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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has not been published previously, it is not under consideration for publication elsewhere, and if accepted it will not be published elsewhere in substantially the same form, in English or in any other language, without the written consent of the Publisher.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

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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

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Nomenclature

y – number of "Conditional Dwellings" per building [-]

N - number of buildings per "Conditional Urban Area" [-]

x - Peak load densities or "Heat Load" [MW/km^2]

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%=$265\cdot10^6$ m^3/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 $600 \cdot 10^6$ m^3 and now it is several times lowers ($285 \cdot 10^6$ 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 km^2 - “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 m·315 m=0.05 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/km^2, 20 MW/km^2, 30 MW/km^2, 40 MW/km^2, 50 MW/km^2, 75 MW/km^2, 100 MW/km^2 or 125 MW/km^2 (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 W/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 W/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/km^2 (not in $MW/0.05\ km^2$ or in $MW/0.5\ km^2$) 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 diagram[2] are caused the discount rate changes (Fig 5.) or by differentiation in the structure of diameters of conduits in the pipeline[3]. 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).

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

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 m^3 per "Conditional Dwelling" - 0.12 €/m^3) and the annual electricity consumption for pumps drive (250 kWh – 0,035 €/kWh^2). The estimated heat losses in the district-heating network are 10%.

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

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 m^3 per “Conditional Dwelling” - 0.12 €/m^3).

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 SEDBUK[4] (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. 5[5]).

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

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[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).

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

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/km^2, 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 CO_2 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 CO_2, 0.1 kg/MWh NO_x and 0.06 kg/MWh SO_2, G system with individual furnace realize 205 kg/MWh CO_2, 0.07 kg/MWh NO_x and 0.001 kg/MWh SO_2, and electrical heating system 559 kg/MWh CO_2, 88 kg/MWh NO_x and 44 kg/MWh SO_2. 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.

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7. Appendix

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

8. References

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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"

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

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

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~~energetic, techno economic, social, ecological and safety constraints.~~ 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

Nomenclature

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

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

x - Peak load densities or “Heat Load” [MW/km^2]

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, in network, heat exchanger station, annual natural gas consumption and annual electricity consumption for pumps drive [€]

MPRS - costs includes 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 have 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].

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

~~In urban areas, the most suitable option for satisfying the heating demands is by using a centralized system.~~ The most suitable option for satisfying heating demands in urban areas is by using a centralized system. The centralised 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 utilisation of modern energetic and ecological ways of combustion, the primar energy sources are better used during the transformation of primar energy into heat energy), the distribution of hot water consumption (the centralised 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 utilisation of low quality fuel, the possible utilisation of some alternative kind of fuel, the centralised storage for fuel, less expenses for the standard discontinuous transportation of fuel (saving motor vehicles’ fuel), due to the centralised and highly controled heating, there is less danger from fire. There is also a well organised, 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 appartment 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 distibution network in relation to thermal network, less possibility for quitting of supply. The disadvantages of the centralised natural gas supply systems are: an increased fire danger, explosions, or possibility of suffocation caused by damaged instalations for different reasons, the combustion is taking place in the appartment, the possible lack of gas or an interrupted distribution pipeline, etc.

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

~~1. Indirect system; natural gas is being combusted in a heating plant and households 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).~~

Life comfort [16] is the same in both options; every individual dwelling has the same network of conduits and radiators. ~~Main~~ The main intention of this model approach is to find a way ~~how~~ to ~~deliver~~ 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). ~~Primarily~~ The primary goal of this paper is not to investigate ~~whole~~ 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.). ~~Main~~ The main subject of the examination is in the "Conditional Urban Areas". ~~Comparisons~~ The comparison of investments in pipelines for both systems ~~are~~ is the most important parameter ~~in~~ of this analysis. ~~The most detailed analyses of the heating in one town must take into consideration other types of fuel for heating plant, alternatives for heating in the cases of the lack of natural gas, etc.~~ 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.

~~Model~~ 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.

~~Strategy~~ The strategy for heating of dwellings in urban areas of Serbia, since ~~from~~ the communist period, had been made to favor district heating systems in towns. ~~Consumer~~ The consumer area of Belgrade is being supplied with thermal energy by district heating system consisting of 15 heating plants which use gas (83%=265·10^6 m^3/year [1]) and crude oil as basic fuel. Statistical data show that 38% of the buildings are connected to the district heating system, ~~that is,~~ which represents 240000 flats and 7500 business offices ~~are~~ heated in that way. ~~In the scope of the Belgrade environmental protection program, construction of thermal network and gas distribution network in downtown area takes an important place~~ 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. ~~Most of these plants nowadays are fueled by natural gas, but in the past they were fueled by liquid fuels or some smaller and obsolete by coal.~~ ~~All of these mini plants have to be closed, and heating for relevant dwellings, according to new strategy, will be provided by some sort of natural gas heating.~~ 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. ~~Government strategy is~~ The government has the strategy to connect almost all ~~dwelling~~ dwellings to some form of natural gas heating system. ~~Goal~~ The goal is not to use solid fuel heating, ~~and~~ especially not ~~electrical~~ 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 $600 \cdot 10^6$ m^3 and now it's several times lower ($285 \cdot 10^6$ m^3) [1]). ~~Note, that~~ The imported gas ~~from import~~ is available for Serbia since 1979. from one direction (from north, through Hungary). ~~Also, Serbia~~ Serbia also has the EU perspective [~~2, 3~~ 17, 18], and ~~government~~ the Government's strategy is to ~~be~~ 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 ~~is faced with~~ and comparably low indigenous gas resources within Europe~~, so that the dependency of Europe on gas imports from abroad will rise in the future~~ 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 [~~4~~ 19] and Algeria, gas resources from the Middle East and the Caspian and ~~the~~ Central Asian regions ~~may be~~ 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 [~~5-8~~ 20-23].

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

The initial decision on choosing one of two systems is based on the number and the size of buildings in a settlement, it's size and heating insulation of the buildings [1]. In boundary cases, if it is possible to achieve both options it is also possible to introduce a sort of hybrid system, not considered in this paper. Economic analysis of the renovation of small-scale district heating systems in Lithuania is available [9]. District heating systems using cogeneration, as well as local fuel-based and electric heating systems for detached houses, are analyzed by L. Gustavsson and A. Karlsson [10]. Their analysis includes the whole energy system, from the natural resource to the end user, with respect to primary energy use, emission and cost. They found that systems based on natural gas 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 greatly used in industrial processes in order to decrease the ratio of greenhouse gases released from coal-based local and industrial processes [11].

Goal of model introduced in this paper is to determine the connections among urban and energy characteristics of settlements in cities, and to be of benefit for more rational usage of natural gas as non-renewable fossil fuel. Energy demands for heating are shown for Canadian case [12] from the economical point of view. The introduction of natural gas in the Greek energy market broadened the options in the field of space heating [13]. Paper by C. Dinca, A. Badea, P. Rousseaux, and T. Apostol [14] 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 has been analyzed). Natural gas in optimized bivalent heating systems is shown in paper of SI. Gustafsson and BG. Karlsson [15]. Study of MS.

~~Torekov, N. Bahnsen, and B. Qvale [16] 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 high concentration of heat demand, primarily areas with apartment buildings [16]. R. Lazzarin and M. Noro [17] have done analyses of local or district heating by natural gas from energetic, environmental and economic point of views. Legal and policy aspects of different energy supply systems utilization in households sector can also be found in available literature [18].~~

2. ~~Concept~~ 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, ~~performing~~ it is not necessary to perform the entire calculation for both systems ~~is avoided~~ and after which the choice ~~on~~ of a heating system in a the settlement is made. ~~Application~~ The application of this model makes easier the job for energy ~~planners~~ and city planners. People with higher living standard~~,~~ often do not take economic parameters into consideration ~~economic parameters~~ when deciding between gas or district heating system. The decision is based on a personal affinity (and often, prejudice) [~~19~~ 24].

~~Parts~~ 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. ~~Zones~~ The zones divided like this, for the model ~~purpose~~ purposes, need to have an area of 0.05 km^2 - “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 m·315 m=0.05 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.) ~~consist~~ consists of ten “Basic ~~segment~~ segments” with an added pipeline (gas and district heating). Only one type of “Basic segment” can exist ~~into~~ in one “Examination segment”. Real zone formed like this can be joined with one of the 96 „Conditional ~~urban~~ Urban Areas“(Fig. 4. and Table 1.). Each particular “Conditional ~~urban~~ Urban Area” ~~consist~~ consists of ten “Basic ~~segment~~ segments” (all the ten belong to one of the six types shown in fig 1.), buildings (all the buildings ~~is~~ 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 Area~~ Urban Areas”. ~~To each one of these basic types of “Examination segment” a~~ 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. ~~In this model there~~ There are 8 different heat loads in this model: 10 MW/km^2, 20 MW/km^2, 30 MW/km^2, 40 MW/km^2, 50 MW/km^2, 75 MW/km^2, 100 MW/km^2 or 125 MW/km^2 (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 ~~type~~ 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 ~~segment~~ segments” (Fig. 1) all the possible densities of built up areas in settlements can be described. ~~In each particular urban area, buildings with different sizes can be found;~~ 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 [~~20-22~~ 25-27]. ~~If within the settlement there are several types of buildings or density of built up areas,~~ 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) [~~23~~ 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 ~~cost of~~ costs for the implementation of gas distribution and district heating ~~system~~ systems (Table 3). ~~Investments are calculated~~ The investment’s calculations are based on the detailed estimate of distribution network for both systems with all ~~of~~ 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 ~~2~~ 4). After that, the values of gas distribution costs are being subtracted from the investment ~~cost~~ costs of the district heating system (Table ~~3~~ 5) and then they are being discounted (Table ~~4~~ 6). For cases with positive values the option of gas distribution is more favorable than the district heating system (negative values).

~~Disposition~~ The disposition of networks for all cases is shown in figure 3 (“Examination segment”). ~~Disposition means length of pipeline~~ The disposition designates the pipeline length, but not structure of diameters of conduits in ~~composition of pipeline~~ the pipeline composition. ~~Determination~~ The determination of structure of diameters of conduits ~~in composition of pipeline~~ the pipeline composition can be done only after the “Conditional Urban Area” is formed. A structure of pipes diameters depends ~~of~~ 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”) ~~exist pipeline network~~ pipeline network exists, while in Fig. 1 or in Fig. 2 ~~don’t~~ 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) ~~Heat~~ A heat demand [~~24~~ 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),

~~Term~~ The term “building” is used here ~~also~~ for family houses also, as well as for the and 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 W/m^2 (heat peak load for lower insulated dwelling) in case of ~~lower~~ a low (bad) insulation, and in case of better (good) insulation it has a heat demand of 95 W/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). ~~Average~~ An average dwelling (60 m^2) is practically "Conditional Dwelling".

