ISTANBUL TECHNICAL UNIVERSITY

MECHANICAL ENGINERING DEPARTMENT

COURSE CODE: MAK483E

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TERM PROJECT – FINAL REPORT

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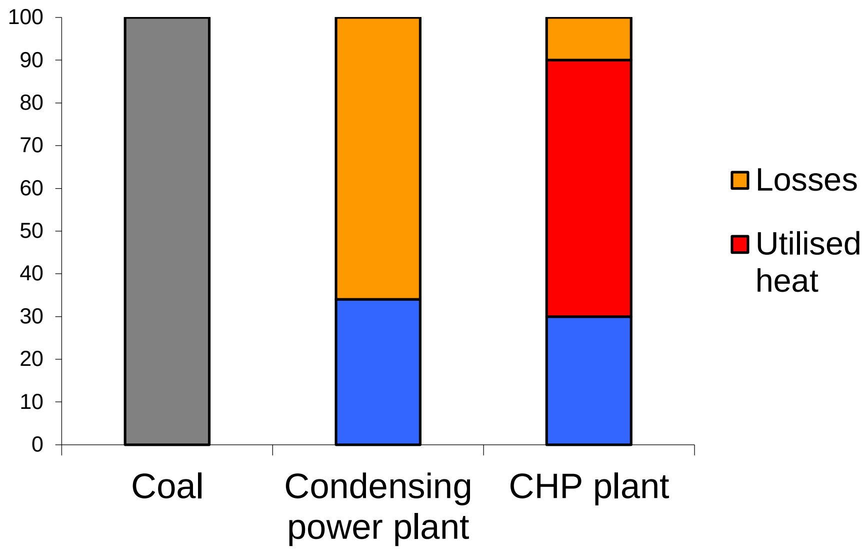
<u>MAK483E Thermal Environmental Engineering - Term Project</u>

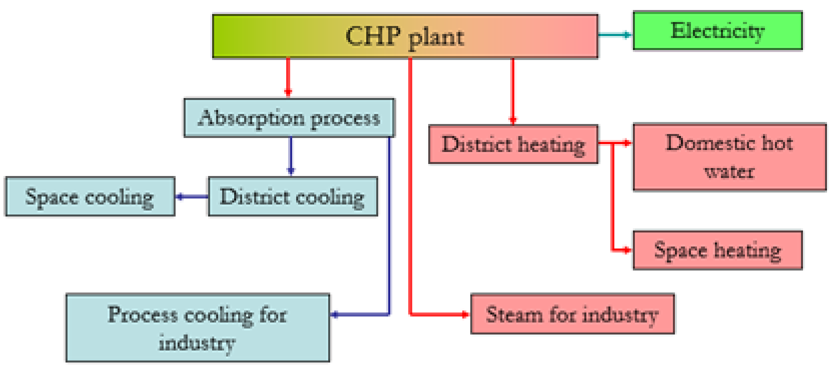
In this project, we will design a thermal system which produces 1 MW power for plant and also does the space heating, cooling and satisfy the power requirements of a nearby house district population of 400 people in the most economical way.

Energy systems consist of technical artifacts and processes as well as actors, organizations and institutions which are linked together in the conversion, transmission, management and utilization of energy. In this project we will use an industrial plant for generating electricity and satisfy other things which are specified about system. There a lot of power plant types which fulfills the design criteria.



Graphic 1: Comparison of Power Plants

With our design criteria, our system will generate electricity and utilizes heat for space heating and cooling. The system accomplishes these criteria by the economic way. For the economic efficiency losses must be minimum percent and technical efficiency must be in high levels. In graphic 1, we can see the comparison of power plants. CHP plant is more suitable for our design criteria. We will use a "***Combined Heat and Power***" (CHP) plant for thermal system.

