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EXPERIMENTAL INVESTIGATION ON WASTE HEAT RECOVERY SYSTEM WITH MULTIPLE EVAPORATOR AND CONDENSER

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Abstract : The refrigeration science have attracted the researchers from the beginning of its perception. These have found application in diverse fields starting from food preservation to human comfort. The current work uses multi evaporator and condenser in vapour compression system to utilize waste heat released from condenser. The fabricated system can be used as refrigerator, air cooler, heat pump and water heater. To accomplish above mentioned objectives various bypass refrigerating circuits are used by incorporating valve mechanism. These valves can be operated in a way so as to use the system as a required by engaging the necessary refrigerating circuits.

Keywords: Vapour compression cycle condenser, waste heat recovery.

LIST OF NOMENCLATURE

SYMBOL	DEFINITION
c_{pr}	Specific heat capacity of refrigerant, kJ/kgK
c_{pw}	Specific heat capacity of water, kJ/kgK
COP	Coefficient of performance
h_1	Enthalpy at inlet of compressor, kJ/kg
h_2	Enthalpy at outlet of compressor,kJ/kg
h_5	Enthalpy at outlet of condenser, kJ/kg
h_6	Enthalpy at outlet of capillary tube, kJ/kg
HCV	Higher calorific value of the fuel used, kJ/kg
m_1	Mass flow rate of refrigerant in condenser tank, kg/s
m_{lpg}	Mass of lpg used in the investigation, kg
m_r	Mass flow rate of refrigerant, kg/s
P	Pressure, bar
Q_{rcf}	Heat rejected by refrigerant in finned condenser, KW
Q_{rcwt}	Heat received by water in condenser tank , KJ
Q_{rct}	Heat rejected by refrigerant in condenser tank , KW
T_1	Inlet temperature of compressor, °C
T_2	Outlet temperature of compressor, °C
T_3	Outlet temperature of condenser tank, °C
T_4	Finned type condenser outlet temperature, °C
T_5	Capillary tube inlet temperature, °C
T_6	Capillary tube outlet temperature, °C
T_7	Evaporator tank outlet temperature, °C
T_8	Finned type evaporator outlet temperature, °C
T_9	Water temperature at evaporator tank, °C
T_{10}	Water temperature at condenser tank, °C
W_{in}	Workdone by compressor,KW

Specifications

Sl.No	Name of the component	Type/Model	Manufacturer	Specification
1	Compressor	RoHS-605003819X	GMCC	200-220 Volts(AC)
2	Capillary Tube	Copper	NA	0.6 mm dia. and length 15 ft.
3	Valve	Gate Valve	Royal	3/8 inches
4	Refrigerant	CFC-12	NA	NA

1. INTRODUCTION

Fossil fuels like coal and petroleum have been a prime source of energy on this planet for the last centuries. But the limited and exhausting source of the fossil fuels have shifted the attention of the modern day researchers to other alternatives [1]. The present work on the experimental investigation on waste heat recovery system with multiple

evaporator and condenser is a leap forward in today's green technology using R-22 as refrigerant[2]. The main objective of the present study is to investigate the performance characteristics of a hybrid vapour compression refrigeration system. This technology utilize waste heat of refrigeration[3] unit and also to incorporate four vital referigerating components i.e. evaporator, condenser, compressor, capillary tube, and exhaust fans.The fabricated system functions as refrigerator, water heater and air heater utilising different bypass refrigerating circuits.

The experimental set-up consists of two evaporator, two condenser, one compressor, one capillary tube, two exhaust fans and R-22 refrigerant [4]. By using it we can get hot water, hot air, cold air and refrigerated space. The main purpose of the system is to utilize the waste heat that is being released from the condenser and use it as water cooled condenser. The experimental system works on vapour compression cycle [5] in which refrigerant flow through various units of compressor, condenser, capillary tube and evaporator.