~~Concept~~ The concept of the "Examination segment" is regarded only for the purpose of exploration on realistic values of diameters in ~~structure of pipeline~~ 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/km^2 (not in MW/0.05 km^2 or in MW/0.5 km^2) and ~~accordingly~~ it is nominally equal for for both "Examination segment" ~~as for~~ and "Basic segment".

3. ~~Model~~ 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 ~~was~~ has been made. For each of the 96 cases ~~investment~~ investment, a calculation ~~was~~ has been made in both of the proposed heating systems (Gas Distribution [~~25~~ 30] vs. District Heating [~~26~~ 31]) including the exploitation in the next 25 years (investments). For each case, a comparison of costs ~~was~~ has been made so that the heating system with the ~~least~~ smallest cost has an advantage in the implementation. ~~Number~~ . The number of ~~dwelling~~

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

~~In the model, both types of heating~~ 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 ~~built with~~ made of steel conduits, pumps and heat exchangers, on the contrary, the gas distribution system is ~~built with~~ made of cheaper polyethylene conduits and has stations for measuring and regulation with internal gas equipment (each dwelling has domestic gas boiler etc). ~~Investment~~ The investment in new capacities ~~in~~ for heating plant ~~are~~ is included in the model in a ~~direct way~~ directly i.e. by increasing the price of natural gas for district heating, or can be added by including the new cost indirectly. ~~Investments~~ The investments in a new heating plant ~~fuel~~ 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 ~~cost~~ costs of 450-680 € per "Conditional dwelling". ~~That~~ It implies that this kind of additional ~~cost~~ costs is not essential for this kind of analyses (Fig 5.). ~~Changes~~ The changes in the slope of borderline in the model diagram[1] are caused ~~by changes in discount rate~~ the discount rate changes (Fig 5.) or by differentiation in the structure of diameters of conduits in the pipeline[2]. Same conclusion can be made with ~~variation in price~~ price variations of domestic boiler (see Table ~~3~~ 5 and Fig 5). L. Gustavsson and A. Karlsson [~~10~~ 3] estimated ~~DH investment costs and DH maintenance costs~~ the DH investment and maintenance costs. ~~Increasing of price of domestic gas boiler simultaneously with introducing of investments in heating plant in the same amount 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

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

~~Relative~~ 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).

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

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 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 [-].

~~Annual costs of maintenance~~ 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 m^3 per “Conditional Dwelling” - 0.12 €/m^3) and the annual electricity consumption for pumps drive (250 kWh – 0,035 €/kWh^2). ~~Assumption of the~~ The estimated heat losses in the district-heating network ~~is~~ are 10%.

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

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 and y – number of "Conditional Dwellings" per building [-].

~~Annual costs of maintenance~~ 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 m^3 per "Conditional Dwelling" - 0.12 €/m^3).

The efficiency of the NG boiler is the best during ~~the~~ winter when space heating is needed. ~~In~~ 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 SEDBUK[3] (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

[3] available from www.sedbuk.com

gas. Condensing boilers guarantee higher efficiencies with respect to ‘‘traditional’’ district heating.

~~Investment~~ An investment in a new heating plant or the increasing ~~of price of~~ domestic gas ~~boiler~~ 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. 5[4]).

In the equations ~~above costs common~~ 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 ~~6~~ 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 diagrams (figures in this paper) are generated for prices ratio in Serbia. Detail calculation for one case of 96 is shown in table ~~2~~ 4.

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

[4] or in case study in Fig 11

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. ~~Higher value of "Discount Rate" is calculated when risks for the safety of investments exist~~ 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) [~~27~~ 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).

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

~~Value~~ 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). ~~Changes~~ The changes of calculated values for dr=5% and dr=7% are shown in Table 4 6. ~~Annual~~ An annual gas consumption calculated for one "Conditional Dwelling" is 857 m^3 for heating only, ~~and for district heating system, this amount is 10% higher~~ and this amount is 10% higher for district heating system. ~~Also,~~ Besides, a statistical approach based on nonlinear regression principles can be made to natural gas consumption estimation of individual residential and small commercial customers [~~28~~ 34]. ~~Annual~~ 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 4 6, case with a bad insulation is shown.

The values in certain cases in table 4 6 vary more or less from zero. For example, for "Conditional Urban Area" with 16 buildings and with "Heat Loads" 50 MW/km^2, the calculated "Net Present Value of Costs" (NPV) is only -5 per "Conditional Dwelling" for a period of 26 years. Therefore, ~~in this case,~~ 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. ~~7~~ 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~~, more or less, the recommended limiting value~~ 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 ~~price of gas~~ 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. ~~7~~ 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 ~~do~~, 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 [~~29~~ 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

~~Characteristics~~ The characteristics of the “Real Urban Area”: number of buildings, disposition and size of buildings, construction type, etc. are the factors of influence. ~~Adoption~~ 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 ~~consumers of gas~~ the gas consumers who use gas distribution systems directly, such discounts are not available. ~~Also, in Serbia,~~ 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 ~~only on urban characteristic of the settlement~~ 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. ~~8~~ 10). That way, the determined “Real Urban Area” can be associated with the “Conditional Urban Area”. ~~Characteristic~~ 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. ~~8~~ 10). The types of insulation of ~~the~~ 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 ~~border~~ boundary cases have been treated, because of heterogeneity of insulation quality of buildings [~~22, 23, 30-32~~ 27, 28, 36-38]; (Fig. ~~9~~ 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 [~~33~~ 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 great deal~~ depends, in a great deal, on the type of insulation of the building; (Fig. ~~7~~ 9. and ~~8~~ 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=tgθ_1) and for bad insulation (K_2=tgθ_2) in Fig ~~9~~ 11 is generated only because of differentiation in structure of diameters of conduits in pipeline (Fig ~~10~~ 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 ~~a~~ 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 ~~11~~ 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 it's 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 lenth 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. ~~Using~~ When using one of the power ~~resource~~ resources (in this case natural gas) in various systems, the difference in the amount of pollution is very ~~little~~ 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 ~~to~~ 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 CO_2 emission of about 56 kg/GJ (which is significant considering the limitations imposed by The Kyoto Protocol) [34-37 44-47] . M.S. Torekov, N. Bahnsen and B. Qvale [16 9] found that DH system realized 78-93 kg/MWh CO_2, 0.1 kg/MWh NO_x and 0.06 kg/MWh SO_2, G system with individual furnace realize 205 kg/MWh CO_2, 0.07 kg/MWh NO_x and 0.001 kg/MWh SO_2, and electrical heating system 559 kg/MWh CO_2, 88 kg/MWh NO_x and 44 kg/MWh SO_2. 1 MWh of delivered energy is 61% cheaper in natural gas in comparison with electrical energy [36 46]. Comparison The comparison of environmental impacts of two residential heating systems in Canada is shown in paper of L. Yang, Zmeureanu R., and Rivard H. [38 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 [39 49]) and the highest quality form of energy – the electric energy, whose usage for heating is by far less rational; (Fig. 12 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 [40 51]. Electricity and natural gas use for residential space heating in USA is shown in paper by D. Bodansky [~~41~~ 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. ~~It should be noted how important it is to reduce the energy consumption level, by changing the forms of consumption and making improvements in technology and lifestyle~~ 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 ~~use~~ 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 G and DH very much ~~depends~~ 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 ~~the~~ 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 ~~was~~ has been chosen from following database: “Seasonal Efficiency of Domestic Boilers in United Kingdom“ [~~42~~ 32]. ~~Efficiency~~ The efficiency of domestic boiler and ~~efficiency of~~ heating plant ~~on that way~~ has equalized by efficiency in this model. ~~Typical~~ The typical efficiencies of plants fueled by natural gas are reported in paper of R. Lazzarin and M. Noro [~~17~~ 10].

Figure 5 is essential for ~~fully~~ 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. ~~Increasing the prize linearly~~ The linear price increase moves the borderline in the model diagram in advantage of the district heating (Fig. ~~8~~ 10. and Fig. ~~9~~ 11.). The same conclusion is made for the investments in new capacities in heating plant, but ~~that~~ 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 ~~boiler~~ boilers or ~~investments~~ 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 [~~43, 44~~ 40, 41]). ~~On the contrary, with~~ 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 ~~a building so high~~ such a high building. Anyway, in this case the G system has a slight advantage, and by the increasing ~~the~~ price of domestic gas ~~boiler~~ boilers, the DH system became the cheaper option (Fig ~~6~~ 8. and Table ~~3~~ 5).

In more ~~detail~~ details, if a certain number of objects N exist in a "Conditional Urban Area", it can be concluded that (Fig. ~~6~~ 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 ~~is appeared rare~~ rarely appears in practice. ~~Gas~~ The gas distribution system is advantageous because all 128 buildings must be equipped with expensive heat ~~exchanger~~ exchangers. That is highly unpractical and expensive for individual houses. For skyscrapers, gas system, theoretically, has a ~~slightly~~ slight advantage, but with an increased ~~prize~~ price of domestic gas ~~boiler~~ boilers, district heating system can be applied in larger buildings. ~~Also,~~ Besides, the implementation of the gas system in skyscrapers is forbidden ~~during~~ according to safety regulations.

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

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

Note that, pipeline is one of the most important parameters in the analyses shown in this paper. Every particular type of “examination segment” has a different length of pipeline route. Length of 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, in the same time length of route is determined. Now, next factor to be varied is heat load. Heat load is directly correlated with the size of buildings, i.e. for fixed length of pipeline, structure of pipeline diameters can vary. Larger diameters of conduits in pipeline structure are correlated to larger buildings. So, length of pipeline route depends on the density of built up areas, and structure of pipe diameters in pipeline depend on the size of buildings. Therefore, in city condition diameters of pipes are more sensitive in some cases (has greater impact) apropos to length of pipeline for decision of heating system. In the conditions of densely populated urban areas, when one type of “examination segment” is considered, decision for implementation of certain heating system has to be done according to above mention criterions. Lengths of pipeline and structures of diameters of conduits are main factor for establishing of these criterions. Accordingly, in villages, distances between the houses are larger, so dwelling’s length of 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 [43, 44] 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 areas of low heat densities. However, 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 cost for the local distribution network. This situation results in high distribution costs. Distribution heat-losses are also higher at low heat-densities.

