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Methodological Approach to Determining the Effect of Parallel Energy Consumption on District Heating System

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Abstract – **District heating (DH) offers the most effective way to enhance the efficiency of primary energy use, increasing the share of renewable energy in energy consumption and decreasing the amount of CO_2 emissions. According to Article 9 section 1 of the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, the Member states of the European Union are obligated to draw up National Plans for increasing the number of nearly zero-energy buildings [1]. Article 2 section 2 of the same Directive states that the energy used in nearly zero-energy buildings should be created covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. Thus, the heat distributed by DH systems and produced by manufacturing devices located in close vicinity of the building also have to be taken into account in determining the energy consumption of the building and the share of renewable energy used in the nearly zero-energy buildings. With regard to the spreading of nearly zero-energy and zero-energy houses, the feasibility of on-site energy (heat and/or electricity) production and consumption in DH areas energy (i.e. parallel consumption, when the consumer, connected to DH system, consumes energy for heat production from other sources besides the DH system as well) needs to be examined. In order to do that, it is necessary to implement a versatile methodological approach based on the principles discussed in this article.**

Keywords – **District heating; energy efficiency; parallel consumption; sustainable energy**

1. INTRODUCTION

Parallel consumption is a situation wherein the heat consumer connected to the DH system also consumes heat produced by other energy sources.

Feedback from the DH systems' operators indicates that more and more consumers in DH areas are starting to install and use individual heating solutions, giving preference to solar heat collectors or heat pumps. There are two main factors causing this trend: relatively high prices of heat in some DH areas due to high share of fossil fuels in DH systems and the governmental support programs for increase of energy efficiency in demand sector (mainly residential buildings renovation).

The reduction of energy consumption by buildings due to renovating the envelope elements, heating and ventilation systems, is important and to be expected. This factor is taken into account while planning the heating grid, by dimensioning the renovated heat grids and the choosing of the optimum capacity for new production equipment. The problem is that during renovations, other heat energy sources sometimes are implemented, thus reducing the heat consumption from the DH system. E.g. electricity may be used for heat production in heat recovery ventilation systems using

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a heat pump or conventional air-to-water heat pumps as well as solar collectors for domestic hot water preparation during the summer.

As a result, the heat demand in residential buildings significantly decreases, and it can come into conflict with sustainability of the DH sector. The feasibility of implementing parallel consumption (if the heat consumer consumes heat produced from other energy sources) needs a diverse, methodological approach, considering mainly the increase in specific heat losses of DH systems due to the decrease in consumption and also the increase in prices.

There are various researches focusing on DH modelling as well as technical and environmental aspects concerning the impact of heat demand reducing due to rising energy efficiency in buildings. Some of them a briefly described below.

Aberg and Henning [2] developed optimisation model for the investigation of the impact of heat demand reduction on heat and electricity production in the Linkoping DH system. Continuing the research scientists developed four models of typical DH systems to represent the Swedish DH sector for studying heat demand reductions due to building energy efficiency improvements [3]. The aim of the research was to analyse the sensitivity of DH systems in terms of CO_2 emissions, heat production and electricity co-generation.

Gustavsson et al. [4] showed that the energy savings of the demand side in combined heat and power (CHP) based DH network, reduce the profitability of electricity production, using Ostersund DH system (Sweden) as a reference system. Sperling & Moller [5] studied the impact of the heating demand reduction on the DH supply cost, fuel costs and CO_2 costs. Conclusion indicated that DH planning in Denmark has to be approached more strategically in the near future. Ziemele [6] analysed the development of DH system in case of decreased heating loads by modelling the scenarios for different temperature regimes. The main conclusion was that the decrease in total heat consumption in case of energy efficient buildings significantly increases the specific costs of DH system.

Mentioned researches were focused on the heat demand reduction aspects. Heat demand reduction in DH system is one of the main risks to DH sustainability, caused by parallel consumption and it can lead to numerous problems, such as:

- The share of network losses in total heat output increases, since the heat supplier has to ensure that the temperature and flow rates of the DH are as intended [7]. It causes the rise of heat distribution costs [8]. The DH system has to be able to cope with winter peak loads, but it makes the system ineffective in long term;
- The effectiveness of centralized heat sources (CHP, biomass boilers) decreases and the operation can become no longer economically feasible. It is even not possible to keep the device working in operation regime when heat load is below the required minimum;
- Summer DH heat load is reduced or even excluded due to the parallel consumption based on solar panels and heat pumps, but winter heat load peaks remain relatively at the same level. When heat load is low or not at all, CHP has to operate in condensation regime;
- CHP have to operate longer time with partial loads, when electrical energy efficiency coefficient reduces, resulting in increasing of CHP electricity-to-heat ratio;
- The sales volume of DH producers is reduced and thus it can lead to an overall raise in the costs needed to supply the consumer with energy.

