Enhancement of a Refrigeration Cycle by Bled Water Atomization from the Conditioned Space into the Condenser Cooling Air

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ABSTRACT
This study aims to the enhancement of the performance of air conditioning system. This action was done by cold water spray into the condenser cooling air to reduce the condensing temperature and hence reducing the compressor power which led to increasing the coefficient of cycle performance. The new in this study is to get the cold sprayed water from the cold conditioned space (bled water) without any external source. This study was performed for cold bled water mass flow of $0.012 \leq m_b \leq 0.029$ kg/s, the inside conditioned space temperatures are 18 °C, 20 °C, 22 °C, and 24 °C (conditioned space) while the outside temperature are 27 °C, 28 °C, 29 °C, 30 °C, 31 °C, 32 °C and 34 °C (summer outside condition).

Key words: Evaporative Condenser, Coefficient of Performance, Cold Bled Water

NOMENCLATURE

C.O.P	Coefficient of performance	-
m_b	Mass flow rate	kg/s
Q_b	Bled heat load	W
Q_t	Total heat load	W
Q_u	Useful heat load	W
T_c	Condensing Temperature	^{o} C
w	Compressor specific work	kJ/kg

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INTRODUCTION
Evaporative cooling systems, such as water cooling towers, evaporative condensers, evaporative fluid coolers, air washers, and dehumidifying coils, are widely used in industry. Recent statistics reveal that refrigeration technology, mainly refrigerating systems using mechanical vapor compression, represents about 15% of the worldwide consumed electricity. Thus, energy saving and environmentally friendly systems in this sector are, more than ever, in the center of political, economic and industrial concerns.
Idrissi et al [1] studied that spraying the condenser seems to be an original solution to improve the energetic performances of refrigeration and air conditioning systems. Investigation for the incorporated evaporative condenser comprises of a system of fins, basin

of water condensates, circuit pump and system of drop cloud via spraying by Michalis et al [2]. Muselli et al [3] studied two prototypes model in order to improve the yield of dew condensation from atmospheric v Chan [4] described how the COP of these chillers can be improved by a new condenser design, using evaporative pre-coolers and variable-speed fans. A simplified mathematical model was developed by Wua et al [5] to describe the heat and moisture transfer between water and air in a direct evaporative cooler. The mass of evaporated water was treated as a mass source of air flow, and the related latent heat of water evaporation was taken as a heat source in the energy equation. Hajidavalloo [6] referred to that reduction of energy consumption is a major concern in the vapor compression refrigeration cycle especially in the area with very hot weather conditions (about 50 ^{o}C), where window-air-conditioners are usually used to cool homes. Manske [7] investigated system utilized a combination of single-screw and reciprocating compressors (each operating under single-stage compression), an evaporative condenser, and a combination of liquid overfeed and direct expansion evaporators. A mathematical model of the existing system was developed. Adnan [8] studied utilization of heat pumps in various industrial technological processes is considered as an important approach to reduce the demand of energy. Chen et al [9] studied the energy saving for using water cooled air conditioners in residential buildings in Hong Kong. A split type air conditioner with air cooled (AAC) and water cooled (WAC) options was set up for experimental study at different indoor and outdoor conditions. Farahania et al [10] studied the results of an investigation on a two-stage cooling system, this system consists of a nocturnal radiative unit, a cooling coil, and an indirect evaporative cooler. Hajidavalloo and Eghtedari [11] studied an evaporative cooler which was built and coupled to the existing air-cooled condenser of a split-air-conditioner in order to measure its effect on the cycle performance under various ambient air temperature sup to 49 ^{o}C. Hu and Huang [12] studied an experimental investigation of a high-efficiency split residential water-cooled air conditioner that utilizes cellulose pad as the filling material of the cooling tower. The cooling tower performance is improved due to good water wet ability of the cellulose pad that causes a uniform water film over the entire surface of the pads and a perfect contact between water and cooling air. Nasr [13] studied vapor compression cycle incorporating the proposed evaporative condenser to evaluate the cycle performance. Wenjian Cai et al [14] studied a model-based optimization strategy for the condenser water loop of centralized heating, ventilation and air conditioning (HVAC) systems. Shahram et al [15] studied that performance of indirect evaporative cooling system (IEC) to pre-cool air for a conventional mechanical cooling system for this purpose, a combined experimental setup consisting of an IEC unit followed by a packaged unit air conditioner (PUA) was designed, constructed and tested. Naphon [16] used the heat pipe for cooling air before entering the condenser to improve the air conditioning system performance. Jahangeer et al [17] studied a numerical investigation of the heat transfer characteristics of an evaporative-cooled condenser. The simulations are performed for a single un finned tube of the condenser with the air flowing across the tube. Water is sprayed on top of the tube in the form of fine sprays and the flow rate is set to achieve film thicknesses of 0.075, 0.1, and 0.15 mm, respectively. This study aims to increasing the performance of air conditioning system. This action was done by cold water spray into the condenser cooling air to reduce the condensing temperature and hence reducing the compressor power which led to increasing the coefficient of cycle performance. The new in this study is to get the cold sprayed water from the cold conditioned space (bled water) without any external source. We hope that we can present some guidelines that will be helpful in the design of such kind of evaporative condenser in the different engineering applications.