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

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 [45-47], with related papers presented in scientific journals [48]. Main achievement of these German researches is in 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 [45] – from densely populated urban areas to villages. A new German study 20 years later refers to this work [46], with projection to 2020 [47]. Valuable information for the energetic situation in city of Belgrade is shown in the paper of M. Jovanović,

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

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

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7. Appendix

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

8. References

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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 km^2)

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

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

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

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

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

~~**Figure 12.**~~ **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: ~~Costs for gas distribution system and district heating system~~ Structure of pipe diameters for one of the cases (example)

Table 3: ~~Initial costs[a] - € per "Conditional Dwelling"~~ Investments in both systems per dwelling; G and DH [€]

Table 4: ~~"Net Present Value of Costs" (NPV)[a] - € per "Conditional Dwelling"~~ 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"

*** Point-to-Point Response to Reviewers**

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.

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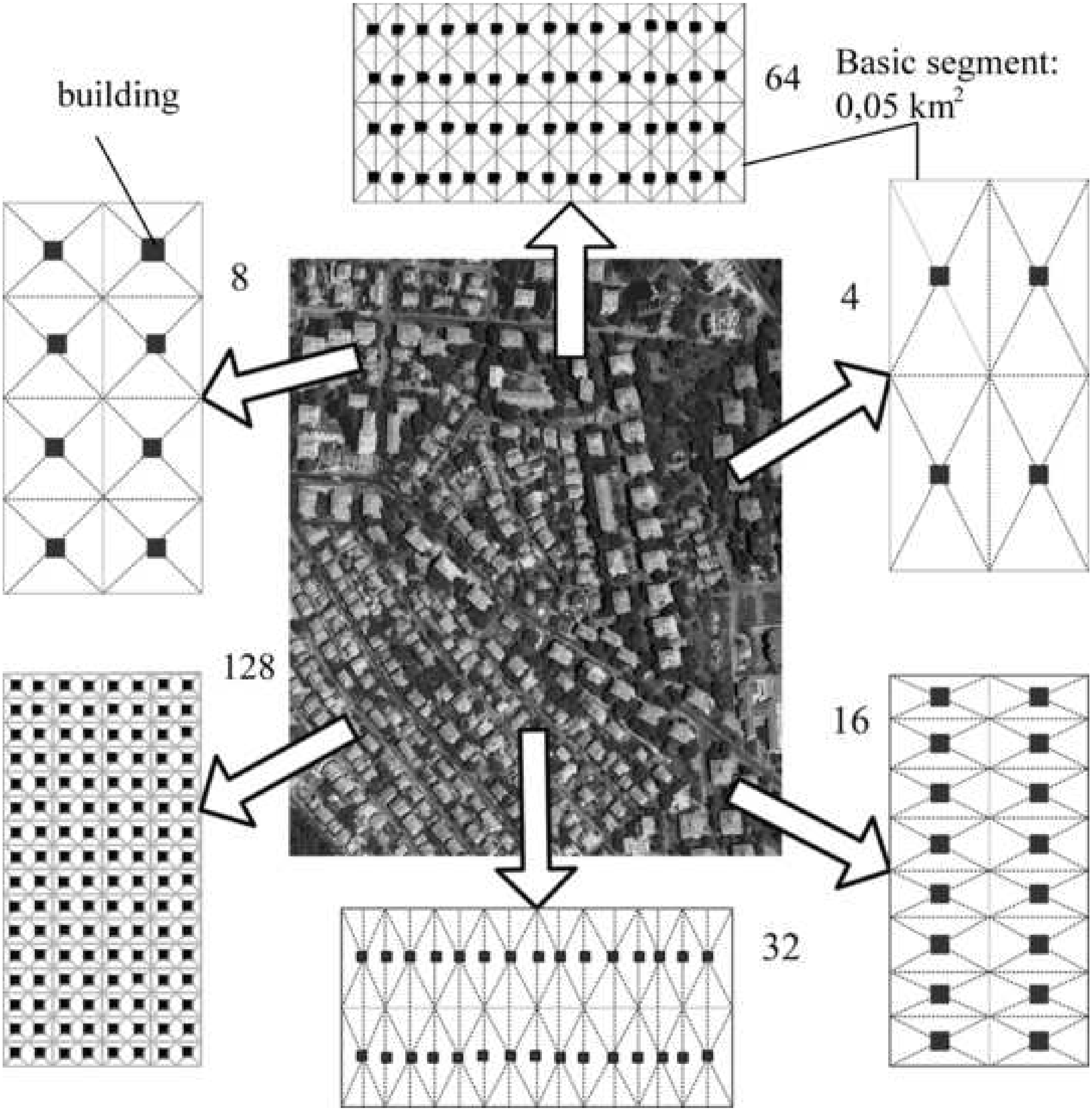

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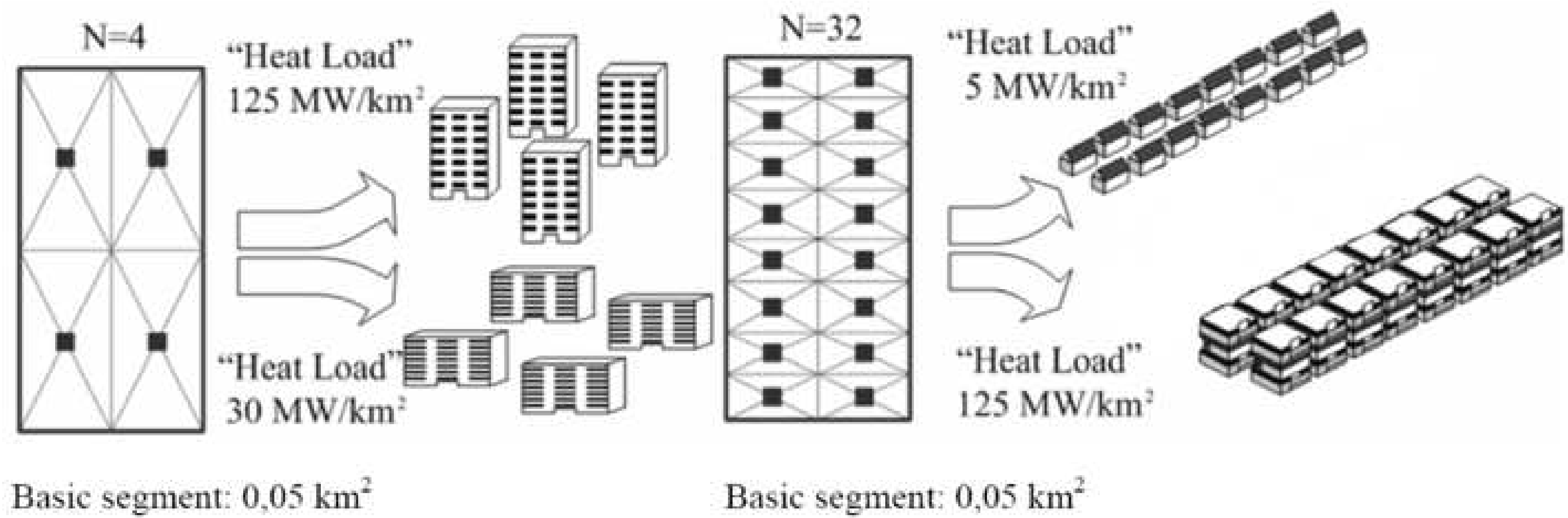

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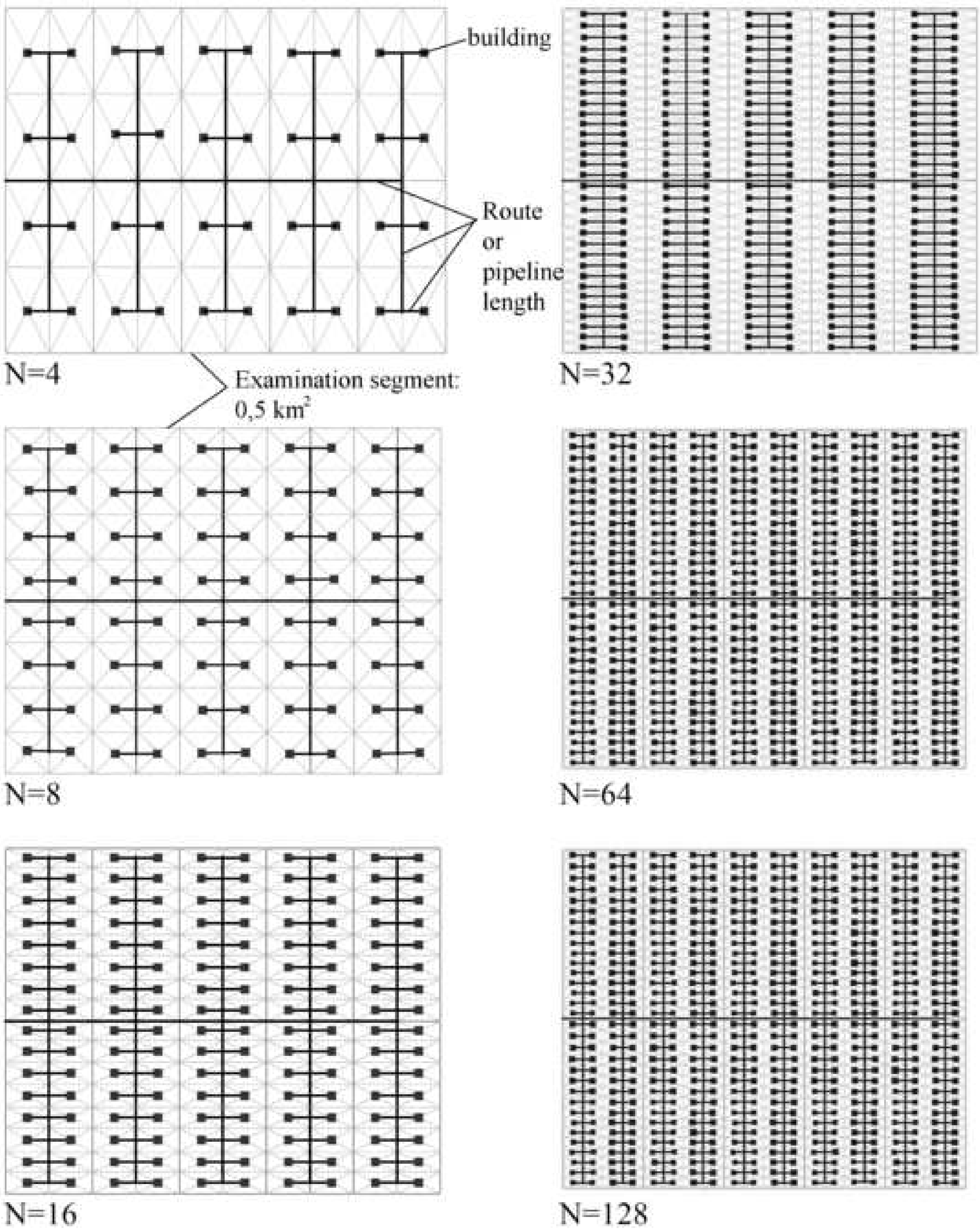

