



Exergy Analysis of Recycled Cooling System in a Process: A Case Study

A K Cakir

Adnan Menderes University, Central Campus, PO Box 09200, Aydin, Turkey

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Heat pumps are devices those allow to use the energy available in nature but cannot be used because of its low temperature. By raising its temperature, heat pumps do this with a cooling cycle similar to that of air conditioners. This study presents the performance analysis of an in-room heating system during mushroom compost fermentation using a heat recovery device with an air source heat pump, which is a type of heat pump. The study was carried out by setting up experimental equipment and providing measurement-based parameters in the university laboratory. The performance analysis of the system was calculated by considering all system elements (compressor, condenser, evaporator, expansion valve etc.) and the results were evaluated numerically. Performance analysis was made according to whether a heat pump is used in the system. Based on the results obtained by these calculations, when heat recovery device is added to the system, the work done by the compressor, loss of exergy, exergy balance and efficiency decrease. While the exergy balance of the condenser decreases, its efficiency increases. Also, while the exergy balance of the expansion valve increase, its efficiency decreases. Overall, the efficiency of the device increases.

Keywords: Exergy, Energy efficiency, Cooling system, Heat recovery, Heat pump

Introduction

Mushroom cultivation is a difficult production method with a lot of variability according to the environment and conditions. Especially the moisture content setting and cellulose ratio are important. First of all, an environment with a high cellulose ratio should be created in mushroom production. This artificial environment created is called compost,¹ then the desired level of humidity should be provided.

Generally, it is desirable that the moisture content in the compost be between 65% and 74%. It has been observed that the ideal humidity ratio is between 67% and 69%.¹ Moisture rate is provided by heat pump in the cooling rooms in mushroom compost production. The continuous operation of the air conditioning system brings costs along with it in the compost production process. Therefore, efficient use of the heat pump is important because of energy costs are high.

The efficient use of energy and the prevention of global warming are among the most important research topics today. Reducing energy intensity is a measure of efficient use of energy.

Today, a significant part of the energy need is met with fossil fuels, and since their reserves are limited, their costs are high. Therefore, energy

sources should be used as efficiently as possible. One of the most remarkable methods in the efficient use of limited energy resources is waste heat recovery.² The share of energy consumed in air conditioning systems in total energy consumption reaches approximately 20%. In this context, the effective and efficient use of energy and even wasted energy is particularly important.^{3,4}

Pre-cooling or preheating of the outside air can be done by an energy recovery unit to be added to the system with the exhaust air discharged from the air conditioning system in summer or winter conditions. In this way, both the investment unit and operating costs of these devices can be reduced by reducing the capacities of the heating unit, cooling unit and other heating and cooling groups.⁵⁻⁷ In order to reduce these costs, energy and exergy calculations of the heat recovery devices used in the system should be made.

Exergy analysis is a thermodynamic analysis technique based on the second law of thermodynamics providing an alternative in order to evaluate and compare the processes and systems in a rational and significant manner. It provides efficiencies of how the real performance approaches the ideal one and identifies the causes and locations of thermodynamic losses more precisely compared to energy analysis.

Since exergy analysis is based on the second law, it ensures that the irreversibility in the process is detected better than the energy analysis. Increased complexity of processes and power plants requires thermodynamic analysis to ensure optimum use of energy sources.⁸

For this reason, some researchers^{9–13} use a new method of combining both first and second law. This method is called usability analysis. In various studies, energy has been considered together with the economy. Today, the concepts "energy costs" and "energy prices" are widely accepted as synonyms. However, the costs are not related to the facts. In general, the energy cost includes a raw material cost because energy generally does not have a value. However, exergy is the basis of the economy. It covers wages and costs precisely. Business is in association with exergy and economy. The relationship between the entropy and economy is discussed in most of the studies and the data are presented successfully. One of the important studies in this field was conducted by Roegen.¹⁴ His book with the title of "Law of Entropy and Economic Process", published in 1971, has been a reference for many researchers and their projects. Many researchers have included the relationship between exergy and economy in their studies.

