Increasing the heat supply quality of an existing building within the University POLITEHNICA of Bucharest campus

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***Abstract* — Development, rehabilitation and technologization of thermal energy supply systems have as main objective ensuring the quality and continuity of the supply services, maintaining an accessible price for the end user. Therefore, the efficiency of the system has to be increased reducing at the same time the production cost by lowering the use of primary energy resources. In this paper the results of a energy analysis, performed during an ongoing project, are presented. The conclusions of the analysis and a proposed concept are presented, while the optimal solution will result from the feasibility study.**

Keywords— ***heat supply quality, energy efficiency, geothermal energy, solar energy.***

I. Introduction

Quality of the thermal energy that supplies a building is determined by ensuring the indoor thermal comfort, according to the activities performed, along with a maximized value of the key performance indicators in order to be aligned with the existing standards. Thermal energy supply systems have to prove operating flexibility, keeping an acceptable value of the environmental impact indicators, and to ensure the quality parameters of the thermal energy which can be quantified with the social impact indicators. The effect of increasing the quality and efficiency of a supply system can be most noticeable when it is integrated with thermal energy production systems based on renewable resources [1,2].

This paper presents the energy evaluation of the thermal supply (heat and cold) of Renewable Energy Sources Laboratory from University POLITEHNICA of Bucharest (UPB), dedicated to research and didactic activities. The evaluation is presented together with proposed solutions to increase the quality and performances of the supply services.

II. Existing Situation

The Renewable Energy Sources Laboratory (Fig. 1) or Target Building (TB) is dedicated to teaching and research activities, having the following characteristics:

- Year of construction: 2005.
- Number of levels: UG + GF + 1F
- Heated surface: 532 m^2.
- Heated volume of the building: 2182 m^3.

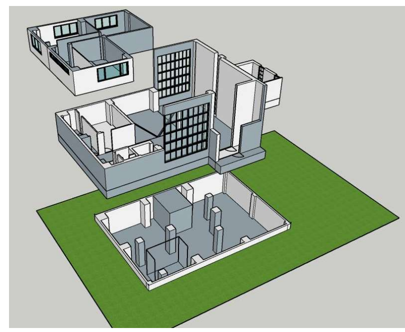

Fig. 1. "Exploded" 3D view of analyzed building.

Placement of analyzed building with respect to the centralized heating system of UPB is presented in Fig. 2.

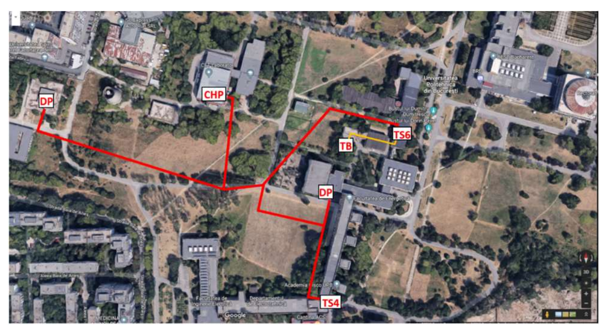

Fig. 2. Layout of the primary circuit of branch B1 from the UPB heating network (CHP – Combined Heat & Power Plant; TB – Target Building; TS6 – Thermal Substation 6; DP – Distribution Point; red line – primary circuit; yellow line – secondary circuit).

The Target Building is connected to the UPB DH through the secondary heating network and supposed to be heat-fed from the TS6. However, the target building could not be supplied from the UPB DH (through the TS6), thus being unable to assure the conditions of thermal comfort, for the following reasons:

- The location of the building at the end of a branch of the secondary thermal network makes it last to receive the heat.

- An additional number of consumers were connected on the same branch, after the DH system was designed and implemented. They are connected between the thermal substation TS6 and the analyzed building (Target Building).
- The hydraulic and thermal regime do not ensure the thermal energy requirement of the analyzed building, neither quantitatively nor qualitatively. The energy audit of the "DH UPB – CHP – primary thermal network – TS6 - secondary thermal network – building" confirmed the actual on-site conditions, highlighted below.
- There is a significant technical wear of the secondary thermal network between TS6 and the building.

