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Energetic Investigation and Economic Feasibility for a University Campus in Romania towards Becoming an Energy Supplier

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Abstract

This research investigates and evaluates the University Politehnica of Bucharest (UPB) possibilities to become an energy self-supplying by building up its own power plant and becoming an energy distributor. The campus has already been connected to the national natural gas supplying pipe and the local district heating and electrical network.

A set of criteria was used to evaluate the feasibility of this project. Technical, financial, and environmental considerations were taken into account to determine the most suitable solution. The feasibility study assumed three proposals of an energy supply system considered for the university buildings / campus. Gas-fired heating plant, gas-fired Internal Combustion Engine cogeneration plant and gas fired Internal Combustion Engine for cogeneration with an Organic Rankine Cycle ORC.

The details of each proposal were discussed to obtain the optimum solution. Elaborate. It was found from a financial and environmental perspective that the most feasible project is gas-fired Internal Combustion Engine cogeneration, considering profit revenue from selling / exporting power to the domestic electricity grid. And the Net Present Value was around one million euros for 15 years life.

Keywords

energy efficiency, economical analysis, Internal Combustion Engine (ICE), recuperative cycle

1 Introduction

Balancing between energy consumption / production and levels of emitted Greenhouse Gases GHG is important to meet the produced energy. Optimum efficiency is the key performance indicator of energy efficiency, keeping in mind fulfilling the growing demand for energy in urban society. Carbon dioxide CO_2 is the primary member of the GHG. CO_2 saving should be considered in the energy production process to minimize the impact of environmental pollution as low as possible [1]. However, due to fossil fuel prices daily growth, designing energy-efficient buildings will conserve the required energy and attempt to lower the costs of energy bills. Which is considered a target should be reached from the energy efficiency point of view [2].

Energy efficiency, climate comfort, and evaluating actual building energy consumption have been studied significantly by different feasibility studies to provide perfect building patterns [3]. Construction engineering and many of such evaluation studies were performed on university buildings / campus to give additional academic vision value of applying energy management / efficiency concepts on construction [4].

University Politehnica of Bucharest (UPB) is the largest technical university in Romania, located at 21° Eastern Longitude and 45° Northern Latitude, Covering a total area of 100 ha (hectare). UPB has almost 10,000 students, consisting of six major buildings of administrative services, classes, and laboratories. All planes area under the building's roof is around 120,000 m^2 [5].

Currently, the campus is importing electricity and thermal energy from the local specialized distributor.

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The thermal energy is used for space heating, domestic hot water, electricity for lighting, cooling, electronic appliances, and essential building utilities. The campus has also been connected to natural gas distribution pipes and the local district heating and electricity grid. This situation has encouraged the university to explore the possibilities of becoming an energy supplier by building its own energy supply system. UPB would become self-sufficient in energy supply and sometimes could export its excess energy to the electricity grid, i.e., energy distributor.

Researchers highlighted previous work in this paper to specify the progress and development of implying different energy supply systems. Bayoumi [6] developed a comprehensive energy plan for a campus in Saudi Arabia to achieve possible results to reduce energy consumption. Kalina [7] studied three different proposals (allothermal wood gasifier, Solid Oxide Fuel Cell (SOFC) and Internal Combustion Engine (ICE) and Organic Rankine Cycle (ORC) for waste heat recovery) for elective utility station. It was found that the proposed integrated biomass gasification small-scale cogeneration plant with allothermal wood gasifier, SOFC, ICE, and ORC for waste heat recovery could be an attractive technological alternative for reduction of consumption of fossil fuels and global CO_2 emission.

Rosato et al. [8] simulated the energy performance that is integrated with the micro-cogeneration system by a TRNSYS simulation software. They compared the proposed plan with a conventional system. The results showed that, in comparison to the traditional design, it allows saving more energy than the conventional system.