Some researchers^{15–17} achieved efficiency by applying exergy analysis in heat pumps systems, while others^{8,9,11} achieved efficiency by applying them in power plants. There are some exergy analysis studies in cooling and air conditioning (HVAC). A study by Hepbaşlı and Ozgener¹⁸ indicate that energy consumption of heating, cooling, and air conditioning (HVAC) systems is approximately 20% of total energy consumption. Consequently, effective and efficient use of energy and even the waste energy has great importance. They also state that for the performance evaluation of heating, cooling and ventilation systems, the first law of thermodynamics has been used; however the required energy for these systems is usable energy in order to have effective work.

However, there is few studies presented performance analysis of the mushroom compost fermentation using a heat recovery device with an air sourced heat pump. In this study, efficiency and thermoeconomic and thermodynamic analyses were performed using the data obtained by operating the

device without heat recovery and with heat recovery. This study will guide those working in this field in analyzing costs and efficiency.

Materials and Methods

The study was conducted at Kastamonu University Central Research Laboratory Mushroom Research Center and the materials to be used in the study included 1 × 5 Hp Heat Pump, construction of 1x Compost Room (6 × 4 × 2.40 m), supply and installation of 1x Humidity Control and Humidification Unit. The installed device is shown in Fig. 1.

The device design is based on the cooling cycle system. Due to the continuous operation of the system to be used and the need for heat and humidity especially in pasteurization processes, efficiency was calculated on the device and the aim was to achieve this efficiency level with revisions on the device. Gas 407 C widely used in heating and cooling processes, was used in the air conditioning system.

In the study, the inlet and outlet points of each unit were determined depending on the flow chart of the device. Thermodynamic properties (temperature, pressure and mass flow) of the determined points were read and obtained instantly on the device. With these properties, enthalpy, entropy and exergy of each point were calculated numerically with the help of energy and exergy formulas. In the study, exergy calculations were made by operating the device without heat recovery and with heat recovery. Various analyzes can be



Fig. 1 — Unit room and air conditioning device

performed by obtaining various data by monitoring the changes in the device as the result of the additions made to the device at different ambient temperatures. In this study, efficiency and thermoeconomic and thermodynamic analyses were performed using the mentioned data. The reference values determined within the scope of the study are given in Table 1.

Exergy Loss for the Condition without Heat Recovery

The corresponding enthalpy and entropy values were obtained by finding the pressure and temperature values obtained from the points determined in the device in the psychometric diagram of the R 407C gas. These obtained values were the main element of the calculation. Measurement points without heat recovery were detected on the device and shown in Fig. 2 below.

In the calculations made for the condition without heat recovery, the values measured from the measurement points on the device and found in the Psychometric table were shown in Table 2.

For 3 °C and 6 bar;

$$z = z_{liquid} + x(z_{steam} - z_{liquid}) \quad \dots (1)$$

$$270,16 = 204,38 + x(413,51 - 204,38)$$

$$x = 0,314 \quad \%31,4$$

By using the x value we find here in formula 2 below, we calculate the s_3 value.

$$s_3 = s_{3 liquid} + x(s_{3 steam} - s_{3 liquid}) \quad \dots (2)$$

Values of $h_3, s_3, Q_E, \dot{m}_{R407C}$ for 3°C and 6 Bar are shown in Table 3.

The following formula (3) was used to find the mass flow in the evaporator, where the value of the cooling load was taken as the reference value of 8.21 kW from the manufacturer's catalog of the device.

$$Q_E = \dot{m}_{R407C} (h_4 - h_3) \quad \dots (3)$$

To find the energy values of points 1, 2, 3, 4, 7 and 8, the formula (4) below¹⁹ was used to