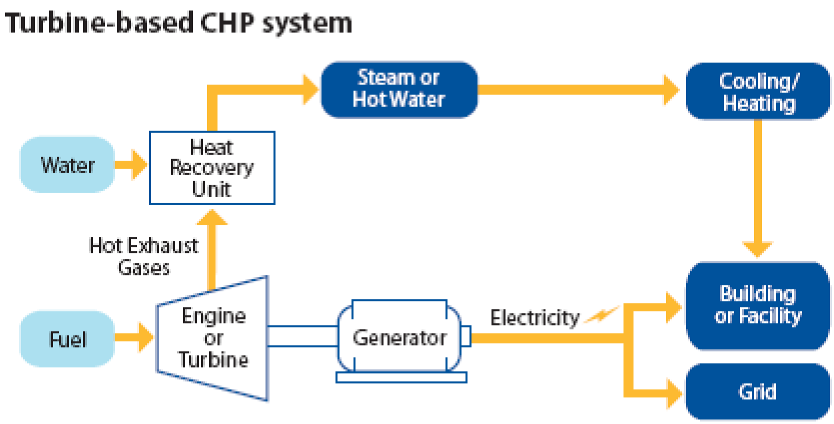


Graphic 2: Benefits of CHP

A CHP plant is used for different king of returns which are shown in graphic 2. In our project, plant must generate electricity, does space heating and cooling. With CHP plant we can satisfy these criteria.

If we can define the CHP plants, combined heat and power (CHP), also known as cogeneration, refers to the simultaneous production of electricity and thermal energy from a single fuel source. CHP systems can significantly reduce a facility's energy use by decreasing the amount of fuel required to meet the facility's electrical and thermal base loads.

The most common CHP system configurations use gas turbine or steam turbine prime movers. A CHP system with a gas turbine generates electricity by combusting a fuel (often natural gas or biogas) and using a heat recovery unit to capture the byproduct heat. Gas turbine configurations are most compatible with large industrial or commercial CHP applications that require large quantities of heat and power. The graphic below demonstrates how a typical gas turbine CHP system is configured.



Graphic 3: Turbine System of CHP Plant

For satisfy the requirements of the system, 20 tons/hour stream at 4MPa and 400^{o}C is available in our plant. We must use stream in a plant which includes turbines for generating energy. So, CHP plant is a wisely selection for our thermal system and also it includes all our requirements in a one system. Hot exhaust gas from the engine enters a heat exchanger that creates steam or hot water for space heating. This configuration is ideally suited to sites requiring ample amounts of both electricity and heat.

The other important section of our project, these requirements satisfy in the most economical way. If we compare power plants about efficiency and production cost, CHP is the most wisely selection. While coal-fired power plants are only about 30 percent efficient (after transmission losses), CHP systems are 65 to more than 80 percent efficient depending on the system design, the equipment and fuel being used, and the site's thermal energy demand. By substantially reducing the amount of fuel needed to produce heat and electricity, CHP systems can deliver significant cost savings and pollution reductions (see the sidebar). And because they generate electricity on-site, they not only eliminate transmission and distribution losses but also help protect against power outages and other grid-related problems. Also it provides important benefits for hospitals, manufacturing plants, government facilities.

We will use stream turbines for our CHP plant because it gives the highest efficiency for our plant than other CHP plants.

Efficiencies of Different CHP Systems

Not every CHP system operates at the same total system efficiency. Total system efficiency typically depends on the prime mover used. The most common prime movers include:

- Steam Turbine: 80% efficiency
- Diesel Engine: 70%-80% efficiency
- Natural Gas Engine: 70%-80% efficiency
- Gas Turbine: 70%-75% efficiency
- Mircroturbine: 65%-75% efficiency
- Fuel Cell: 65%-80% efficiency

Sources: U.S. EPA, 2007; 2007b.

Graphic 4: Efficiencies of Different CHP Systems

1) ALTERNATIVES AND KEY PARAMETERS

There are three alternatives about supplying requirements of system;

Heating	Cooling	Electricity
1) HW	HW-ABS	E
2) HW	E-VRC	E
3) E	E-VRC	E

We will design the system with 2 and 3.Then, results will be compared and we will select the economic one with selected parameters. We can make assumption about heating, cooling and electricity requirements. Systems which have nearby parameters with our system indicate average values for IZMIR. These are;

