A SIMPLIFIED CHART USED TO PREDICT THE UTILIZATION OF HEAT PUMP SYSTEM+

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Abstract

The present work gives a simple chart that helps the designer to make a quick estimation and decision if the heat pump system is feasible or not compared with traditional system and the economic limitation for use this type of systems by defining the annual ratio of cooling load to the heating load (R), the ratio of annually operating hours (C), Boiler efficiency (η_B) and coefficient of performance of chillers (COP).

The results showed ability to use heat pump systems within a certain limit of annually cooling to heating load ratio to produce energy saving within certain value of other factors.

المستخلص

يقدم هذا البحث مخطط بسيط يساعد المصمم على أخذ قرار ابتدائي إن كانت منظومة المضخة الحرارية مجدية اقتصاديا أم لا بالمقارنة مع المنظومات التكييف التقليدية والمحددات الاقتصادية لاستخدام هذا النوع من المنظومات بعد تحديد النسبة السنوية لحمل التبريد إلى حمل التدفئة والنسبة بين ساعات العمل السنوية و كفاءة المرجل و معامل أداء المثلج. وقد بينت النتائج أن هنالك إمكانية لاستخدام المضخة الحرارية عند حدود معينة من النسب و العوامل المذكورة أعلاه للحصول على ادخار في الطاقة.

Nomenclature

Q_1, CL	: yearly cooling load	[kW.hr]
Q_2	: yearly energy rejected in Chiller 1	[kW.hr]
Q_3, AUX	: yearly auxiliary load	[kW.hr]
Q_4	: yearly energy input to Chiller 2	[kW.hr]
Q_5, HL	: yearly heating load	[kW.hr]
COP	: coefficient of performance	
OH_T	: total operating hours	[hr]
OH_X	: auxiliary operating hours	[hr]
OH_C	: cooling operating hours	[hr]
OH_H	: heating operating hours	[hr]
CH_1	: chiller no. 1 capacity	[kW]
CH_2	:chiller no. 2 capacity	[kW]
C	: ratio of cooling operating hours to heating operating hours	
R	: ratio of yearly cooling load to the yearly heating load	

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RR : ratio between energy consumption in heat pump to energy consumption in traditional system

η_B : boiler efficiency

Introduction

The idea of heat pump system comes back to year 1852 but the real product for a heat pump system was not complete before the year 1924. Continuing its production till over about 2 million in year of 1977 [1], and its utilization took a large is form in world with many poly applications. Also increase the importance in heat pump is due to the energy conservation. But the utilization of this system is still limited in hot climate area [2].

For a long time one question arise when the utilization of heat pump system offered to be replaced instead of traditional system (chiller and boiler), this question "is the utilization of heat pump system feasible or not " and the answer to this question is very important because it supports the designer to select the correct unit and make the right decisions [3].

Theoretical Analysis

Two typical systems have been selected for comparison analysis, first consists of chiller for cooling and boiler for heating (traditional system) and the second utilizes heat pump that consists of two chillers as shown in Fige (1) [4].

Imposing the definition of coefficient of performance (COP), we can get:

$$COP = \frac{Q_{evap}}{W_{comp}} = \frac{Q_{evap}}{Q_{cond} - Q_{evap}} \qquad \text{. . . . . (1)}$$

but

$$Q_{cond} = Q_{evap}\left(1 + \frac{1}{COP}\right) \qquad \text{. . . . . (2)}$$

For the first chiller

$$Q_2 = Q1\left(1 + \frac{1}{COP_1}\right) \qquad \text{. . . . . (3)}$$

and the second chiller

$$Q_5 = Q_4\left(1 + \frac{1}{COP_2}\right) \qquad \text{. . . . . (4)}$$

but

$$Q_4 = Q_2 \pm Q_3 \qquad \text{. . . . . (5)}$$

The sign (-) means the auxiliary equipment is cooling tower and the sign (+) means the auxiliary equipment is the boiler.