2. EXPERIMENTAL SET-UP

The experimental set-up is based on simple vapor compression cycle. In a vapour compression cycle heat rejection from condenser takes place, during which superheated vapor refrigerant condenses in saturated liquid refrigerant. The heat released from condenser is not only latent heat of condensation of the refrigerant but sensible heat also. The main objective of this work is to utilize the heat energy released from condenser by heating water and to use that hot water to meet various daily needsalong with some industrial applications. The system consists of two condensers which are connected in parallel, a compressor, two evaporator which are also connected in parallel and an expansion

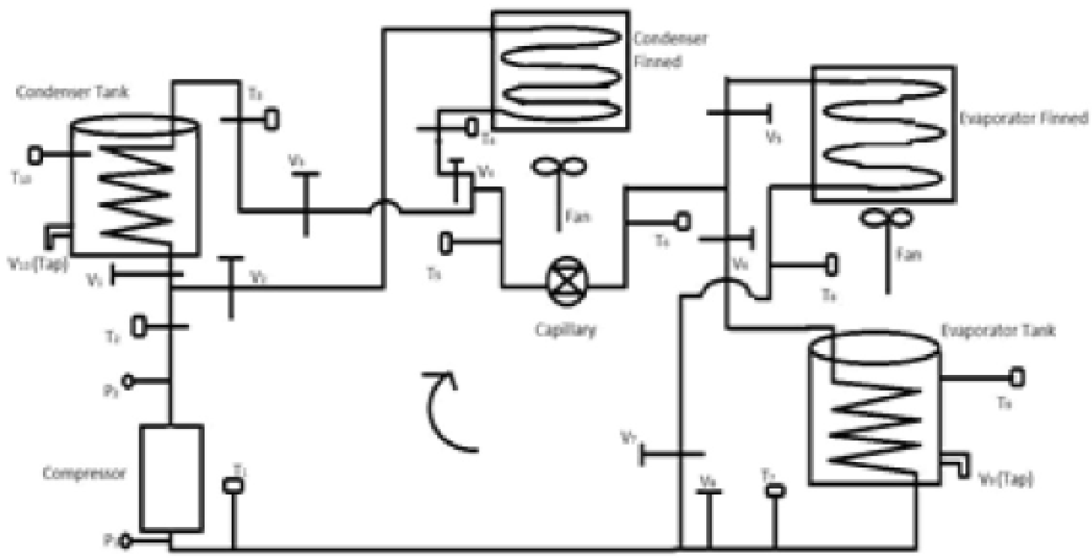

Fig 2.1: Schematic Diagram of the Experimental Set-up

device i.e. a capillary tube. At the same time two exhaust fans, one at evaporator finned and another at condenser finned are fixed to increase rate of heat transfer from those heat transfer devices. Two stainless steel tanks are used, one as evaporator tank and another as condenser tank. Some valves are also used to control or restrict the flow of refrigerant through the refrigeration circuit. The evaporator is used for absorbing heat from the control volume. At the inlet of evaporator, the condition of refrigerant is wet saturated and while passing through the evaporator, it changes into saturated vapor. The evaporator is divided into two sections which are connected in parallel. The first section is used for maintaining refrigerated space and the second oneis used to get cooled air. The outlet of both the evaporator section goes to compressor inlet which is used to compress the superheated vapour refrigerant. The refrigerant remains in the superheated state and then enters into the condenser. In the condenser, isobaric heat rejection process occurs. Thus, in this heat rejection process superheated refrigerant changes its state into saturated liquid refrigerant. This heat rejected by the condenser is used for heating water as well as air. Hence, we can get hot water as well as hot air simultaneously. The refrigerant flow can be bypassed as per requirement without affecting the condensation. Then the condensed refrigerant enters into the capillary tube. Finally, it goes to the evaporator inlet, completing the cycle.

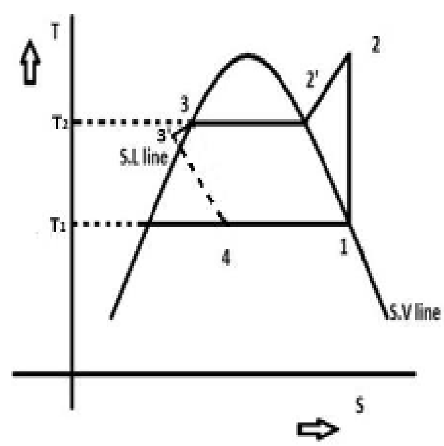

Fig.2.2: Temperature vs. Entropy plot

3. MATHEMATICAL MODEL ASSUMPTION

The thermodynamic processes occurring in the condenser are isobaric under the prevailing occurring conditions while in the compressor the working substance is assumed as an ideal gas. Hence, h= f(T).