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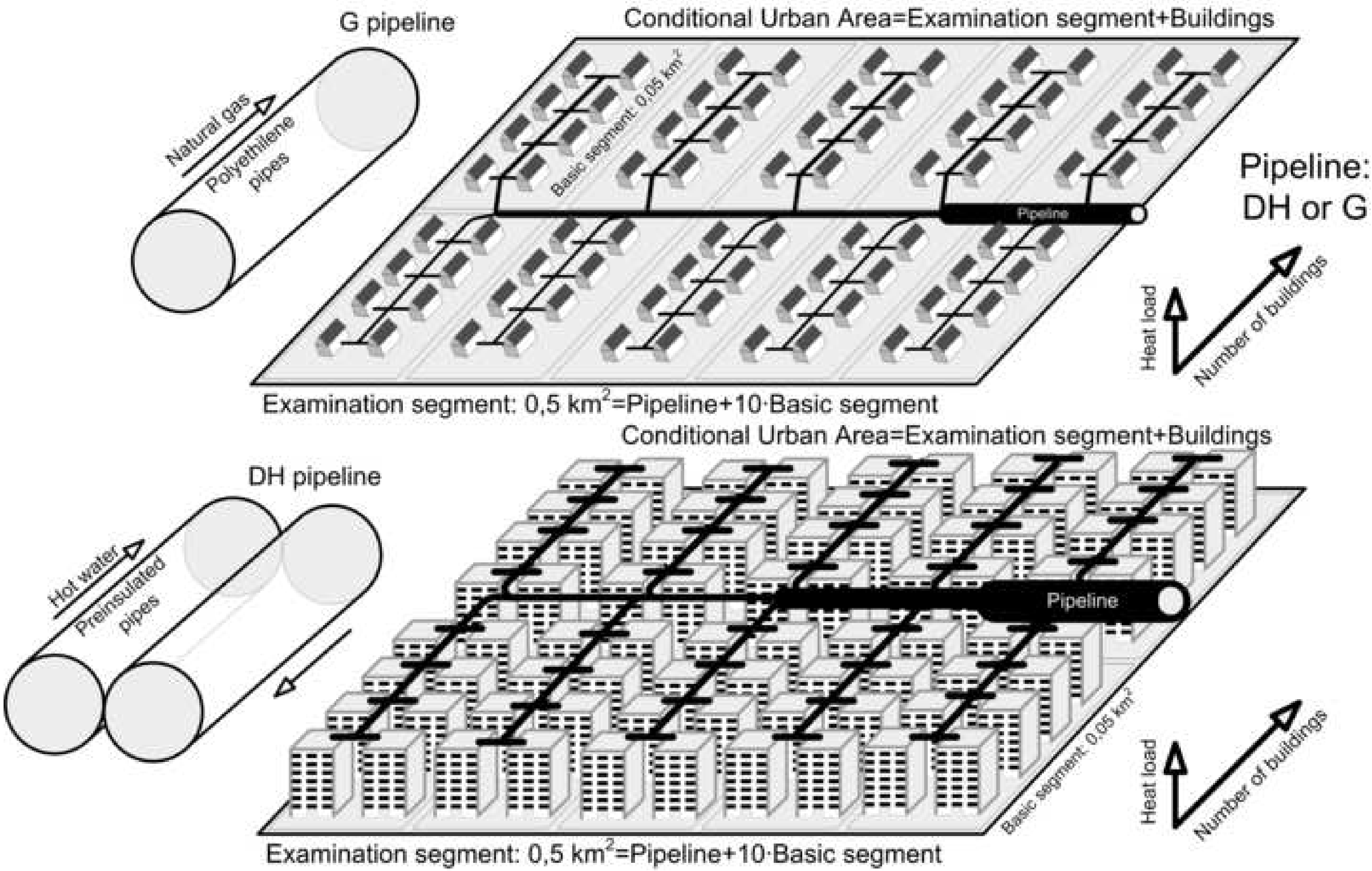

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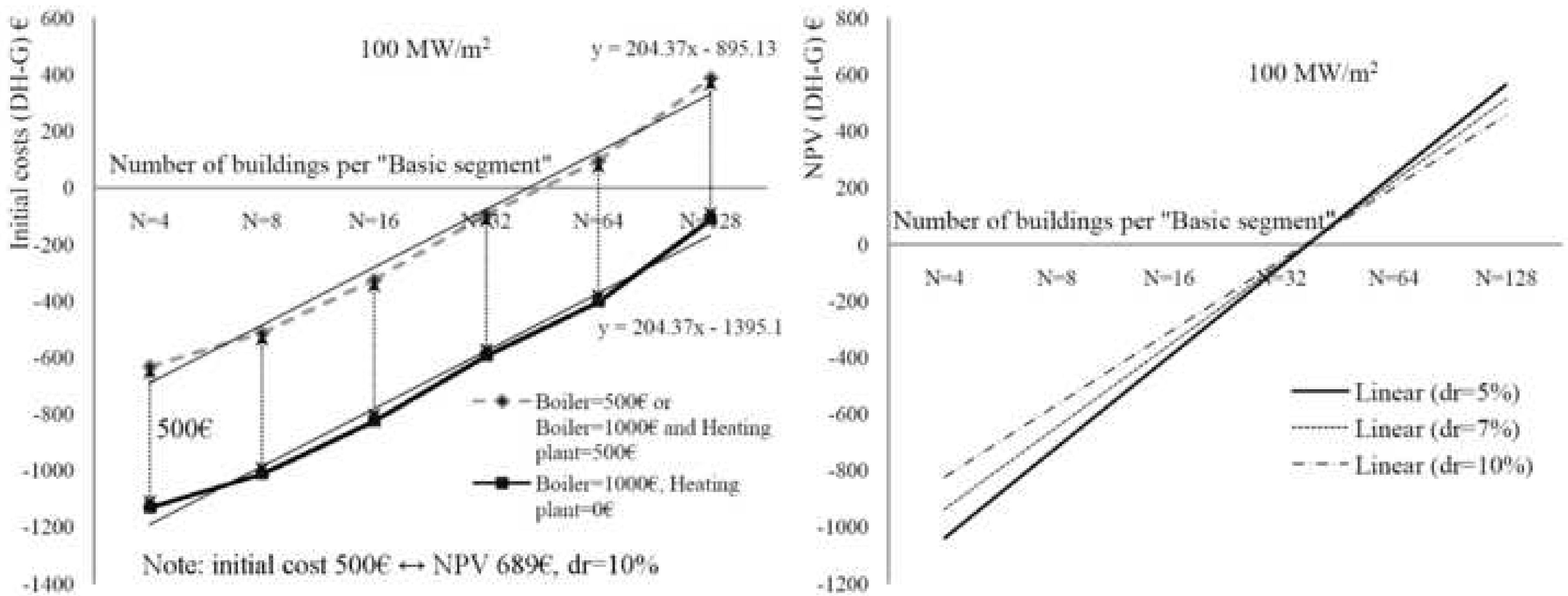

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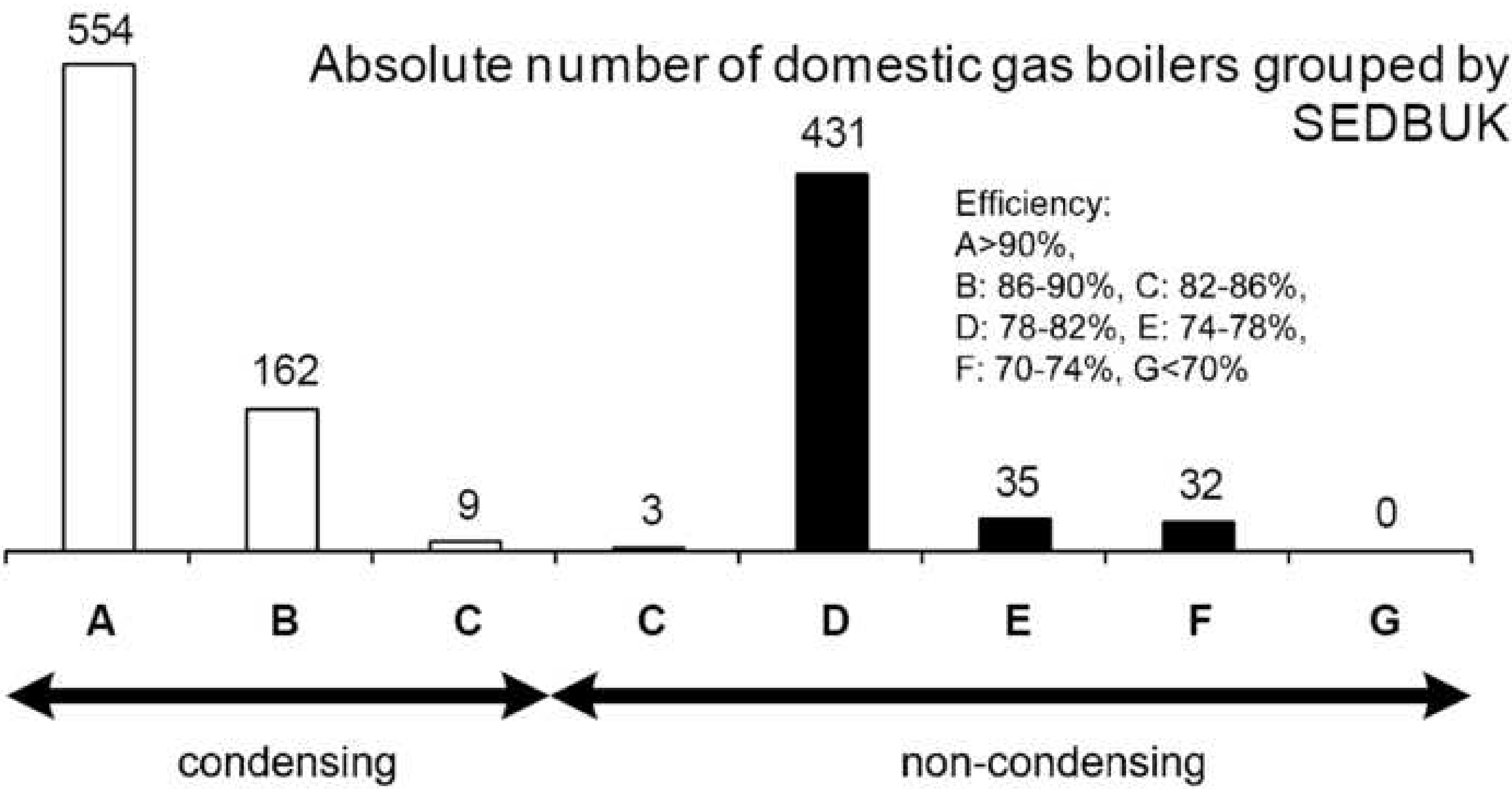