Substitute in Eq. 5 in Eq. 4 gives

$$\mathbf{Q}_5 = (\mathbf{Q}_2 \pm \mathbf{Q}_3)\left(1 + \frac{1}{\mathbf{COP}2}\right) \qquad \text{. . . . . (6)}$$

Substituting Eq. 2 in Eq. yields 6

$$Q_5 = \left[Q_1\left(1 + \frac{1}{COP_1}\right) \pm Q_3\right]\left[1 + \frac{1}{COP_2}\right] \qquad \text{. . . . . (7)}$$

Let us assume that the coefficients of performance of the two chillers are equal and (M) is equal to

$$M = 1 + \frac{1}{COP} \qquad \text{. . . . . (8)}$$

Therefore

$$Q_5 = M(MQ_1 \pm Q_3) \qquad \text{. . . . . (9)}$$

From the definitions of Q_1 & Q_5

$$HL = M(M \times CL \pm AUX) \qquad \text{. . . . . (10)}$$

$$AUX = \frac{HL}{M} - M \times CL \qquad \text{. . . . . (11)}$$

But the energy consumed in any devices is equal to [5]
Energy = Power × Operating hour
Therefore

$$HL = CH_2 \times OH_T \qquad \text{. . . . . (12)}$$

$$CL = CH_1 \times OH_T \qquad \text{. . . . . (13)}$$

$$AUX = AX \times OH_X \qquad \text{. . . . . (14)}$$

From the Eq. 14

$$AX \times OH_X = \frac{CH_2 \times OH_T}{M} - M \times CH_1 \times OH_T \qquad \text{. . . . . (15)}$$

$$AX = \frac{CH_2}{M} \times \frac{OH_T}{OH_X} - M \times CH_1 \times \frac{OH_T}{OH_X} \qquad \text{. . . . . (16)}$$

Let $N = \dfrac{OH_X}{OH_T}$

$$AX = \frac{CH_2}{MN} - \frac{M}{N} \times CH_1 \qquad \text{. . . . . (17)}$$

$$= \frac{1}{N}\left(\frac{CH_2}{M} - M \times CH_1\right) \qquad \text{. . . . . (18)}$$

When the auxiliary is cooling tower (-ve)

$$\frac{CH_2}{M} < M \times CH_1$$

And when the auxiliary load is boiler (+ve)

$$\frac{CH_2}{M} > M \times CH_1$$

But when the auxiliary load is zero

$$\frac{CH_2}{M} = M \times CH_1 \qquad \text{. . . . . (19)}$$

When that case happens, this means the system does need not any types of auxiliary load, it will be

$$M^2 = \frac{CH_2}{CH_1} \qquad \text{. . . . . (20)}$$

This case represents the ideal system that can be received from heat pump system which is the suggested case with respect to initial cost.

To find the relation between the energy consumption in heat pump and traditional system, defined the ratio (R) as follows[6]

For traditional system

$$R = \frac{CH_1}{B} \times \frac{OH_C}{OH_H} \qquad \text{. . . . . (21)}$$

$$\frac{B}{CH_1} = \frac{1}{R} \times \frac{OH_C}{OH_H} \qquad \text{. . . . . (22)}$$

The energy consumption in heat pump system is:

$$E_{HP} = \frac{CH_1}{COP} \times OH_T + \frac{CH_2}{COP} \times OH_T + \frac{AX}{\eta_X} \times OH_X \qquad \text{. . . . . (23)}$$

The energy consumption in traditional system is:

$$E_{TR} = \frac{CH_1}{COP} \times OH_C + \frac{B}{\eta_B} \times OH_H \qquad \text{. . . . . (24)}$$

The ratio between the energy consumption in heat pump system to traditional system is:

$$RR = \frac{E_{HP}}{E_{TR}} \qquad \text{. . . . . (25)}$$

$$RR = \frac{\frac{CH_1}{COP} \times OH_T + \frac{CH_2}{COP} \times OH_T + \frac{AX}{\eta_X} \times OH_X}{\frac{CH_1}{COP} \times OH_c + \frac{B}{\eta_B} \times OH_H} \quad \text{........ (26)}$$

Dividing by OH_T and multiplying by COP the equation above can be written as:

$$RR = \frac{CH_1 + CH_2 + \frac{AX}{\eta_X} \times COP \times \frac{OH_X}{OH_T}}{CH_1 \times \frac{OH_C}{OH_T} + \frac{B}{\eta_B} \times COP \times \frac{OH_H}{OH_T}} \quad \text{.......... (27)}$$

As mentioned previously the best utilization of heat pump system occurred when the auxiliary load is minimum (AX=0) [7], at that condition RR approached to $RR_{max.}$ [8]

$$RR_{max.} = \frac{CH_1 + CH_2}{CH_1 \times \frac{OH_C}{OH_T} + \frac{B}{\eta_B} \times COP \times \frac{OH_H}{OH_T}} \quad \text{.......... (28)}$$