Dragomir-Stanciu [9] proposed a solution to increase a Combined Heat and Power (CHP) plant's efficiency incorporated with Internal Combustion Engines by using the available thermal energy produced from hot water to generate electricity in an Organic Rnakine Cycle (ORC). A numerical model was applied based on two assumptions made by Mărcuş et al. [10] using the lower heating value and the higher heating value of the natural gas. The results showed that the efficiency values from the model determine the efficiency with a very close approximation to the actual model ($R^2 = 0.9443$). Besides, the variation trend of thermal and global efficiency increases with the increasing of the partial load.

Kalantzis et al. [11] presented an energy model for an Internal Combustion Engine (ICE) for cogeneration (heat and electricity) systems that were simulated using MATLAB. The engine model results were found to be adequate in predicting the measured engine outputs.

Experimental and numerical analysis of combined heat and power equipped with a biomass, gas purification system, and gas piston engine was studied by Elsner et al. [12]. It was found that it is more feasible to use the generated electricity and heat for its self-consumption rather than selling it on the market.

In this work, there are three different schemes on how UPB could develop its energy supply system. However, all of them are based on the use of natural gas as a primary fuel. The proposed schemes are:

1. Build up classical/condensation gas-fired heating plants (boilers) and keep buying electricity from the local distributor.
2. Build up a classical/condensation gas-fired heating plant (boilers) together with a gas-fired Internal Combustion Engine cogeneration plant to supply electricity and heat as well.
3. Build up as the previous schemes but with additional Organic Rankine Cycle (ORC) recuperative cycle.

This work's novelty is to highlight the most suitable solution schemes to be utilized for future plans in such cases.

2 Methodology

The following procedure was applied to select the best proposal for the campus

1. Estimate the heating and electricity demands of the buildings.
2. Define equipment characteristics used in each proposal, such as boilers, cogeneration engine, and turbine.
3. Estimate the amount of energy delivered, fuel consumption, and emission

The study analyzed each proposal's economic feasibility and performed strategic planning to identify each proposal's strengths and weaknesses to ensure the maximum efficiency for the primary/peak load. Special operations on the plant components were performed using RETScreen software. The study takes into consideration calculating pollutants and CO_2 emission of the system along with a one-year operation. It acquired electric energy considering that this coal-fired produced energy at a general efficiency of 35 %. Three solutions have been compared from both the technical efficiency and the financial point of view, including the green certificates policies, before selecting the most suitable proposal.

3 Heating and electricity demands

The first step in setting up an energy supply system is determining the energy demand, i.e., heating and electricity demands. There are several methods to estimate heating and electricity demands. The most common way is by calculating the heat load of a building based on tabulated climate data. The electricity demand can also be estimated by knowing the total electricity load. Another method, which is more straightforward and more practical, is by analyzing the energy bills. Using data from energy bills, one can simply figure out the actual energy consumption of a building representing the heating and electricity demands. In this project, heating demand was determined using both methods mentioned above; electricity demand was estimated using energy bills data.

3.1 Heating demand

There are two critical parameters to be calculated when one estimates the heating demand. The first parameter is the total annual heat demand. Two kinds of heating loads are considered to estimate the total annual heat demand of a building,

1. Q_H, the sum of the energy use for space heating, and
2. Q_{SH}, and the energy use from domestic water heating, Q_{DHW}.

$$Q_H = Q_{SH} + Q_{DHW} \tag{1}$$

The energy use for space heating can be calculated using heating degree-days, which depends on climate conditions. The energy use for domestic water heating was 3,400 MWh, depending on the technical calculation performed previously by the university's building facility team. The calculation using this concept was performed using RETScreen software [13] to simplify the analysis; the whole building is a single cluster building. Based on this method, the energy use for space heating was estimated to be 13,673 MWh. Therefore, the total annual heat demand of the building was 17,448 MWh.

