comments are added in new version of the text to improve analysis. Tables 2 and 3 have been added in new version of the text to support the analysis section. Also, Excel file is added as electronic annex to support understanding of the calculations presented in our paper.

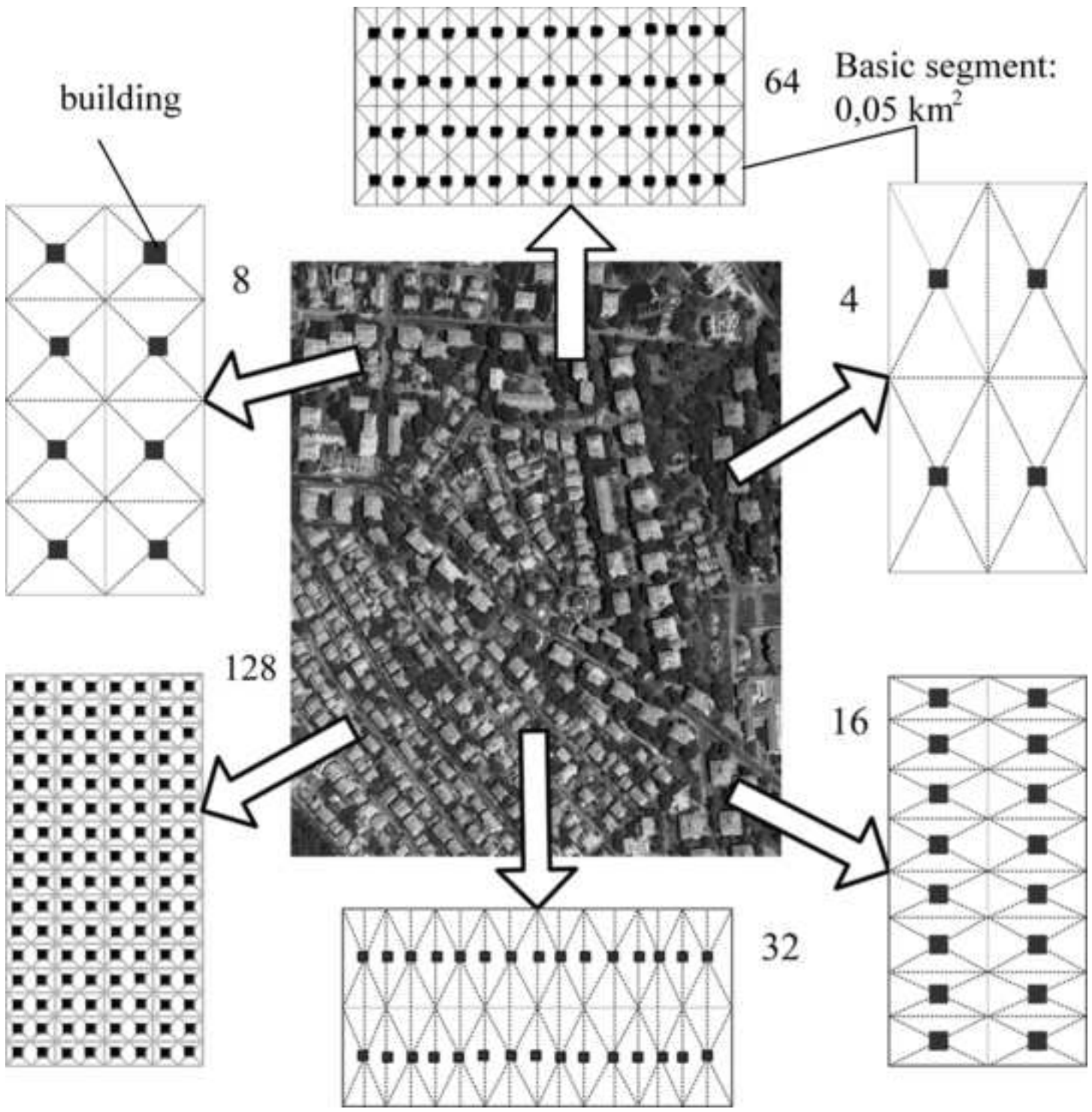
Reviewer 2: is missing

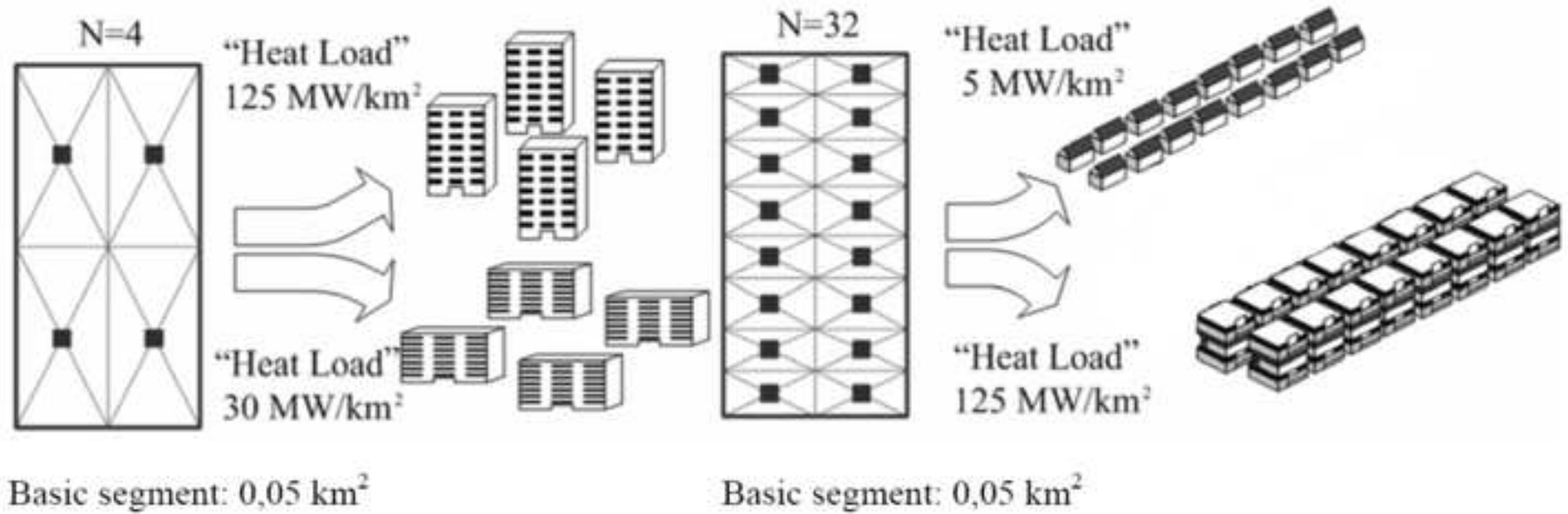
Reviewer 3: is missing

Reviewer 4:

Meaning of variables is now incorporated in the text: line 396-402 and line 412-418 in marked text
Text in conclusion is shorter, and some remarks from previous are now in section 4. Line 585-624
References are renumbered. Special thanks for the previous comments by reviewer 4. According to his/her comment quality of our paper are significantly improved.

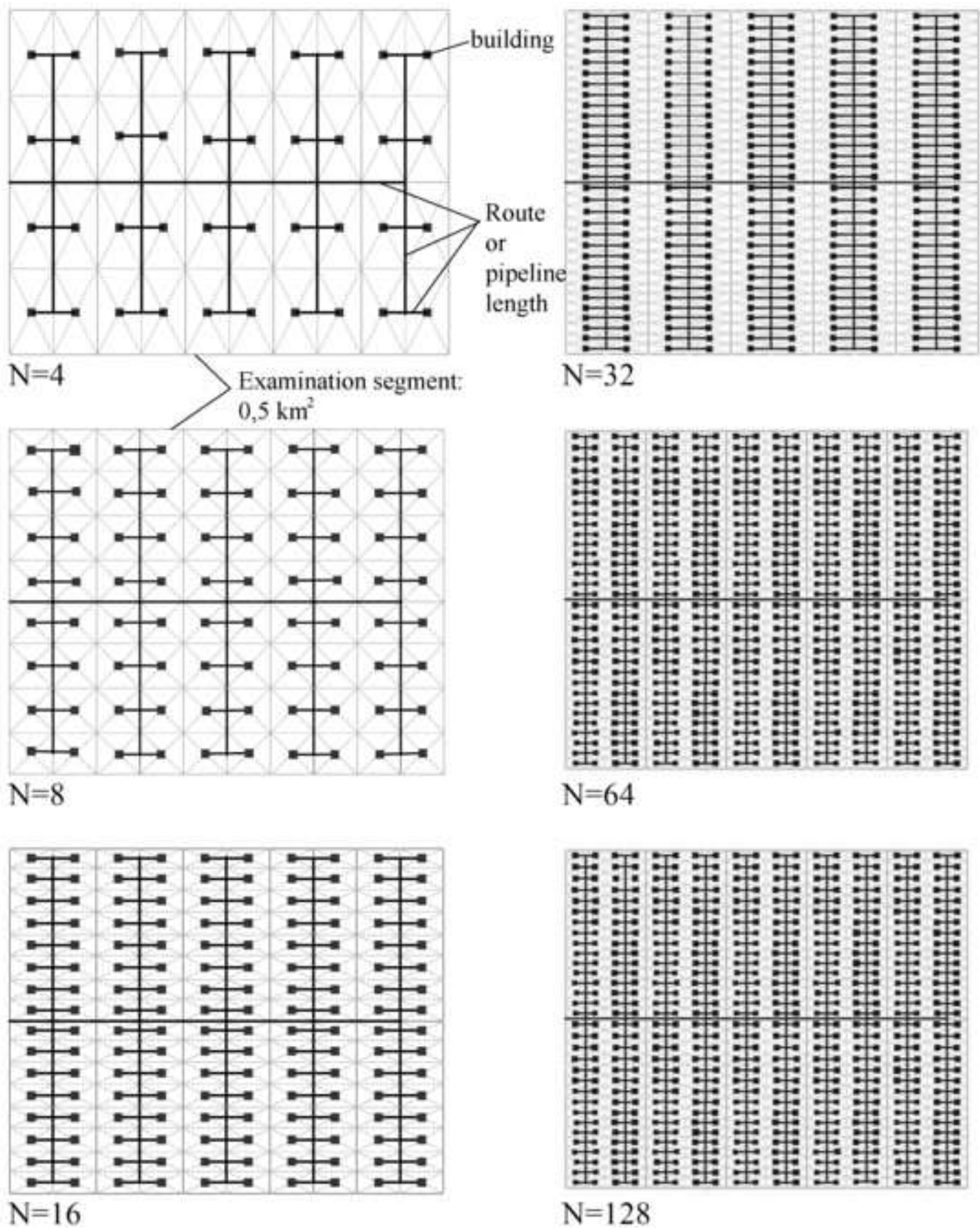
Figure(s)
[Click here to download high resolution image](#)