Divided by CH_1

$$RR_{max.} = \frac{1 + \frac{CH_2}{CH_1}}{\frac{OH_C}{OH_T} + \frac{B}{CH_1} \times \frac{COP}{\eta_B} \times \frac{OH_H}{OH_C}} \quad \text{............ (29)}$$

Using Eq. 20

$$RR_{max.} = \frac{1 + M^2}{\frac{OH_C}{OH_T} + \frac{1}{R} \times \frac{COP}{\eta_B} \times \frac{OH_C}{OH_T}} \quad \text{............ (30)}$$

Assume $C = \frac{OH_C}{OH_T}$

$$RR_{max.} = \frac{1 + M^2}{C\left(1 + \frac{1}{R} \times \frac{COP}{\eta_B}\right)} \quad \text{............ (31)}$$

From the definitions of RR in Eq. 25

$$E_{HP} = E_{TR} \times RR \quad \text{........... (32)}$$

Therefore the gain in energy is

$$E_G = E_{TR} - E_{HP}$$

$$E_G = E_{TR}(1 - RR) \qquad \text{.............} (33)$$

It is clear that the energy gain depend directly on RR

If RR $>$ 1 There is no gain in energy

RR $<$ 1 There is gain in energy

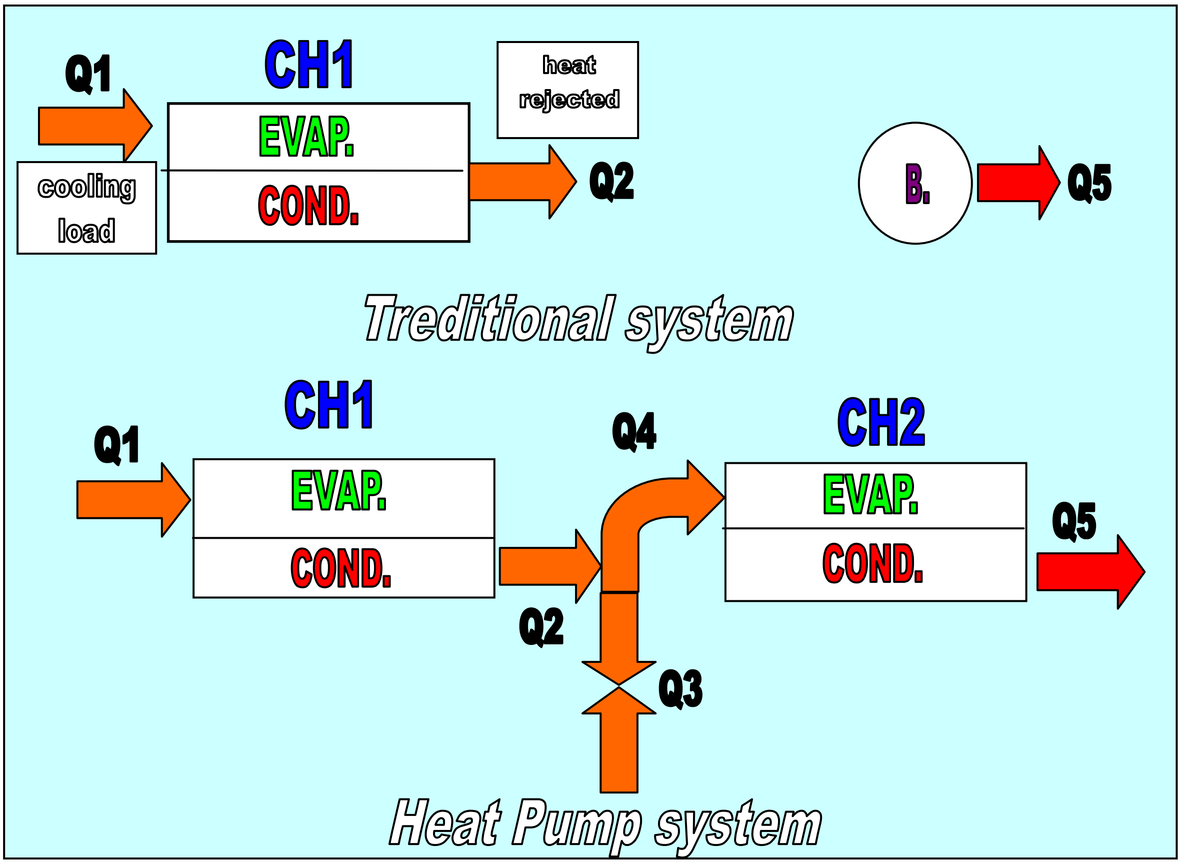

Figure (1) Systems Configuration

Result and Discussion

Figures (2) to (4) represent the relations between the ratio of yearly cooling load to yearly heating load (R), the ratio of energy consumption in heat pump system to energy consumption in traditional system (RR) for different values of boiler efficiency and coefficient of performance of chillers and ratio of operating hours.

