SIMULATION AND ANALYSIS OF A DIRECT CURRENT OPERATED AUTOMOTIVE AIR-CONDITIONING SYSTEM

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SIMULATION AND ANALYSIS OF A DIRECT CURRENT OPERATED AUTOMOTIVE AIR-CONDITIONING SYSTEM

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

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FEBRUARY 2017

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Dedicated to my beloved

mother, Sinah binti Kasipan

wife, Hasimah binti Ahmad

and

children, Nur Insyirah binti Mohamad Firdaus, Umar bin Mohamad Firdaus, Nur Khadeeja binti Mohamad Firdaus, Nur Syamimi binti Mohamad Firdaus

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ABSTRACT

The automotive air-conditioning (AAC) system is the second largest consumer of energy after the power train in a typical passenger vehicle. An improvement on the performance of this system will save a significant amount of energy and significantly improve the vehicle performance. The study was divided into two main sections, namely, experimental work and parametric simulation. The experimental work was conducted to obtain the off-road air-side evaporator heat transfer correlation and refrigerant-side correlations of compressor work, refrigerant mass flow rate, cooling capacity, and heat rejected from the condenser. The experimental rig comprised the original components from the AAC system of a medium-sized passenger car equipped with an appropriately sized electric compressor and electronic expansion valve. Cabin compartment thermal load, air-side evaporator-cabin compartment, and thermal and energy AAC system performance mathematical models had been developed based on models proposed by previous studies. Comparison exercises indicated that the simulation from the cabin compartment thermal load mathematical model and experimental results were within 5% error and were highly consistent with published results. Parametric simulation studies revealed that vehicle surface with darker color, an increment in the number of occupants, vehicle speed and fractional ventilation of air intake, and lower cabin temperature tend to increase the cooling load and require additional cooling capacity up to 144.16 W (5.01%). As a result, compressor work increased, up to 89.12 W (10.82%). Consequently, maximum reduction of COP up to 5.53% was recorded due to dominant increase in compressor work, as opposed to an increase in cooling capacity. In short, the proposed simulation model is able to help designers and/or engineers to understand the best type of vehicles and AAC operating system that can enhance the overall performance of the vehicle, particularly an electric vehicle, in the most efficient way. Consequently, it can reduce the effort, time, and cost to develop AAC systems and vehicles in the future.

ABSTRAK

Dalam operasi sebuah kereta, sistem penyamanan udara kereta (AAC) merupakan pengguna tenaga ke dua terbesar selepas sistem aliran kuasa. Penambahbaikan prestasi sistem tersebut akan menghasilkan satu kesan yang signifikan dalam penjimatan tenaga dan prestasi keseluruhan kereta tersebut. Kajian dibahagikan kepada dua bahagian iaitu kerja ujikaji dan simulasi parametrik. Ujikaji dijalankan bagi mendapatkan kolerasi bahagian-udara, pemindahan haba penyejat dan kolerasi bahagian-bendalir pendingin kerja pemampat, kadar alir jisim bendalir pendingin, kapasiti penyejukan dan haba yang disingkirkan dari pemelwap. Pelantar ujikaji terdiri daripada komponen asal sistem AAC kereta bersaiz sederhana, dilengkapkan dengan pemampat elektrik dan injap pengembangan elektronik yang bersesuaian. Model matematik bagi beban haba ruangan kabin, bahagian-udara penyejat-ruangan kabin, dan prestasi haba dan tenaga sistem AAC telah dibangunkan berdasarkan gabungan model-model yang telah dibangunkan sebelumnya. Perbandingan di antara data simulasi dari model beban haba ruangan kabin dan keputusan ujikaji berada dalam ralat 5% dan sangat konsisten dengan keputusan kajian-kajian yang sudah diterbitkan. Kajian simulasi parametrik mendapati warna luaran kenderaan yang lebih gelap, pertambahan penumpang, kelajuan kenderaan dan peratusan kemasukan udara luar, serta suhu kabin yang lebih rendah cenderung meningkat beban penyejukan dan memerlukan kapasiti penyejukan tambahan sehingga 144.16 W (5.01%). Kesannya, kerja pemampat meningkat sehingga 89.12 W (10.82%). Oleh itu, penurunan COP sehingga maksimum 5.53% direkodkan disebabkan peningkatan kerja pemampat lebih dominan jika dibandingkan dengan peningkatan dalam kapasiti penyejukan. Secara ringkasnya, model simulasi yang dicadangkan mampu membantu pereka-pereka dan/atau jurutera-jurutera dalam memahami jenis kenderaan dan operasi sistem AAC yang terbaik, yang boleh meningkatkan prestasi keseluruhan kenderaan, terutamanya kenderaan elektrik dengan cara yang paling cekap. Dengan itu, ia dapat mengurangkan penggunaan tenaga, masa dan kos dalam membangunkan sistem-sistem AAC dan kenderaan-kenderaan pada masa depan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A/C	-	air-conditioning
AAC	-	automotive air-conditioning
ANN	-	artificial neural network
ASHRAE	-	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
COP	-	coefficient of performance
DC	-	direct current
EER	-	energy efficiency ratio
EEV	-	electronic expansion valve
EVAC	-	electric vehicle air-conditioning
EVs	-	electric vehicles
FCC	-	fixed capacity compressor
GHG	-	greenhouse gas
HBM	-	heat balance method
HVAC	-	heating, ventilation, and air conditioning
ICE	-	internal combustion engine
OD	-	opening degree
SAE	-	Society of Automotive Engineers
TFM	-	transfer function method
TXV	-	thermostatic expansion valve
VCBLDC	-	variable capacity brushless direct current
VCC	-	variable capacity compressor
VCREVAC	-	vapor compression refrigerant electric vehicle air-conditioning
VCRC	-	vapor compression refrigeration cycle
XOA	-	fractional ventilation air intake

LIST OF SYMBOLS

A	-	surface area $\left(\mathrm{m}^2\right)$
B	-	blockage $(\%)$
c	-	percentage of energy input $(\%)$
CG	-	heat transmitted due to the difference between outside and inside temperature (W)
CL	-	cooling load (W)
CR	-	compression ratio
CLS	-	sensible cooling load (W)
D	-	day number of the year
EOT	-	equation of time
ER	-	heat extraction rate (W)
EX	-	exergy destroyed (W)
Gr	-	Grashof Number
h	-	specific enthalpy $(\mathrm{kJ/kg})$
m	-	amount of refrigerant (kg)
$\dot{m}$	-	mass flow rate $(\mathrm{kg/s})$
I	-	current (A)
I_D	-	direct solar radiation $\left(\mathrm{W/m^2}\right)$
I_d	-	diffuse sky radiation $\left(\mathrm{W/m^2}\right)$
I_{DN}	-	direct normal irradiance $\left(\mathrm{W/m^2}\right)$
I_r	-	solar radiation reflected from surrounding surfaces $\left(\mathrm{W/m^2}\right)$
I_t	-	total short-wavelength irradiance $\left(\mathrm{W/m^2}\right)$
k	-	surface conductive heat transfer coefficient $(\mathrm{W/m \cdot K})$

LI	-	light intensity $\left(\mathrm{W/m^2}\right)$
N	-	rotational speed (rpm)
NL	-	number of lights
P	-	power consumption $\left(\mathrm{W}\right)$
Pr	-	Prandtl number
p	-	pressure $\left(\mathrm{bar}\right)$
Q	-	heat transfer $\left(\mathrm{W}\right)$
q	-	heat transfer per unit refrigerant $\left(\mathrm{kJ/kg}\right)$
R	-	resistance $\left(\mathrm{m^2 \cdot K/W}\right)$
Ra	-	Rayleigh number
Re	-	Reynolds number
RF	-	air recirculated fraction
RPM	-	engine rotational speed $\left(\mathrm{rpm}\right)$
$SGHa$	-	absorbed radiation that travels to air-conditioned space $\left(\mathrm{W}\right)$
$SGHt$	-	transmitted radiation through glass $\left(\mathrm{W}\right)$
sc	-	refrigerant sub-cooling $\left(\mathrm{K}\right)$
$SCHE$	-	ratio of average wattage in use between hour *t* and maximum used wattage in space
$SCHI$	-	ratio of ventilation load at hour *t* to maximum ventilation load
$SCHL$	-	ratio of equipment heat load at hour *t* to maximum equipment heat load
sh	-	refrigerant super-heating $\left(\mathrm{K}\right)$
T	-	temperature $\left(^{\circ}\mathrm{C}\right)$
t	-	time $\left(\mathrm{s}\right)$
v	-	velocity $\left(\mathrm{m/s}\right)$
v_{afc}	-	condenser air face velocity $\left(\mathrm{m/s}\right)$
v_{vhc}	-	vehicle speed $\left(\mathrm{km/h}\right)$
$\dot{V}$	-	volumetric flow rate $\left(\mathrm{m^3/h}\right)$
V	-	voltage $\left(\mathrm{Volt}\right)$

W	-	work done (W)
w	-	work done per unit refrigerant $(\mathrm{kJ/kg})$
ω	-	specific air humidity $(\mathrm{kg\,w.v/kg\,d.a})$
δ	-	thickness (m^2)
x	-	quality of refrigerant entering evaporator
$\bar{x}$	-	average value
z	-	motor frequency (Hz)
f	-	surface convective heat transfer coefficient $(\mathrm{W/m^2 \cdot K})$
λ	-	compressor expansion coefficient
η	-	efficiency
θ	-	angle of incidence between incoming solar rays and line normal to surface $(^\circ)$
ϕ	-	air relative humidity $(\%)$
μ'	-	experimental uncertainty $(\%)$
σ	-	standard deviation
$\varepsilon - \mathrm{NTU}$	-	effectiveness number of transfer units

Subcript

1,2, …, n	-	measurement points
a	-	air
A	-	type A
bwr	-	blower
B	-	type B
c	-	compressor
C	-	combined
cab	-	cabin
cd	-	condenser / condensing
CL	-	coil latent

cpt	-	component
CS	-	coil sensible
CT	-	coil total
d	-	discharge
db	-	dry bulb
dvr	-	driver
e	-	evaporator/evaporating
E	-	expended
eng	-	engine
exh	-	exhaust
f	-	floor
g	-	glass
i	-	inside/inlet
leak	-	leakage
L	-	length
LT	-	latent
m	-	motor
o	-	outside / outlet
ocp	-	occupant
pgr	-	passenger
r	-	refrigerant
s	-	suction
so	-	sol-air
S	-	sensible
sp	-	sampling
sys	-	system
t	-	total
vnt	-	ventilation
wb	-	air wet-bulb
wi	-	inside wall
wo	-	outside wall

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Transport activity is a key component of economic development and human welfare, and this activity is increasing around the world as economies grow (Kahn Ribeiro *et al.*, 2007). Sand and Fischer (1997) found that automobiles are used approximately 249 h on average every year. Automobile air-conditioning (A/C) is also used at nearly 107–121 h per year, which accounts for 43%–49% of vehicle consumption (Fischer, 1995). Therefore, an automotive A/C (AAC) system as a standard accessory is vital to provide thermal comfort to passengers and drivers. Comfort is not the only reason for using AAC systems; another reason is road safety, which improves with the comfort of drivers because a pleasant environment reduces driver fatigue (Konz, 2007).

Many land transport vehicles in the world are powered by internal combustion engines (ICEs), and 95% of worldwide total energy is derived from petroleum (Kahn Ribeiro *et al.*, 2007), thereby resulting in energy-related greenhouse gas (GHG) emissions. In 2004, the transport sector was responsible for 23% of the total GHG emissions in the world, with nearly three-fourths coming from ground vehicles (Kahn Ribeiro *et al.*, 2007). The continuing annual growth of human populations and economies around the world will lead to a higher volume of GHG emissions in the future. Therefore, electric vehicles (EVs) are important to realize a sustainable transport system (Strömberg *et al*., 2011).

The driving range of an EV is around 140–160 km on a single charge; however, with the application of heating, ventilation, and air-conditioning (HVAC) systems, the driving range decreases by 20%–30% (Kwon *et al*., 2012). Farrington and Rugh (2000) showed that an increase of the accessory load from 500 W to 3500 W would decrease the EV range by 7%–38%. Chen *et al*. (2011) observed that the total mileage of an EV decreases by 50% when the A/C system is applied, thereby making the vehicle infeasible for long-distance transportation. Figure 1.1 shows the effect of the HVAC system on the cruising range of EVs.

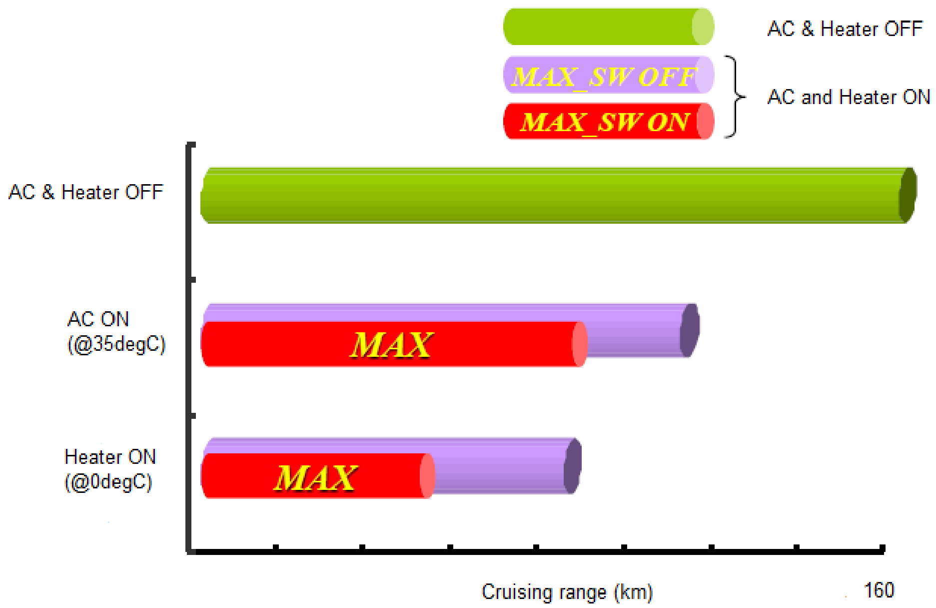


Figure 1.1 Effect of heating, ventilation, and air-conditioning system on cruising range (Kwon *et al*., 2012)

The usage of the HVAC system varies considerably depending on factors such as climate, time of day, time of year, type of vehicle (including vehicle color), outdoor/indoor parking, occupant clothing, recent occupant activity levels, length of trip, vehicle speed, and personal preference (Farrington and Rugh, 2000). Thus, the usage is expected to be higher than that reported in hot humid countries. An energy-efficient air conditioner is significant for EV to achieve vehicular thermal comfort in the cabin compartments and to extend the traveling range as far as possible. Therefore, an improved understanding of the AAC system behavior interacting with various factors mentioned by Farrington and Rugh (2000) is needed to obtain an efficient AAC system for future vehicles.

1.2 Problem Statement

One of the major factors for the success of future EVs is the capability to meet consumer needs, such as city driving and long-distance driving, during various occasions. Another type of consumer need is thermal comfort, which can be provided by the AAC systems that run on battery. AAC cooling loads are the most significant auxiliary loads (Zhang *et al*., 2009; Kaushik *et al*., 2011), and AAC systems consume the second largest amount of energy after powertrains (Roscher *et al*., 2012). Thus, its operation becomes critical for full EVs because of limited battery storage capacity, limited battery charging station, and longer time required to charge the battery compared with conventional fuel-driven ICE-powered vehicles. The battery is used not only to operate the electric motor to run the EV, but also to run the A/C system as well as other accessories. Accordingly, the driving range of the EV is reduced. Therefore, an energy-efficient A/C of EV (EVAC) system is significant.

As highlighted in Section 1.1, an in-depth understanding of the AAC system behavior interacting with various factors, such as ambient conditions and vehicle operation, is necessary to obtain an efficient AAC system for future vehicles. To accomplish this goal, an efficient tool for rapid design and prototyping of the AAC system that can interact with the aforementioned factors is necessary. Consequently, the overall performance of the vehicle, especially that of the AAC system, can be investigated and confirmed before mass production.

Given that the increase of experimental and prototyping procedures for any AAC system increases development time, workforce, and cost, a simulation program can be used to carefully analyze the AAC system. Thus, the simulation program of an EVAC system is proposed to predict the AAC system performance under the influence of the aforementioned factors. Through this simulation program, the performance of the A/C system can be simulated to improve or optimize the system. As a result, the energy efficiency of the EVAC system can be enhanced, thereby improving the overall performance of the EVs.

A thermal environment in a passenger car compartment is created according to the performance of its A/C system (Mohamed Kamar, 2008). Therefore, two main aspects need to be considered to develop a comprehensive AAC simulation program: analysis of thermal load in the cabin compartment, and analysis of thermal and energy performance of the AAC system. By connecting the analysis of cabin compartment thermal load to the analysis of thermal and energy performance of the AAC system in both, air and refrigerant sides via the evaporator, we can describe the thermal behavior in the passenger compartment, as well as the thermal and energy performance of the AAC system under the influence of outside environment and various operating conditions. Therefore, the complete simulation program consists of three mathematical models: mathematical model of cabin compartment thermal load, mathematical model of refrigerant-side thermal and energy performance of the AAC system, and mathematical model of air-side evaporator that links the first two models.

In this case, experimental investigation can be conducted to obtain the required empirical correlations of each model. An experimental test rig for the EVAC system can be developed by modifying the existing AAC system available in the market, that is, the AAC system of a 1.6-L Proton Wira Aeroback passenger car with original components of heat exchangers and internal and external fans. Modification of the EVAC system can be performed in the compressor and expansion valve sections. In particular, an appropriate variable capacity brushless direct current motor–compressor and an electronic expansion valve (EEV) for valve opening control can be used.

In this study, a complete simulation program of direct current-operated AAC system is developed. Without requiring complicated experimental work, this simulation program significantly reduces the effort and cost in determining the performance characteristics of the AAC system. Thus, planning toward enhanced overall performance of vehicles through an energy-efficient AAC system is possible in the future.

1.3 Objectives of Study

The importance of a complete simulation program to evaluate realistically and accurately the thermal and energy performance of the AAC system, led this study to focus mainly on the development of comprehensive predictive model. Accordingly, the objectives of this study are as follows:

a. to predict the thermal load characteristics in the cabin compartment for the AAC system,
b. to develop empirical correlations in order to link cabin compartment thermal load characteristic to the air and refrigerant sides of the AAC system, and
c. to perform a parametric study to assess the thermal and energy performance of the AAC system.

1.4 Scope of Research

The research scope is divided into three categories: coverage (limiting of the variables covered), method used (preferred method), and validity of results (range of applicability of results).

The independent operational variables of the complete AAC system modeling are restricted to ambient air dry and wet bulb temperatures, desired cabin air dry bulb temperature and humidity, evaporator air volumetric flow rate, condenser air face velocity, number of passengers, vehicle thermophysical properties, and vehicle speed. The AAC system performance is confirmed by evaluating the performance dependent variables including cabin cooling load, refrigerant mass flow rate, evaporating capacity and temperature, compressor work, coefficient of performance (COP), and condensing temperature.

The parametric study for the case of predicting the thermal load characteristics in the cabin compartment are only focused on the changing effect of weather, vehicle surface color, number of passengers, desired cabin air-dry bulb temperature and vehicle speed. Meanwhile, parametric study for the case of assessing the thermal and energy performance of the AAC system in the cabin compartment are only focused on the changing effect of vehicle surface color, vehicle speed, fractional ventilation air intake and evaporator air volumetric flowrate. Both parametric studies cover changing effect of weather from 11.00 am to 3.00 pm.

Only analytical and experimental approaches are used in this study. Compressor and EEV are selected based on the predicted maximum cooling capacity that will be supplied to the cabin compartment. For thermal and energy performance analysis of the AAC system, an analytical method is proposed based on a mathematical model developed from experimental data. The cabin compartment thermal load model and the experimental data used for modeling are validated through available results published in the open literature.

The results collected from this study are considered for steady-state condition with few assumptions. The air velocity, humidity, and temperature measured at the coils are considered uniform along the cross-sectional area of the duct/coils. The heat loss at the EEV and at the wall of the coils where the temperature is measured is assumed to be negligible by considering proper insulation of expansion valve and proper insulation between temperature sensors and coils, respectively. Heat loss from the surface of the compressor is also assumed negligible. The evaporating and condensing temperatures are measured on the surface of the refrigerant pipeline at the inlet of the evaporator and at the outlet of the condenser, respectively.

The air-side evaporator heat transfer correlation, and refrigerant-side correlations of compressor work, refrigerant mass flow rate, cooling capacity, and heat rejected from the condenser are model specific. Thus, the simulation model is only valid for application on an AAC system as in the experimental test rig in which the EEV is fixed at 100% opening degree (OD).

1.5 Thesis Outline

This thesis is composed of six chapters. Chapter 1 introduces the importance of the study.

Chapter 2 presents the literature review. First, the basic concept of an actual vapor compression refrigeration cycle (VCRC) system is presented. Then, the analysis of thermal load in the passenger compartment is comprehensively reviewed, as well as the analysis of the thermal and energy performance of the AAC system. The methods for linking the model of thermal load in the passenger compartment with that of thermal and energy performance of the AAC system are also presented.

In Chapter 3, a complete research approach is outlined. Next, the novel procedures to perform cabin compartment thermal load analysis and energy performance analysis of an AAC system are presented. Then, procedures to integrate the mathematical model of the cabin compartment thermal load with that of energy performance of the AAC system for the complete system simulation are presented. Finally, the method of selecting components to fabricate the experimental test rig; the purpose of the experimental work; and the method for data mining, data analysis, and data accuracy check are briefly described.

Chapter 4 presents the experimental set up of this study. It consists of two main sub-sections. The first sub-section presents the method of equipment selection (EEV and electric compressor) to develop the experimental test rig using the mathematical model of cabin compartment thermal load. This sub-section starts with the verification process of the model, followed by analysis of maximum cooling capacity estimation. Finally, based on the maximum cooling capacity estimation, the selection procedures of possible electric compressor and EEV are presented.

Then, the experimental work to obtain empirical correlations for the performances of the air-side steady-state evaporator heat transfer and refrigerant-side steady-state AAC system is presented in the following sub-section. One empirical evaporator coil performance correlation and three empirical AAC performance correlations are then developed using the experimental data. The development of the experimental test rig, the test conditions, and the procedures of collecting data are also explained. A validation exercise of the experimental data is also presented before the data are utilized for the complete simulation of the AAC system.

In Chapter 5, the simulation results through parametric study are presented. This chapter discusses the effects of selected parameters including vehicle surface color, number of occupants, desired cabin air-dry bulb temperature, vehicle speed, fractional ventilation air intake and evaporator air volumetric flow rate on the cabin cooling load profile, and thermal and energy performance of the AAC system.

Finally, the main findings, conclusions, contributions to the field of knowledge and recommendations for future works are presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review is organized into several sections. The first and second sections briefly review the AAC system and actual VCRC system as a basic principle of a typical AAC system respectively. The succeeding sections review the literature related to the development of a complete AAC system performance simulation model (mathematical modeling).

The thermal environments in a cabin compartment are created according to the performance of its A/C system (Mohamed Kamar, 2008). Therefore, two main aspects need to be considered to develop a comprehensive DC-operated AAC system simulation model: cabin compartment thermal load analysis and A/C system performance analysis. Then, the thermal behavior in the cabin compartment (cooling load profile) and the thermal and energy performance of the AAC system under the influence of external environment and various operating conditions of the AAC system can be described by connecting cabin compartment thermal load analysis with A/C performance system analysis. Thus, the third and fourth sections of this chapter review the cabin compartment thermal load analysis and A/C system performance analysis. The review of the link between these two analyses is then presented separately in the last section.

2.2 Automotive Air-conditioning System

Generally, the AAC system consists of four main components, i.e., compressor, condenser, evaporator (cooling coils) and expansion valve, and several secondary components, i.e., receiver, air-conditioning pipelines, high and low pressure service valves, internal fan (blower motor), sight-glass and temperature sensing bulb. Figure 2.1 shows the arrangement of these components on VCRC, AAC system. In general, a belt driven compressor is used for ICE powered vehicles, while electric driven compressor is used for EVs. For example, full EV of Mitsubishi i-MiEV uses a 4.5 kW with 30 cc/rev displacement of rare earth metal motor-scroll compressor (Umezu and Noyama, 2010).

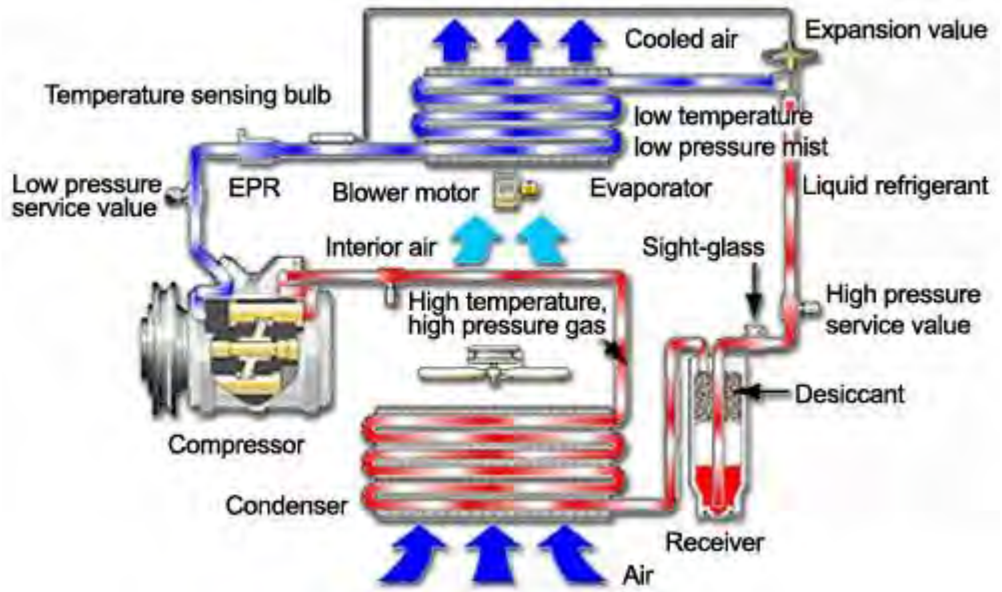


Figure 2.1 A schematic diagram of vapor compression refrigeration cycle automotive air-conditioning system (Denso Corporation, 2012)

The AAC system is used to cool or maintain a cabin compartment at a temperature below that of the ambient (surroundings) in order to provide thermal comfort to the driver and passenger/s. Hence heat must be made to flow from low temperature (cabin compartment) to high temperature (surroundings), a process in which some work shall be done.

The heat and work interactions of the processes on the cycle are as follows:

a. The refrigerant flows around the whole system through the pipelines and it evaporates at a low temperature (in the evaporator). During the evaporation process, heat load from the cabin compartment is absorbed by the evaporation of a liquid refrigerant.
b. Work is done by the compressor on the refrigerant to compress the refrigerant vapor to a higher pressure and temperature. This high temperature must be higher than the ambient temperature.
c. Heat is then rejected from thr refrigerant in the condenser to the ambient air at high temperature.
d. The remaining liquid refrigerant moves to the receiver, which is a small reservoir vessel to store any excessive liquid refrigerant (especially during low cooling load), and removes any moisture that may has leaked into the refrigerant.
e. The expansion valve releases pressure from the liquid refrigerant to allow expansion or change of state from a liquid to a vapor in the evaporator. The evaporation process occurs at the evaporator is repeated again and the cycle continues.

2.3 Actual Vapor Compression Refrigeration Cycle

The actual flow of the refrigerant through the condenser, evaporator, and piping causes a pressure drop in the VCRC system. In addition, heat losses or gains occur depending on the temperature difference between the refrigerant and ambient air. The actual VCRC process may involve some or all of the following items (also shown in Figure 2.2) (Arora, 2009):

a. Superheating of the vapor in the evaporator, 1d – 1c.
b. Heat gain and superheating of the vapor in the suction line, 1c – 1b.
c. Pressure drop in the suction line, 1b – 1a.
d. Pressure drop at the compressor-suction valve, 1a – 1.

e. Polytrophic compression with friction and heat transfer to ambient air instead of isentropic compression, 1 – 2.

f. Pressure drop at the compressor-discharge valve, 2 – 2a.

g. Pressure drop in delivery line, 2a – 2b.

h. Heat loss and de-superheating of the vapor in the delivery line, 2b – 2c.

i. Pressure drop in the condenser, 2b – 3.

j. Subcooling of the liquid in the condenser or subcooler, 3 – 3a.

k. Heat gain in the liquid line, 3a – 3b.

l. Pressure drop in the evaporator, 4 – 1d.

Given the cumulative effect of the frictional and momentum pressure drop, the pressure drop in the evaporator is large, as shown in Figure 2.2. However, the pressure drop in the condenser is not very critical given that the frictional pressure drop is positive, and the momentum pressure drop is negative (Arora, 2009). The temperature in the evaporator does not remain constant because of the pressure drop from p_{01} at the inlet evaporator to p_{02} at the outlet of the evaporator; this pressure drop correspondingly changes T_{01} to T_{02}. Furthermore, given the various pressure drops, the cooling capacity of the VCRC plant is decreased; the unit power consumption (per unit refrigeration) is increased. In addition, the compressor cylinder loses heat to ambient air given the large temperature difference between the hot compressor cylinder and the ambient air. Correspondingly, the COP of the actual VCRC is reduced.

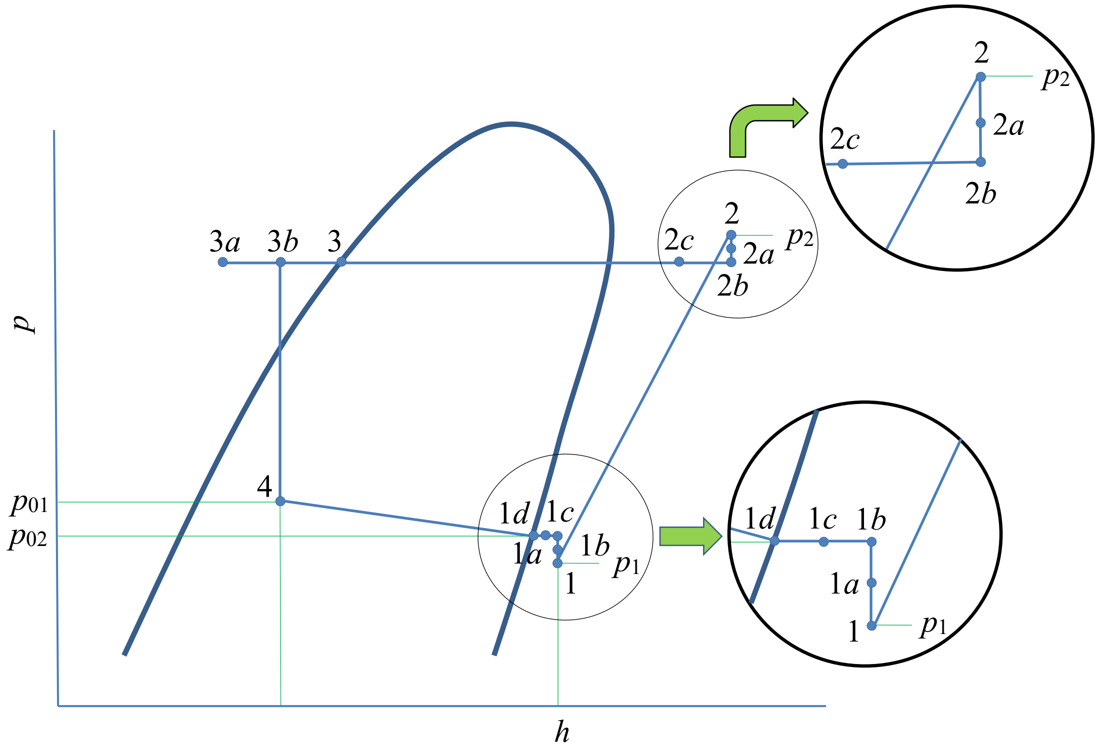


Figure 2.2 Actual vapor compression refrigeration cycle system on *p*-*h* diagram (Arora, 2009)

2.4 Cabin Compartment Thermal Load Studies

ASHRAE (1993) identified three closely related terms of heat flow rates in air-conditioned spaces, namely, heat gain, cooling load, and heat extraction rate. Heat gain is the rate at which heat enters into and/or is generated within an enclosure at a specific time. Heat gain is either sensible or latent heat depending on the mode of heat entry. The heat gain is sensible if heat is directly transferred to the conditioned space by conduction, convection, or radiation (Mohamed Kamar, 2008). The heat gain is latent if moisture is added to the space, typically by occupants (Mohamed Kamar, 2008). Space cooling load is the rate at which sensible heat must be removed from the conditioned space to maintain a desired space air temperature (Mohamed Kamar, 2008). The space cooling load is the actual heat being transferred to the air in the conditioned space at a specific time. However, given the thermal storage effect of any object in the conditioned space, the summation of all heat gains at a specific time is not equal to the space cooling load. Heat extraction rate is the rate at which sensible heat load is removed from the conditioned space, typically using a mechanical cooling system, such as an A/C system.