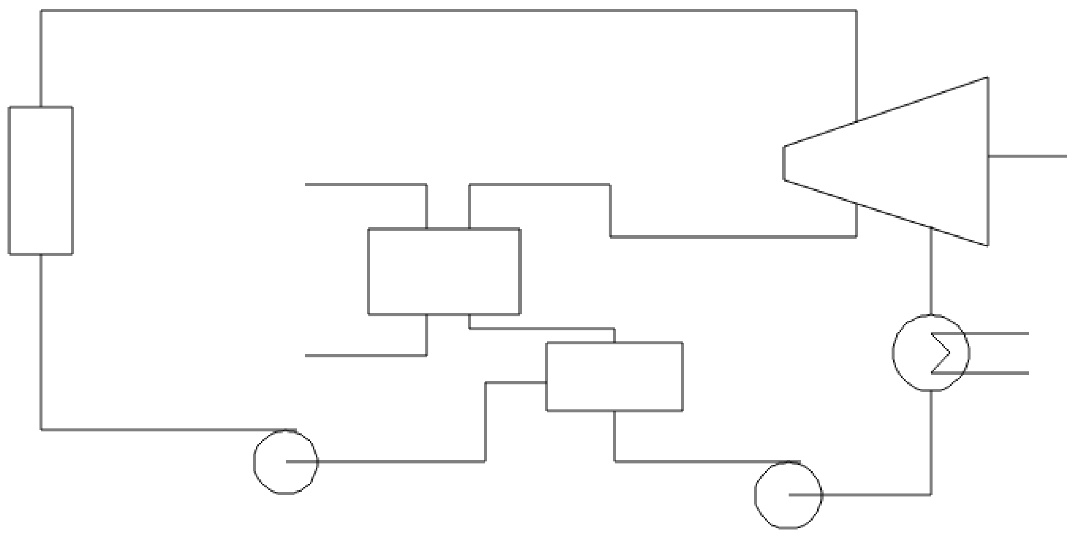
- Heating Requirements: 8-9 kW
- Cooling Requirements: 3-5 kW
- Electricity Requirements: 1kW

So, our energy requirements must be nearby to these values through parameters and calculations.

Parameters of our System:

- Q: 20 tons/hours
- P: 4 Mpa
- T: 400 ^{o}C
- Number of Houses: 100
- 200 m away from plant

With these parameters, we designed a thermal system which produces energy to supplying requirements:



2) THERMAL CALCULATIONS AND SIZING THE COMPONENTS

Location : İZMİR

Building : Single storey reinforced concrete, land-based flooring, detached

Structural Elements

- **Outer Wall**

3 cm exterior plaster

10 cm full brick (suitable for TS-704, TS-705)

5 cm polyurethane rigid foam sheet

10 cm full brick (suitable for TS-704, TS-703)

2 cm interior plaster

- **Floor**

3 mm PVC marley

5 cm cement mortar screed

20 cm normal reinforced concrete

20 cm clay fill soil

- **Ceiling**

10 cm glass foam sheet

20 cm normal reinforced concrete

- **Roofing**

% 33 inclined

K = 1.5 kcal/(h*m^2*°C)   wood-tile

- **Window**

Plastic frame, double glazed, dipterous openable window (1.5m*1.5m)

İZMİR : 0 ℃ → Exterior design air temperature

Interior conditions : 20 ℃

Temperature of attic : 6 ℃

Temperature of underfloor : 9 ℃

Overall heat transfer coefficients;

- **Outer Wall**

Exterior plaster : n = 0.87 W/(m*K) (0.75 kcal/(h*m^2*°C) L_{pe} =0.03m

Full Brick : n = 0.50 W/(m*K) (0.43 kcal/(h*m^2*°C) L_b =0.1m

Polyurethane : n = 0.035 W/(m*K) (0.030 kcal/(h*m^2*°C) L_p =0.05m

Interior plaster : n = 0.70 W/(m*K) (0.60 kcal/(h*m^2*°C) L_{pi} =0.02m

According to average wind speed, heat transfer coefficient of outer surface is

α_o = 25 W/(m^2*K)

According to natural air movement at closed volume, heat transfer coefficient of inner surface is α_i = 7.7 W/(m^2*K)

$$\frac{1}{K} = \frac{1}{\alpha(i)} + \sum \frac{L(i)}{\lambda(i)} + \frac{1}{\alpha(i)}$$

$$\frac{1}{K} = \frac{1}{7.7\,W/(m2K)} + \frac{0.03\,m}{0.87\,W/(mK)} + \frac{0.1\,m}{0.50\,W/(mK)} + \frac{0.05\,m}{0.035\,W/(mK)} + \frac{0.1\,m}{0.50\,W/(mK)} + \frac{0.02}{0.7\,W/(mK)} + \frac{1}{25\,W/(m2K)}$$

$\frac{1}{K}$ =0.129 + 0.034 + 0.2 + 1.428 + 0.2 + 0.028 + 0.04 =2.059 (m^2*K)/W

K = 0.485 W/ (m^2*K)