For these reasons, the building was supplied with heat from its own gas-fired boiler until December 2019, when the boiler failed. The heat source of the Target Building is a 110 kW gas boiler, Keston C110 Gas Boiler. It is 15 years old (year of commissioning is 2005).

The building is equipped with the following types of installations:

- Heating installations: to ensure the indoor comfort temperature of the spaces according to the regulations in force, there are radiators grouped into 3 categories according to capacity.
- Air conditioning installations: the building is partially air-conditioned - only 3 offices, in which split air conditioners (Daikin: FTXC35B + RXC35B) of 12000 BTU each are installed.
- Mechanical ventilation installations: the building has a mechanical ventilation system which is currently functional without heating or cooling. Is also operating only during laboratory tests.
- Domestic hot water system: the building does not have an internal secondary network for the distribution of hot water for consumption. Currently, an instant electric appliance is used to prepare hot water at the point of consumption.

III. METHODOOGY FOR ENERGY EVALUATION

A. Reference boundary system

The objectives of the energy audit of the Target Building and UPB DH were:

- Evaluation of the current energy situation of the Target Building, as well as of the district heating system of UPB (UPB DH), specifically of the segment defined in Fig. 3
- Establishing a plan of measures to increase the energy efficiency of the building and of the system.
- The opportunity to implement a new solution for supplying thermal energy to the Target Building, based on renewable energy sources.

The reference system boundary (Fig. 3) on which the energy audit is composed of *5 subsystems*, as following:

- CHP UPB (Sb1)
- Primary Thermal Network – branch B1 from CHP to TS6 (Sb2)
- Thermal substation TS6 (Sb3)
- Secondary Thermal Network (connection from TS6 – Target Building) (Sb4)
- Target Building (Sb5)

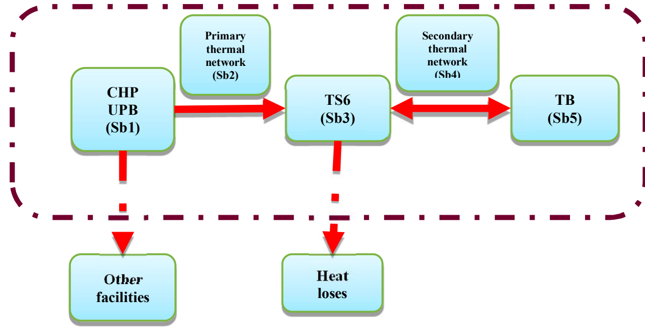

Fig. 3. Energy evaluation system's boundaries.

B. Methodological steps

1. Definition of the audited reference system boundaries.
2. Identifying the technical characteristics of the main equipment and installations within the system analyzed, including present condition and depreciation of each equipment for subsystems Sb1-Sb5.
3. Elaboration of the scheme of energy flows for every subsystem (Sb1-Sb5).
4. Brief presentation of the conversion process: i.e. fuel (natural gas); primary thermal agent – secondary thermal agent (technical and economic parameters).
5. Indicating the reference unit associated with the energy balances.
6. Performing energy balances for each subsystem.
7. Analysis of the results.
8. Plans of measures and actions to increase energy efficiency.
9. Economic and environmental evaluation of the proposed solutions.

Based on the above-mentioned methodological steps, the energy evaluation of the system was conducted which resulted in a proposed concept. The optimal thermal energy supply unit will be defined within the feasibility study [3].

IV. ANALYSIS OF HEATING, COOLING, DHW DEMAND PROFILES

According to the methodology of Energy Audit for buildings in Romania, for the evaluation of the energy performances class and the attribution of the energy rating for the audited building, a virtual building, called Reference Building, is taken as a benchmark for comparison [4,5].