Studies on cabin compartment thermal load as a load to an A/C system have increased since the 1990s. Senawi (1998) stated that the accurate prediction of the design cooling load is important for equipment sizing. Farrington and Rugh (2000) added that the size of the AAC system is related to the peak thermal load in the vehicle; this peak thermal load is generally related to the maximum temperature reached by the compartment when exposed to the sun. Li and Sun (2013) mentioned that determining the cooling load and understanding their variations are critical for the efficient design of the transport A/C system. The adequate cooling capacity supplied by the system can be calculated through the design cooling load; this calculation allows for the determination of the correct size of components of the VCRC system, such as the condenser, compressor, expansion valve, and evaporator.

According to Zheng *et al*. (2011) and Li and Sun (2013), the first challenge in the proper sizing of a vehicle air-conditioning system is to accurately determine the compartment cooling load. Calculating the cooling load is a complex and time-consuming task; its accuracy, however, is important for correct system sizing. Given that the accuracy of the cooling load calculation highly depends on the assumptions being made, Arora (2009) proposed that 5% heat should be added to the sensible and latent heats because of probable error in load estimation. The importance of the cooling load estimation especially in the earlier stage of A/C system development has gained significant research interest; most studies have been performed on obtaining accurate load estimates.

ASHRAE (2005) mentioned that the cooling load is estimated on the basis of the following five methods: transfer function method (TFM), total equivalent differential method with time averaging (TETD/TA), cooling load temperature differential method with solar cooling load factor (CLTD/CLF), heat balance method (HBM), and radian time series method (RTS).

RTS is a simplified method derived from HBM (ASHRAE, 2005). In this method, two time-delay effects inherent in the heat transfer process must be addressed, namely, the delay of conductive heat gain through opaque massive exterior surfaces and the delay of radiative heat gain conversion to the cooling load (ASHRAE, 2005). A substantial time delay in heat input exists at the exterior surface; this heat input becomes heat gain at the interior surface because of the mass and thermal capacity of the wall or roof construction material (ASHRAE, 2005). The RTS methodology is illustrated in Figure 2.3.

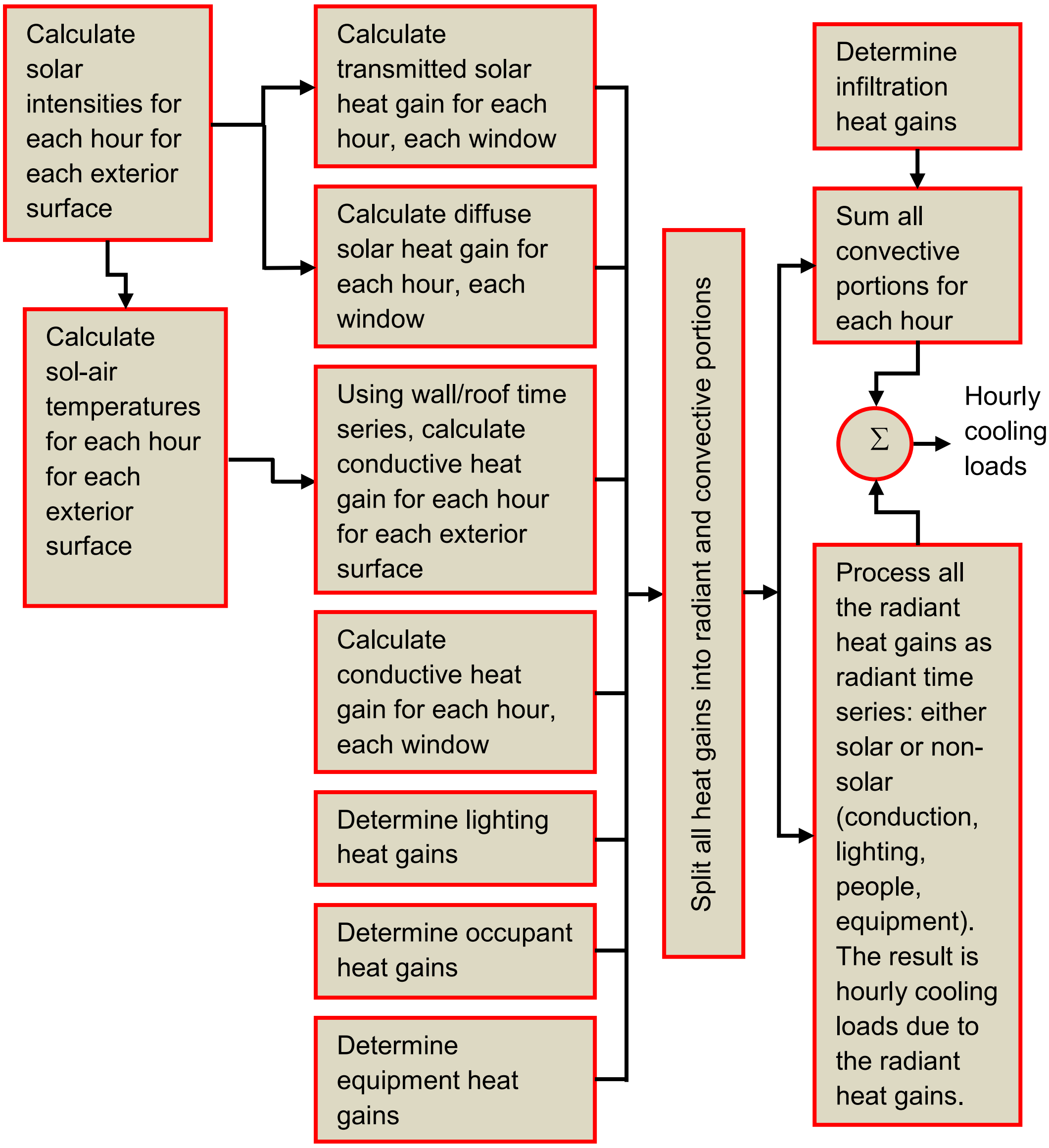


Figure 2.3 Overview of radiant time series method (ASHRAE, 2005)

Previous research on vehicular cooling load has developed analytical models to estimate heat transmission and solar radiation to the cabin compartment. These studies determined that the following factors contribute to the vehicular cooling load: conduction heat load through body walls, glasses, and engine/motor compartment panels, solar radiation through glasses, heat gain from passengers, heat gain from ventilation/fresh air intake/infiltration, heat gain from lights, heat gain from power equipment (Stancato *et al*., 1992; Stancato and Onusic, 1997; Konz, 2007; Huang *et al*., 2007; Mohamed Mansor, 2007; Zheng *et al*., 2011; Liu *et al*., 2011; Fayazbakhsh and Bahrami, 2013; Jha *et al*., 2013; Li and Sun, 2013; Marcos *et al*., 2014; Solmaz *et al*., 2014). In general, most of the basic calculation procedures for each source of these heat gains have been discussed in detail (ASHRAE, 1985; ASHRAE, 1993; ASHRAE, 1997; ASHRAE, 2005; ASHRAE, 2009).

Stancato *et al*. (1992) and Stancato and Onusic (1997) numerically and experimentally analyzed the heat loads in a cabin of a road bus. They ignored the thermal storage effect given that its automotive panels and internal components were constructed from relatively thin materials and had low-density specific heat products compared with those for houses and buildings (Stancato *et al*., 1992; Stancato and Onusic, 1997). A comparison between the measured and calculated cooling loads showed that the accuracy was less than 5%. A simulation from the model demonstrated that light-colored paint and tinted glasses can reduce the conduction through walls and glasses and the solar radiation by up to 30%. They claimed that this model can be used as a tool for the correct fitting of the AAC system through the localities, routes, color of the external paint, and tint of the glasses. However, given that the heat flow was estimated using the outside surface temperature (Stancato *et al*., 1992; Stancato and Onusic, 1997), this approach has limited applications because the ambient air temperature is usually known, but the external surface temperature is not.

Konz (2007) used ambient air temperature to estimate heat transfer through doors. However, the door is exposed to direct solar radiation during the peak cooling load. The author ignored the solar radiation effect by using the surrounding air temperature to estimate the conduction heat load through the vehicle envelope. In this case, the complexity of the analysis is significantly reduced; however, this method creates a substantial error. In short, the solar radiation significantly influences the surface that is directly exposed to sunlight. The amount of heat transferred is actually higher than the conductive heat transfer without the influence of solar radiation as described by ASHRAE (ASHRAE, 1997; ASHRAE, 2005; ASHRAE, 2009). The actual heat conduction is due to the combined effect of the absorbed solar radiation and ambient-to-cabin air temperature difference.

The concept of sol-air temperature as proposed by ASHRAE (ASHRAE, 1997; ASHRAE, 2005; ASHRAE, 2009) was used by Mohamed Mansur (2007) to calculate heat gain through the walls, roof, and floor of a bus, and by Mohamed Kamar (2008) to calculate the same for a car (Kamar, 2008). The sol-air temperature represents the realistic outdoor conditions under the influence of the solar radiation effect. In addition, Mohamed Mansur (2007) used the lumped method with negligible thermal storage effect as proposed by Stancato *et al.* (1992) and Stancato and Onusic (1997). Mohamed Mansur (2007) also established that a ventilation air rate of 5 liter/s per passenger is recommended. He also proposed that the infiltration thermal load can be ignored with respect to the ventilation load because of the sealed construction of the windows and doors. However, the model did not consider the effect of vehicle speed variation on the hourly and daily vehicular cooling load profile. By contrast, Mohamed Kamar (2008) used the transfer function method (TFM) with thermal storage effect in his cabin compartment heat load analysis. This model is relatively complicated compared with that proposed by Mohamed Mansur (2007), where the heat gain weighting factor and air weighting factor must be determined before the cooling load can be analyzed.

Using a different approach, Huang *et al*. (2007) calculated solar radiation using the anisotropic HDKR model. The occupant heat load is determined by calculating the heat and moisture generated by the occupants. The model validation presented the satisfactory matched results with the test-averaged interior cabin and discharge air temperature. Zheng *et al*. (2011) used the CLTD method to calculate heat gain through a sun roof and wall/door. In cooling load calculation, fresh air of 15 cfm per person and a leak rate of 40 cfh/ft were selected for the recirculated mode and infiltration heat gain, respectively. They also considered the coefficient 1.5 to calculate the infiltration heat gain for the vehicle speed of 50 mph given that high speed results in increased infiltration. The heat gain from one blower motor was estimated at 280 W. After performing comparisons using test data at various vehicle speeds and air modes, the author claimed that the deviation of ±8% was achieved.

Liu *et al*. (2011) built a cooling load mathematical model to simulate the dynamic cooling load of an air-conditioned train compartment. A ventilation rate of 25 m^3/h per person in summer is selected for the ventilation heat gain. Furthermore, the conditions of the train compartment were assumed to be 25ºC, 55%, and 56 kJ/kg d.a. for air dry-bulb temperature, humidity ratio, and enthalpy, respectively. The simplified formula is introduced for the outside surface convective heat transfer coefficient, f_o, where it is estimated at 16 $\mathrm{W/m^2 \cdot K}$ for $v_{vhc} = 0$, and $f_o = 9 + 3.5 v_{vhc}{}^{0.66}$ for $v_{vhc} > 0$. For Malaysian climate, one of the possible correlations between f_o and v_{vhc} can be found in the work of Shahril *et al*. (2013), where $f_o = 5.108 v_{vhc}{}^{0.643}$. The internal surface convective heat transfer coefficient f_i is estimated at 8 $\mathrm{W/m^2 \cdot K}$ (Liu *et al*., 2011). Arora (2009) considered that f_i for buildings is 11.5 $\mathrm{W/m^2 \cdot K}$. Compared with results published by other researchers, a linear relationship between outdoor-indoor temperature differences with the variable of dynamic cooling load was introduced by Liu *et al*. (2011), as shown in Figure 2.4.

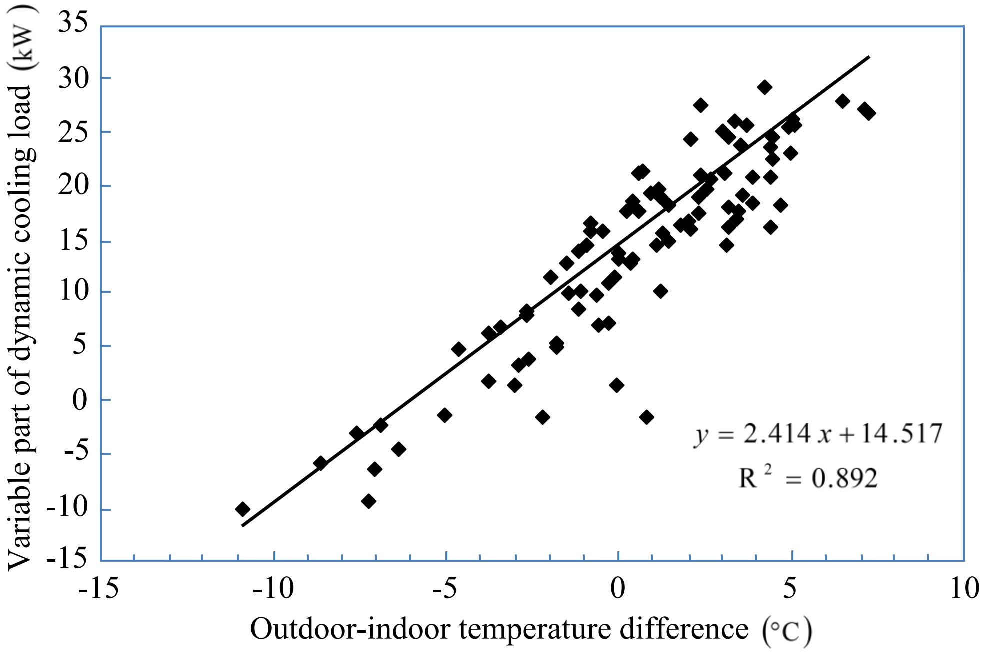


Figure 2.4 Relationship between outdoor-indoor temperature difference (x) and variable part of dynamic cooling load (y) of a train (Liu *et al*., 2011)

Li and Sun (2013) also used an external surface convective heat transfer coefficient as proposed by Liu *et al*. (2011). For the occupant thermal load, they highlighted that the total load from one occupant is 116.3 W at room temperature of 26ºC; the value at the temperature range 20–35ºC did not vary significantly. However, they calculated the sensible heat per occupant as $Q_S = 186 - 4.65T_{cab}$.

Fayazbakhsh and Bahrami (2013) used the heat balance method to estimate the thermal and cooling loads encountered in a vehicle cabin for ICE-powered vehicles. They considered a lumped model of a typical vehicle cabin with an additional source of cabin heat gain from the exhaust component. Simulations of different driving conditions found that certain load categories, i.e., ambient and ventilation loads, play important roles in the variation of cabin temperature.

Jha *et al*. (2013) determined solar load as proposed by ASHRAE. Unlike previous researchers, they used Churchill's equation and the average Nusselt number for laminar flow to determine outside and inside convective heat transfer coefficients, respectively. A comparison with experimental results showed that the model results are ±15% of the experimental value.

Recently, Marcos *et al*. (2014) developed a dynamic cabin compartment thermal load model. The model calculated the variation of the cabin air temperature and energy gained by the cabin compartment based on cabin compartment energy balance. The model is based on theoretical heat transfer, thermal inertia, and radiation treatment equations. This model was validated experimentally under three different test conditions, namely, stopped and unoccupied while outdoors, stopped and unoccupied while indoors, and running with one person inside the vehicle. A validation exercise indicated that the deviation of the cabin air temperature is less than 5ºC with RMS error at less than 4ºC.

Applying a different approach, Solmaz *et al.* (2014) predicted the hourly cooling load of a vehicle using artificial neural networks (ANNs). They considered that the cabin heat load was contributed by the following factors: convection and conduction heat load through the body walls, roof, floor, and glass; heat gain by solar radiation; heat gain by occupants; heat gain by equipment; and heat gain by ventilation. They highlighted that the heat gain by all the equipment and each occupant are 100 W and 58 W, respectively. ANNs are computational models based on the information processing system of the human brain (Atik *et al*., 2010). Hosuz and Ertunic (2006) highlighted that the ability of ANNs to learn by example makes them more flexible and powerful than parametric approaches. Thus, by utilizing data from experimental work, ANNs can be applied to problems with either no algorithmic solutions or overly complex algorithm solutions to be found (Hosuz and Ertunic, 2006). In general, ANN consists of three layers, namely, input, hidden, and output. Details of the ANNs can be found in the works of Hosuz and Ertunic (2006), Atik *et al*. (2010), and Mohamed Kamar *et al*. (2013). Figure 2.5 shows the overview of the ANN model for the cooling load prediction by Solmaz *et al.* (2014); they found that the cooling load of a vehicle can be successfully predicted by means of ANNs from geographical characteristics and meteorological data. Table 2.1 summarizes the work of previous researchers.

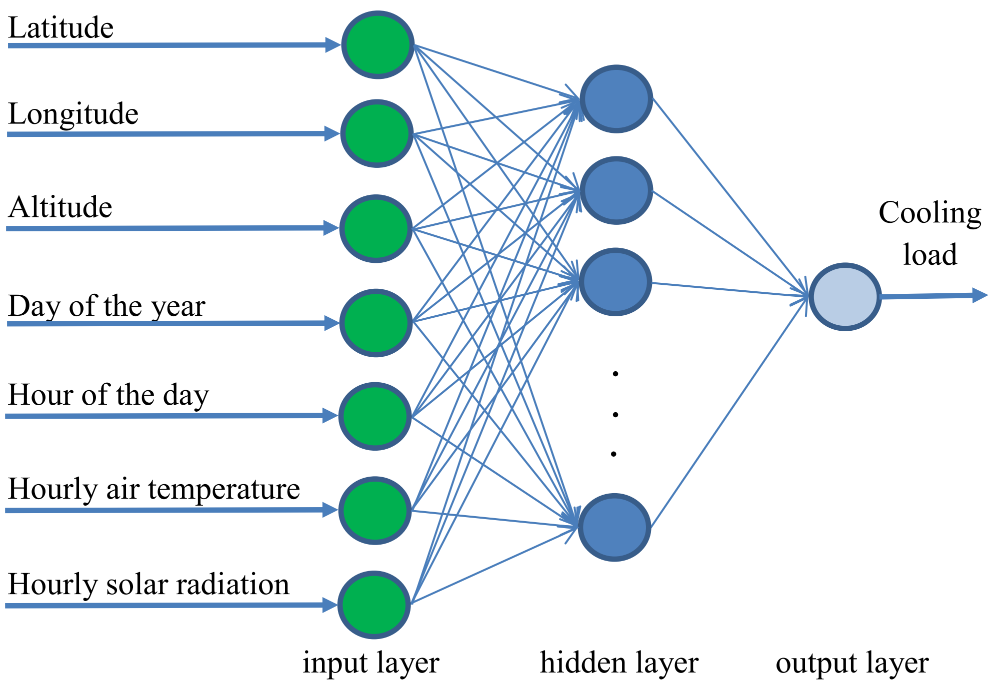


Figure 2.5 Overview of artificial neural network model for cooling load prediction (Solmaz *et al*., 2014)

From the reviews discussed in this subsection, useful information on cabin compartment heat load is described. Thermal storage effect and infiltration thermal load can justifiably be ignored as proposed by Stancato *et al*. (1992), Stancato and Onusic (1997), and Mohamed Mansor (2007). Given that the thermal storage effect is ignored, the heat conduction is in a steady state; all instantaneous heat gains are equal to the cooling loads. Thus, the complexity of the heat load model is significantly reduced. In addition, the heat gain from the lighting of small to medium-sized vehicles, i.e., passenger cars, can also be ignored; this specific heat gain can be ignored given that the lighting is switched off most of the time, and this portion is relatively small compared with other sources of heat gain. However, the consideration of all those sources of heat gain can increase the accuracy of the heat load model, as well as the complexity of the model.

Furthermore, a lumped model of a typical cabin compartment can be considered; a heat balance method can be used in the cabin compartment thermal load modeling. To determine the effect of vehicle speed on the cabin compartment thermal load variations, simplified correlations of the external surface convective heat transfer coefficient can be utilized as proposed by Zheng *et al*. (2011) or Shahril *et al*. (2013). In addition, the calculation procedures for any possible heat source of vehicular heat gains based on ASHRAE fundamental handbooks (ASHRAE, 1985; ASHRAE, 1993; ASHRAE, 1997; ASHRAE, 2005; ASHRAE, 2009) or previous research can be adopted to develop a new novel cabin compartment thermal load model.

Table 2.1 Summary of previous research on vehicular thermal load

		Sources of cabin compartment heat loads/gains							
Author/s	General Method	Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
Stancato *et al.* (1992), Stancato and Onusic (1997)	HBM	• $f_i = 1.42\left(\frac{T_{es}-T_i}{\delta_g}\right)$ OR $f_i = 3.78$ $\mathrm{W/m^2 \cdot °C}$ • Thermal storage effect is negligible given that automotive panels have a low density-specific heat product.	• According to ASHRAE (1989).	• Q = 375 W (driver, considered for heavy vehicle [bus]) • Q = 100 W/passenger	• -	• Ignored given very low measured air flow rate of 2.81E-5 $\mathrm{m^3/s}$.	• $Q = \frac{P_m}{\eta_m}$	• Q = total light wattage	*Disadvantages* • T_{es} is used instead of T_o. In many cases, T_o is known instead of T_{es}. • Information of ventilation heat load is unknown. *Advantages* • Information of f_o is not necessary because T_{es} is used instead of T_{es}.
Konz (2007)	HBM	• $k_B = 2.3$ $\mathrm{W/m^2 \cdot K}$ • $k_S = 2.3$ $\mathrm{W/m^2 \cdot K}$ • $kA_M = 7$ $\mathrm{W/m^2 \cdot K}$ • TA_M = 100°C • $f_o = 25$ $\mathrm{W/m^2 \cdot K}$ (minimum) • $f_{o,FS} = 3.79 v_{vhc}^{0.8}$, $\mathrm{W/m^2 \cdot K}$	• According to ASHRAE (2005).	• Q = 220 W (driver) • Q = 102 W/passenger	• -	• $\dot{m}_I = (v_{vhc}/100) \cdot (0.75 \cdot RF + 0.25)$, kg/min	• -	• -	*Disadvantages* • Heat load from power equipment and light are ignored by author. • Information of ventilation heat load is unknown. *Advantages* • Heat capacity of the automotive panels is considered.

Table 2.1 (continued)

Author/s	General Method	Sources of cabin compartment heat loads/gains: Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
		• $f_{o,SS} = 7.21 v_{vhc}^{0.8}$, $\mathrm{W/m^2 \cdot K}$ • $f_{o,HS} = 4.65 v_{vhc}^{0.8}$, $\mathrm{W/m^2 \cdot K}$ • $f_{o,AD} = 4.41 v_{vhc}^{0.8}$, $\mathrm{W/m^2 \cdot K}$ • v_{vhc} is in $\mathrm{m/s}$ • $f_i = 7\ \mathrm{W/m^2 \cdot K}$ (minimum) • $f_{i,FS} = 0.584 \dot{V}_e^{0.5}$, $\mathrm{W/m^2 \cdot K}$ • $f_{i,SS} = 0.495 \dot{V}_e^{0.5}$, $\mathrm{W/m^2 \cdot K}$ • $f_{i,HS} = 0.700 \dot{V}_e^{0.5}$, $\mathrm{W/m^2 \cdot K}$ • $f_i = 2.3\ \mathrm{W/m^2 \cdot K}$ • $\dot{V}_e$ is in $\mathrm{m^3/h}$.							• Heat transfer coefficients are simpler and more specific.

Table 2.1 (continued)

	General Method	Sources of cabin compartment heat loads/gains: Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
Mohamed Mansor (2007)	HBM	• Convective heat transfer correlations are governed by Nu number under mixed convection (forced and natural). • Vertical plate: $Nu = 0.555(Gr.\Pr)^{0.25}(1+6.26\left((\mathrm{Re}/[Gr]^{0.5})^{1.29}\right) = fL/k$ • Horizontal plate: $Nu = 0.27(Gr.\Pr)^{0.25}(1+4.3\left((\mathrm{Re}/[Gr]^{0.5})^{1.74}\right) = fL/k$ • Surface engine is in the range of 50–60°C. • Thermal storage effect is negligible given that automotive	• According to ASHRAE (1997).	• According to ASHRAE (1997). • $Q = 375$ W (driver, considered for heavy vehicle (bus)) • $Q = 115$ W/passenger	• $Q = \left(\dot{V}_a / 3600 v_o\right)(h_o - h_i) SCHI$ • $\dot{V}_a = 5$ l/s per passenger	• Ignored with respect to ventilation load owing to sealed construction of windows and doors.	• $Q = \frac{RP}{\eta_m} \cdot SCHE$	• $Q = LI \cdot A_f \cdot NL \cdot SCHL$	*Disadvantages* • Correlation for f_i and f_o is complex. *Advantages* • Actual heat conduction is considered given the combined effect of absorbed solar radiation and ambient-to-cabin air temperature difference. • Heat load from engine compartment is considered for internal combustion engine-powered vehicle. • All sources of heat load are justified. • AAC system has hourly cooling load analysis.

Table 2.1 (continued)

Author/s	General Method	Sources of cabin compartment heat loads/gains: Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
		panels have a low density specific heat product.							
Mohamed Kamar (2008)	TFM	• According to ASHRAE (1993) • $f_o = 1.163\left(4 + 12 v_{vhc}^{0.5}\right)$, $\mathrm{W/m^2 \cdot °C}$	• According to ASHRAE (1993).	• According to ASHRAE (1985). • Q = 150 W (driver) • Q = 120 W/passenger	• -	• -	• -	• -	*Disadvantages* • Many calculation steps are required. • Heat gain and air weighting factors must be determined before cooling load can be analyzed. • Information of ventilation heat load is unknown. • Heat loads from infiltration, power equipment, and light are ignored by the author. *Advantages* • Calculation of vehicular heat load is computerized. • Actual heat conduction is considered given the

Table 2.1 (continued)

Author/s	General Method	Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
		Sources of cabin compartment heat loads/gains							
									combined effect of absorbed solar radiation and ambient-to-cabin air temperature difference.
Huang *et al.* (2007)	HBM	• Conductive and convective heat loads are calculated through numerical method.	• According to HDKR model. • Ground Reflectance is 0.2 to 0.7.	• According to Fanger model with assumptions of thermal equilibrium and negligible heat storage within the body.	• -	• -	• -	• -	*Disadvantages* • Information of ventilation and infiltration heat loads are unknown. • Heat loads from power equipment and light are ignored by the authors. *Advantages* • Heat load is calculated using tool of computer- aided engineering (CAE). • Simulation results are validated with experimental data.

Table 2.1 (continued)

Author/s	General Method	Sources of cabin compartment heat loads/gains: Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
Zheng *et al.* (2011)	CLTD	• $Q = U \cdot A \cdot CLTD$ • $f_o = Nu_L \cdot k/L$ • $Nu_L =$ $0.0359\,\mathrm{Re}_L^{4/5} \cdot \mathrm{Pr}^{1/3} - 830\,\mathrm{Pr}^{1/3}$ for $0.6 < \mathrm{Pr} < 60$, $5E5 < \mathrm{Re}_L < E8$, turbulent flow over flat plate $\mathrm{Re}_L = 4E6$ and $Nu_L = 5360$ at 105°F.	• According to ASHRAE (2005).	• $Q = 290$ W/occupant	• $Q = \dot{m}_{vnt}(h_o - h_{cab})$ • $\dot{V}_{vent} = 15$ cfm/person.	• $Q = \dot{m}_{leak}(h_o - h_{cab})$ • $\dot{V}_{leak} = 40$ cfm/foot leak rate for idle condition. • 1.5 coefficient for v_{vhc} = 50 mph.	• $Q = 280$ W/ blower.	• -	*Disadvantages* • Heat load from light is ignored by the authors. • Heat gain from driver and passenger are equal. • Correlations for f_i and f_o are complicated. *Advantages* • More realistic f_i and f_o.
Liu *et al.* (2011)	Dynamic cooling load model	• $f_o = 9 + 3.5 v_{vhc}^{0.66}$ $(v_{vhc} > 0)$ • $f_o = 16\ \mathrm{W/m^2 \cdot K}$ $(v_{vhc} = 0)$ • $f_i = 8\ \mathrm{W/m^2 \cdot K}$ Thermal storage effect is negligible given that automotive panels have a low	• $Q(t) = \sigma c_r \beta J$	• $Q = 116.3$ W (68.9 W for sensible and 46.5 for latent) at $T =$ 26°C.	• $Q = \dot{m}_{vnt}(h_o - h_{cab})$ • Ventilation air rate of 25 $\mathrm{m^3/h}$ per passenger in summer.	• -	• $Q = 3$ kW for train com-part-ment.	• -	*Disadvantages* • Heat load from infiltration, power equipment, and light are ignored by the authors. *Advantages* • Correlations of f_i and f_o are simplified.

Table 2.1 (continued)

Author/s	General Method	Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
		Sources of cabin compartment heat loads/gains							
		have a low density specific heat product.							
Li and Sun (2013)	HBM	• $f_o = 9 + 3.5 v_{vhc}^{0.66}$ $(v_{vhc} > 0)$ • $f_o = 16\ \mathrm{W/m^2 \cdot K}$ $(v_{vhc} = 0)$ Heat transfer rate between refrigerant and air for each heat exchanger's segment is calculated using ε-NTU method.	• Solar position is according to National Renewable Energy Laboratory Solar radiation calculation is according to ASHRAE (2009).	• Q = 116.3 W/occupant at 26°C. • Q_S = 186–4.65T.	• Fresh air volume of 3100 $\mathrm{m^3/h}$ for 310 passengers. • Supply air volume of 10,000 $\mathrm{m^3/h}$ for 310 passengers.	• -	• Heat gain from electri-cal power of supply air fan for train is 3 kW.	• -	*Disadvantages* • Heat gains from infiltration and light are ignored by the authors. • The procedures, i.e., correlations being used to calculate ventilation heat gain are not discussed in detail. *Advantages* • The simulation results are compared with experimental data. • Cabin heat load model is coupled with the air conditioning system to enable prediction of suction and discharge pressures.