3.1: Compressor

The energy balance equation can be expressed as,

$$w_{in} = \dot{m} \times (h_2 - h_1) \quad (1)$$

$$w_{in} = \dot{m} \times c_{pr} \times (T_2 - T_1)$$

$$\therefore \dot{m} = \frac{w_{in}}{c_{pr} \times (T_2 - T_1)} \quad (2)$$

3.2. Condenser

3.2.1. Heat Rejected by Refrigerant at Condenser Tank

The energy balance equation for condenser tank can be expressed as, Heat added to water = heat rejected by refrigerant at condenser tank Heat received by water can be expressed as,

$$Q_{rcwt} = m_1 \times c_{pw} \times (T_{10} - T_i) \quad (3)$$

Heat rejected by refrigerant is expressed as,

$$Q_{rct} = \dot{m}_1 \times c_{pr} \times (T_2 - T_1) \quad (4)$$

$$m_w \times c_{pw} \times (T_{10} - T_i) = \dot{m}_1 \times c_{pr} \times (T_2 - T_3)$$

$$\therefore \dot{m}_1 = \frac{m_w \times c_{pw} \times (T_{10} - T_i)}{c_{pr} \times (T_2 - T_3)} \quad (5)$$

3.2.2 Heat Rejected by Refrigerant at Condenser Finned

The energy balance equation for condenser tank can be expressed as;

Heat added to environment = heat rejected by refrigerant at condenser finned

$$Q_{rcf} = \dot{m}_2 \times c_{pr} \times (T_2 - T_4) \quad (6)$$

$$Q_{rcf} = (\dot{m} - \dot{m}_1) \times c_{pr} \times (T_2 - T_4) \quad (7)$$

Total mass balance of refrigerant trough condenser is,

$$\dot{m} = \dot{m}_1 + \dot{m}_2 \quad (8)$$

3.3. Expansion Valve

The mass balance for the refrigerant flow through the expansion valve is expressed as

$$m = m_r \quad (9)$$

In absence of heat loss the energy balance may be :

$$\therefore h_5 = h_6 \quad (10)$$

3.4. Evaporator

3.4.1. Heat Absorbed to Refrigerant Evaporator Tank

The energy balance equation for evaporator tank can be expressed as;

Heat rejected from water = heat absorb to refrigerant at evaporator tank

Heat rejected by water can be expressed as,

$$Q_{rewt} = m_1 \times c_{pw} \times (T_9 - T_i) \quad (11)$$

Heat rejected by refrigerant expressed as,

$$Q_{ret} = \dot{m}_1 \times c_{pr} \times (T_6 - T_7) \quad (12)$$

$$m_w \times c_{pw} \times (T_9 - T_i) = \dot{m}_3 \times c_{pr} \times (T_6 - T_7)$$

$$\therefore \dot{m}_3 = \frac{m_w \times c_{pw} \times (T_9 - T_i)}{c_{pr} \times (T_6 - T_7)}$$

3.4.2. Heat Absorbed to Refrigerant Evaporator Finned

The energy balance equation for evaporator tank can be expressed as;

Heat rejected at environment = heat added to refrigerant at evaporator finned

$$Q_{aef} = \dot{m}_4 \times c_{pr} \times (T_6 - T_8) \quad (14)$$

$$\therefore Q_{aef} = (\dot{m} - \dot{m}_3) \times c_{pr} \times (T_6 - T_8)$$

Total mass balance of refrigerant trough condenser is,

$$\dot{m} = \dot{m}_3 + \dot{m}_4 \quad (15)$$

3.5. Coefficient of Performance of the System

It is defined as the ratio of desired effect of the system to work input on the system.

$$COP_{system} = \frac{RE}{w_{in}} = \frac{Q_{aei} + Q_{aef}}{w_{in}} \quad (16)$$

3.6. Improvement of COP

The waste heat which is released from the condenser, by utilizing that waste heat one can increase the COP of the system

$$COP_{improved} = \frac{RE}{w_{in} - Q_{total,con}} \quad (17)$$

$$\therefore COP_{improved} = \frac{RE}{w_{in} - (Q_{rci} + Q_{rcf})}$$

$$\%\text{Improvement} = \frac{COP_{improved} - COP_{system}}{COP_{system}} \times 100\% \quad (18)$$

Cost to heat 10L water to increase water temperature by LPG is,

$$C.V \times m_{lpg} = m_w \times c_{pw} \times \Delta T \quad (19)$$

$$\therefore m_{lpg} = \frac{m_w \times c_{pw} \times \Delta T}{HCV}$$

4. RESULTS AND DISCUSSION

Remark- Fig 4.1 shows the variation of hot water temperature (T_{10}) with Time (min). It is known that condenser coil releases heat which increases water temperature at condenser tank. So the water temperature increases upto 50.6 ^{0} C at 44 min. After 46 min temperature of water in condenser tank becomes almost constant.