The second parameter to estimate is the peak heating load by determining using the building heating chart, as shown in Fig. 1. The peak load for space heating occurs under very cold conditions. In this project, the peak heating load was estimated at approximately 6.75 MW, using the heating design temperature of 25 °C and the building heating load of 75 W/m^2, based on the medium type of insulation used in the building.

As a countermeasure for the first method, the energy bills were also used to estimate the heat demand. The energy bills were reflecting the thermal energy consumption in UPB. The summary of this data is shown in Table 1.

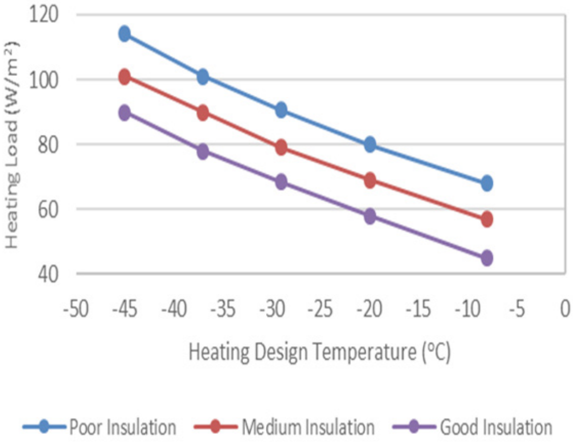

Fig. 1 The building heating chart

Table 1 The thermal energy consumption of University Politehnica of Bucharest selected building campus

Month	Thermal energy usage (MWh)	Heat load (kW)
January	5,236,653	7,039
February	5,341,154	7,948
March	3,204,692	4,307
April	1,228,465	1,706
May	362,270	487
June	354,142	492
July	181,135	243
August	29,028	39
September	328,597	456
October	1,236,593	1,662
November	3,169,859	4,403
December	4,539,981	6,102

The total annual heat demand was around 25,213 MWh, and the average heating load was around 2,100 kW. It appears that the energy bill gave a higher heat demand compared to the previous method. The different result is due to the simplification used in the first method, which may not represent the actual condition. Thus, the heating demand calculation from the energy bills shall be used as a basis for the next analysis.

3.2 Electricity demand

The electricity load was determined from the monthly electricity bills of UPB University for the selected buildings in the year 2018. Table 2 shows the monthly average load of electricity.

Based on Table 2 data, the total electricity consumption and the power peak load can be determined. The total annual electricity use was 5,779 MWh, and the power peak load was around 1,000 kW.

Table 2 The electricity consumption of University Politehnica of Bucharest selected buildings campus

Month	Electricity Usage (MWh)	Power Load (kW)
January	594	958
February	620	923
March	590	793
April	582	808
May	579	778
June	423	588
July	375	504
August	123	165
September	256	356
October	487	655
November	563	782
December	587	789

4 Equipment sizing

4.1 Gas fired heating plant

In the first stage, a review of the most relevant boiler available in the market was performed. The selection process is based on the availability of information on the capacity, as indicated in the current bill and its price for the financial review.

The high efficient boiler Weil McClain manufacturer is selected, an ultra commercial boiler 94 series, the description of this boiler is shown in Appendix (Table 6).

The selection is based on the current bill, which indicates the energy use of 25 MWh. After the review and the boiler's selection, the next step is to establish the best approach to determine the natural gas consumption in the selected boiler and the university's available data. The best approach found up to now is provided by RETScreen software [13], which has considered these factors in its calculation:

- Area covered for space heating and its heat load per square meter.
- A direct calculation to obtain natural gas consumption in m^3.
- A proportion of heat water demand.
- Heat delivered to the system.

The boiler efficiency is 80 % and seasonal efficiency 75 %, along with its operations. The result is obtained, as shown in Appendix (Table 6). Other assumptions used in this case are:

- The total number of boilers required is five, with four boilers in operation and one standby.
- One boiler will be used to meet the base load capacity, and four boilers will be used in peak load capacity.