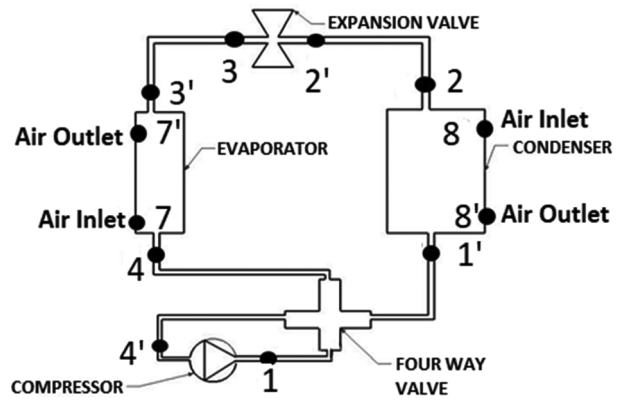


Fig. 2 — Measurement points without heat recovery were detected on the device

Table 1 — References values for R_{407C} gas, air and water

References	R _{407C}	Air	Water
T_0	298.15	298.15	298.15
h_0	439.66	298.33	104.89
s_0	2.023	1.696	0.3672

Table 2 — The values measured from the measurement points on the without heat recovery device and found in the psychometric

Measurement Points	Equipment Name	Gas	T (°C)	P (bar)	m (kg/s)	h (kJ/kg)	s (kJ/kgK)
1	Compressor Outlet	R _{407C}	90	28	0.054	467.81	1.818
1'	Condenser Inlet	R _{407C}	89	28	0.054	466.57	1.814
2	Condenser Outlet	R _{407C}	44	28	0.054	270.16	1.23
2'	Expansion Valve Inlet	R _{407C}	44	28	0.054	270.16	1.23
3	Expansion Valve Outlet	R _{407C}	3	6	0.054	270.16	1.251
3'	Evaporator Inlet	R _{407C}	3	6	0.054	270.16	1.251
4	Evaporator Outlet	R _{407C}	11	6	0.054	420.45	1.792
4'	Compressor Inlet	R _{407C}	11	6	0.054	420.45	1.792
7	Indoor Temperature	Air	48	1	2.82	321.3	1.774
7'	Indoor Unit Blowing Temperature	Air	67	1	2.82	340.42	1.827
8	Outdoor Temperature	Air	17	1	1.86	290.16	1.668
8'	Outdoor Unit Blowing Temperature	Air	8.5	1	1.86	281.15	1.641

calculate the Q values and shown in Table 4 below.

$$Q_n = \dot{m}_{R407C} \times n \quad \dots (4)$$

We found the external mass flow rate with the formula (5). External unit flow rate was taken as 5580 m³/h and air density was taken as 1.2 in the device catalog.

$$\frac{m(\text{external unit})/3600}{d(\text{air})} = m (\text{external environment}) \quad \dots (5)$$

The internal mass flow rate is found with the formula (6) below. Internal unit flow rate was 8470 m³/h and air density was taken as 1.2 kg in the device catalog. Internal unit flow rate was 8470 m³/h and air density was taken as 1.2 kg in the device catalog.

$$\frac{m(\text{internal unit})/3600}{d(\text{air})} = m (\text{internal environment}) \quad \dots (6)$$

Table 3 — Values of h₃, s₃, Q_E, \dot{m}_{R407C} for 3°C and 6 Bar

<i>h_{3 liquid}</i>	<i>h_{3 steam}</i>	<i>s_{3 liquid}</i>	<i>s_{3 steam}</i>
204.38	413.51	1.015	1.767
Q _E (kW)	\dot{m}_{R407C}	<i>s₃</i>	
8.21	0.054	1.251	

Also, to find the exergy values of points 1, 2, 3, 4, 7 and 8, E_x values were calculated by using the formula (7) below¹⁹ and shown in Table 4.

$$Ex (n) = \dot{m}_{R407C} ((h_n - h_0) - T_0 (s_n - s_0)) \dots (7)$$

Exergy Balance and Efficiency in Device without Heat Recovery

In exergy balance and efficiency calculation studies without heat recovery, compressor power was found with the help of the formula (8). The compressor energy value was calculated with formula as well (9). The energy balance value of the compressor was calculated using the formula (10). The exergy efficiency value of the compressor was calculated by the formula (11). The energy balance of the condenser was calculated with the formula (12). The exergetic efficiency of the condenser was calculated with the formula (13). The energy balance value of the expansion valve was calculated with formula (14). The exergetic efficiency value of the expansion valve was calculated with the formula (15). Evaporator energy balance value was calculated with the formula (16). The evaporator exergy efficiency value was found using the formula (17). Also, the total exergy efficiency is shown by the formula (18).⁽¹⁹⁾

$$W_{comp} = \dot{m}_{R407C} (1 - 4') \quad \dots (8)$$

Table 4 — Values measured and calculated from the measuring points in the device without heat recovery