EXPERIMENTAL SET UP AND MEASURING TECHNIQUE

Experimental apparatus was designed and manufactured for studying the effect of cold spray water on the condenser performance and hence the cycle performance. The general layout of the apparatus is shown in Fig. 1. The idea of the apparatus is to spray cold bled water from the conditioned space onto the air that cool the condenser, the amount of water sprayed was changed to optimize the amount of cooling which is extracted from the evaporator and the power saving in the compressor. The experiment is implemented with suitable instruments to control and measure the different variables affecting the problem.

TEMPERATURE MEASURMENT

The apparatus operates in small temperature limit below 60 ^oC for the inside and outside air around the tested wall. So, thermocouple was used as temperature sensor. The thermocouple for this temperature range is more stable, Fig.2 .The numbers of thermocouple used are 13 and distributed in the apparatus as following:

Table1. Location of Thermocouples through the Apparatus

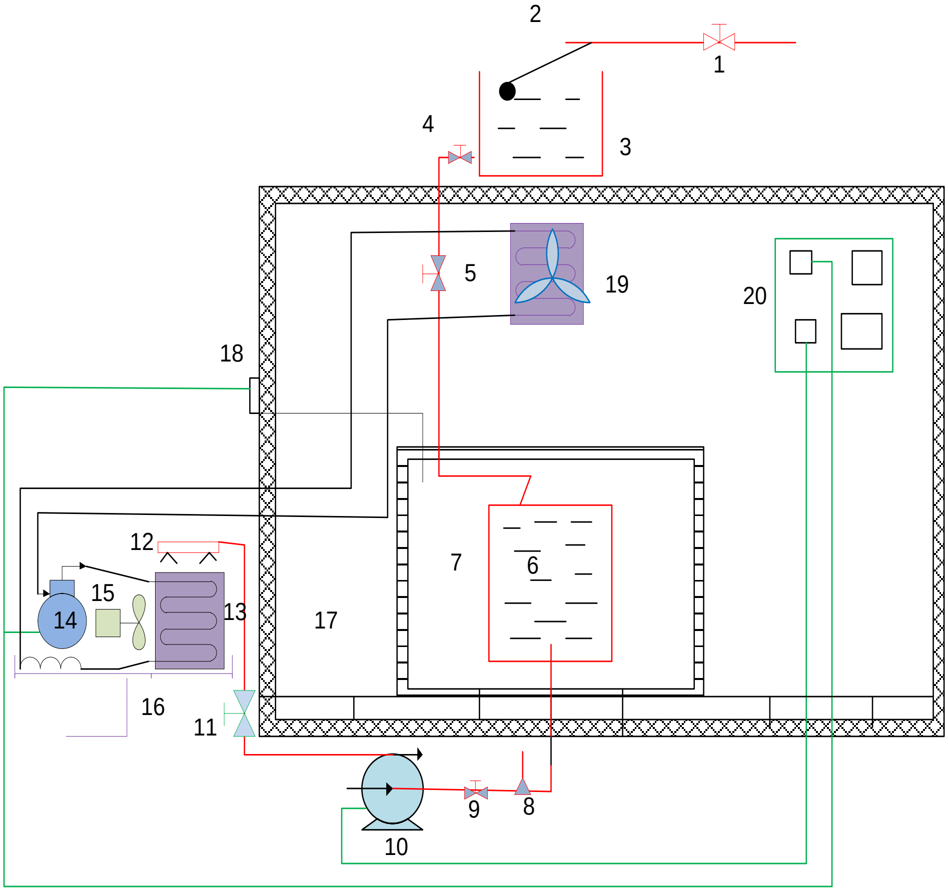
Thermocouple number	*Location*
T_1	*Cold space Temperature*
T_2	*Cold water temperature inside the cold space*
T_3	*Sprayed water temperature*
T_4	*Refrigerant temperature at compressor inlet*
T_5	*Refrigerant temperature at evaporator inlet*
T_6	*Refrigerant temperature at condenser inlet*
T_7	*Refrigerant temperature at condenser outlet*
T_8	*Air wet bulb temperature before condenser*
T_9	*Air dry bulb temperature before condenser*
T_{10}	*Air wet bulb temperature after condenser*
T_{11}	*Air dry bulb temperature after condenser*
T_{12}	*Exit water temperature from conditioned space*
T_{13}	*Inlet water temperature to conditioned space*

WATER CYCLE

The sprayed cooling water cycle is closed cycle consists of:

- Feed water source (storage water tank has temperature equals the ambient temperature).
- Inside storage tank in the conditioned space with cold water temperature equal the conditioned space temperature.
- Regulate flow valve for controlling the sprayed water mass flow rate.
- Small water circulating pump to circulate water from the conditioned space to the nozzles.

