EKSERJİ VE UYGULAMALARI YAZ KURSU

(SUMMER COURSE ON EXERGY AND ITS APPLICATIONS)
(2-4 May 2024)
Pamukkale University, Denizli

Exergy Analysis of Geothermal (Ground Source) HPs

Jeotermal (Toprak Kaynaklı) Isı Pompalarının Ekserji Analizi

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OUTLINE

1. Main Objectives of the Study

2. Two Illustrative Examples
    a) Description of the GSHP System
    b) Theoretical Analysis of the GSHP System

3. Conclusions

1. Main objectives are:

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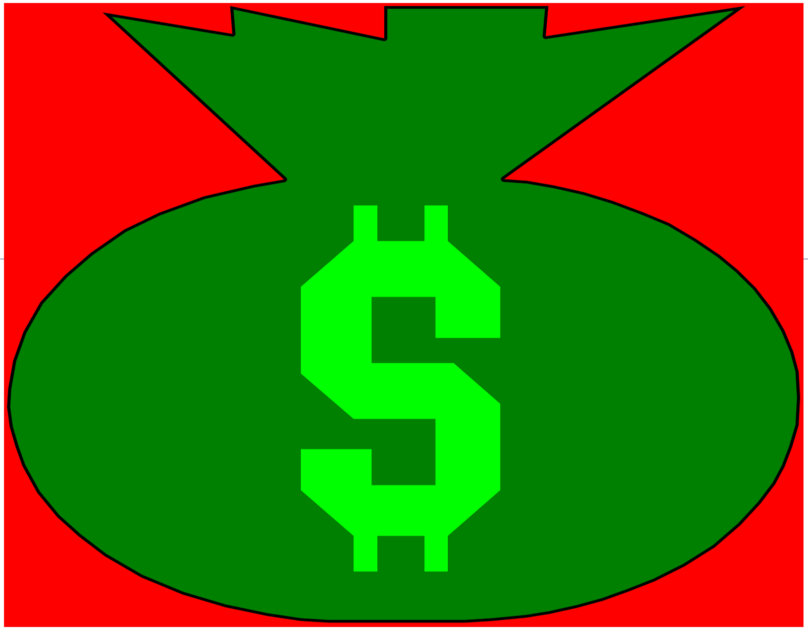
- to denote the importance of exergy analysis in GSHP systems

- to present a methodology for performing exergy analysis of GSHPs

2. GSHP Systems

a) A GSHP System

A Schematic of a GSHP System



A Sketch Showing the Meaning of GSHPs

GSHPs are **money minters**.

2.b) Terminology

Some Terms used to describe GSHPs

Item no.	Description
1	Earth energy heat pumping systems
2	Surface water heat pump systems
3	Earth energy systems
4	Ground-source systems
5	Groundwater heat pumps (GWHPs)
6	Earth-coupled heat pumps (ECHPs)
7	Well-source heat pump system
8	Ground-source heat pumps (GSHPs)
9	Geothermal heat pumps (GHPs)
10	Ground-coupled heat pumps (GCHPs)
11	Ground-water source heat pumps
12	Well water heat pumps
13	Solar energy heat pumps
14	GeoExchange systems
15	GeoSource heat pumps

Source : Hepbasli, A. & Ertoz, O. "GSHPs : The Technology of the Future", the Proceedings of HVAC and Plumbing Congress, Izmir, Turkey, 1999 (in Turkish).

2.b) Terminology

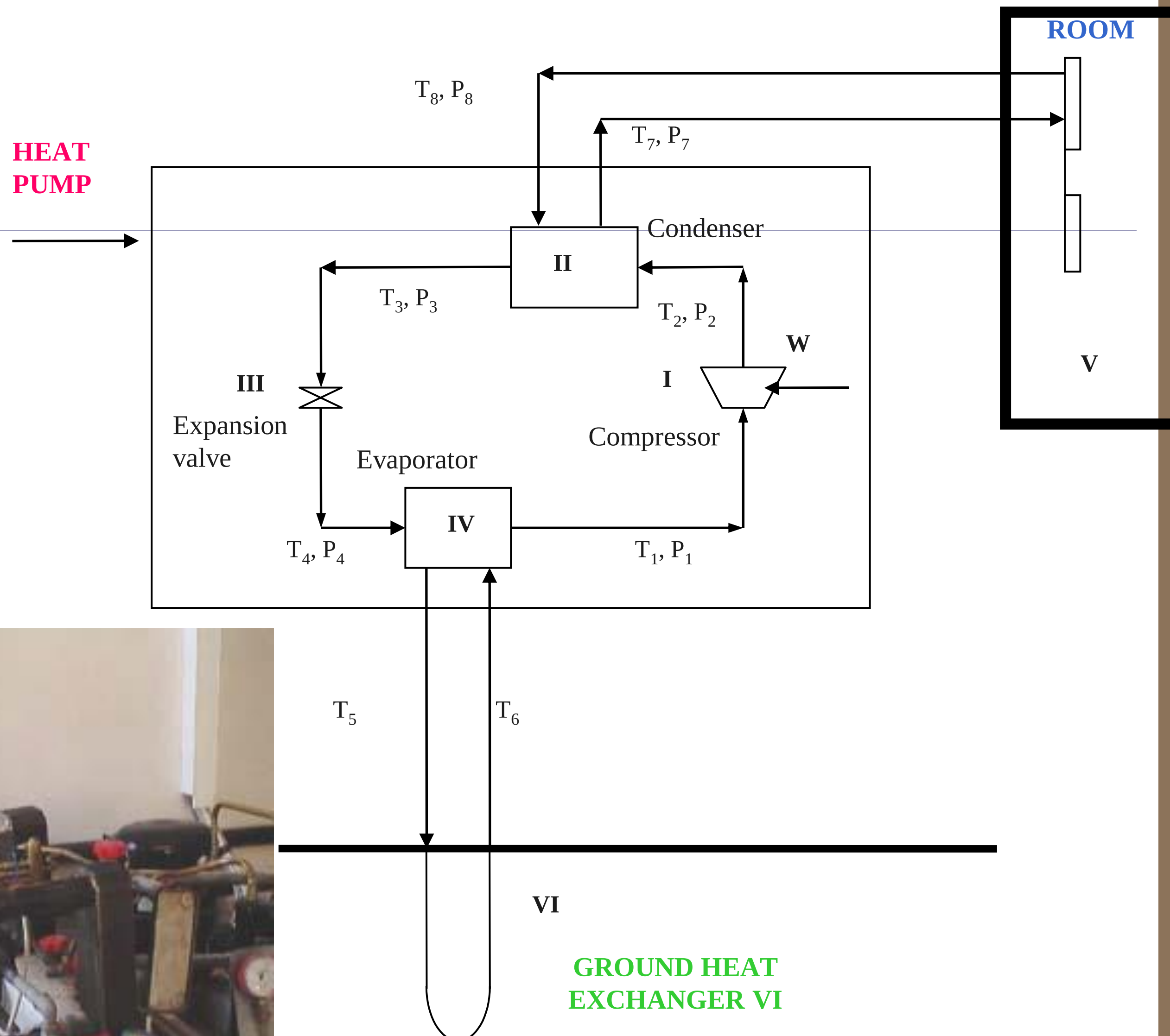
Efficiency and Performance Terms used in Heat Pumps