Points	Equipment Name	Gas	T (° C)		m (kg/s)	h (kJ/kg)	s (kJ/kg)		Q (Kw)	Ex (kW)
				P			K			
1	Compressor Outlet	R _{407C}	90	28	0.054	467.81	1.818		25.8017	4.821
1'	Condenser Inlet	R _{407C}	89	28	0.054	466.57	1.814		25.7347	4.818
2	Condenser Outlet	R _{407C}	44	28	0.054	270.16	1.23		14.5886	3.614
2'	Expansion Valve Inlet	R _{407C}	44	28	0.054	270.16	1.23		14.5886	3.614
3	Expansion Valve Outlet	R _{407C}	3	6	0.054	270.16	1.251		14.5886	3.276
3'	Evaporator Inlet	R _{407C}	3	6	0.054	270.16	1.251		14.5886	3.276
4	Evaporator Outlet	R _{407C}	11	6	0.054	420.45	1.792		22.7043	2.682
4'	Compressor Inlet	R _{407C}	11	6	0.054	420.45	1.792		22.7043	2.682
7	Indoor Temperature	Air	48	1	2.82	321.3	1.774		906.066	-0.806
7'	Indoor Unit Blowing Temperature	Air	67	1	2.82	340.42	1.827		959.984	8.551
8	Outdoor Temperature	Air	17	1	1.86	290.16	1.668		539.6976	0.331
8'	Outdoor Unit Blowing Temperature	Air	8.5	1	1.86	281.15	1.641		522.939	-1.454

$$W_{comp,el} = \frac{W_{comp}}{\eta_{el}\eta_{mac}} \quad \dots (9)$$

$$E\dot{D}_{comp} = (Ex_4' + Ex_1) + W_{comp,el} \quad \dots (10)$$

$$\eta_{Ex\ comp} = \frac{Ex_4' - Ex_1}{W_{comp,el}} \quad \dots (11)$$

$$E\dot{D}_{cond} = (Ex_1' + Ex_8) - (Ex_2 + Ex_8')$$

$$\eta_{Ex,cond} = \frac{Ex_2 + Ex_8'}{Ex_1' + Ex_8} \quad \dots (13)$$

$$E\dot{D}_{expa} = Ex_3 - Ex_2' \quad \dots (14)$$

$$\eta_{expa} = \frac{Ex_2'}{Ex_3} \quad \dots (15)$$

$$E\dot{D}_{evap} = (Ex_3' + Ex_7) - (Ex_4 - Ex_7') \quad \dots (16)$$

$$\eta_{Ex\ evap} = \frac{Ex_4 + Ex_7}{Ex_3' + Ex_7'} \quad \dots (17)$$

$$\eta_{II} = \frac{E\dot{D}_{evap}}{W_{comp,el}} \quad \dots (18)$$

Exergy Loss for the Condition with Heat Recovery

The corresponding enthalpy and entropy values were obtained by finding the pressure and temperature values obtained from the points determined in the device in the psychometric diagram of the R_{407C} gas. These obtained values were the main element of the calculation. Measurement points with heat recovery were detected on the device and shown in Fig. 3 below.