- Spray holes (nozzles) for water spraying.
- Collected basin for the cold water remained after water spray section.
- Recirculation cold water pump to recirculate the cold water remained after water spray section to the inside storage tank in the conditioned space.



Item	*Name*	*Item*	*Name*
1	*Flow Control valve*	*11*	*Flow Control valve*
2	*Ball Float valve*	*12*	*Spray nozzles*
3	*Fresh water tank*	*13*	*Condenser*
4	*Flow Control valve*	*14*	*Compressor*
5	*Flow Control valve*	*15*	*Fan*
6	*Cold water tank*	*16*	*Drain*
7	*Conditioned space*	*17*	*Guarded room*
8	*Side glass*	*18*	*Compressor switch*
9	*Flow Control valve*	*19*	*Fan coil*
10	*Pump*	*20*	*Control unite*

Fig.1: Apparatus Components

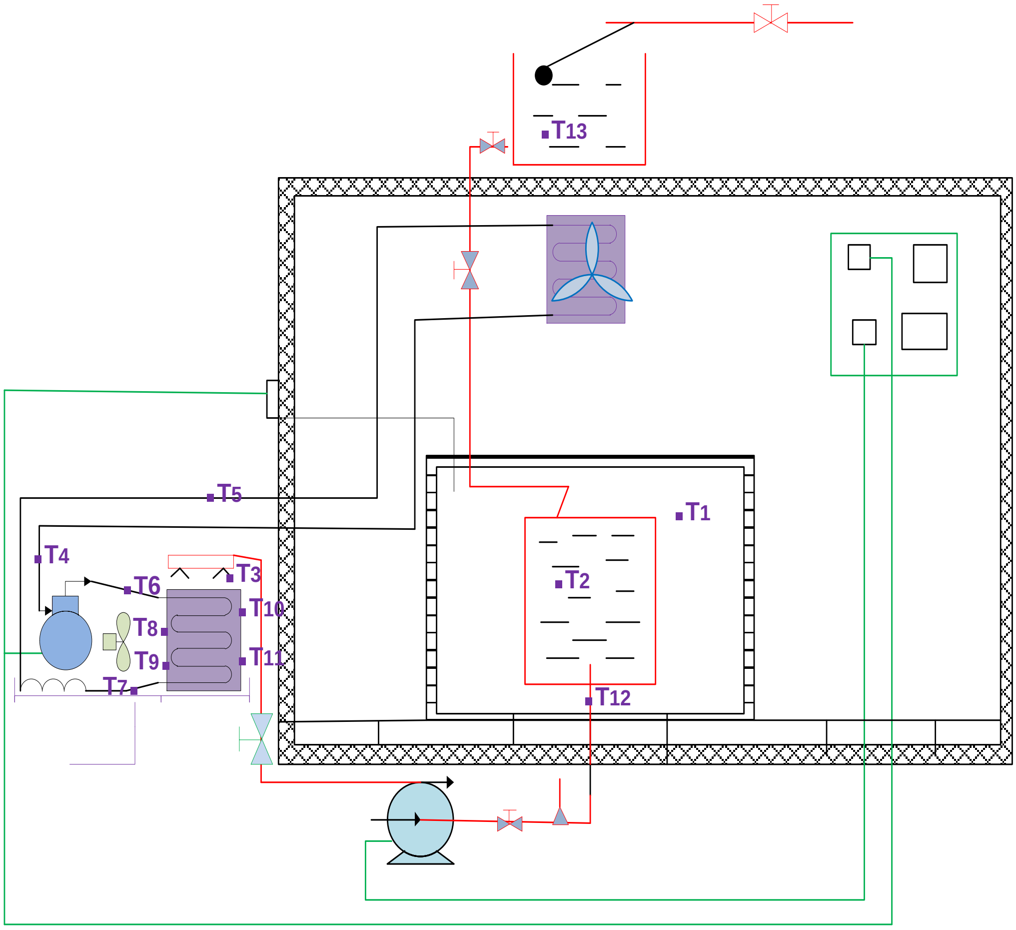


Fig.2: Thermocouples Distribution in the System

RESULTS AND DISCUSSION

BASIC EQUATIONS

$$C.O.P_t = \frac{Q_u + Q_b}{W_c} \quad (1)$$

$$C.O.P_t = \frac{Q_u + Q_b}{W_c} \quad (2)$$

$$C.O.P_t * W_c = Q_u + Q_b \quad (3)$$

$$C.O.P_t * W_c = Q_u \left(1 + \frac{Q_b}{Q_u}\right) \quad (4)$$

$$C.O.P_t = \frac{Q_u}{W_c}\left(1 + \frac{Q_b}{Q_u}\right) = C.O.P_u \left(1 + \frac{Q_b}{Q_u}\right) \quad (5)$$

