Optimization of the composition of the structure of heat sources as applied to the problems of the development of heating systems

V A Stennikov¹, O A Edeleva¹ and E S Fereferov²

¹Melentiev Energy Systems Institute of SB RAS, Russia
²Matrosov Institute for System Dynamics and Control Theory of SB RAS, Russia

E-mail: edel@isem.irk.ru

Abstract
The study outlines the concept of the structure of heat sources of developing heating systems and states the problem of searching through structures of heat sources of maximum redundancy for the optimal one. As one of the techniques of solving this problem, the authors propose to split the process of designing heating systems into multiple stages. Within the scope of the above-stated problem, the difficult part is the need to create an automated system to solve the entirety of problems arising at these stages and to reconcile them with each other. We provide a brief overview of the the available software package that we propose to integrate into the process of solving and we underline the complex nature of the interaction of individual software components between each other. The authors propose an approach in the form of the computational experiment setup that enables to consistently coordinate computational procedures with each other. The approach is based on the concept of the energy hub as its theoretical backbone, while in terms of the software implementation it is an instance of an automated information system.

1. Introduction
The structure of heat sources is understood as a set of certain parameters and indicators that are telling of their position within the heating systems: territorial distribution within the boundaries of the area covered by heat supply; type and composition of the equipment of heat sources; installed heat and electric power capacity; their place in the total composition of the sources; connected heat load. The adopted structure of heat sources corresponds to a certain configuration (layout) of the heat network that links heat sources to consumers. Each such structure of heat sources has a set of certain technical and economic features (heat and electric power production capacity, emissions of pollutants, cost of equipment, efficiency, etc.).

The paper considers the problem of automation of building redundant structures of heat sources and a method for their optimization as applied to the problems of heating systems development of settlements.

2. Determining the optimal structure of heat sources
The problem of searching for the optimal structure of heat sources under the heating systems development conditions is a problem of the optimization of the layout and structure. It consists in the
choice of locations, types, and composition of heat sources equipment together with the efficient
distribution of loads between heat sources and the choice of the optimal configuration of the heat
network linking heat sources to consumers with minimal atmospheric pollution. The main features of
the problem are discreteness, integralness, and the nonlinear nature of technical and economic
dependences.

The solution to this problem, as based on the methodology of building the structure of heat sources
that is as redundant as possible and is a part of the redundant layout of the heating systems, is to
determine the optimal solution among all alternatives. The structure or superstructure [1] of maximum
redundancy includes all combinatorially available options with respect to the given problem of
synthesis of the equipment that converts primary energy resources into heat and electric power energy
with due attention to emissions of pollutants into the environment. For example, the maximum
structure always contains exactly one unit of each possible type of equipment, i.e. such equipment, the
installation or operation of which can be justified in combinatorial options of the synthesis of energy
conversion processes.

The development of redundant options of structures of heat sources of municipal heating systems
depends on the heat supply policy of the city, the current condition of housing and public utilities
infrastructure of the heat sources and heat networks, specific geographical features of the area, the
specific features of fuel and water supply systems of the city, the availability of access roads, as well
as existing and planned prospective heat loads of heat consumers of the city (Figure 1).

Figure 1. Flowchart of the process of the development of redundant options of the heating systems
to be designed and the types of competition between redundant structures.

3. Problem statement
There are three individual stages of heating systems design process as per the approach to optimization
of redundant structures of heat sources [2]:
1. Establishment of redundant structures;
2. Development of a model for the optimization of redundant structures;
3. Identifying the optimal structure.

Problem statements for all three design stages were stipulated in [3-4], where the authors provided a formalized statement of the problem of optimizing the redundant structure of heat sources, proposed a methodological approach to its solution and shared a practical example of creating such a redundant layout and searching for the most advantageous solution for the heating systems of a small settlement.

The complexity of the problem of optimizing the redundant structures of heat sources makes it necessary to create an automated system to solve the problems arising at stages one to three (Figure 1), and reconcile them with each other.