For 6 °C and 5 bar in Heat Recovery Device;

$$z = z_{liquid} + x(z_{steam} - z_{liquid}) \quad \dots (19)$$

$$x = 0,273 \quad \%27,3$$

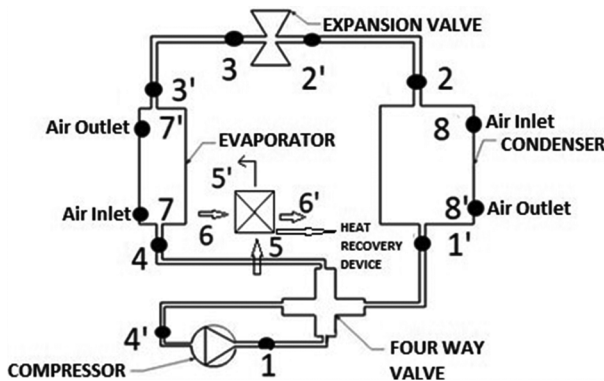


Fig. 3 — Measurement Points for Heat Recovery Device

By using the *x* value we find here in formula (20) below, we calculate the *s*₃ value.

$$s_3 = s_{3\ liquid} + x(s_{3\ steam} - s_{3\ liquid}) \quad \dots (20)$$

Data for *h*₃, *s*₃, *Q*_E, *m*_{R407C} values for 6°C and 5 bar in heat recovery device are shown in Table 5.

Cooling load was taken as 8.21 kW₍₁₂₎ from the manufacturer catalog of the device. With this data, we find the evaporator mass flow rate using the formula (21).

$$Q_E = \dot{m}_{R407C} (h_4 - h_3') \quad \dots (21)$$

In order to find the energy values of points 1, 2, 3, 4, 5, 6, 7, 8 and 9 for the device with heat recovery, the *Q* values were calculated by using the formula (22) below [19] and shown in Table 6 below.

$$Q_n = \dot{m}_{R407C} x_n \quad \dots (22)$$

Exergy Balance and Efficiency in Device with Heat Recovery

In exergy balance and efficiency calculation studies for operation with heat recovery, compressor power was found with the help of formula (23). The compressor energy value was calculated with formula (24). The energy balance value of the compressor was calculated using formula (25). The exergy efficiency value of the compressor was calculated by formula (26). The energy balance of the condenser was calculated with the formula (27). The exergetic efficiency of the condenser was calculated with the formula (28). The energy balance value of the expansion valve was calculated with the formula (29). The exergetic efficiency value of the expansion valve was calculated with the formula (30). Evaporator energy balance value was calculated with formula (31). The evaporator exergy efficiency value was found using the formula (32). Also, the total exergy efficiency is shown by the formula (33).⁽¹⁹⁾

$$W_{comp} = \dot{m}_{R407C} (1 - 4') \quad \dots (23)$$

Table 5 — Values *h*₃, *s*₃, *Q*_E, *m*_{R 4 0 7 C} for 6°C and 5 Bar for heat recovery device

<i>h</i> _{3 liquid}	<i>h</i> _{3 steam}	<i>h</i> ₃	<i>s</i> _{3 liquid}
208.82	417.80	265.88	1.031
<i>Q</i> _E (kW)	<i>m</i> _{R 4 0 7 C}	<i>s</i> _{3 steam}	<i>s</i> ₃
8.21	0.052	1.798	1.24

Table 6 — Values (Q and Ex) measured and calculated from the measuring points in the device with heat recovery