Table 2.1 (continued)

Author/s	General Method	Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
		Sources of cabin compartment heat loads/gains							
Fayazbakhsh and Bahrami (2013)	HBM	• $f_o = 0.06 + 6.64 v_{vhc}^{0.5}$, $\mathrm{W/m^2 \cdot K}$ • $T_{exh} = 0.138 RPM - 17$ • $T_{eng} = -2\mathrm{E}-6 RPM^2 + 0.0355 RPM + 77.5$	• According to ASHRAE (1989).	• Metabolic load is considered as a function of metabolic heat product rate (85 W/m^2 for driver and 55 W/m^2 for passenger) and DuBois area. • DuBois area is a function of weight and height of occupants.	• $Q = \dot{m}_{vnt} (h_o - h_{cab})$ • $h = 1060T + (2.501\mathrm{E}6 + 1770T)\omega_a$ • $\omega_a = 0.62198 \left(\frac{\phi P_s}{100P - \phi P_s} \right)$	• Ventilation load has to consider leakage air flow rate because of higher cabin pressure than ambient pressure.	• -	• -	*Disadvantages* • Heat load from power equipment is ignored. • Heat load from light is ignored. • f_i is not explained in detail. *Advantages* • Heat load from exhaust is considered. • Further details on occupant heat load are provided.
Jha *et al.* (2013)	HBM	• $\overline{Nu}_L = \frac{f_o L}{k} = 0.45 + \left(0.6774\varphi^{1/2}\right) \left(\frac{1 + (\varphi/12500)^{3/5}}{\left[1 + (\varphi_{um}/\varphi)^{7/2}\right]^{2/5}} \right)$	• According to ASHRAE (2009).	• $Q = 115$ W/occupant	• -	• $Q = \rho_{out} \cdot V_{instrution} \cdot (h_{out} - h_{in})$ • $V_{instrution} = 25.2\,\mathrm{m^3/h}$ $(v_{vhc} = 0)$	• A load factor coeffi-cient of 0.8 is used to predict what fraction	• -	*Disadvantages* • Equations of f_i and f_o are complex. • Ventilation load is not discussed. • Heat gain from light is ignored. • Heat gains from

Table 2.1 (continued)

Author/s	General Method	Sources of cabin compartment heat loads/gains Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
		• $\overline{Nu}_L = \frac{f_i L}{k} =$ $0.6795\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}$ for $\mathrm{Pr} \geq 0.6$ • T = 100°C (engine compartment) • T = 60°C (firewall and floor panel)				• $V_{instrution}$= $37.8\,\mathrm{m}^3/\mathrm{h}$ $(v_{vhc} = 80$ km/h$)$	of the power rating of the motor is conver-ted to heat.		driver and passenger are equal. *Advantages* • f_i and f_o is more realistic.
Marcos *et al*. (2014)	HBM	• Considers free or forced convection, laminar, or turbulent flow, where • Laminar flow: • $Nu_L =$ $0.644\,\mathrm{Re}^{0.5}\,\mathrm{Pr}^{3/2}$ • Turbulent flow: • $Nu_L = (0.037\,\mathrm{Re}^{4/5} - 871)\mathrm{Pr}^{1/3}$ • Horizontal flat plate (roof): • Upper surface of hot plate or lower surface of cold plate:	• Incidence of solar irradiance is calculated using horizontal global irradiance and normal beam irradiance, both measured via the method described by Duffie	• Calculated using ISO 7730 norm.	• -	• -	• -	• -	*Disadvantages* • Heat gains from ventilation, infiltration, power equipment, and light are ignored. *Advantages* Analysis of convection heat transfer are detailed and deep. • Simulation results are compared with experimental data.

Table 2.1 (continued)

Author/s	General Method	Sources of cabin compartment heat loads/gains: Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
		• $Nu_L = 0.54 Ra_L^{1/4}$ $(\text{E4} < Ra_L < \text{E7})$ • $Nu_L = 0.15 Ra_L^{1/3}$ $(\text{E7} \le Ra_L \le \text{E11})$ • Upper surface of cold plate or lower surface of hot plate: • $Nu_L = 0.27 Ra_L^{1/4}$ $(\text{E5} < Ra_L < \text{E10})$ • Vertical flat plate: • $Nu = \left(0.825 + \left(0.837 Ra^{1/6} / \left(1 + 0.492 \Pr^{9/16}\right)^{8/17}\right)\right)^2$	and Bechman (2006).						
Solmaz *et al.* (2014)	HBM with ANN	• Calculation at $v_{vhc} = 120$ km/h .	• Orgill and Hollands model was used to calculate the defuse radiation on the horizontal surface.	• $Q = 116$ W/occupant	• $Q = \rho \dot{V} C_p Z$ $(T_o - T_i)$	• -	• $Q =$ 100 W	• -	*Disadvantages* • Study is limited to vehicle speed of 120 km/h . • Heat gains from driver and passenger are equal. • Heat gains from infiltration and light are ignored.

Table 2.1 (continued)

Author/s	General Method	Sources of cabin compartment heat loads/gains: Conduction and convection through body walls, glasses, and engine/motor compartment panels	Solar radiation through glass	Heat gain from passengers	Heat gain from ventilation/ fresh air intake	Heat gain from infiltration	Heat gain from power equipment	Heat gain from lights	Advantages and disadvantages
			• Koronakis model was used to calculate the hourly diffuse radiation on tilted surfaces. • Liu and Jordan model was used to calculate hourly beam and reflect radiations on tilted surfaces						*Advantages* • AAC system has hourly cooling load analysis.

2.5 Air-conditioning System Performance Studies

Previous A/C system performance studies have been conducted using two methods, namely, a numerical technique with/without experimental study (Lee and Yoo, 2000; Saiz Jabardo *et al*., 2002; Shao *et al*., 2004; Kaneko *et al*., 2011; Zhu *et al*., 2013; Cipollone and Di Battista, 2016) and a total experimental study (Kiatsiriroat and Euakit, 1997; Joudi *et al*., 2003; Kaynakli and Horuz, 2003; Tamura *et al*., 2005; Wang *et al*., 2005; Nagaya *et al*., 2006; Hosoz and Direk, 2006; Hosoz and Ertunc, 2006; Park *et al*., 2006; Wongwises *et al*., 2006; Qi *et al*., 2007; Ravikumar and Mohan Lal, 2009; Alkan and Hosoz, 2010; Qi *et al*., 2010; Atik *et al*., 2010; Zhou and Zhang, 2010; Desai *et al*., 2011; Cho *et al*., 2013; Han *et al*., 2013; Mohamed Kamar, 2013; Datta *et al*., 2014; Wu *et al*., 2014).

Lee and Yoo (2000) experimentally analyzed the performance of the laminated type evaporator and the parallel flow condenser of an AAC system using R134a as the working fluid. The AAC system also consisted of a swash plate compressor, a receiver drier, and an externally equalized thermostatic expansion valve (TXV). Through experimental study, they developed the refrigerant pressure drop correlation in the evaporator and condenser at various operating conditions in terms of Reynolds number. These correlations were then embedded in a performance simulation program of the integrated AAC system. The simulation program was used to predict the effect of the compressor speed, condenser size, condenser air inlet temperature, and refrigerant charge on the performance parameters of the cooling capacity and COP. Results obtained from the performance simulation of the integrated system were consistent, being within 7% of the experimental results.

Saiz Jabardo *et al.* (2002) developed a steady-state computer simulation model that included a variable capacity compressor (VCC), TEV, evaporator, and micro-channel parallel flow condenser for the AAC system. All these major components and all the refrigerant pipes connecting all major components were analyzed in detail. The modeling of the evaporator and condenser sections was conducted considering both refrigerant and air sides, including the phases and regions, by using the heat transfer correlation developed by previous researchers. This model is able to predict the cooling capacity, compressor power, refrigerant mass flow rate, and COP at various operating conditions of refrigerant charge, compressor speed, evaporator air inlet temperature, evaporator air inlet humidity, and condenser air inlet temperature. They found that the COP decreases with the increase of compressor speed, evaporator return air temperature, and condensing air temperature. Given the generic correlations from previous studies, significant deviation of within 20% was reported between the model and the experimental study.

Kaneko *et al*. (2011) also utilized generic correlations developed by previous researchers to develop a performance prediction method of the AAC system with CO_2 as the refrigerant. The pressure drop correlation in terms of Lockhart and Martinelli parameter expression was used. The evaporating convective heat transfer by Chen (1966) was utilized for the refrigerant side to represent the superposition of the convective and boiling heat transfer. For the air side, the heat transfer correlation was determined through power series correlation for Colburn j factor with respect to fin geometry as a parameter developed by Chang and Wang (1997). The comparison between the simulation and the experimental test results using a real AAC system showed that the developed simulation method can predict the cooling capacity successfully within ±10%. Furthermore, by considering the lubricant oil effect, the simulation results improved to ±5% and ±15% for the cooling capacity and pressure drop for evaporator simulation, respectively.

Recently, Cipollone and Di Battista (2016) presented a mathematical model of a fixed orifice AAC system using conservation equations (mass, momentum, and energy). The model considers the off-design behavior of main components, namely, the compressor, condenser, expansion valve, and evaporator; the model starts from a single model of these components. Then, the individual models are integrated into an overall system model using a two-level iterative procedure, as shown in Figure 2.6. In addition, the model utilized the following established generic heat transfer correlations from previous researchers: Dittus–Boelter forced convective heat transfer coefficient and Shah and Klimenko's two-phase flow heat transfer coefficient. The model supports AAC system optimization in terms of power reduction through correct sizing, comparison of different working fluids, component optimization considering frequent off-design conditions (i.e., condenser and evaporator sizing and orifice diameter variation), and liquid cooled condenser. However, the model validation is not discussed by the authors.

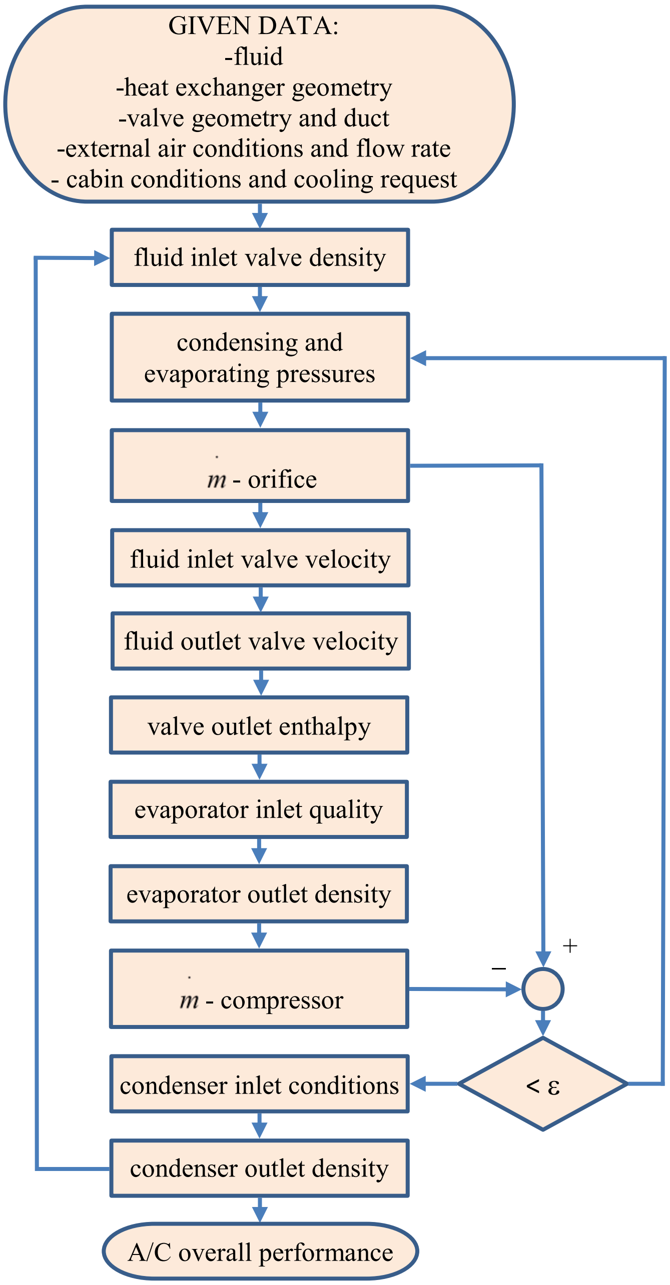


Figure 2.6 Iterative procedure for equilibrium of automotive air-conditioning system (Cipollone and Di Battista, 2016)

Shao *et al.* (2004) developed a modeling method for building application based on experimental data to represent the performance of the variable speed compressor for inverter air conditioners. The refrigerant mass flow rate and compressor power input are fitted in the second-order function of the condensation temperature and evaporation temperature at a basic compressor frequency. Then, they proposed an equation correction at different frequencies. Compared with the data provided by the compressor manufacturers, the average relative errors of this method are less than 2%, 3%, and 4% for the refrigerant mass flow rate, compressor input power, and coefficient of performance, respectively.

Zhu *et al*. (2013) developed two generic simulation models, namely, AGM-I and AGM-II, for the performance and control analysis of a variable refrigerant flow A/C system. Their method also adopted the approach of individual component modeling before being integrated into an overall A/C system model. The model validation exercise used experimental data from an open research work; the validation showed error percentages of 4.69%, 4.64%, and 1.19% for cooling capacity, energy consumption, and COP, respectively.

In general, pure physics-based models, such as those developed by Saiz Jabardo *et al.* (2002), Kaneko *et al*. (2011), Zhu *et al*. (2013), and Cipollone and Di Battista (2016), have good generalization capabilities but can experience poor accuracy. In addition, pure physics-based models have a high degree of complexity given the many variables involved in the analysis. By contrast, data-driven models, such as those developed by Lee and Yoo (2000) and Shao *et al.* (2004), are less complex and more accurate in terms of results but do not perform deep analysis compared with pure physics-based models. However, both types of models are more complex in analyzing the performance of the AAC system compared with the total experimental approach. Thus, limited findings on numerical analysis have been reported in the open literature compared with those on experimental analysis.

Total experimental analysis is one of the effective methods to analyze the performance of the AAC system (Wang *et al*., 2005). This method is effective because its results are less complex than those obtained by numerical analysis. Thus, a large amount of studies describing the performance of the ACC system through the experimental method has been published. Most of them conducted experimental work off-road with a belt-driven compressor coupled to an electric motor and controlled by a frequency converter (Kaynakli and Horuz, 2003; Wang *et al*., 2005; Hosoz and Direk, 2006). However, on-road tests (Park *et al*. 2006; Ravikumar and Mohan Lal, 2009) and testing by using tunnels (Qi *et al*., 2007) have also been reported. A capillary tube (Kaynakli and Horuz, 2003; Wang *et al*., 2005) or TXV (Kiatsiriroat and Euakit, 1997; Hosoz and Direk, 2006; Wongwises *et al*., 2006; Ravikumar and Mohan Lal, 2009; Zhou and Zhang, 2010; Desai *et al*., 2011; Cho *et al*., 2013; Datta *et al*., 2014), or EEV (Li *et al*., 2004) has been used as an expansion valve.

Experimental studies equipped with VCC (Park *et al*., 2006; Qi *et al*., 2007; Alkan and Hosoz, 2010), internal heat exchanger (Desai *et al*., 2011; Cho *et al*., 2013; Datta *et al*., 2014), and desiccant-assisted (Nagaya *et al*., 2006) and micro-channel heat exchangers (Kiatsiriroat and Euakit, 1997; Cho *et al*., 2013; Datta *et al*., 2014; Wongwises *et al*., 2006; Nagaya *et al*., 2006; Qi *et al*., 2010) have also been conducted; these studies have generally exhibited operational performance improvement. Previous studies have also reported the effect of alternative refrigerants on the performance of the AAC system as a replacement for R-12 (Kiatsiriroat and Euakit, 1997; Joudi *et al*., 2003; Ravikumar and Mohan Lal, 2009) or R134a (Tamura *et al*., 2005; Wongwises *et al*., 2006; Han *et al*., 2013; Cho *et al*., 2013; Qi, 2013; Wu *et al*., 2014).

Wang *et al*. (2005) and Kiatsiriroat and Euakit (1997) used a water cold condenser rather than a typical air cold condenser to control the condition of the condenser, i.e., T_{cd}. Wu *et al*. (2014) determined the refrigerant capacity by using a calorimeter that consists of an evaporator, electric heaters, second refrigerant (R11), and a stainless steel tank. Most researchers inserted the condenser and evaporator into a well-insulated air ductwork/chamber to provide uniform air flow and temperature (Joudi *et al*., 2003; Hosoz and Direk, 2006; Wongwises *et al*., 2006; Mohamed Kamar, 2008; Alkan and Hosoz, 2010; Mohamed Kamar *et al*., 2013). An electric air heater with an air blower was used to simulate the cabin environmental conditions; and the heater and blower circulated the air inside the evaporator ductwork and cabin compartment, respectively (Wang *et al.*, 2005; Hosoz and Direk, 2006; Alkan and Hosoz, 2010). Joudi *et al.* (2003) also used halogen lamps to produce a wide range of cabin air temperatures and loads. A mass flowmeter was installed at the condenser outlet to measure the total mass flow rate of the refrigerant; a sight glass tube was placed at the outlet of the flowmeter to ensure that the flowmeter chamber was filled with single-phase sub-cooled liquid refrigerant (Wang *et al.*, 2005).

Table 2.2 summarizes the system operational parameters and system performance parameters set and measured by previous researchers. Table 2.3 summarizes the system operational parameters and system performance parameters by previous researchers in studies related to alternative refrigerants. Key findings by all authors are also highlighted.

Table 2.2. System operational parameters and system performance parameters by previous researchers

Authors	System operational parameters	System performance parameters	Key findings
Kaynakli and Horuz (2003)	T_o (14–20°C), T_c (16–42°C), N_c (1750–3150 rpm), $T_{a,i,e}$ (12–30°C)	COP, Q_e, p_e, P_{sys}, $\dot{m}_r$, T_{cd}, W_c	• During constant T_o, when N_c increases, $\dot{Q}_e$, P_{sys}, $\dot{m}_r$, P_c and T_{cd} increase, while COP and p_e decrease.
Wang *et al.* (2005)	m (1.2–1.8 kg), $T_{a,i,e}$ (10–40°C), T_c (25–50°C), N_c (1750–2000 rpm)	COP, CL, p_e, p_d, CR, x, $\dot{m}_r$, W_c	At constant $T_{a,i,e}$, T_c, and N_c, when refrigerant charge increases, • $\dot{m}_r$ increases but x decreases. • COP, CR slightly decrease. • W_c, p_e, and p_d slightly increase. • CL is almost constant. At constant refrigerant charge, T_c and N_c, when $T_{a,i,e}$ increases, • $\dot{m}_r$, COP, CL, W_c, p_e, and p_d increase. • x is slightly constant but CR decreases. At constant $T_{a,i,e}$, refrigerant charge and N_c, when T_c increases,

Table 2.2 (continued)

Authors	System operational parameters	System performance parameters	Key findings
			• $\dot{m}_r$, W_c, p_e, p_d, and CR increase. • COP, CL, and x decrease. At constant $T_{a,i,e}$, refrigerant charge and T_c when N_c increases, • $\dot{m}_r$, CL, P_c, p_d, and CR increase. • COP, x, and p_e decrease.
Nagaya *et al.* (2006)	t (0–600 s), N_c (900–240 rpm)	T, ϕ	• T and ϕ are controlled precisely by using an adaptive control combining the PD control. • Energy consumption in developed system is smaller than that of the conventional system.
Hosoz and Direk (2006)	T_e (13,18°C), T_{cd} (13–30°C), N_c (750–2000 rpm)	T_d, EX_{cpt}, COP, Q_e, EX_t/Q_e	In cooling period, at constant T_e and T_{cd}, and increasing N_c, • Q_e increases but tends to decrease during higher N_c. • COP declines but T_d, EX_t/Q_e, and EX_{cpt} increase. In cooling period, at constant N_c and T_{cd}, and increasing T_e, • Q_e and COP increase but T_d decreases.
Park *et al.* (2006)	t (20 s), T_o (25, 35ºC)	p_e, p_d, T_{cab}, fuel consumption	• Fixed swash plate compressor has larger pressure change while variable displacement swash plate compressor has less pressure change. Suction pressure is maintained evenly regardless of vehicle speed. • Variable displacement swash plate compressor showed fuel consumption improvement of 6.1% at 60 km/h, 25ºC, and 6.7% during city driving. With T_o of 35ºC, an improvement of 6.7% at 60 km/h and 8.6% during city driving was observed.
Qi *et al.* (2007)	t (0–45 min), T_o (22–35°C), SL (up to 1000 W)	T_{cab}, T_e	• A control method based on changes of T_{cab} and T_e is proposed. • The deviation between actual and desired T_{cab} is less than 2ºC and is better at high T_o. • Compared with FCC, VCC responds quicker to T_{cab} and T_o.
Qi *et al.* (2010)	$T_{a,i,e}$ (27°C), ϕ_c (50%), sh (5ºC), sc	COP, Q_e, P_c	• COP of the enhanced system is slightly lower than that of the baseline under idle conditions, but under all the other test conditions, COP of the enhanced system is higher than that of the baseline system.

Table 2.2 (continued)

Authors	System operational parameters	System performance parameters	Key findings
	(5ºC), $\dot{V}_e$ (200–500 $\mathrm{m^3/h}$), p_d (14.72 bar), p_s (2.27 bar), $T_{a,i,c}$ (35°C), ϕ_{cd} (40%), v_{afc} (1.5–4.5 $\mathrm{m/s}$), T_d (80ºC)		• Q_e is increased by 5% and COP is improved by 7.9% under high vehicle speed.
Alkan and Hosoz (2010)	$v_{a,i,e}$ (1.5–3.0 $\mathrm{m/s}$), $T_{a,i,cd}$ (35, 40°C), N_c (700–1500 rpm), v_{afc} (1.4–4.2 $\mathrm{m/s}$), $T_{a,i,e}$ (35°C)	COP, Q_e, EX_t, EX_c	An increase in N_c causes the following: • Q_e rises during FCC operations but remains almost constant during VCC operations after a certain N_c owing to the intervention of the capacity control system. • The VCC operations offer almost constant EX_t and EX_c after a certain N_c is exceeded, while EX_t and EX_c in the FCC operations increases. • COP in the lower N_c of VCC is slightly poorer, but it surpasses the COP of FCC at higher N_c. • Compared with VCC operations, COP in the FCC operations decreases persistently. An increase in $T_{a,i,cd}$ causes the following: • Q_e increases gradually in FCC operations but is slightly influenced in VCC operations. • COP in FCC operations rises continually but is unchanged after a certain $T_{a,i,cd}$ is exceeded in VCC operations. • EX_t in FCC operations gradually decrease, but in the VCC operations, it initially drops sharply and is almost constant after a certain value of $T_{a,i,cd}$.
Desai *et al.* (2011)	sh (5–12K), sc (up to 10K)	COP, Q_e, W_c	• Overall improvements in cooling performance of system using Cu and Al IHX are 4.84% and 3.17%, respectively. • COP increases by 11 % and 7.18% in case of Cu and Al IHX, respectively. • W_c decreases by 6.05% and 4.18% in case of Cu and Al IHX, respectively.
Datta *et al.* (2014)	B_{cd} (0–50%), N_c (1000-1600 rpm), CL (900 W)	$T_{a,o,cd}$, COP, Q_e, p_e, p_d, $\dot{m}_{a,cd}$, $\dot{m}_r$,	• The reduction of airflow is the minimum in case of peripheral blockage, whereas it is the maximum in case of side blockage. • The increase of B_{cd} influences all system

Table 2.2 (continued)

Authors	System operational parameters	System performance parameters	Key findings
		Δp_{cd}, W_c, η, v_{afc}	performance parameters depending on the type of blockage..

Table 2.3. Summary of previous studies related to performance of AAC system with alternative refrigerants

Authors	Alternative refrigerants	System operational parameters	System performance parameters	Key findings
Kiatsiriroat and Euakit (1997)	Mixture of R22/R124/ R152	N_c (900–3500 rpm), R22 (20, 30, 40%), R152 (23%), $T_{a,i,e}$ (19–29 °C), $T_{a,i,c}$ (30–45 °C)	COP, EER, Q_e, W_c, Q_{cd}	• COP and EER increase with reduction of mass fraction of R22. • A suitable composition is when the mass fraction of R22 is in the range between 20% and 30%.
Joudi *et al.* (2003)	R134a, R290, R600a, mixture of R290/R600a (62/28%, molar percentage)	T_o (35–50°C), CL (1000–3500 W), N_c (700–3000 rpm), T_s (45–65°C)	p_c/p_e, COP, Q_e, $T_{a,o,e}$, t_{sp}, sh, sc, W_c	• The best replacement for R-12 is a mixture of R290 and R600.
Wongwises *et al.* (2006)	mixture of R290/ R600/ R600a	Ratio of hydrocarbon mixture, N_c (800–3000 rpm)	Q_e, W_c, COP, T_d, T_{cd}, T_e	• The mixture of R290/ R600/R600a:50%/40 %/10% is the most appropriate alternative refrigerant to replace R134a.
Ravikumar and Mohan Lal (2009)	mixture of R134a/ R600a/ R290	v_{vhc} (50–80 km/h), T_o (26–35°C)	Q_e, W_c, COP, T_{cab}, p_c/p_e	System with new mixture of alternative refrigerant compared to system with R-12 has the following results: • T_{cab} is 2–3ºC higher for all operating conditions. • Q_e is 25% to 33% higher, P_c is 43% higher, and COP decreases by 5% to 15%.
Cho *et al.* (2013)	R1234yf	N_c (800–2500 rpm),	Q_e, W_c, COP, T_d	Compared to system with R134a, system with R1234yf has the following results:

Table 2.3 (continued)

Authors	Alternative refrigerants	System operational parameters	System performance parameters	Key findings
		$T_{a,i,c}$ (35°C), $T_{a,i,e}$ (27°C)		• Lower W_c and Q_e as much as 4% and 7%, respectively. • Q_e and COP decreases by up to 7% and 4.5%, respectively, for system without IHX, and decreases by 1.8% and 2.9% for system with IHX.
Han *et al*. (2013)	Mixture of R161/R134a (60%/40%)	T_e (-5-10ºC), T_{cd} (50–65ºC), sc (5ºC), sh (20ºC)	Q_e, W_c, COP, T_d, p_c/p_e	Compared to system with R134a, that with mixture refrigerant has the following results: • slightly higher COP • higher Q_e and W_c of about 32% and 30%, respectively • higher T_d of about 15% • lower p_c/p_e of about 10.9%
Qi (2013)	R1234yf	$T_{a,i,e}$ (35–40°C), $\phi_{a,i,e}$ (40, 60%), $\dot{V}_e$ (144–474 $\mathrm{m^3/h}$), p_{cd} (1.32–1.84 MPaG), sc (5–9°C), p_e (0.2–0.25 MPaG), sh (5°C)	Q_e, refrigerant pressure drop along evaporator, $T_{a,i,e}$	• Q_e of laminated type evaporator of R1234yf is reduced up to 8.0%, but in microchannel PF, Q_e is comparable and/or larger than that of R134a up to 6.5%. • Deviation of $T_{a,o,e}$ for system with R1234yf is larger than that of system with R134a. • R1234yf refrigerant side pressure drop is larger than that of R134a for both evaporators.
Wu *et al*. (2014)	R161	T_e (-5–10°C), $T_{o,d}$ (50–65°C)	p_c/p_e, W_c, Q_e, COP, T_d	COP, Q_e, W_c, and T_d of R161 were better than those of HFC-134a.

The following four studies used experimental data to model the performance of an AAC system via ANN: Hosoz and Ertunc (2006), Atik *et al*. (2010), Mohamed Kamar *et al*. (2013), and Tian *et al*. (2015). The input and output layers used by all authors are summarized in Table 2.4. All authors found that the correlation coefficients for all performance parameters are very close to unity; these results indicate that their ANN models can be used to estimate the performance of the AAC system with very good accuracy.

Table 2.4 Input and output layers for artificial neural network

Authors	Input layer	Output layer
Hosoz and Ertunc (2006)	Q_e, N_c, T_{cd}	W_c, Q_{cd}, $\dot{m}_r$, and T_d
Atik *et al*. (2010)	m and N_c	Q_e, W_c, and COP
Mohamed Kamar *et al*. (2013)	N_c, $T_{a,i,e}$, $T_{a,i,cd}$, and v_e	Q_e, W_c, and COP
Tian *et al*. (2015)	N_c, EEV openings, $T_{a,i,e}$, and $T_{a,i,cd}$	$\dot{m}_r$, Q_e, Q_{cd}, and W_c

From the reviews discussed in this subsection, useful information in the area of AAC system modeling is described. Most of the studies are from total experiments instead of numerical simulation techniques with or without experimental study. In general, the performance of the AAC system has been experimentally studied in many ways, i.e., by variation of refrigerant charge, compressor speed, environmental temperature, actual road test, alternative refrigerants, and air velocities through the condenser and evaporator. Moreover, useful information on the experimental test rig set up and modeling method through experimental data have also been described. This information can be adopted to develop a novel and comprehensive AAC system simulation program. Although the results of total experimental studies are model-specific, the complexity is significantly reduced. In addition, many parameters can be investigated using much simpler methods; these parameters can be determined through a few different methodologies, such as the alternative refrigerant effect and ANN method. Thus, many papers describing the performance of the AAC system have been published.

2.6 Cabin Compartment Thermal Load Coupled with Air-conditioning System Performance Studies

Studies on combining the cabin compartment thermal load model with the AAC system performance model have been conducted in the last few years (Konz, 2007; Mohamed Kamar, 2008; Li and Sun, 2013). This approach is unique because it allows an optimized design of a cabin compartment climate control system derived from the realistic and accurate behavior of the AAC system; it also portrays the mutual effect between the AAC system and the cabin compartment (Mohamed Kamar, 2008). Furthermore, it offers an improved understanding of the synergistic effect of the various parameters in the vehicle design; these parameters can affect the comfort and performance of the AAC system, as well as the possible tradeoffs between such parameters.

The AAC system and the compartment cooling load are connected through an evaporator. Therefore, the load analysis in the cabin compartment and the characteristic of the evaporator coil need to be considered when developing a comprehensive and accurate compartment thermal and energy performance model. Thus, Konz (2007) and Mohamed Kamar (2008) developed a simulation program of the AAC system, which consisted of the cabin compartment thermal load model coupled with the passenger compartment thermal performance analysis through an evaporator.

Konz (2007) used the effectiveness number of transfer units (ε-NTU) for the parallel-flow type evaporator to calculate the air temperature at the entrance of the cabin compartment. This model is generic. However, its main limitation is that it does not consider the variation of humidity in the cabin compartment.

Mohamed Kamar (2008) conducted experimental work to obtain the off-design air side evaporator heat transfer correlations. These empirical correlations relate evaporator air outlet dry bulb temperature and humidity to evaporator air inlet dry-bulb temperature, humidity ratio, evaporator air velocity, condenser inlet air dry-bulb temperature, condenser air velocity, and compressor speed. These correlations were embedded in a semi-empirical computerized simulation program called CARSIM to simulate the effects of the air-conditioning volumetric air flow rate, number of occupants, glass thickness, vehicle speed, car color, and fractional ventilation air intake on the thermal and energy performance of a 1.6-L Proton Wira Aeroback. The cabin compartment heat load model of the CARSIM program was developed based on the elegant z-transfer function method. This model is generic (i.e., it can be used to simulate any type of vehicle), but its empirical correlation is model-specific to the original components of the A/C system of the 1.6-L Proton Wira Aeroback. In addition, the mathematical model only analyzed the air side; the performance analysis of the AAC system remains unknown.