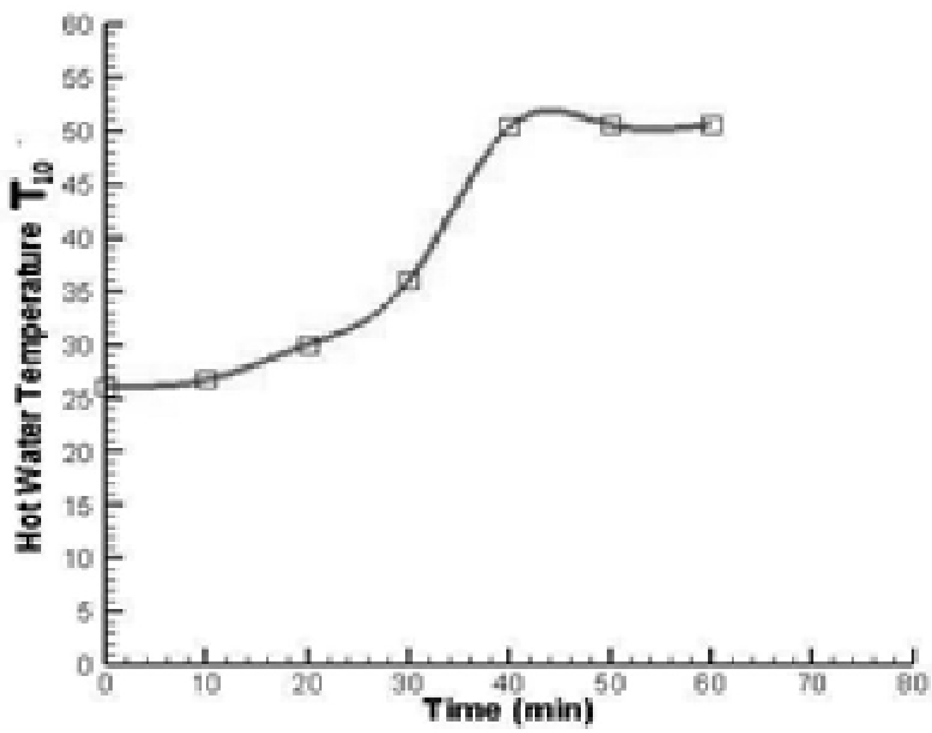

Fig 4.1: Hot water Temperature (T_{10}) vs. Time

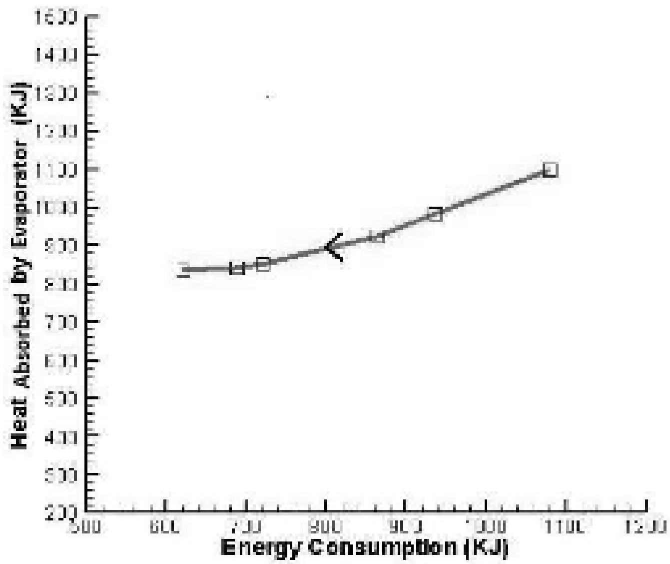

Fig 4.2 : Heat Absorbed by Evaporator vs. Energy Consumption

Remarks- Fig 4.2 shows the variation of heat absorbed (KJ) by the evaporator of the experimental setup to energy consumption (KJ). If we move in leftward direction of the graph, we can see that heat absorbed by the evaporator and the energy consumed by the system decreases. The maximum heat absorbed by the evaporator is 1099.464 KJ whereas energy consumption is 1080 KJ.

