Proceedings of ECOS 2009
Copyright © 2009 by ABCM

22nd International Conference on Efficiency, Cost, Optimization
Simulation and Environmental Impact of Energy Systems
August 31 – September 3, 2009, Foz do Iguaçu, Paraná, Brazil

ENERGY SAVINGS USING TRIGENERATION ON BUSINESS AND HOTEL COMPLEX "AIRPORT CITY BELGRADE"

Ivan Glisic, B.Sc.M.E., hvac.plus@sezampro.rs
Consultant in HVAC projects, HVAC plus, Kneginje Ljubice 15, Belgrade, Serbia

Goran Vuckovic, MSc.M.E., vucko@masfak.ni.ac.rs
Faculty of Mechanical Engineering, University of Niš, A. Medvedeva 14, Nis, Serbia

Aleksandra Sretenovic, B.Sc.M.E., alexandrica011@yahoo.com
Termotrade, Glavna 18, Zemun, Serbia

Abstract. *As a basic foundation for this study, expenses of exploitation are used, electric and gas bills, as well as general costs and expenses in the present Airport City business complex in Belgrade (ACB). To improve energy efficiency of similar buildings, the authors of this study wanted to present the various investment possibilities concerning energy saving. ACB is representative of typical (modern) business complexes that are being built intensively in Serbia and throughout Europe. Today, most similar constructions are designed in similar manner, with air cooled chillers on the roofs of the buildings. These installations are simple and less expensive for investors, quicker to erect, and much cheaper for commissioning. However, over an exploitation period of 15 years, it was proved that energy waste is much higher in these installations, which implicates a rise in cost of monthly fees. Ultimately, common citizens are paying for this through various products and services. At the time of writing of this study, at least six similar complexes are in the planning phase to be constructed in Belgrade. The suggestions in this study can be implemented on other complexes with some or no modification.*

The basic idea of this study is to demonstrate an analysis of the investment and the exploitation wages with regard to the payback time for an investment in CCHP trigeneration. On the one side, the example of a plant with boiler and air cooled chillers will be used, vs. CCHP with gas cogeneration on the other side.

The basic structure of the building is a core and shell structure with an aluminum-glass façade. The height of the building is 35 floors.

Cooling and heating calculations have been done using HAP software (Hourly Analysis Program).

Keywords*: trigeneration, CCHP, absorption chillers, energy savings, economic analysis*

1. INTRODUCTION

Trigeneration can be defined as combined heat and power production with the additional production of cooling. Trigeneration systems produce these three useful forms of energy from a primary source of energy such as natural gas or oil. They typically produce electrical power via a reciprocating engine or gas turbine and recover a large percentage of the heat energy that is retained in the coolant water and exhaust gas. The heat produced can be totally or partially used to drive absorption refrigerators. Although the investment cost of trigeneration systems is initially higher, they are more economical compared to those systems where power, heat and cooling are obtained individually.

Another important advantage of the system is its reduction of CO2 and other emissions. Yet another advantage of the system is its reliability of supply. There is no doubt that industry will be using these systems increasingly in the coming years.

Combined cooling, heating and power (CCHP) for buildings is a concept that encompasses the local production of electricity for applications along with the utilization of waste heat produced during the power production process. The waste heat can be made available for heating and/or cooling applications using thermally activated technologies such as absorption chillers. The advantage of CCHP for buildings is the high primary energy efficiency of the system, the environmental benefits, and economic feasibility. This is accomplished as a result of the utilization of the heat made available from electricity generation as well as elimination of losses due to transmission and distribution because the power is produced on site.

To improve trigeneration, we will observe as an example true calculations for the project of the hotel and business centre in Airport City Belgrade (ACB). Heat loads were done in HAP 4.3 (Hourly Analysis Program 4.3).

2. ECONOMICAL REVIEW OF THE BUILDING BUSINESS IN SERBIA

Investors are usually interested in small initial investment, not in LCC (Life Cycle Cost). In these conditions, the renting of office space is a favorable and very profitable business. Banks are interested in quick capital revenue, so they support this kind of investment and its short pay-off time. Electricity bills are paid by tenants multiplied by the factor of the owner (as a fee for manipulative expenses, usually 3-5%). Consequence of this money flows is the fact that services of the tenants are becoming more and more expensive. Ultimately, someone other than the investors will pay for the electricity being consumed.