Figure 2.7 shows the simplified schematic of the AAC system of a passenger vehicle developed by Mohamed Kamar (2008). Seven air-side governing equations are introduced with seven unknowns ($T_{1,k}$, $T_{2,k}$, $T_{3,k}$, $\omega_{1,k}$, $\omega_{2,k}$, $\omega_{3,k}$, and ER_k), where

$$ER_k - CLS_k = \sum_{j=0}^{\infty} g_j \left(TRC - T_{3,k-j}\right) \tag{2.1}$$

$$ER_k = 1.23 \dot{V}_e \left(T_{3,k} - T_{2,k}\right) \tag{2.2}$$

$$T_{2,k} = 2.67104 \left(N_c\right)^{-0.2155} \left(T_{1,k}\right)^{0.4472} \left(v_e\right)^{0.4319} \left(v_{afc}\right)^{-0.0882} \left(T_{0,k}\right)^{0.4799} \left(\omega_{0,k}\right)^{0.4623} \tag{2.3}$$

$$\omega_{2,k} = 0.00206 \left(N_c\right)^{-0.1590} \left(T_{1,k}\right)^{0.4289} \left(v_e\right)^{0.5103} \left(v_{afc}\right)^{-0.0977} \left(T_{0,k}\right)^{0.4438} \left(\omega_{0,k}\right)^{0.4784} \tag{2.4}$$

$$Q_{L,k} = 3010 \dot{V}_e \left(\omega_{3,k} - \omega_{2,k}\right) \tag{2.5}$$

$$T_{1,k} = XOA\left(T_{0,k}\right) + \left(1 - XOA\right) T_{3,k} \tag{2.6}$$

$$\omega_{1,k} = XOA\left(\omega_{0,k}\right) + \left(1 - XOA\right) \omega_{3,k} \tag{2.7}$$

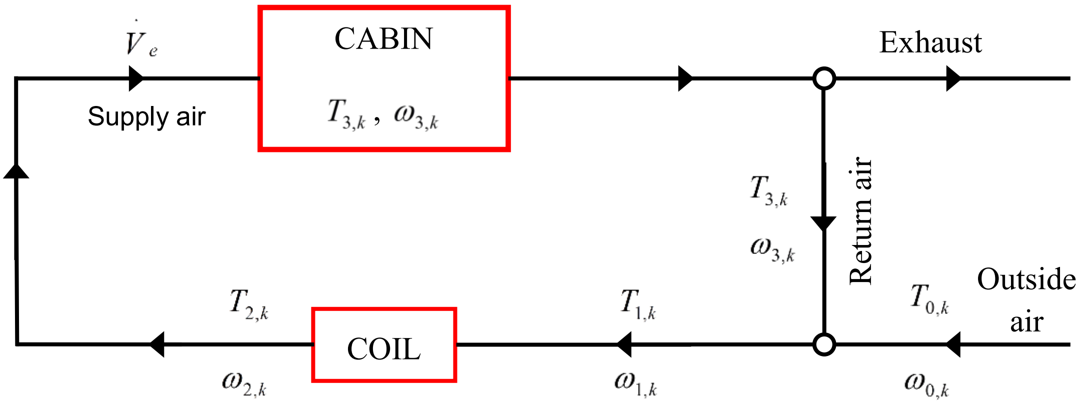


Figure 2.7 Simplified schematic of car air-conditioning system (Mohamed Kamar, 2008)

Recently, generic simulation analysis of the AAC system coupled with a passenger compartment thermal load model for a railway car was conducted by Li and Sun (2013). For the side of the A/C model, the compressor was modeled by applying ARI standard rating method (ARI Standard 540, 1999); the ARI standard 10-coefficient formulations were used to compute $\dot{m}_r$ and W_c (Li and Sun, 2013). The heat exchanger was modeled using the ε-NTU method and was validated with experimental data. The capillary tube was modeled as 1D flow, steady, adiabatic, and two-phase flow was homogeneous (Li and Sun, 2013). The loss coefficient in the inlet entrance was highlighted as 1.5 (Li and Sun, 2013). For model validation, the model of the capillary tube was compared with experimental data produced by Kim *et al.* (2002); the deviation is ±6.1%.

Dullinger *et al.* (2015) presented a modular structured simulation model that combines HVAC system with a dynamic vehicle thermal load model, which includes the operational and weather input of a light rail vehicle. The dynamic vehicle thermal load simulation model was integrated in a tool, equipped with a graphical user interface. The tool processes simulation datasets, visualizes time-domain results, and computes the annual energy consumption of the HVAC system. Figure 2.8 summarizes the work flow of the simulation tool. The main contributions of their study are a validated dynamic thermal load model with a precision of 10 s in sampling time and simulation tool for rail vehicles with the following characteristics: a modular and easy to parameterize HVAC model, a data-based dynamic vehicle thermal model and an application of GUI for model parameterization, processing of a real weather/route data, computation/visualization of time domain signals, and calculation of the annual energy consumption of the HVAC system. However, the authors realize that the framework of the study is limited to the air side only. Thus, the refrigerant side of the HVAC system is ignored. As a result, the refrigerant-side characteristics and performance of the HVAC system are unknown.

So far, the studies published on this research domain are very limited, at least to the author's knowledge. This type of study is challenging because of its complexity and the involvement of many coupled components. To date, the study on this research domain has tended to focus on the linkage of cabin compartment thermal load models to the air-side model of the evaporator rather than the linkage of these models to the refrigerant-side of each component on the AAC system. Therefore, no effort has been exerted to investigate the effect of the various parameters in vehicle design, as well as the environmental conditions that can affect the AAC system performance. Thus, a limitation of this study is its failure to address the effect of compressor energy consumption, which influences the AAC system performance.

Experimental results can provide a foundation for the establishment of performance prediction models. The methodologies of Shao *et al.* (2004) and Mohamed Kamar (2008) used experimental data to obtain their required empirical correlations, which are embedded in their final models; these methodologies can be adopted in the present study. Extended work can be performed to link the cabin compartment thermal load model with the AAC system performance model via the evaporator. They can be linked using the air-side evaporator heat transfer correlation (derived with new experimental data) and other air-side governing equations (Equations 2.1 to 2.7) to the refrigerant-side AAC system performance empirical correlation (also derived with experimental data). The development of another refrigerant-side AAC system performance empirical correlation through experimental data can create a linkage between an evaporator to other main components of the compressor and condenser. Thus, conducting an investigation on the effect of the various parameters in vehicle design (i.e., ambient weather conditions, vehicle operating conditions, and so on) on the comfort and performance of the AAC system and the possible tradeoffs between such parameters is feasible.

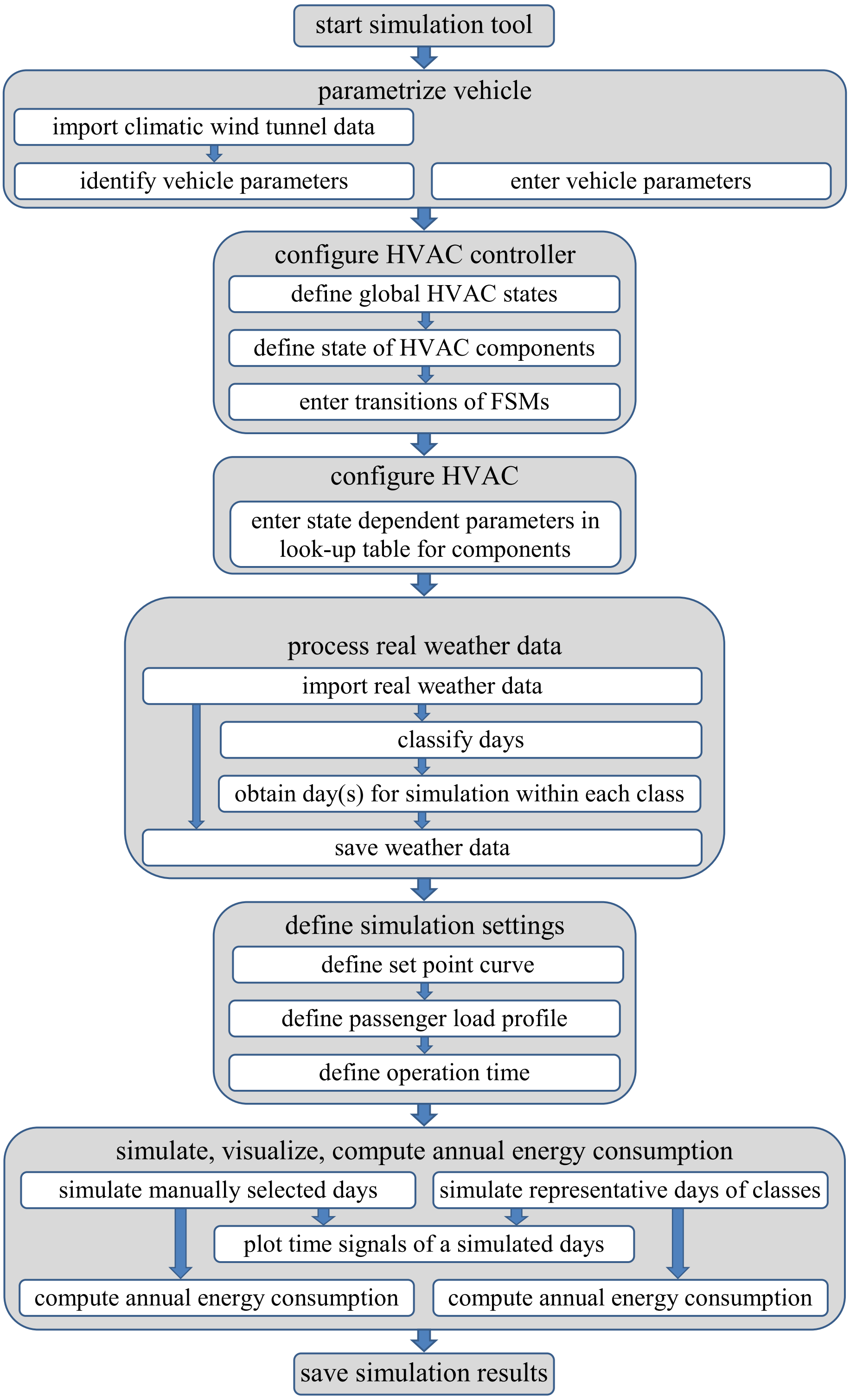


Figure 2.8 Work flow of simulation tool (Dullinger *et al.* 2015)

2.7 Summary

The thermal and energy performance analysis of the AAC system can be comprehensively investigated by combining the cabin compartment thermal load model with the AAC system performance model. These two models can be linked via the evaporator. Due to complexity, research on this domain has tended to focus on the linkage of cabin compartment thermal load model to the air-side model of the evaporator, rather than to also linkage to the refrigerant-side of each component on the AAC system. As a results, a comprehensive AAC system performance analysis is unavailable.

Therefore, a study to link the cabin compartment thermal load model to the air-side model of the evaporator and to the refrigerant-side model of each component on the AAC system is proposed. Consequently, an investigation on the effect of the various parameters in vehicle design, i.e., vehicle specifications, ambient weather conditions and vehicle operating conditions on the thermal and energy performance of the AAC system and the possible tradeoffs between such parameters is feasible. It is because the effect of compressor energy consumption, which influences the thermal and energy performance of the AAC system can now be addressed. In the other aspect, the complexity of related models can be reduced using data-driven models, where experimental data and results can be used as a foundation for the establishment of the models.

As discussed in Section 2.4, a cabin compartment thermal load model can be proposed without heat gain from the lighting (for small to medium-sized vehicles), thermal storage effect and infiltration thermal load. However, due to significant effect, the concept of sol-air temperature that represents the realistic outdoor conditions under the influence of the solar radiation effect must be considered. Meanwhile, the effect of vehicle speed on the cabin compartment thermal load variations can be investigated using correlation of the external surface convective heat transfer coefficient, as proposed by previous researchers, i.e., by Shahril *et al*. (2013). The combinations of various models from previous researchers form a new and novel approaches on cabin compartment thermal load analysis.

In short, the combination of these new and novel approaches on cabin compartment thermal load model with linked to data-driven models of the refrigerant-side of the AAC system, produces a new dimension in analyzing thermal and energy performance of the AAC system in more comprehensive way. These new and novel methodologies are proposed to be adopted in the present study.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The following subsection explains in detail the procedures employed in this study. The main content is the explanation on the development of proposed mathematical model, utilized in this study.

3.2 Research Methodology Flow Chart

Figure 3.1 shows the adopted research approach compressed in diagrammatic form.

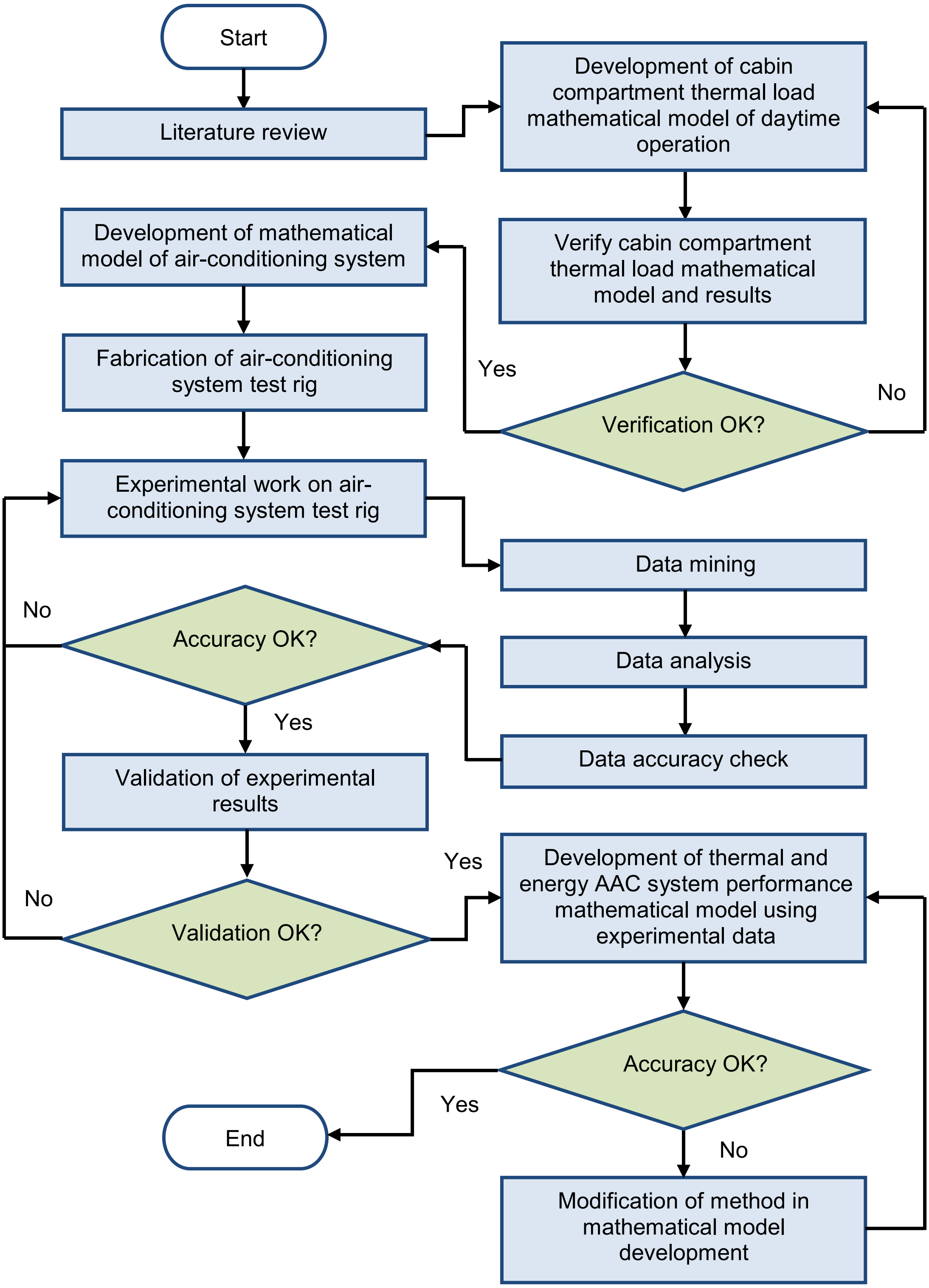


Figure 3.1 Methodology flow chart

3.3 Development of Proposed Mathematical Model

The purpose of this mathematical model is to analyze the thermal behavior in the passenger compartment, and the thermal and energy performance of the AAC system under the influence of the outside environment and various operating conditions of the AAC system. As described in Section 2.1, two main aspects need to be considered to develop a comprehensive AAC simulation program: cabin compartment thermal load analysis and AAC system performance analysis (including evaporator air-side analysis). Thus, two sets of mathematical models, namely, cabin compartment thermal load mathematical model and cabin compartment with thermal and energy performance mathematical model of the AC system, are presented.

The AAC refrigerant plant experimental rig is developed based on maximum cooling load specifications as highlighted by Senawi (1998) and Farrington and Rugh (2000). Therefore, the proposed cabin compartment thermal load mathematical model is also utilized for system component selection. Ultimately, these two sets of mathematical models are combined for complete performance simulation of the AAC system.

3.3.1 Cabin Compartment Thermal Load Mathematical Model

In this study, the thermal storage effect of the vehicle envelope and internal objects are ignored, as proposed by Stancato *et al*. (1992), Stancato and Onusic (1997) and Mohamed Mansor (2007). As a result, heat conduction is in a steady state and all summations of instantaneous heat gains are equal to cooling loads. An assumption is that electrical lighting and heat release from the motor compartment do not contribute to the total cooling load. The procedure to determine hourly vehicle compartment thermal load is shown in Figure 3.2.

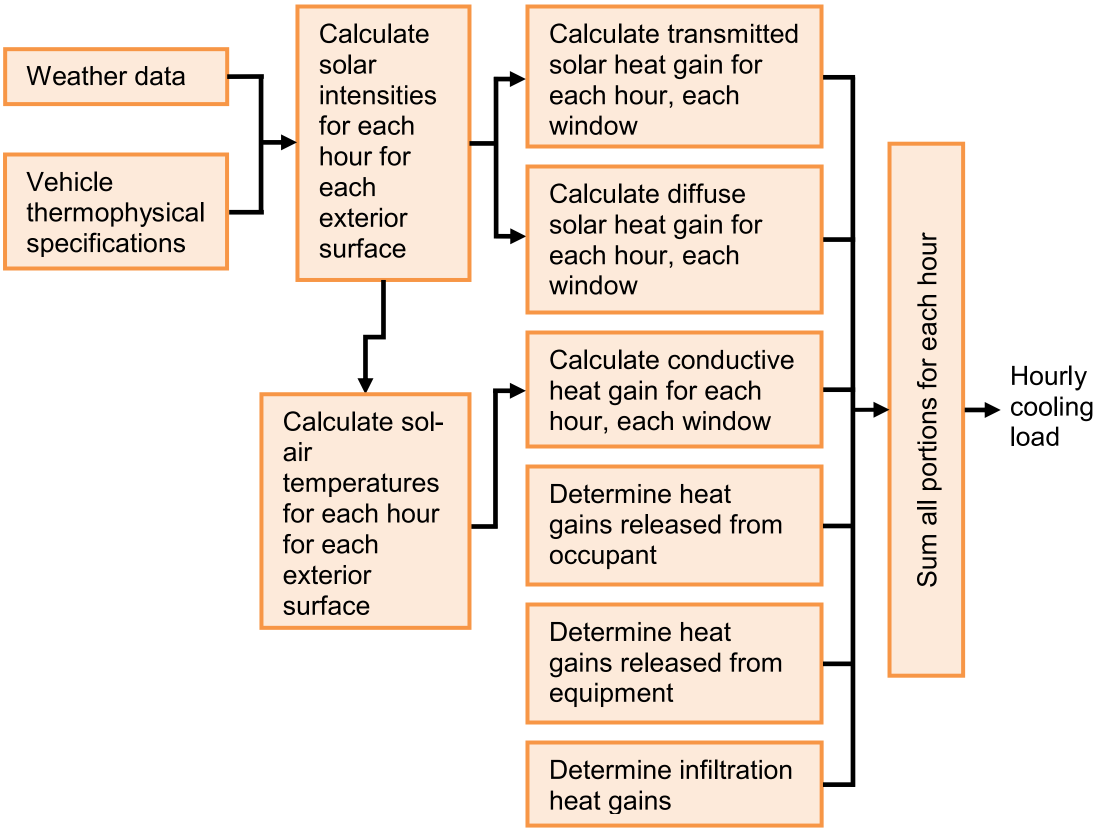


Figure 3.2 Simplified hourly vehicle compartment thermal load calculation procedure

3.3.1.1 Conductive Heat Gain through Exterior Surfaces

For exterior door/wall and roof exposed to direct solar radiation, the conductive heat gained through these surfaces with m layers for a constant cabin air temperature (Mohamed Mansor, 2007) is

$$Q_{es} = f_o A(T_{so} - T_{wo}) + f_i A(T_{wi} - T_i) + \sum_{j=1}^{j=m} \frac{k}{\delta} A(T_{wo} - T_{wi}) = UA(T_{so} - T_i) \tag{3.1}$$

where

$$U = \left[\frac{1}{f_i} + \frac{1}{f_o} + \sum_{j=1}^{j=m} \frac{k}{\delta}\right]^{-1} \text{ and } T_{so} = T_o + \frac{f}{f_o} I_t - \frac{\varepsilon \Delta R}{f_o}$$

f/f_o is the surface absorptivity and the value 0.026 or 0.052 represents light- or dark-colored surfaces, respectively (ASHRAE, 2009). The correction factor, $\varepsilon\Delta R/f_o$, is estimated 0 for vertical surface and 4°C for horizontal surface (ASHRAE, 2009). The correction factor for surfaces with tilt angle less than 90° is also considered as 0°C. As proposed by Arora (2009), the inside convective heat transfer coefficient, f_i, for buildings was considered, where f_i = 11.5 $\mathrm{W/m^2 \cdot K}$. The outside convective heat transfer coefficient, f_o, which is estimated by the correlation proposed by Shahril *et al*. (2013), depends on vehicle speed, v_{vhc}, where

$$f_o = 5.108 v_{vhc}{}^{0.643} \tag{3.2}$$

Total short wavelength irradiance, I_t, which reaches a surface, is the sum of the direct solar radiation, I_D; the diffuse sky radiation, I_d; and the solar radiation reflected from the surrounding surfaces, I_r (ASHRAE, 2005). If the direct normal irradiance, I_{DN}, and the angle of incidence between the incoming solar rays and the line normal to the surface θ are known, then

$$I_t = I_D + I_d + I_r = I_{DN} \cos\theta + I_d + I_r \tag{3.3}$$

where

$$I_{DN} = IDH/\sin\beta \text{ (Arora, 2009)}$$
$$\sin\beta = \cos l \cos d \cos hr + \sin l \sin d$$
$$d = 23.45 \sin(360(284 + D)/365)$$

D is the number days of the year, ranging from 1 to 365 from the 1st of January to the 31st of December, with February assumed to have 28 days (ASHRAE, 2005; ASHRAE, 2009). hr is positive, zero, and negative for morning, noon, and afternoon hours, respectively, calculated from ASHRAE (2005), where

$$hr = 15(AST - 12) \tag{3.4}$$

with

$$AST = LST + EOT/60 + ((LSM - LON)/15)$$

EOT for the 1st, 8th, 15th, and 22nd of each month is given by Arora (2009). θ can be expressed in terms of other known solar angles where (ASHRAE, 2005; ASHRAE, 2009)

$$\cos\theta = \cos\beta \sin\gamma \sin\Sigma + \sin\beta \cos\Sigma \tag{3.5}$$

with

$$\gamma = \phi - \psi$$

ψ = 180°, −90°, 0°, and 90° for north, east, south, and west, respectively

Figure 3.3 shows the solar angles related to the inclined surfaces exposed to direct solar radiation. I_d and I_r are given by ASHRAE (1993), where

$$I_d = Idh \cdot F_{ss} \tag{3.6}$$

$$I_r = (IDH + Idh)g \cdot F_{sg} \tag{3.7}$$

with g typically 0.2. IDH and Idh for specific hours are given in Appendix A. F_{ss} and F_{sg} are given as

$$F_{ss} = (1 - \cos\Sigma)/2 \tag{3.8}$$

$$F_{sg} = 1 - F_{ss} \tag{3.9}$$

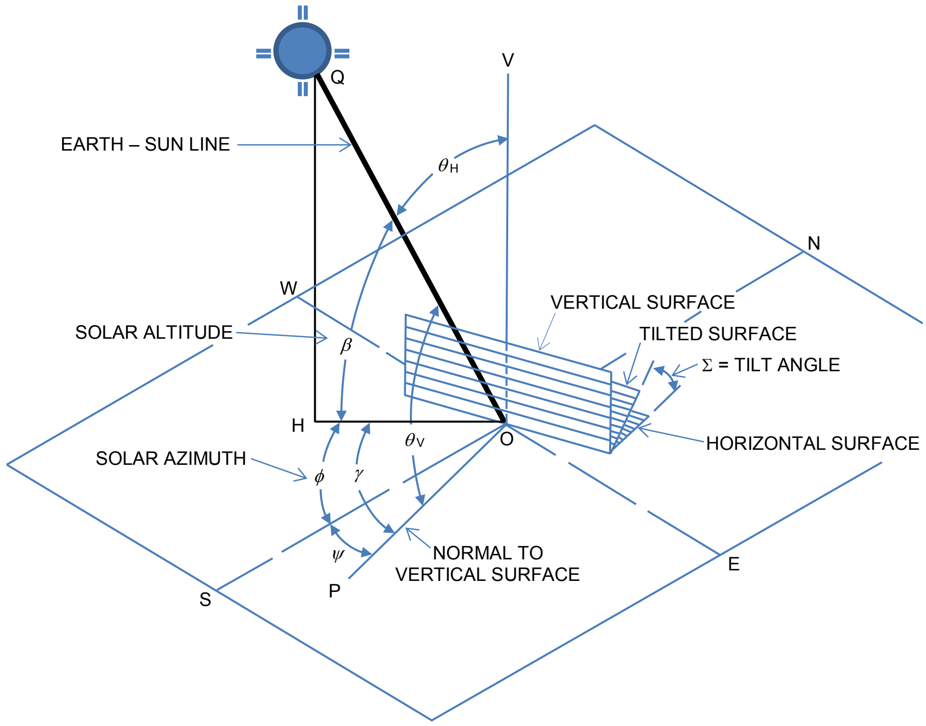


Figure 3.3 Solar angles for vertical and horizontal surfaces (ASHRAE, 2009)

3.3.1.2 Heat Gain through Glazing Surface

Direct and diffuse solar radiation incident upon a glass surface is transmitted, reflected, and absorbed (ASHRAE, 1993; Arora, 2009), as shown in Figure 3.4. Therefore, heat gain through glazing, Q_g, comprises of three components; all the transmitted radiation through glass, $SGHt$; a part of the absorbed radiation that travels to the air conditioned space, $SGHa$; and heat transmitted because of the difference between the outside and inside temperature, CG. Thus,

$$Q_g = SGHt + SGHa + CG \tag{3.10}$$

$SGHt$ is given by ASHRAE (1993), where

$$SGHt = A_g \cdot SC[(ITD \cdot SLF) + ITd] \tag{3.11}$$

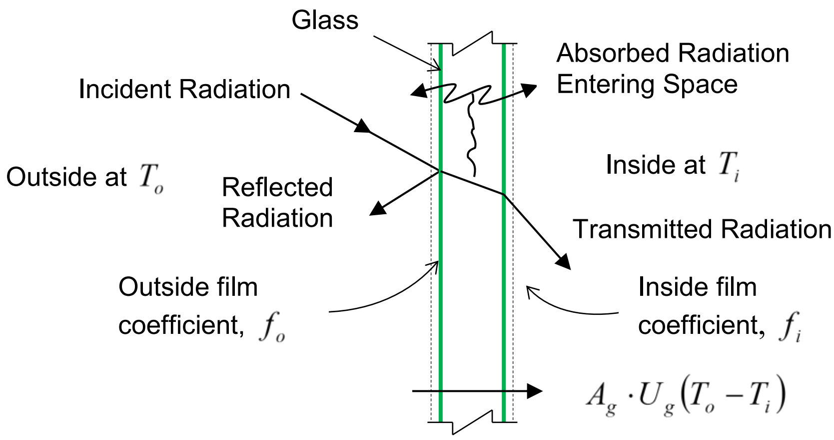


Figure 3.4 Heat transfer through glass (Arora, 2009)

According to ASHRAE (1993), the direct component of the transmitted radiation per unit fenestration area, ITD, can be calculated as

$$ITD = I_{DN} \cos\theta \sum_{j=0}^{5} t_j \cos^j \theta \tag{3.12}$$

where I_{DN} is given by the equation in Section 3.3.1.1 and SLF is assumed to be 1 (Mohamed Kamar, 2008). Meanwhile, ITd can be computed from (ASHRAE, 1993)

$$ITd = (I_d + I_r) 2 \sum_{j=0}^{5} \frac{t_j}{(j+2)} \tag{3.13}$$

with I_d and I_r also determined through the equations in Section 3.1. Next, $SGHa$ can be expressed as follows (ASHRAE, 1993):

$$SGHa = A_g \cdot N_i \cdot SC[(IAD \cdot SLF) + IAd] \tag{3.14}$$

SC is 1 because of the assumed maximum effect, and $N_i = f_i / (f_i + f_o)$ with the values of f_i and f_o given in Section 3.1. IAD is obtained from ASHRAE (1993), where

$$IAD = (I_d + I_r) 2 \sum_{j=0}^{5} \frac{a_j}{(j+2)} \tag{3.15}$$

The values of t_j and a_j for standard glass are given in Table 3.1. Meanwhile, CG is expressed as

$$CG = A_g \cdot U_g (T_o - T_i) \tag{3.16}$$

Table 3.1 Values of t_j and a_j for standard glass (ASHRAE, 1985)

j	a_j	t_j
0	0.01154	-0.00885
1	0.77674	2.71235
2	-3.94657	-0.62062
3	8.57881	-7.07329
4	-8.38135	9.75995
5	3.01188	-3.89922

3.3.1.3 Heat Gains Released from Occupants

Heat generated by occupants depends on the type of activity and the number of occupants. Higher activity leads to higher cooling load. Therefore, heat generated by the driver is higher than that of the passenger under typical conditions. Chen *et al.* (2012a) stated that the cooling requirement of a passenger is approximately 100–150 W. However, constant heat gain released by a human, as proposed by ASHRAE (2009), is taken as a basis. If n represents the number of passengers, then the instantaneous cooling load produced by the occupants is given by

$$Q_{ocp} = Q_{dvr} + n \cdot Q_{pgr} \tag{3.17}$$

For a typical passenger car, the maximum number of passengers is four. Using Equation (3.8) with driver and each passenger produce 220 and 115 W of heat loads (as in Table 3.2) respectively, the constant maximum heat gain released from the occupants is Q_{ocp} = 680 W.

Table 3.2 Constant heat gain by driver and passenger (ASHRAE, 2009)

Author	Heat gain per person (W)	
	Driver	Passenger
ASHRAE, (2009)	220[a] (80[c] + 140[d])	115[b] (70[c] + 45[d])

[a]assumed under criteria of light work in factory at room dry-bulb temperature of 24°C (sensible + latent); [b]assumed under criteria of seated, very light work at room dry-bulb temperature of 24°C (sensible + latent); [c]sensible heat load; [d]latent heat load.