$$C.O.P_t = C.O.P_u \left(\frac{Q_t}{Q_t - Q_b}\right) \quad (6)$$

$$C.O.P_t = C.O.P_u \left(\frac{1}{1 - \frac{Q_b}{Q_t}}\right) \quad (7)$$

$$\left(\frac{1}{1 - \frac{Q_b}{Q_t}}\right) = \frac{C.O.P_u}{C.O.P_t} \quad (8)$$

Where:

$$C.O.P_u = \frac{Q_u}{W_c} \quad (9)$$

DISCUSSION

The above Eq.(8) represent the relation between the amount of extracted heat from the cold space Q_b to the total heat Q_t for the cycle with the ratio between the useful C.O.P to the total C.O.P of the cycle, this equation is represented in Fig.3.
From this figure it was found that the relation between the useful C.O.P is inversely proportional with the amount of extracted heat from the cold space Q_b. According to the space load Q_u the amount of extracted heat from the cold space Q_b must be determined as hyper load from the conditioned space i.e if the space load Q_u is maximum one (full load) no need for extracting heat from the cold space Q_b because it will reduce the cycle useful C.O.P but if the space load Q_u is less than the peak value (part load operation) it will be an advantages to extract heat from the cold space Q_b equal to Q_t-$Q_{b(part\ load)}$for spraying cold water into the condenser cooling air. As shown in Figs.4 to 19, if the conditioned space temperature decreased the cycle C.O.P increased due to the bled sprayed water temperature decreased and so cold moist air for condenser cooling which led to decreasing the condensing temperature and compressor work. Also as the outside environmental temperature decreased the cycle C.O.P increased due to low condensing temperature observed due to that the condenser cooling air was taking from the outside and also that as the outside temperature decreased the conditioned space load decreased and hence large amount bled water was available. Spraying cold water onto the condenser cooling air increases the performance of the refrigeration cycle especially if this water at low temperature as possible.

CONCLUSION

This study was performed for cold bled water mass flow of $0.012 \leq m_b \leq 0.029$ kg/s, the inside conditioned space temperatures are 18 ^oC, 20 ^oC, 22 ^oC, and 24 ^oC (conditioned space) while the outside temperature are 27 ^oC, 28 ^oC, 29 ^oC, 30 ^oC, 31 ^oC, 32 ^oC and 34 ^oC (summer outside condition).

The experimental data are also listed and the results are concluded as:

- The relation between the useful C.O.P is inversely proportional with the amount of extracted heat from the cold space Q_b.
- According to the space load Q_u the amount of extracted heat from the cold space Q_b must be determined as hyper load from the conditioned space i.e if the space load Q_u is maximum one (full load) no need for extracting heat from the cold space Q_b because it will reduce the cycle useful C.O.P but if the space load Qu is less than the peak value (part load operation) it will be an advantages to extract heat from the cold space Q_b equal to Q_t-$Q_{b(part\ load)}$ for spraying cold water into the condenser cooling air.
- As the conditioned space temperature decreased the cycle C.O.P increased due to the bled sprayed water temperature decreased and so cold moist air for condenser cooling.
- As the outside environmental temperature decreased the cycle C.O.P increased due to low condensing temperature observed.
- Spraying cold water onto the condenser cooling air increases the performance of the refrigeration cycle especially if this water at low temperature as possible.