The reference building is a virtual building valid for all types of buildings considered according to the national standard MC001 /PIII Methodology regarding the methodology for calculating the energy performance of buildings [5,6,7].

According to Methodology for calculating the energy performance of buildings – MC001/PIII, it is required to classify the analyzed building in an energy class and compare with a reference building. The energy class of the reference building is A/100 (having a total heat demand under 145 kWh/m2/year) while the energy class for the Target Building was determined to be C/89.8 (having a total heat demand between 251 and 378 kWh/m2/year). [5,6,7]

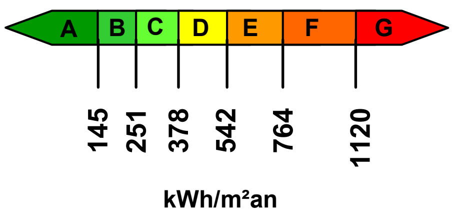

Fig. 4. Definition of energy classes for buildings [6].

A. *Heating demand*

The Target Building was determined to have a peak demand of 58.9 kW and the annual design thermal energy required to heat the entire building is 127 MWh (see **Error! Reference source not found.**), according to the calculations made using the National Design standards. Again, note that the peak demand in the national regulation is calculated for an outdoor design temperature of -15ºC.

The most important aspects that were considered during the analysis are:

- Heating period 15 Oct – 15 Apr in which continuous heat supply was considered.
- Keeping the comfort level constant (21 °C as mean value) inside Target Building no matter the outside temperature.

TABLE I. HEATING ENERGY DEMAND FOR TARGET BUILDING

Characteristic parameters [U.M]	Value
Outside design temperature [ºC]	-15
Peak heat demand [kW]	58.9
Mean heat demand [kW]	29.1
Operating hours [h]	4,392
Annual design energy consumption [kWh/an]	127,705

Similar results of peak heat demand were obtained in numerical simulations using Design Builder software, therefore it was relevant to analyze temperature variations and the positive thermal energy components inside target building during the heating period.

The annual thermal energy demanded by TB differed by up to 17% from the value obtained by using the national standards. This can be explained by the fact that within the numerical model, numerous other parameters are considered such as occupancy and activity of each occupant, thermal inertia of the building, changes of air between different zones, schedules and usages of the building. In order to diminish the computational errors a sub-hourly time step of 1 minute (60 steps each hour) was used and the results are presented below.

Fig. 5 plots the duration curve of the heat demand of Target Building.

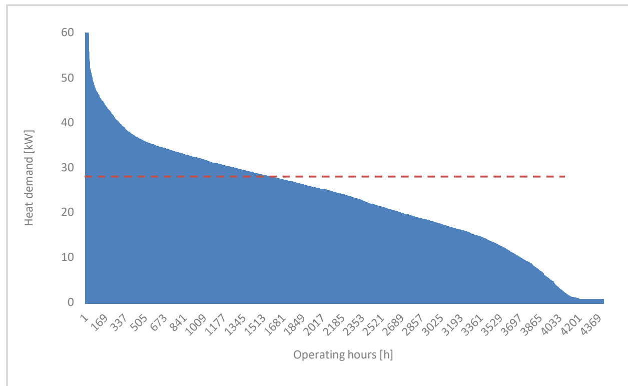

Fig. 5. Duration curve of heat demand.

Duration curves are used to illustrate the dependence between generating capacity requirements and capacity utilization. The duration curve for heat demand has a degree of flattening of 0.5 (ratio between mean value and peak value) which represents a typical value in this case. This explains that in most of the heating period the heat demand is close to the mean value. It can be seen, from Fig. 5, that the duration of peak demand is very low throughout the heating period (under 1,300 hours), while the mean value is maintained for more than 3,000 hours.