At present, there are software packages available for solving individual problems at stages one to three. For example, of all existing approaches to automatic construction of redundant structures of heat sources, one should highlight the P-graphs approach [5, 6] that covers the methods of automated generation of superstructures of technological processes [7] and their optimization [8]. These methods are implemented in the P-Graph Studio software [9]. In [10], the theory of P-graphs is employed to build superstructures of distributed generation systems taking into account the redundancy of equipment and topological constraints. The generated superstructure of the energy source is automatically transformed into a mathematical model by means of a universal component approach to modeling.

Another approach to solving the problems of the first stage is the energy hub concept that is akin to the theory of P-graphs [11]. The concept was developed for designing and searching for the optimal configuration as applied to prospective energy systems [12]. Here, the energy system is designed as a device (energy hub) with multiple inputs and outputs. A coupling matrix is used to describe the energy flows between inputs and outputs. In [13, 14], the authors proposed an automatic approach to creating and optimizing the coupling matrices, in which all possible links between the inputs and outputs of the hub are searched through. First, the structure of the energy system to be designed is described on the basis of the graph theory, then matrices are formed that are reflective of the topology of the system and energy conversion processes. They serve as the basis for formulating the equations of energy flows. Optimal flows are calculated using the Gaussian method.

The problems of stage two and stage three are usually solved simultaneously. Examples of software products that solve these problems include the tools shipped with Oemof [15], Ficus [16], and P-Graph Studio. The difference between P-Graph Studio and oemof, ficus and similar tools is that the latter should be fed with a pre-defined redundant layout of heat sources, while P-Graph Studio creates the required superstructure itself.

The main problem of automation of the entire multistage process is the integration of various software products capable of solving consistently the problems of stages one to three with the transfer of input and output data. The difficulty lies not only in the variety of problems to be solved and the heterogeneity of the transferred data, and the availability of logical procedures, but also in the fact that each software product uses its own format for storing input data and calculation results.

4. Proposed approach

For the purpose of storing technical and economic parameters that are pertinent to options of the structures of heat sources, a Firebird-driven database (DB) was developed. For the purpose of implementing stage one, the database contains a dedicated procedure that generates a redundant layout of heat sources for the specified requirements for the capacity of heat sources and reliability of their operation. The redundant layout of heat sources is essentially a set of energy hubs, each of which corresponds to a specific competing option of the heat source structure.

To solve the problems of stages two to three, we use Ficus that makes actual use of the energy hub concept. For the interface between DB and Ficus, we propose to develop an automated information system (AIS) based on GeoARM [17], which is designed to automate the creation of such information systems through the adoption of declarative specifications of applications. The specification contains the minimum required information about the database structure, which is sufficient for automated implementation of the application, and, in particular, for the development of user interfaces, user
querying, support for interaction with spatial data, as well as the procedures for interaction with external software to solve computational problems.

The complete procedure of the computational experiment (Fig. 2) that implements stages one to three of the optimization of redundant layouts of structures of heat sources, is made up of the following steps:

1. Generate a redundant structure of heat sources in the database.
2. Create input data for Ficus.
3. Calculate.
4. Import into the Database. View the results.

![Figure 2. Computational experiment setup.](image)

5. Practical evaluation

We have built the AIS that handles the creation of the database and populates it with data; debugging of the stored procedure that generates the redundant layout of heat sources based on the specified requirements with respect to the capacity and reliability of heat sources; and implementation of the subsystem responsible for interfacing with the database.

6. Conclusion

We proposed a possible way to automate the creation and optimization of the redundant structure of heat sources within the scope of a single computational process. The approach is based on the concept of the energy hub as its theoretical backbone, while in terms of the software implementation it is an instance of an automated information system that integrates the database, the Ficus toolkit to optimize the structure of energy systems, and the interface that ensures their interaction.

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