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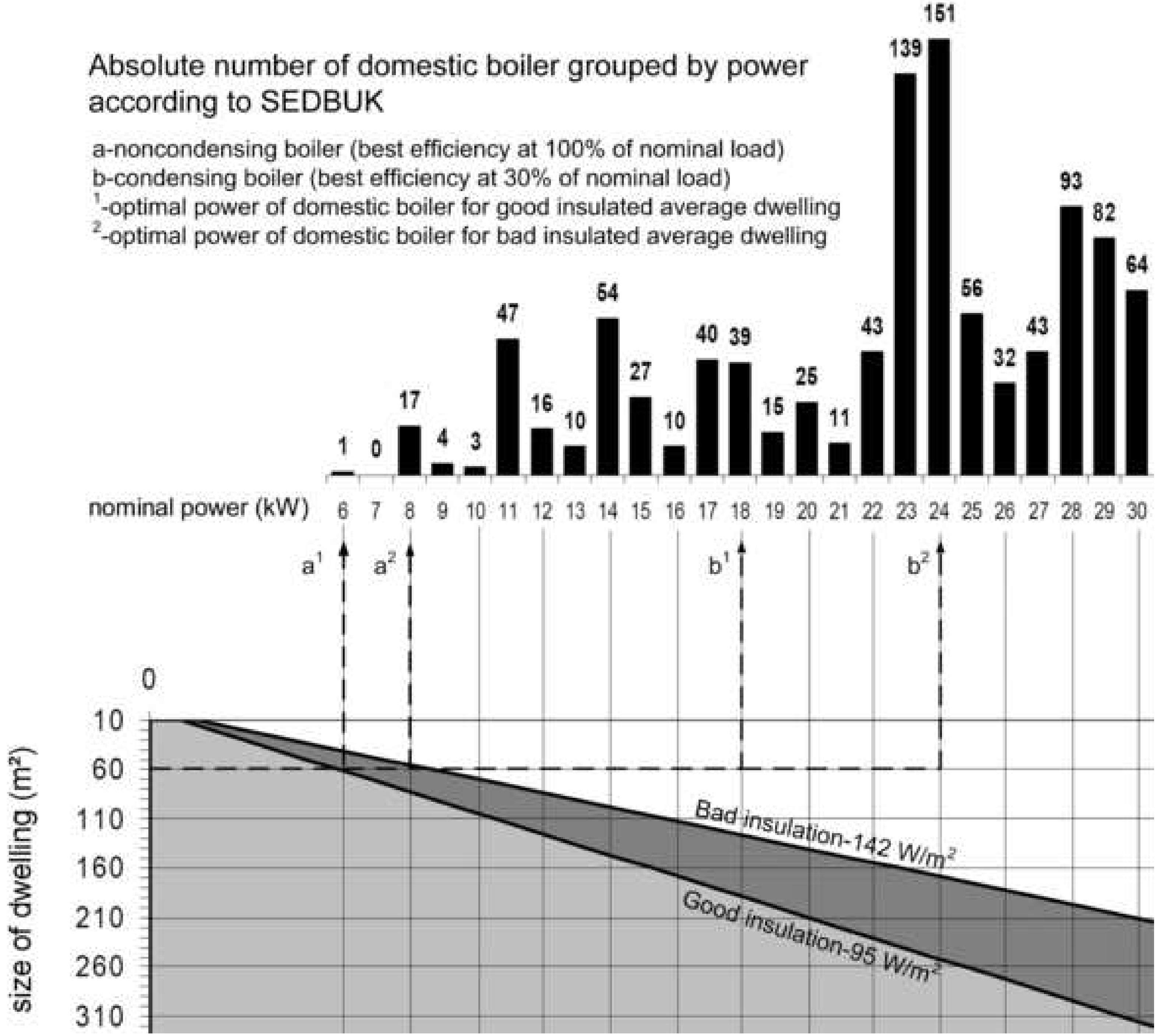

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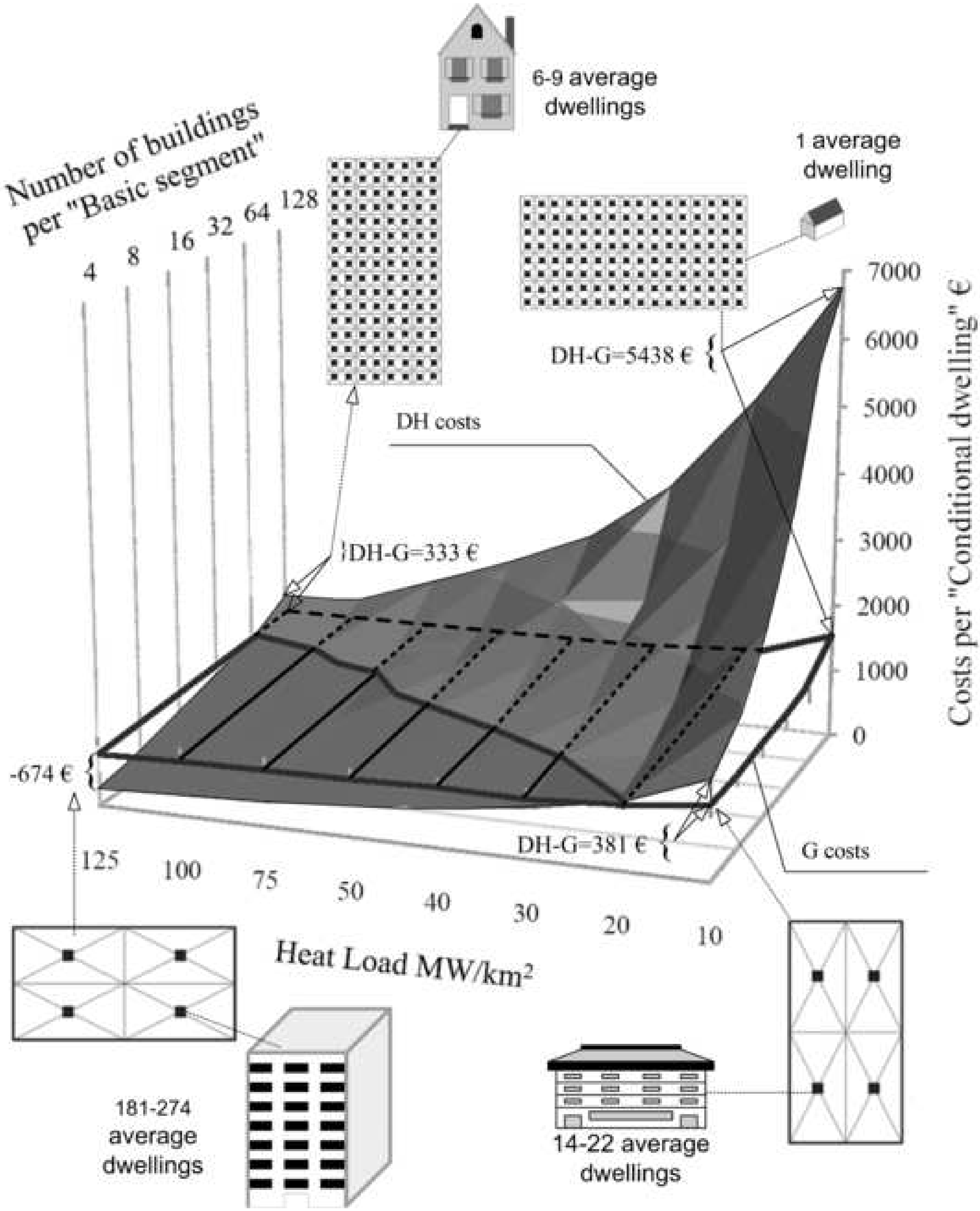