- **Floor**

PVC marley : n = 0.23 W/(m*K) L_m =0.003m

Cement mortar screed : n = 1.40 W/(m*K) L_s =0.05m

Normal reinforced concrete : n = 2.10 W/(m*K) L_c =0.20m

Clay fill soil : n = 2.1 W/(m*K) L_f =0.20m

$$\frac{1}{K} = \frac{1}{7.7\,W/(m2K)} + \frac{0.03\,m}{0.23\,W/(mK)} + \frac{0.05\,m}{1.40\,W/(mK)} + \frac{0.20\,m}{2.1\,W/(mK)} + \frac{0.2\,m}{2.1\,W/(mK)}$$

$\frac{1}{K}$ =0.129 + 0.013 + 0.035 + 0.095 + 0.095 = 0.367 (m^2*K)/W

K = 2.724W/ (m^2*K)

- **Ceiling**

Glass foam sheet : n = 0.050 W/(m*K) L_g =0.010m

Normal reinforced concrete : n = 2.10 W/(m*K) L_c =0.020m

$$\frac{1}{K} = \frac{1}{7.7\,W/(m2K)} + \frac{0.01\,m}{0.050\,W/(mK)} + \frac{0.020\,m}{2.1W/(mK)} + \frac{1}{25W/(m2K)}$$

$\frac{1}{K}$ =0.129 + 0.2 + 0.009 + 0.04 = 0.378 (m^2*K)/W

K = 2.645W/ (m^2*K)

- **Window**

2.6 W/ (m^2*K)

Dimensions : (4-6-4) mm

Radiation emission rate : ≤ 0.4 Interspace filling : Argon

- **Outer Door**

Wooden outer door : 3.5 W/ (m^2*K)

- **Calculation of Loss of Heat**

Mark	**Direction**	**Thickness**	**Length**	**Height or Width**	**Total Area**	**Quantity**	**Removed Area**	**Calculation Area**	**Heat Transfer Coefficient**	**Difference of Temrature**	**Loss of Heat**
		cm	m	m	m^2	Ad	m^2	m^2	W/m^2K	K	W
ÇP	B	-	1.5	1.5	2.25	1	-	2.25	2.6	20	117
DD	B	30	10	3	30	1	2.25	27.75	0.485	20	269
ÇP	G	-	1.5	1.5	2.25	3	-	6.75	2.6	20	351
DD	G	30	10	3	30	1	6.75	23.75	0.485	20	230
ÇP	D	-	1.5	1.5	2.25	1	-	2.25	2.6	20	117
DD	D	30	10	3	30	1	2.25	27.75	0.485	20	269
DK	K	-	1	2.5	2.5	1	-	2.5	3.5	20	175
DD	K	-	10	3	30	1	2.5	27.5	0.485	20	266
DÖ	-	45.3	10	10	100	1	-	100	2.724	11	2996
Ta	-	30	10	10	100	1	-	100	2.645	14	3703
									Total Loss of Heat 8494.25 W		

- **Cost Estimator of Pipe**

Length of horizontal pipe : 1485 m

Length of vertical pipe : 1000 m

Length of transfer line pipe : 190 m

Length of total pipe : 2675 m

“Siyah Boru Dişli Manşonlu DN 100”