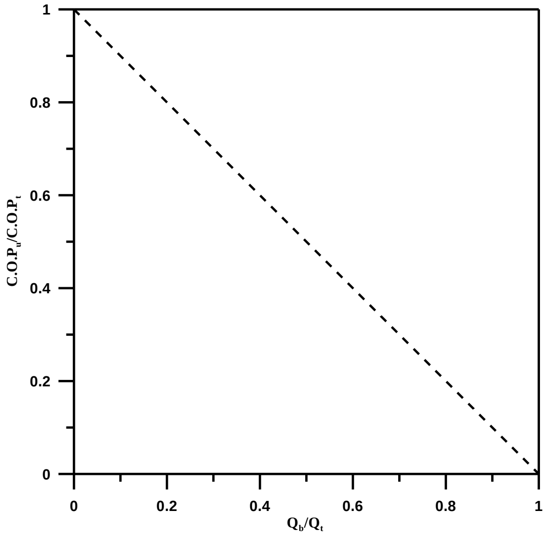


Fig.3: The useful C.O.P versus the amount of extracted heat Qb

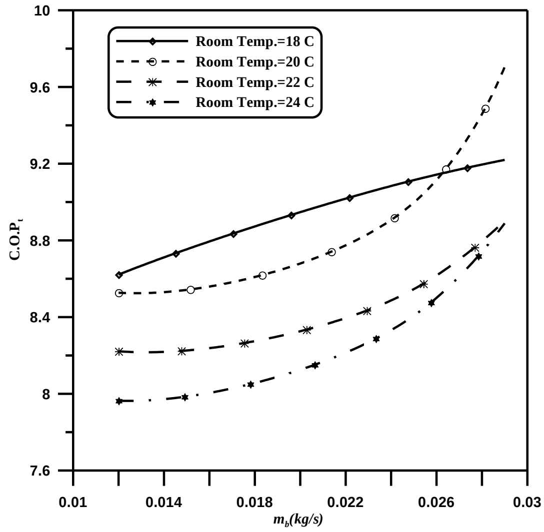


Fig.4: Effect of bled mass flow versus C.O.P at outside temp. of 27 ^{o}C

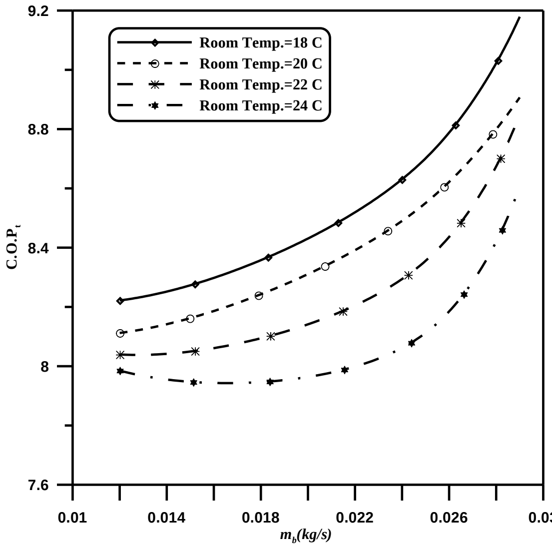


Fig.5: Effect of bled mass flow versus C.O.P at outside temp. of 28 ^{o}C

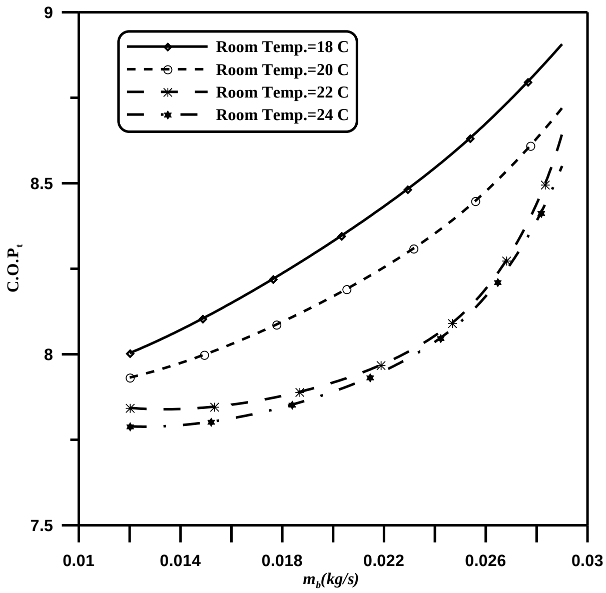