On the other hand, (even) the wealthiest countries are far more concerned with the subject of energy conservation, in particular Japan, Denmark and Norway. The reason for this is the very high cost of electrical energy in these countries. According to data from Saibugas, one of the leading and biggest gas distributors in Japan, Japan is the leading country in homes using gas. Figure 1 shows proved reserves of natural gas in 2005.

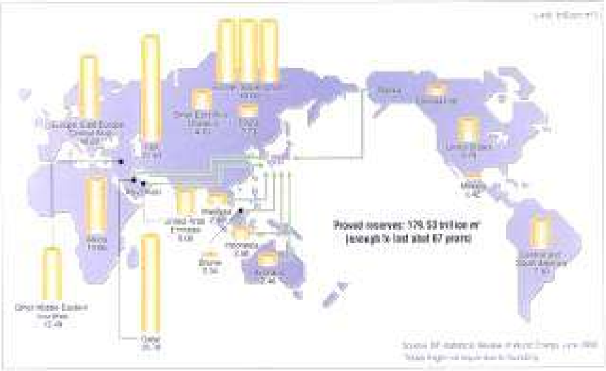

Figure 1. Proved gas reserves in 2005

Japan is also one of the leading countries in gas exploitation. They are currently using cogeneration combined cycles even in small capacities in home appliances.

According to energy low in Serbia the energy production is only theoretically possible. The sale, resale and distribution of energy is reserved only for the state owned EPS Company. That is one of the reasons why gas cogeneration is practically not present in Serbia. Gas cogeneration presence can be improved if we inform the investors all of the benefits that can be gotten from combined power plants, even small ones. When the price of electricity increases enough, these combined power plants will be of increasingly greater interest.

3 THEORETICAL BASES FOR CALCULATIONS

Nomenclature

COP_{RC}	coefficient of performance of a vapor-compression chiller, *kW/kW*
COP_{RA}	coefficient of performance of absorption chiller, *kW/kW*
PER	primary energy rate *kW/kW*
E	exergy flow, *W*
e	specific exergy, *kJ/kg*
h	enthalpy, *kJ/kg*
$\dot{m}$	mass flow, *kg/s*
Q	heat flow, *kW*
CCHP	combined cooling, heating and power
Q_{jw}	recovered heat from cooling jacket of gas engine
$T_{jw\ IN,\ OUT}$	inlet, outlet temperature of the water from cooling jacket of gas engine
Q_{eg}	recovered heat from exhaust gases of gas engine
$T_{eg\ IN,\ OUT}$	inlet, outlet temperature of the water from exhaust gases of gas engine
Q_{acRP}	refrigeration power of the adsorption chiller
$T_{ac\ RP\ IN,\ OUT}$	inlet, outlet temperature of the water from absorption chiller
Q_{acHP}	heating power of the adsorption chiller
$T_{ac\ HP\ IN,\ OUT}$	inlet, outlet temperature of the hot water for absorption chiller
$c_{p,w}$	specific heat of water, *kJ/kgK*
r_{elth}	electricity to thermal heat recovered ratio, -
P_{el}	electric power output, *kW*
η_{el}	the electrical efficiency
h_{total}	the total thermal and electrical efficiency,
m_g	natural gas consumption rate
CPU	Central Process Unit
t_{oa}	temperature of outside air, ºC

t_{wb}	wet bulb temperature, °C
t_{in}	inlet temperature, °C
t_o	outlet temperature, °C

Theoretical bases of proposed combined cooling, heating and power production cycle (CCHP system)

The refrigeration system is designed with a gas engine, compression chiller and absorption chiller. The gas engine is driven to supply electrical power and the recovered waste heat from the cylinders and exhausted gases are used to drive the lithium bromide absorption chiller for cooling purposes, or to output heating or hot water. The electricity from the gas engine is used for consumers and the vapor-compression refrigeration cycle. This refrigeration system has a higher energy utilization efficiency; the owners of the building can reduce operating (general expenses) costs. Figure 5. shows proposed CCHP