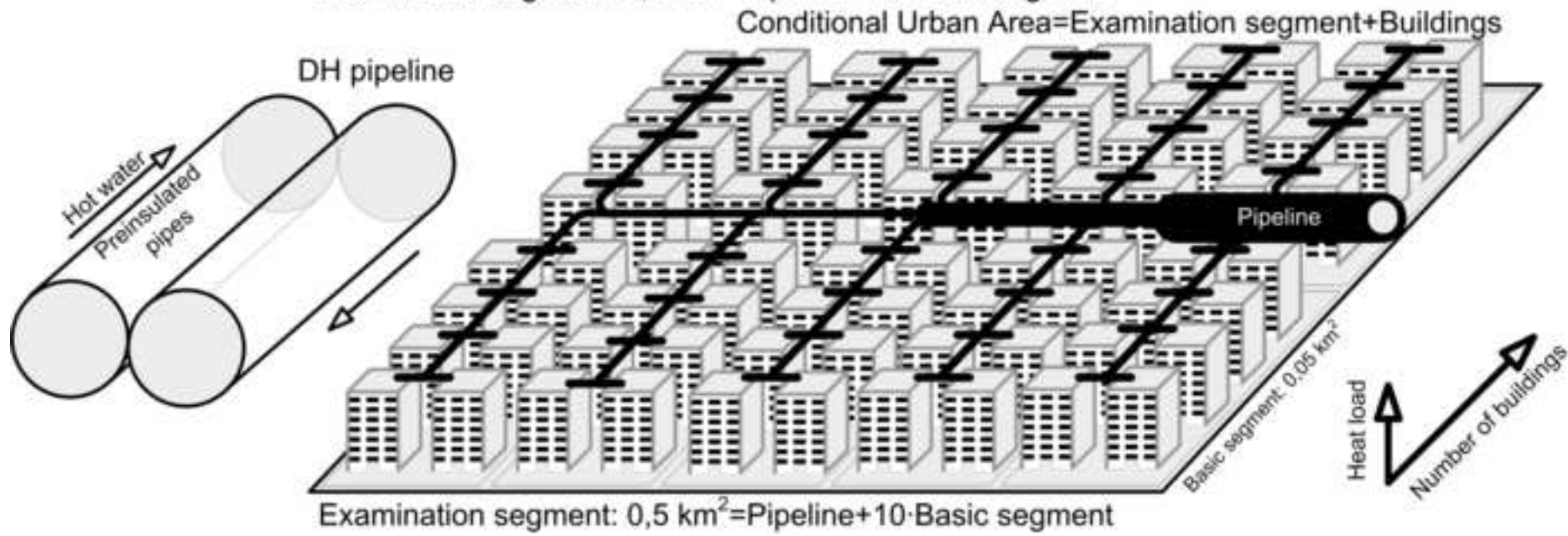
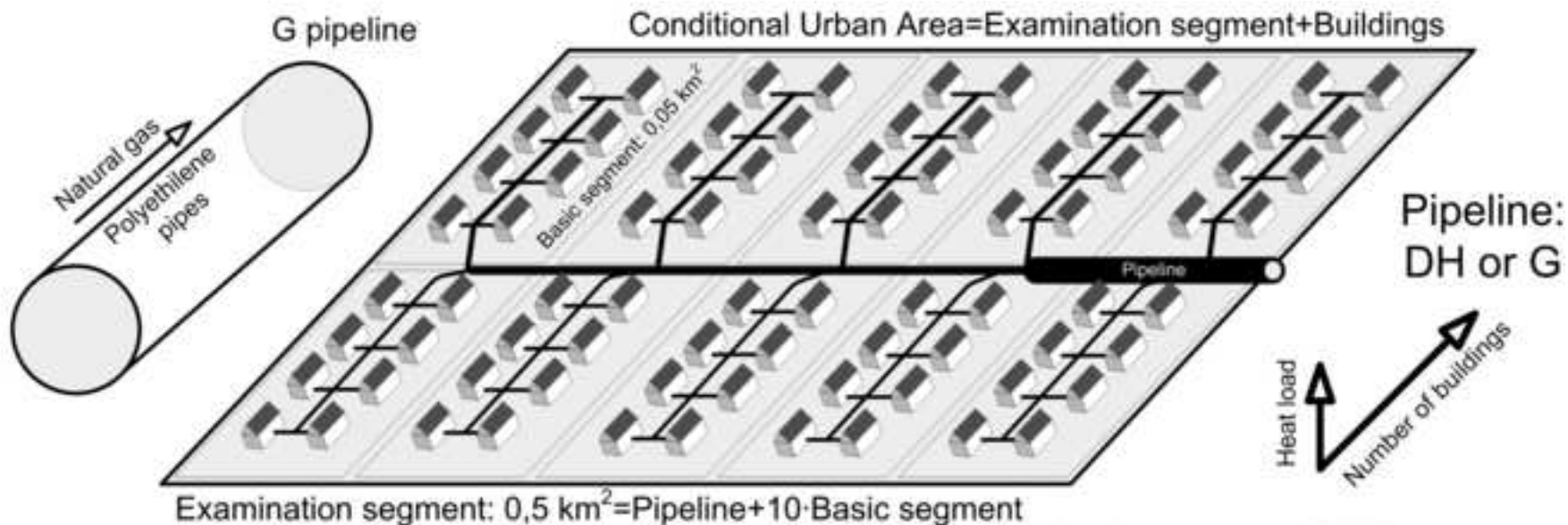
Figure(s)

[Click here to download high resolution image](#)



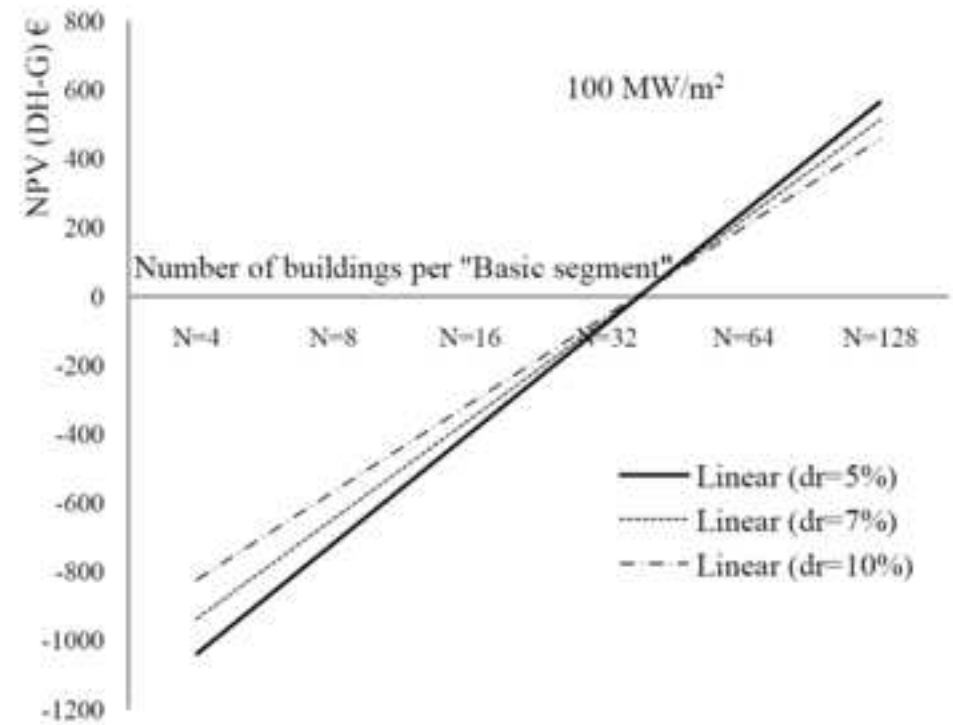
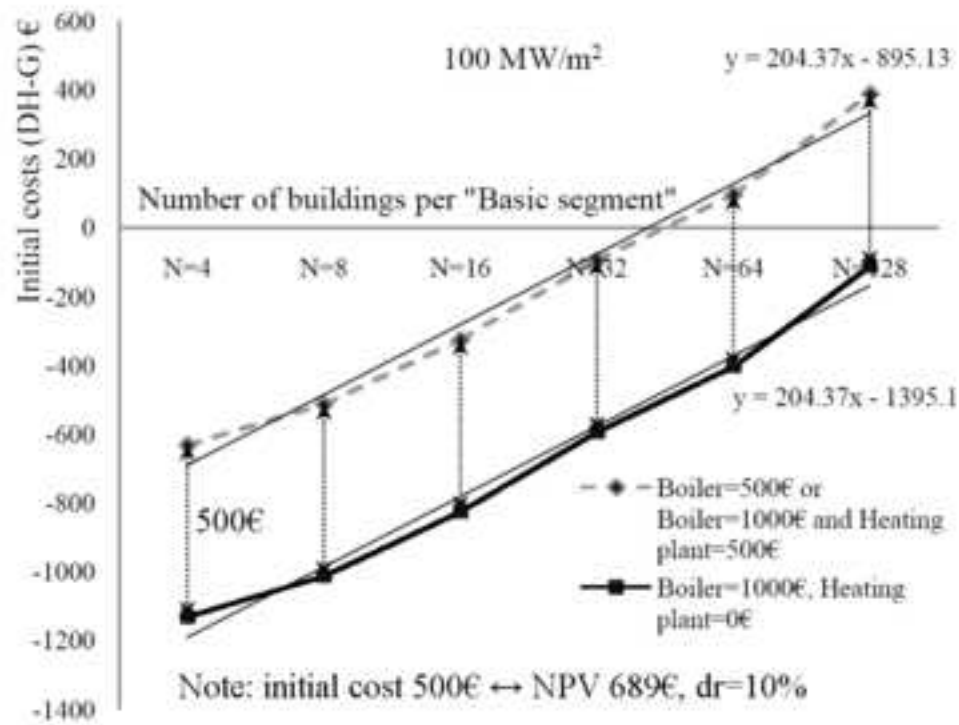
Figure(s)