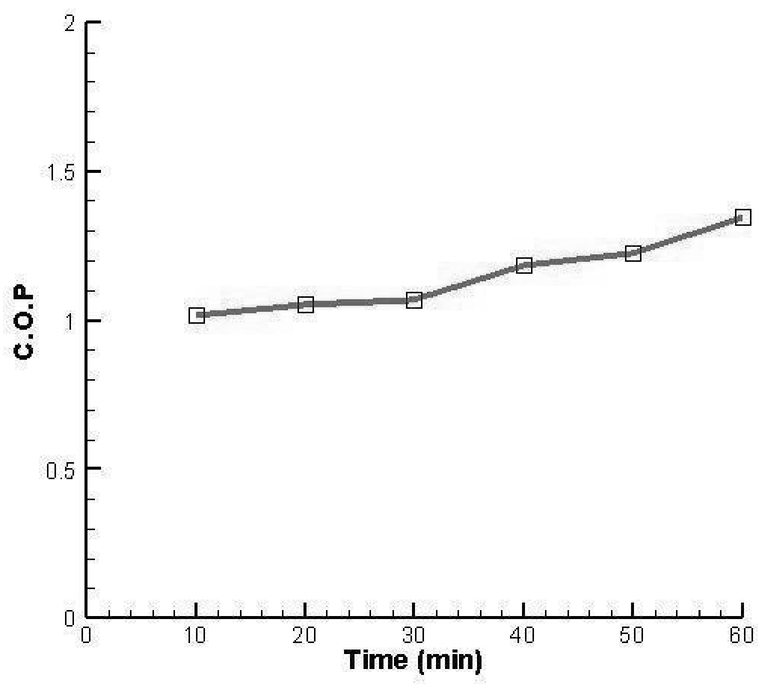

Fig 4.3: C.O.P vs. Time

Remarks- Fig 4.3 shows the variation of Co-efficient of Performance (COP) with Time (min). It can be understood that heat energy is absorbed by evaporator coil and it is called refrigeration effect. It is seen that both energy consumption and refrigeration effect are decreasing. So, COP is almost constant with time.

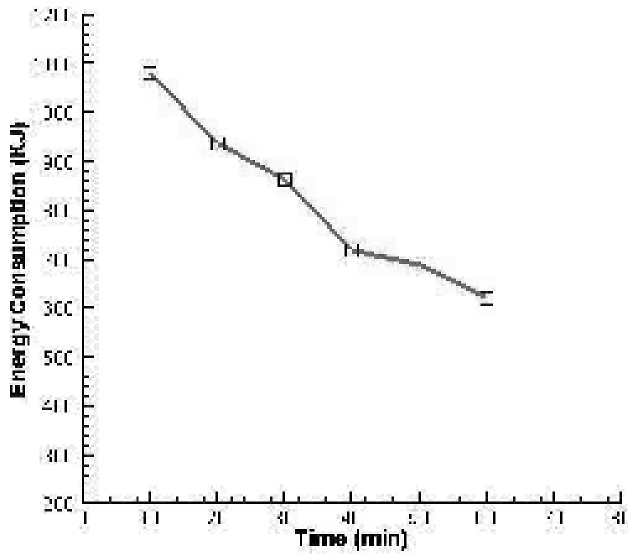

Fig 4.4 : Energy Consumption vs. Time

Remarks- Fig 4.4 shows the variation of Energy Consumption (KJ) by the system with Time (min). As the Time increases, the system tends to enter into steady state. So, the energy consumed by the system decreases with time.