Cost of unıt pipe : 16.38 TL/m

Cost of total pipe : 16.38*2675 =43816.5 TL

Q = ṁ/ρ

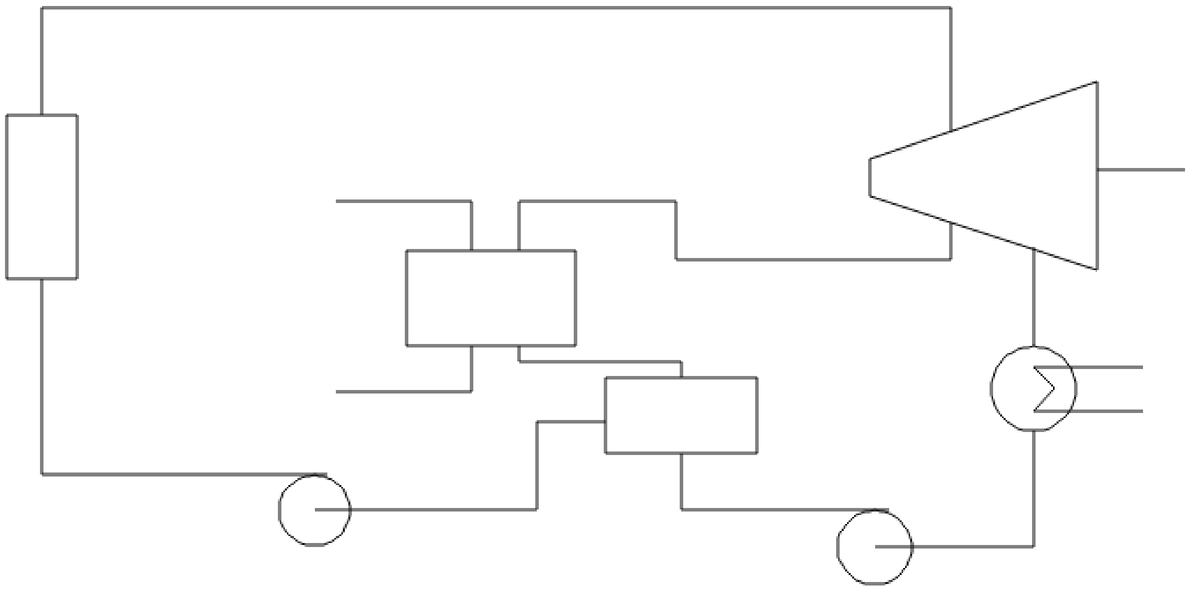
Q = (17400 kg/h) /(1000 m^3/kg)

Q = 17.4 m^3/h

3) THERMAL AND ECONOMICAL CALCULATIONS

We selected system parameters and requirements. In this section we will make calculations to supplying these requirements.

- **Heat Requirement: 8,5 kW**



State 4

P_4 = 4 MPa Vapor

T =400 °C ϑ_4 = 0.7341 m^3 / kg

T_{doyma} = 250.4 °C h_4 = 3213.6 kJ/kg s_4 =6.7690 kJ/kg K

State 5

$s_4 = s_5$ = 6.7690 kJ/kg K $s_5 = s_f + x * s_g$ x = 0.96

P_5 = 300 kPa $h_5 = h_f + x * h_{fg}$

s_f = 1.6718 kJ/kg K h_{5s} = 2638.72

s_g = 6.9919 kJ/kg K

s_{fg} = 5.3201 kJ/kg K

State 1

P_1 = 10 kPa (Saturated fluid)

$h_1 = h_{f,10\ kPa}$ = 191.83 kJ/kg

$\vartheta_1 = \vartheta_{f,10\ kPa}$ = 0.00101 m^3 / kg

State 2

$P_2 = 300$ kPa

$s_1 = s_2$

$W_{p,inlet} = \vartheta_1 * (P_2 - P_1) = h_2 - h_1$

$W_{p,inlet} = 0.00101*(300-10) = h_2 - 191.83$

$h_2 = 192.123$ kJ/kg

State 7

$P_7 = 200$ kPa

$s_4 = s_7 = 6.7690$ kJ/kg K $s_7 = s_f + x * s_g$ x = 0.94

$s_f = 1.5301$ kJ/kg K $h_{7s} = 2574.49$ kJ / kg

$s_g = 7.1271$ kJ/kg K

$s_{fg} = 5.597$ kJ/kg K

State 8

$P_8 = 300$ kPa

$h_8 = 561.47$ kJ/kg

$s_8 = 1.6718$ kJ/kg K

$\vartheta_8 = 0.001073\ m^3/\ kg$

State 3

$P_2 = 300$ kPa

$s_1 = s_2$

$W_{p,inlet} = \vartheta_8 * (P_3 - P_8) = h_3 - h_8$

$W_{p,inlet} = 3.9701 = h_3 - 561.47$

$h_3 = 565.44$ kJ/kg

y = 0.13;

$(1-y) * h_2 + y * h_6 = h_8$

$h_6 = 616.66$ kJ/kg

A) LOAD OF HEAT

8494 W * 100 house = 850 kW

$y * \dot{m} * (h_6 - h_5) = \dot{m}_{home} * c_p * (T_2 - T_1)$ = 850 kW

y = 0.13

$0.25* \frac{20000\ kg}{3600\ s}$ *(616.66–2667.5)=$\dot{m}_{home}$ kg/s*4.184 kJ/kg K*(110 - 70)= 850 kW