Points	Equipment	Gas	T (° C)	P(bar)	m (kg/s)	h (kJ/kg)	s (kJ/kgK)	Q (Kw)	Ex (Kw)
1	Compressor Outlet	R _{407C}	87	27	0.052	465.62	1.814	24.2122	4.590214
1'	Condenser Inlet	R _{407C}	86	27	0.052	464.39	1.811	24.1483	4.572766
2	Condenser Outlet	R _{407C}	41	27	0.052	265.88	1.22	13.8258	3.412991
2'	Expansion Valve Inlet	R _{407C}	41	27	0.052	265.88	1.22	13.8258	3.412991
3	Expansion Valve Outlet	R _{407C}	6	5	0.052	265.88	1.24	13.8258	3.102915
3'	Evaporator Inlet	R _{407C}	6	5	0.052	265.88	1.24	13.8258	3.102915
4	Evaporator Outlet	R _{407C}	13	5	0.052	423.79	1.82	22.0371	2.322031
4'	Compressor Inlet	R _{407C}	13	5	0.052	423.79	1.82	22.0371	2.322031
7	Indoor Temperature	Air	46	1	2.82	319.29	1.765	900.398	0.917684
	Indoor Unit lowing		68	1					
7'	Temperature	Air			2.82	341.43	1.83	962.833	8.701589
8	Outdoor Temperature	Air	18	1	1.86	291.16	1.67	541.558	0.967
	Outdoor Unit Blowing		9	1					
8'	Temperature	Air			1.86	282.13	1.642	524.762	-0.30156
	Fresh Air Intake with Heat		18	1					
5	Recovery	Air			0.36	291.16	1.67	104.818	0.187081
	Fresh Air Outlet with Heat		36	1					
5'	Recovery	Air			0.36	209.97	1.344	75.5892	5.949565
	Indoor suction with Heat		46	1					
6	Recovery	Air			0.36	219.97	1.391	79.1892	4.504867
	Outdoor Suction with Heat		26	1					
6'	Recovery	Air			0.36	299.19	1.699	107.708	-0.0348
9	pulverized water	Water	15	5	0.0083	61.92	0.22	0.51394	0.007617

$$W_{comp,el} = \frac{W_{comp}}{\eta_{el} \eta_{mac}} \quad \dots (24)$$

$$\dot{E}D_{comp} = (Ex_{4'} + Ex_{x1}) + W_{comp,el} \quad \dots (25)$$

$$\eta_{Ex\ comp} = \frac{Ex_{4'} + Ex_{x1}}{W_{comp,el}} \quad \dots (26)$$

$$\dot{E}D_{cond} = (Ex_{x1'} + Ex_{x8}) - (Ex_{x2} + Ex_{x8'}) \quad \dots (27)$$

$$\eta_{Ex\ cond} = \frac{Ex_{x2} + Ex_{x8}}{Ex_{x1'} + Ex_{x8'}} \quad \dots (28)$$

$$\dot{E}D_{expa} = Ex_{x3} - Ex_{x2'} \quad \dots (29)$$

$$\eta_{Expa} = \frac{Ex_{x2'}}{Ex_{x3}} \quad \dots (30)$$

$$\dot{E}D_{evap} = (Ex_{x3'} + Ex_{x7} + Ex_{x5'}) - (Ex_{x4} + Ex_{x7'} + Ex_{x6}) \quad \dots (31)$$

$$\eta_{Ex\ evap} = \frac{Ex_{x4} + Ex_{x7} + Ex_{x6}}{Ex_{x3'} + Ex_{x7'} + Ex_{x5'}} \quad \dots (32)$$

$$\eta_{II, eat\ recovery} = \frac{\dot{E}D_{evap}}{W_{comp,el}} \quad \dots (33)$$

Q and E_x values were calculated by using the existing formulas above to find the energy values of points 1, 2, 3, 4, 5, 6, 7, 8 and 9 and are shown in Table 6.

The measurement point number 9 is the final product output of the device (pulverized water) and it is sent to the mushroom compost room environment.

Thermoeconomic Analysis

The financial efficiency of the device can be found by different calculations for conditions with heat recovery and without recovery. The data cost and operating cost of the device are required before using those calculations. The following formula (34) was used for the cost of the device.

$$C_T = C_{inv} + C_{op} \quad (\text{Total cost} = \text{Capital cost} + \text{Operating cost}) \quad \dots (34)$$

If we estimate that the device is operated for 4380 hours and the total payment for the device is 5525\$ (5249\$ (device fee) and an additional 276\$ (heat recovery device fee)), thermoeconomic calculations can be made with the following formulas for the device without heat recovery.