In general the values of (RR) increase when (R) increases that is because of the increasing of (R) decreases the effect of heating in the total yearly load i.e. the contribution of second chiller (use for heating in heat pump system) will decrease and disappear in overall value of (RR).

Figure (2) shows the effect of boiler efficiency (η_B) on the ratio (RR) with constant value of (COP) and (C). It is easy to say that increasing in boiler efficiency increases (RR) and makes the heat pump system not economic. Figure (3) and Figure (4) show other factors effecting (RR) and the economy zone are also plotted.

Figure (5) shows a very simple and useful chart to give the designer a first prediction about the heat pump system in energy wise.

Finally the result shows important points which must be considered before deciding to utilized heat pump system instead of traditional system, and they are as follows [9]

A. There is a little chance to use heat pump system in hot climate area (R more than 75 %), but this chance increases in industrial applications (when R is small).
B. Using heat pump system when the boiler efficiency is low (less than 50 %).
C. Using heat pump system when the coefficient of performance is less than 3.
D. Using heat pump system when the ratio of cooling operating hours to heating operating hours is less than 40 %.

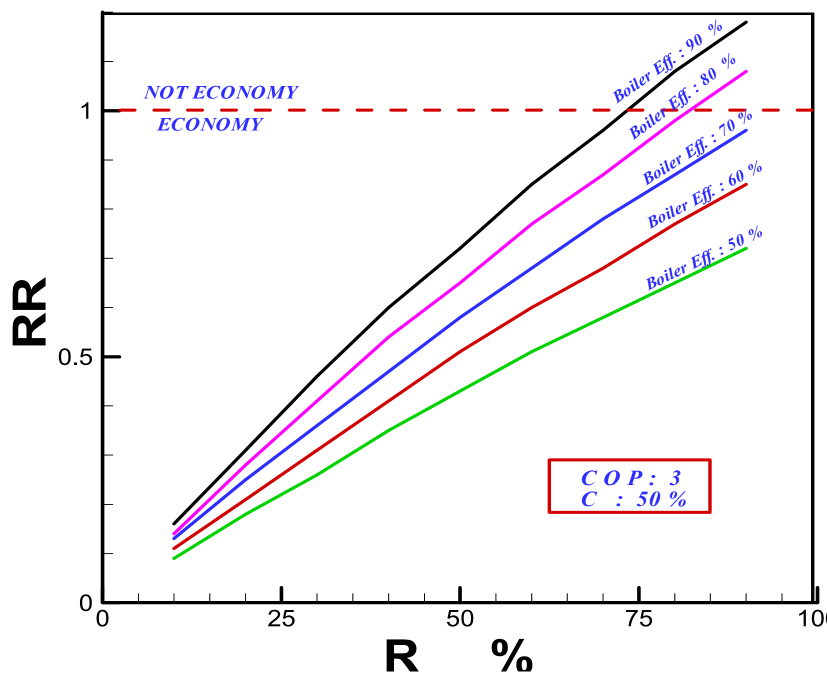

Figure (2) Effect of Boiler Efficiency on the Ratio RR With constant COP & C

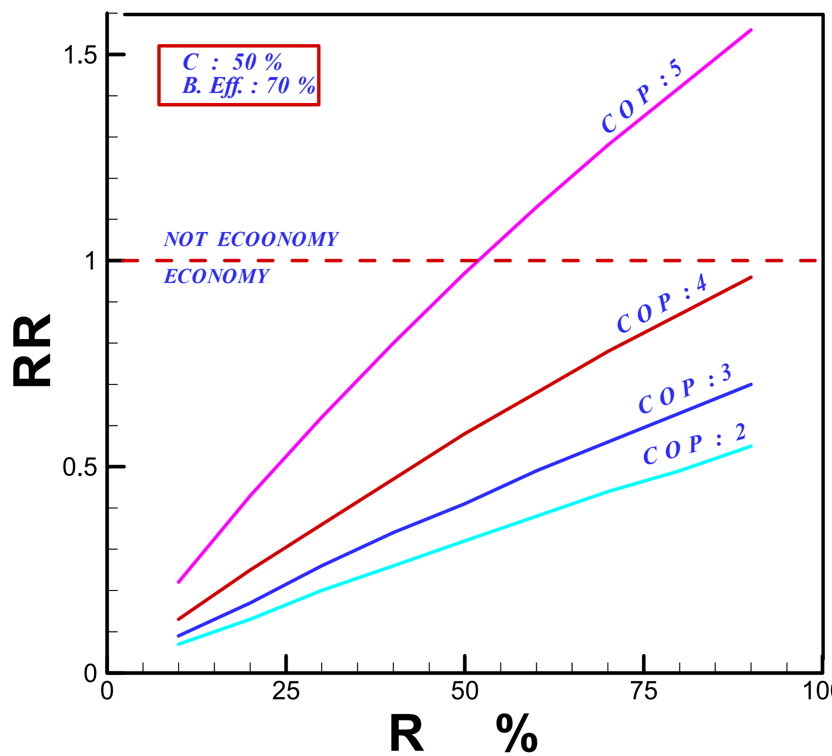

Figure (3) Effect of Coefficient Of Performance on the Ratio RR With constant η_B & C

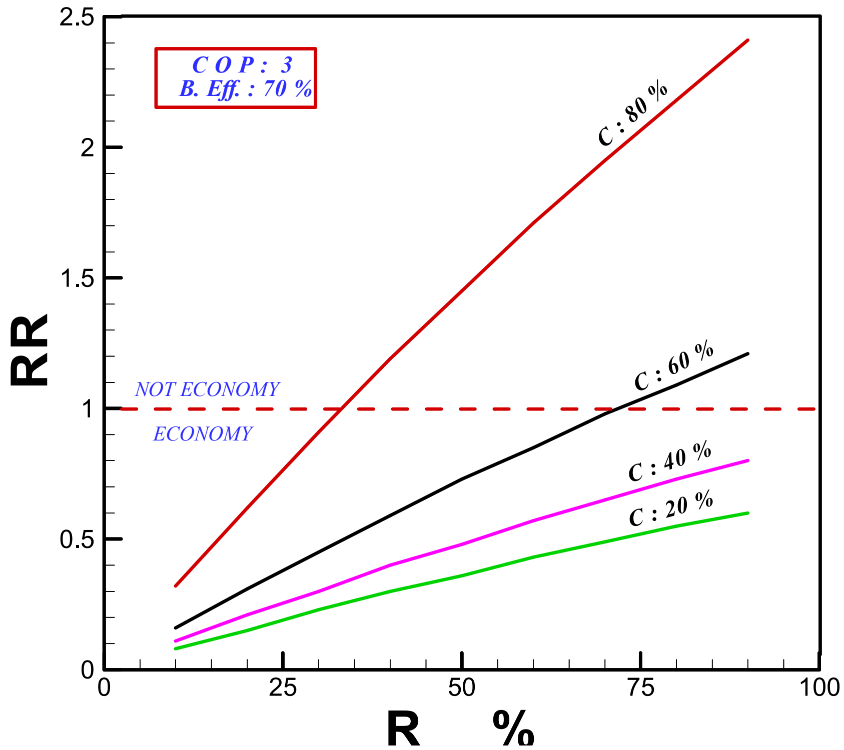

Figure (4) Effect of Operating Hours Ratio on the Ratio RR With constant COP & η_B