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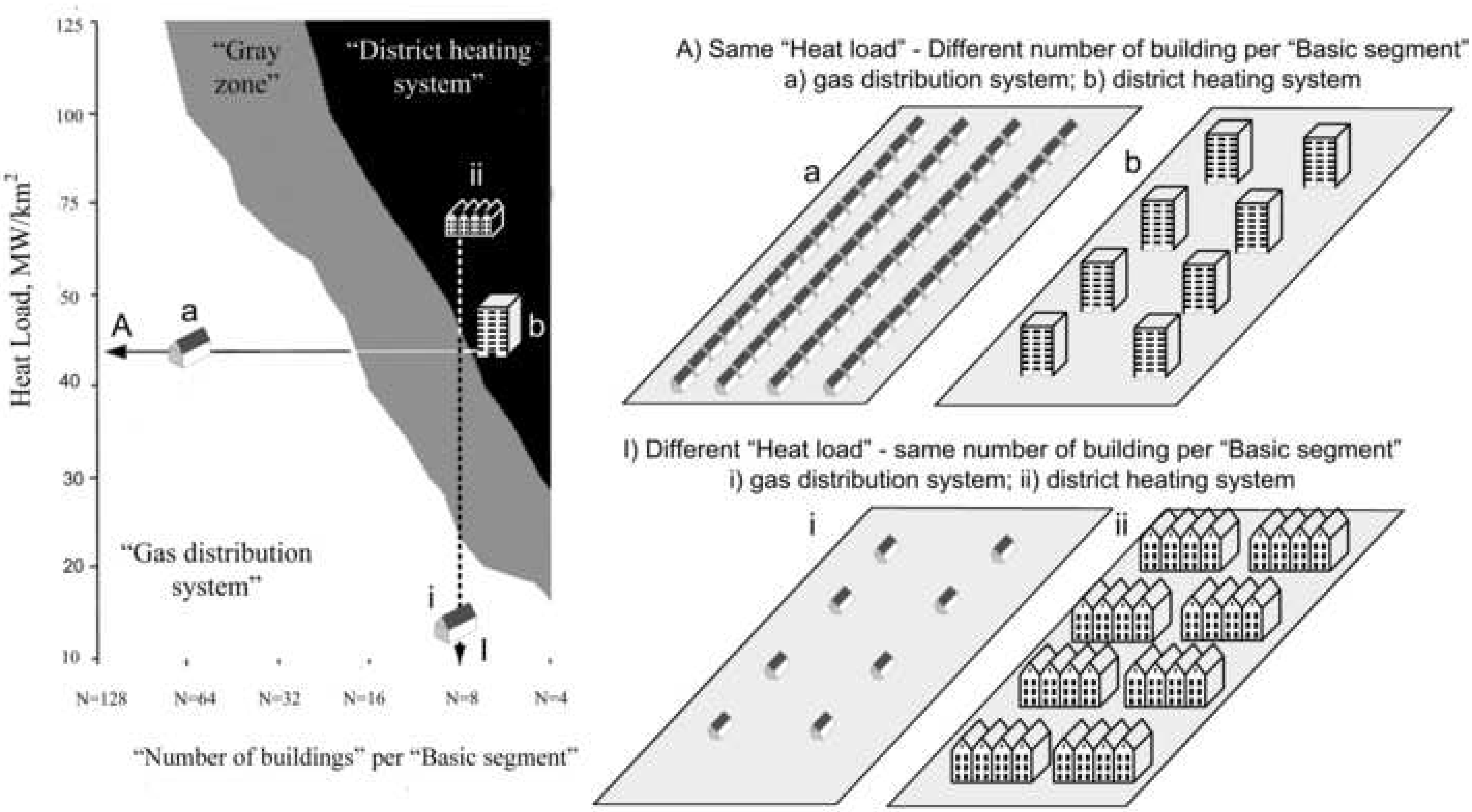

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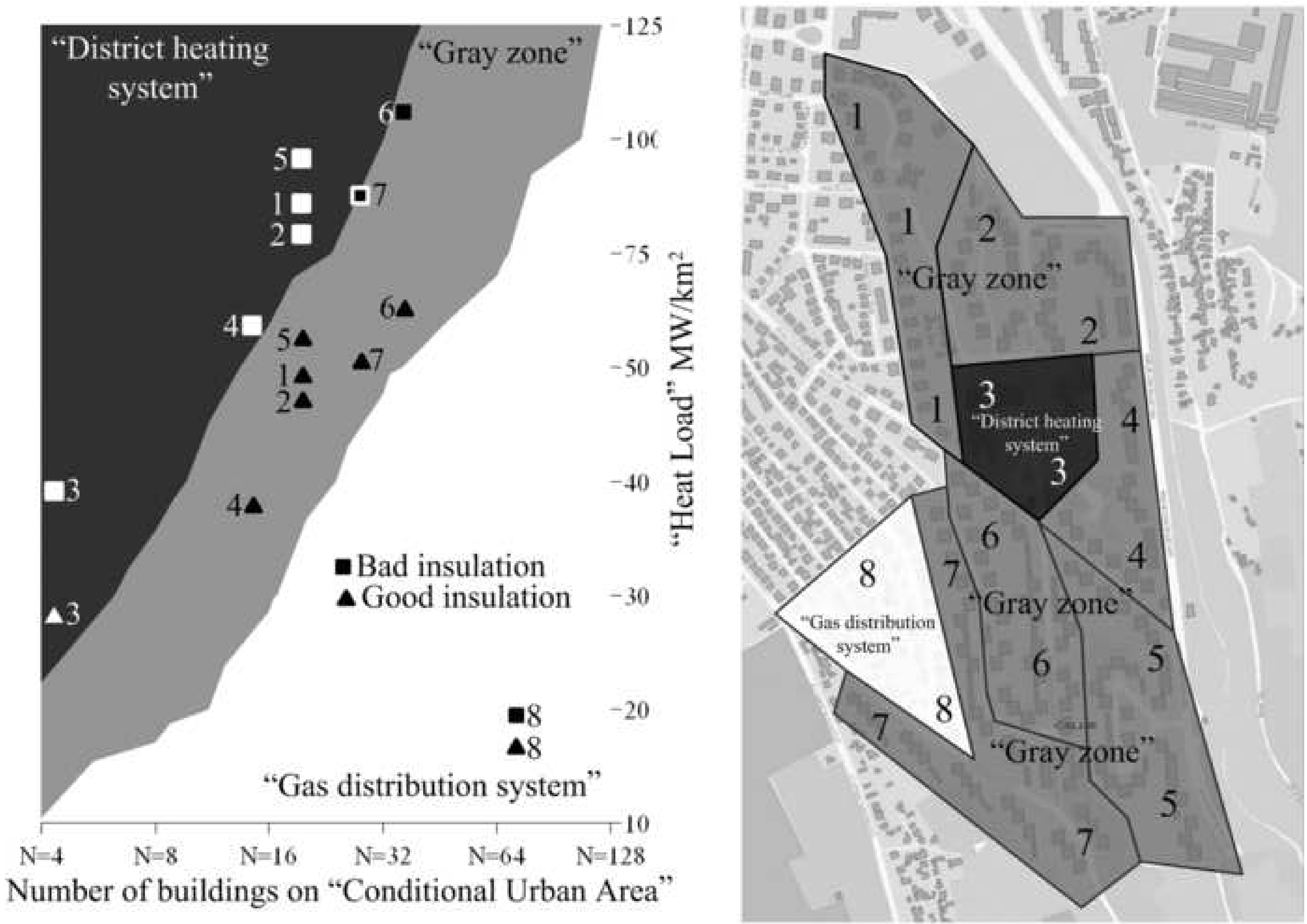

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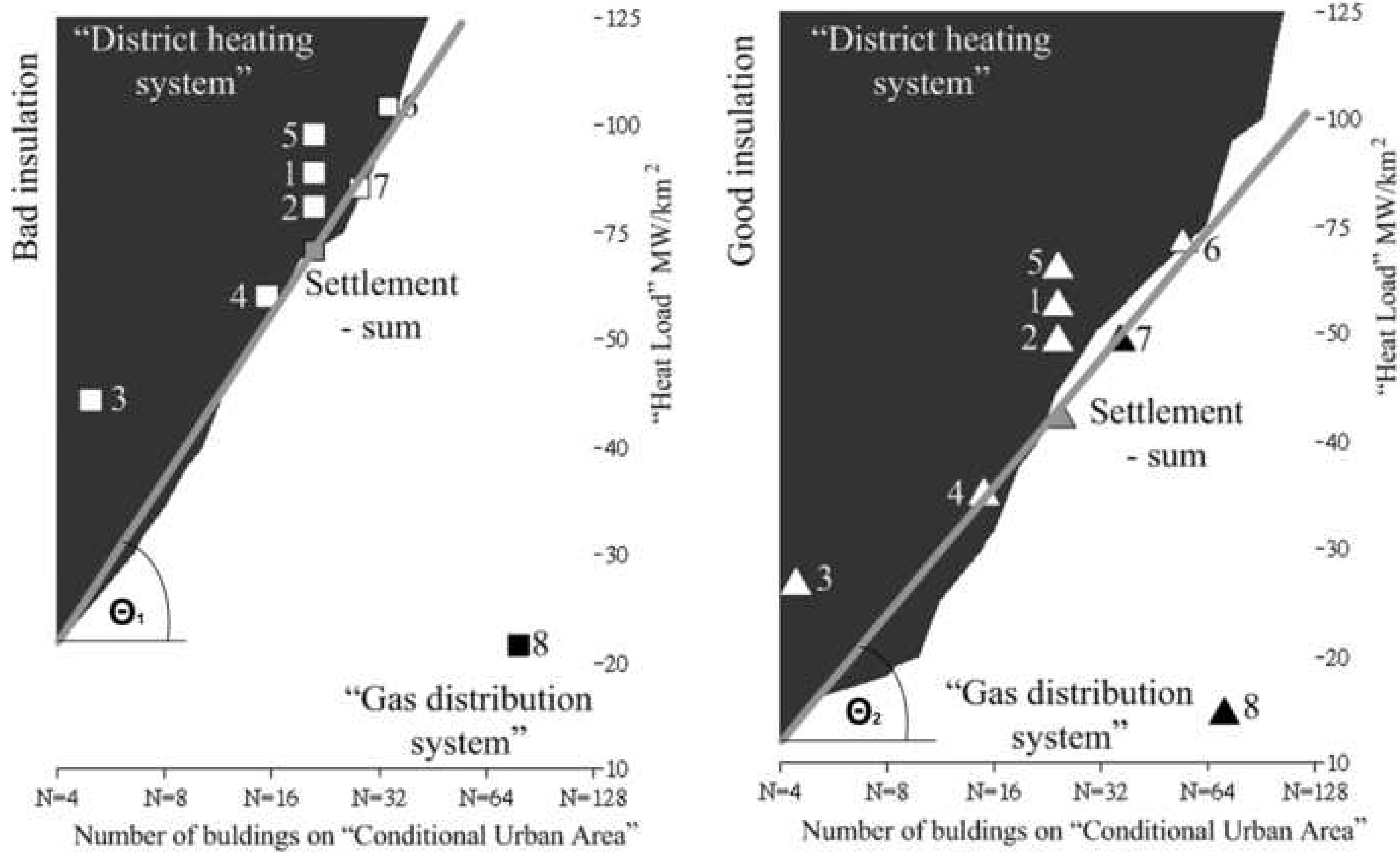