4.2 Gas fired internal combustion engine for cogeneration

The cogeneration plant's basic principle is using the energy from natural gas to generate electricity and recover the flue gas thermal energy for heating purposes.

The IC engine's sizing calculation is based on the electricity peak load capacity at 1,000 kW and the average heat load at 2,100 kW. To fulfill this energy demand, two units of GE JGS 320 were selected. Each unit of GE JGS 320 has an electrical and thermal output of 1,064 kW and 1,222 kW, respectively. The cogeneration system's technical performance is indicated by the overall efficiency, total annual electricity, thermal energy production, and fuel consumption.

To ensure the maximum utilization rate, the engines are running at full capacity mode. The IC engines can deliver the total annual electricity and total annual heat recovery of 18,641 MWh and 21,409 MWh, respectively, with an overall maximum efficiency of 85.94 %.

Since the annual electricity production is larger than the annual power demand, the excess power of 12,862 MWh can be exported to the grid. On the other hand, the total annual heat recovery is insufficient to cover the heat demand during the peak period. Thus, the natural gas-fired heating plant indicated by the blue bar in Fig. 2 should cover the remaining heat demand of 3,804 MWh. Since the IC engine runs at full capacity mode, it produces a constant heat recovery for the whole year. Thus, a heat excess during the summer period must be considered, either as a potential thermal energy or heat loss indicated by the yellow bar in Fig. 2.

The total annual fuel consumption can be estimated by adding the natural gas consumption of cogenerating engines and the auxiliary boilers used during peak season.

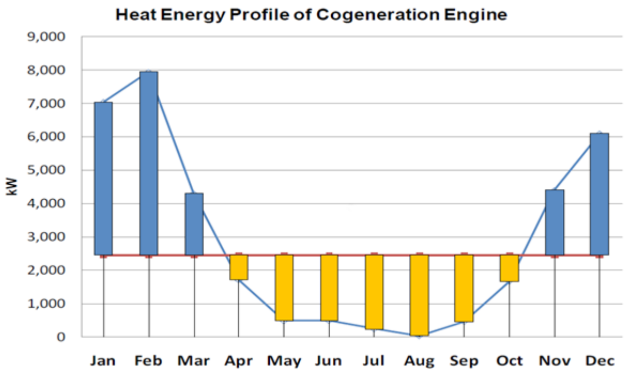

Fig. 2 The heat energy profile of cogeneration engine

Using the gas lower heating value of 10.8 kWh/m^3, the total annual fuel consumption is estimated as follow:

$$\begin{aligned}&\text{Natural gas consumption of cogenerating engines}\\&= \text{Cogeneration Engine Heating}\\&/\big(\text{Calorific value of natural gas}\\&\times \text{Electrical Efficiency } \left(\mu_{El}\right) = 40.1\ \%\big) = 4{,}315{,}111\ \text{m}^3\end{aligned}$$

$$\begin{aligned}&\text{Natural gas consumption of Auxiliary Boiler}\\&= \text{Auxiliary Boiler calorific value}\\&/\big(\text{Calorific value of natural gas}\\&\times \text{Auxiliary Boiler thermal efficiency } \left(\mu_{T}\right) = 80\ \%\big)\\&= 1{,}462{,}417\ \text{m}^3.\end{aligned}$$

The Total Natural gas consumed is 5,777,528 m^3. The summary of the technical performance of cogeneration engine system is shown in Appendix (Table 7).

4.3 Gas fired internal combustion engine for cogeneration with an ORC recuperative cycle

The basic principle of an ORC addition to the cogeneration engine is to recover the thermal energy production excess or waste heat during summer. In this proposal, the cogeneration system and boilers capacity remain the same as the second proposal. ORC's sizing calculation is based on the excess thermal energy during the summer period, which is equal to 8,689 MWh. This amount of heat can be converted into electricity by using a unit of Cogeneration Engine with the model Turbogen 4 HR with an electrical efficiency of 18 %. The electrical output of the engine is 400 kW.