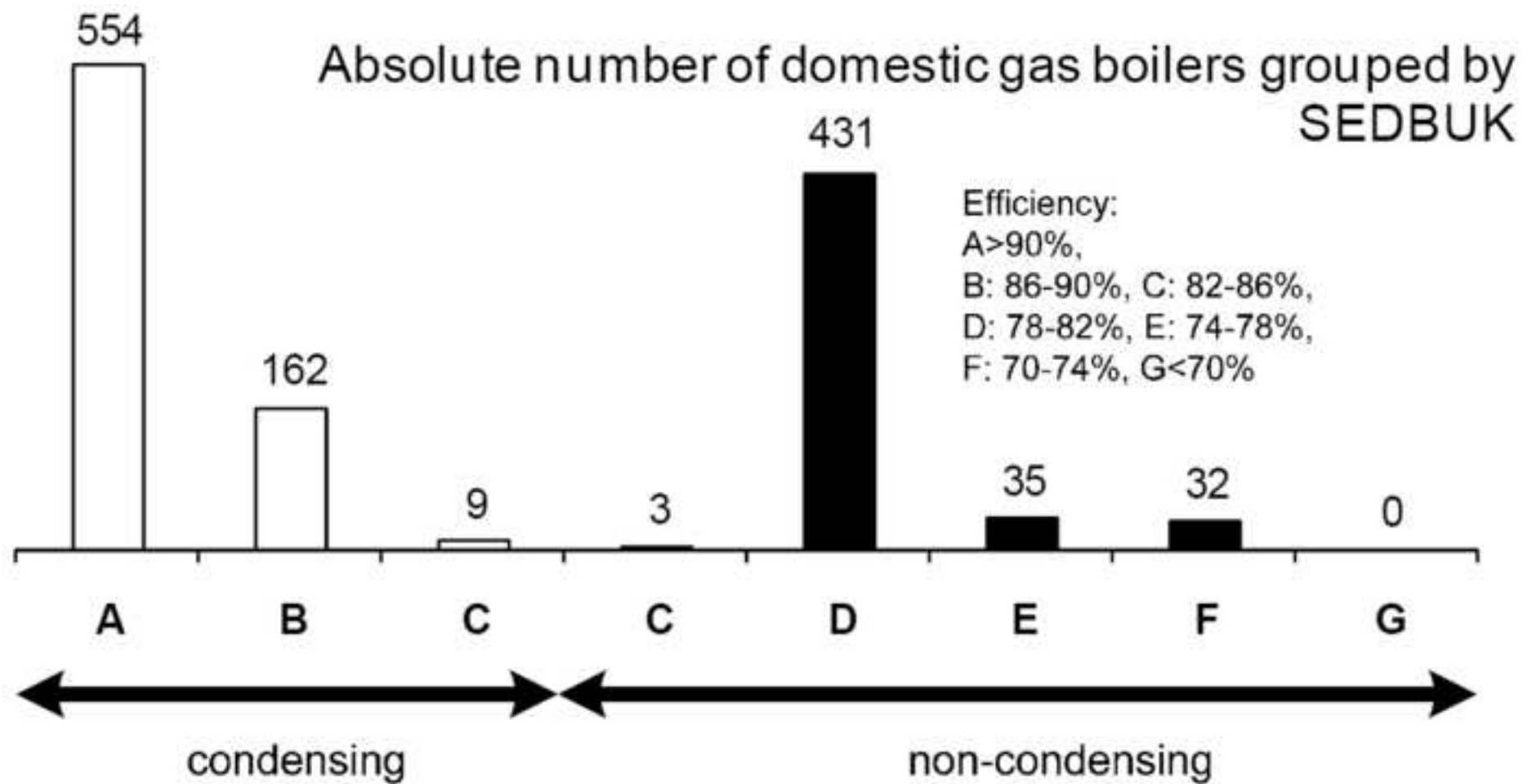
[Click here to download high resolution image](#)



Figure(s)

[Click here to download high resolution image](#)





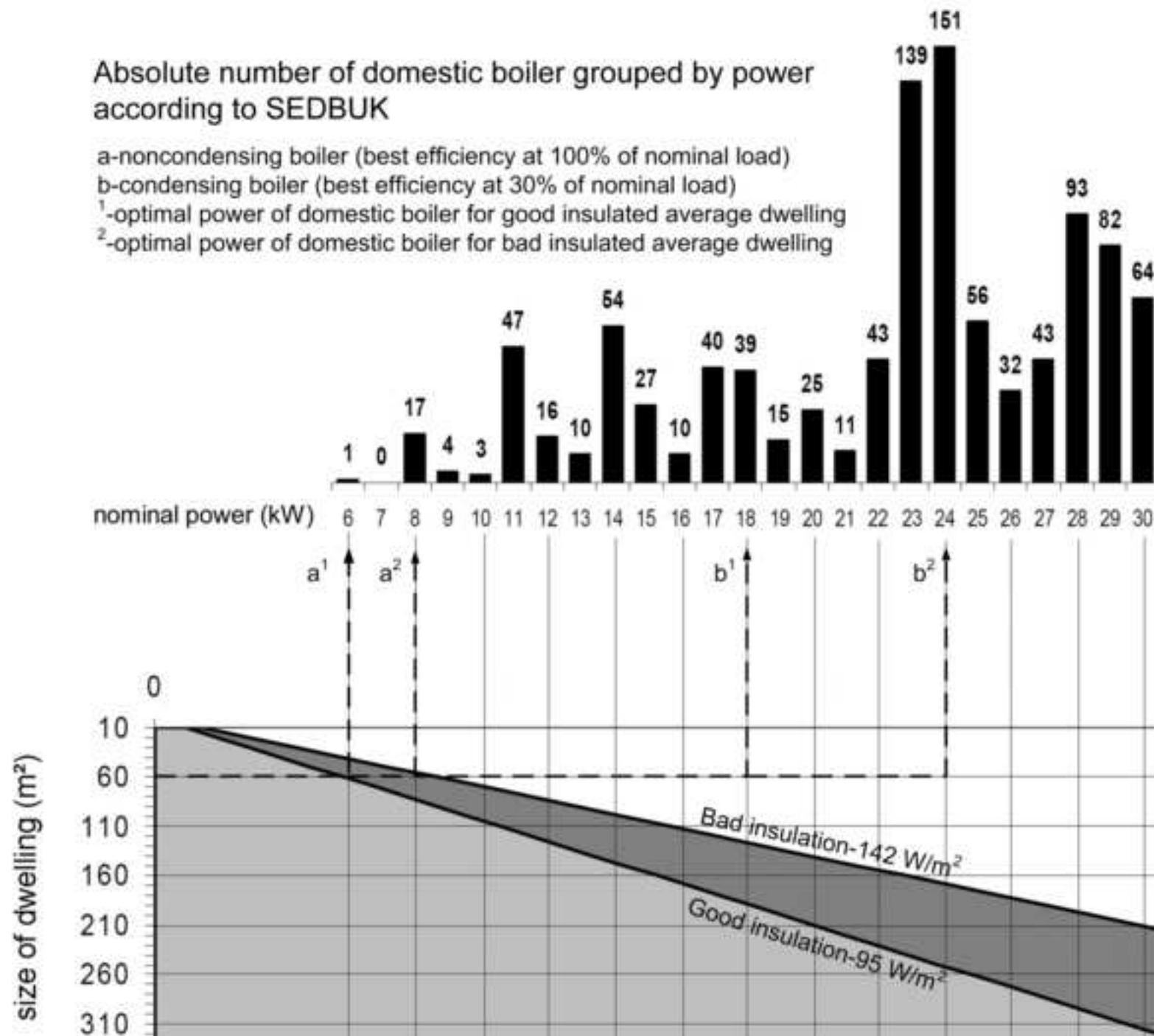
Absolute number of domestic boiler grouped by power according to SEDBUK

a-noncondensing boiler (best efficiency at 100% of nominal load)