And furthermore there are other possible negative impacts of parallel consumption on DH. Detailed list of possible impacts is presented below:

- Efficiency of CHP, producing heat in DH, can be reduced, because of the decrease in the production of flue gas condensers and the decrease in the electrical efficiency factor of the CHP heat plants [7];

- Parallel consumption with heat pumps increases the consumption of electricity. When electricity is produced on fossil-based rising fossil fuel consumption, it can lead to rise of CO_2 emissions in energy sector;
- Air pollution increases in case of parallel consumption implemented using local boilers. The concentration of pollutants in the air is lower when centralized heat source is used for heat production. Besides that, the rules for environmental pollution are stricter for bigger equipment in comparison to individual heating devices.

Heat demand reduction and other possible negative impacts, mentioned above, can lead to DH becoming unsustainable and unprofitable, when apartment buildings should use an additional heat source in order to fulfil the need for heat during winter peaks. This could be done via direct electric heating or in-site boiler. Creating new electrical and thermal capacity in order to cover only the peak loads is definitely not reasonable from the viewpoint of the state. So negative impacts to DH in a long term perspective resulted by reduction of DH heat consumption are well studies and an appropriate methodologies and models are proposed. At the same time there was no interdisciplinary methodologies found which describes impacts total impacts both for DH systems (heat engineering) and buildings/consumers (civil engineering). The main task of this study is to provide a base guidelines and directions for a new methodological approach to be used for evaluation of parallel consumption synergy impacts on DH system and consumers in general. Expected implementation fields and probable tasks to be solved by using this approach are analyzed. The article also gives an overview of the problems associated with parallel consumption and the impact this has on DH system.

2. METHODOLOGY

Building smart is building according to the local climate by using passive design measures to increase energy efficiency in an integrated design. After using passive design measures the next step is the adequate and resource oriented integration of technical and renewable energy systems where building optimizations mainly comes first. Selected solutions should be easy to maintain and use, healthy, good for the environment and affordable for the user.

While designing new or renovating old buildings the same energy performance indicator (EPI) can be achieved using different techniques, technologies and their combinations (integrated technical energy solutions, hereinafter ITES) where selection process is mainly performed from the perspective of the user (building). So ITES consists of architectural design, selection of building construction materials (including insulation type, thickness of insulation, *U*-values for windows and so one) and HVAC solutions. ITES covers all technical solutions which has an effect on building energy consumption (energy sources and amounts for every energy source).

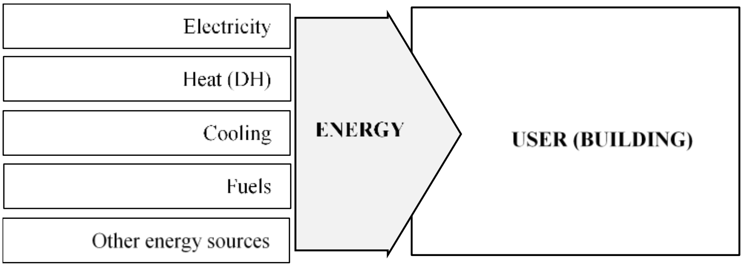

Fig. 1. Scheme of energy consumption from the perspective of the user (building).

EPI is mainly based on numerical indicator of primary energy use expressed in kWh/m^2 per year, where primary energy is an energy used multiplied by primary energy factors which may be based on national or regional yearly average values (see Fig. 1) and may take into account relevant European standards [1]. So EPI depends on used energy sources and implemented ITES. Solutions used to achieve energy efficiency in the building connected to bigger external systems (located outside building boundaries such as electrical networks and DH systems) will effect on those systems differently. Synergy effect can be positive, neutral and even negative.

The core idea for proposed methodology for determining the effect of parallel consumption on DH systems is to extend the selection process of ITES used for achieving certain EPI from the perspective of the user (building) to the larger systems scale. In the case of DH expand evaluation to DH area scale where DH area includes DH system (heat production and distribution) and users/consumers (mainly buildings), see Fig. 2. Energy outflows from the system mainly will depend on electricity production and selling to the grid during CHP production, if any.