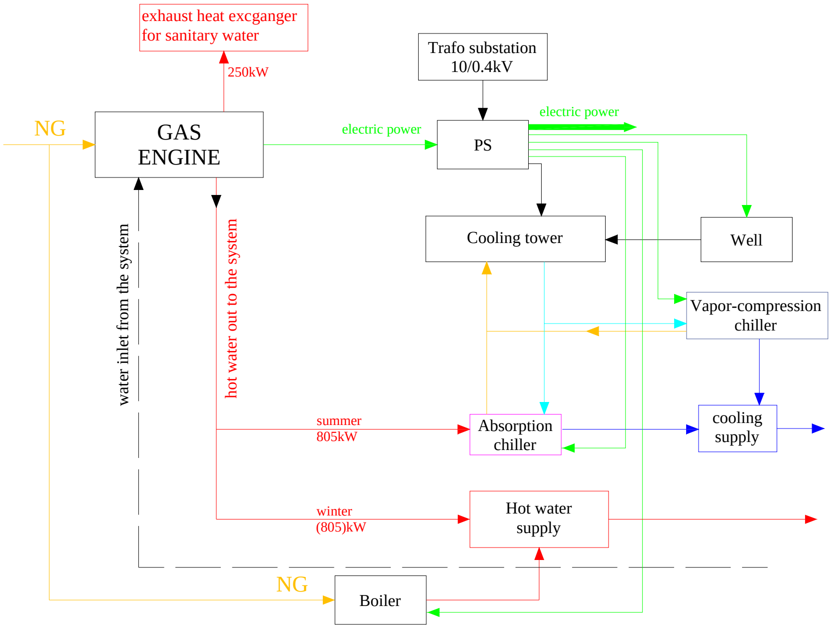

Figure 2. CCHP for the ACB buildings 1000 N+S

In the following equations we observe the calculation parameters and formulas that were used. In the combined process we can not use the usual COP, instead we use PER (PRIMARY ENERGY RATE [2], [3], [4]), as it is shown onwards (in the rest of this study). The performance parameters are calculated as follows:

$$Q_{jw} = c_{p,w} m_{jw} (T_{jw,OUT} - T_{jw,IN}) \tag{1}$$

$$Q_{eg} = c_{p,w} m_{eg} (T_{eg,OUT} - T_{eg,IN}) \tag{2}$$

The heat flow rate can be gathered from the cooling jacket of gas engine, as well as heat from exhaust gases, where the water temperature from the jacket heat exchanger, in and out represent inlet and outlet, respectively.

Electricity to thermal heat recovered ratio $r_{el\ th}$, and electrical power output P_{el}.

$$r_{elth} = \frac{P_{el}}{Q_{jw} + Q_{eg}} \tag{3}$$

The electrical efficiency, η_{el}, and the thermal efficiency are defined as:

$$\eta_{el} = \frac{P_{el}}{Q_{NG}},\ \eta_{th} = \frac{Q_{jw} + Q_{eg}}{Q_{NG}} \tag{4}$$

where NG is natural gas, and the total thermal and electrical efficiency can be defined as

$$\eta_{tot} = \eta_{el} + \eta_{th} \tag{5}$$

The COP of vapor-compression chillers and absorption chillers can be defined as:

$$COP_{RC} = \frac{Q_c}{P_{el}}, \text{ including fans, } COP_{RA} = \frac{Q_a}{Q_{hpa}} \tag{6}$$

where Q_{hpa} is input hot power in absorption chiller. Coefficient of performance (COP) is an effective parameter that is used to evaluate the energy efficiency of systems for cold production. But it is not satisfactory criterion for the combined system. Primary energy rate (PER) is a satisfactory criterion to evaluate the combined system. PER is defined as the ratio of the required output (sum of the heating, cooling and electrical power) to primary energy demand. The system with the higher value of PER is considered as the better.

