Romanian Journal of Civil Engineering, Volume 16 (2025), No. 1

A look at the large capacity shallow geothermal systems with heat pumps units in terms of optimal control

O privire asupra sistemelor geotermale de mică adâncime și de mare capacitate cu pompe de căldură, din punct de vedere al controlului optim

Răzvan –Silviu ȘTEFAN[1], Daniel CORNEA[1]
[1]Technical University of Civil Engineering of Bucharest, Romania
Lacul Tei Blvd, No 124

Email: razvan.stefan@eli-np.ro, danielcornea@hidraulica.utcb.ro

DOI: 10.37789/rjce.2025.16.1.7

ABSTRACT: Today, the best option - and only one that is feasible - for obtaining sustainable solutions for the responsible use of resources is to approach the energy efficiency of an HVAC system by recognizing and seizing the opportunities offered by automation and optimization seen as a whole, in close connection.

Key-words: geothermal system, heat pumps, sustainability

CONTEXT

The construction and commissioning of the ELI-NP's geothermal HVAC System provides a unique opportunity to study the possibilities to optimize of the high-capacity geothermal HVAC Systems by acquiring and capitalizing on the data available as a result of the operational monitoring and to perform mathematical modeling for high-capacity geothermal HVAC Systems.

The case study "Geothermal HVAC System installed at ELI-NP", through monitoring in time and in operation, will provide new information related to the behavior and performance of high-capacity geothermal HVAC systems, which can be exploited and can practically confirm the conclusions / results of the studies achieved so far.

The geothermal HVAC System with heat pumps units serving the ELI-NP research infrastructure is a complex, large-scale system, the largest in Europe, with an

The article was received on 05.06.2024, accepted on 24.02.2025 and published on 04.03.2025

The geothermal HVAC System with heat pumps units serving the ELI-NP research infrastructure is a complex, large-scale system, the largest in Europe, with an installed capacity of 6.2 MW (heating and cooling). Thus, it allows 1) the modeling of many processes, the creation of impact models that can be verified practically, and which will lead to familiarization with the response of high-capacity geothermal HVAC Systems, but also 2) the creation of studies and models for optimization / optimal control which contribute to energy efficiency.

Strictly for the ELI-NP case, the modeling will aim, in the end, to achieve an optimal distribution scheme of the heat transfer fluid and to get predictions in the medium and long term regarding efficiency, benefits and operating costs, impact on the environment.

The impact of automated control on optimized operation

In recent decades, many efforts have been made for the proper design and optimal sizing of geothermal HVAC Systems. At the same time, intensive research activities of HVAC systems have been carried out for several years, aiming at their operation and control with minimum energy consumption, but satisfying the quality and comfort conditions of the environment inside the buildings.

Control strategies can be classified into two categories, local control and optimal control respectively.

The areas addressed by the studies related to HVAC Systems are presented in the diagram in Fig. 1. It can be seen from the diagram that the share of studies associated with optimal control is still small compared to the research carried out in relation to the local control of the systems. This fact is due to the easier implementation of local control strategies and the inconveniences related to the difficulty of collecting a large amount of data needed in the case of optimal control strategies.

These efforts have led to the development of optimal control strategies to make operation more efficient while satisfying indoor thermal comfort requirements, to mitigate soil thermal imbalance (beneficial action for long-term operation) that equally pays attention to both control as well as optimization.

The optimal control of the HVAC systems aims to determine the optimal solution (mode of operation and reference values, also called "set-points") that minimizes the energy demand of the system (implicitly also the cost of operation), under the conditions that are respected indoor comfort parameters and taking into account the inherent and continuous change in indoor environmental requirements and outdoor conditions and in some cases even the characteristics of the HVAC System.

Efficiency is defined as minimizing energy usage while keeping the operational parameters at the required levels. Such an approach is currently known as intelligent building operation and control.

In the last two decades, efforts to develop optimal monitoring and control strategies for HVAC Systems in buildings have intensified, given that modern buildings are now equipped with complete automation systems that allow this. These efforts have materialized in numerous studies and researches added to the specialized literature, which anticipate and even demonstrate that significant reductions in the energy consumption of HVAC Systems can be achieved, even with small increases in operating efficiency.

However, many of the optimal control strategies developed so far have not been implemented due to certain impediments, such as the need to use a complex mathematical apparatus, the reduced possibilities of generalization caused by the constraints imposed by the particularities of each practical application, etc. In practice, the proper, high-energy-efficiency operation of HVAC Systems is a difficult engineering task, both for designers and in their operation.