3.3.1.4 Heat Gain from Ventilation

The introduction of fresh outside air to the conditioned cabin space is necessary to dilute carbon dioxide and odors as well as other air contaminants to maintain the purity of cabin air. ASHRAE (2000) recommends the ventilation air rate of 5 l/s per passenger. Since thermal load infiltration can be ignored with respect to the ventilation load owing to the sealed construction of the windows and the door, the instantaneous ventilation load, Q_{vnt}, can be expressed as follows (Mohamed Mansor, 2007):

$$Q_{vnt} = \frac{\dot{V}_a}{v_o}\left(h_{o,a} - h_{i,a}\right)SCHI \tag{3.18}$$

where free stream-specific air enthalpy, h_a, in terms of a given dry-bulb temperature, T_o, and air-specific humidity ratio, ω_a, is obtained from ASHRAE (1993) as:

$$h_a = 1006\,T_o + \omega_a\left(2501000 + 1{,}805\,T_a\right) \tag{3.19}$$

ω_a can be expressed in terms of saturated air vapor pressure, p_v, and total pressure, p_t, where:

$$\omega_a = \frac{0.662\, p_v}{p_t - p_v} \tag{3.20}$$

p_t is assumed at an atmospheric pressure of 101.325 kPa and p_v is estimated using the modified Apjohn equation, where (ASHRAE, 1993):

$$p_v = p_v^{'} - \frac{1.8p\left(T_o - T_{wb}\right)}{2700} \tag{3.21}$$

$p_v^{'}$ is also given by ASHRAE (1993) as follows:

$$\begin{aligned} \ln p_v^{'} &= \frac{-5800.2006}{T_{wb}} + 1.3914993 - 0.04860239\, T_{wb} + \\ & 0.41764768 \times 10^{-4} T_{wb}^{\ \ 2} - 0.14452093 \times 10^{-7} T_{wb}^{\ \ 3} + 6.5459673 \ln T_{wb} \end{aligned} \tag{3.22}$$

The hourly T_o and T_{wb} are given in Appendix A.

3.3.1.5 Heat Gain from Power Equipment

The experimental study by Zheng *et al*. (2011) indicates that the maximum possible heat gain from one blower motor is 280 W. Therefore, if *n* blowers are used, the heat gain from all blowers in a conditioned space, in Watts, is given by

$$Q_{bwr} = 280n \tag{3.23}$$

Thus, for AAC systems with a single blower (internal fan), the heat gain is $Q_{bwr} = 280$ W.

3.3.2 Cabin Compartment-Automotive Air-conditioning Mathematical Model

The cabin compartment integrated with the AAC thermal and energy performance model is proposed to predict and justify the aspects of cabin compartment thermal environments and the AAC system performance under various operating conditions. Owing to complex air and refrigerant behaviors in the system, few correlations used in the model are developed based on experimental data as conducted by Lee and Yoo (2000), Shao *et al*. (2004), Mohamed Kamar (2008), and Navarro-Esbrí *et al*. (2010). This approach significantly reduces the complexity of the model and increases the accuracy of the results for the proposed system. The model considers both air and refrigerant sides. The next subsection explains in detail the approach of the mathematical model adopted in this study.

3.3.2.1 Evaporator-Cabin Compartment Air-side Mathematical Model

In general, air-side evaporator-compartment mathematical model is used to link the cabin compartment thermal load model to the thermal and energy AAC system performance model. Mohamed Kamar (2008) proposed seven air-side governing equations to analyze the compartment environments of a passenger car. Thus, modified equations from Mohamed Kamar (2008) are proposed for air-side steady-state conditions. Since the thermal storage effect of the vehicle envelope and internal objects are ignored and cabin compartment temperature is assumed constant at desired value, Equation (2.1) becomes

$$ER = CLS \tag{3.24}$$

From Figure 3.5, the steady-state heat extraction rate of cabin, coil-sensible load, and coil latent load are expressed as

$$ER = 1.23\,\dot{V}_e\left(T_{cab} - T_{a,o,e}\right) \tag{3.25}$$

$$Q_{CS} = 1.23\dot{V}_e\left(T_{a,i,e} - T_{a,o,e}\right) \tag{3.26}$$

$$Q_{CL} = 3010\,\dot{V}_e\left(\omega_{a,i,e} - \omega_{a,o,e}\right) \tag{3.27}$$

The coil total load is the summation of coil sensible load and coil latent load; thus,

$$Q_{CT} = Q_{CS} + Q_{CL} \tag{3.28}$$

Cabin latent load (from occupant) is estimated as

$$Q_{LT} = 3010\,\dot{V}_e\left(\omega_{cab} - \omega_{a,o,e}\right) \tag{3.29}$$

As shown in Figure 3.5, the relationship between $T_{a,i,e}$ with T_o and T_{cab}, and the relationship between $\omega_{a,i,e}$ with ω_o and ω_{cab} can be drawn as

$$T_{a,i,e} = XOA(T_o) + (1 - XOA)T_{cab} \tag{3.30}$$

$$\omega_{a,i,e} = XOA(\omega_o) + (1 - XOA)\omega_{cab} \tag{3.31}$$

Specific humidity, ω, in terms of relative humidity, ϕ, can be shown as (Arora, 2009)

$$\omega = 0.622\phi\frac{p_s}{p_a} \tag{3.32}$$

where p_s is the saturation pressure of water vapor, taken from the saturation properties of the water table at respective dry-bulb temperatures. p_a is the partial pressure of dry air, which is calculated as (Arora, 2009)

$$p_a = p_t - p_v \tag{3.33}$$

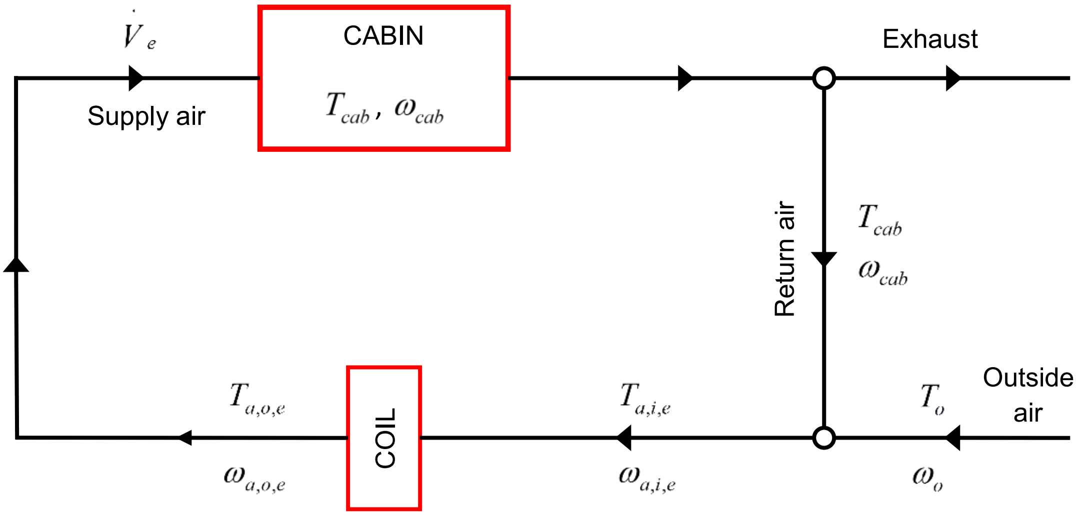


Figure 3.5 Simplified steady-state air-side schematic of automotive air-conditioning system

p_t is assumed at an atmospheric pressure of 101.325 kPa and p_v is the partial pressure of water vapor, estimated as (Arora, 2009)

$$p_v = \phi p_s \tag{3.34}$$

According to Mohamed Kamar (2008), the evaporator air outlet dry-bulb temperature is the function of compressor speed, condenser air face velocity, air velocity through the evaporator, evaporator air inlet specific humidity, and evaporator and condenser air inlet dry-bulb temperatures, given by

$$T_{a,o,e} = f\left(N_c, v_{afc}, v_e, \omega_{a,i,e}, T_{a,i,e}, T_{a,i,cd}\right) \tag{3.35}$$

Since many variables are involved, dimensional analysis is adopted to greatly simplify the experimental work in the development process of semi-empirical correlation of evaporator air outlet dry-bulb temperature. In this analysis, the Buckingham π theorem is chosen because this theory can organizes steps to ensure dimensional homogeneity. In this novel approach, compressor speed, condenser air face velocity, and condenser air inlet dry-bulb temperature are selected as repeating variables. In addition, evaporator air inlet relative humidity instead of evaporator air inlet specific humidity and evaporator air volume flow rate instead of evaporator air velocity are considered because of simplification and constant value at any measuring point, respectively. Thus, $\phi_{a,i,e}$ is considered instead of $\omega_{a,i,e}$ because of its direct measurement value from the humidity transducer. Thus,

$$\frac{T_{a,o,e}}{T_{a,i,cd}} = f\left(\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}}, \frac{T_{a,i,e}}{T_{a,i,cd}}, \phi_{a,i,e}\right) \tag{3.36}$$

A detailed analysis using the Buckingham π theorem is presented in Appendix B. Obviously, Equation (3.36) has a much simple relationship compared to Equation (3.35). An experiment with a fixed $\phi_{a,i,e}$ (say, $\phi_{a,i,e}$ = 40%) and $T_{a,i,e}/T_{a,i,cd}$ $\left(\text{say}, T_{a,i,e}/T_{a,i,cd} = 30°\text{C}/40°\text{C} = 0.750\right)$ could be performed by varying $\dot{V}_e N_c^{\,2}/v_{afc}^{\,3}$, by simply varying N_c and/or $\dot{V}_e$, and/or v_{afc}. Then, the quantity of $\phi_{a,i,e}$ is changed so that $\phi_{a,i,e}$ = 50% and the experiment is repeated. This result has greatly reduced the effort and the cost in determining the actual coil sensible semi-empirical correlation. Finally, through eight governing equations from Equations (3.25) to (3.31) and (3.36), the eight unknowns are $T_{a,i,e}$, $\omega_{a,i,e}$, $T_{a,o,e}$, $\omega_{a,o,e}$, N_c, Q_{CL}, Q_{CS}, and Q_{CT}.

3.3.2.2 Thermal and Energy Automotive Air-conditioning System Performance Mathematical Model

A simple VCRC 1-2-3-4 shown in Figure 3.6 is considered. A decrease in the evaporating pressure corresponds to a decrease in the evaporating temperature (Figure 3.6(a)). Meanwhile, an increase in the condensing pressure corresponds to an increase in the condensing temperature (Figure 3.6(b)). As shown in Figure 3.6(a), a drop in the evaporating pressure $\left(p_e \text{ to } p_e'\right)$ and temperature $\left(T_e \text{ to } T_e'\right)$ increases the compressor work per unit mass of refrigerant from $h_2 - h_1$ to $h_{2'} - h_{1'}$ and decreases the cooling capacity per unit mass of refrigerant from $h_1 - h_4$ to $h_{1'} - h_{4'}$. Meanwhile, an increase in the condensing pressure $(p_{cd}$ to $p_{cd}')$ and temperature $(T_{cd}$ to $T_{cd}')$ increases the compressor work per unit mass of refrigerant from $h_2 - h_1$ to $h_{2'} - h_1$ and decreases the cooling capacity per unit mass of refrigerant from $h_1 - h_4$ to $h_1 - h_{4'}$ (Figure 3.6(b)). Further, the following assumptions are made:

a. Isentropic compression process from point 1 to 2, point 1′ to 2′ and point 1 to 2′.

b. Isentalphic throttling process from point 3 to 4, point 3 to 4′ and point 3′ to 4′.

c. The condition where the refrigerant leaving an evaporator coil and enter the inlet compressor (points 1 and 1′) is saturated vapor.

d. Pressure drop inside the evaporator and condenser coils are small and ignored.

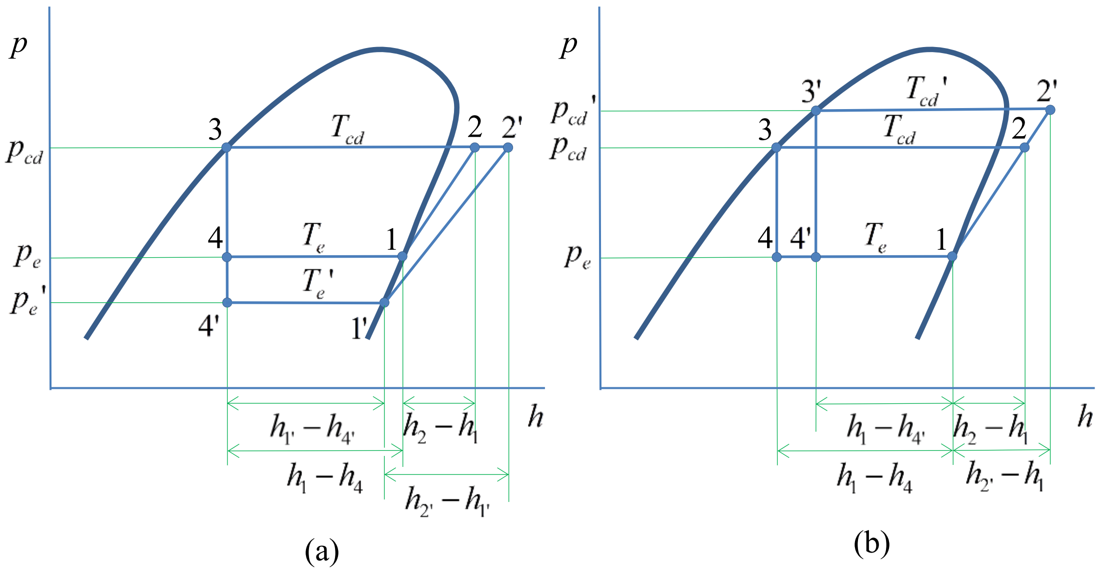


Figure 3.6 (a) Effect of evaporating temperature/pressure; (b) effect of condensing temperature/pressure on vapor compression refrigeration cycle system

Consequently, the compressor rotational speed, the heat rejection rate from the condenser per unit mass of refrigerant, and the refrigerant mass flow rate correspondingly change with the change of compressor work per unit mass of refrigerant and cooling capacity per unit mass of refrigerant in the VCRC system. Therefore, in the refrigerant side of the VCRC of the AAC system, relating the compressor work per unit mass of refrigerant, cooling capacity per unit mass of refrigerant, heat rejection rate from condenser per unit mass of refrigerant, and refrigerant mass flow rate to the functions of evaporating temperature, condensing temperature, and compressor rotational speed are justified, where

$$w_c = f(T_{cd}, T_e, N_c) \quad (3.37)$$

$$\dot{m}_r = f(T_{cd}, T_e, N_c) \quad (3.38)$$

$$q_e = f(T_{cd}, T_e, N_c) \quad (3.39)$$

$$q_{cd} = f(T_{cd}, T_e, N_c) \quad (3.40)$$

This idea is supported by Shao *et al*. (2004), who modeled the inverter compressor power input and refrigerant mass flow rate operated at a constant speed in the form of second-order functions of the condensing temperature and evaporating temperature. In addition, for different compressor speed, the compressor work per unit refrigerant can be formed in the function of condensing temperature, evaporating temperature, and compressor rotational speed.

Meanwhile, according to the first law of thermodynamics, the energy balance in the AAC system as shown in Figure 3.7 is

$$w_c + q_e = q_{cd} \quad (3.41)$$

Then, the performance of the developed system at respective operating conditions can be estimated based on the coefficient of performance as follows (Hosoz and Direk, 2006):

$$COP = \frac{q_e}{w_c} \quad (3.42)$$

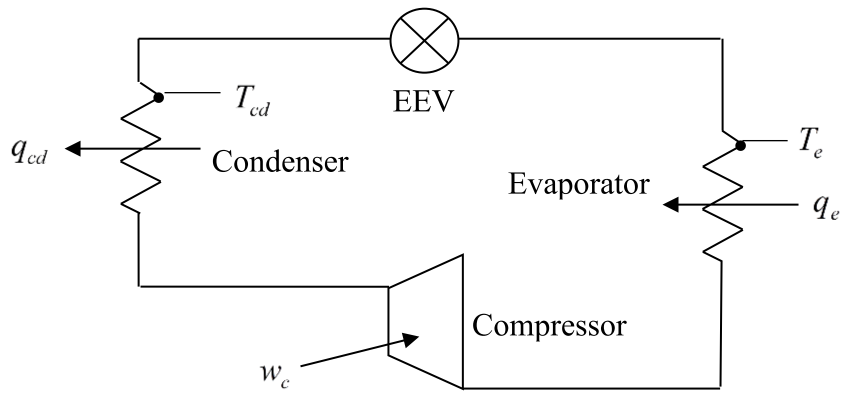


Figure 3.7 Simplified refrigerant-side energy balance of automotive air-conditioning system

Through six governing equations from Equations (3.37) to (3.42), the six unknowns are T_e, T_{cd}, w_c, q_{cd}, $\dot{m}_r$, and COP. Equations (3.37) through (3.40) can be fitted as power equations from the experimental data as conducted by Mohamed Kamar (2008), with the general form as in Equations (3.43) through (3.46), respectively. c_0 through c_3, d_0 through d_3, e_0 through e_3, and f_0 through f_3 are compressor input power, refrigerant mass flow rate, cooling capacity, and condensing capacity correlation coefficients, respectively, determined from experimental data. Then, six unknowns and six governing equations from Equations (3.41) to (3.46) are solved.

$$w_c = c_0 T_{cd}^{\,c_1} T_e^{\,c_2} N_c^{\,c_3} \tag{3.43}$$

$$\dot{m}_r = d_0 T_{cd}^{\,d_1} T_e^{\,d_2} N_c^{\,d_3} \tag{3.44}$$

$$q_e = e_0 T_{cd}^{\,e_1} T_e^{\,e_2} N_c^{\,e_3} \tag{3.45}$$

$$q_{cd} = f_0 T_{cd}^{\,f_1} T_e^{\,f_2} N_c^{\,f_3} \tag{3.46}$$

3.3.3 Complete Simulation of Air-conditioning System

Figure 3.8 shows a flow chart of a complete AAC system simulation. The calculation procedures for evaporator and cabin compartment air-side analysis are shown in Figure 3.9. Due to possible error in assumption made during cabin compartment heat load estimation process, 5% heat is added to all cabin-sensible and latent heat loads as proposed by Arora (2009). In addition, the following assumptions are made:

a. The condenser air inlet temperature is simulated as equal to the outside air temperature.
b. The condenser air inlet humidity is simulated as equal to the outside air humidity.
c. From the amount of heat load, 3% is lost during the heat transfer process from hot air to cold refrigerant at the evaporator coil as reported by Cho *et al*. (2013).

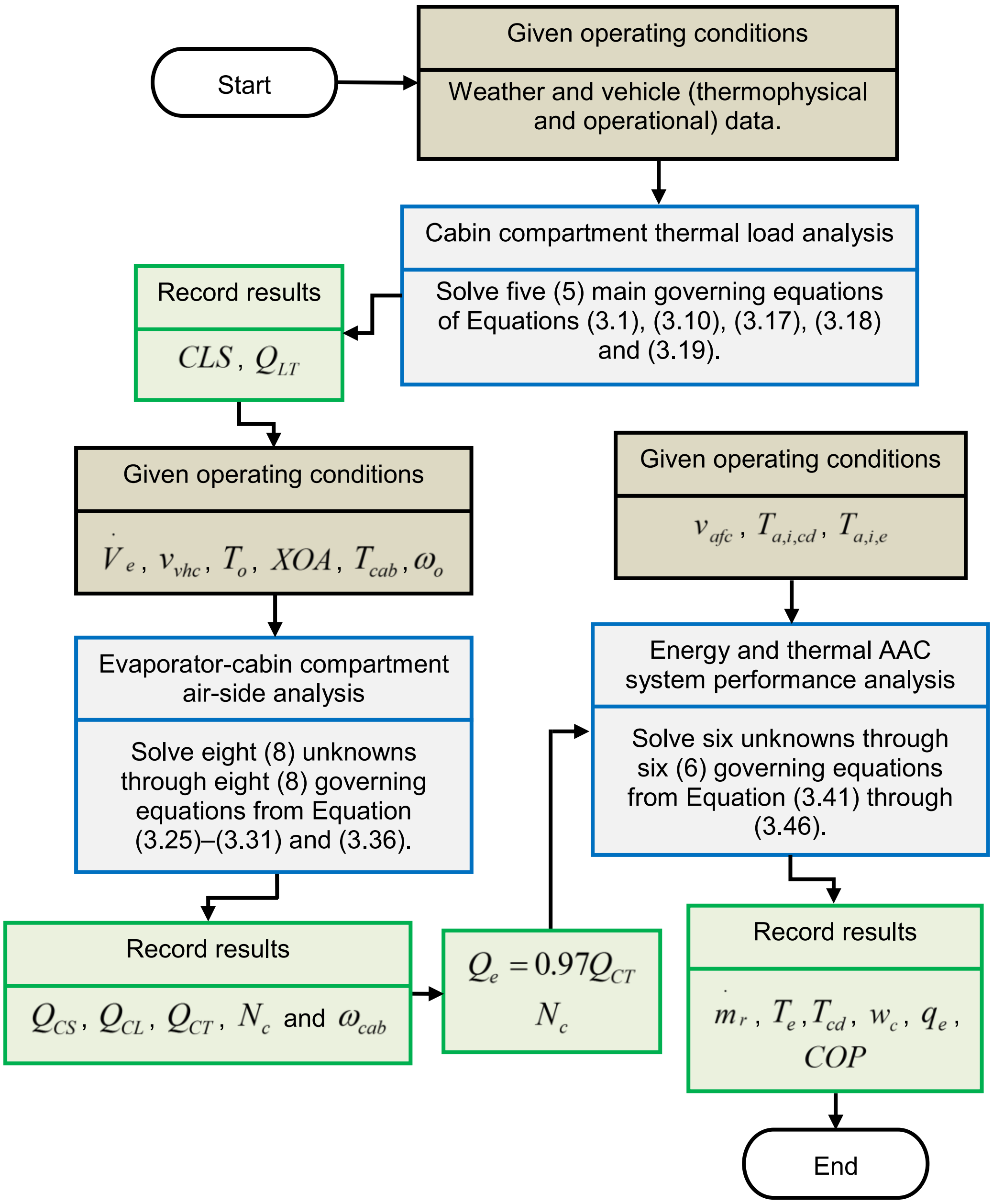


Figure 3.8 Integrated simulation compartment with thermal and energy performance of automotive air-conditioning system

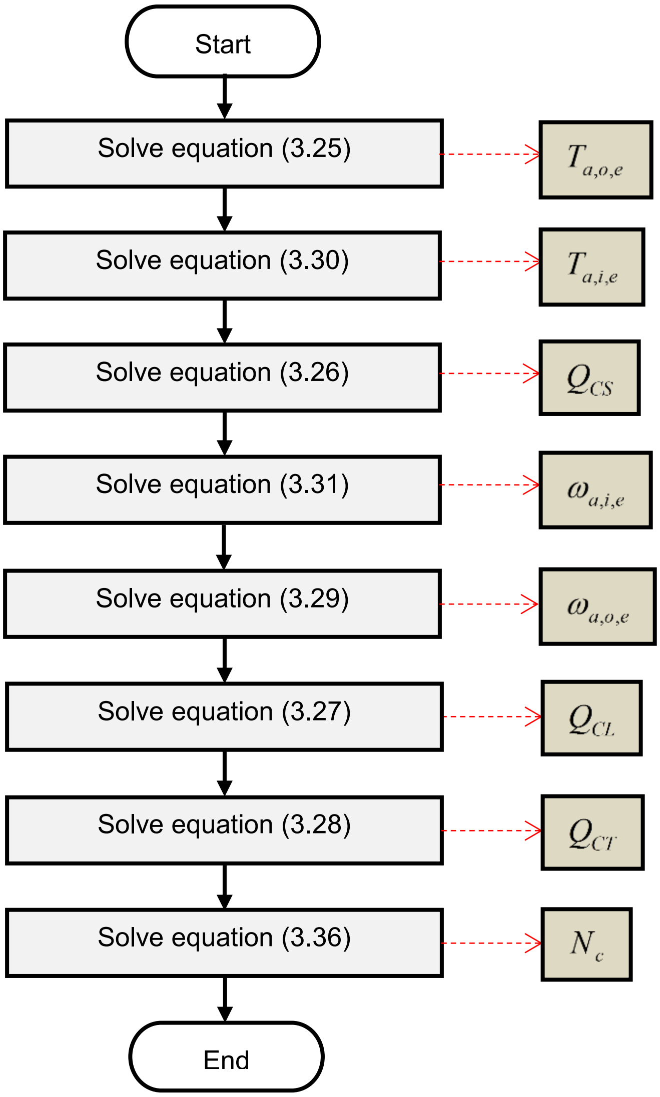


Figure 3.9 Calculation procedures for evaporator and cabin compartment air-side analysis

3.4 Fabrication of Air-conditioning System Test Rig

The main components of the AAC system, i.e., compressor and EEV are selected according to possible maximum cooling load imposed to the cabin compartment as in Figure 3.10. The selection of the EEV and compressor are determined by matching/mapping the maximum cooling capacity (predicted from thermal load model) with compressor and EEV manufacturer data published in open literature. Details of the selection process and working principles of the system are described in Chapter 4.

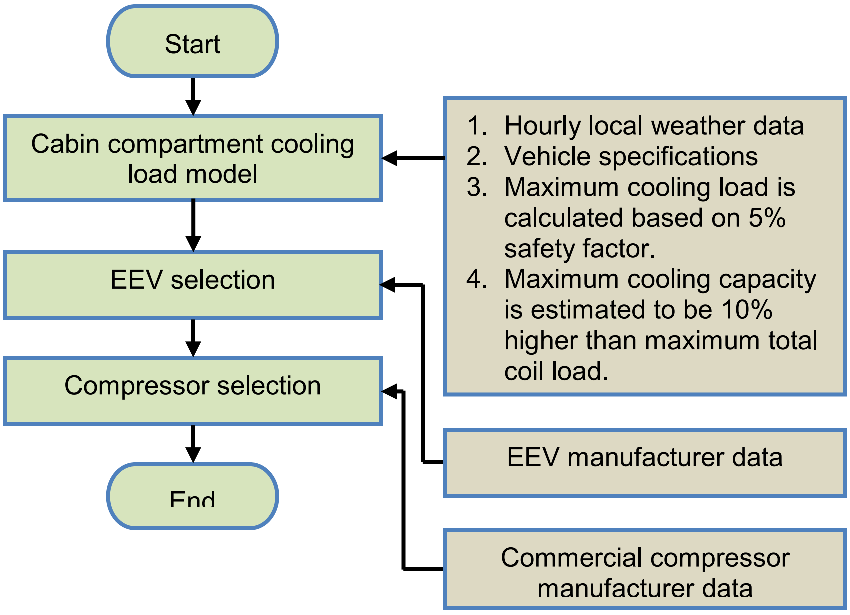


Figure 3.10 Flow chart of component selection methodology for experimental test rig

3.5 Experimental Work

All experimental studies are conducted in a steady-state condition. The purpose of this experimental work is to find experimental data for fitting correlations of Equations (3.36) and (3.43)–(3.46). The experimental work is explained in detail in Chapter 4.

3.6 Data Mining

The type of data collected is quantitative-based data with discrete upper and lower values. Data are collected by means of TC-08 USB data logger for temperature and data acquisition module for refrigerant pressure. Data for air velocity and refrigerant mass flow rate are collected manually using air flow and refrigerant mass flow rate meters, respectively. In addition, a DC meter from an AC/DC converter is used to measure input compressor power (compressor work).

3.7 Data Analysis and Accuracy Check

The quality of the data is checked through a statistical method of means, variance, and standard deviation. In addition, uncertainty analysis is conducted to check the accuracy of the results. Furthermore, a method of multilinear regression using standard regression method is adopted to fit four power equations, namely, Equations (3.31)–(3.34).

3.8 Verification or Validation of Results

The results for cabin compartment thermal load profile are verified with results published by previous researchers. Meanwhile, results from the experimental approach are validated with previous results published by other researchers before the experimental data are used for the development of empirical correlations. These data-driven correlations are required to complete the proposed performance simulation model.

CHAPTER 4

EXPERIMENTAL SETUP

4.1 Introduction

This section describes two main aspects; system component selection and experimental work. The section of system component selection explains the selection process of four primary components for the AAC system experimental test rig, that is, compressor, heat exchangers (evaporator and condenser), and expansion valve. The section of experimental work explains the specification of the experimental test rig apparatus, variables measuring method, accuracy and uncertainty of measurement, experimental procedure, validation of experimental results and development of empirical correlations obtained from experimental data.

4.2 System Component Selection

The selection of the electric compressor and expansion valve is obtained from the cabin compartment thermal load mathematical model. The cabin compartment thermal load mathematical model is described in Section 3.3.1. Accordingly, this section begins by verifying the cabin compartment thermal load mathematical model, followed by the selection process of the electric compressor and expansion valve using this model. The heat exchangers (evaporator and condenser) utilized from the original components of the AAC system for the 1.6 L Proton Wira Aeroback passenger car are discussed in the following sub-section.

4.2.1 Verification of Cabin Compartment Thermal Load Mathematical Model

Mohamed Kamar (2008) reported a coil load profile equipped with a single blower for a 1.6 L Proton Wira Aeroback between 11.00 am and 1.00 pm for days in November/December. To validate the proposed model, the same reference as Mohamed Kamar (2008) is chosen. The details of this comparison are shown in Table 4.1. Weather data for the present work are tabulated in Table 4.2. The 1.6 L Proton Wira Aeroback passenger car thermophysical data as in Table 4.3 are utilized with additional inside and outside air layers.

Table 4.1 Reference work by Mohamed Kamar (2008) and present work

Parameters	Mohamed Kamar (2008)	Present work
Method	Dynamics TFM with thermal storage effect	Steady-state cooling load with heat balance concept
Vehicle specification	1.6 L Proton Wira Aeroback	1.6 L Proton Wira Aeroback
Number of passengers	1 (driver)	1 (driver)
Vehicle orientation	Front windscreen facing East	Front windscreen facing East
Selected day	November/December	November/December
v_{vhc} (km/h)	90	90
Vehicle surface color	Yellow $(\alpha = 0.5)$	Dark $(f/f_o = 0.052)$
T_{cab} (°C) and ϕ_{cab} (%)	18.6°C, 47.3% (11.00 am), 18.8°C, 47.5% (12.00 pm), 18.6°C, 47.6% (1.00 pm)	18.6°C, 47.3% (11.00 am), 18.8°C, 47.5% (12.00 pm), 18.6°C, 47.6% (1.00 pm)

Table 4.2 Compressed Singapore weather data for typical day six (Nov/Dec): frequency = 61 days (Senawi, 1998)

Parameters	Time of day (hours past midnight)		
	11	12	13
T_o (°C)	28	29	29
T_{wb} (°C)	19	19	19
IDH $(\mathrm{W/m^2})$	252	229	197
Idh $(\mathrm{W/m^2})$	260	291	289

Figure 4.1 shows a comparison between the results on the calculated cooling load of the present work and the results obtained by Mohamed Kamar (2008). Generally, cooling load calculated based on present work is approximately less than 5% as reported by Mohamed Kamar (2008) mainly because of the different methods used and the thermal storage effect. Revised cooling load is calculated by adding 5% heat to the sensible and latent heats as proposed by Arora (2009).