Item no.	Nomen.	Description
1	COP	Coefficient of Performance
2	COP_h	Coefficient of Performance for Heating
3	COP_c	Coefficient of Performance for Cooling
4	EER	Energy Efficiency Ratio
5	HSPF	Heating Seasonal Performance Factor
6	IPLV	Integrated Part Load Value
7	KWT	kW/ton
8	SEER	Seasonal Energy Efficiency Ratio
9	SPF	Seasonal Performance Factor
10	SCOP	Seasonal Coefficient of Performance
11	CSPF	Combined Seasonal Performance Factor

2. Two Illustrative Examples
2.1.

Objectives:

- To conduct an energy and exergy analysis of a a GSHP system installed at Ege University in Izmir, Turkey
- To study exergy efficiency aspects.
- To compare the calculated exergy efficiencies with actual data for different thermodynamic parameters.


ROOM
HEAT PUMP
T8, P8
T7, P7
Condenser
II
T3, P3
T2, P2
W
III
I
Expansion valve
Compressor
Evaporator
V
IV
T4, P4
T1, P1
T5
T6
VI
GROUND HEAT EXCHANGER VI

General balance equations

The mass balance equation in the rate form:

$$\sum \overset{\circ}{m}_{in} = \sum \overset{\circ}{m}_{out} \qquad (1)$$

The general energy balance:

$$\underbrace{\overset{\circ}{E}_{in}}_{\substack{\text{Rate of net energy} \\ \text{transfer in by heat,} \\ \text{work, and mass}}} = \underbrace{\overset{\circ}{E}_{out}}_{\substack{\text{Rate of net energy} \\ \text{transfer out by heat,} \\ \text{work, and mass}}} \qquad (2a)$$

The general energy balance:

$$\overset{\circ}{Q} + \sum \overset{\circ}{m}_{in} h_{in} = \overset{\circ}{W} + \sum \overset{\circ}{m}_{out} h_{out} \qquad (2b)$$

General balance equations

The general exergy balance can be expressed in the rate form as

$$\underbrace{\dot{X}_{in} - \dot{X}_{out}}_{\substack{\text{Rate of net exergy} \\ \text{transfer by heat,} \\ \text{work, and mass}}} = \underbrace{\dot{X}_{dest}}_{\substack{\text{Rate of exergy} \\ \text{destruction}}} \tag{3a}$$

The rate form of the general exergy balance can also be written as

$$\sum\left(1-\frac{T_o}{T_k}\right)\dot{Q}_k - \dot{W} + \sum \dot{m}_{in}\psi_{in} - \sum \dot{m}_{out}\psi_{out} = \dot{X}_{dest} \tag{3b}$$

with

$$\psi = (h - h_0) - T_0(s - s_0) \tag{3c}$$

General balance equations

The rate form of the entropy balance:

$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\substack{Rate\ of\ net\ entropy \\ transfer\ by\ heat \\ and\ mass}} + \underbrace{\dot{S}_{gen}}_{\substack{Rate\ of\ entropy \\ generation}} = 0 \qquad (4a)$$

$$\dot{S}_{gen} = \sum \dot{m}_{out} s_{out} - \sum \dot{m}_{in} s_{in} - \sum \frac{\dot{Q}_k}{T_k} \qquad (4b)$$

Exergetic efficiency:

$$\eta_{O,R} = \frac{\dot{X}_{desired,output}}{\dot{X}_{used}} \qquad (5)$$

Thermodynamic characteristic of the GSHP system investigated

State	T (°C)	T (K)	P (MPa)	h (kJ/kg)	s (kJ/kgK)	$\dot{m}$ (kg/s)	Ψ (kJ/kg)	$\dot{E}$ (kW)
1	6	279	0.51	409.44	1.7640	0.0193	45.4700	0.8788
2s	106.07	379.07	3.1	457.02	1.7640	0.0193	93.0500	1.7984
2a	118	391	3.1	468.92	1.7954	0.0193	95.5997	1.8476
3	73	346	3.1	297.98	1.3082	0.0193	69.8503	1.3500
4	0.76	273.76	0.51	297.98	1.3575	0.0193	55.1470	1.0658
5	9.4	282.4	-	38.61	0.1390	0.3056	1.7297	0.5285
6	11.1	284.1	-	45.66	0.1638	0.3056	1.3893	0.4245
7	49	322	-	205.47	0.6915	0.1150	3.9357	0.4527
8	42.2	315.2	-	176.75	0.6015	0.1150	2.0596	0.2369
$0_{ref\ w}$	25	298	0.1	104.13	0.3647	-	-	-
$0_{ref\ R\text{-}22}$	25	298	0.1	429.53	1.9840	-	-	-