$$PER_{CCHP} = \frac{Q_h + Q_R + P_{el}}{P_{NG}}, \tag{7}$$

4. DESCRIPTION OF THE DESIGNED INSTALLATION (CLASSICAL TYPE OF DESIGN AN HVAC INSTALLATION)

As an integral part of the Airport City business complex in Belgrade (ACB), there are two front towers, named 1000 S and 1000 N, and they are designed as standard hotel and office space. The gross leasable area (GLA) of the towers is approximately 46 000 m^2. Both towers are designed as core and shell structures, so this study can be applied more or less to many other new buildings in Serbia. Nevertheless, the core and shell concept of the designing is increasingly in use all over the world.

Both towers are supplied with electricity from the same transformer substation 10/0.4kV via a main feeder. In the office building there are open space offices on each floor and sanitary utility in the core of the building. Air conditioning is designed as a four pipe fcu system and fresh air supply. Hotel rooms are also designed with four pipe fan coil units (fcu) and supply of fresh air. FCU and ducts are placed within a suspended ceiling; the supply of fresh air is designed at the entrance of each fcu/room. Occupation of the room is detected by use of a magnetic card. Indoor conditions of the room are standard 20/26 ºC (winter/summer). When a room is in use, the fcu is in use and damper of fresh air is open. Otherwise, the fcu is set to economic mode, to maintain temperature on the Δt of 4 ºC and fresh air damper is closed. Each fcu has a three-way valve controlled by PLC on the floor. Temperature in the office space is regulated through a local thermostat.

AHU for the rooms is driven according to the Δp on the supply duct via a frequency converter. Cold water is obtained by an air cooled chiller placed on the roof. The main pumps are driven by f.c. There On each fcu is two way valve controlled by local thermostat. Cold and hot water system are defined as variable flow system.

The heat source for both towers is a boiler house (two boilers with equal capacity). Natural gas (NG) is used as the combustion fluid. As mentioned before, the purpose of this work is to demonstrate how power efficiency can be improved significantly and to persuade investors and the Serbian government to invest in CCHP in future investments. In a building with similar construction and purpose, energy consumption is similar. An etalon for future electrical billing are the present electrical bills for the rest of the complex. The demands for cooling and heating for this building are shown in Table 1. The quantity of fresh air in demand for both towers is approximately 50.000m^3/h.

Table1. Heating and cooling loads for the 1000N and 1000S buildings,
simultaneous maximum of System 1 and System 2

	System 1						System 2- CCHP					
	Cooling loads			Heating loads			Cooling loads			Heating loads		
	N office	S hotel	**Total**	N office	S hotel	**Total**	N office	S hotel	Total	N office	S hotel	Total
System	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW	kW

FCU	1,764	1,852	3,616	840	970	1,810	1,764	1,852	3,616	840	970	1,810
AHU	150	190	340	298	351	649	80	100	180	220	270	490
el power for hum.				50	70	120						0
Restaurant	65	260	325	40	67	107	65	260	325	40	67	107
swimming pool		73	73		220	220		73	73		220	220
hot water				70	180	250				70	180	250
radiators, convectors				60	48	108				60	48	108
Total			4,354			3,144			4,194			2,985

4.1 Description of the new designed system (combined CCHP in HVAC installation), dimensioning of the gas engine

In the proposed concept only the heat source will be changed. Instead of using classical Air Cooled Chillers, absorption chillers combined with vapor-compressor chillers will be used for cooling and gas firing boilers will be replaced with a combination of a gas engine and a classical gas firing boiler for heating. Reduction in cooling and heating demands for AHU will be achieved by adding recuperation from the exhaust air from building. Additional reductions in exploitation cost will be achieved by adding an additional stage of filtering fresh air. According to EUROVENT literature, the payback period for this investment in two stage filtering is 2 years.

