The impact of the decreasing number of users on the evolution of a centralized heating system

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Abstract: The paper presents an analysis of a centralized heating system located in a city in the west-central part in Romania. We examined the last 15 years of functioning of the system from a technical and economic point of view. One of the main factors that led to the inefficiency of this system, and in the end to collapse, was the reduction of the system's thermal efficiency due to the decrease of customers over time. In conclusion, we highlighted the necessity of a periodic diagnosis of system’s efficiency and a risk analysis to avoid economic problems and collapse.

1. Introduction
The supply of thermal energy to consumers can be done in a centralized or decentralized system. In central heating systems energy is produced in one location (source) and is distributed to consumers through pipelines network, and in decentralized systems thermal energy is produced and consumed in the same location [1].

In Romania, in the period 1951-1989, the thermal energy system was formed and developed by introducing centralized thermal energy production systems for industry and for residential buildings in urban areas. Until the 90s, in Romania, the Centralized Thermal Energy Supply Systems (CTESS) were almost the only form of heating for apartment buildings, a solution imposed by the state for the controlled combustibles consumption [1, 2].

After 1991, the distribution of natural gas is taken over by the companies that aim to increase sales, and the demand for thermal energy in a centralized system began to decrease quite quickly by the disconnection of industrial consumers from CTESS, mainly for the following reasons:
- replacement of the centralized source with own one for cost control;
- reduction and reorientation of activities on industrial platforms.

This decrease in the demand for thermal energy has resulted in the shutdown of some production units within CTESS, with an important unfavorable influence on their economic indicators, the decrease of energy efficiency and the increase of the price of delivered energy.

After 1995, a second stage of disconnections began, that of residential consumers (population) who considered more attractive the solution of heat supply from wall mounted boiler, in their own apartment, powered with natural gas.

After 2003, heating plants began to be gradually subordinated to local municipalities. This created the possibility of unifying the production activity with the transport and distribution of thermal energy, thus creating the possibility of correlating modernization, investment and operation programs
throughout the system that could have led to increased economic efficiency of CTESS [1, 3]. However, in most cases these networks, over time, have become dysfunctional and local governments have abandoned them.

The number of localities connected to the centralized heat supply system in Romania decreased in the period 1989-2014 by approximately 78%, respectively from 315 to 70 localities [1, 4, 5] with the possibility, for some of them, to cease or close their activity in the years to come. Due to some unfavorable decisions and lack of support from the local and national authorities, in 2018 only 52 localities remained supplied with thermal energy and domestic hot water from centralized system with district heating plants (DH) [6].

This paper describes the involution of a centralized system with district heating plants, powered by natural gas, in order to understand that a periodic diagnosis of the efficiency of the system and a risk analysis that considers the development of competing alternative systems, can avoid huge economic problems for local public administrations which are unfortunately also associated with special social problems.

2. Materials and methods

2.1. District heating system location and description

The district heating system is in a city in the west-central part in Romania with a temperate climate. The climate features in Romania respect the temperate-continental type which is characteristic for Central Europe. Temperatures in winters vary from very cold to cool, summer range from very warm to hot, so seasons are very distinct. The climate is classified as Dfb by the Köppen-Geiger system [7].

As part of the infrastructural base of the city, the centralized heating system had 31 heating facilities, with a total installed thermal power of 129 Gcal/h. The distribution pipelines network totalized more than 25 km. The district heating system covered the demand for heat and domestic hot water for 16 635 apartments and 457 economic agents.

2.2. Methodology

The methodology used in this paper was through measurements and analysis of different indicators of the DH system. The main indicators followed in our investigation were: the system’s thermal energy production and thermal efficiency, specific consumptions of utilities (electric energy and natural gas) and the number of consumers connected to the heating network.

2.3. Materials

The materials used in our research involved monitorizations and recordings of the produced and delivered thermal energy, utility bills, annual reports and official websites of the Romanian government [1, 8, 9]. The amount of analyzed materials and information were significant since the evaluation of the DH system focused on the last 15 years of functioning.