The following are specified as effects of the automated control:

- Reducing energy costs

Automation and optimization make it possible to operate mechanical systems at maximum efficiency.

- Equipment can be programmed to operate only when required and will therefore generate only the required load at any time.
- The level of control for the construction itself and for all related systems is high.
- Provides automatic detection of the HVAC System failure.
- Provides control over occupant actions.
- Facilitates reporting of equipment performance and problems encountered during operation.
- Creates the possibility of readjusting the parameters with the change of working conditions.
- Ensures knowledge of the long-term operation pattern of the installation, under different operating conditions
- Sophisticated graphic interfaces of the automatic control applications allow the creation, preservation, ranking of the construction documentation of the building with the possibility of easy access to the data of interest.
- Plants require less maintenance, resulting in lower maintenance costs.

- Makes it possible to reduce labor costs through remote monitoring and troubleshooting.
- Modern automated control systems (especially digital ones) are programmable; if a building's needs change, the system can be reprogrammed to meet the new requirements.

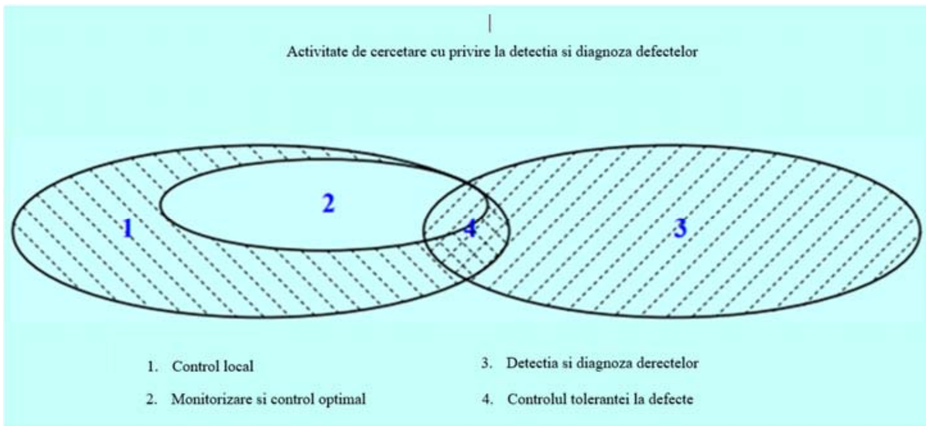

Fig. 1. Studies and research related to the field of control of HVAC systems

The DDC control System at ELI-NP

The Shallow GSHP System at ELI-NP is unique due to its size and technical requirements.

The constraints considered in the design and implementation of the GSHP System at ELI-NP are reviewed here:

- the precise humidity control requirements in many of the laboratories, low temperature and relative humidity being required
- the high air change rates requirements
- multiple operating conditions
- the pressurization requirements
- the limited options to use the energy recovery strategies, in order to avoid the cross-contamination
- the difficulty to anticipate the equipment thermal loads and exhaust requirements
- the high energy consumption of the process and of the research equipment

The system, as described below, is designed to ensure the required air change rates at the optimum energy consumption.

The installation of the Shallow GSHP System at ELI-NP was an important step towards responsible use of the environment. The optimization labels the step taken to rational use of resources.

Optimizing the operation of large consumers brings significant energy savings. Identifying and implementing efficient and inexpensive optimization techniques can bring great benefits to the society, especially in the long run.

Testing integrated optimization techniques for large Shallow GSHP systems is an innovation in itself, and it adds value to the existing ELI-NP Shallow GSHP System. Furthermore, the future results could contribute to the development of optimization criteria for Large Shallow Geothermal Systems.

The geothermal HVAC system installed at ELI-NP is monitored and controlled through the Digital Direct Control (DDC) automation system. Thus, temperature and humidity are continuously monitored, recorded and adjusted, with the information being transmitted in real time to the Building Management System (BMS), which monitors all building systems.

The parameters that should be maintained in research laboratories at ELI-NP are as follows:

- temperature in the Laser room 22 +/- 0.5 ^{o} C
- the temperature in some Laboratories 20 +/- 0.5 ^{o} C
- relative humidity in the Laser room and Laboratories 35-50%, without condensation
- overpressure in the Laser room and Laboratories 40 Pa
- cleanliness class in the Laser room ISO7
- cleanliness class in Laboratories ISO6, ISO7
- and negative pressure of 14 Pa in some laboratories

Preserving the stability of the parameters is the first priority considered in operation of the HVAC System installed at ELI-NP. The energy efficiency is of major importance, considering the high energy consumption involved in the research activity carried out in the ELI-NP research infrastructure.