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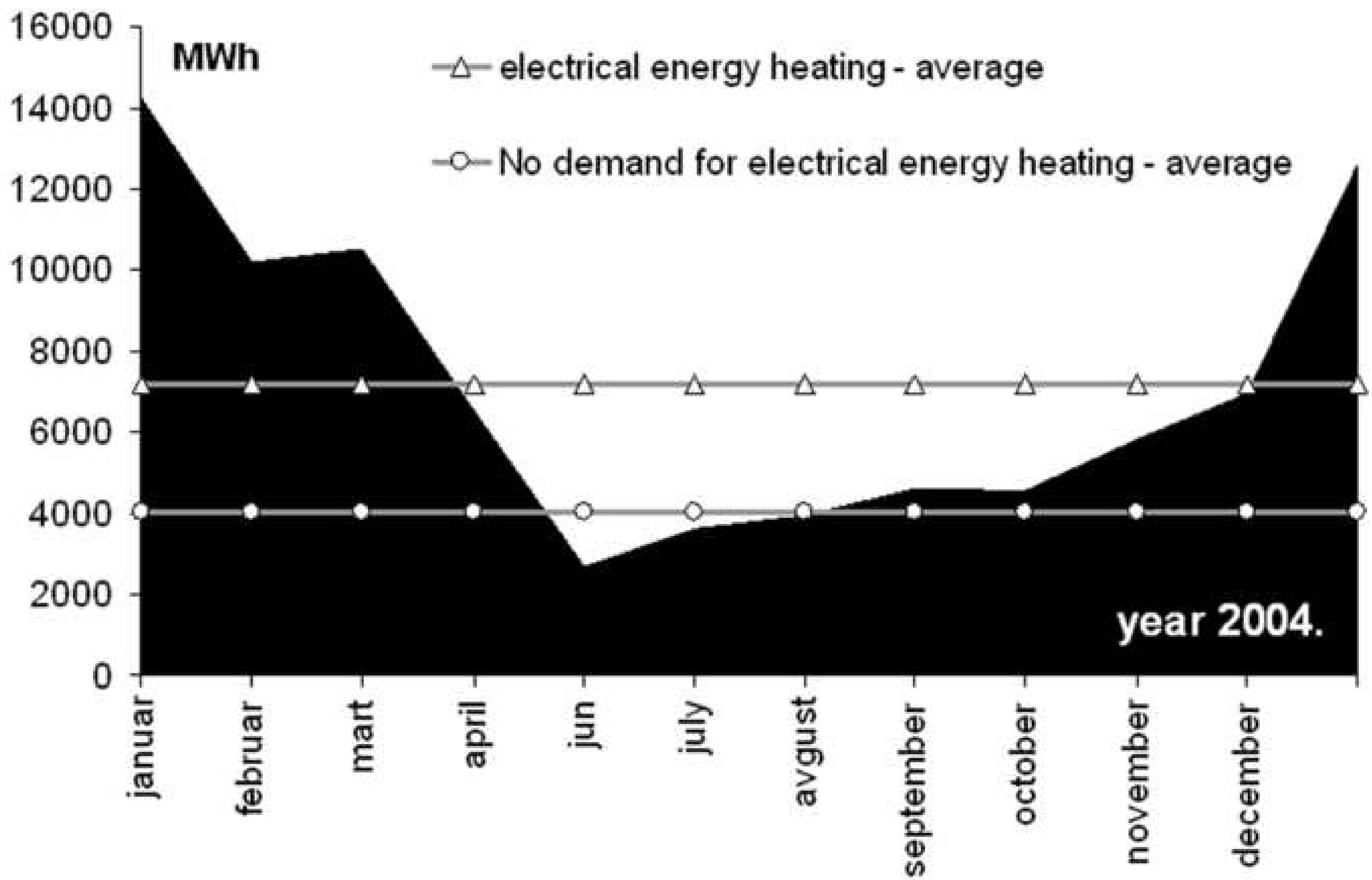

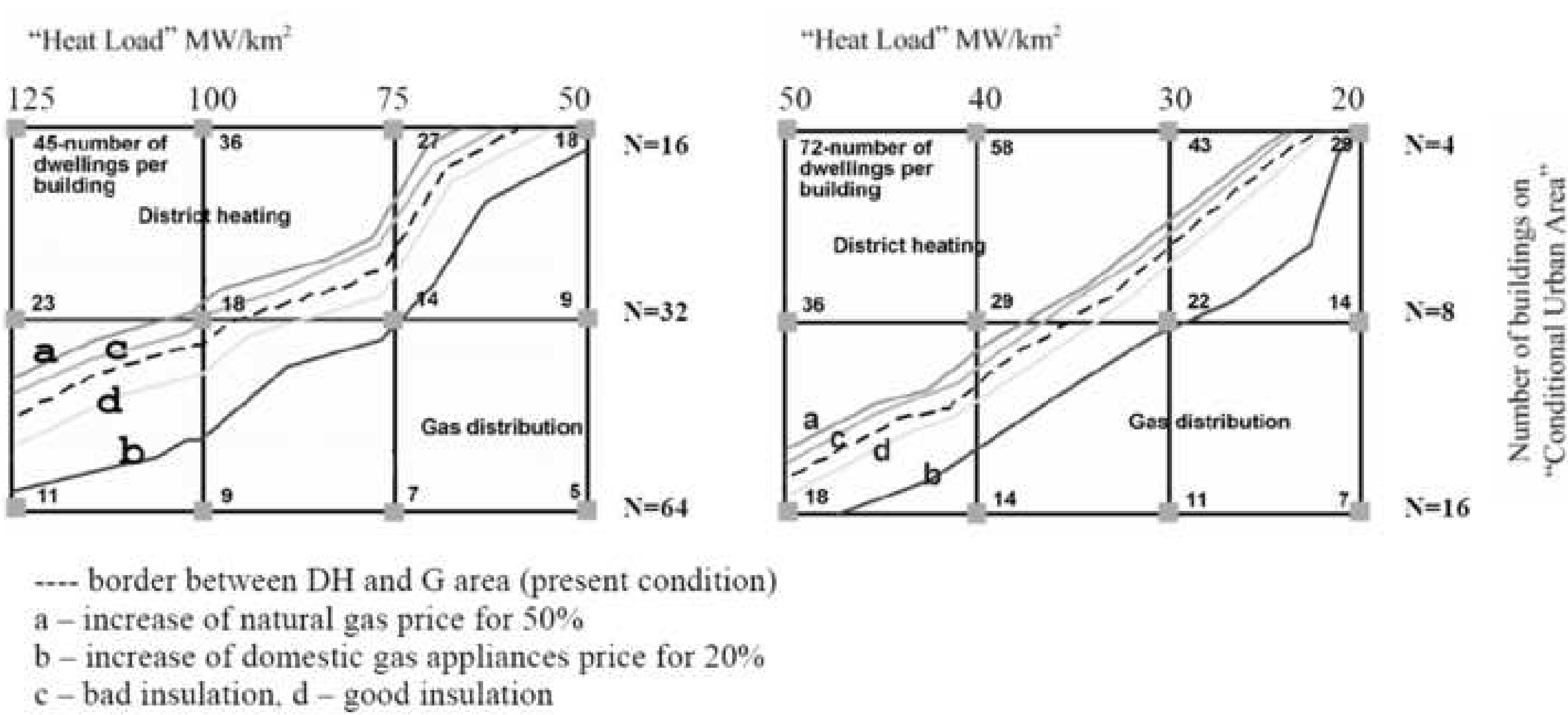
"Heat Load" MW/km²
125
100
75
50
45-number of dwellings per building
36
27
18
N=16
District heating
23
18
14
9
N=32
a
c
d
b
Gas distribution
11
9
7
5
N=64
"Heat Load" MW/km²
50
40
30
20
72-number of dwellings per building
58
43
29
N=4
District heating
36
29
22
14
N=8
a
c
d
b
Gas distribution
18
14
11
7
N=16
Number of buildings on "Conditional Urban Area"
---- 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

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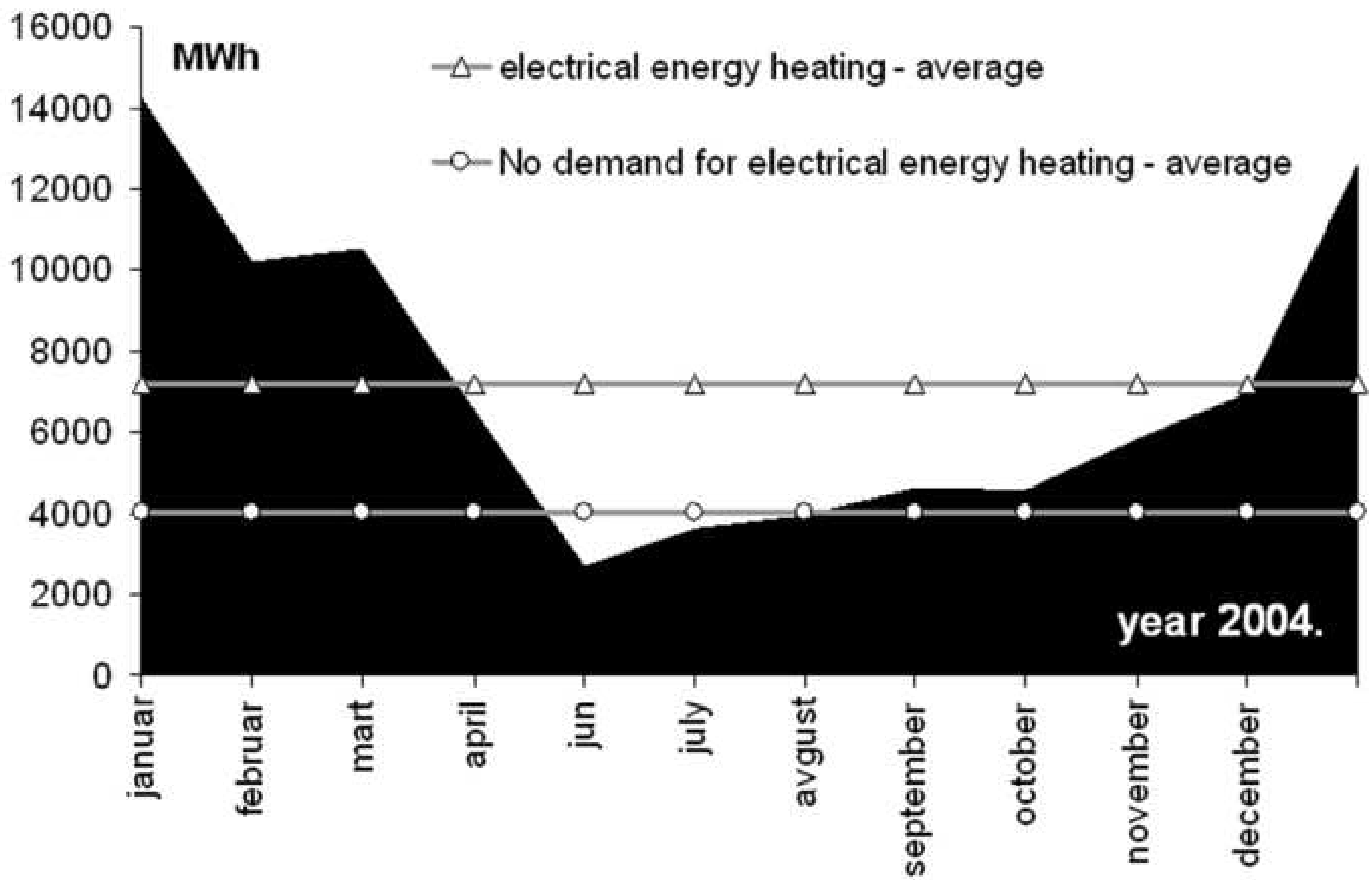