Table 4.3 Material specifications of 1.6 L Proton Wira Aeroback passenger car (Mohamed Kamar, 2008)

<table>
<tr><th>Vehicle section</th><th>Layers/ Materials</th><th>A (m^2)</th><th>δ (mm)</th><th>Σ $(°)$</th><th>k $(W/m \cdot K)$</th><th>R $(m^2 \cdot K/W)$</th><th>U $(W/m^2 \cdot K)$</th></tr>
<tr><td rowspan="7">Front and rear wall/ door</td><td>Outside air</td><td rowspan="7">1.75</td><td>-</td><td rowspan="7">90</td><td>-</td><td>0.0134</td><td rowspan="7">1.298</td></tr>
<tr><td>Sheet metal</td><td>0.8</td><td>89</td><td>8.9888E-6</td></tr>
<tr><td>Air space</td><td>-</td><td>-</td><td>0.16</td></tr>
<tr><td>Plastic</td><td>0.2</td><td>0.1</td><td>0.002</td></tr>
<tr><td>Wood</td><td>4.0</td><td>0.115</td><td>0.0348</td></tr>
<tr><td>Rubber + fabric</td><td>-</td><td>-</td><td>0.217</td></tr>
<tr><td>Inside air</td><td>-</td><td>-</td><td>0.343</td></tr>
<tr><td rowspan="3">Front wall</td><td>Outside air</td><td rowspan="3">2.44</td><td>-</td><td rowspan="3">90</td><td>-</td><td>0.0134</td><td rowspan="3">2.806</td></tr>
<tr><td>Sheet metal</td><td>0.8</td><td>89</td><td>8.9888E-6</td></tr>
<tr><td>Inside air</td><td>-</td><td>-</td><td>0.343</td></tr>
<tr><td rowspan="7">Rear wall</td><td>Outside air</td><td rowspan="7">0.44</td><td>-</td><td rowspan="7">90</td><td>-</td><td>0.0134</td><td rowspan="7">0.241</td></tr>
<tr><td>Sheet metal</td><td>0.8</td><td>89</td><td>8.9888E-6</td></tr>
<tr><td>Air space</td><td>-</td><td>-</td><td>0.16</td></tr>
<tr><td>Fabric</td><td>-</td><td>-</td><td>0.07</td></tr>
<tr><td>Foam</td><td>150</td><td>0.043</td><td>3.4884</td></tr>
<tr><td>Fabric</td><td>-</td><td>-</td><td>0.07</td></tr>
<tr><td>Inside air</td><td>-</td><td>-</td><td>0.343</td></tr>
<tr><td rowspan="6">Floor</td><td>Outside air</td><td rowspan="6">2.33</td><td>-</td><td rowspan="6">0</td><td>-</td><td>0.0134</td><td rowspan="6">2.220</td></tr>
<tr><td>Metal</td><td>5</td><td>89</td><td>0.0056</td></tr>
<tr><td>Plastic</td><td>-</td><td>-</td><td>0.04</td></tr>
<tr><td>Fabric</td><td>-</td><td>-</td><td>0.01</td></tr>
<tr><td>Rubber</td><td>5</td><td>0.13</td><td>0.0385</td></tr>
<tr><td>Inside air</td><td>-</td><td>-</td><td>0.343</td></tr>
<tr><td rowspan="6">Roof</td><td>Outside air</td><td rowspan="6">1.96</td><td>-</td><td rowspan="6">0</td><td>-</td><td>0.0134</td><td rowspan="6">1.814</td></tr>
<tr><td>Sheet metal</td><td>0.8</td><td>89</td><td>8.9888E-6</td></tr>
<tr><td>Air space</td><td>-</td><td>-</td><td>0.16</td></tr>
<tr><td>Wood board</td><td>3.2</td><td>0.115</td><td>0.0278</td></tr>
<tr><td>Nylon fabric</td><td>-</td><td>-</td><td>0.007</td></tr>
<tr><td>Inside air</td><td>-</td><td>-</td><td>0.343</td></tr>
</table>

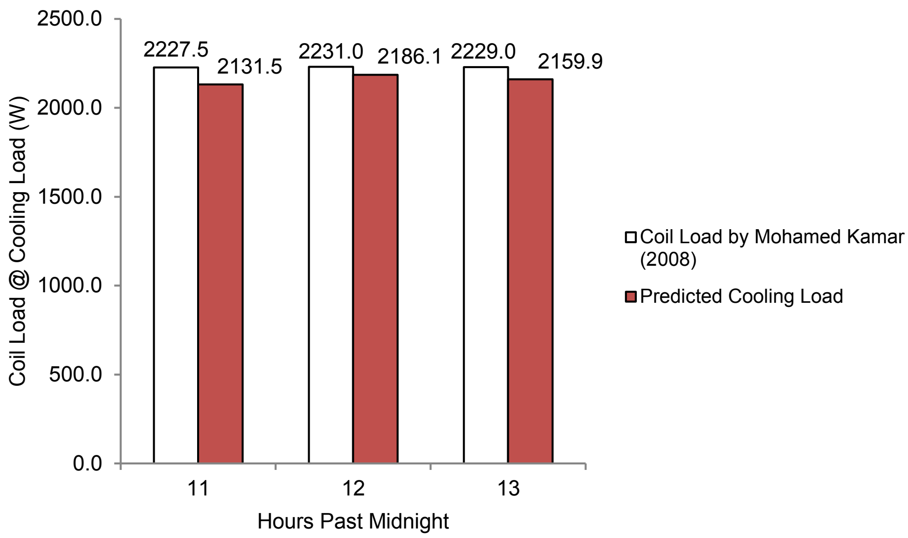


Figure 4.1 Comparison between present work and previous work by Mohamed Kamar (2008)

As shown in Table 4.4, an excellent agreement is noticeably achieved between the results of the present work and the numerical findings of Mohamed Kamar (2008), with differences of 4.31%, 2.01%, and 3.10% for 11.00 am, 12.00 pm, and 1.00 pm, respectively.

Table 4.4 Percentage difference between present and previous work by Mohamed Kamar (2008)

Hours past midnight	Coil load or Cooling capacity (W)		Difference (%)
	Mohamed Kamar (2008)	Present work	
11	2227.5	2131.5	4.31
12	2231.0	2186.1	2.01
13	2229.0	2159.9	3.10

4.2.2 Maximum Designed Cooling Capacity Estimation

The maximum cooling capacity estimation for the new AAC system development is a crucial task that necessitates correct sizing of the system. A wrong estimation can lead to oversizing, high capital cost, over cooling (thermal discomfort and inefficient energy usage), and unnecessary extra vehicle weight. Meanwhile, undersizing leads to inadequate cooling, which is also related to thermal discomfort and inefficient energy usage.

In this chapter, the capacities of the electric compressor and EEV for the AAC system experimental rig are selected according to the possible maximum cooling capacity imposed on the cabin compartment. The cooling capacity calculation methodology is illustrated in Figure 4.2. Given that the sun moves from East to West from morning to afternoon hours with different exterior vehicle surfaces, that is, glass and composite door/wall, roof and floor; vehicle orientation consequently becomes one of the main parameters that significantly affect the amount of cooling load imposed on the cabin compartment. Therefore, the maximum cooling capacity is determined from the hourly cooling capacity profile on six typical days of the year, while considering where the front windscreen is facing with the four different orientations as basis, namely, North, East, South, and West (for simplification).

Given that MS 1525:2007 recommends a dry bulb temperature of 23–26°C and relative humidity of less than 70% for human thermal comfort (Malaysian Standard Department, 2007), the maximum cooling capacity was calculated with the designed cabin temperature and humidity ratio of 24°C and 50%, respectively. Furthermore, the enveloping dark color of the vehicle, vehicle speed of 110 km/h, and four passengers including a driver, are further considered for possible maximum designed cooling capacity. The maximum cooling capacity is further calculated based on the standard vehicle specifications of the 1.6 L Proton Wira Aeroback passenger car. The vehicle specifications are shown in Table 4.3.

Subsequently, designed maximum cooling capacity is estimated at 5% higher than the designed maximum cooling load. The latter is predicted based on the steady state cabin compartment thermal load mathematical model as described in Chapter 3, with 5% safety factor as proposed by Arora (2009). The EEV and compressor are selected by matching/mapping the maximum cooling capacity with the compressor and EEV manufacturer data published in the open literature as shown in Figure 4.2.

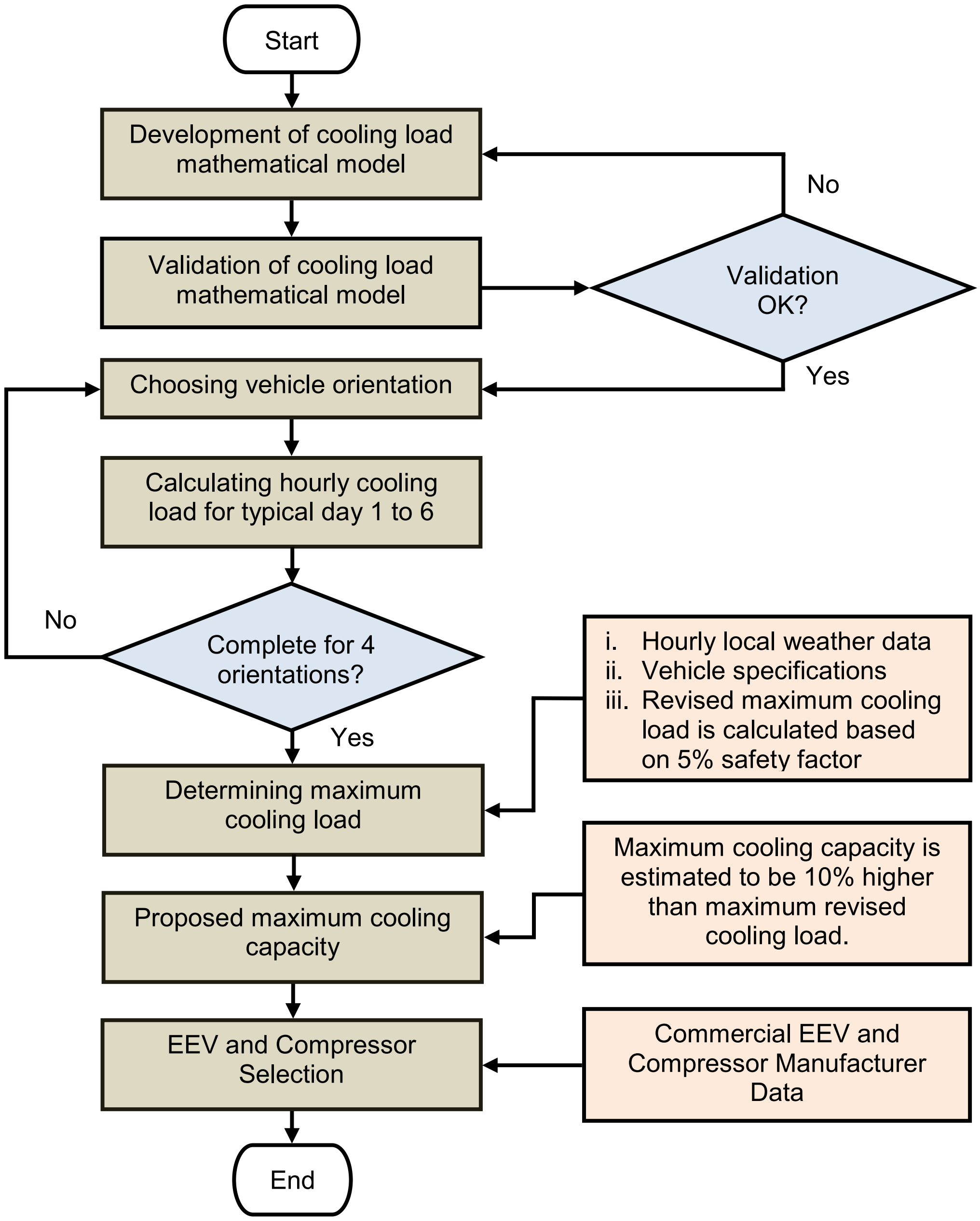


Figure 4.2 EEV and compressor selections methodology flow chart

Considering that the latest comprehensive weather data are unavailable in the open literature, this study used the compressed Singapore weather data for six typical days, which were as highlighted by Senawi (1998), as input data as shown in Appendix A. Such data are selected because of the small difference in longitude and latitude between Malaysia and Singapore and the less than 2°C dry-bulb temperature difference compared with the actual maximum–minimum daily 2011 Singapore weather data available from the National Environment Agency website (National Environment Agency, 2013), as shown in Table 4.5.

Table 4.5 Comparisons between compressed data and actual 2011 Singapore weather data

Typical Days	Compressed Singapore Weather Data (Senawi, 1998)		Actual 2011 Singapore Weather Data (National Environment Agency, 2013)		Differences	
	Maximum T_{db} (°C)	Minimum T_{db} (°C)	Mean Maximum T_{db} (°C)	Mean Minimum T_{db} (°C)	Maximum T_{db} (°C)	Minimum T_{db} (°C)
Day 1	29	24	30.7	23.8	1.7	-0.2
Day 2	30	25	31.6	24.3	1.6	-0.7
Day 3	30	25	31.9	25.2	1.9	0.2
Day 4	30	25	31.5	25.6	1.5	0.6
Day 5	30	25	31.0	24.9	1.0	-0.1
Day 6	29	24	30.5	24.6	1.5	0.6

One of the major contributors to the vehicle cooling load is solar radiation. The exterior surfaces exposed to direct sunlight will experience high surface temperature, thereby creating higher heat transfer rate to the cabin compartment. The heat transfer rate becomes much higher if the exterior surface is made of glass, such as the front and rear windscreens and side windows, as found by Sukri *et al*. (2012).

Figures 4.3 to 4.6 show the hourly cooling capacity profile for six typical days with front windscreen facing North, East, South, and West, respectively. The cooling capacity is low in the early morning hours, gradually increasing to a maximum between 12 noon to 1 pm, and then slowly decreasing to approximately its initial value. The highest cooling capacity typically occurs between 12.00 noon to 1.00 pm. Figures 4.3 to 4.6 further show that the hourly cooling capacity profiles for all four orientations are nearly identical. This finding is due to the continuing effect of all exterior surfaces of the right and left doors and windows, front and rear windscreens, floor and roof, to contribute to the conductive/convective heat loads despite the change in orientation. Therefore, the weakest exterior surfaces exposed to direct solar radiation at critical hours, lead to the highest cooling capacity required by the cabin compartment. Critical hours are defined as the hour where T_o, IDH, and Idh are high. As shown in Figures 4.3 to 4.6, the highest required cooling capacity is 2.896 kW, when the front windscreen is facing South at 1.00 pm.

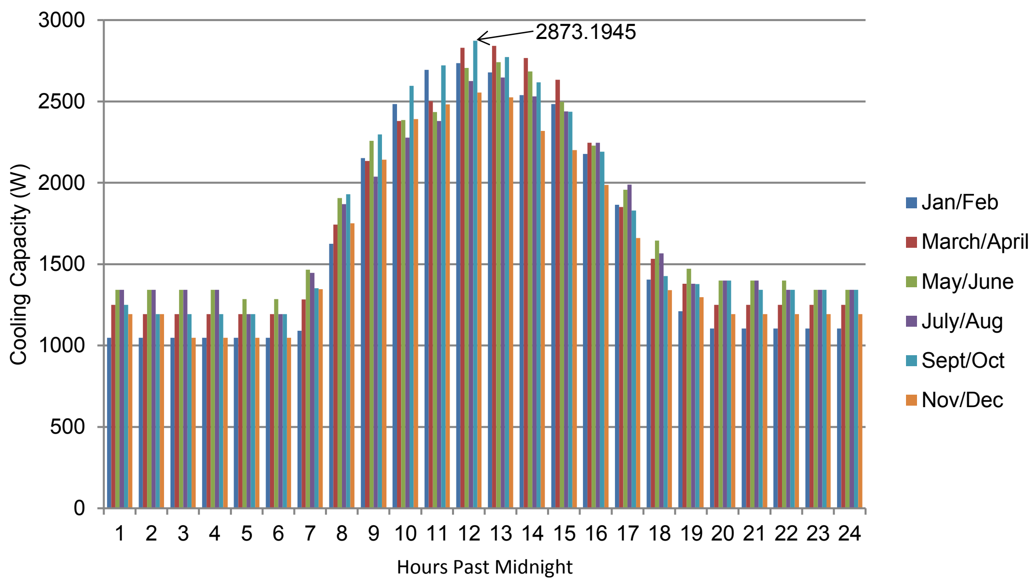


Figure 4.3 Cooling capacity profile when front windscreen is facing North

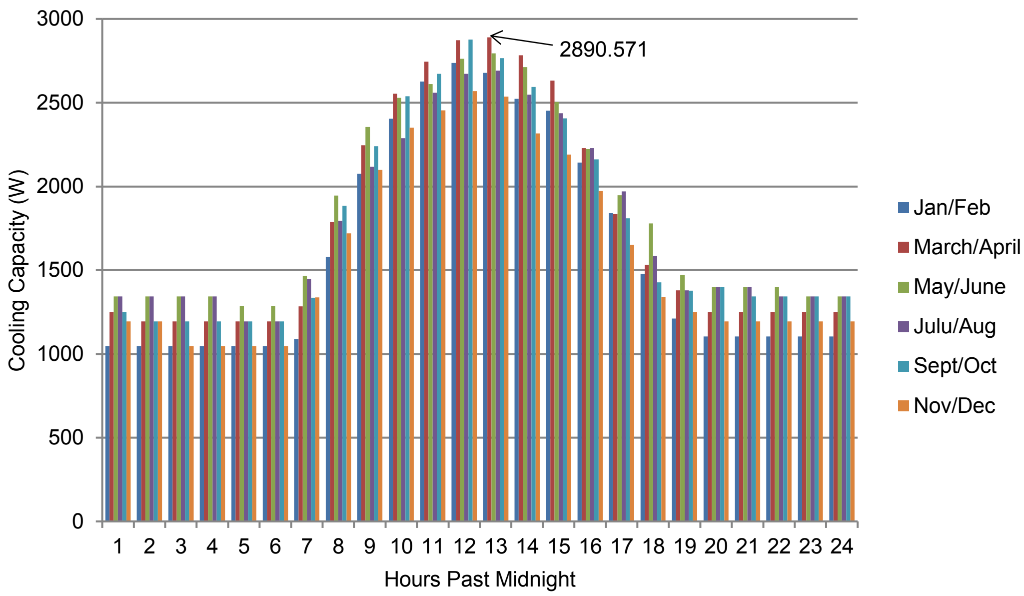


Figure 4.4 Cooling capacity profile when front windscreen is facing East

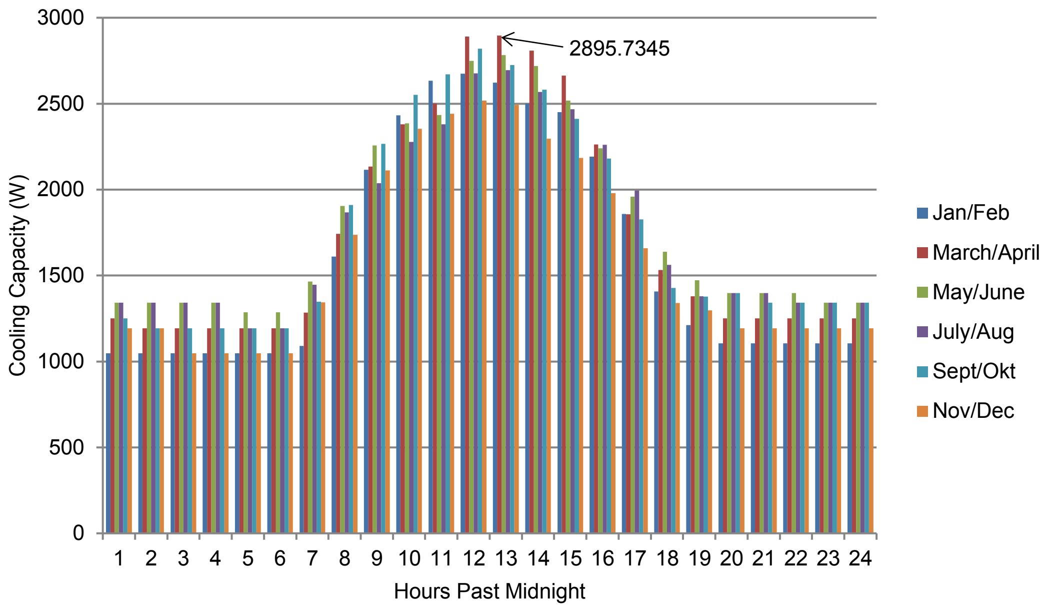


Figure 4.5 Cooling capacity profile when front windscreen is facing South

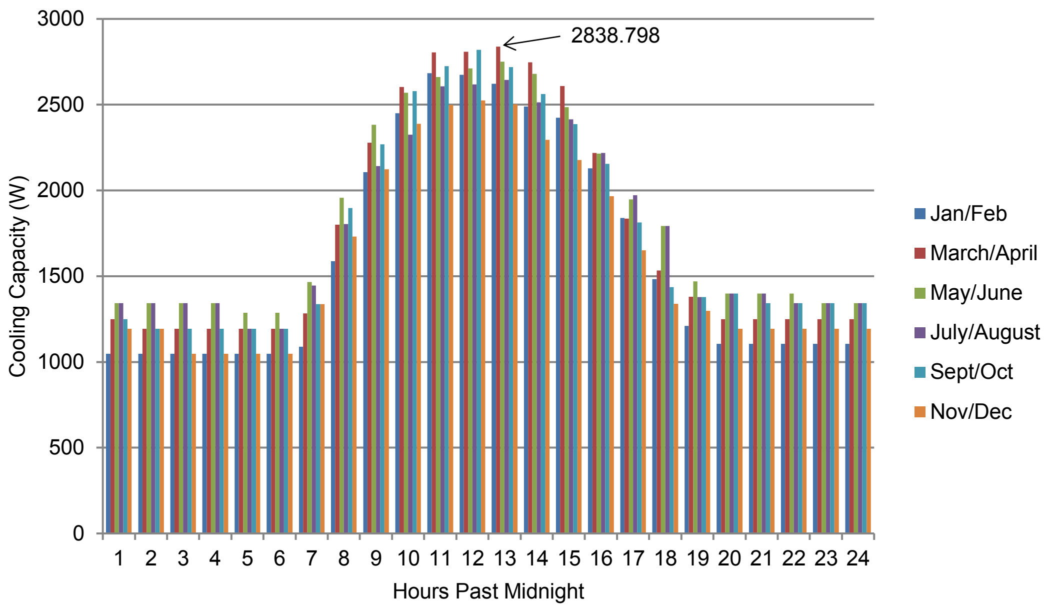


Figure 4.6 Cooling capacity profile when front windscreen is facing West

4.2.3 Compressor and Motor Controller

The selected compressor unit is from a high-voltage brushless DC variable speed hermetic compressor, type SIERRA06-0982Y3, as shown in Figure 4.7. According to manufacturer technical data as in Appendix C, this compressor can produce a cooling capacity between 967 W to 5401 W at evaporating temperature of 4°C to 13°C, compressor input voltage of 150 VDC to 300 VDC, and compressor speed of 1800 rpm to 6500 rpm, respectively. This compressor is selected given that the designed maximum cooling capacity of 2896 W is in the compressor output range. The compressor is powered by a custom-made 5 kW AC/DC power supply. This power supply can support up to 350 VDC and the current up to 15 ADC.

Figure 4.7 SIERRA06-0982Y3 high-voltage brushless DC compressor (Masterflux, 2013a)

The 025F0140-03 motor controller as shown in Figure 4.8 is used to provide efficient control and fault monitoring of the compressor. The controller provides a constant speed as specified by the speed command inputs, unless one of the following limitations are exceeded: average power limitation of 2500 W and voltage limitation between 100V and 450V, as shown in Table 4.6.

Figure 4.8 025F0140-03 motor controller

Table 4.6 025F0140-03 motor controller operating conditions

Parameter	Minimum	Maximum
Input power (VDC)	120	420
V_M low-voltage shutdown (VDC)	100	120
V_M high-voltage shutdown (VDC)	420	450

Run/Stop and speed are controlled by a 0 V to 5 V analog input. When the speed input is less than 1 V, the motor stops. When the analog input is 1 V, the motor runs at 1800 rpm. When the analog input is 5 V, the motor runs at 6500 rpm. When the controller is commanded to run from a stopped condition, it runs the motor at 3000 rpm for 30 seconds; thereafter, it reaches a point where it runs the motor at the commanded input speed.

The fault conditions of under/over voltage, over-current, drive over-temperature, pump over-temperature, low speed, and locked rotor are monitored continuously by the motor controller. Upon detection of a fault, the controller shuts down the motor. Depending on the cause of the fault, the controller may pause to allow time for the fault to clear, and then, restarting the motor is attempted.

Two one-position screw lug connectors are provided to connect the input power to the controller. Three one-position screw lug connectors provide connection to the motor outputs for the compressor. A two-position locking connector is supplied to connect to the shell temperature switch from the compressor. The isolated control and indicator signals connect to an eight-pin locking Molex header. Each connector function is labeled on the printed circuit board. Furthermore, the motor drive transistor assembly is cooled by a large aluminum-finned heat sink. The heat sink is electrically isolated from the circuitry. A temperature sensor embedded in the power assembly measures the module temperature.

4.2.4 Electronic Expansion Valve

The refrigerant flow control strategy is used to let the refrigerant being circulated in the AAC pipeline circuit through 100% of the valve opening at all times. However, the selection of EEV with appropriate controller enables the valve to operate at various control strategies in the future.

The Danfoss EEV model no. ETS 6–14 (Figure 4.9) with nominal capacity of 4.5 kW for refrigerant R134a, as shown in Figure 4.10, is chosen as the EEV of the AAC system. This nominal capacity is acceptable for the maximum designed cooling capacity of 2.89 kW.

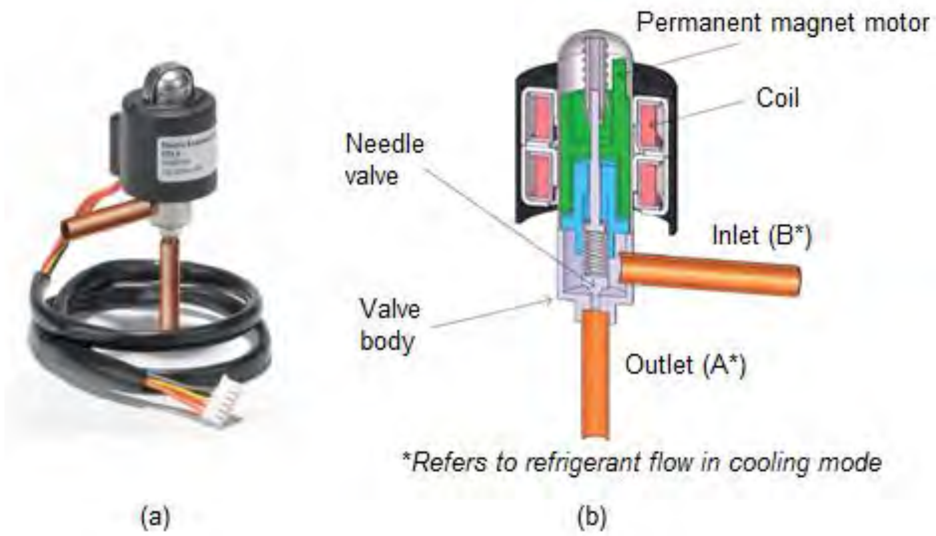
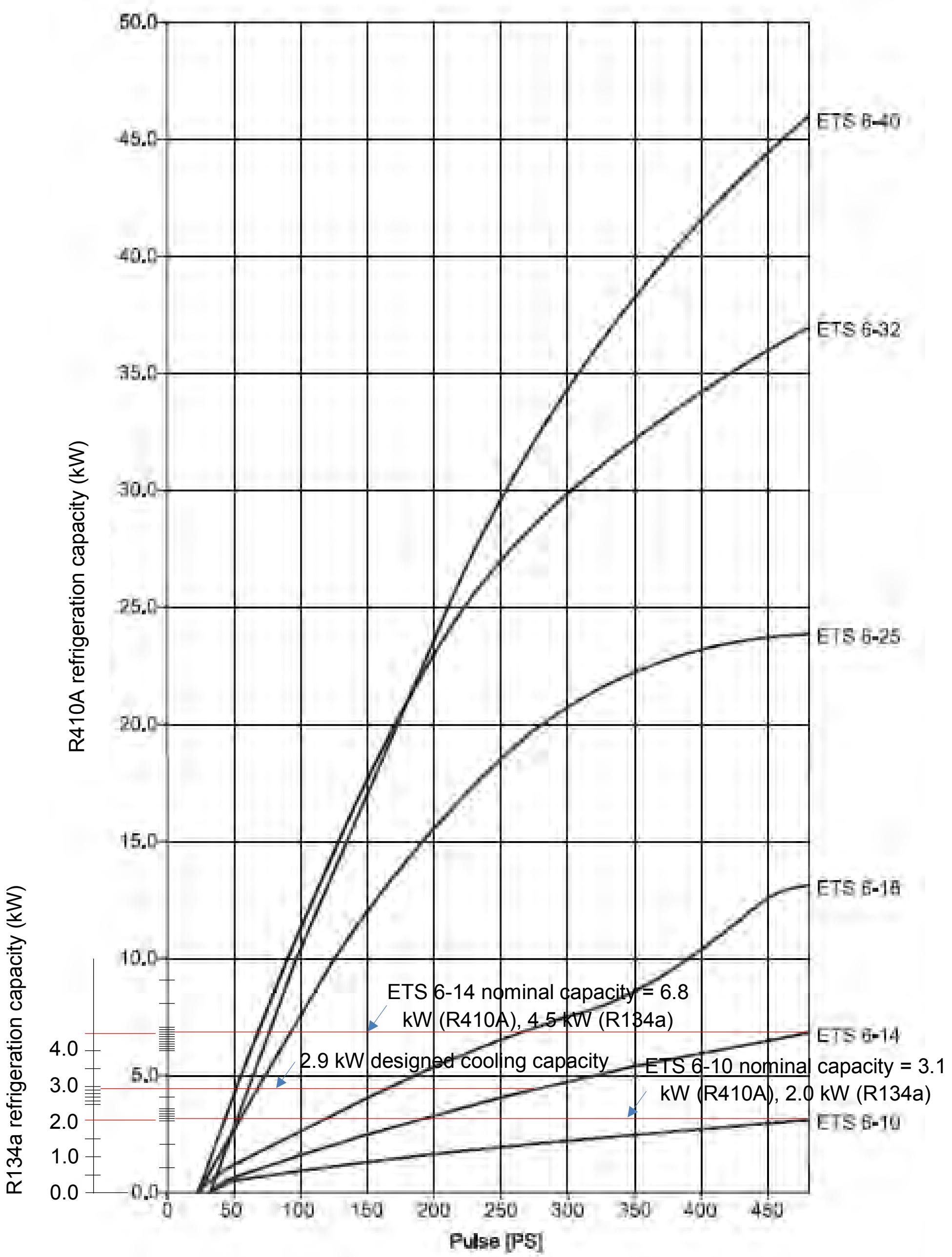


Figure 4.9 Danfoss EEV model no. ETS 6. (a) actual view (b) cross-sectional view (Danfoss Group, 2013)

For an EEV to work properly, a Danfoss pressure sensor type AKS32R measuring the evaporator pressure and a Danfoss temperature sensor type AKS21A, which measures the refrigerant temperature, are used as proposed by Danfoss. The Danfoss superheat controller type EIM 336 is further used in this AAC system as a controller, with the Danfoss programmable controller type MMIMYK used as the gateway. Arrangements of all components are presented in Figure 4.11.



Conditions: T_e = 5°C, T_c = 38°C, Subcooling = 0°C, Superheat = 0°C

Figure 4.10 Refrigerant capacity at different numbers of pulses for Danfoss EEV, model ETS 6, modified from Danfoss (2013)

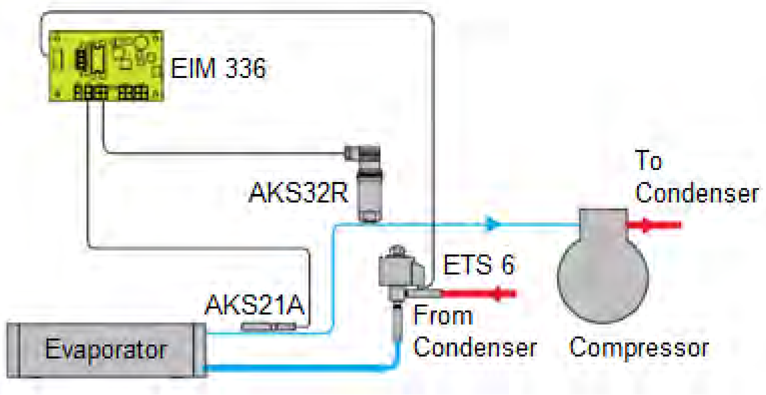


Figure 4.11 Arrangements of ETS 6, EIM 316, AKS32R, and AKS21A in developed system (Danfoss Group, 2013)

4.2.5 Heat Exchangers

The original heat exchangers (evaporator and condenser), internal and external fans, and secondary components, namely, receiver drier and sight glass of actual/standard AAC system of the 1.6 L Proton Wira Aeroback are used in fabricating the experimental test rig. The original drawn cup-type evaporator is equipped with a variable speed internal fan and four air outlet vents. Meanwhile, the original condenser is a three-pass type, equipped with a standard external fan. The cross-sectional areas of the evaporator and condenser coils are 0.034 m^2 and 0.218 m^2, respectively.