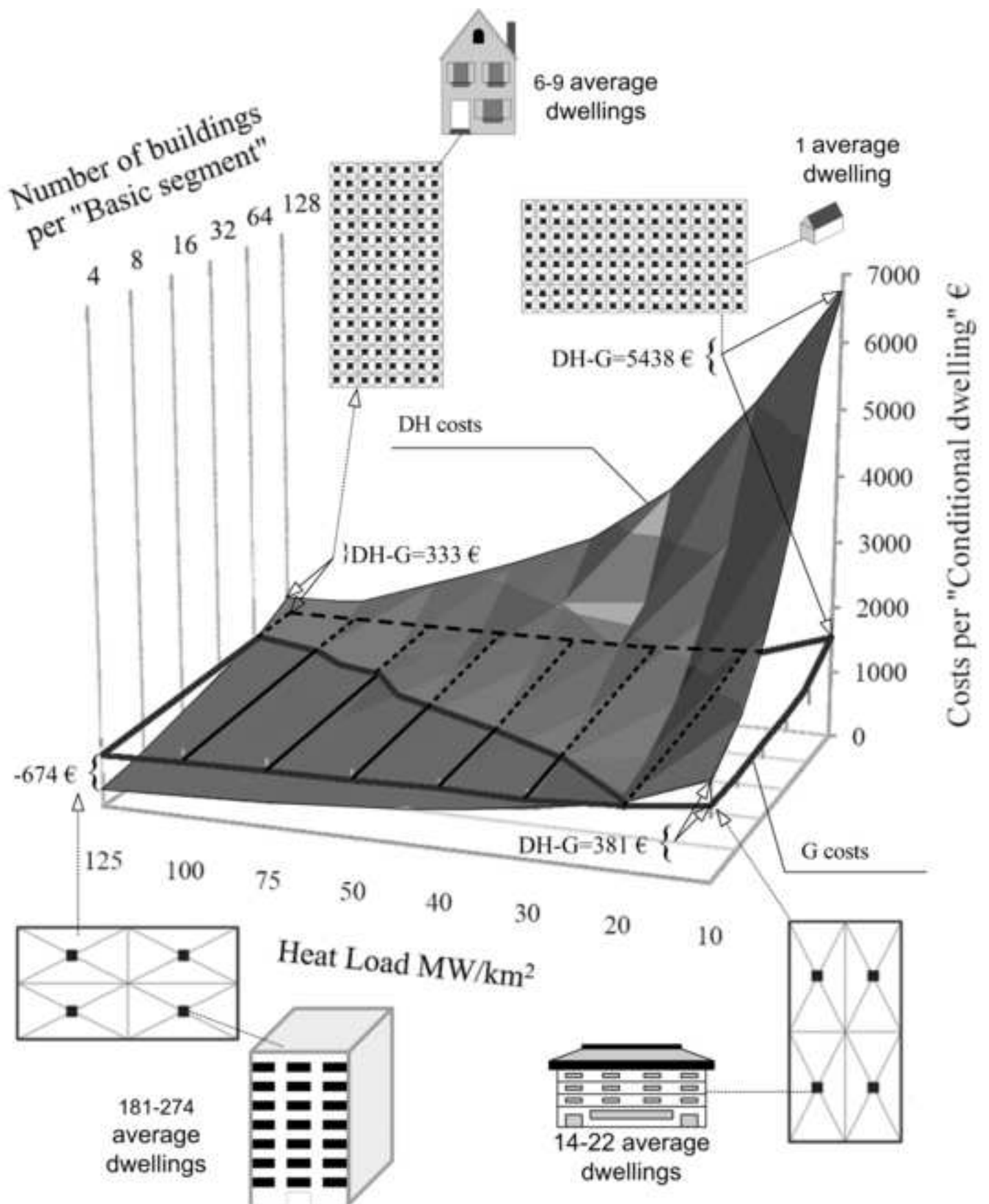
b-condensing boiler (best efficiency at 30% of nominal load)

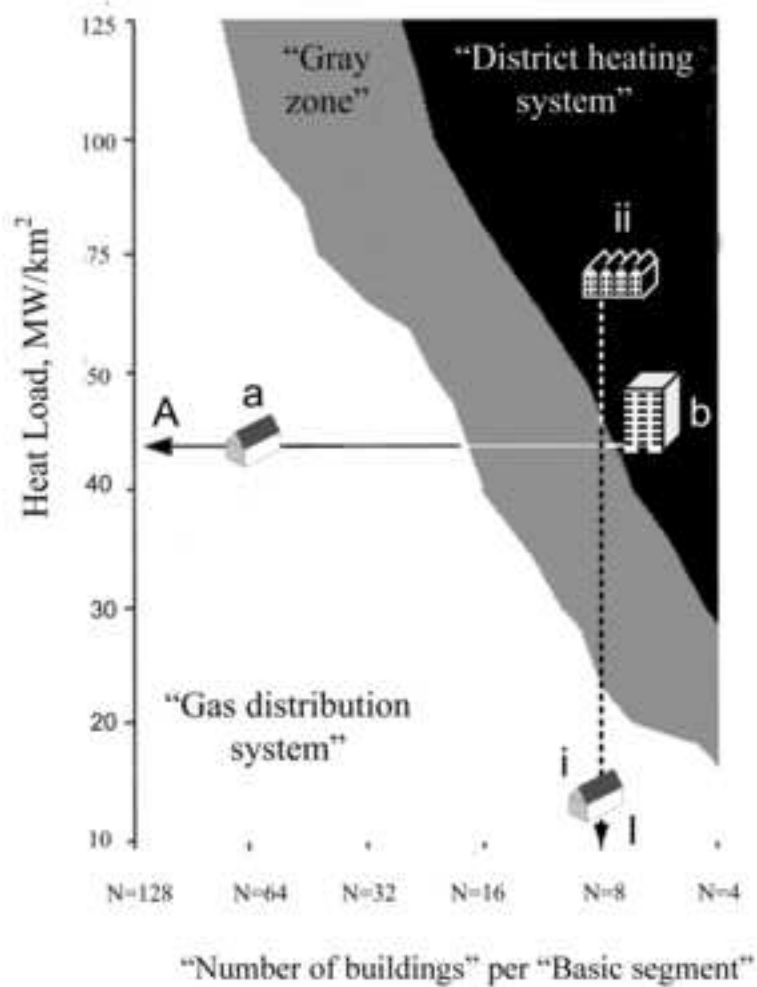
¹-optimal power of domestic boiler for good insulated average dwelling

²-optimal power of domestic boiler for bad insulated average dwelling

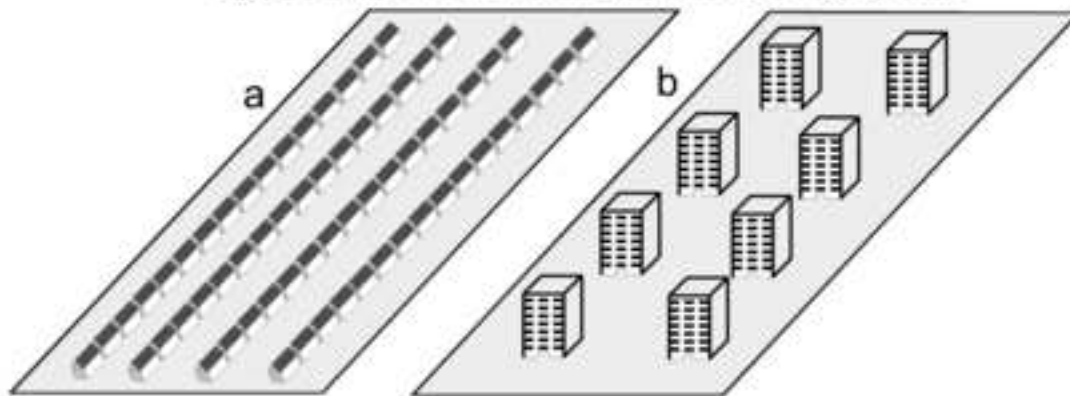


Figure(s)
[Click here to download high resolution image](#)

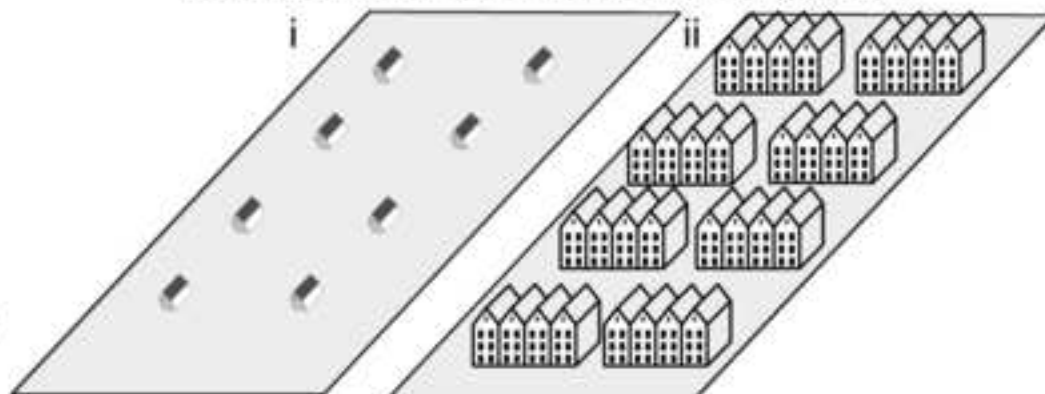




A) Same "Heat load" - Different number of building per "Basic segment"
a) gas distribution system; b) district heating system