The two high-power lasers operate in an ISO 7 clean room with an area of approximately 2,500 m^2.

The high hourly air rate change, the overpressure conditions and the requirements of strict control of temperature and relative humidity, as well as the limited options of using energy recovery strategies, lead to a very high energy requirement.

The monitoring and control system of the HVAC System installed at ELI-NP infrastructure monitors all buildings, is similar to a SCADA system and performs the following functions:

- collects all parameter values from the geothermal HVAC System controllers
- allows displaying the values of the parameters read by the sensors installed in the system
- records all parameter values on the server dedicated to data acquisition, in order to create and visualize their time variation graphs

The proposed DDC system is structured according to a system logic of data acquisition, processing and distributed control, based on application programs resident in the controllers' memory, with the possibility of transmission and communication with a central DDC server connected to the intranet network of the BMS system or remotely using TCP/IP communication over the Internet.

The DDC system allows:

- real-time recording of the parameters of interest (temperature and relative humidity of the air introduced), through the sensors located in the piping
- adjusting the values of these parameters to the reference values required by the process
- data storage and development curves for different periods

In the LASER room real-time temperature and relative humidity are recorded inside the duct as well as in the vicinity of the research equipment, at various points of interest.

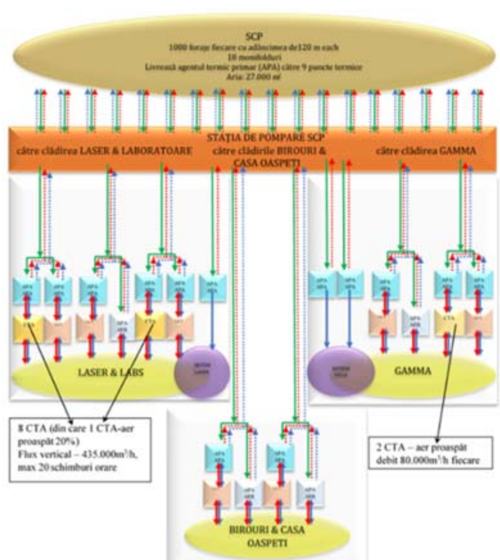

Fig. 2. The Shallow geothermal System in operation at ELI-NP

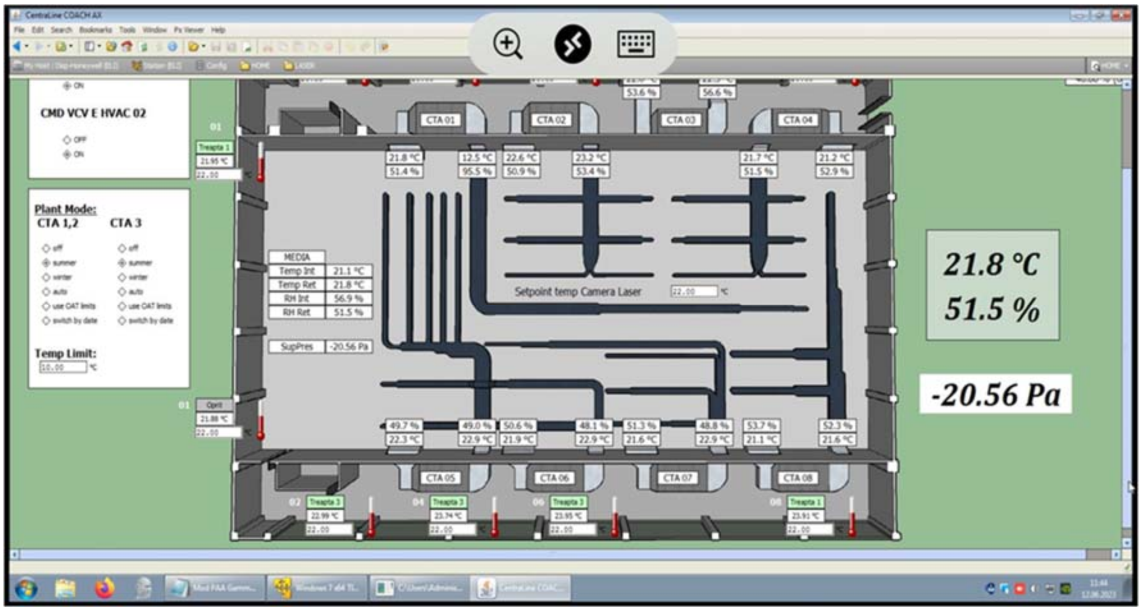

Fig. 3. DDC Screen

Aspects of optimal control and operation of large scale shallow geothermal HVAC Systems

Optimization makes sense in conjunction with the system automation. These, viewed as a whole, in close connection, represent today the best option for obtaining sustainable solutions for the responsible use of resources.