Simultaneous consumption of electricity in both towers is approximately 2.3MW. The main problem is dimensioning of the gas engine. The idea is to have maximum efficiency of the fuel combustion and system in general. For this purpose a piston gas engine is applied. The amount of pressure on the gas train is 300mbar. If we know that in Serbia it is not possible to sell excess of electrical energy to the power system network, at least for the sake of practicality, we choose a gas engine only for the self usage, as the main source of energy. This type of gas engine has a best performance in a range from 80-100%. However, the transformer sub-station is designed to function in full capacity in case of failure of the gas engine and during its reparation period. When we evaluated a gas engine, we were lead by the recommendations of the manufacturer.

The most important qualities we sought were: required power output; (whether it is for self usage or connected to a power network); voltage of the network; heat dissipation needed, does the motor run as a support or main source of electrical power; what is the application for the rejected heat (heating, cooling?); temperature level of the fluid; is there additional safety cooling, what is predicted working period (daily, monthly, and yearly?); is there a back-up system?

After careful analysis of the whole system and answers to all of the above mentioned questions, the following model gas engine was proposed: G3516E LE, manufactured by Caterpillar. This model is intended for continuous work, its electrical rate being 2000kVA on 1500rpm. The idea was to use the gas engine as much as possible. LCC of the gas engine is approximately 15 years. It has a daily efficiency period of 16 hours. During weekends that period is 12 hours. At night, the common (default) system is used. But even then water cooled chillers are used, not air cooled. The SCADA system will provide calculation based on trends of consumption and wages for the rates schedules. A Citect SCADA system was proposed for this building complex. For BMS a Mitsubishi Electric system was designed, system Q with redundant CPU.

Values which were used are based on the LHV (Low Heat Value) of 35.6 MJ/Nm^3 at 101.60kPa and 0 ºC.

4.2 Dimensioning of the chillers and cooling towers

Heat rejection from the gas engine at full load is 1817 kW including stage 1, stage 2, oil cooler, exhaust and generator, with η_h=46.7%. Temperature of the exiting water is 95 ºC. This Energy is used in two ways: in absorption chillers for cooling as well as for the heating. In the buildings like high standard hotels, there is always a demand due to customers' needs for simultaneous cooling and heating in different locations of the venue such as the kitchen, swimming pool, spa, HW (hot water) etc.

For the constant consumption of the heating energy (hot water) approximately 250kW is used and it is pumped directly to the system parallel with gas fired boilers.

The rest of the heat rejected energy from gas engine will be split into two identical but independent absorption chillers. The important point during the process of dimensioning the absorption chiller is to choose the working fluid. In the absorption cycle, H_2O/LiBr and NH_3/H_2O are the two preferred refrigerants- and absorbent-pairs. While H_2O/LiBr absorption systems operate at vacuum pressures between 0.8 and 20 kPa, NH_3/H_2O absorption systems operate at much higher pressures, between 400 and 2500 kPa. A disadvantage of H_2O/LiBr is its narrow solution field, which is limited by crystallization, resulting in an absorber temperature limitation of approximately 40 ºC thus requiring a cooling tower.

NH_3/H_2O can operate at higher temperatures but the toxicity of NH_3 requires careful attention to system design, installation, and general expenses. $H_2O/LiBr$ is used for small to large capacity applications (residential to industrial installations from 10 to 26,000 kW) while NH_3/H_2O is used for either very small (small refrigerator and residential application less than 70 kW) or large capacity installations. As standard working fluid, LiBr was chosen for this case.

The appropriated chillers are 16LJ-22, manufactured by Sanyo&Carrier. Maximum cooling capacity of a single chiller is 545 kW. This result is very close to the minimum cooling capacity of the building in question all year round (approximately 15% of the maximum cooling capacity). Temperature regime of the cooling water was chosen to be set as 38/28 ºC, Δt=10 ºC due to best chiller energy performance. To reach a temperature less than the outgoing temp from the cooling tower, storm softened water will be used via an injection system. As a parallel secured system, a small plate heat exchanger for fresh potable water which will go to reservoir of hot potable water. That represents one more step of energy saving within the whole system. That point is to show that every machine in the mechanical plant can be used for energy conservation when it is meticulously planned and designed.