Exergy and entropy balance equations of the GSHP system

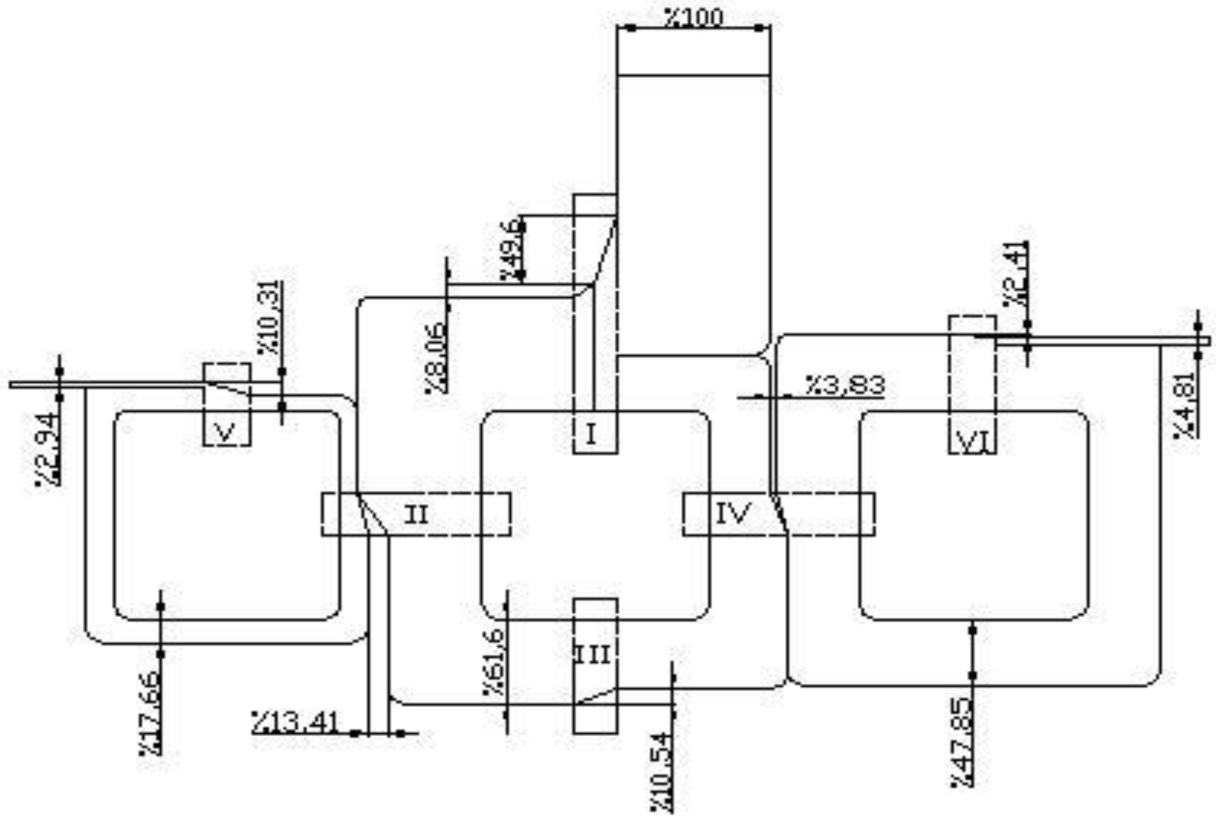
Item no	Unit	Exergy balance	Entropy balance
I	Compressor	$\dot{E}_1 + \dot{W}_c = \dot{E}_2 + \dot{I}_I$ (9)	$\dot{I}_I = T_0 . [\dot{m}_{ref} . (s_2 - s_1)]$ (15)
II	Condenser	$\dot{E}_2 + \dot{E}_8 = \dot{E}_3 + \dot{E}_7 + \dot{I}_{II}$ (10)	$\dot{I}_{II} = T_0 . [\dot{m}_{ref} . (s_3 - s_2) + \dot{m}_w . (s_7 - s_8)]$ (16)
III	Expansion valve	$\dot{E}_3 = \dot{E}_4 + \dot{I}_{III}$ (11)	$\dot{I}_{III} = T_0 . [\dot{m}_{ref} . (s_4 - s_3)]$ (17)
IV	Evaporator	$\dot{E}_4 + \dot{E}_6 = \dot{E}_1 + \dot{E}_5 + \dot{I}_{IV}$ (12)	$\dot{I}_{IV} = T_0 . [\dot{m}_{ref} . (s_1 - s_4) + \dot{m}_{ghe} . (s_5 - s_6)]$ (18)
V	Room (Fan-coil units)	$\dot{E}_7 - \dot{Q}_r . \left(\frac{T_r - T_0}{T_r} \right) = \dot{E}_8 + \dot{I}_V$ (13)	$\dot{I}_r = T_0 . [\dot{m}_w . (s_8 - s_7)] + \frac{\dot{Q}_r}{T_r}]$ (19)
VI	Ground heat exchanger	$\dot{E}_5 + \dot{Q}_{ghe} \left(\frac{T_{ghe} - T_0}{T_{ghe}} \right) = \dot{E}_6 + \dot{I}_{VI}$ (14)	$\dot{I}_{VI} = T_0 . [\dot{m}_{ghe} . (s_6 - s_5) - \dot{Q}_{ghe} / T_{ghe}]$ (20)

Exergy rates and eficiency values

State	Used exergy (kW)	Available exergy $\dot{E}$ (kW)	$\dot{I}$ (kW)	Exergy efficiency η
I	1.8476	2.0283	0.1806	0.9110
II	1.8027	2.0845	0.2818	0.8648
III	1.0658	1.3500	0.2842	0.7895
IV	1.4073	1.4903	0.0830	0.9443
V	0.2369	0.4750	0.2381	0.4987
VI	0.4245	0.4537	0.0292	0.9356

Exergy balance diagram

(Grassmann diagram)