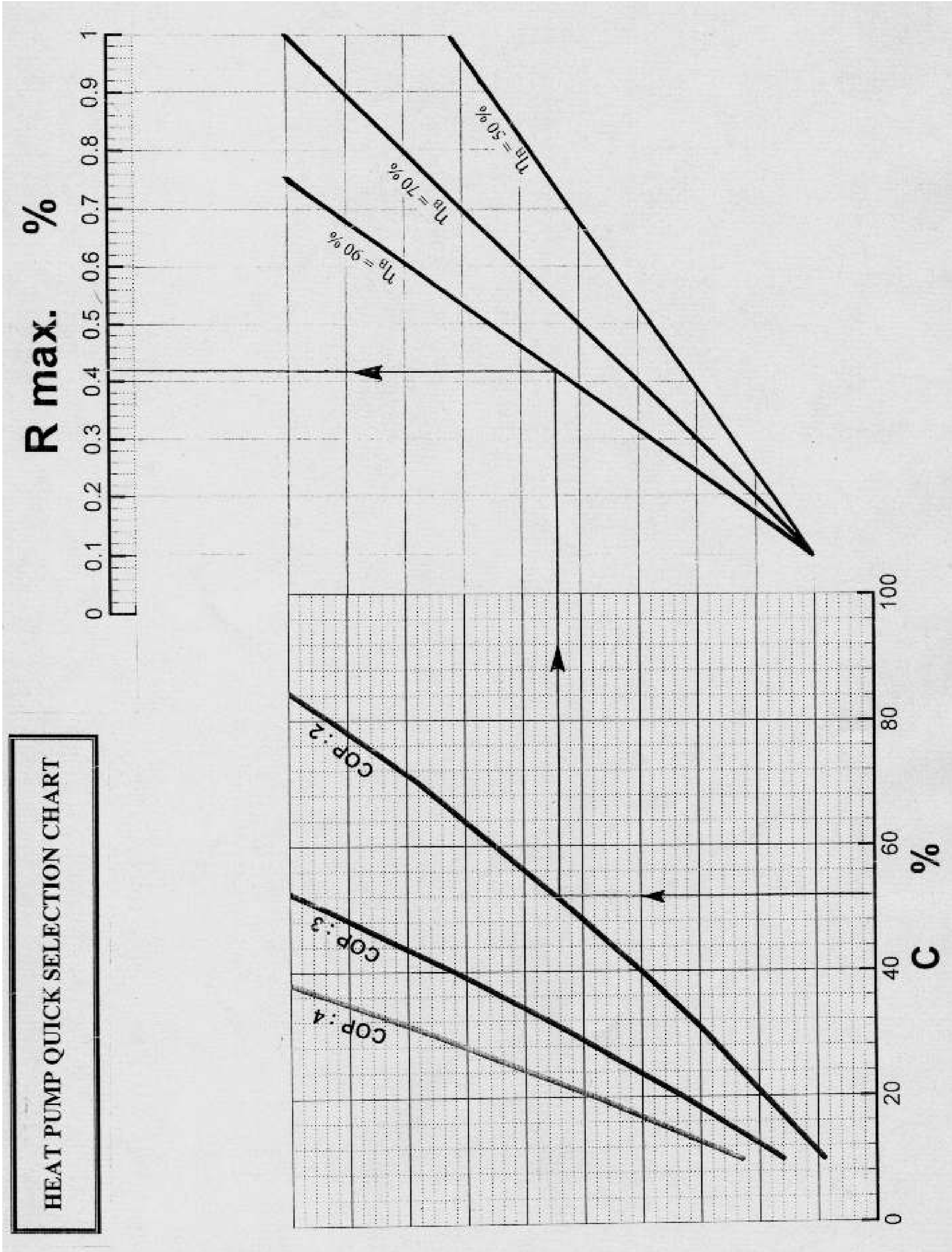

Figure (5) *Simple Heat Pump Selection Chart*

References

1. W. F. Stoecker, J. W. Jones, *"Refrigeration and air-conditioning*", McGraw-Hill International Edition, 1988.
2. ARI, *"Refrigeration and Air-Conditioning*. Second Edition", Printic-Hall, INC, 1987
3. Ashrae *Hand book of Fundamental* 1989.
4. Trane Company, *"Trane Air-Conditioning Manual"*, McILL/Jensen, INC, 1988.
5. Kavanaugh, S., *Ground and water source heat pump-A manual for the design and installation of ground-coupled*, University of Alabama. 1991.
6. Nedo. *"Feasibility study on utilization of geothermal heat pump (GHP) system for space heating / cooling, Warm-water supply and rod heating in Japan"* p133 , 1999..
7. International Ground Source Heat Pump Association (IGSHPA), *Geothermal Heat Pump Introduction Guidance*., Oklahoma State University .1997.
8. Natural Resources, *Heating and Cooling with a Heat Pump*, Canada, Energy Publications. 2004.
9. Shinji Takasugi, Tsukashi Akazawa. "*Feasibility study on the utilization of Geothermal Heat Pump (GHP) system in Japan*" *World Geothermal Congress*, Tohoke, Japan., 2000.