3. Results and discussions

3.1. The installed thermal power of the district heating system

The district heating system, with its 31 heating centrals, had, between 1997 and 2005, an installed thermal power of 129.25 Gcal/h. By 2006, with less consumers connected to the network, the installed thermal power had a significant decrease of 65%, reaching a value of 84.35 Gcal/h. In figures 1 and 2 are presented the evolutions of the installed thermal power and apartment disconnections over the last 15 years of functioning.

The reasons for consumers to disconnect were plenty. The main one that influenced the householders to separate from the centralized heating system was the liberalization of the natural gas market. There were companies who were selling natural gas to individual consumers at a competitive price compared to the one established by the DH system for the sold thermal energy. Another was the emerging market
and intense publicity of wall mounted boilers, whose sellers were promising better control of interior microclimate at smaller prices. The last factor was the consumers’ wish and opportunity to control thermal comfort, namely the possibility to choose when to turn on or off the heat. Thus, the evolution of consumers disconnections from the DH system, as it can be seen in figure 2, had a decreasing path, with an average diminishment rate between 1997 and 2003 of 12%/year. The maximum value of the decreasing rate was reached in 2004 with 71%. After this year, the collapse of the district heating system was predictable. From 2005 and the years to come, the disconnections rate continued to be around 50%.

![Figure 1. The installed thermal power of the district heating system.](image1)

![Figure 2. Evolution of the apartments connected to the DH system.](image2)

3.2. **Thermal efficiency of the DH system**

By the start of the '90, Romania faced a major economic crisis with many political and social changes. In short time, the industrial sectors demanded less and less thermal energy reaching the point to disconnect from DH systems, as the goods production decreased significantly. The massive disconnections put serious challenges on the district heating system as it was meant to operate an oversized energy supply, with different parameters from its design, but with less demand [5].

The DH system was seriously affected on one hand by the overall thermal efficiency and on the other hand by hydraulic misbalances of the distribution pipeline network. Almost immediately with the decline of the industrial sector, many householders disconnect from the district heating, forced by economic reasons. As it can be seen in figure 3 the thermal efficiency of the DH system decreases to the level of not being feasible.

Thermal energy losses exceeding 30% cannot be tolerated for this type of system (district heating system with combustible natural gas). The lower the thermal (consumer) density determines the lower efficiency of the system. Likewise, the decrease in demand (output reduction) can’t be technically diminished with reduction in inputs leading to performance decline due to the partial use of heating facilities [10, 11].

After 2004, to maintain the DH system above the threshold of economic profitability, the owner of the system decided to shut down some heat facilities. Its evolution, or proper said its involution, with operative heating centrals is shown in figure 4.
At this stage of system’s operation, we can state that a thermal efficiency and risk analysis of the system would have been required few years earlier. In addition, a market study would have been necessary to understand consumers’ choices and needs.

In figure 4, the first 5 heating facilities were disconnected from the district heating system in 2005 after its thermal efficiency reached a level of 71.6% (see figure 3). Although other technical measures were taken, the performance of the system which was supposed to stagnate or increase, followed it’s decreasing path. Along with this thermal efficiency drop and the fact that consumers continued to disconnect, the DH system is forced to close in the next year another 7 heating facilities. Likewise, the decreasing path of the performance DH system reaching a value of 56.5%, continued in the next three years until other 6 heating centrals were shut down. With only 13 operative heating facilities the DH system efficiencies finally started to increase until 72.2% (see figure 3) but still under the threshold of economic profitability. The performance of the DH system didn’t last long and started to diminish again in 2010. From this point the collapse of the centralized heating system was imminent, a fact that happened in 2012.

3.3. Evolution of system’s specific consumptions

One of the main reasons for the accentuated decrease in the overall DH system’s thermal efficiency in 2008 (see figure 3), is related to the increase of consumption of specific electricity reported to sold thermal energy (see figure 5), reaching a level of 58.3 kWh/Gcal [9].