The gas consumption of the existing boiler through the heating period is similar in shape as the heat consumption of the target building, and it follows the dry bulb outside temperature. The peak value 1,286.4 kWh of gas consumption was determined to be in December. The mean value of gas consumption is of 576.9 kWh while the annual value is 105,580.3 kWh [8,9].

The total CO_2 emissions of 24,299 kg was obtained by summing CO_2 emissions from electricity consumptions and gas consumptions of Target Building. The CO_2 production only for heating is 22,703 kg [8,9].

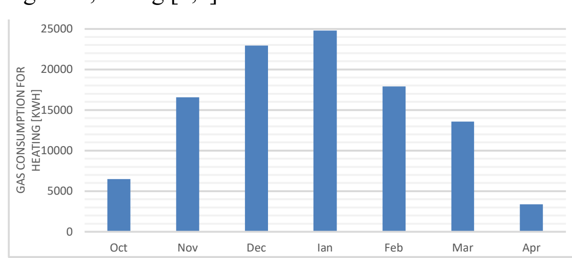

Fig. 6. Monthly natural gas consumption for the target building.

B. Cooling demand

The calculation of the thermal energy requirement for air conditioning for the whole building (not only for the 3 currently cooled rooms) is done according to the National standard Mc001 / PII.2 Methodology. The cooling period has a number of 386 hours within 15 May -15 September. The mean cooling demand was determined to be 34.4 kW. Regarding the electrical energy consumption, an efficiency of the AC unit of 3.5 was considered. Results of the calculations are presented in **Error! Reference source not found.**.

TABLE II. COOLING ENERGY DEMAND.

Characteristic parameters [U.M]	**Value**
Cooling peak demand [kW]	43
Electricity required for cooling [kW]	12.3
Annual cooling demand [kWh/year]	13,285
Annual electricity demand for cooling [kWh/year]	3,795.7
Specific cooling energy demand, [kWh/year/m2]	24.97
Specific electricity demand for cooling [kWh/year/m2]	7.13

Fig. 7 depicts the calculated monthly electricity consumption for cooling in the blue bars.

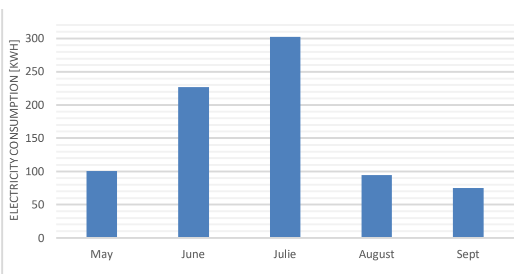

Fig. 7. Electricity consumption during the cooling period.

C. Domestic hot water

The annual thermal energy requirement for domestic hot water for the analyzed building was determined according to the MC001 / PII.3 methodology and is based on the values of consumption specific to the activities carried out in the building (5 l/person/day). The average annual temperature of cold water is t_{cw} = 10 °C and the temperature of the domestic hot water is t_{hw} = 60 °C.

The following values were calculated:

- Annual thermal energy consumption for domestic hot water: Q_{dhw} = 625 kWh/year.
- Specific annual consumption for domestic hot water: q_{dhw} = 1.17 kWh/m2/year.

The thermal energy requirement for domestic hot water of the building was determined, with the calculation value being 0.87 kW (an operating time of 720 hours / year was considered).

The peak heat/cooling design values was determined by using national standard, Design Builder simulation and TRNSYS software. The peak values obtained through the numerical simulations (both TRNSYS and Design Builder) were close to the values obtained through the national standards. Since Target Building has few metering devices installed on site and there is no records of previous data, the numerical models were used in order to assess the energy baseline.

D. Summary of thermal energy demand

In TABLE III a summary of the thermal energy demand values are presented while in TABLE IV the values of the key performance indicators of the existing situation are shown.

TABLE III. DESIGN ENERGY VALUES.