4.3 Experimental Work

Complete simulation of VCRC of AAC system of a passenger vehicle requires the performance data of the air-side evaporator coil, which can be obtained using Equation (3.36), and those of the refrigerant-side AAC system, which can be obtained using Equations (3.43)–(3.46). Lee and Yoo (2000), Shao *et al*. (2004), Mohamed Kamar (2008), and Navarro-Esbrí *et al*. (2010) obtained their data for system modeling from experimental data. This method significantly reduces the complexity of the model and increases the accuracy of the results for the proposed system. Similarly, the actual performance data of the air-side evaporator coil and refrigerant-side VCRC of the AAC system in this study are obtained through experimental work.

4.3.1 Description of Air-conditioning Experimental Test Rig Apparatus

The test rig is mounted on an actual 1.6 L Proton Wira Aeroback. This type of vehicle is chosen because of its AAC system represent the AAC system for medium size of passenger vehicles available on road, beside cost effective in the development and fabrication of the experimental test rig. Figure 4.12 shows the actual AAC experimental test rig. The schematic of the experimental test rig is shown in Figure 4.13. Specifications of all instrumentations used in the experimental test facility are shown in Table 4.7. The table also provides information on operating range and systematic uncertainty, based on the data of the manufacturer. For safety precaution, the experimental test rig is equipped with one Danfoss high/low pressure cut-off unit to monitor the high and low pressures of the compressor in the safety range of 2–14 bar of gauge pressure.

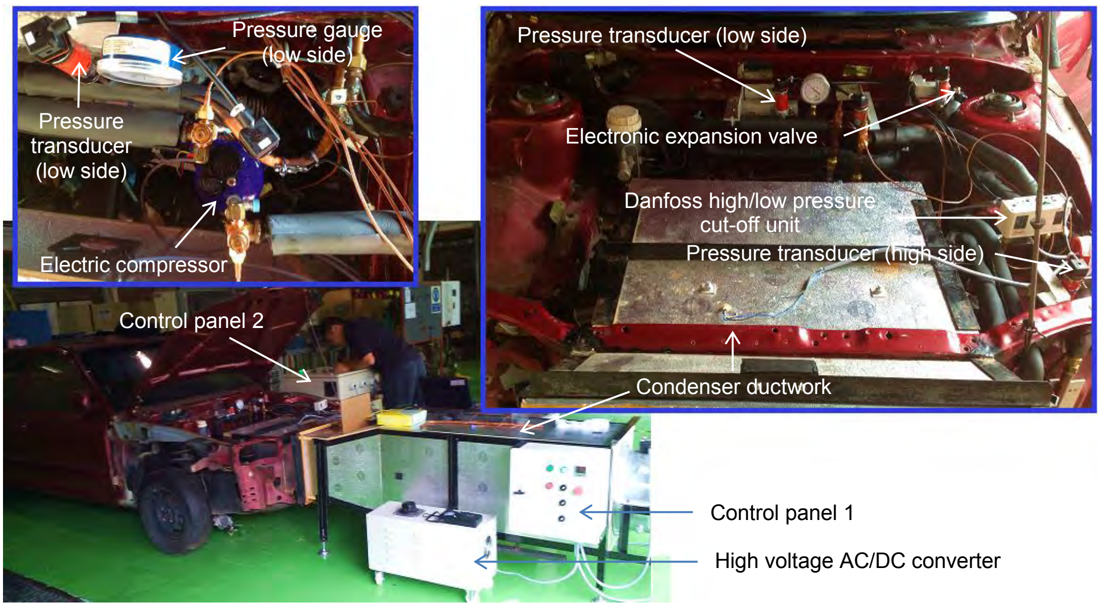


Figure 4.12 Actual AAC experimental test rig

Table 4.7 Specification of experimental instrumentations

Instrumentation	Manufacturer/Model	Measuring Range	Systematic Uncertainty
Refrigerant side			
Thermocouple	• *T*-Type with TC-08 USB Pico Data Logger	• -200:350°C	• ±0.75%
	• Danfoss/AKS11	• -50:100°C	• ±(0.3 + 0.005 T) @ ±0.5°C
Pressure transducer	• Danfoss/AKS32	• -1:24 bar	• ±0.3% FS (typical)/±0.8% FS (maximum)
	• Danfoss/AKS32R	• -1:9 bar	• ±0.3% FS (typical)/±0.8% FS (maximum)
Mass flow meter	• Platton/NGX	• 4:56 g/s	• ±1.25% FSD
Air side			
Thermocouple grid	• *T*-Type with TC-08 USB Pico Data Logger	• -200:350°C	• ±0.75%
Thermocouple (air sampling tube)	• *T*-Type with TC-08 USB Pico Data Logger	• -200:350°C	• ±0.75%
Air flow rate meter	• Fluke/923	• 0.20:20.00 m/s	• ±5% + 3 digit of reading or ±1% + 1 digit full scale
Humidity transducer	• -	• 0:90 RH	• ±3%
Compressor			
Current meter	• Hobut	• 0:15 A	• ±1.5%
Volt meter	• Hobut	• 0:300 V	• ±1.5%

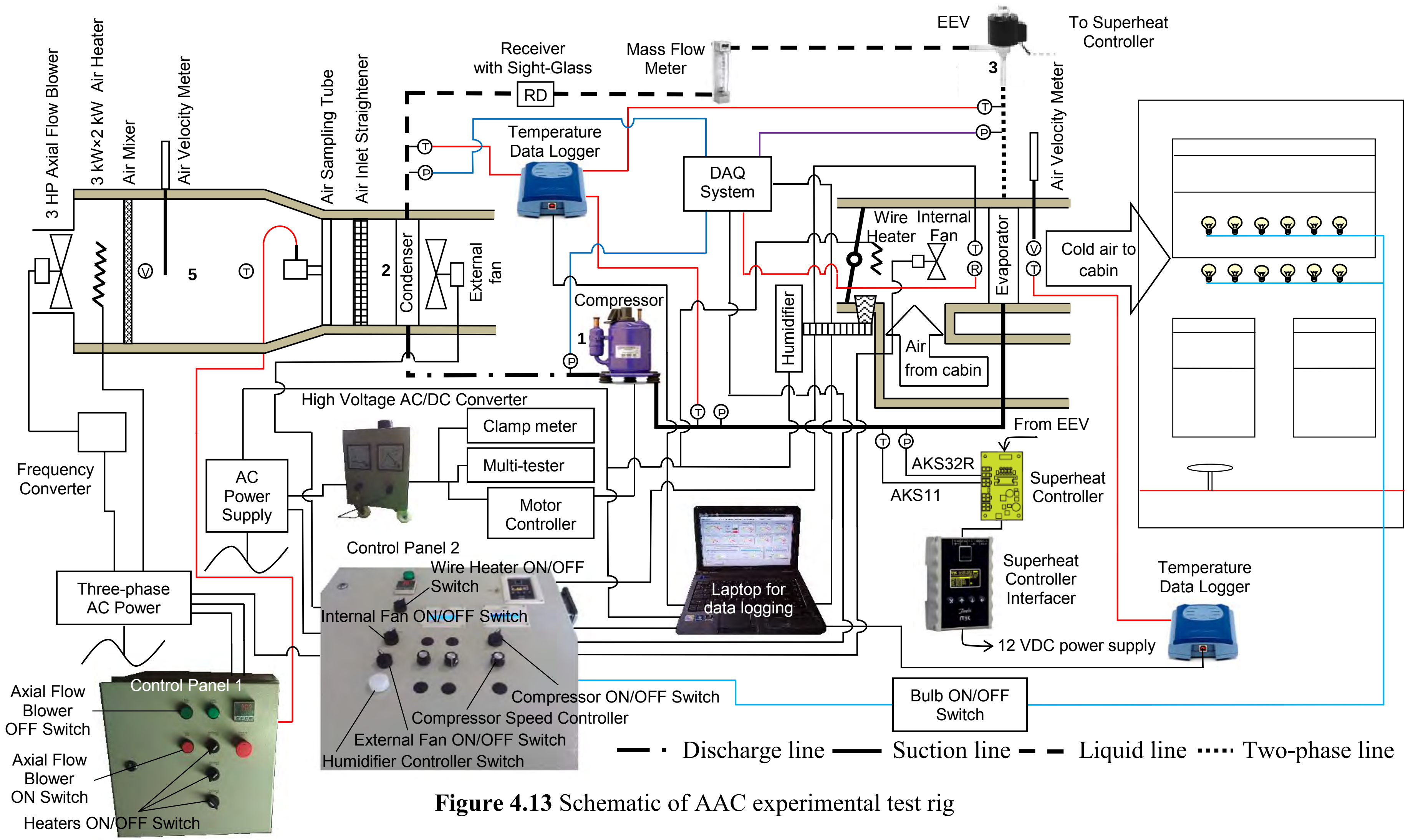


Figure 4.13 Schematic of AAC experimental test rig

4.3.1.1 Air Duct–Condenser Section

The effect of two independent operating variables related to the condenser section, namely, averaged condenser inlet air dry bulb temperature, $T_{a,i,cd}$, and averaged condenser air face velocity, v_{afc}, on the performance of the AAC system is considered. $T_{a,i,cd}$ and v_{afc} are measured at point 5 (Figure 4.13) and controlled to produce repeatable and comparable results as recommended by the Society of Automotive Engineers (SAE, 2008). The proposed setup of the condenser ductwork is shown in Figure 4.14.

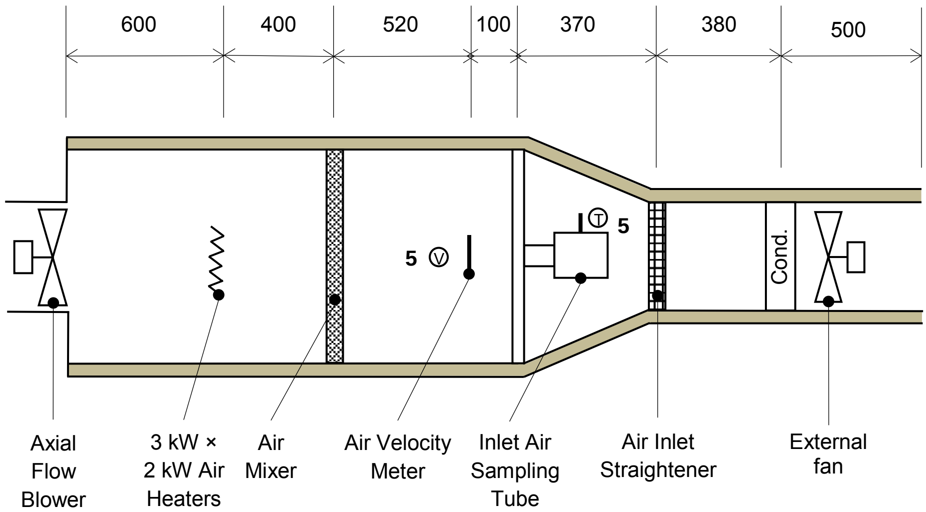


Figure 4.14 Different cross sections of air duct–condenser section with dimensions in mm

The duct is designed in an open tunnel, rectangular shaped, and made of 20 mm-thick insulation form (isoform type) with an overall length of 2870 mm. Air is forced through the ductwork using an upstream 3 HP axial flow blower. The air flow rate is controlled at desired value by manually adjusting the blower speed through an inverter motor drive. This procedure varies the v_{afc}. In addition, three units of 2-kW air heater are used to vary the $T_{a,i,cd}$. The axial flow blower and heater are powered by a three-phase electrical power source. The original condenser fan connected directly to a 12-VDC power supply is operated at all times.

To provide a uniform air flow through the face of the condenser, air mixer and honey comb-type air flow straightener are installed upstream of the condenser coil. However, velocity measurement data indicated that uniform air flow at the same point is not achieved with large difference between lower and upper limits. Therefore, the condenser ductwork should be improved in future research.

4.3.1.2 Air Duct–Evaporator Section

The original evaporator ductwork of 1.6 L Proton Wira Aeroback (Figure 4.15) is utilized as the experimental evaporator ductwork. It consists of three sections: blower, evaporator coil, and cold air distribution sections. The evaporator air volume flow rate is measured in the cold air distribution section, in the same location where the measurement of evaporator air outlet temperature is conducted. The evaporator air volume flow rate is controlled by controlling the percentage of energy input supplied to the fan.

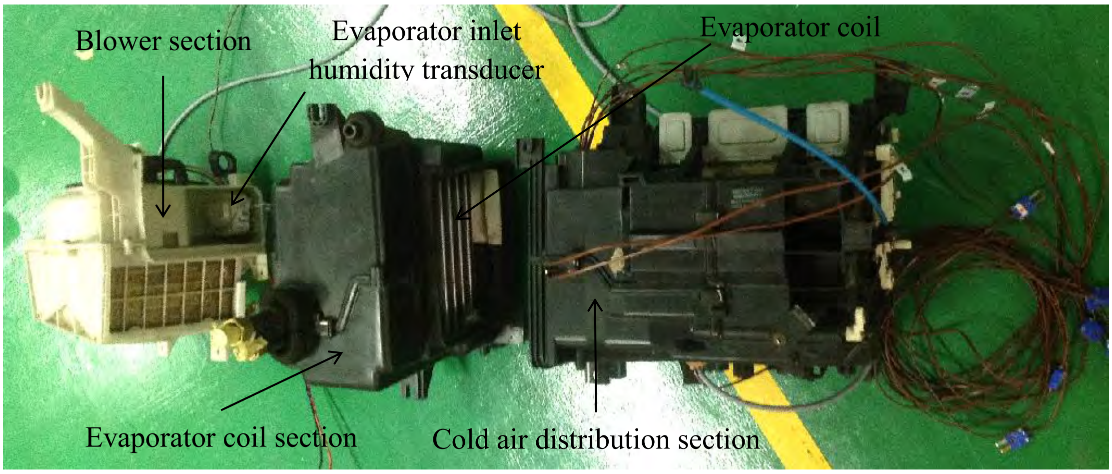


Figure 4.15 Evaporator ductwork

4.3.1.3 Airflow Measurement

The condenser air face velocity profile is measured in the condenser ductwork with cross-sectional area of 500 mm × 500 mm at point 5, as shown in Figure 4.13. The profile is measured according to the SAE International Surface Vehicle Standard "Procedure for Measuring System COP of a Mobile Air Conditioning System on a Test Bench" (Society of Automotive Engineers, 2008). To obtain an average velocity, the readings are collected by using a 923 Fluke hot-wire air velocity meter, placed successively at each measuring point from point A to I (at the same measuring plane) as shown in Figure 4.16. The 923 Fluke hot-wire air velocity meter is calibrated by the manufacturer and conformed for measurement processes. For each point, data are recorded for 5 min with an average of 10 s sampling time. A total of 30 data are recorded for each point. The data are tabulated in Appendix D.

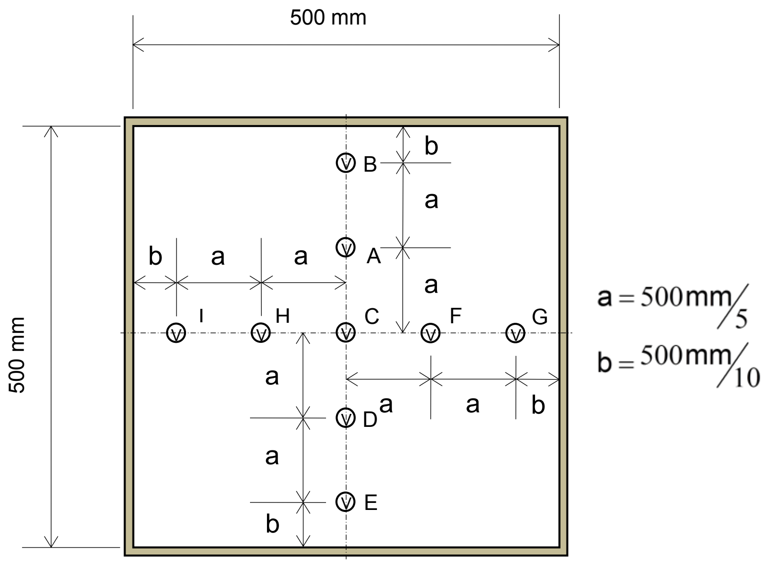
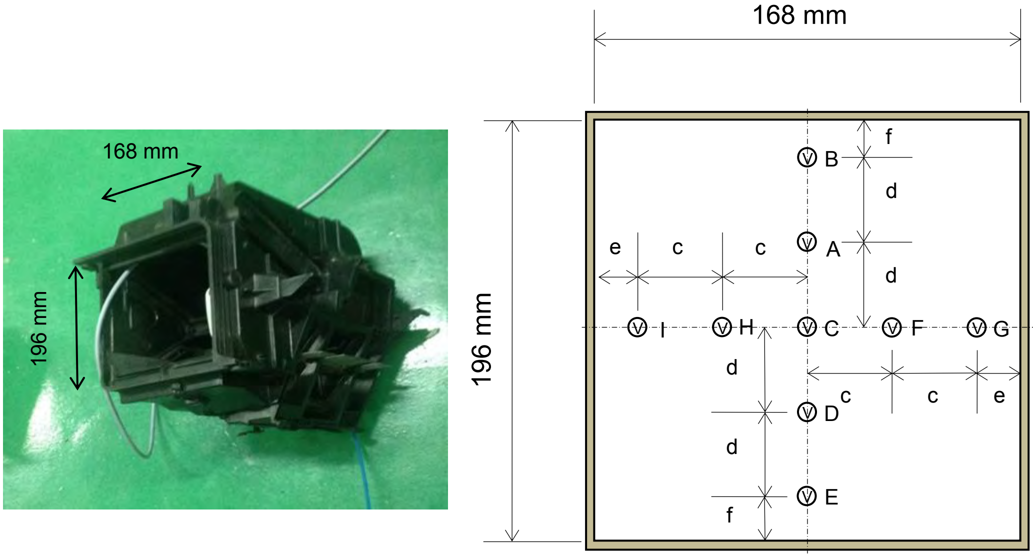


Figure 4.16 Condenser air face velocity measurement points

The evaporator air volume flow rate, $\dot{V}_e$, is measured at point 4 (Figure 4.13). At this point, the cross-sectional area of the original ductwork is 168 mm × 196 mm, as in Figure 4.17. The methodology adopted in measuring the averaged condenser air face velocity profile is also used in measuring the averaged evaporator air velocity.

The data are tabulated in Appendix E. The $\dot{V}_e$ is then calculated by multiplying the averaged evaporator air velocity, v_e, with its cross-sectional area. Thus,

$$\dot{V}_e = 0.032928\, v_e \qquad (\mathrm{m^3/s}) \tag{4.1}$$



$c = 168\text{mm}/5 ; d = 169\text{mm}/5$

$e = 168\text{mm}/10 ; f = 169\text{mm}/10$

Figure 4.17 Evaporator air velocity measurement points

Given that point sampling for each set of experimental work is time consuming, the relationships between averaged condenser air face velocity and frequency of the inverter motor drive, and between evaporator air volume flow rate and percentage of energy input, are obtained. Simple linear regression created using Microsoft Excel is used to yield correlations for condenser and evaporator ductworks. These correlations are shown in Figures 4.18 and 4.19.

The subsequent experiments are conducted by setting the input frequency of the inverter motor drive and percentage of energy input. The averaged air face velocity and averaged evaporator air volume flow rate are obtained from Equations (4.2) and (4.3), respectively.

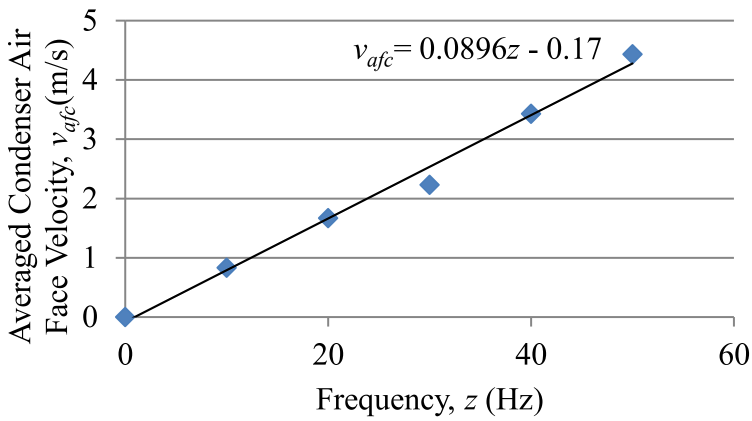


Figure 4.18 Liner regression between averaged condenser air face velocity and frequency

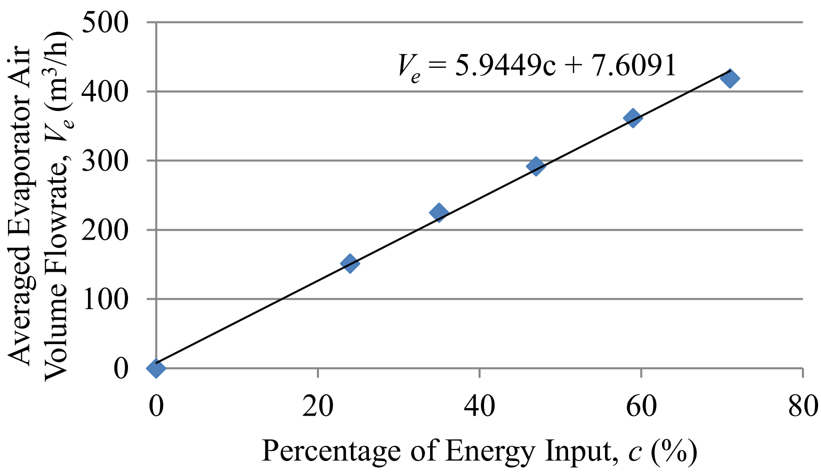


Figure 4.19 Linear regression between averaged evaporator air volume flow rate and percentage of energy input

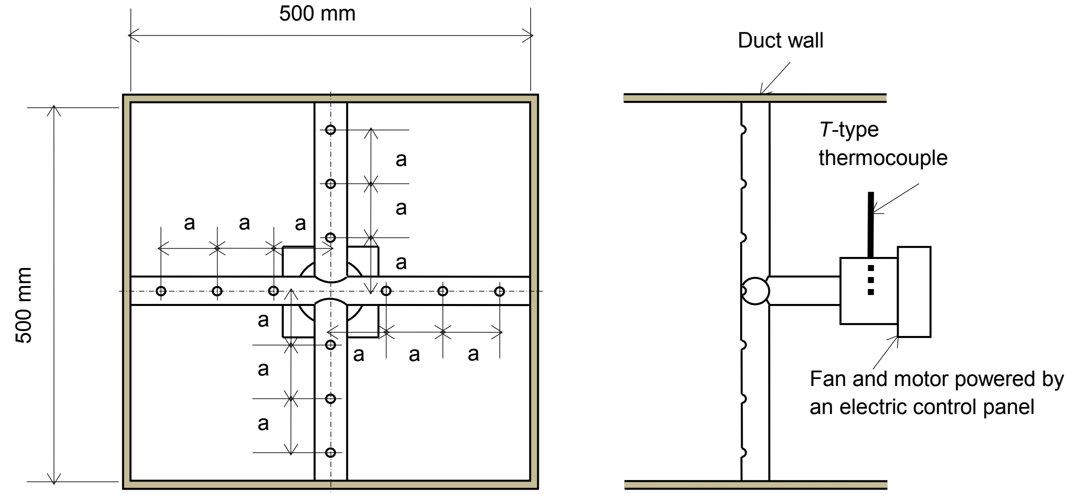
$$v_{afc} = 0.0896\,z - 0.17 \tag{4.2}$$

$$\dot{V}_e = 5.9449\,c + 7.6091 \tag{4.3}$$

4.3.1.4 Temperature Measurement

Temperature is measured at eight points as shown in Figure 4.13. All points are measured using a *T*-type thermocouple. Except points 4 (inlet evaporator) and 5 and the point where temperature is measured for EEV control, all data for each point are recorded using eight channels of USB TC-08 thermocouple data logger furnished with a PicoLog software. All thermocouples are calibrated using a calibrated thermohygrometer. Figure 4.20 shows one of the thermocouples being calibrated using a calibrated thermohygrometer and a mini refrigerator/heater. According to the calibration process, the accuracy of all thermocouples is between ±0.2 and ±0.3°C. Measurements at points 5 and evaporator inlet are fed back to the air heater to simulate the condenser and evaporator air inlet temperatures, respectively. The thermostats used for these purposes provide a precise control of the desired constant temperatures within ±2°C. Given the large ductwork cross-section area, the temperature measurement at point 5 is connected to the air sampling tube (Figure 4.21), following BS 5141-1:1975 "Part 1: Method of Testing for Rating of Cooling Coils" (British Standard Institution, 1975).

Figure 4.20 Calibration process of *T*-type thermocouple



(a) Front view (b) Side view

Figure 4.21 Condenser air inlet sampling tubes made according to BS 5141-1:1975 (Part 1)

Given the internal structures and smaller cross-sectional area than the condenser section, the evaporator air outlet temperature is measured according to BS 306:1997 "Heat Exchangers–Methods of Measuring the Parameters Necessary for Establishing the Performance" (British Standard Institution, 1997). Deviations in temperature between different thermocouples in the same measurement plane occurred; thus, the local temperatures are weighted considering the local air velocity of the measurement point, k, to obtain the correct heat quantity as stated in BS 306:1997. The BS 306:1997 proposed Equation (4.4), where the mean value of the evaporator air outlet temperature, $\overline{T}_{k,a,o,e}$, is calculated and used as averaged evaporator air outlet temperature.

$$\overline{T}_{a,o,e} = \frac{1}{n} \times \frac{1}{\overline{v}_{a,o,e}} \times \sum_{k=1}^{n} v_{k,a,o,e} \times T_{k,a,o,e} . \tag{4.4}$$

Accordingly, seven units of T-type thermocouples are installed in the same measurement plane, that is, in the evaporator air outlet (point 4) as shown in Figure 4.22. These thermocouples are installed at points A, C, E, F, G, H, and I (Figure 4.17). The averaged evaporator air velocities and averaged evaporator local air velocities (Table 4.8) of these points (measured during averaged evaporator air velocity verification shown in Appendix E) are used as weightage of temperature. For simplification, simple interpolation is adopted for other values of percentage of energy input.

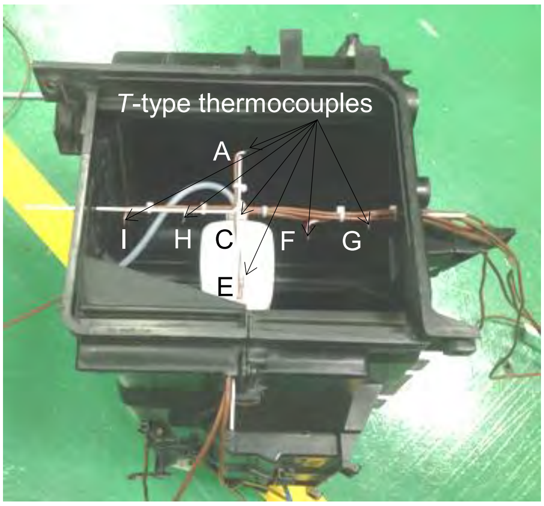


Figure 4.22 *T*-type thermocouple arrangement after evaporator coil made according to BS 306:1997

Table 4.8 Local air velocity at evaporator outlet

Percentage of energy input, c (%)	Total averaged air velocity, $\bar{v}_{a,o,e}$ (m/s)	Local air velocity at evaporator outlet measuring point k, $v_{k,a,o,e}$ (m/s)						
		A	C	E	F	G	H	I
24.00	1.66	1.74	1.76	1.96	1.62	1.79	1.25	1.52
30.68	2.13	2.23	2.15	2.54	2.03	2.32	1.67	2.02
35.00	2.44	2.55	2.41	2.91	2.29	2.66	1.94	2.35
40.77	2.78	2.92	2.69	3.27	2.57	3.06	2.22	2.73
47.00	3.14	3.31	2.99	3.66	2.88	3.49	2.53	3.14
49.18	3.26	3.45	3.09	3.78	2.99	3.63	2.63	3.28
59.00	3.81	4.08	3.53	4.30	3.51	4.26	3.08	3.92
71.00	4.41	4.77	4.01	4.87	3.96	4.98	3.61	4.65
74.42	4.58	4.97	4.15	5.03	4.09	5.19	3.76	4.86

4.3.1.5 Humidity and Pressure Measurements

The data related to air humidity at inlet of the evaporator and refrigerant pressure at inlet and outlet of each main component (electric compressor, condenser, EEV, and evaporator) are fully recorded. The data acquisition system consists of a customized LabVIEW data acquisition programming software, installed in a standard laptop equipped with two units of PCB module interface and hardware or software control function. In addition, two units of LCD modules are used to display all the information for local control functions.

Four units of AKS 32 Danfoss pressure transducer (code no: 060G2083) are used to measure low and high sides of refrigerant pressures. The output of each pressure transducer is between 0 and 10 VDC, equivalent to -1–24 bar of gauge pressure. The power supplied to the transducer is 24 VDC (manufacturer power supply requirement: 15–30 VDC). As shown in Appendix F, the pressure transducer is calibrated using two units of standard pressure gauge, installed close to the pressure transducer at the inlet and outlet of the compressor. Experimental observation indicated that low and high side pressure transducers read 0.2 and 0.4 bar less than their standard pressure gauge. Therefore, the final gauge pressure recorded through the pressure transducer is added with 0.2 and 0.4 bar for low and high side pressures, respectively.

In addition, one unit of the brand-new humidity transducer is used to measure the air humidity at the inlet of the evaporator (air side). The output of the humidity transducer is between 0 and 10 VDC, equivalent to air humidity ranging from 0% to 99%. The power supplied to the transducer is 24 VDC (manufacturer power supply requirement: 15–30 VDC). The manufacturer has calibrated and conformed that this transducer is acceptable for measuring processes.

4.3.1.6 Compressor Current and Voltage Measurements

Electric current and voltage supplied to the compressor are measured using direct current and voltage meters located at the AC/DC converter, as shown in Appendix G. Readings from direct current and voltage meters are calibrated using clamp meter and multi-tester, respectively. Experimental observation indicated that readings from direct current meter are within ±1.5 ADC compared with readings from the clamp meter. Meanwhile, readings from the direct voltage meter are within ±2.0 VDC compared with readings from the multi-tester.

4.3.2 System Setup Tests

A refrigerant charge determination as proposed by the SAE International Surface Vehicle Standard “Procedure for Measuring COP of Mobile Air Conditioning System on a Test Bench” is used. Thus, a charge determination is performed under the following conditions:

a. compressor speed at 6500 rpm, full displacement;
b. condenser air inlet temperature of 40°C;
c. condenser air face velocity of 3.7 $\mathrm{m/s}$;
d. evaporator air inlet temperature of 40°C;
e. evaporator air face velocity of 2.5 $\mathrm{m/s}$ (equivalent to average evaporator air volume flow rate of 296 $\mathrm{m^3/h}$).