The continuous reduction of consumers with the preservation of less and less charged thermal networks leads to an alarming increase in the electricity consumption necessary for the production and distribution of thermal energy in the centralized system. Thus, if the production of the thermal energy unit (Gcal) in 1997 required 13.6 kWh, in 2004 it needed about three times more electricity (30.8 kWh/Gcal), making it clear that the system is facing serious problems.

To produce thermal energy, the DH system had an annual natural gas consumption of 30 441 024 m$^3$ in 1997 reaching only 163 441 m$^3$ in 2011 [8]. The consumption of specific natural gas reported to the sold thermal energy follows the same path of the consumption of specific electricity, i.e. an overall increase. If in ’97 the amount of natural gas consumed by the DH system on the sold thermal energy was 154.4 m$^3$/Gcal, in 2004 increased to 171.5 m$^3$/Gcal, reaching a level of 219.7 m$^3$/Gcal.
Figure 5. The evolution of the DH system’s specific consumptions reported to annual sold thermal energy.

3.4. Analysis of the main annual indicators in the DH system

We analyzed the evolution of the main annual indicators through an overlap graph that is presented in figure 6. These indicators are the main factors that are considered for the establishment of the district heating system’s economic efficiency, i.e. annual produced energy, annual consumption of natural gas and electricity and number of system’s employees.

Figure 6. The evolution of the main analyzed indicators of the DH system.
As can be seen in figure 6, the measures taken by the management, being restricted by the safety rules of the installations, the system technology and the need to ensure the thermal energy of all customers remaining in the system, cannot make the slope of heat production decrease be followed by an identical slope of the main costs for the production of useful thermal energy.

In 1997 the DH system produced and distributed with each employee 1224.3 Gcal, in 2004 with the same employee it produced and distributed only 394.2 Gcal and in 2011 only 78 Gcal. Analyzing the graph, we can state that the efficiency of staff use was in an alarming decline throughout this period.

Given the performance indicators presented on the graph and the lack of clear regulations in the field, a steeper slope of the graph occurred after the year 2004, meaning after this year the financial balance of the business was broken and the collapse of the system was imminent.

As a result, the thermal energy tariff continues to rise steadily, reducing its competitiveness, and the subsidy system of local authorities can only delay an inevitable collapse.

The following graph (figure 7) represent an eloquent image of our research outcome, in which we determined a collapse threshold for the district heating system.

![Graph showing energy consumption and costs over time.](image)

**Figure 7.** Relevant specific consumptions to the cost of sold thermal energy by DH system.

The collapse threshold for the studied district heating system is somewhere between the years 2002 and 2004. For that period, it can clearly be seen on the graph that while the annual sold energy slope decreases drastically, the slopes of consumption and operational costs with employees are rising almost exponentially. After that period, when the supply was exceeding the demand and the consumption of resources were higher and higher, the slope of sold thermal energy continued to decrease constantly while the costs of resources in order to produce the thermal energy were growing uncontrollably.

### 4. Conclusions

Given the analysis of the main indicators of the thermal system we can state that the collapse of the system was predictable, a long time before this happened.
The main scope of the study was to identify in the first stage a graphical threshold for the economic efficiency of the considered DH system, following that in a second stage we can frame the curves of the graphs in mathematical functions and thus they can be used for exact determinations of the critical points for the DH systems that are still in operation. To do that, we will expand this case study for other several DH systems who had the same sad fate.

Considering the above, the team lays the foundations for an assessment tool for determining the economic efficiency of a DH to apply it and forecast for existing DH systems.

To achieve that scope, the team identified the main technical-economic indicators, the variation of which can determine both the current state of a DH system and the forecasts for the coming years.

The main conclusions that can be highlighted from our analysis are:

1. the lack of performance and risk analysis for DH systems in operation can lead to their collapse with significant economic and social costs;
2. the performance and risk analysis must be carried out periodically through the care of the owner (usually the local public authority) by independent qualified consultants;
3. the risk analysis should focus on the alternative heat supply options available in the area.

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