Extending the evaluation process to DH area scale will help to identify those ITESs (to achieve expected energy efficiency of the building) which maximise synergy potential between DH system and users and avoid implementation of ITES with a small or negative impacts on the large system levels.

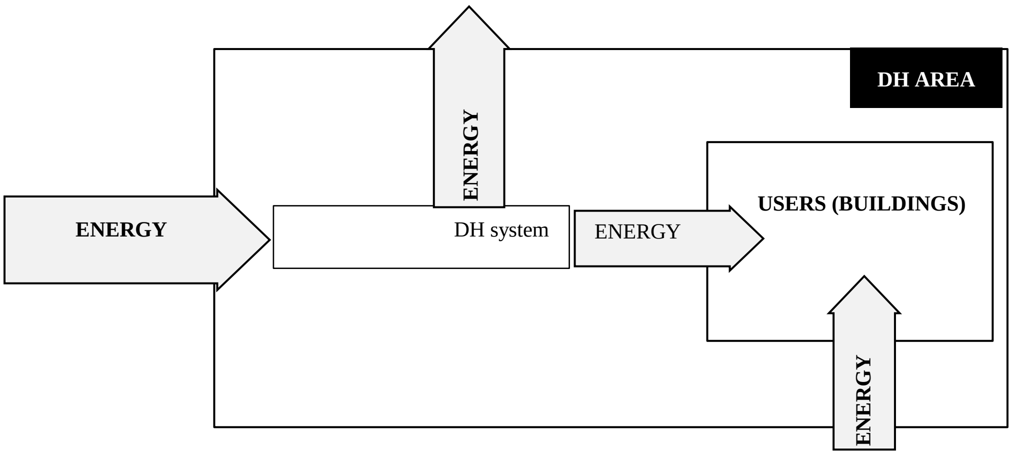

Fig. 2. Scheme of energy consumption from the perspective of the DH area.

To compare different ITESs for reaching expected EPI the basic DH area conditions should be defined (basis for comparison). Basic conditions include both definition of users and DH system. After that changed conditions can be applied (alternative ITESs to achieve the same EPI as for basic conditions). It will be possible to check how will act DH system in a new user consumption conditions in term of environmental impacts, primary energy consumption and total energy costs for users.

2.1. Basic DH Area Conditions

Definition of DH area basic conditions should be started from the user (consumer) side.

Users/consumers. Real DH network consists of numerous consumers with a different EPIs, energy consumption profiles and integrated technical solutions. To simplify the calculations a tentatively averaged or more commonly used building type (user/consumer) located in a specific

DH area should be defined and used for further evaluations. It is reasonable to select ITESs without or with a minimal parallel consumption (heat delivered from the grid, no local heat production from external energy sources exists). This is valid for parallel consumption evaluation both for new planed users/consumers and existing building to be renovated.

Basic user/consumer related calculations should include heat demand and profile, electricity demand, how heat and electricity demands are covered (purchased from the external systems, recovered, etc.) as well as the cost estimation for implementation of ITES to reach expected EPI. In the case of renovation of existing buildings it is reasonable to simulate return DH temperature profile. User (building) model can be performed by using different software like *EnergyPlus*, *eQUEST*, *ESP-r*, *DeST* [9]–[13]. One of the modelling examples can be found in [7] where typical 5-story large panel apartment building from the period 1960–1980 was chosen to do energy simulations with dynamic simulation model IDA-ICE 4.7.

DH system. Composition and main properties of DH system should be specified. Selection of energy production units (boilers, CHPs, heat pumps, etc.), their capacities, used fuels (natural gas, fuel oil, peat, biomass, etc.), data about supply and return temperatures, composition of energy production costs (fixed costs in EUR and variable costs in EUR/MWh_{heat} for each energy production unit) absolute heat losses in the distribution networks can be selected in accordance with requirements/tasks. As an example, for general evaluation of parallel consumption in a specific country it is reasonable to select DH system properties which are common for this country. It is possible to simulate DH systems with a different sizes by multiplying users/consumers DH heat demand profile the desired number of times (as an example small DH area may have 10 basic users/consumers and more than 1000 for large systems).

2.2. Changed DH Area Conditions

Users/consumers. To evaluate impacts of other ITESs (with higher parallel consumption rate) to reach expected EPI in comparison with basic DH area conditions an updated simulations for user/building should be performed. Updated simulations should reflect the same model outputs as for a basic user/consumer, where reference user/building main technical parameters (parameter which do not depend on selected ITESs to reach expected EPI) are the same. It is reasonable to select alternative ITES with a higher share of parallel consumption in comparison with basic ITES.