$\dot{m}_{home}$ =5.1 kg/s = 18360 kg/h

$W_{türbine} = (y*(h_4 - h_5) + (1 - y)*(h_4 - h_7)) * \dot{m}$

$W_{türbine}$ =(0.13 * (3213.6 – 2667.5) +0.87 * (3213.6 – 2606.5)) * 5.55 kg/s

$W_{türbine}$ = 3.33 MW

B) COST ANALYSIS

-Electrıcıty consumptıon of a house : 1.5 kW/day

1.5 kW/day* (1 day / 24 hours) = 36 kWh

Number of house : 100

100 house * 36 kWh = 3600 kWh

-Cost of turbine:

1000 $ /kW → 3300 kW * 1000 $ /kW = 3300000 $

If coil is consumed, cost of investment is 1500 $ /kW for power plant.

3300 kW * 1500 $ /kW = 4.950.000 $

-Mass flow rate:

12552 kJ/kg for lignite

$Q_{boiler} = \dot{m}* (h_4-h_3)$

14721 kW = $\dot{m}$ * 12552 kJ/kg

$\dot{m}_{coil}$ = 1.17 kg/ s =101 ton/ day

The price of lignite is 270 TL/ton

-Consumption of day:

(270 TL/ton) * (101 ton/ day) = 27000 TL/day

(27000 TL/day) *(365 day / year) = 9855000 TL/year

-Cost of investment:

4950000 $ → 9900000 TL

Life of power plant: 20 year

-Annual investment cost:

Insurance %2, interest %10 , amortization %3 , total %15

(9900000 TL * 1.15) / 20 = 569250 TL (YYM)

-Annual operating cost:

(2400 TL * 6 engineer + 1700 TL * 10 technician) * 12 month =376800

-Cost of maintenance (%10 of the annual capital cost):

0.1 * 569300 TL = 56.930 TL

-Total annual operating cost:

56.930 TL + 9.855.000 TL = 10.288.730 TL

-Annual total cost:

Annual Capital Cost + Annual operating cost = 10.288.730 TL + 569.250 TL = 10.857.980 TL

3300 kW * 24 hour * 365 day = 28.908.000 kWh

TL/kWh	Income[TL]
0,2	578.1600
0,3	867.2400
0,4	11.563.200
0,5	14.454.000

If we want to earn money we have to earn more money than annual total cost because of that we have decided to sell electricity 0,4 TL/kWh.

C) COMPARISON: SUPPLYING REQUIREMENTS WITH ELECTIRICTY

We designed a power generation system and calculated basic parameters to make comparison with other selections. We will use an air conditioner to supplying heating and cooling requirements. Thus, we can check our system about being economic or not.

-Heating Requirement: 850 kW (for 100 house)

Air conditioner: 2 kW/h (for each one)

For 100 house, air conditioner gets 200kW/h so it must be worked 4,25 h.

(850 kW) / (200kW/h) = 4,25 h

We have decided to sell electricity 0,4 TL/kWh so;

4,25 x 2 x 0,4 x 100 = 340 TL (for 100 house)

Annual cost : 124.100 TL

Installation cost: 1500 TL(for each)

Total installation cost: 150.000 TL

Total cost: 274.000 TL

Heating with hot water has radiators, pipes and installation cost. It is nearby to 2000 TL.

Total cost: 2000 x 100 = 200.000 TL (for 100 house)

Heating with air conditioner has electricity cost and variable installation costs but heating with hot water has installation cost and some transient costs. It provides hot water from cogeneration system and more cheap than heating with air conditioners.

-Cooling Requirement: We detected cooling requirement between 3 and 5 for İZMİR.

Air conditioner: 1,06 kW/h (for each one)

For 100 house, air conditioner gets 106 kW/h

Assumption: Air conditioner works 4 hours per day.

4 x 0,4 x 106= 169,6 TL (for 100 house)

Annual cost : 61904

Installation cost: 1500 TL (for each)

Total installation cost: 150.000 TL

Total cost: 211904 TL

Cooling Requirement: 106 x 4 = 424 kW (for 100 house)

In conclusion, cogeneration system has economic advantages about supplying heating, cooling and electricity requirements. They also environmentally friendly if fuel type is selected with this criterion. We analyzed and designed thermal structure of system and detected cost of all the system with assumption and calculations. So, we determined TL/kWh of electricity which produced by our system. Also, we compared heating section and examined economic results and project completed.

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