Rest of cooling capacity will be covered with screw water cooled chillers. Cooling demands are reduced on recuperation for AHU up to 40%, and cooling capacity for both towers 1000N+S is 4200kW. Screw chillers were selected due to their reliability, long life and possibility for changing capacity from 8-100%. Most important thing is choosing the chillers. Guided idea was COP and performance data. Chillers with best performance on the market, at the present time were chosen. COP of these chillers is going over 5 without cooling tower (IPLV can reach almost 7.5). That almost overcome centrifugal chillers, and they are chipper and easer to maintain. Proposed configuration of chillers is 3pcs 30XW-1012. Detailed data performance of chillers and cooling towers can be given upon request.

Cooling towers are dimensioned according to maximum capacity for absorption and water cooled chillers. The open cooling towers will be used in system. As any other object with same or similar purpose, hotel and office building need to have fire fighting installation. For those purposes one appropriate water tank were designed, with active volume of 250m3. Next to this tank an accumulation rain water tank were designed. Those tanks are placed under parking line. This tank is also used for the flushing and technical water for irrigation in and out of the buildings. As main supply of the water the well near tank is used. Depth of the well is 40m.

For cooling of absorption chillers and for the cooling of the vapor compressor chillers, we need flow of 833.74 m3/h. Temperature difference of incoming and outgoing water from cooling tower is 6 ºC (36/30 ºC). Mixture from absorption chiller and vapor compressor chiller is approximately 35.8 ºC. For the incoming temperature in cooling tower temp. was determined as 36 ºC. For the Belgrade twb is 24 ºC, as worst case. Those are the start conditions of dimensioning cooling towers. As the best solution proposed solution was 4 units of same cooling towers type VXT N265, manufactured by BAC, with frequency inverter driven fan. Fan power is 30 kW.

Difference in initial investments is 800.000 €. Common parts of the installation were not counted. It is shown in Table 2

Table 2. Initial investment of two systems: classical and CCHP

Equipment	**manufacturer**	**type**	**unit price**	**qty**	**total price**
			€		€
System 1					
Boiler	Viessmann	Vitoplex SX2 1600	25,000	2	50,000
Burner O_2 regulation freq. inv.	Weishaupt	G30	19,500	2	39,000
AHU, one filter, without rec. 18000m^3/h	Ciat		20,500	2	41,000
AHU, one filter, without rec. 9500m^3/h	Ciat		14,200	2	28,400
Chillers, air cooled screw compressor	Train	RTAC 350 STD	120,000	4	480,000
Basic BMS	Honewell		70,000	1	70,000
Total					**708,400**
System 2-CCHP					
Boiler	Viessmann	Vitoplex SX2 1600	25,000	1	25,000
Burner O_2 regulation freq. inv.	Weishaupt	G30	19,500	1	19,500
Gas engine 2000kVA,	Caterpillar	G3516E	650,000	1	650,000
AHU, two stages filter, with recuperation 18000m^3/h	Carrier		26,800	2	53,600
AHU, two stages filter, with recuperation 9500m^3/h	Carrier		19,300	2	38,600
Chillers, Absorption machine, hot water	Sanyo&Carrier	LJ-22	78,000	2	156,000
Chillers, water cooled, screw compressor	Carrier	WX 1012	98,000	3	294,000

Cooling towers	BAC	VXT N265	26,500	4	106,000
Pumps	KSB	Etanorm 150-200	6,500	4	26,000
Additional piping			25,000	1	25,000
Additional BMS redundant CPU	Mitsubishi El., system Q		85,000	1	85,000
SCADA system	Citect		35,000	1	35,000
Total					**1,513,700**

Calculated PER of the proposed CCHP with configuration described above was performed according to equations 6-7. During calculation all power inputs including pumps, fans, burners etc were taken into consideration. This calculation showed that a plant like this has PER_{CCHP}=1.295, while, on the other side, the PER of the classical system is PER_{CL}=0.893.

The next step was comparing the costs of a classical plant vs. a CCHP plant. To analyze this, we must take into consideration investment cost, fuel cost, and maintenance cost. We will not take into consideration pollution, reactive power, bigger barkers, bigger cables etc. Those factors will be excluded from this study.