The effects of the operation and automatic control of buildings lead to the reduction of the impact on the environment as well as the reduction of the carbon footprint for buildings in the industrial area considered to be the main vector of impact on the environment.

By capitalizing on the data obtained from the monitoring and exploitation of the high-capacity geothermal HVAC system with heat pumps installed at ELI-NP, together with the related automatic DDC system, the sustainability of geothermal energy as an alternative for high energy efficiency can be practically tested. Compared to similar infrastructures, the ELI-NP research infrastructure has a high energy efficiency, the calculated HVAC system performance coefficients are currently low, but an improvement is expected following the completion and implementation of the ongoing optimization strategy.

Given that there is a worldwide concern to study the energy consumption of infrastructures and research laboratories, the ELI-NP case study can provide information on the reduction of energy consumption due to the use of the HVAC geothermal system with heat pumps.

Together with the multitude of tools / software applications currently in existence, the ELI-NP system allows the creation of several models that can bring new data on the behavior and impact of geothermal heat pump systems. The aim is to evaluate the future performance and optimization of the geothermal system from ELI-NP, itself, but also to use the models for the realization of other similar systems.

From the point of view of the optimization of systems that use closed-loop heat pumps, the main aspects to be followed are those related to the energy efficiency of the pumping stations, also the hydraulic balancing of the system both on the primary circuit and on the secondary circuit.

Studies have been performed to follow these aspects from the perspective of the user of systems. There are similarities with the geothermal system in operation at ELI-NP (i.e. similar usage graphs) but also differences from the current operating situation of the ELI-NP infrastructure in that the thermal parameters of the respective facilities do not require such restrictive operating conditions as in the case of ELI-NP. As a result, the entire operating schedule of the ELI-NP infrastructure will have to be adapted according to operational requirements that take precedence over energy saving requirements.

Having as a starting point the continuous operation of the hydraulic circuits of the primary loop, any operation strategy should consider the reduction of energy consumption by modulating the two control parameters of such a system: flow rate of the heat transfer fluid, respectively the temperature on the primary loop.

The positive effects of the modulation of the flow rate of the heat transfer fluid through the use of variable speed pumping systems, without touching the subject of the conjugate modulation of both the heat transfer fluid flow and the loop temperature. A future research direction involves the simultaneous use as reference parameters of the coolant flow rate and the temperature on the primary loop by using mixing valves mounted on such closed systems. Also, within the ELI-NP infrastructure, out of the desire to increase the system's performance coefficient, a landmark area is used for which the mixing of the heat transfer fluid from the primary loop with the secondary related to the technological cooling circuits was adopted.

So far, the outcomes have been impacted by the primary loop control circuits' ability to detect the parasitic injection of certain flows incident to the primary loop without allowing the system to redefine a control structure to take that combination into account. A second line of research follows from this, involving the installation of field equipment that would be able to give the system simultaneous control capability in terms of both quantitative (heat transfer fluid flow) and qualitative (control temperature on each individual loop).

The control strategy performed was validated by the results obtained during the seven years of operation of the system installed at ELI-NP, generating an insignificant impact on the groundwater temperature. This result leads to the premise that the operation of this system will be possible in nominal load conditions over a period of more than 20 years as thermal response tests in the design phase indicated.

To save energy, any intervention in the operation strategy must be carried out taking into account the fact that the energy source in this case involves an instability factor generated by the geothermal potential, unlike the stability of conventional energy sources (boiler and chiller).

Bibliography

1] *Răzvan Silviu-Ştefan; Contributions to the improvement of the energy efficiency of heating fluid supply circuits in a shallow geothermal system with large capacity, Doctoral thesis, UTCB, Bucharest, 2024*

2] *Z. Ma, „Online Supervisory and Optimal Control of Complex Building Central Chilling Systems. A thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy," The Hong Kong Polytechnic University, April, 2008*