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Energy and Buildings 39 (2007) 1211–1217
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Exergetic modeling and assessment of solar assisted domestic hot water tank integrated ground-source heat pump systems for residences

Arif Hepbasli *

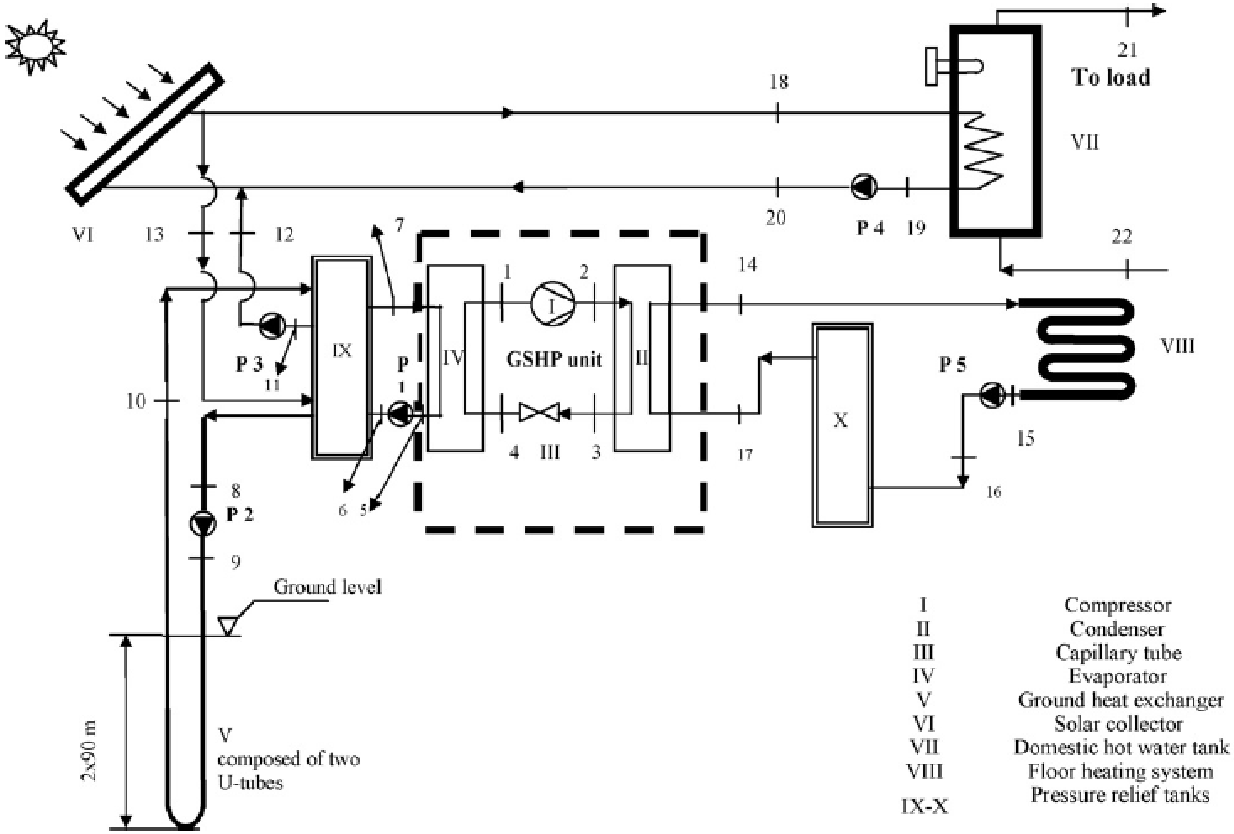


Fig. 1. Solar assisted domestic hot water tank integrated GSHP system (Adapted from ref. [7]).

State no. Description Fluid Phase

Temperature, T (°C) Pressure, P (kPa) Specific enthalpy, h (kJ/kg) Specific entropy, s (kJ/kg K) Mass flow rate, $\dot{m}$ (kg/s) Specific exergy, ψ (kJ/kg) Energy rate, $E = \dot{m}h$ (kW) Exergy rate, $\dot{E}x = \dot{m}\psi$ (kW)