Fig.6: Effect of bled mass flow vers. C.O.P at outside temp. of 29 ^{o}C

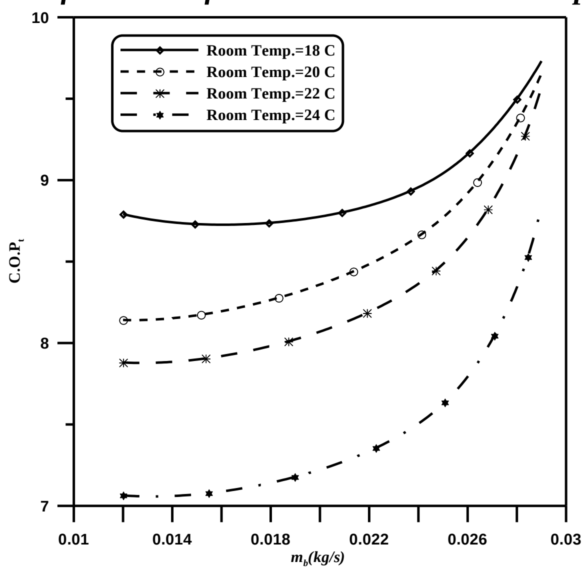


Fig.7: Effect of bled mass flow vers. C.O.P at outside temp. of 30 ^{o}C

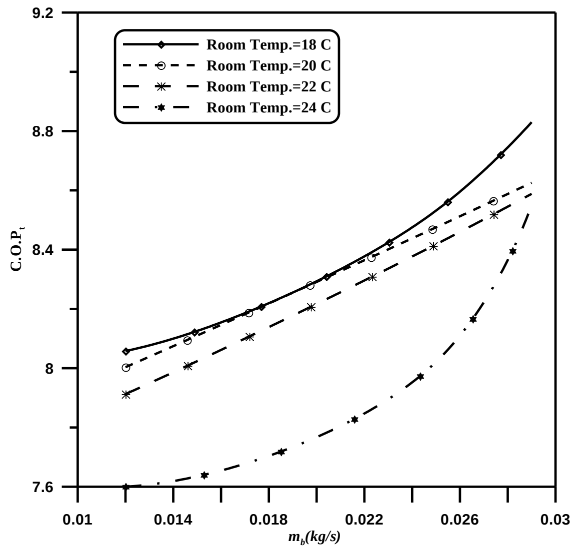


Fig.8: Effect of bled mass flow vers. C.O.P at outside temp. of 31 ^{o}C

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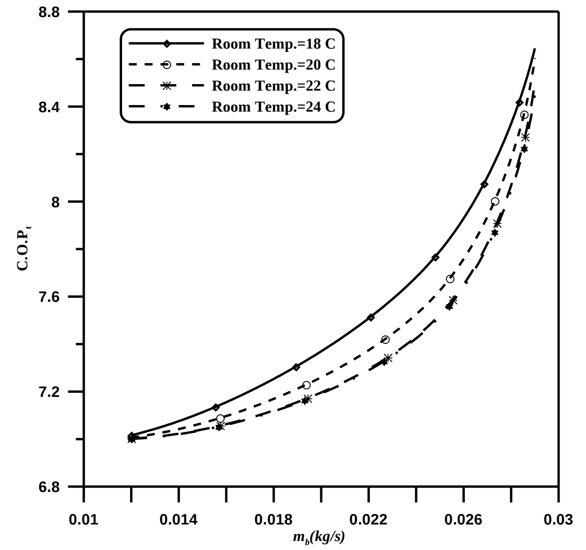