The Turbogen engine can deliver the total annual electricity of 1,581 MWh, exported to the electricity grid. This system's main drawback is its low utilization rate since it only runs in the summer. Since the ORC system's energy input is waste-heat from cogeneration engine. The addition of an ORC turbine in the cogeneration system does not increase the fuel consumption. The summary of cogeneration's technical performance with an ORC recuperative cycle is shown in Appendix (Table 8).

5 Financial analysis

Many parameters were engaged in calculating the financial assessment for each case presented earlier. The parameters used in our analysis are:

1. Operating cost is the recurring expenses to the operation of facilities/equipment. For this analysis, the parameter is fuel cost.
2. Revenue is income received by a business from its normal business activities. In case 1, there is no revenue. In case 2, revenue is the sum of the export of electricity from CHP to the grid and the potential saving of electricity and thermal consumption, as indicated in the current bill. In case 3, revenue is the same as case 2, plus the export of electricity by utilizing gas waste.
3. Profit is gross profit less all operating expenses. In case no 1, profit is taken from the potential saving of fuel consumed by the boiler and the current bill annually. In case 2, profit is generated from the difference between its revenue and the fuel cost annually. In case 3, the profit is produced as case 2 Net Present Value (NPV). The net present value is the indicator used for the financial assessment. It is a time series of cash flow, both incoming and outgoing, defined as the sum of the individual cash flows' present values. All the values used for NPV calculation are taken from Europe's Energy portal, as indicated in Table 3.

Along with the NPV calculation, these assumptions are applied:

1. The lifetime expectation for each equipment is 15 years.
2. The depreciation method used is linear depreciation
3. The tax rate for exporting electricity in Romania is 35 %.
4. The discount rate in Romania for investment is 16 %.
5. Technician's salaries are not included in the calculation since they do not reflect the changes before and after the implementation of cases.

The financial assessment result for all the proposed cases is shown in Fig. 3.

As shown in Fig. 3, the expected loss for case 1 is negative, and obviously, the net present value shows negative as well. The second proposed system can generate considerable revenue due to the electricity sold to the grid. It also confirms that both saving and net present value are positive. The massive saving is made, besides selling electricity, because the equipment's investment is small compared to the output. Therefore, it can be concluded that the project is promising for further study as long as it is allowed to export or sell the electricity to the grid.

Table 3 Energy prices in Romania [14]

Parameter	Unit	Value
Fuel rate – base case	Eur/kWh	0.0200
Electricity rate – base rate	Eur/kWh	0.0847
Fuel rate – proposed case	Eur/kWh	0.0198
Electricity export rate	Eur/kWh	0.0700
Electricity rate – proposed case	Eur/kWh	0.0847

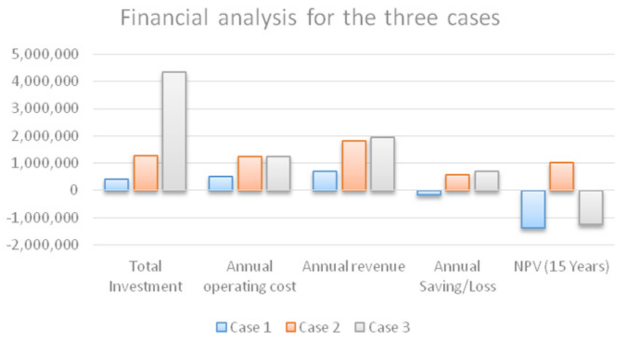

Fig. 3 Financial analysis for the three cases

The third case makes savings during its operation annually, but the net present value calculation is the opposite. This happens due to the high investment cost on the ORC system, and its saving cannot cover it for 15 years of operations. Hence, it is not recommended for further development.