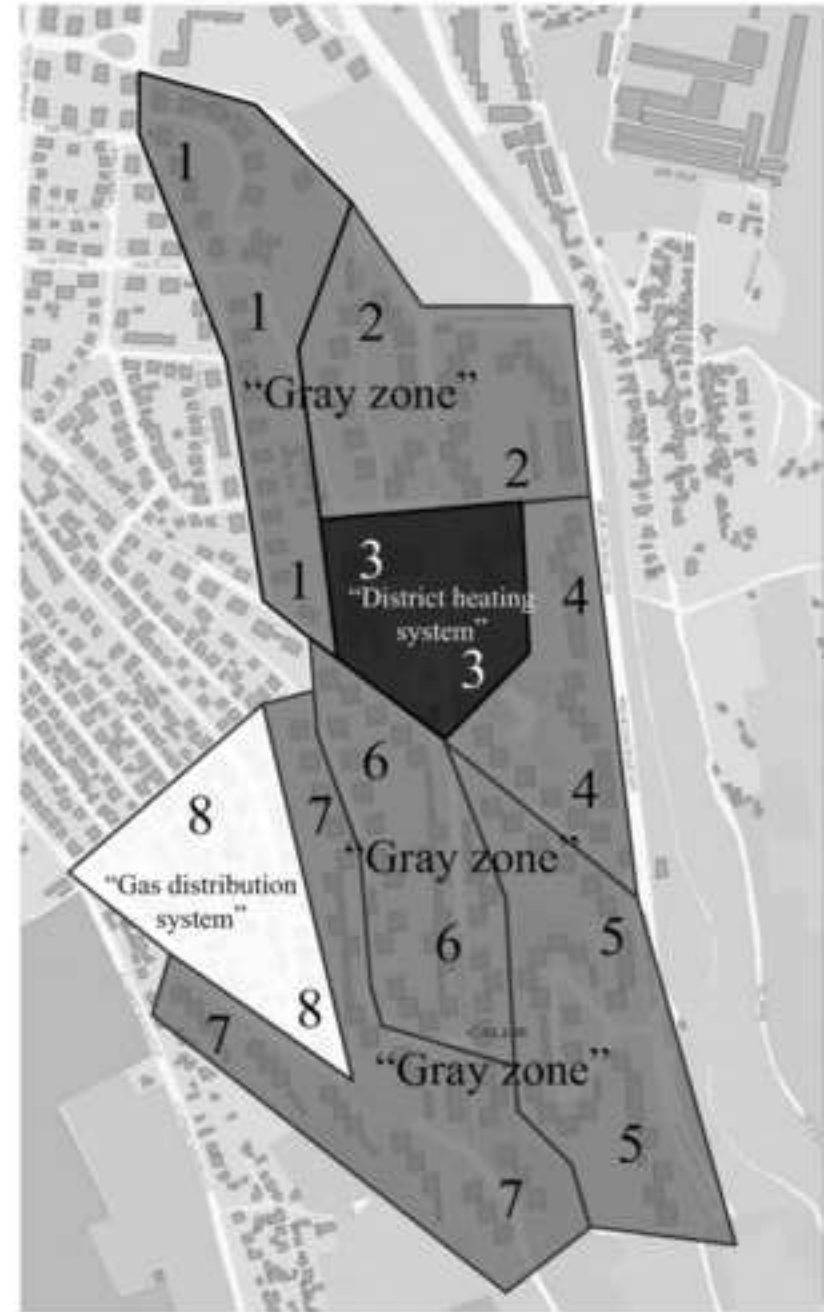
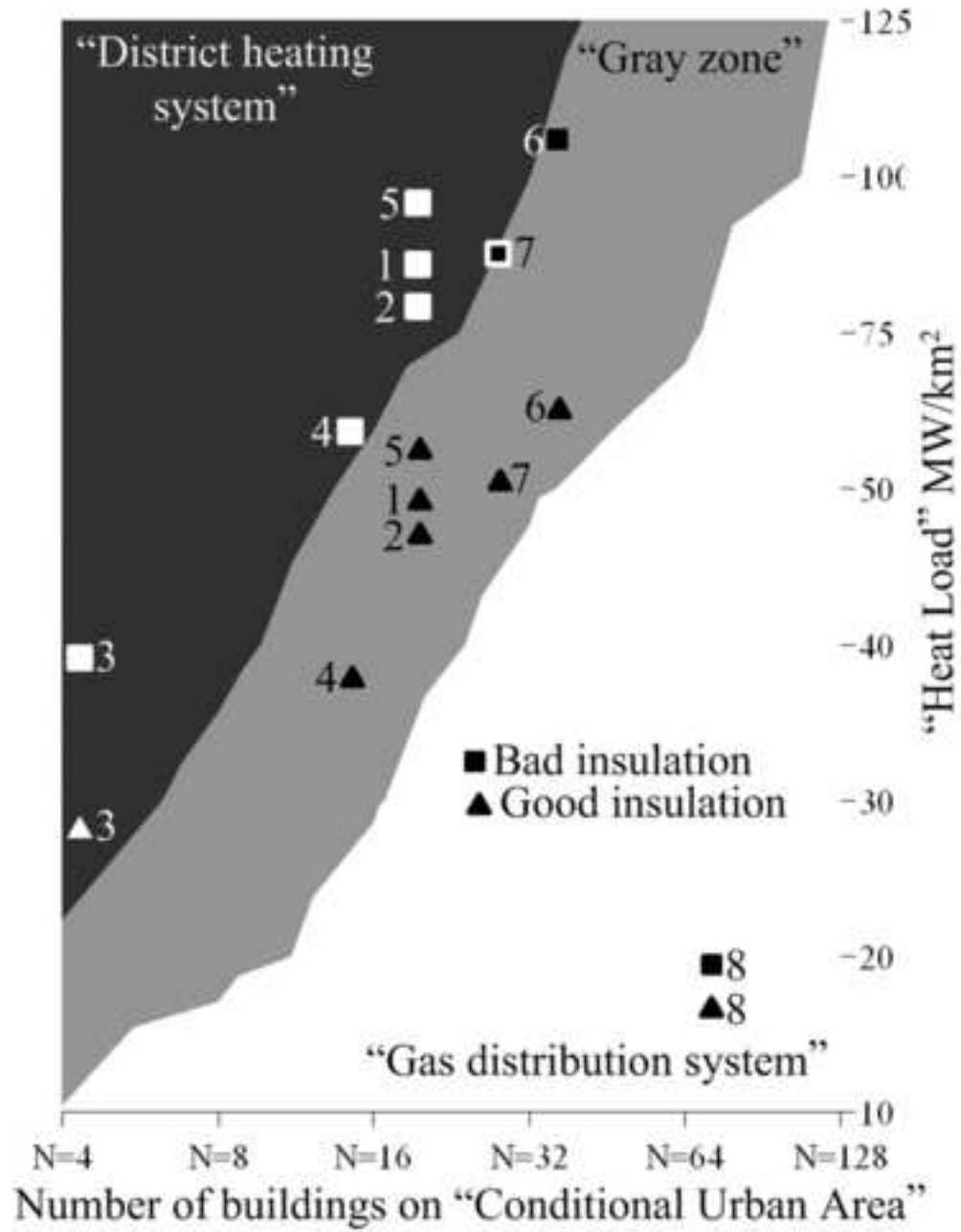


I) Different "Heat load" - same number of building per "Basic segment"
i) gas distribution system; ii) district heating system

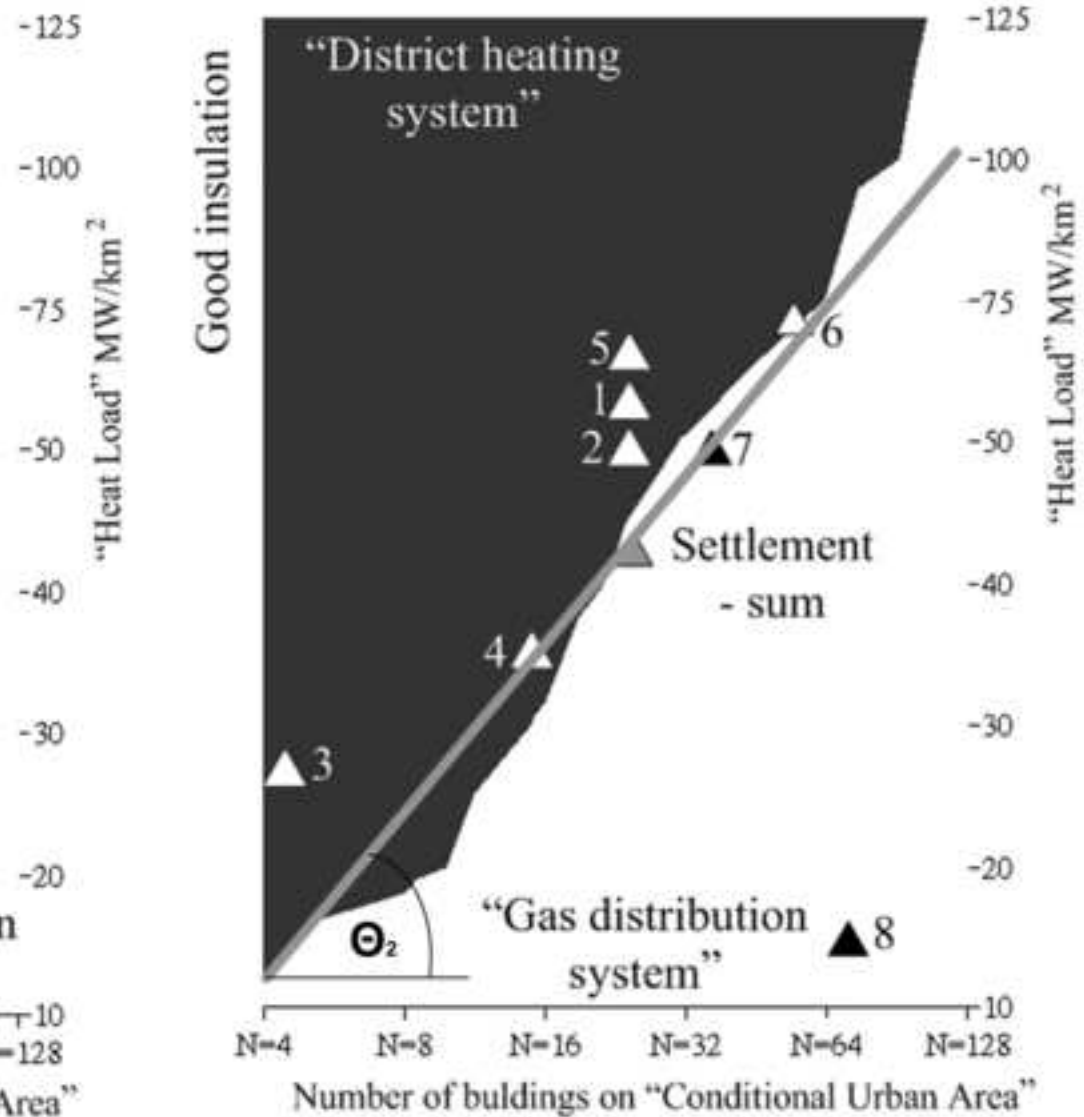
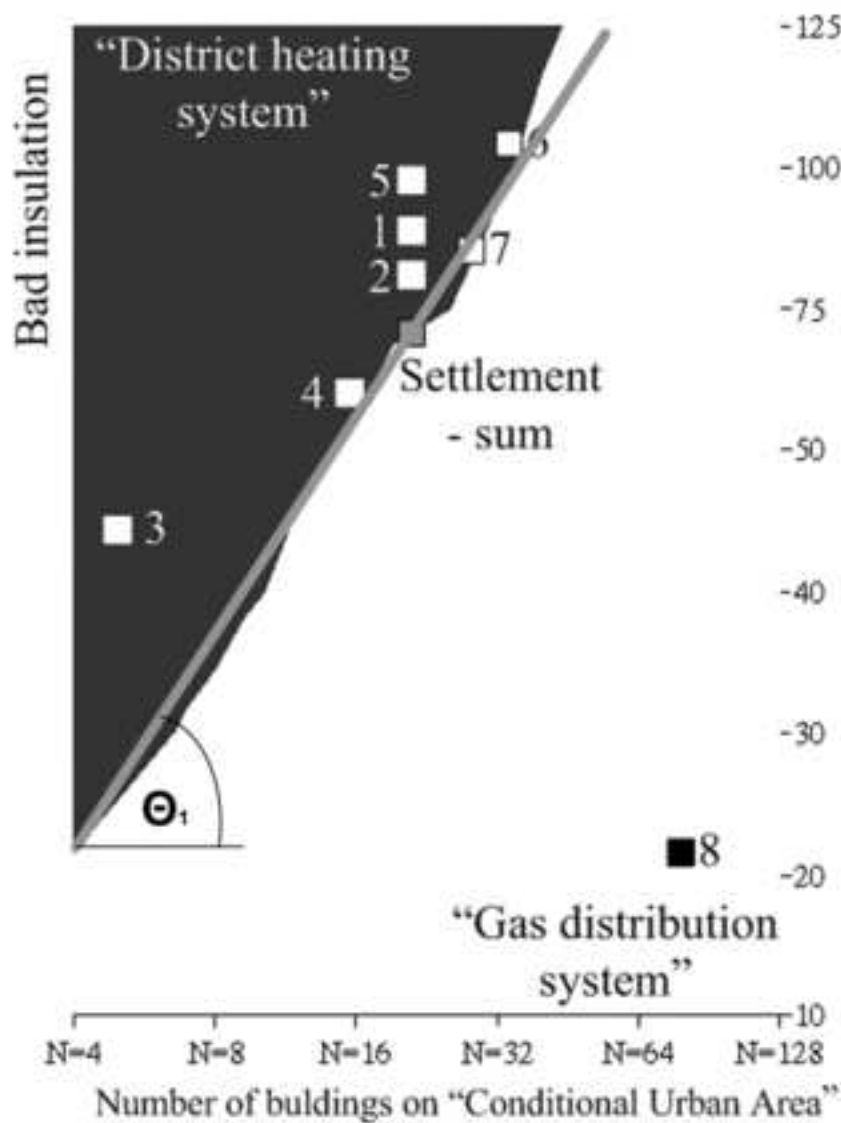