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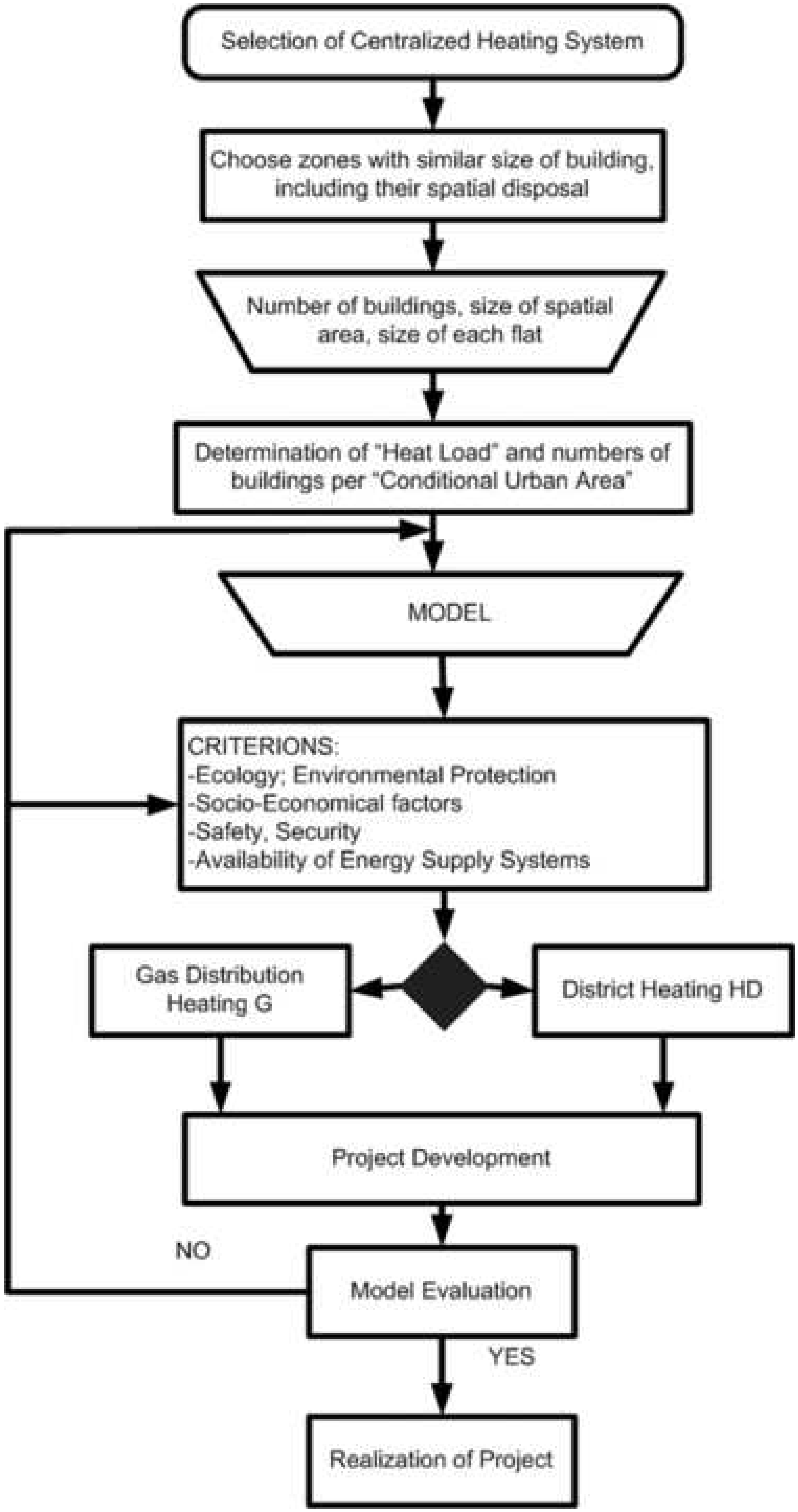

Table(s)

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

Number of buildings – N per basic segment									
		"Heat Loads", $MW \cdot km^{-2}$							
	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]

[a]Good insulated dwelling, [b]Poor insulated dwelling
[c]274 good insulated dwellings per building, 4 buildings per "Basic segment"
[d]less than 1 average dwelling (<60 m^2) per building; poor insulated, 128 houses per "Basic segment"

Table(s)

Table 2

Structure of pipe diameters for one of the cases (example)

Number of buildings – N=8 per basic segment – bad insulation (example; 1 of 96 cases), pipe length 6676.25 m for G, and (2·6676.25)= 13352.5 m for DH																
	“Heat Loads”, $MW \cdot km^{-2}$															
	125		100		75		50		40		30		20		10	
Pipe diameter [mm]	DH	G	DH	G	DH	G	DH	G	DH	G	DH	G	DH	G	DH	G
25	0	0	0	0	0	3200	0	3200	0	3357.5	0	3987.5	0	4302.5	6400	5798.75
32	0	3200	0	3200	0	630	0	787.5	0	945	6400	787.5	6400	1496.25	1575	157.5
40	0	630	0	787.5	6400	157.5	6400	787.5	6400	1260	1575	1181.25	1575	157.5	3150	160
50	0	157.5	6400	630	0	787.5	1575	1181.25	1575	393.75	0	0	1575	160	787.5	160
63 (G); 65 (DH)	6400	787.5	0	945	1575	1181.25	0	0	1575	0	3150	160	2362.5	0	320	320
75 (G); 80 (DH)	1575	1102.5	1575	-	1575	0	3150	160	2362.5	160	787.5	160	320	320	320	80
90 (G only)	-	78.75	-	0	-	160	-	0	-	160	-	0	-	160	-	0
110 (G); 100 (DH)	3150	160	3150	160	2362.5	0	787.5	160	320	160	320	320	320	80	640	0
125	787.5	0	787.5	0	0	160	320	160	0	160	320	80	320	0	0	0
140 (G); 150 (DH)	0	0	320	160	320	0	320	160	320	80	320	0	480	0	160	0
160 (only G)	-	160	-	0	-	160	-	80	-	0	-	0	-	0	-	0
180 (only G)	-	0	-	160	-	240	-	0	-	0	-	0	-	0	-	0
200	320	160	320	160	640	0	640	0	800	0	480	0	0	0	0	0
225 (only G)	-	160	-	80	-	0	-	0		0		0	-	0	-	0
250	320	80	320	0	320	0	160	0	0	0	0	0	0	0	0	0
300 (only DH)	320	-	320	-	160	-	0	-	0	-	0	-	0	-	0	-
350 (only DH)	320	-	160	-	0	-	0	-	0	-	0	-	0	-	0	-
400 (only DH)	160	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-

Table(s)

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

[a]see Table 4

Table(s)

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

[a]Year of project,
[b]District heating pipeline and construction of new heating plant, [c]Heat exchanger, [d]District heating system maintenance, [e]Cost for additional gas (10%), [f]Cost for electrical energy
[g]Gas Distribution pipeline, [h]Cost for regulation station, [i]Cost for household connection set, [j]Cost for Gas Boiler (variant I-price of domestic boiler is 500€), [k]Gas distribution system maintenance
[l]one of cases shown in Table 5., [m]one of cases shown in Table 6.

Table(s)

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

[a]DH-G (see eq. 1 and 2 and Table 3)

[b]Number of buildings per 0,05 km^2 ("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

[c]Price 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%;

[d]Example from Table 2, [e]NPV (**II**)–NPV (**I**); dr=10%

Table(s)

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**
	5%	-1,010	-946	-870	-679	-576	-371	-34	529
N=4	7%	-911	-852	-784	-609	-517	-329	-22	499
	10%	-802	-749	-689	-532	-451	-283	-9	467
	5%	-846	-757	-624	-378	-223	34	243	1,161
N=8	7%	-763	-682	-562	-337	-196	38	233	1,078
	10%	-671	-599	-492	-291	-166	42	223	985
	5%	-573	-462	-262	-23	174	472	822	2,357
N=16	7%	-516	-416	-234	-15	166	437	761	2,168
	10%	-454	-364	-203	-5	157	398	695	1.959
	5%	-197	-111	16	446	762	1,229	1,999	4,336
N=32	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
	5%	79	196	441	891	1,664	1,722	3,211	7,103
N=64	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
	5%	584	657	1,305	1,858	2,642	3,931	5,971	8,062
N=128	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

[a]see eq. 3.
[b]Variant I-gas boiler price: 500€ (see Table 5)
[c]Value of "Discount Rate"
[d]Example from Table 4

Table(s)

Gas distribution system vs. District heating system

Note: calculations are in hidden layers

INPUT PARAMETERS (edit only green cells)			
Investments per dwelling	€	ear-replacemen	% 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	m³/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	€/m³ (here is equal price for gas in both system for Energy read	
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 read

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

N/0.05km² \ MW/km²	125	100	75	50	40	30	20	10
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"

N/0.05km² \ MW/km²	125	100	75	50	40	30	20	10
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"

N/0.05km² \ MW/km²	125	100	75	50	40	30	20	10
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