In the Table 3. Comparative savings of primary energy demand are shown. This can be defined as the ratio of the saved primary energy in CCHP system to the primary energy consumption in a conventional separate system of the same energy output required and the formula for energy saving is written as follows [2-5]:

$$\Delta Q = 1 - \frac{PER_{CL}}{PER_{CCHP}} \tag{9}$$

Table 3. Primary energy saving comparing classical system with CCHP

	summer	winter	spring	autumn	average
PER_{CCHP}	1.295	0.778	1.009	0.852	0.984
PER_{CL}	0.893	0.528	0.786	0.658	0.716
ΔQ	0.311	0.321	0.221	0.228	0.270

For the financial calculation of the payback period for the CCHP, the following tariff rates were used. Table 4. shows tariff rates for the electricity consumption and fuel rate for Natural Gas. LHV (Low Heat Value) is calculated as 35.6 MJ/Nm^3. The price is given in 0.01€ cent/kW for Active high and low tariff, 0.01€/kVAr for reactive high and low tariff, 0.01€ cent/kW for calculated power (maximum power taken from the network during one month) and 0.01€cent/ Nm^3 of the gas.

Table 4. Current tariff rates for the electricity and natural gas n Serbia

tariff	AHT	ALT	RHT	RLT	Calc. power	NG
	kWh	kWh	kVAr	kVAr	kWh	Nm^3
0.01 €	3.88	1.29	0.32	0.64	541.65	33.68

During calculation, other positive aspects of the CCHP were not taken into consideration. A maxi graph function of payment was not calculated. Nevertheless, this could be more financially benefitting than anything else in industrial production.

Maintenance costs for the classical system 1 wages were provided by the ACB maintenance office, which was very helpful. For the maintenance of CCHP costs were taken from manufacturers of the equipment in CCHP. As we were witness to the 30 day long gas crises in the EU last winter, we can assume that price of gas will not be stable in the years to come. In this calculation, it is demonstrated that CCHP in not a profitable investment at all. But that is just the current situation, and proof that electricity prices are unrealistic, much lower then in rest of Europe. If the price of el energy increases 26.7% energy bills for system 1 and CCHP will be the same. In the figure 6. a relative price is shown of the annual energy rate due to the relative ratio of natural gas and higher active rate of electricity. In the figure 7 LCC for S1 and CCHP for period of 5 and 10 years are shown, respectively. The relative ratio of el/NG are in (€ cent/kWh)/(€cent/Nm^3), and prices of LCC are in €.

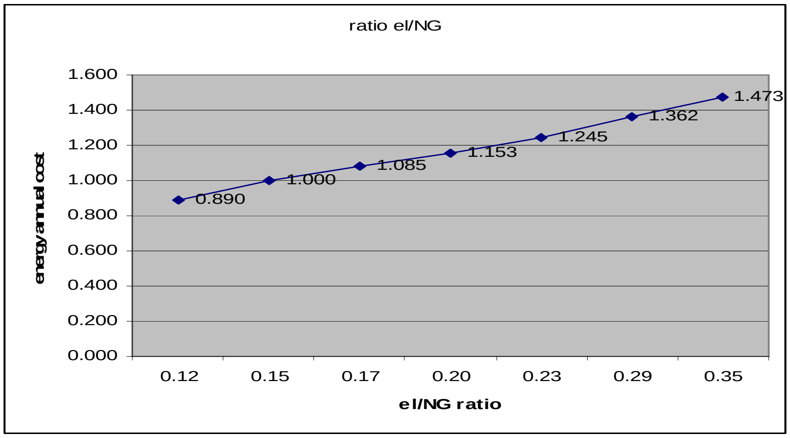

Figure 3. Relative energy rate due to relative ratio electric vs. natural gas price