Figure(s)

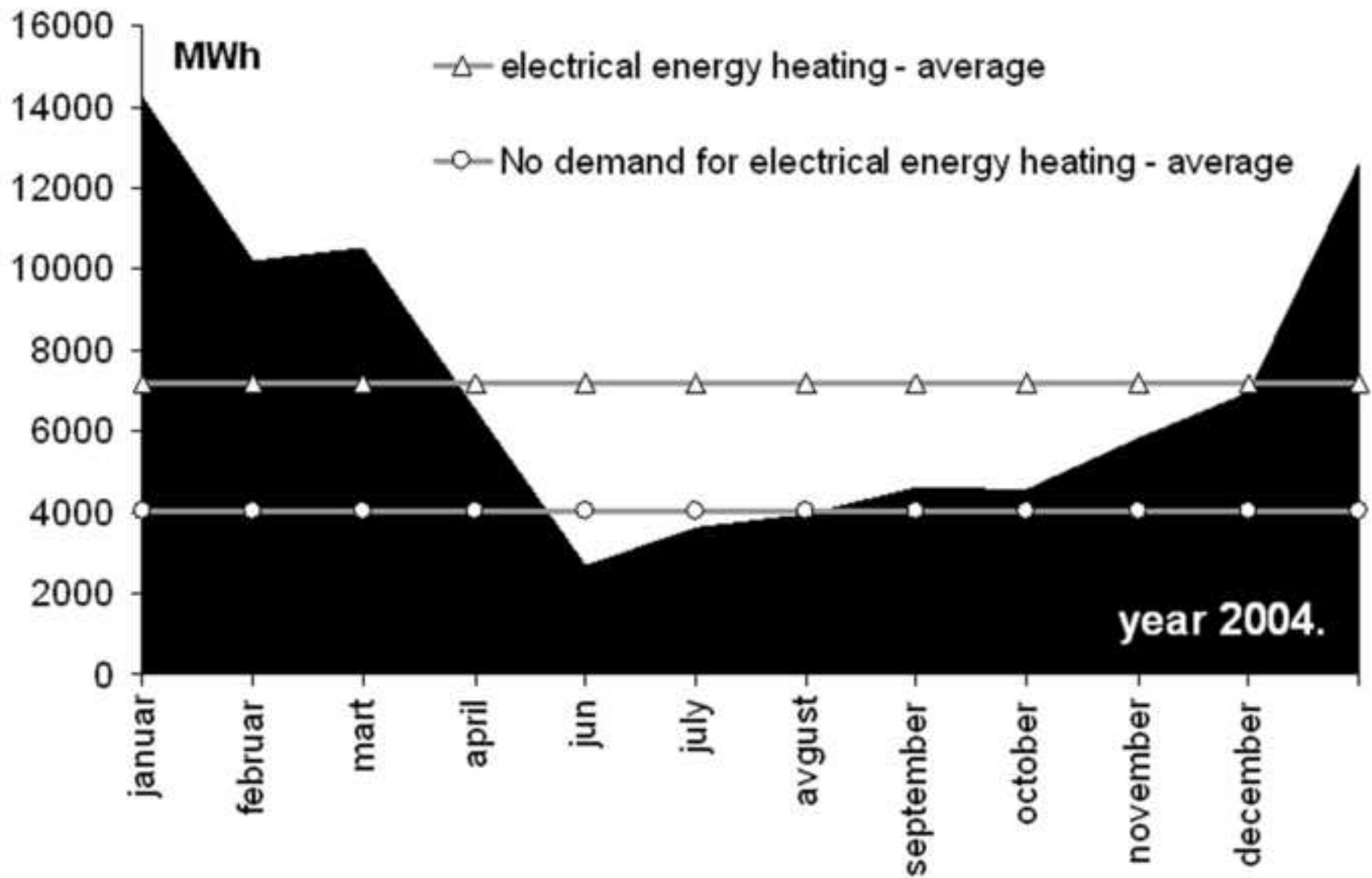
[Click here to download high resolution image](#)

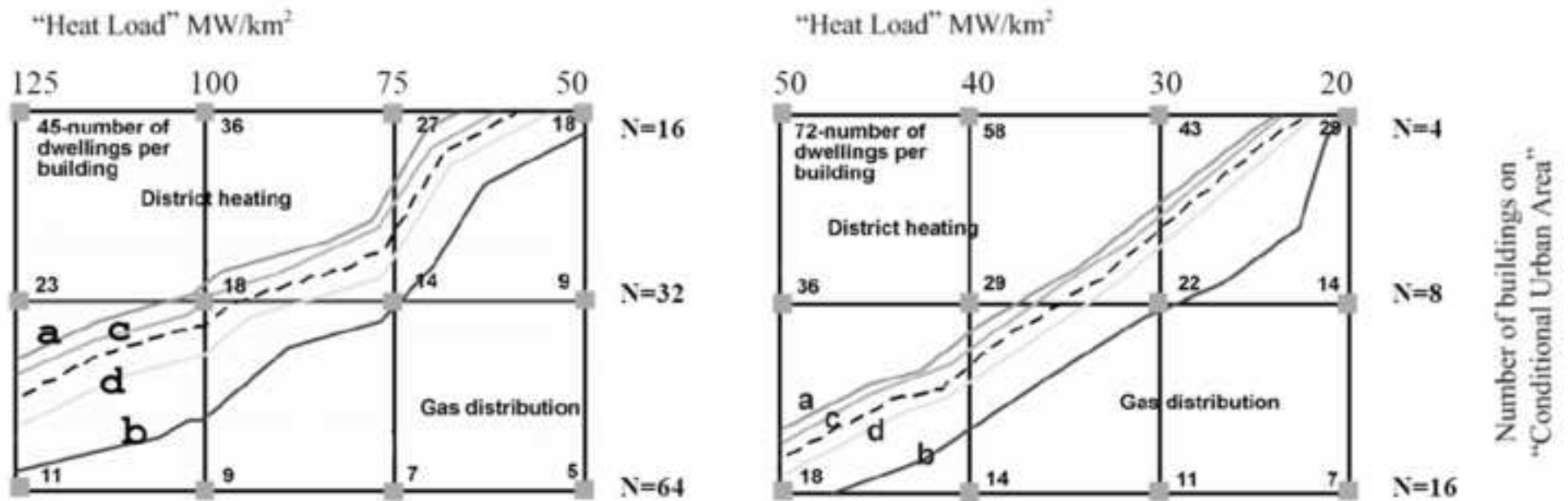


Figure(s)
[Click here to download high resolution image](#)



Figure(s)
[Click here to download high resolution image](#)