Fig.9: Effect of bled mass flow vers. C.O.P at outside temp. of 32 °C

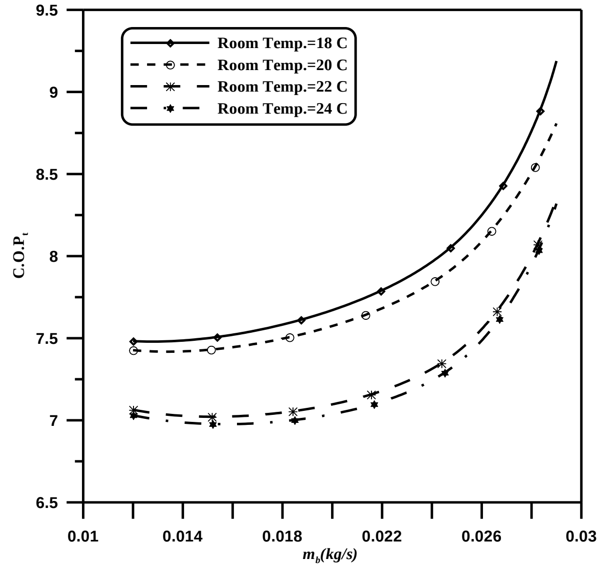

Fig.10: Effect of bled mass flow vers. C.O.P at outside temp. of 33 °C

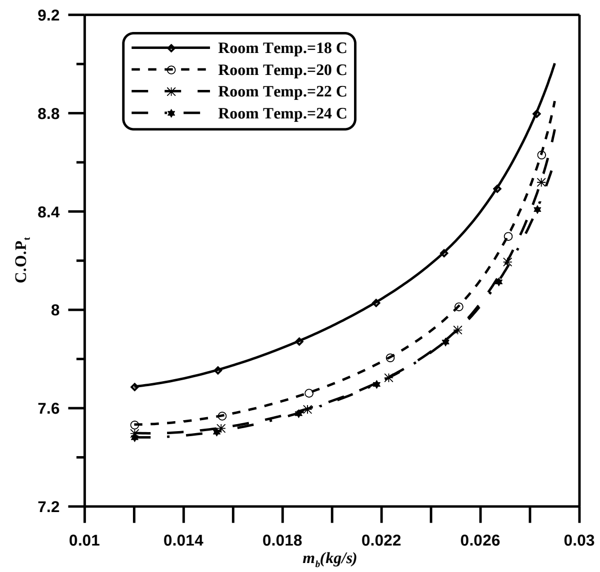

Fig.11: Effect of bled mass flow vers. C.O.P at outside temp. of 34 °C

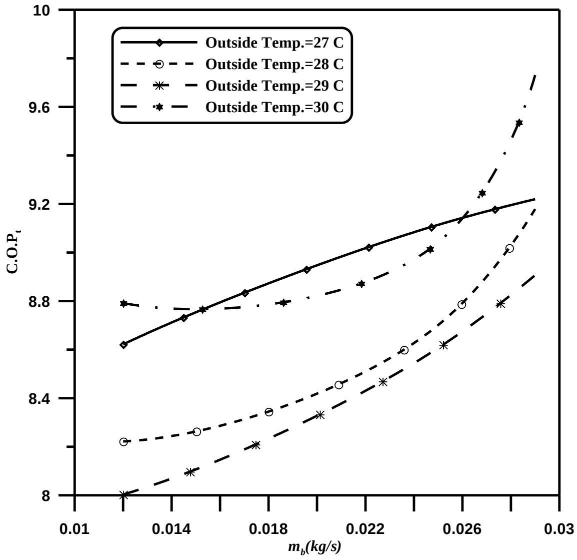

Fig.12: Effect of bled mass flow vers. C.O.P at room temp. of 18 oC

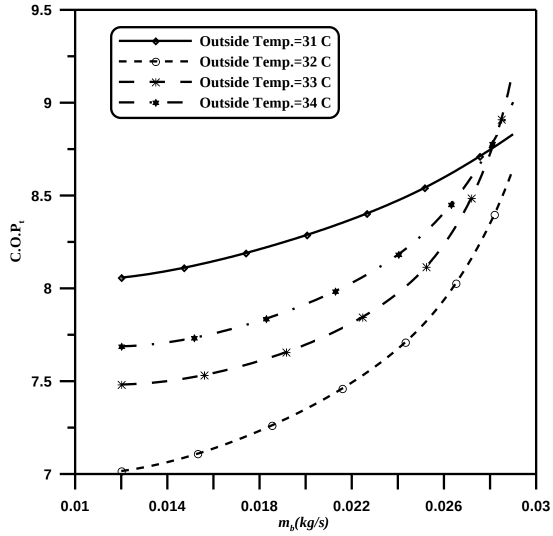

Fig.13: Effect of bled mass flow versus C.O.P at room temp. of 18 oC

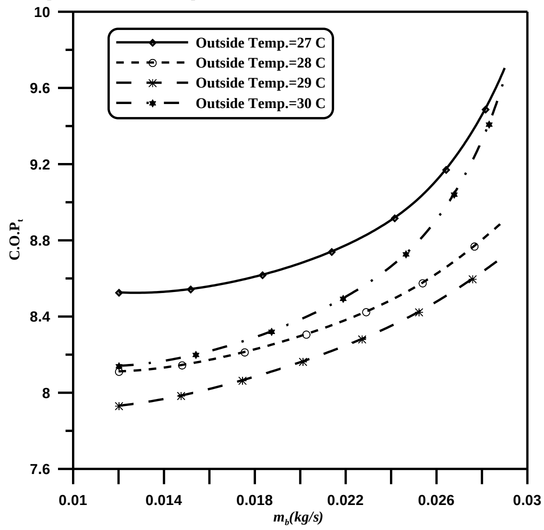

Fig.14: Effect of bled mass flow vers. C.O.P at room temp. of 20 oC