6 Emission analysis

In Section 6, the greenhouse gas emission will be analyzed to assess the overall greenhouse gas (GHG) impacts of fuel and to calculate the total reduction of CO_2 when implementing the proposed cases in this work

This project's greenhouse gas emission analysis method is based on the RETScreen GHG Analysis Reduction model [13].

$$\Delta R_{\text{GHG}} = \left[\text{FC} \times \text{tCO}_2\right]_{\text{BC}} - \left[\text{FC} \times \text{tCO}_2\right]_{\text{PC}} \tag{2}$$

For base case emission analysis, it is considered that the electricity is produced by a coal-fired power plant with general efficiency of 35 %, and thermal energy is produced by a gas district heating system with boiler efficiency of 70 %. The GHG emission factors are taken from the RETScreen database [13]. The overall annual GHG emission for the base case is estimated at around 26,063 tCO_2. In the first proposed case, the GHG emission has resulted from the combustion of natural gas in boilers and the electricity purchased from the coal-fired power plant. The overall annual GHG emission for the first case is estimated at around 24,862 tCO_2. In the second proposed case, the GHG emission results from the combustion of natural gas in the cogeneration engine and the transportation and distribution losses of electricity exported to the grid. The T&D loss is estimated at around 8 %. The overall annual GHG emission for the second case is estimated at 7,740 tCO_2.

The third proposed case GHG emission similarly results from the combustion of gas in the cogeneration engine and the transportation and distribution losses of electricity exported to the grid. But in this case, the T&D loss is higher than the second case since the quantity of electricity exported to the grid is also higher due to the addition of an ORC turbine. The overall annual GHG emission for the second case is estimated at around 7,875 tCO_2.

By using GHG emission analysis, it appears that the second proposed case produces the least amount of annual greenhouse gases emission. This result should be taken into considerations for technology selection. The detail of the GHG emission calculation is shown in Table 4.

7 Conclusion

In determining the building's heat supply, many factors should be considered, i.e., heating degree days of the location, coverage area, building insulation, the proportion of water and space heating, total hours, and seasonal efficiency. Technology selection should also consider the equipment efficiency factor and the Technical, financial, and environmental feasibility.

To select the most feasible energy system proposal, strategic planning was used to identify each proposal analysis's strengths and weaknesses are elaborated to compare all option's viability. By comparing each proposal's strengths, weaknesses, opportunities, and threats using technical, financial, and environmental criteria, one can decide which proposal is to be selected. The detailed analysis is shown in Table 5.

From a financial and environmental point of view in this case study. It is concluded that the most feasible project is gas-fired Internal Combustion Engine cogeneration, considering profit revenue from selling/exporting power to the domestic electricity grid that will support the financial feasibility of this choice.

Table 4 Greenhouse gas analysis method

Proposal	GHG emission factor (tCO_2/MWh)		Fuel consumption (MWh)		GHG emission (tCO_2)		Total GHH emission (tCO_2)
	Heating	Electricity	Heating	Electricity	Heating	Electricity	
Base Case	0.179	1.05	40,020	17,947	7,164	18,899	26,063
Case 1	0.179	1.05	33,617	17,947	6,017	18,845	24,862
Case 2	0.179	1.05	37,204	1029	6,659	1,80	7,740
Case 3	0.179	1.05	37,204	1158	6,659	1,215	7,875

Table 5 Strategic planning to identify strengths, weaknesses of each proposal (SWOT analysis)

Proposal	Case 1	Case 2	Case 3
Strength	High efficiency for heating system	1- Higher overall efficiency 2-Relatively low GHH emission 3-Economically feasible	1-Higher overall efficiency 2-Relatively low GHH emission
Opportunity	Excess thermal energy during the summer period can be utilized	1-Excess of thermal energy during the summer period can be utilized 2-able to generate revenue from electricity exported to the grid	1-Excess of thermal energy during the summer period can be utilized 2-more electricity exported to the grid due to additional ORC
Weakness	Not economically feasible due to the high investment of heating system and high operating cost	T&D losses to electric grid contribute to GHG emission	1-Not financially feasible due to the high investment of ORC turbine 2-T&D losses to electric grid contribute to GHG emission
Threat	Lack of gas supply in time of shortage may disrupt the operation	Lack of gas supply in time of shortage may disrupt the operation	Lack of gas supply in time of shortage may disrupt the operation