	Thermal energy demand [kWh/year]	**Peak Power [kW]**	**Mean demand [kW]**	**Operating hours**
Heating	127,705	58.9	29.1	4,392
Cooling	13,285	43	34.4	254
DHW	625	0.87	0.7	720

TABLE IV. KPI'S OF TARGET BUILDING.

KPI		**U.M**	**Value**
Specific heating energy demand		[kWh/m²/year]	240.1
Specific cooling energy demand		[kWh/m²/year]	24.97
Specific DHW energy demand		[kWh/m²/year]	1.17
Specific total thermal energy demand		[kWh/m²/year]	266.24
Specific primary energy consumption	Heating	[kWh/m²/year]	282.5
	Cooling		8.34 [a]
	DHW		1.4 [a]
Specific total primary energy consumption		[kWh/m²/year]	292.25 [a]
Specific CO2 equivalent	Heating	[kg/m²/year]	57.92 [b]
	Cooling		1.7 [b]
	DHW		0.29 [b]
Specific total CO2 equivalent		[kg/m²/year]	59.92 [b]

a. All the calculations were performed with the surface of Target Building of 532 m2

b. The calculation was performed considering the conversion factor from final energy to primary energy of 1.17, according to national order "Ordinul 2641/2017".

c. The calculation was performed considering the conversion factor from primary energy to CO2 production of 0.205, according to national order "Ordinul 2641/2017".

Even if the Target Building is connected to UPB DH it is not thermally supplied from. Therefore, there is no need to define reference indicators for UPB DH.

A new thermal supply unit will be installed through the implementation of an H2020 project (WEDISTRICT). The system implies production of thermal energy based on renewable energy sources and the thermal connection between UPB DH and Target Building will be re-designed. Therefore, it is necessary to define the renewable energy ratio for both Target Building and UPB DH.

The renewable energy ratio (RER), or share of renewables, is the fraction of renewable primary energy used by network compared to total primary energy consumed by in order to fulfil the heating and cooling demand [12].

Considering the system boundaries presented in Fig. 3, the equation for RER is explained below.

$$RER = E_{Pren} / E_{Ptot} \quad (1)$$

where

E_{Pren}: Renewable primary energy used by UPB DH/Target Building.

E_{Ptot}: Total primary energy used by UPB DH/Target Building.

In the current case, both KPI are equal to zero since there is no renewable primary energy used by either of subsystems.

$$RER_{UPB\ DH} = EPren / EPtot = 0 \quad (2)$$

$$RER_{TB} = EPren / EPtot = 0 \quad (3)$$

V. Conclusions and Proposed Measures

The energy evaluation of the current situation of the other subsystems (Sb1-Sb4, Fig. 3) was carried out in order to establish the necessary measures to be applied for the reintegration of the Target Building in the DH system of UPB, with the new heat supply solution of the building.

The main objective was to realize the energy audit of the Target Building (Sb5, Fig. 3). It was prepared in accordance with the legislation in the field of constructions, as well as with the technical regulations in force in Romania.

A. *Conclusions of the energy audit of the Target Building*

The analyzed building is connected to the DH of UPB and is located at the end of a branch of the secondary thermal network fed from the thermal substation TS6.

- The causes for which the heat supply of the building from DH UPB was not possible are:
  - the location of the building at the end of the secondary thermal network
  - the connection of an additional number of consumers on the same branch, between the thermal substation TS6 and the target building, after the initial design and implementation of the DH UPB system.
  - the hydraulic and thermal regimes do not allow the supply of the necessary heat to the building (quantitative, qualitative). The energy audit of the district heating system within UPB: “CHP - primary thermal network - TS6 - secondary thermal network - building” confirmed the real conditions on site (a drop in the thermal agent flow rate by about 82%).
  - technical wear of the secondary thermal network between TS6 and Target Building.
- The current heat source that supplies the building is a 110 kW gas fired boiler. It is 15 years old (the year of commissioning is 2005).
- At the moment the boiler is non-functional, the building lacks any heat source.
- The building is partially air-conditioned. Only in 3 offices 12,000 BTU split type air conditioners are installed.
- The building does not have an internal secondary network for the distribution of domestic hot water. An instant electrical appliance is currently used to prepare hot water at a point of consumption.