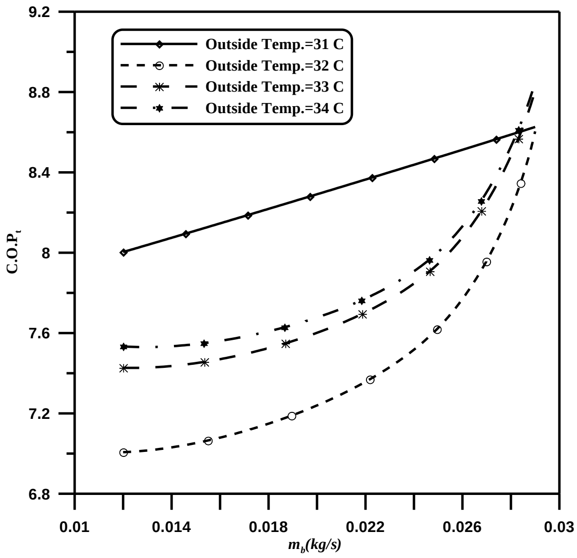

Fig.15: Effect of bled mass flow versus C.O.P at room temp. of 20 oC

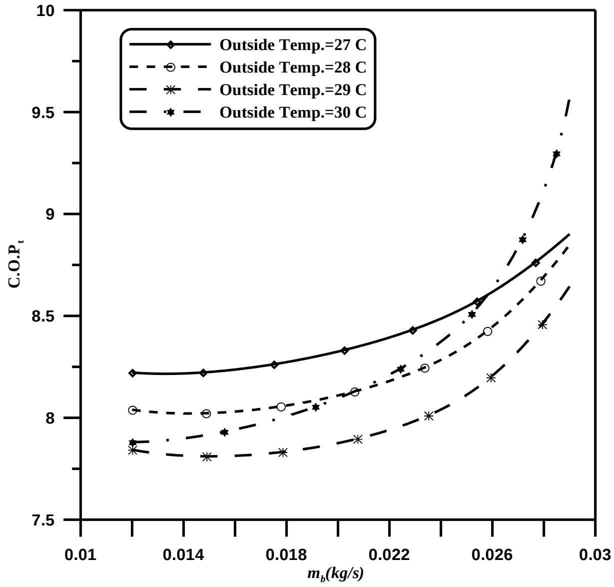

Fig.16: Effect of bled mass flow vers. C.O.P at room temp. of 22 oC

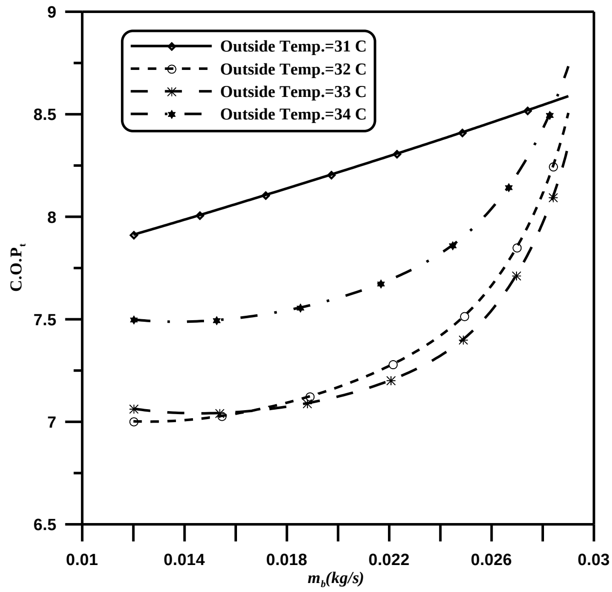

Fig.17: Effect of bled mass flow versus C.O.P at room temp. of 22 oC

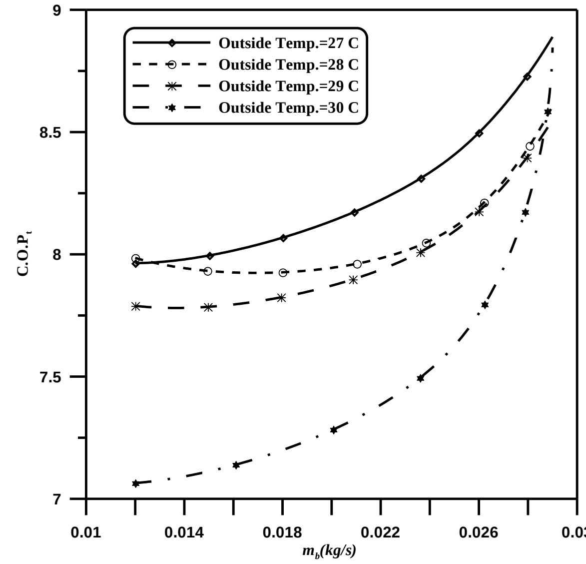

Fig.18: Effect of bled mass flow vers. C.O.P at room temp. of 24 oC

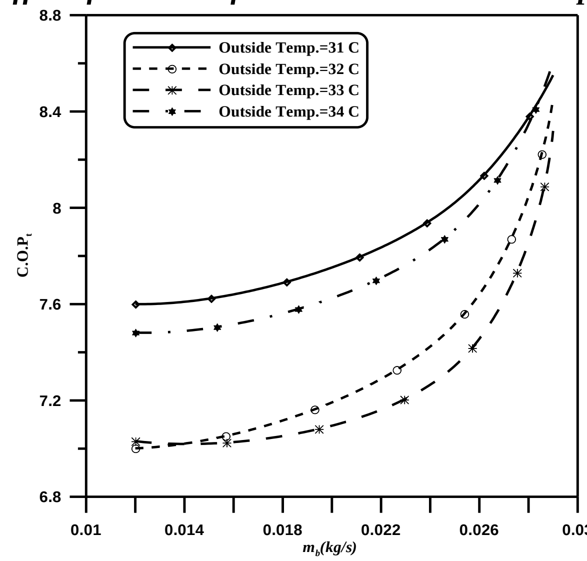

Fig.19: Effect of bled mass flow versus C.O.P at room temp. of 24 oC

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