Thermoeconomic Analysis of the Device without Heat Recovery

C = Total purchasing cost of device (5249 \$)

I = Annual interest (%15)

N = Operating time (10 years)

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad \dots (35)$$

$$C_{inv} = \frac{CRF \times \text{Total device cost}}{\text{Cooling load (Qc)} \times \text{Estimated operating time}(4380)} \quad \dots (36)$$

$$C_{inv} = \frac{CRF \times C}{Q_c \times 4380}$$

$$C_{op} = \frac{C_{el} \times P_{inp}}{Q_c} = \frac{C_{el}}{COP} \quad \dots (37)$$

$$C_T = C_{inv} + C_{op} \quad \dots (38)$$

Thermoeconomic Analysis of the Device with Heat Recovery

C = Total purchase cost of device (5525 \$)

i = Annual interest (%15)

n = Operating time (10 years)

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad \dots (39)$$

$$C_{inv} = \frac{CRF \times C}{Q_c \times 2280} \quad \dots (40)$$

$$P_{inp} = \frac{\text{amps used by the device} \times \text{volt}}{1000} \quad \dots (41)$$

$$C_{op} = \frac{C_{el} \times P_{inp}}{Q_c} = \frac{C_{el}}{COP} \quad \dots (42)$$

$$C_T = C_{inv} + C_{op} \quad \dots (43)$$

Calculation of Coefficient of Performance (COP) Value

COP value, the efficiency of the heat pump according to the 1st law of thermodynamics, is calculated by the ratio of the evaporator load to the compressor load. For cases with heat recovery and without heat recovery, we can express the calculation of compressor power with formula (44) and formula (46) below. COP values calculated for cases without heat recovery and with heat recovery are shown in formula (45) and formula (47), respectively.

$$W_{comp} = \dot{m}_{R407C} (h_1 - h_4) \quad \dots (44)$$

$$COP_{without \text{ heat recovery}} = \frac{\dot{Q}_{Evap}}{W_{Comp}} \quad \dots (45)$$

$$W_{comp} = \dot{m}_{R407C} (h_1 - h_4) \quad \dots (46)$$

$$COP_{with \text{ heat recovery}} = \frac{\dot{Q}_{Evap}}{W_{Comp}} \quad \dots (47)$$

Results and Discussion

According to these calculations, when heat recovery device is added to the system, the work done by the compressor, loss of exergy, exergy balance and efficiency decreases. While the exergy balance of the condenser, expansion valve and evaporator decreases, their efficiency increases. Overall, the efficiency of the device increases. The total exergy balance and efficiencies obtained as a result of the calculations are shown in Table 7.

The overall efficiency of the device is increasing. The work done by the compressor has decreased from 2.55 to 2.17. The exergy breakdown of the compressor decreased from -0.66 to -0.83 and the exergy balance decreased from 10.73 to 9.66. The exergy balance of the expansion valve, and evaporator increased from approximately -0.34 to -0.31, -6.80 to -5.56 respectively. The exergy balance of the condenser decreased from -0.37 to -0.86. The exergy efficiency of the condenser and evaporator increased from approximately 0.48 to 0.89, 0.31 to 0.44, respectively. The comparison of exergy values based on measurement point for both cases (with and without using the heat recycled device) is shown in Fig. 4.

As can be seen from Fig. 4, it is seen that the 5' point is effective in increasing the exergy value of the system. The exergy value continued to increase

Table 7 — The total exergy balance and efficiencies obtained because of the calculations (Using the non-heat recovery and heat recovery device, respectively)

W_{comp}	2.557	2.1752
$W_{comp,el}$	3.228	2.7464
ED_{comp}	10.7304	9.658645
$\eta_{Ex \text{ comp}}$	-0.662589	-0.825875
ED_{cond}	-0.366118	-0.858215
$\eta_{Ex \text{ cond}}$	0.48139	0.8986
ED_{Expa}	-0.338102	-0.310076
$\eta_{Ex \text{ pa}}$	1.00	1.09
ED_{evap}	-6.800084	-5.558323
$\eta_{Ex \text{ evap}}$	0.31436	0.43621
η_{ll}	2.106593	2.123857

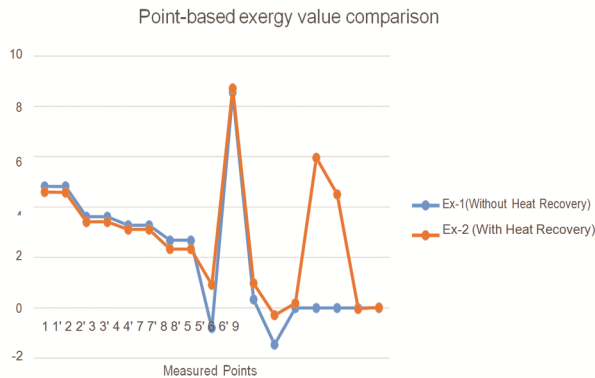


Fig. 4 — Exergy Values Comparison on the Measured Points

with the introduction of heat from the recovery system on the measured 6th point.