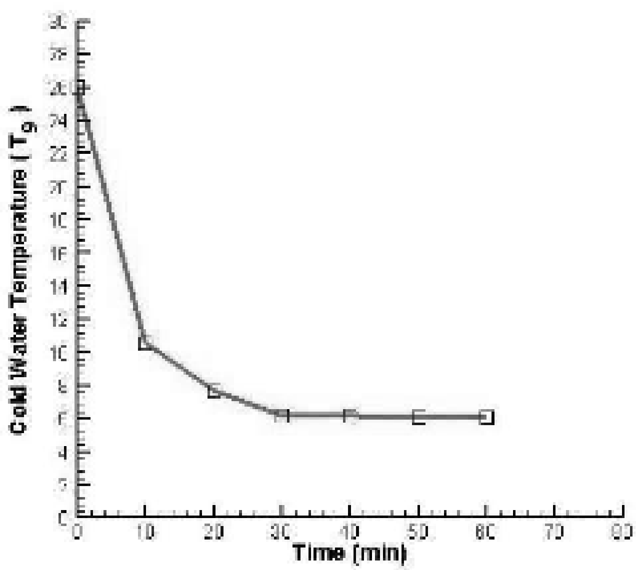

Fig 4.5: Cold Water Temperature (T_9) vs. Time

Remarks- Fig 4.5 shows the variation of water temperature at evaporator tank with Time (min). It is seen that temperature of water decreases rapidly with time upto 30 min, due to heat extraction from water by the evaporator coil. After 30 min, temperature of water becomes almost constant. It indicates the system tends to enter into steady state condition.

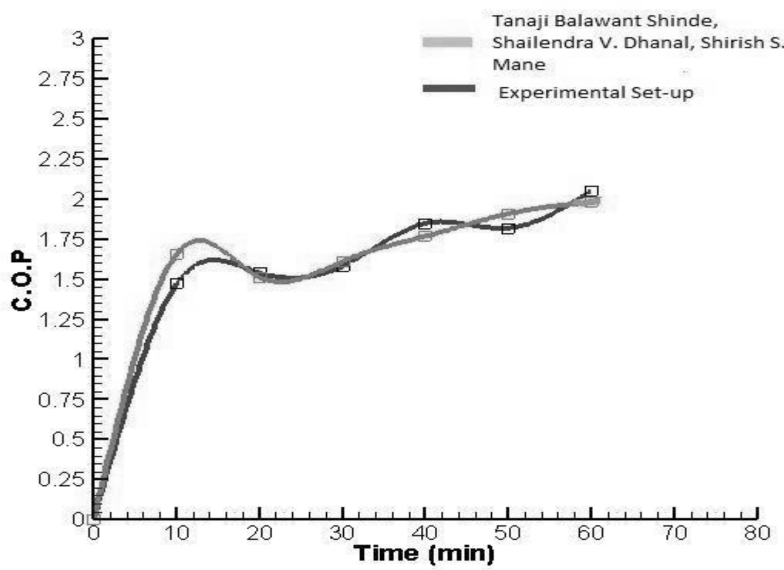

Fig. 4.6: Validation Graph (C.O.P vs. Time)

4.1. VALIDATION

In Fig. 4.6, authors have compared this experiment “Experimental Investigation on Waste Heat Recovery System with Multiple Evaporator and Condenser” with “Experimental Investigation of Waste Heat Recovery System for Domestic Refrigerator” of **Tanaji Balawant Shinde, Shailendra V. Dhanal, and Shirish S. Mane,** to check the validation of this work. The above mentioned scientists have used waste heat of a domestic refrigerator by circulating water through pipe around the condenser. Thus, water temperature has been raised and C.O.P is increased. They have got C.O.P upto 2.017.

In this experimental set-up, authors have also recovered heat from a refrigerator. Thus, C.O.P has been increased. They have got C.O.P as 2.052 which is mentioned in the Table 4.3.

5. CONCLUSION

Energy conservation is the present concern in today's era. Recovering energy in the form of heat from the refrigeration unit adds a new dimension in the realm of energy conservation. The current experimental is based on waste heat recovery from a refrigerator system. This waste heat can be utilized in the various purposes like as geyser, food or snacks warmer, process heat in different industries, grain dryer, hair dryer etc. As the waste heat is recovered the COP of the system increases a bit. Summing the above discussion, it may be concluded that:

- The experiment has shown that such system is practically feasible.
- The maximum temperature attained by the hot water tank is about 59^{o}C by using waste heat which has to be rejected otherwise.
- Heat recovery reduces the heat load to the surrounding. Thus, it makes the surrounding comfortable.

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