Reducing heat losses and increasing energy efficiency using thermal insulation has a wide degree of applicability in current practice and also involves medium investment costs. In the case of this building its application is restricted from a technical point of view.

The sandwich structure of exterior walls, composed of 6 cm polystyrene placed between two metal sheets of 3 mm each, 10 cm mineral wool and interior plasterboard, does not allow the application of external insulation because it damages the surface of the walls, risking the occurrence of infiltrations and areas that in time may be affected by corrosion.

Therefore, the energy audit of the Target Building led to the opportunity of implementation of a new solution for thermal energy supply of the building, which ensures heating, cooling, and domestic hot water. It integrates technologies based on renewable sources, namely: ground-to-water heat pump, PV/T or solar thermal panels, PV panels (to ensure the supply of electricity of the thermal supply unit).

The proposed solution also involves the development of a new heat, cold and DHW distribution system of the building.

The energy capacities of the proposed solution will allow ensuring:

- indoor comfort in the building spaces
- safety and flexibility of the thermal energy supply
- delivery in the UPB DH of a share of heat energy produced from renewable sources (depending on the operating regime), including the re-design of the connection between Target Building and UPB DH.

B. *Conclusions regarding the secondary thermal network (supply / return) - TS6 thermal – Target Building, proposed measures*

In order to reintegrate the Target Building in the UPB DH a complete reconfiguration and redesign of the secondary thermal network is proposed. The following aspects are considered:

- Layout reconfiguration and optimization.
- Design, sizing, and installation of new pre-insulated pipes, in order to ensure the optimal hydraulic and thermal regimes for heat injection in TS6.
- The new pre-insulated pipes must be provided with a system for control, detection, and location of faults.
- Data acquisition, remote management and tele-transmission system at the boundary of the Target

Building, as well as of the other buildings connected to the secondary thermal network.

C. Conclusions regarding thermal substation TS6, proposed measures

The implementation within thermal substation TS6 of a data acquisition, remote management and tele-transmission system is proposed. This ensures the acquisition, remote management, and transmission of data from the connected heat consumers, as well as of the thermal substation operating data (pressures, temperatures, flows, pump conditions, etc.).

The provided system will allow:

- Notice to the occurrence of operation malfunctions or to exceeding the predetermined limit values.
- Automatic regulation of the preparation of the thermal agent for heating.
- Ensuring a constant pressure drop of the primary agent (by means of a differential pressure regulator).
- Operation and control of the equipment.
- Metering in the thermal point (on the primary and secondary circuit).
- Data acquisition, archiving and processing (monitoring of parameters - temperature, pressure, flow rate, electricity consumption).
- Ensuring a communication interface with a data remote management system - through the equipment for communication to a dispatcher.

Simultaneously with the new centralized data acquisition and communication system, the following are also provided:

- Replacement of the distributor/collector which ensures the distribution for supply/return of the thermal energy to the secondary thermal network for the Target Building and the other consumers located on this secondary thermal network (according to the new flow rates, hydraulic and thermal regimes);
- Replacement of the fittings on the TS6 distributor/collector and on the secondary network segments that are being replaced.
- Replacement of non-compliant pipes and fittings in TS6.
- Replacement of local sensors (temperature, pressure) within the thermal substation, compatible with the new data acquisition system.
- Electrical installations of TS6 building will be checked and if deemed appropriate, replaced.

The energy efficiency measures, above mentioned for the thermal substation TS6, as well as for the secondary thermal network branch (the connection between TS6 and the Target Building) will be implemented based on a technical-economic analysis, together with the proposed heat supply solution, detailed in the feasibility study.

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