The efficiency increase in the device has reduced the electricity consumption and increased the capacity, thus enabling the system to operate more efficiently. Especially the electricity savings in compressor power made the device more economical in terms of cost.

The electrical energy purchasing, and total costs of the system were calculated. Cooling powers, purchasing costs and energy costs were also calculated with the help of the consumed electrical power. During the calculation, the operating period was taken as 10 years and the annual interest was taken as 10%. While the cost of the device without heat recovery was around 5249 \$, the cost of the device with heat recovery was around 5525 \$. Taking these data into consideration, the total cost of application (sum of capital and operating costs) without using a heat recovery device is 0.0685 \$/h, while the total cost of application with the addition of a heat recovery device is 0.0678 \$/h. This translates into a per hour cost reduction of approximately 1%. As a result of the calculations and the results obtained, it was determined that the addition of a heat recovery device increased the COP value at the time of operation. While the COP value in the device without heat recovery was approximately 2.69, this value increased to 3.77 in the device with the heat recovery addition. This provided a great efficiency increase for the device, while reducing electricity consumption and increasing capacity.

The standard environmental conditions taken as reference also directly affect the calculations. Exergy values decrease as the difference between the thermodynamic properties of the standard

environment and the thermodynamic properties of the fluids used in the system decreases. As this difference increases, exergy values also increase. In order to reduce exergy losses, the system should be designed using fluids with properties close to the reference environmental conditions.

Based on the thermoeconomic analysis performed during application, it is evident that by using this system, a sufficient amount of savings has been achieved. Considering that the initial investment costs of the system are also low, the system is favourable in today's conditions. Energy and exergy analyses were performed with various analysis methods, and the results showed that the device is suitable in today's conditions. These values will change positively with the development of the system and the system will become even more suitable. The methods applied in this study increase device efficiency, while saving energy and having positive effects on the environment.

Conclusions

In this study, performance analysis of the in-room heating system was performed during mushroom compost fermentation using a heat recovery device with an air sourced heat pump. While trying to prevent energy losses, the system was also examined and interpreted in terms of exergic economics. In order to make this interpretation in a healthy manner, calculations were made using various data. The following conclusions were reached due to the outcomes of the paper:

- ✓ When heat recovery device is added to the system, the work done by the compressor, loss of exergy, exergy balance and efficiency decreases.
- ✓ While the exergy balance of the condenser decreases, its efficiency increases.
- ✓ While the exergy balance of the expansion valve increase, its efficiency decreases.
- ✓ The efficiency increase in the device has reduced the electricity consumption and increased the capacity, thus enabling the system to operate more efficiently.
- ✓ Operational costs have been reduced by using the heat recovery device. There was a cost reduction of approximately 1% per hour.
- ✓ There has been an increase of approximately 40% in COP values with the use of heat recovery device.

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Nomenclature

Symbols	Meaning	Symbols	Meaning
W	Work	h	Enthalpy
E/D	Exergy balance	s	Entropy
n_{Ex}	Exergy efficiency	Q	Head Load
n_{ll}	Total efficiency	T	Temperature
C_{inv}	Cost of capital	P	Pressure
C_{op}	Operating cost	cm	Centimeter
C_T	Total cost	gr	Gram
C	System	kg	Kilogram
	installation cost		
°C	Degree celsius	Ex	Exergy
m	Mass	R407C	Refrigerant gas
\dot{m}	Mass flow rate	CRF	Capital repayment factor
S	Second	i	Annual interest
n	Molar fraction	n	System uptime
kW	Kilowatts		

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