Table 1
Energy and exergy analyses results of the system studied

State no.	Description	Fluid	Phase	Temperature, T (°C)	Pressure, P (kPa)	Specific enthalpy, h (kJ/kg)	Specific entropy, s (kJ/kg K)	Mass flow rate, $\dot{m}$ (kg/s)	Specific exergy, ψ (kJ/kg)	Energy rate, $E = \dot{m}h$ (kW)	Exergy rate, $\dot{E}x = \dot{m}\psi$ (kW)
0	–	Refrigerant (R-410a)	Dead state	19	101.325	316.1	1.394	–	–	–	–
0′	–	Water	Dead state	19	101.325	79.7	0.282	–	–	–	–
0″	–	Water–antifreeze mixture	Dead state	19	101.325	70.3	0.249	–	–	–	–
1	Evaporator outlet/Compressor inlet	Refrigerant	Superheated vapor	-2	677.1	283.1	1.070	0.051	61.66	14.44	3.14
2, s	Condenser inlet/Compressor outlet	Refrigerant	Superheated vapor	68.6	2724.1	322.2	1.070	0.051	100.76	16.43	5.14
2, act	Condenser inlet/Compressor outlet	Refrigerant	Superheated vapor	75.9	2724.1	331.9	1.098	0.051	102.28	16.93	5.22
3	Condenser outlet/Expansion valve inlet	Refrigerant	Saturated liquid	45	2724.1	135.6	0.488	0.051	84.19	6.92	4.29
4	Expansion valve outlet/Evaporator inlet	Refrigerant	Mixture	–5	677.1	135.6	0.520	0.051	74.84	6.92	3.82
5	Circulating pump inlet (P 4)	Water–antifreeze mixture	Compressed liquid	2		7.4	0.027	0.508	1.96	3.76	0.99
6	Circulating pump outlet (P 4)/Pressure relief tank inlet	Water–antifreeze mixture	Compressed liquid	2.1		7.77	0.028	0.508	2.04	3.95	1.04
7	Pressure relief tank outlet (Evaporator side)	Water–antifreeze mixture	Compressed liquid	6		22.2	0.080	0.508	1.27	11.28	0.65
8	Circulating pump inlet (P 2)	Water–antifreeze mixture	Compressed liquid	2.1		7.77	0.028	0.508	2.04	3.95	1.04
9	Circulating pump outlet (P 2)/Ground heat exchanger inlet	Water–antifreeze mixture	Compressed liquid	2.2		8.14	0.030	0.508	1.82	4.14	0.92
10	Ground heat exchanger outlet	Water–antifreeze mixture	Compressed liquid	6		22.2	0.080	0.508	1.27	11.28	0.65
14	Floor heating system supply	Water	Compressed liquid	35		146.7	0.505	0.345	1.85	50.61	0.64
15	Floor heating system return/Circulating pump inlet (P 5)	Water	Compressed liquid	28		117.4	0.409	0.345	0.60	40.50	0.21
16	Circulating pump outlet (P 5)/Pressure relief tank inlet	Water	Compressed liquid	28.1		117.8	0.410	0.345	0.71	40.64	0.24
17	Pressure relief tank outlet/Condenser inlet (water side)	Water	Compressed liquid	28.1		117.8	0.410	0.345	0.71	40.64	0.24
18	Solar collector outlet/Domestic hot water tank inlet	Water–antifreeze mixture	Compressed liquid	71		297.3	0.967	0.350	17.24	104.06	6.03
19	Domestic hot water tank outlet/Circulating pump inlet (P 4)	Water–antifreeze mixture	Compressed liquid	67		280.5	0.918	0.350	14.75	98.18	5.16
20	Circulating pump outlet (P 4)/Solar collector inlet	Water–antifreeze mixture	Compressed liquid	67.1		280.9	0.919	0.350	14.86	98.32	5.20
21	Hot water supply (to load)	Water	Compressed liquid	65		272.1	0.893	0.034	13.90	9.25	0.47
22	Cold water inlet	Water	Compressed liquid	30		125.8	0.436	0.034	1.11	4.28	0.04

- GSHP unit (I–IV):

$$\varepsilon_{GSHP} = \frac{\dot{E}x_{heat}}{\dot{W}_{comp,elec}} = \frac{\dot{E}x_{14} - \dot{E}x_{17}}{\dot{W}_{comp,elec}} \quad (20)$$

- Overall GSHP system:

$$\varepsilon_{GSHP,sys} = \frac{\dot{E}x_{14} - \dot{E}x_{17}}{\dot{W}_{comp,elec} + \sum \dot{W}_{pump,elec}} \quad (21)$$

- The exergetic coefficients of performance of the GSHP unit and whole system are as follows:

$$COP_{ex,GSHP} = \frac{\dot{Q}_{cond}(1 - (T_0/T_{cond}))}{\dot{W}_{comp,elec}} \quad (22a)$$

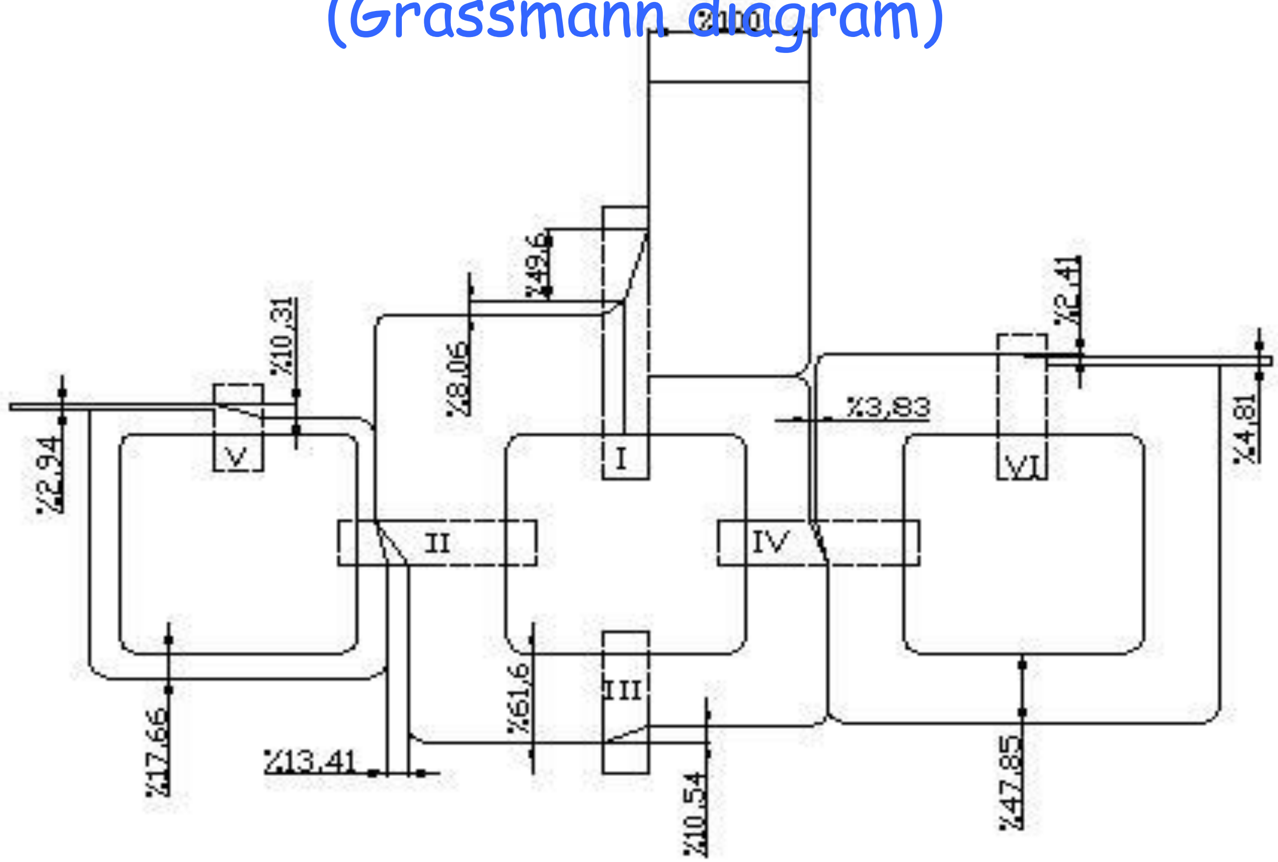
$$COP_{ex,sys} = \frac{\dot{Q}_{cond}(1 - (T_0/T_{cond}))}{\dot{W}_{comp,elec} + \sum \dot{W}_{pump,elec}} \quad (22b)$$