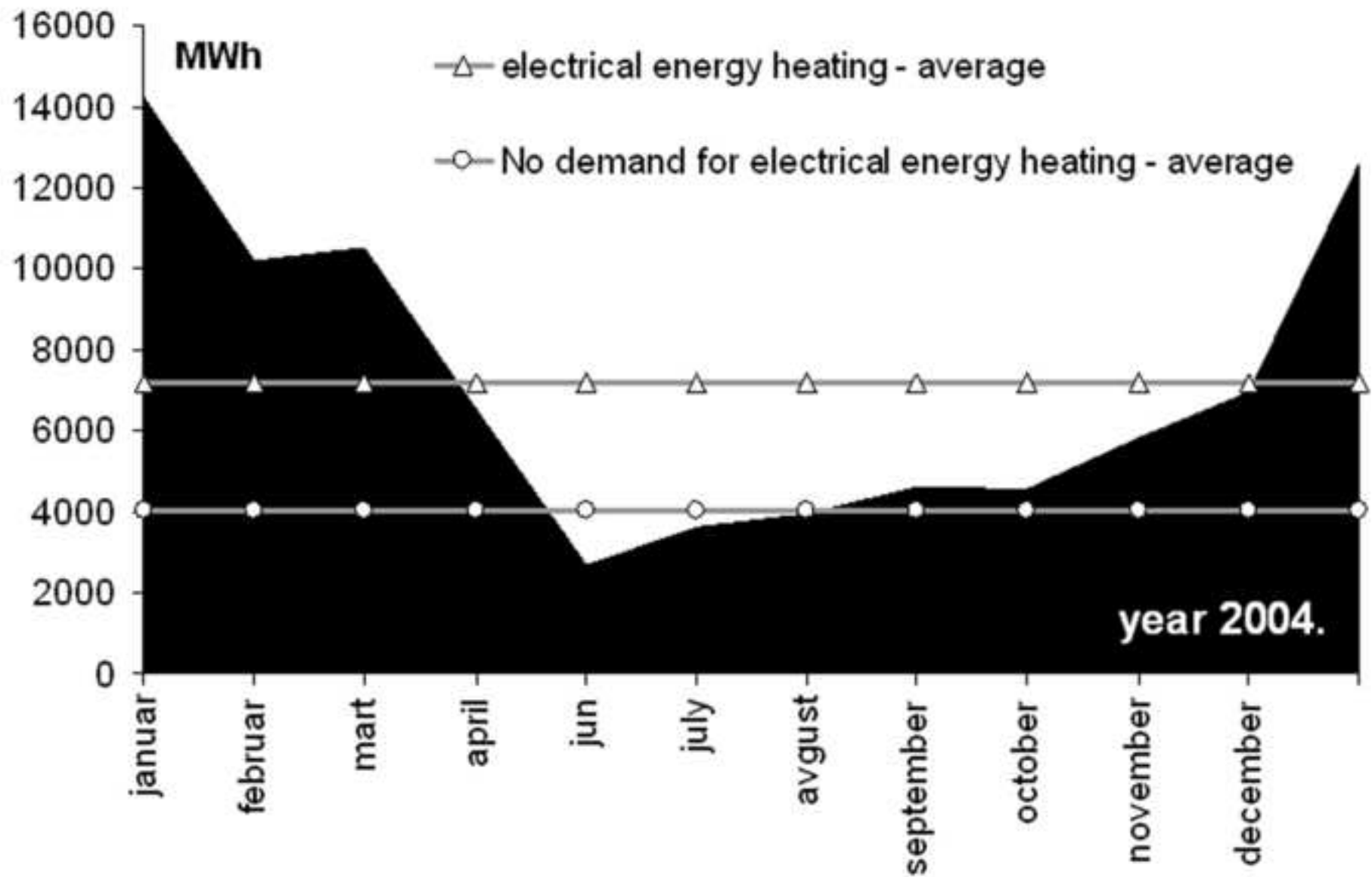
---- border between DH and G area (present condition)

a – increase of natural gas price for 50%

b – increase of domestic gas appliances price for 20%

c – bad insulation, d – good insulation

Figure(s)
[Click here to download high resolution image](#)



Figure(s)

[Click here to download high resolution image](#)

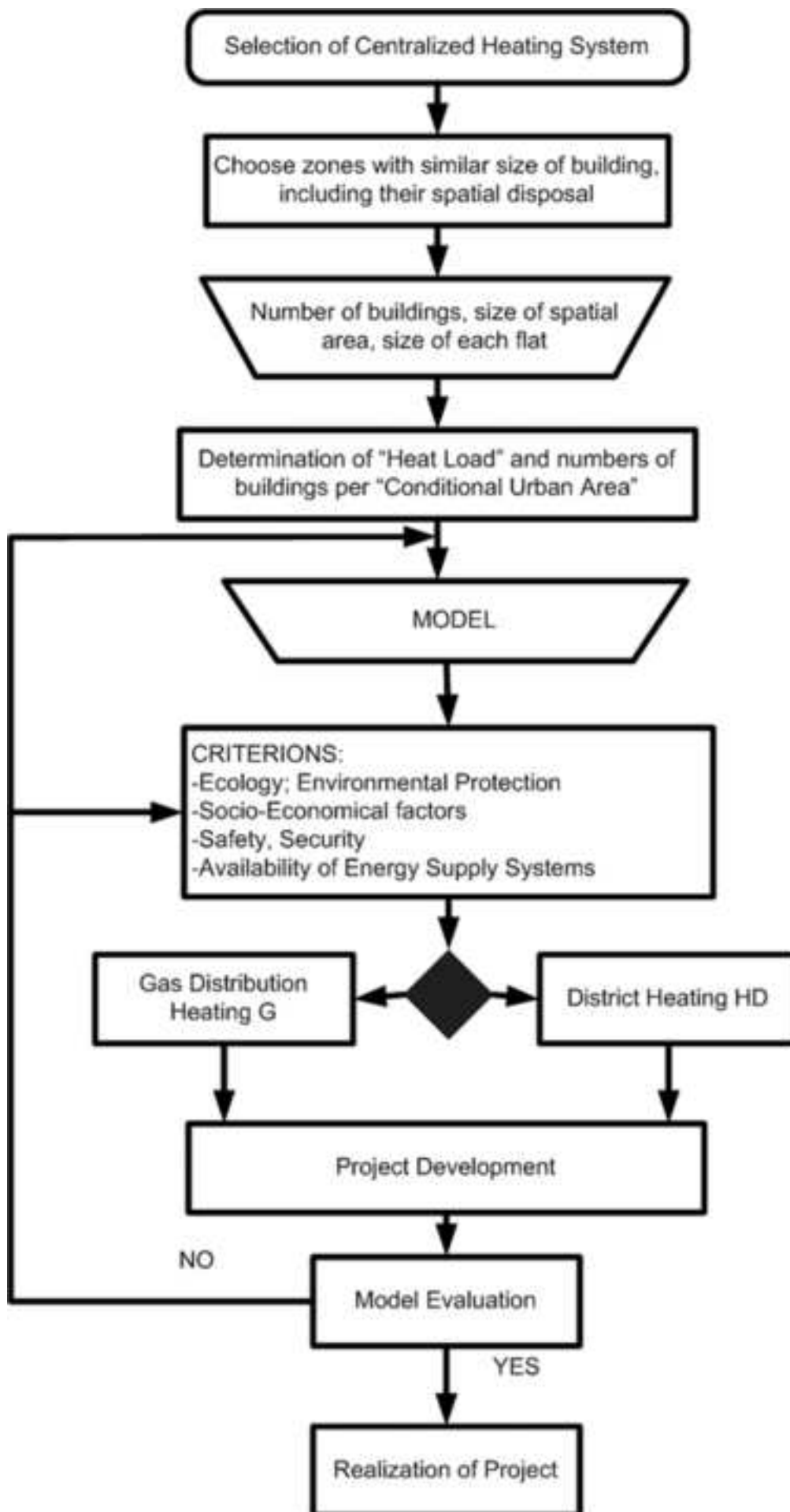


Table 1

Identification of all of 96 considered case (number of average dwelling per building)

Number of buildings – N per basic segment		“Heat Loads”, MW·km ⁻²							
	W/m ²	125	100	75	50	40	30	20	10
N=4	95^a	274 ^c	219	164	110	88	66	44	22
	142^b	181	145	109	72	58	43	29	14
N=8	95	137	110	82	55	44	33	22	11
	142	90	72	54	36	29	22	14	7
N=16	95	69	55	41	27	22	16	11	5
	142	45	36	27	18	14	11	7	4
N=32	95	34	27	21	14	11	8	5	3
	142	23	18	14	9	7	5	4	2
N=64	95	17	14	10	7	5	4	3	1
	142	11	9	7	5	4	3	2	1
N=128	95	9	7	5	3	3	2	1	1
	142	6	5	3	2	2	1	1	0 ^d

^aGood insulated dwelling, ^bPoor insulated dwelling^c274 good insulated dwellings per building, 4 buildings per “Basic segment”^dless than 1 average dwelling (<60 m²) per building; poor insulated, 128 houses per “Basic segment”

Table 3

Investments in both systems per dwelling; G and DH [€]

Bad insulation		"Heat Loads", MW·km ⁻²							
Number of buildings per basic segment		125	100	75	50	40	30	20	10
N=4 (DH)	∑	752	798	850	988	1059	1208	1453	1912
	-pipeline	147	174	189	267	291	374	504	914
	-heat exchanger	105	124	161	221	268	334	449	498
	-heat plant	500	500	500	500	500	500	500	500
N=4 (G)	∑	1427	1429	1434	1442	1450	1461	1484	1530
	-pipeline	15	16	20	25	29	34	47	78
	- regulation station	12	13	14	17	21	27	37	52
	- connection set and domestic boiler	1400	1400	1400	1400	1400	1400	1400	1400
N=8 (DH)	∑	857	919	1010	1184	1296	1480	1665	2367
	-pipeline	169	198	234	325	381	473	667	1176
	-heat exchanger	188	221	276	359	415	507	498	691
	-heat plant	500	500	500	500	500	500	500	500
N=8 (G)	∑	1429	1433	1437	1446	1456	1470	1496	1557
	-pipeline	17	20	23	29	35	43	59	105
	- regulation station	12	13	14	17	21	27	37	52
	- connection set and domestic boiler	1400	1400	1400	1400	1400	1400	1400	1400
N=16 (DH)	∑	1033	1110	1247	1427	1573	1787	2076	3212
	-pipeline	212	251	305	429	520	623	885	1606
	-heat exchanger	321	359	442	498	553	664	691	1106
	-heat plant	500	500	500	500	500	500	500	500
N=16 (G)	∑	1431	1436	1443	1456	1468	1486	1520	1604
	-pipeline	19	23	29	39	47	59	83	152
	- regulation station	12	13	14	17	21	27	37	52
	- connection set and domestic boiler	1400	1400	1400	1400	1400	1400	1400	1400
N=32 (DH)	∑	1283	1351	1448^a	1758	1987	2324	502.405	4658
	-pipeline	296	353	417	594	727	902	1.299	2499
	-heat exchanger	487	498	531	664	760	922	1.106	1659
	-heat plant	500	500	500	500	500	500	500	500
N=32 (G)	∑	1438	1445	1455^a	1474	1490	1517	1565	1695
	-pipeline	26	32	41	57	69	90	128	243
	- regulation station	12	13	14	17	21	27	37	52
	- connection set and domestic boiler	1400	1400	1400	1400	1400	1400	1400	1400
N=64 (DH)	∑	1456	1545	1722	2046	2556	2663	3700	6453
	-pipeline	319	381	485	661	812	1057	1541	2953
	-heat exchanger	637	664	737	885	1244	1106	1659	3000
	-heat plant	500	500	500	500	500	500	500	500
N=64 (G)	∑	1442	1449	1461	1483	1501	1529	1583	1738
	-pipeline	30	36	47	66	80	102	146	286
	- regulation station	12	13	14	17	21	27	37	52
	- connection set and domestic boiler	1400	1400	1400	1400	1400	1400	1400	1400
N=128 (DH)	∑	1783	1846	2274	2679	3209	4079	5489	7261
	-pipeline	398	461	594	852	1050	1367	1989	3761
	-heat exchanger	885	885	1180	1327	1659	2212	3000	3000
	-heat plant	500	500	500	500	500	500	500	500
N=128 (G)	∑	1450	1458	1471	1496	1518	1555	1626	1823
	-pipeline	38	45	57	79	97	128	189	371
	- regulation station	12	13	14	17	21	27	37	52
	- connection set and domestic boiler	1400	1400	1400	1400	1400	1400	1400	1400