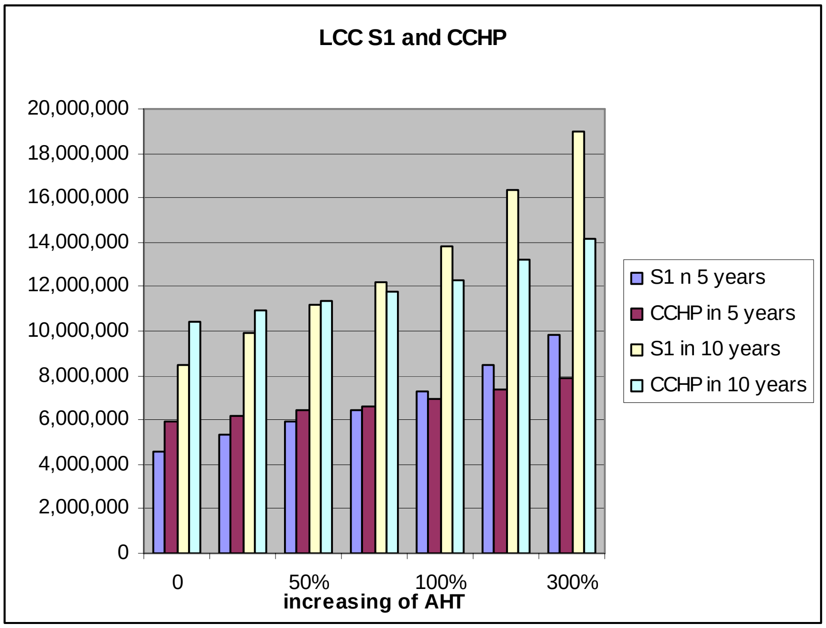

Figure 4. LCC of system 1 and CCHP due to increasing price of electricity for period of 5 and 10 years

5. CONCLUSIONS

Instead of a classical system for heating/cooling of business buildings and hotels consisting of boilers and air cooled chillers, CCHP was discussed. Major equations were shown, presenting a base for calculation. It was proven that the price of electricity in Serbia is still unrealistically low (even several times less then in EU). The proposed system saves more then 27% primary energy. It was also proven why the state and investors need to support this kind of investments. Instead of using electricity only for air conditioning in buildings and industry we can use gas for such purposes and save energy in the process. In this thesis, economically the price of electricity shows us when trigeneration will be very interesting in Serbia as it is in EU now. In the analysis, all aspects of the system were taken into consideration, initial cost, maintenance costs, and energy costs for period on 5 and 10 years. With the knowledge that the active period of a gas engine is more than 15 years, we can say with complete confidence that CCHP will soon be one of the main sources of energy. We can also transform wasted heat energy either into the cooling or heating potential for exploitation in buildings. A new approach to the comparison of these systems is the relative ratio of annual energy waste, and relative LCC for periods of 5 and 10 years. Concerning the relative ratio of energy prices (Electrical Energy price/Natural gas price), it is easy to see annual energy costs, upon which investors can plan an investment in CCHP, knowing the trends of energy prices. That figure can be crucial for the quick estimation of annual costs. Also, this could be very helpful to the people who are not mechanical engineers to estimate future savings.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Airport City Belgrade for the data for this work, Carrier for the support in software for dimensioning system for HVAC installations, Caterpillar for the data for gas engine, LCC and maintenance costs of the CCHP. Also from the field of BMS, literature from Mitsubishi Electric-Industrial Automation was very helpful. It was much easier to finish this paper with help provided from mentioned Companies.

REFERENCES

[1] Baehr HD, “Thermodynamik” (1978) Springer-Verlag
[2] Kong X.Q, R.Z. Wang, J.Y.Wu, X.H. Huang, Y.Huangfu, D.W.Wu, Y.X. Xu “Experimental investigation of a micro-combined cooling, heating and power system driven by a gas engine”
[3] Poredos A., A. Kitanovski, M.Tuma, “The energy efficiency of chillers in a trigeneration plant”
[4] Sun Zhi-Gao, “Energy efficiency and economic feasibility analysis of cogeneration system driven by gas engine”
[5] Sun Zhi-Gao, “Experimental investigation of integrated refrigeration system (IRS) with gas engine, compression chiller and absorption chiller”
[6] Tozer Robert, Ron W. James, “Heat powered refrigeration cycles”