Table 2
Energy, exergy, improvement potential rate ($I\dot{P}$) and relative irreversibility (RI) data for a representative unit in the whole system

Device no.	Device	Exergetic product rate, $\dot{P}$ (kW)	Exergetic fuel rate, $\dot{F}$ (kW)	Exergy destruction rate, $E\dot{x}_{dest}$ (kW)	Power use (kW)	Exergy efficiency, ε (%)	Exergetic improvement potential rate, $I\dot{P}$ (kW)	RI (%)		
								GSHP unit	GSHP heating system	Overall system
I	Compressor	2.08	3.33	1.25	3.33	62.46	0.47	36.87	33.24	9.17
II	Condenser	0.40	0.93	1.33	10.01	43.01	0.76	39.23	35.37	9.76
III	Expansion valve	3.82	4.29	0.47	–	89.04	0.05	13.86	12.50	3.45
IV	Evaporator	0.34	0.63	0.34	7.52	50.00	0.17	10.04	9.04	2.49
V	Ground heat exchanger	0.65	0.82	0.21	7.14	79.17	0.04		5.59	1.55
VI	Solar collector	0.83	7.85	8.68	5.74	10.57	7.76			63.68
VII	Domestic hot water tank	0.43	0.87	0.44	5.88	49.42	0.22			3.22
VIII	Floor heating system	0.27	0.43	0.16	10.11	62.79	0.06		4.26	1.18
P1	Circulating pump	0.05	0.26	0.21	0.26	19.23	0.17			1.55
P2	Circulating pump	0.12	0.26	0.38	0.26	46.15	0.20			2.78
P5	Circulating pump	0.03	0.19	0.16	0.19	15.79	0.14			1.17
I–IV	GSHP unit	6.64	9.18	3.39		72.33	0.94	100.00		(24.87)
VI–VII	Solar domestic hot water system	1.26	8.67	8.89		14.53	7.60			(66.90)
I–V and VIII	GSHP heating system	7.56	10.43	3.76		72.48	1.03		100.00	(27.60)
P1, P2 and P5	Circulating pumps	0.20	0.71	0.75		28.17	0.54			(5.50)
Overall system		8.75	19.86	13.63		44.06	7.62			100.00

An Example of Exergy Loss and Flow Diagram for a Heat Pump System

(Grassmann diagram)



5. Conclusions

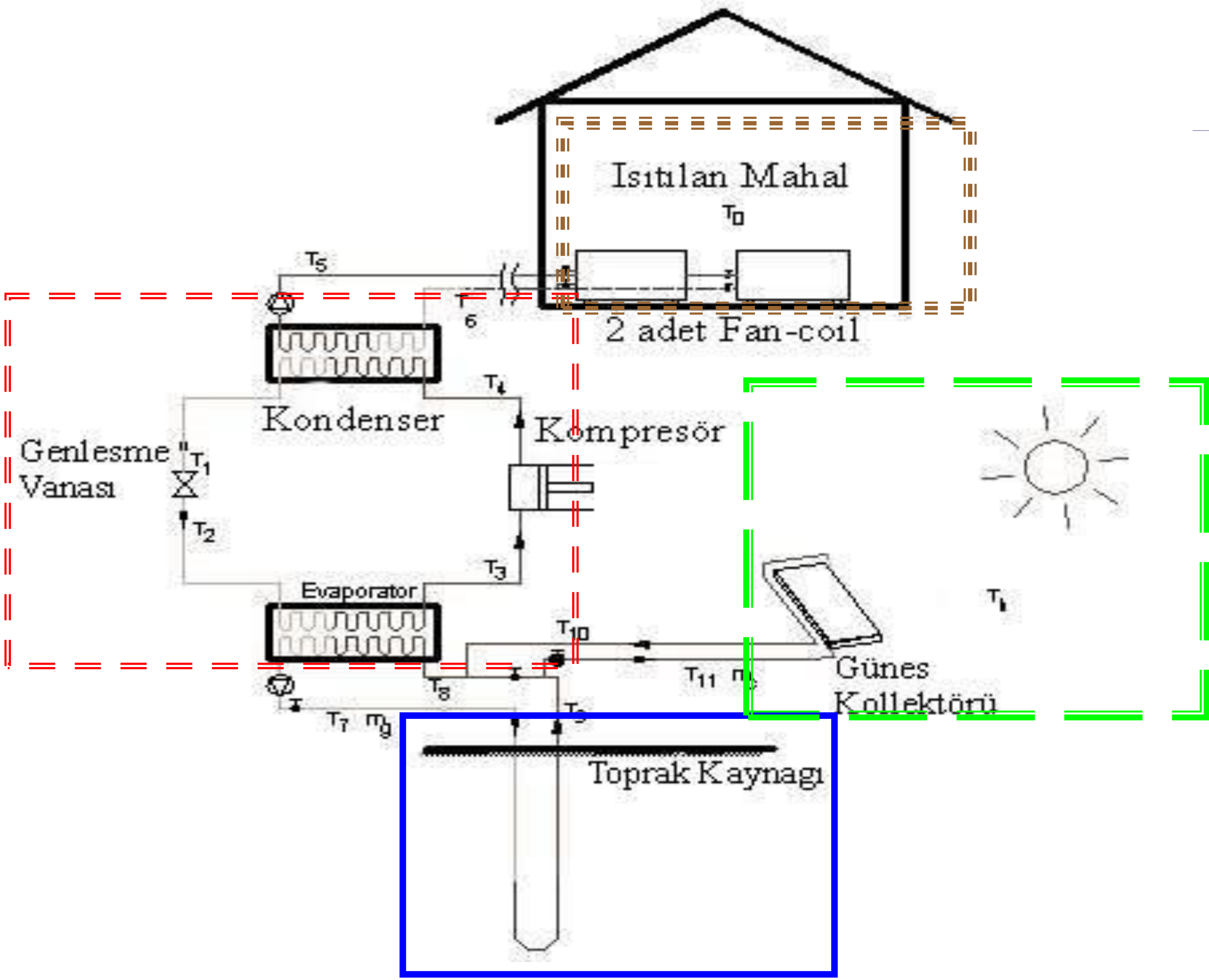
- ✓ Exergy analysis is an effective method, using the conservation of mass and conservation of energy principles together with the SLT, that can be employed for the design and analysis of thermal systems.
- ✓ It is therefore an efficient technique revealing whether or not and by how much it is possible to design more efficient thermal systems by reducing the inefficiencies.
- ✓ Two illustrative examples are presented to highlight the importance of understanding and considering exergy as a potential tool.
- ✓ The potential usefulness of exergy analysis in addressing and solving environmental problems is substantial.