Implementation of alternative ITESs (alternatives) will change building energy requirements, energy consumption profiles, investments to achieve expected EPI and may effect on DH return temperature.

DH system. Changes in DH return temperature and DH heat demand profiles and DH heat consumption reduction will effect on DH economic and technical figures in comparison with basic DH area conditions. Evaluation of impacts related to changes on user/building side can be performed differently. Some of the studies mentioned in section 1.1 describe researches and methods which were focused on the heat demand reduction aspects.

2.3. Comparison Principles and Indicators for Comparison

For the clear ITES demonstration of the results, it is proposed to compare how the techno-economic indicators of the DH system and apartment buildings change between conditions when almost all consumers in DH area are renovated/build in accordance to basic ITES (expected, that almost all buildings are renovated without parallel consumption) and minimum (the amount of buildings renovated according to specified alternative ITES is almost 100 %, the usage of basic ITES is near zero).

Such a presumable comparison helps to better understand what advantages the consumers of DH system without or with low parallel consumption will have in comparison to those who have chosen alternative ITES with prevail parallel consumption and what are the disadvantages. In other world what are the consumers of DH system going to pay for and in opposite what are these components in the case of being in an advantageous position in the matter of parallel consumption (Fig. 3).

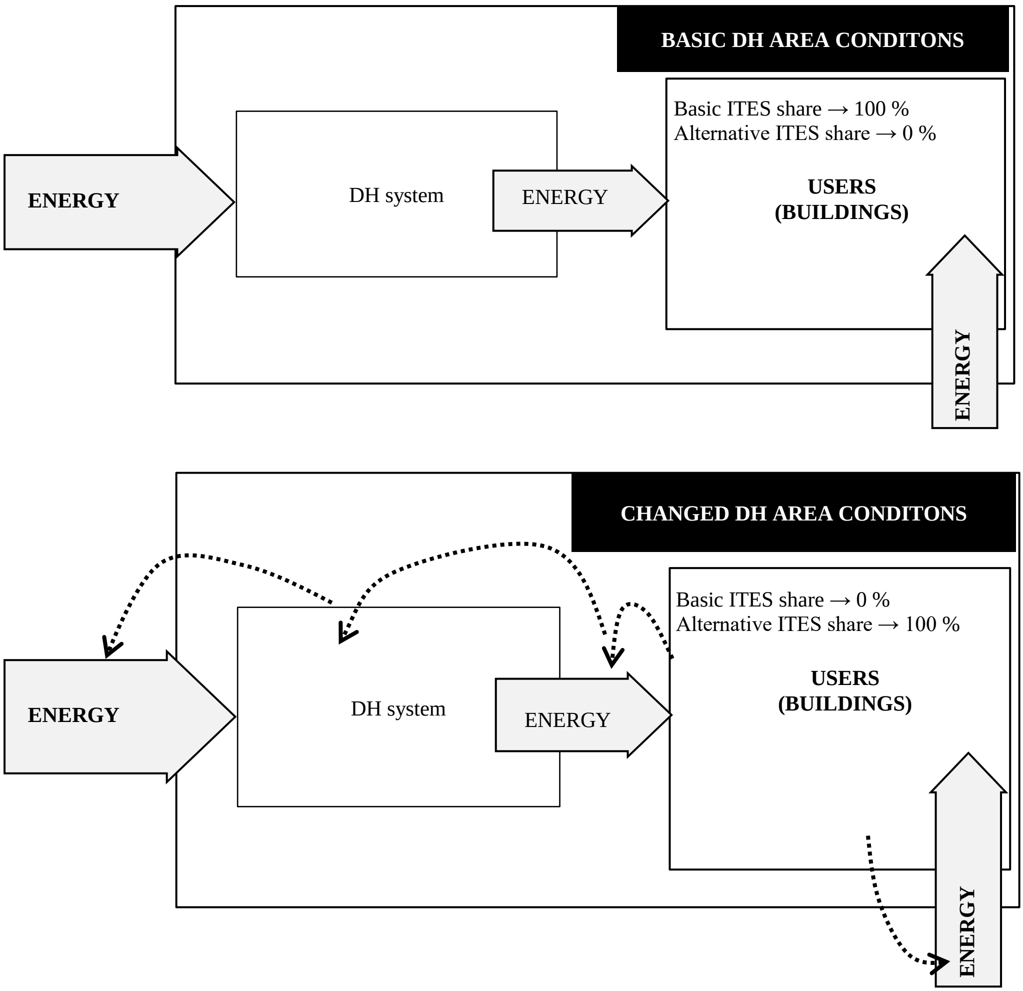

Fig. 3. Comparing principles of the DH system and apartment buildings techno-economic indicators under basic and alternative ITESs.