^asee Table 4

Table 4
Costs for gas distribution system and district heating system (example)

€ per “Conditional dwelling” N=32 buildings per 0,05km ² , x=“Heat Load”=75 MW/km ² , y=14 “Conditional Dwellings” per building													
District Heating System							Gas Distribution System						
a	DH	b	c	d	e	f	G	g	h	i	j	k	DH-G
1	1447,5	916,6	530,8	0	0	0	1454,5	40,7	13,7	400	1000	0	-7,0
2	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
3	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
4	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
5	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
6	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
7	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
8	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
9	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
10	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
11	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
12	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
13	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
14	568,2	0	530,8	18,38	10,2	8,75	921,7	0	0	100	800	22	-353,5
15	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
16	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
17	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
18	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
19	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
20	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
21	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
22	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
23	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
24	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
25	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
26	37,4	0	0	18,38	10,2	8,75	21,7	0	0	0	0	22	15,7
Σ	2913	917	1062	459	255	219	2897	40,7	13,7	500	1800	544	16,0^l

“Discount Rate” = 10,0 %

“Net Present Value of Costs”; NPV = **24,88^m**

Small differences in sum are generated by omission of decimal places

^aYear of project,

^bDistrict heating pipeline and construction of new heating plant, ^cHeat exchanger, ^dDistrict heating system maintenance,

^eCost for additional gas (10%), ^fCost for electrical energy

^gGas Distribution pipeline, ^hCost for regulation station, ⁱCost for household connection set, ^jCost for Gas Boiler (variant I-price of domestic boiler is 500€), ^kGas distribution system maintenance

^lone of cases shown in Table 5., ^mone of cases shown in Table 6.

Table 5
Initial costs^a - € per “Conditional Dwelling”

Number of buildings – N ^b (bad insulation)		“Heat Loads”, MW·km ²							
	c	125	100	75	50	40	30	20	10
N=4	I	-674	-631	-583	-454	-390	-253	-30	381
	II	-1,174	-1,131	-1,083	-954	-890	-753	-530	-119
N=8	I	-571	-513	-426	-261	-159	10	168	810
	II	-1,071	-1,013	-926	-761	-659	-490	-332	310
N=16	I	-398	-325	-195	-28	106	301	556	1.608
	II	-898	-825	-695	-528	-394	-199	56	1,108
N=32	I	-156	-94	-7 ^d	284	497	807	1.339	2.963
	II	-656	-594	-507	-216	-3	307	839	2,463
N=64	I	14	96	262	563	1.056	1.134	2.117	4.714
	II	-486	-404	-238	63	556	634	1,617	4,214
N=128	I	333	388	1.183	1.183	1.691	2.524	3.863	5.438
	II	-167	-112	303	683	1,191	2,024	3,363	4,938
	II-I	500	500	500	500	500	500	500	500
	e	689	689	689	689	689	689	689	689

Negative values: gas distribution system is more expensive

Positive values: district heating system is more expensive

^aDH-G (see eq. 1 and 2 and Table 3)

^bNumber of buildings per 0,05 km² (“Basic segment”; see Fig. 1 and 2), note that all examination are done on ten time larger segment (“Examination segment”; see Fig. 3) because this size of segment is more suitable for examination of pipeline costs; more representative pipe diameters are included in model

^cPrice of domestic boiler; **I**-500 € (value also used in Table 6, see also Fig. 6.), values for **I** are the same in case of increasing the prize of domestic gas boiler for 500 € (sum 1000 € for boiler), but with simultaneously adding of investments (500 € per average dwelling) in new heating plant on the other side **II**-1000 €; dr=10%;

^dExample from Table 2, ^eNPV (**II**)–NPV (**I**); dr=10%

Table 6
 “Net Present Value of Costs” (NPV)^a - € per “Conditional Dwelling”

Number of buildings (bad insulation)		“Heat Loads”, MW·km ⁻²							
I ^b	dr ^c	125	100	75	50	40	30	20	10
N=4	5%	-1,010	-946	-870	-679	-576	-371	-34	529
	7%	-911	-852	-784	-609	-517	-329	-22	499
	10%	-802	-749	-689	-532	-451	-283	-9	467
N=8	5%	-846	-757	-624	-378	-223	34	243	1,161
	7%	-763	-682	-562	-337	-196	38	233	1,078
	10%	-671	-599	-492	-291	-166	42	223	985
N=16	5%	-573	-462	-262	-23	174	472	822	2,357
	7%	-516	-416	-234	-15	166	437	761	2,168
	10%	-454	-364	-203	-5	157	398	695	1,959
N=32	5%	-197	-111	16	446	762	1,229	1,999	4,336
	7%	-176	-97	20	413	701	1,127	1,834	3,980
	10%	-152	-80	25 ^d	377	635	1,015	1,652	3,587
N=64	5%	79	196	441	891	1,664	1,722	3,211	7,103
	7%	72	180	404	814	1,514	1,576	2,931	6,479
	10%	65	163	363	730	1,348	1,415	2,623	5,791
N=128	5%	584	657	1,305	1,858	2,642	3,931	5,971	8,062
	7%	528	596	1,182	1,689	2,400	3,569	5,423	7,374
	10%	467	530	1,048	1,504	2,135	3,171	4,820	6,614

Negative values: gas distribution system is more expensive

Positive values: district heating system is more expensive

^asee eq. 3.

^bVariant I-gas boiler price: 500€ (see Table 5)

^cValue of “Discount Rate”

^dExample from Table 4

Gas distribution system vs. District heating system Note: calculations are in hidden layers

INPUT PARAMETERS (edit only green cells)			
Investments per dwelling	€	Year-replacement	% maintenance
Pressure Reduction Stations - G (€ per flat)	12	25	2.3%
Domestic measurement sets - G (€ per flat)	400	12	2.3%
Domestic gas boiler - G (€ per flat)	1000	12	2.5%
Heat exchanger - DH (see hidden layers for used prize)	*****	12	1.5%
Gas Distribution network		25	2.3%
District Heating network		25	2.5%
Annual gas consumption - G	857	m ³ /year per flat for heating in G system	
Annual gas consumption - DH	1.10	DH/G	
Investment in heating plant	500	€/flat	
Annual electric energy consumption	250	KWh/year per flat for pumps in DH system	
Natural gas price	0.12	€/m ³ (here is equal price for gas in both system for Energy reader)	
Price of el. Energy	0.035	€/KWh	
Discount rate	10.0%		

*****fixed and locked for Energy readers in hidden layers
 note: calculation only for poor insulated dwellings for Energy reader

Price of network conduits			
Gas distribution pipeline		District heating pipeline	
Diameter	€/m	Diameter	€/m
25	8.1	20	40
32	11.0	25	43
40	13.0	32	49
50	13.6	40	52
63	19.3	50	55.5
75	20.0	65	58.5
90	27.0	80	74
110	30.0	100	93
125	37.0	125	118
140	39.5	150	124
160	47.5	200	158
180	51.5	250	224
200	55.5	300	254
225	62.5	350	295
250	69.4	400	313
		450	322
		500	380

Main results

MW/km ²	125	100	75	50	40	30	20	10
--------------------	-----	-----	----	----	----	----	----	----

N/0.05km ²									
		4	8	16	32	64	128		
	4	DH	DH	DH	DH	DH	DH	DH	G
	8	DH	DH	DH	DH	DH	G	G	G
	16	DH	DH	DH	DH	G	G	G	G
	32	DH	DH	G	G	G	G	G	G
	64	G	G	G	G	G	G	G	G
	128	G	G	G	G	G	G	G	G

(NPV) - € per "Conditional Dwelling"

MW/km ²	125	100	75	50	40	30	20	10
--------------------	-----	-----	----	----	----	----	----	----

N/0.05km ²									
		4	8	16	32	64	128		
	4	-802	-1,335	-689	-532	-451	-283	-9	467
	8	-671	-599	-492	-291	-166	42	223	985
	16	-454	-364	-203	-5	157	398	695	1,959
	32	-152	-80	25	381	635	1,015	1,652	3,587
	64	65	163	363	730	1,348	1,415	2,623	5,791
	128	467	530	1,048	1,504	2,135	3,171	4,820	6,614

initial costs - € per "Conditional Dwelling"

MW/km ²	125	100	75	50	40	30	20	10
--------------------	-----	-----	----	----	----	----	----	----

N/0.05km ²									
		4	8	16	32	64	128		
	4	-674	-1,131	-583	-454	-390	-253	-30	381
	8	-571	-513	-426	-261	-159	10	168	810
	16	-398	-325	-195	-28	106	301	556	1,608
	32	-156	-94	-7	288	497	807	1,339	2,963
	64	14	96	262	563	1,056	1,134	2,117	4,714
	128	333	388	803	1,183	1,691	2,524	3,863	5,438