THANK YOU VERY

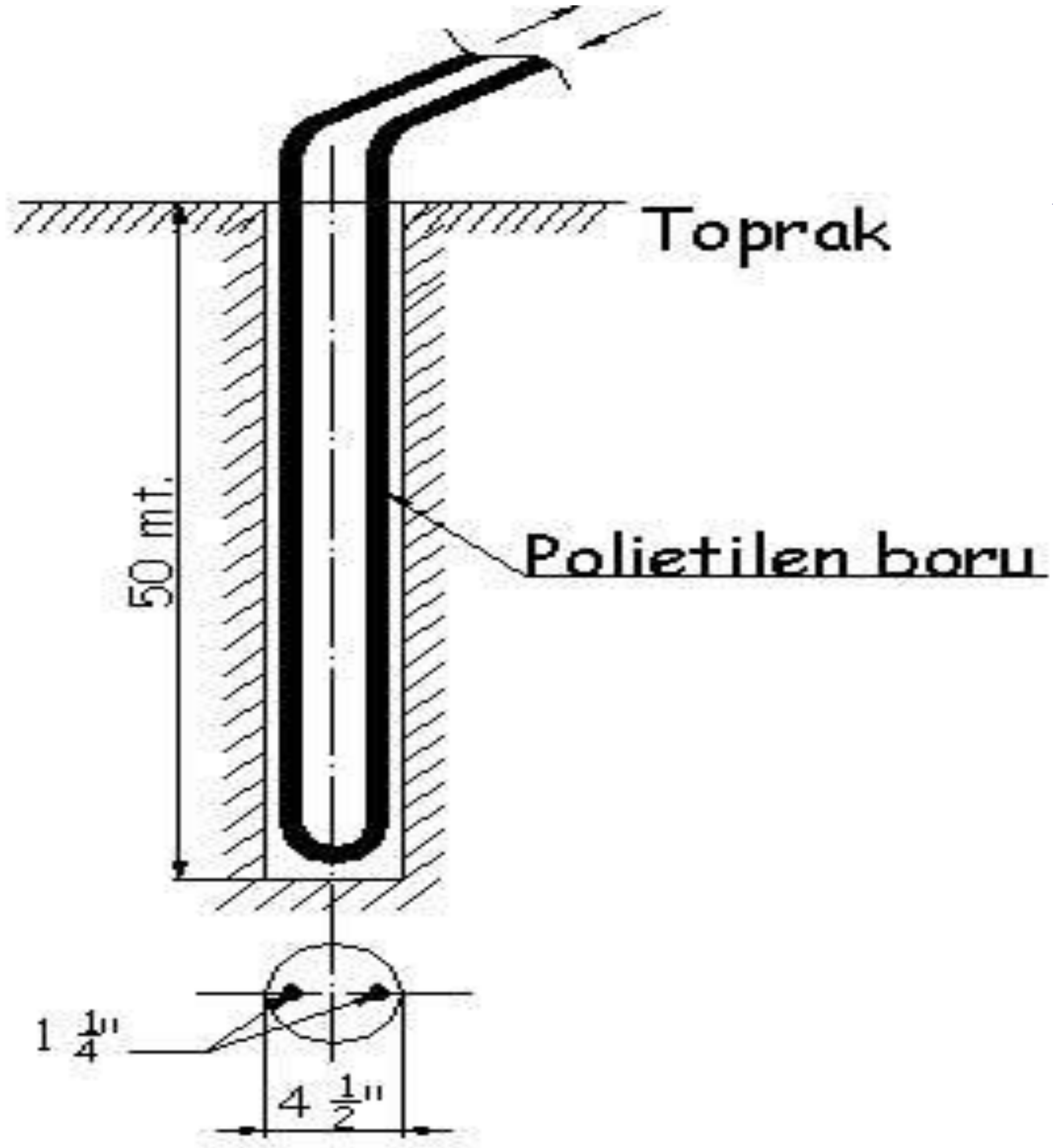
MUCH FOR YOUR STANDING

TILL THE END.