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Nomenclature

Q_{H}	Total Heating Demand of a Building (MWh)
Q_{SH}	Heating Demand for Space Heating (MWh)
Q_{DHW}	Domestic Hot Water Heating (MWh)
μ	Efficiency
ORC	Organic Rankine Cycle
NPV	Net Present Value
GHG	Green House Gas
ΔR_{GHG}	Annual GHG emission reduction ($\mathrm{tCO_2}$)
FC	Fuel consumption (MWh)
$\mathrm{tCO_2}$	GHG emission factor ($\mathrm{tCO_2/MWh}$)
PC	Proposed Case
BC	Base Case

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Appendix

Table 6 The characteristics of boilers

System summary	Unit	Description
Baseload heating system		
Technology		Boiler
Fuel type		Natural gas
Unit capacity	MW	2.04
Installed capacity	MW	2.04
Heating delivered	MWh	14,216
Annual fuel consumption	m^3	1,755,122
Manufacturer		Weil-MacLaine
Model		Ultra commercial boiler
Seasonal efficiency		75 %
Peak load heating system		
Technology		Boiler
Fuel type		Natural Gas
Unit capacity	MW	2.04
Installed capacity	MW	6.12
Heating delivered	MWh	10,439
Annual fuel consumption	m^3	1,432,073
Manufacturer		Weil-MacLaine
Model		Ultra commercial boiler
Seasonal efficiency		70 %

Table 7 The characteristics of cogeneration engine

System summary	Unit	Description
Overall efficiency	%	85.94 %
Power		
Technology		NG Cogeneration engine
Operating strategy		Full power capacity output
Fuel type		Natural gas
Annual fuel consumption	m^3	4,315,111
Electricity output	kW	2,218
Electricity efficiency	%	40 %
Electricity produced	MWh	18,641
Electricity delivered to load	MWh	5,779
Electricity delivered to grid	MWh	12,862
Baseload heating system		
Technology		NG Cogeneration engine
Capacity	kW	2,444
Heating delivered	MWh	21,409
Peak load heating system		
Technology		Boiler
Fuel type		Natural Gas
Fuel consumption	m^3	1,462,417
Capacity	kW	6,120
Heating delivered	MWh	3,804
Manufacturer		Weil-MacLaine
Model		Ultra commercial boiler
Boiler efficiency		80 %

Table 8 The characteristics of cogeneration engine + ORC

System summary	Unit	Description
Overall efficiency	%	89.39 %
Power		
Technology		NG Cogeneration engine
Operating Strategy		Full power capacity output
Fuel type		Natural Gas
Annual fuel consumption	m^3	4,315,111
Electricity output	kW	2,218
Electricity efficiency	%	40 %
Electricity produced	MWh	18,641
Electricity delivered to load	MWh	5,779
Electricity delivered to grid	MWh	12,862
Electricity efficiency		ORC turbogen heat recovery
Thermal power load	kW	2,200
Net electric efficiency	%	18 %
Electrical output	kW	400
Annual thermal output	MWh	8,689
Annual electricity output	MWh	1,581
Base load heating system		
Technology		NG Cogeneration engine
Capacity	kW	2,444
Heating delivered	MWh	21,409
Peak load heating system		
Technology		Boiler
Fuel type		Natural Gas
Fuel consumption	m^3	467,080
Capacity	kW	4,080
Heating delivered	MWh	4,036
Manufacturer		Weil-MacLaine
Model		Ultra commercial boiler
Boiler efficiency		80 %