Calculations for both basic and alternative ITESs taking into account basic and changed DH area conditions allow to highlight short term benefits/drawbacks of parallel consumption solutions (the share of this solution is negligible) and long term impacts (parallel consumptions is used widely).

In order to characterise the differences of the basic and alternative solution and their impact on the DH system, the following core parameters assumed to be calculated and analysed (Table 1). According to DH area specifics and analysis tasks some other parameters for comparison can be used.

TABLE 1. PARAMETERS FOR COMPARISON OF THE BASIC AND ALTERNATIVE SOLUTION AND THEIR IMPACT ON THE DH SYSTEM

Component	Parameters	Units
User/consumers (for basic and alternative solution)	Annual DH consumption	MWh
	Annual electricity consumption	MWh
	CO_2 emissions associated with producing the annually consumed energy (electricity and DH)	tCO_2
	Cost of the purchased energy (electricity and DH)	EUR per year
	Capital costs associated with renovation	EUR per year
	Total cost (purchase of energy and capital costs)	EUR per year
DH system	Relative heat losses in the DH system (for basic and alternative solution)	%
	Change in the structure of heat production costs (variable and fixed costs) the impact of buildings renovated according to alternative 2 on the CO_2 emissions	EUR and %
	The impact of DH on the price of heat, the impact on consuming heat from the DH system	%
	The impact on electricity consumption compared to the basic situation, where all consumers are renovated according to alternative 1	%

To simplify evaluation of electricity consumption impacts is reasonable to evaluate this component if there is a significant change in consumption between basic and alternative ITES. If difference is significant, than it should be used in comparison as an additional costs, energy consumption and environmental impacts component.

3. RESULTS AND DISCUSSION

The article gives an overview of the problems associated with parallel consumption and the impact this has on DH system. The feasibility of implementing parallel consumption (if the heat consumer consumes heat produced from other energy sources) needs a diverse, methodological approach, considering mainly the increase in specific heat losses of DH systems due to the decrease in consumption and also the increase in prices.

The article provides methodology basics and guidelines for evaluation of parallel consumption impacts on DH area level. Proposed approach is interdisciplinary and includes elements from building energy management/efficiency assessment and DH system evaluation models (how DH acts when heat demand is reduced due to energy savings in the buildings). New proposed assessment level is district heating area, which includes DH system (heat production and distribution) and users/consumers (mainly buildings).

Proposed basis for evaluating alternative solutions is the energy EPI similar of the proposed renovated/built building. This approach gives possibilities to compare different ITES combinations (including parallel consumption options) in complex.

To vividly display the results, it is recommended to compare how the techno-economic indicators of the DH system and apartment buildings change when the usage of the basic ITES (for example known reference solutions without parallel consumption in order to ensure expected EPI) in the DH is near 100 % and near zero (most buildings are renovated with parallel consumption according to alternative EPI). Such a comparison helps to better understand what advantages the consumers of DH system have in comparison to those who have chosen parallel consumption and what are the disadvantages of it. What are the consumers of DH system going to pay for and in opposite what are these components in the case of being in an advantageous position in the matter of parallel consumption in a short term (the share of alternative THIs is negligible) and in a long term (the share of alternative THIs prevails).

The authors of the article assume, that implementation of described evaluation principles will have a scientific and practical contribution in energy efficiency policy sector. As an example, providing calculation on the State level by taking into account those consumers and DH systems which are common for specific state allows to indicate impacts of different EPIs on DH area. Selection of those ITESs which provides higher synergy between consumers and DH systems can be useful (especially during renovation of existing buildings), because renovation of buildings and development of DH systems are important and actively subsidised EU energy policy objects. Highlighting and wider implementation of those ITESs which provides better synergy allows increasing the efficiency and value of subsidies as well as sustainability of DH areas.

The authors of the article plan to implement the methodological approach described in the article. The first calculation is associated with comparing the central supply and exhaust ventilation with heat recovery and exhaust ventilation with air heat pump – which were the examples used in describing the methodological approach.

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