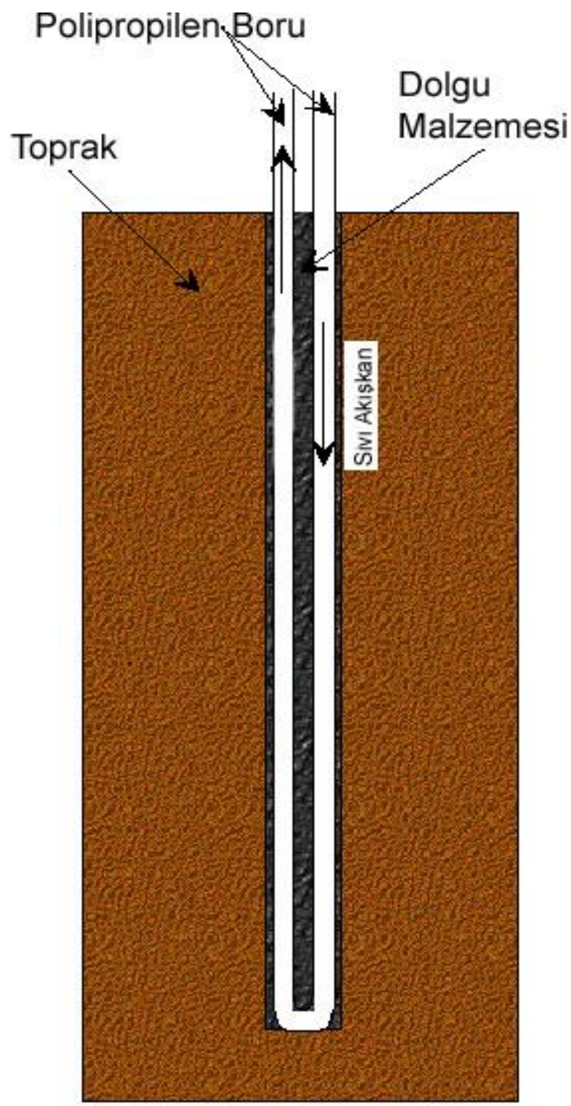
- ADDITONAL SLIDES TO BE INDICATED ACC. TO THE PRESENTATION DURATION

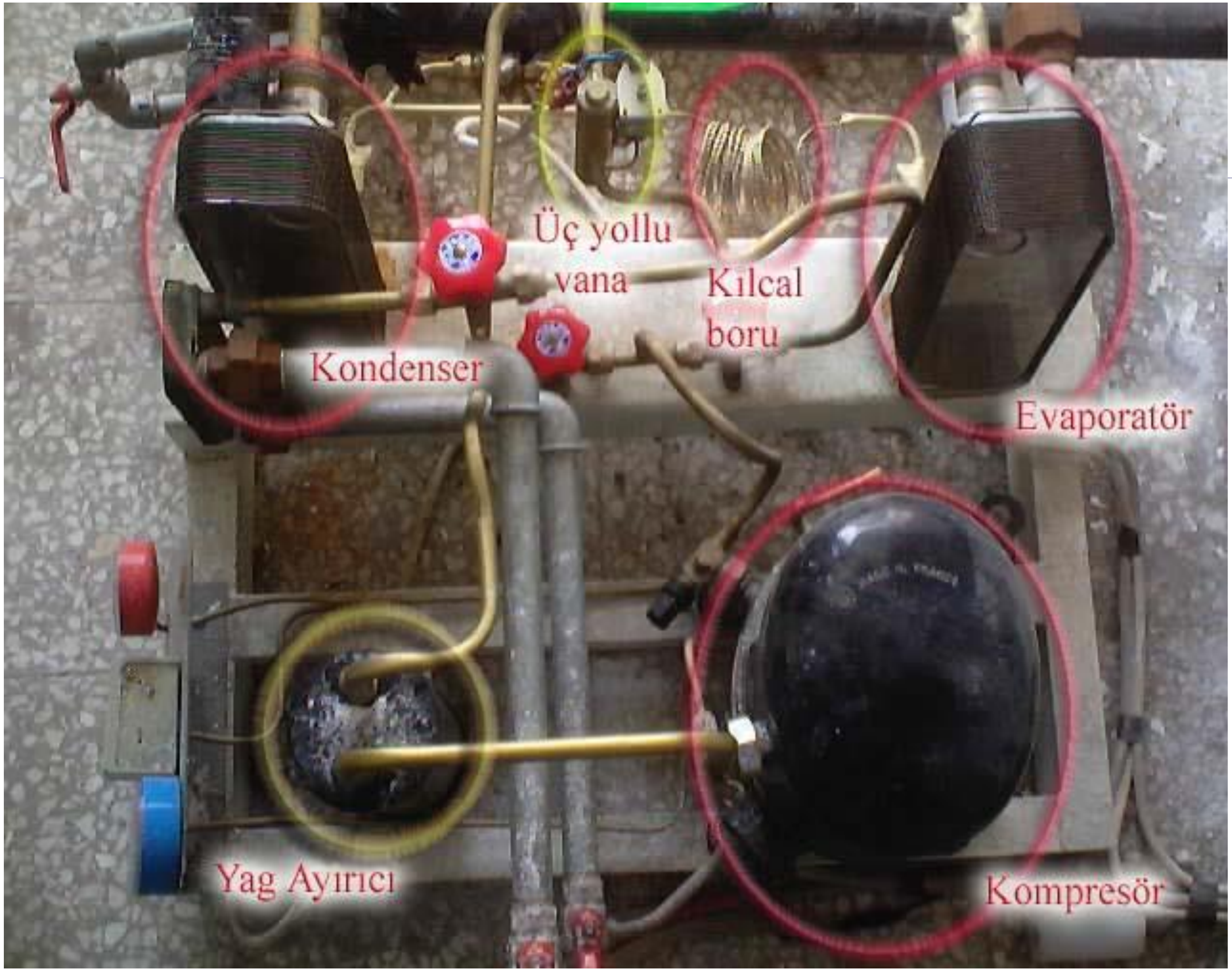


Isıtılan Mahal
2 adet Fan-coil
Kondenser
Kompresör
Genlesme
Vanası
Evaporator
Güneş
Kollektörü
Toprak Kaynagı



Toprak
50 mt.
Polietilen boru
1 1/4"
4 1/2"


Polipropilen Boru
Dolgu
Malzemesi
Toprak
Sıvı Akışkan



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