For safety reasons, the amount of refrigerant added to the system with compressor discharge pressure is limited to less than 1300 kPa; the Society of Automotive Engineers (2008) recommends 1800 kPa. Standard industry practice for typical passenger car is approximately 1300 kPa and 210 kPa for high and low side pressures, respectively (Appendix H). To ensure stable operation during the charge determination, the system is operated for 10 min before the refrigerant is added if the recommended criteria are not achieved. After the refrigerant is added to the system (if necessary), the system is allowed to stabilize for another 10 min before the recommended criteria are checked. This procedure is repeated until the recommended criteria are achieved.

4.3.3 Description of Testing Procedures

The experimental work is conducted in a steady-state condition to develop the empirical correlations of Equations (3.36) and (3.43)–(3.46). The test is conducted at varying heat load by applying different values of $\dot{V}_e N_c^2 / v_{afc}^3$, $T_{a,i,e}/T_{a,i,cd}$, and $\phi_{a,i,e}$. The range and control method of N_c , $T_{a,i,cd}$, v_{afc} , $T_{a,i,e}$, $\dot{V}_e$, and $\phi_{a,i,e}$ are summarized in Table 4.9. Based on the experimental ranges in Table 4.9, the structure of the test operating procedures is developed and shown in Figure 4.23.

The values of $\dot{V}_e N_c^2 / v_{afc}^3$ are set as 4.96, 9.67, 11.74, 17.36, and 22.92 by controlling or adjusting the value of N_c, v_{afc}, and $\dot{V}_e$, as shown in Table 4.10. At each value of $\dot{V}_e N_c^2 / v_{afc}^3$, the values of $T_{a,i,e}/T_{a,i,cd}$ are kept at 0.750, 0.875, and 1.00 by varying $T_{a,i,cd}$ as shown in Table 4.10. At each value of $T_{a,i,e}/T_{a,i,cd}$, the values of $\phi_{a,i,e}$ are maintained at 40%, 50%, and 60% with ±5% by manually controlling the humidifier. During the entire experimental study, the EEV is operated at 100% of valve opening degree. Thus, the EEV works as a capillary tube. Supplied direct current voltage to the compressor is fixed at 300 VDC at all times. To stabilize the AAC system, the system is run at least 30 min prior to each test before measured output data are recorded following the SAE Standard (Society of Automotive Engineers, 2008). After allowing the system to stabilize, data are recorded for 10 min according to the SAE Standard (Society of Automotive Engineers, 2008). The chosen sampling time is 30 s. As shown in Figure 4.23, the experimental data (measured variables) are refrigerant mass flow rate, current and voltage consumed by the compressor, local evaporator air outlet temperature, and inlet and outlet refrigerant pressures and temperatures of each main component (except refrigerant temperature at compressor outlet). Samples of the experimental data are tabulated in Appendix I. Notably, all pressures tabulated in Appendix I represent the final absolute refrigerant pressure.

Table 4.9 Ranges of input test variables (independent variable) applied in the study

Variables	Experimental Ranges	Control Method	References
N_c (rpm)	2300–6500	Input voltage signal to compressor	Lowest to highest possible speed allowed in experimental test rig
$T_{a,i,cd}$ (°C)	30–40	Temperature control	32, 35, 40 (Mohamed Kamar, 2008)
v_{afc} (m/s)	2.5–4.0	Inverter motor drive	1.5, 2, 3, 4 (Society of Automotive Engineers, 2008)
$T_{a,i,e}$ (°C)	30	Temperature control	25, 30, 35 (Mohamed Kamar, 2008)
$\dot{V}_e$ $(\mathrm{m^3/h})$	190–450	Percentage energy input	Lowest to highest possible speed allowed in the experimental test rig
$\phi_{a,i,e}$ (%)	40, 50, 60	Manual control by injecting steam into ductwork	25, 40, 50, 80 (Society of Automotive Engineers, 2008)

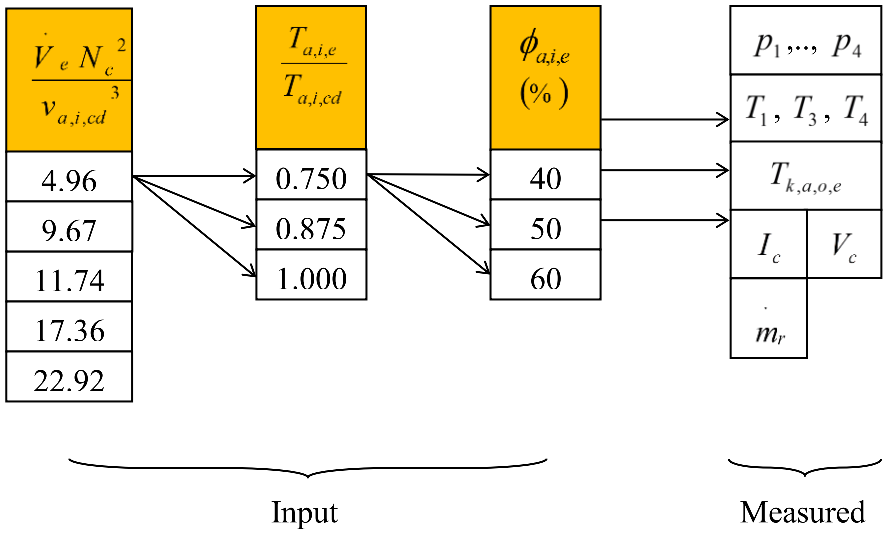


Figure 4.23 Structure of test operating procedures

Table 4.10 Input values of input test variables

$\frac{\dot{V}_e N_c^2}{v_{afc}^3}$	$\frac{T_{a,i,e}}{T_{a,i,cd}}$	N_c (rpm)	$\dot{V}_e$ (m^3/h)	v_{afc} (m/s)	$T_{a,i,e}$ (°C)	$T_{a,i,cd}$ (°C)
4.96	-	2300	190	2.5	-	-
9.67	-	2800	250	2.5	-	-
11.74	-	3700	300	3.0	-	-
17.36	-	4500	300	3.0	-	-
22.92	-	6500	450	4.0	-	-
-	0.750	-	-	-	30	40
-	0.875	-	-	-	30	35
-	1.000	-	-	-	30	30

The compressor work, W_c, is determined through the input power supplied to the compressor, which is measured from direct voltage and current meters. Therefore,

$$W_c = I_c V_c \tag{4.5}$$

From the refrigerant side, W_c can be determined based on refrigerant enthalpy difference between the inlet and outlet of the compressor, where

$$W_c = \dot{m}_r(h_1 - h_2) \tag{4.6}$$

Therefore, replacing W_c in Equation (4.6) with W_c from Equation (4.5) yields

$$h_2 = h_1 + \frac{I_c V_c}{\dot{m}_r} \tag{4.7}$$

Then, refrigerant temperature at the compressor outlet, T_2, can be determined, where

$$T_2 = f(h_2, p_2) \tag{4.9}$$

The cooling capacity and heat rejected by the condenser to ambient air are calculated based on refrigerant enthalpy difference between the inlet and outlet of the evaporator and condenser. In particular,

$$Q_e = \dot{m}_r(h_1 - h_2) \tag{4.9}$$

$$Q_{cd} = \dot{m}_r(h_2 - h_3) \tag{4.10}$$

where

$h_n = f(T_n, p_n)$ with n = 1, 3, 4.

Determining refrigerant enthalpies at point n = 1, 3, 4 and refrigerant temperature at point n = 2 is based on REFPROP program (Lemmon *et al.*, 2013). The following assumptions are then made:

a. Properties of refrigerant and air are constant over the cross section (one dimensional).
b. Heat transfer only occurs at the condenser and evaporator coils.
c. The refrigerant flow across the EEV is isenthalpic.
d. The evaporating and condensing temperatures are measured at the refrigerant inlet evaporator, T_4, and refrigerant outlet condenser, T_3, respectively.

The entire calculated variables are tabulated in Appendix J. Samples of *p–h* diagrams are presented in Appendix K.

4.3.4 Experimental Uncertainty Analysis

Many factors, such as measuring instruments, the item being measured, the environment, the operator, and repetition, can result in some experimental uncertainties. Therefore, statistical analysis is applied to quantify the experimental uncertainties. Standard deviation is one of the statistical methods used to quantify the spread value (Diaz, 2009; Sumeru, 2015). The standard deviation of a set of data indicates how different the individual readings are from the average of the set of data. The standard uncertainty of measured variables of this study is calculated using the statistical method of experimental standard deviation, σ, where

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2} \tag{4.11}$$

In this equation, $\bar{x}$ is mean (average) value of a N number of x, where

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \tag{4.12}$$

Based on the measured data as shown in Appendix I and Equation (4.11), the experimental standard deviations of absolute refrigerant pressure, refrigerant temperature, refrigerant mass flow rate, compressor input current, compressor input voltage, and air temperature with varying input variables are obtained as 0.01–0.35 bar, 0.02–0.65°C, 0.0 g/s, 0.0 ADC, 0 VDC, and 0.04–0.43°C, respectively.

The uncertainties of measurement results, namely, cooling capacity, compressor work, and *COP*, can be analyzed using types A and B uncertainty evaluations (Zhou and Zhang, 2010). Zhou and Zhang (2010) highlighted that type A evaluations employ statistical methods to determine the standard uncertainty, that is, the experimental standard deviation of the measured variables. Meanwhile, type B evaluations involve all other methods, such as accuracy data of transducers and engineering judgment.

For cooling capacity, compressor work, and *COP*, the type A relative standard uncertainties, $\mu'_A(Q_e)$, $\mu'_A(W_c)$, and $\mu'_A(COP)$, are given by

$$\mu'_A(Q_e) = \sqrt{\frac{\sum_{i=1}^{N}\left(Q_{e,i} - \overline{Q}_e\right)^2}{N(N-1)\overline{Q}_e^{\,2}}} \tag{4.13}$$

$$\mu'_A(W_e) = \sqrt{\frac{\sum_{i=1}^{N}\left(W_{e,i} - \overline{W}_e\right)^2}{N(N-1)\overline{W}_e^{\,2}}} \tag{4.14}$$

$$\mu'_A(COP) = \sqrt{\frac{\sum_{i=1}^{N}\left(COP_i - \overline{COP}\right)^2}{N(N-1)\overline{COP}^2}} \tag{4.15}$$

where $\overline{Q}_e$, $\overline{W}_c$, and $\overline{COP}$ are mean values of N calculated values for cooling capacity, compressor work, and *COP*, respectively. Based on Equations (4.13)–(4.15), the type A relative standard uncertainties for Q_e, W_c and *COP* with varying input variables are obtained as 1.92%–7.23%, 0%, and 0.07%–0.30%, respectively.

In the experiment, the cooling capacity is calculated using Equation (4.9). According to the law of propagation of uncertainty, the type B relative standard uncertainty of cooling capacity is the function of relative standard uncertainty of each input measurement (Zhou and Zhang, 2010), and can be described as

$$\mu'_B(Q_e) = \sqrt{\mu'^2_B\left(\dot{m}_r\right) + \mu'^2_B(h_1) + \mu'^2_B(h_4)} \tag{4.16}$$

In this study, the uncertainty components are mainly evaluated with the calibrated accuracy of instrumentations used for measurement (Table 4.7) as proposed by Zhou and Zhang (2010). Uniform distribution is assumed for each uncertainty component with coverage factor $k=\sqrt{3}$ (Zhou and Zhang, 2010). For example, the relative uncertainty of $\mu'^{2}_{B}\left(\dot{m}_r\right)$ is evaluated according to the maximum error limit of mass flow meter (±1.25%) that has a uniform distribution. In particular, $\mu'_{B}\left(\dot{m}_r\right)=1.25\%/\sqrt{3}=0.72\%$. The relative uncertainty of $\mu'_{B}\left(h_1\right)$ is evaluated according to the maximum error limit of *T*-type thermocouple (±0.75%) and pressure transducer (±0.8%) that has a uniform distribution. Specifically, $\mu'_{B}\left(h_1\right)=\sqrt{\left(0.75\%/\sqrt{3}\right)^2+\left(0.80\%/\sqrt{3}\right)^2}=0.63\%$. The same measuring instrumentation shows that the relative uncertainty of $\mu'_{B}\left(h_2\right)$ is also equal to $\mu'_{B}\left(h_1\right)$. Therefore, the type B relative standard uncertainty of Q_e is $\mu'_{B}\left(Q_e\right)=\sqrt{\mu'^{2}_{B}\left(\dot{m}_r\right)+\mu'^{2}_{B}\left(h_1\right)+\mu'^{2}_{B}\left(h_4\right)}=\sqrt{0.72^2+0.63^2+0.63^2}=1.15\%$. Similarly, the type B standard uncertainty of W_c and *COP* are determined by

$$\mu'_{B}\left(W_c\right)=\sqrt{\mu'^{2}_{B}\left(I_e\right)+\mu'^{2}_{B}\left(V_e\right)} \tag{4.17}$$

$$\mu'_{B}\left(COP\right)=\sqrt{\mu'^{2}_{B}\left(I_c\right)+\mu'^{2}_{B}\left(V_c\right)+\mu'^{2}_{B}\left(\dot{m}_r\right)+\mu'^{2}_{B}\left(h_1\right)+\mu'^{2}_{B}\left(h_4\right)} \tag{4.18}$$

Based on Equations (4.16)–(4.18), the type B relative standard uncertainties for Q_e, W_c, and COP are obtained as 1.15%, 1.22%, 1.90%, respectively.

The combined standard uncertainties are then evaluated as follows (Zhou and Zhang, 2010):

$$\mu'_{C}\left(Q_e\right)=\sqrt{\mu'^{2}_{A}\left(Q_e\right)+\mu'^{2}_{B}\left(Q_e\right)} \tag{4.19}$$

$$\mu'_C(W_c) = \sqrt{\mu'^2_A(W_c) + \mu'^2_B(W_c)} \tag{4.20}$$

$$\mu'_C(COP) = \sqrt{\mu'^2_A(COP) + \mu'^2_B(COP)} \tag{4.21}$$

Based on Equations (4.19)–(4.21), the combined standard uncertainties for Q_e, W_c, and COP over variation of all input variables are obtained as 2.24%–7.32%, 1.22%, and 1.90–1.92%, respectively.

With a 95% confidence level considered for normal distribution, the coverage factor is set as $k = 2$ (Zhou and Zhang, 2010), and the relative expanded uncertainties are then calculated as

$$\mu'_E(Q_e) = k \times \mu'_C(Q_e) \tag{4.22}$$

$$\mu'_E(W_c) = k \times \mu'_C(W_c) \tag{4.23}$$

$$\mu'_E(COP) = k \times \mu'_C(COP) \tag{4.24}$$

Based on Equations (4.22)–(4.24), the relative expanded uncertainties for Q_e, W_c, and COP with varying input variables are obtained as 5.72%–14.64%, 2.44%, and 3.80%–3.84%, respectively.

The measurement uncertainty of compressor work mainly depends on the accuracy of current and voltage meters, and test repetitions. For cooling capacity, the uncertainty comes from many factors such as measurement of temperature and pressure, mass flow rate of refrigerant, test repetitions, and Refprop software in determining refrigerant enthalpies. The accuracy of refrigerant mass flowrate meter, *T*-type thermocouples, and pressure transducers plays an important part in the cooling capacity measurement in this study. The uncertainties of cooling capacity and input power consequently contribute to the deviation of the measured *COP*. Details of the uncertainty components for each experimental setup are shown in Appendix J.

4.3.5 Validation of Experimental Results

The current experimental results are validated with experimental results published by Wang *et al*. (2005). They investigated the effect of the condenser water temperature (which represent condenser temperature) on the performance of the vapor compression refrigeration, AAC system of refrigerant mass flow rate, refrigerant quality, cooling load, power input (compressor work), *COP*, suction and discharge pressure, and compression ratio. The comparison between test conditions by Wang *et al*. (2005) and those by the current study for the purpose of experimental validation is shown in Table 4.11.

Table 4.11 Comparison between current experimental study and study by Wang *et al*. (2005)

Conditions	Wang *et al*. (2005)	Current study
R-134a refrigerant charged during test	Constant at 1.8 kg	Constant accordance to Section 4.3.2
Evaporator air inlet temperature	Constant at 30°C	Constant at 30°C
Compressor speed	Constant at 1500 rpm	Constant at 2800 rpm*
Medium to heat up the condenser	Water	Air
Condenser temperature during test	Increasing from 25°C, 30°C,…., 50°C	Increase of condenser air inlet temperature from 30°C to 35°C and then to 40°C

* The entire test is conducted between compressor speeds of 2300–6500 rpm. For validation, this speed is chosen with $\phi_{a,i,e}$ = 50%RH.

When the condenser air inlet temperature or condenser temperature increases, the temperature difference between air and refrigerant in the condenser decreases. Such a decrease reduces the heat exchange of the condenser. Consequently, the cooling capacity or cooling load decreases with the increase of the condenser air inlet temperature, as shown in Figure 4.24(a). Meanwhile, the compressor work increases depending on an increase in the condenser temperature. The reason is that, if the condenser temperature increases, then the condenser pressure also increases (Figure 4.25(a)). The latter increase also increases the compressor work (Figure 4.24(a)). In addition, suction pressure increases because of system energy balance. When the condenser temperature increases, the refrigerant mass flow rate increases slightly, as shown in Figure 4.26(a). The *COP* of the AAC system decreases because of the condenser pressure. Accordingly, the compressor input work increases but the cooling capacity decreases, as shown in Figure 4.24(a). All these results agree well with those published by Wang *et al*. (2005), as shown in Figures 4.24, 4.25, and 4.26.

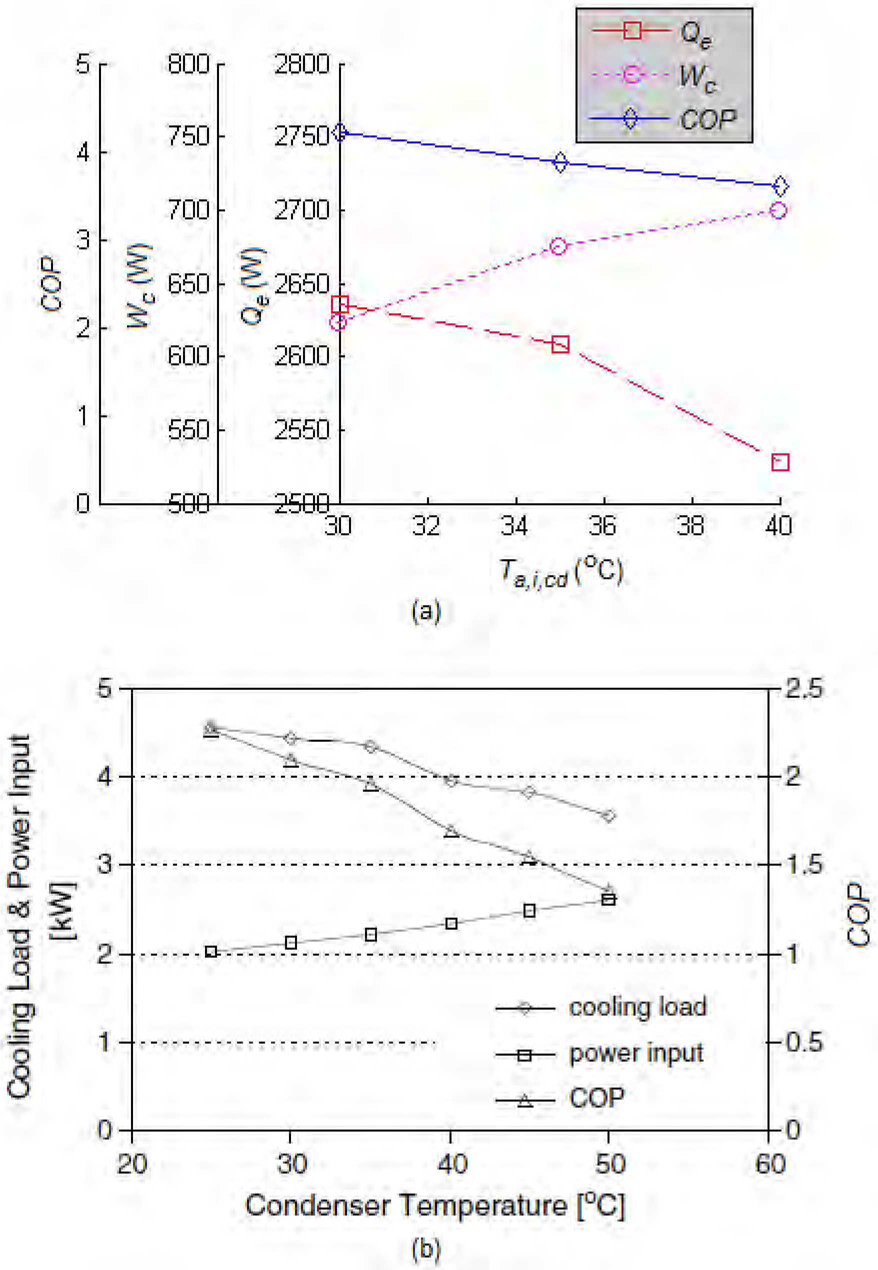
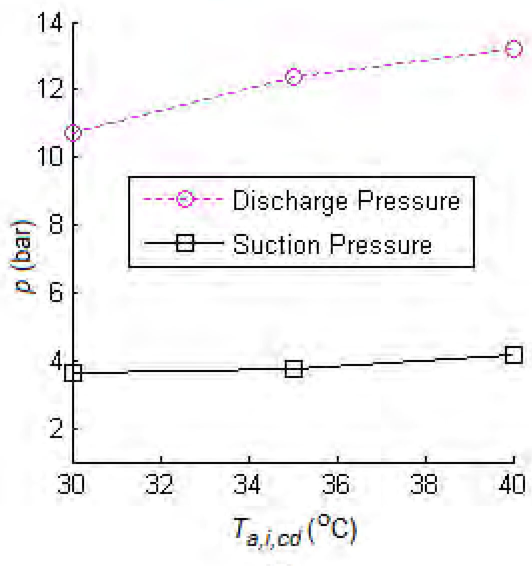


Figure 4.24 Effect of condenser air inlet temperature or condenser temperature on cooling load, compressor input power or compressor work, and *COP*. (a) current study (b) study by Wang *et al*. (2005)



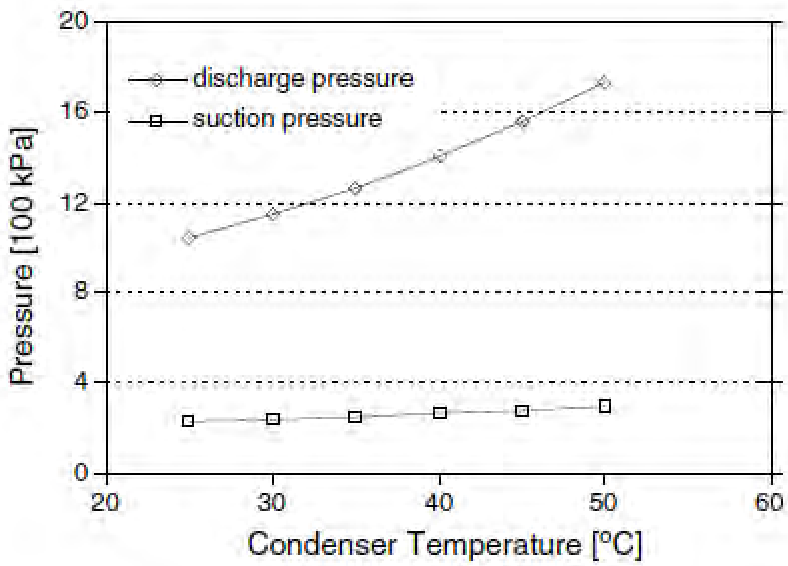


Figure 4.25 Effect of condenser air inlet temperature or condenser temperature on compressor discharge and suction pressures. (a) current study (b) study by Wang *et al*. (2005)

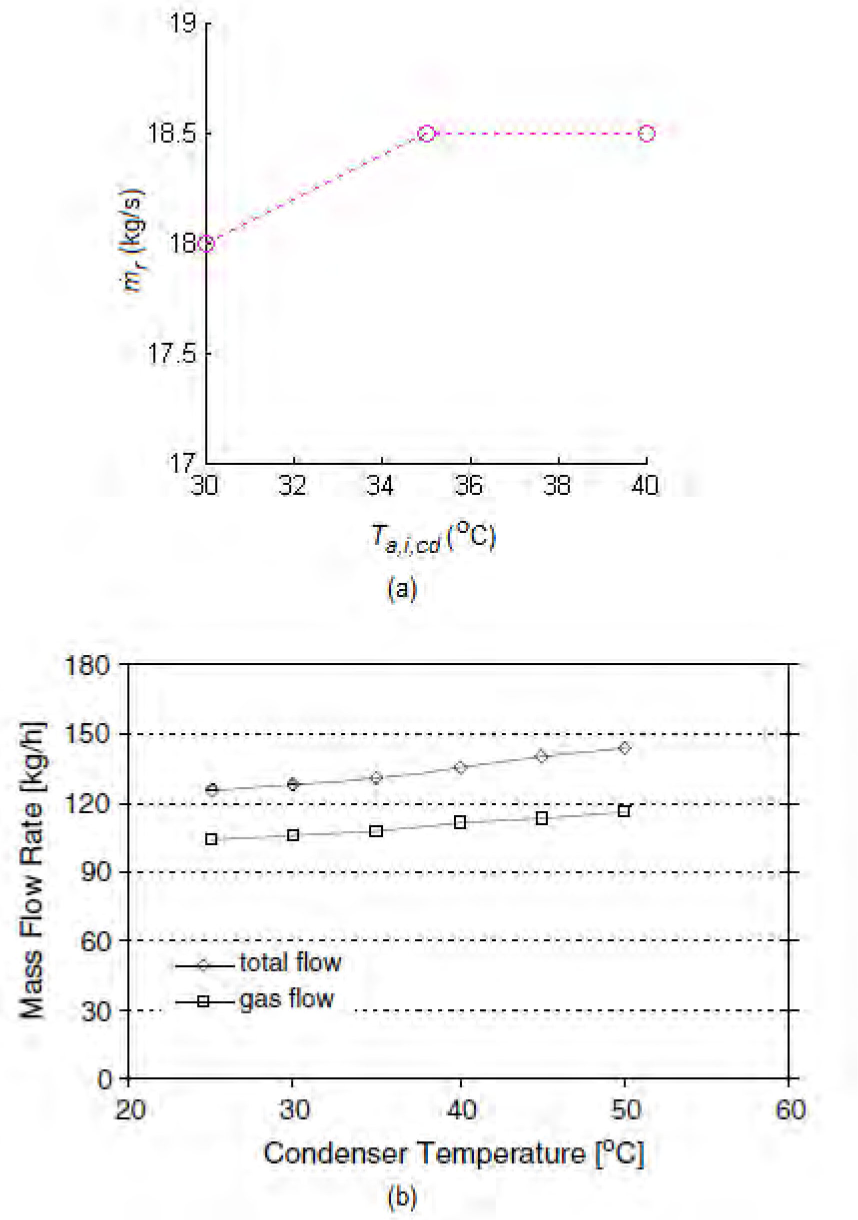


Figure 4.26 Effect of condenser air inlet temperature or condenser temperature on refrigerant mass flow rate. (a) current study (b) study by Wang *et al*. (2005)

4.3.6 Development of Empirical Correlations

For simplification, the temperatures of evaporator refrigerant inlet and condenser refrigerant outlet are treated as evaporating and condensing temperatures.

Meanwhile, the pressures of evaporator refrigerant inlet and condenser refrigerant outlet are treated as evaporating and condensing pressures.

A regression method described by Rao (2002) is used to obtain the best fit to the set of experimental data. A linear regression of the 100 experimental data of each experimental setting denotes a good fit, as shown in Table 4.12.

Table 4.12 Empirical correlation of air-side evaporator coil

$\phi_{a,i,e}$ (%)	$\frac{T_{a,i,e}}{T_{a,i,cd}}$	$\frac{T_{a,o,e}}{T_{a,i,cd}} = \text{a - b}\left(\frac{\dot{V}_e N_c^2}{v_{afc}^3}\right)$ a	b	r
	0.750	0.370825	0.004443	0.979
40	0.857	0.385084	0.003851	0.983
	1.000	0.407156	0.004345	0.990
	0.750	0.386034	0.004307	0.991
50	0.857	0.400074	0.003837	0.961
	1.000	0.440861	0.005313	0.994
	0.750	0.399714	0.003833	0.991
60	0.857	0.425821	0.004503	0.974
	1.000	0.464780	0.005484	0.986

Figures 4.27–4.29 show the tabulation of predicted $T_{a,o,e}/T_{a,i,cd}$ against the measured values for $\phi_{a,i,e}$ = 40%, 50%, 60%.

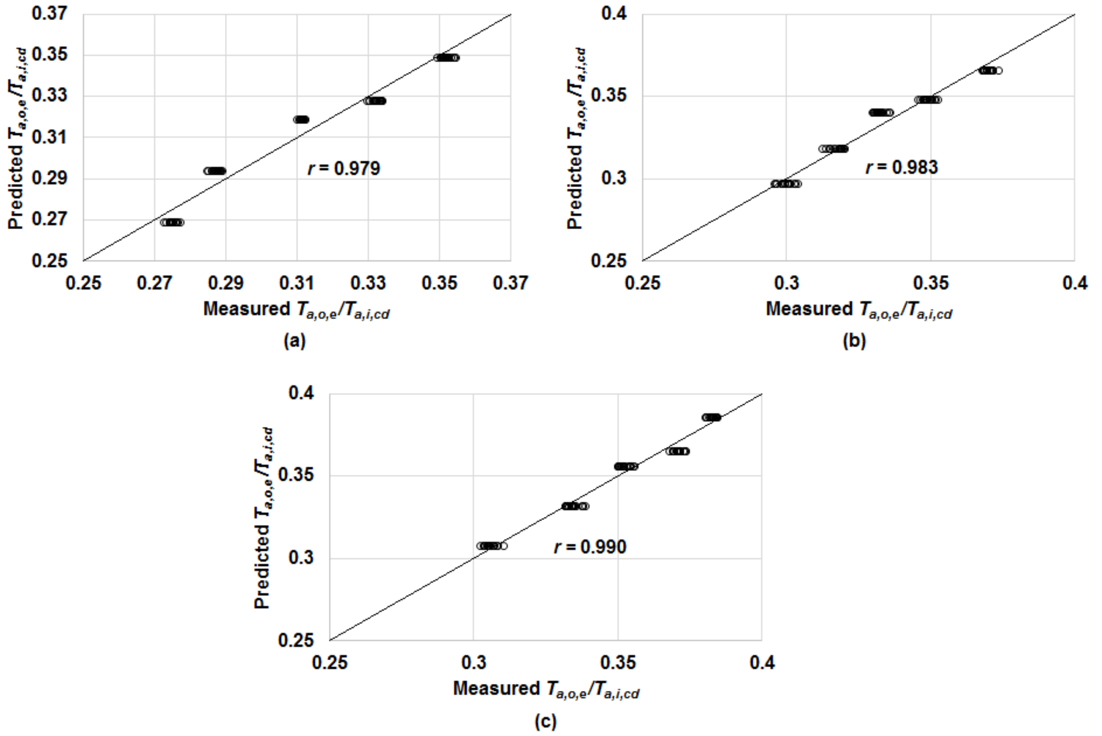


Figure 4.27 Predicted and measured $T_{a,o,e}/T_{a,i,cd}$ for $\phi_{a,i,e}$ 40%. (a) $T_{a,i,e}/T_{a,i,cd}$ = 0.750, (b) $T_{a,i,e}/T_{a,i,cd}$ = 0.857, (c) $T_{a,i,e}/T_{a,i,cd}$ = 1.000

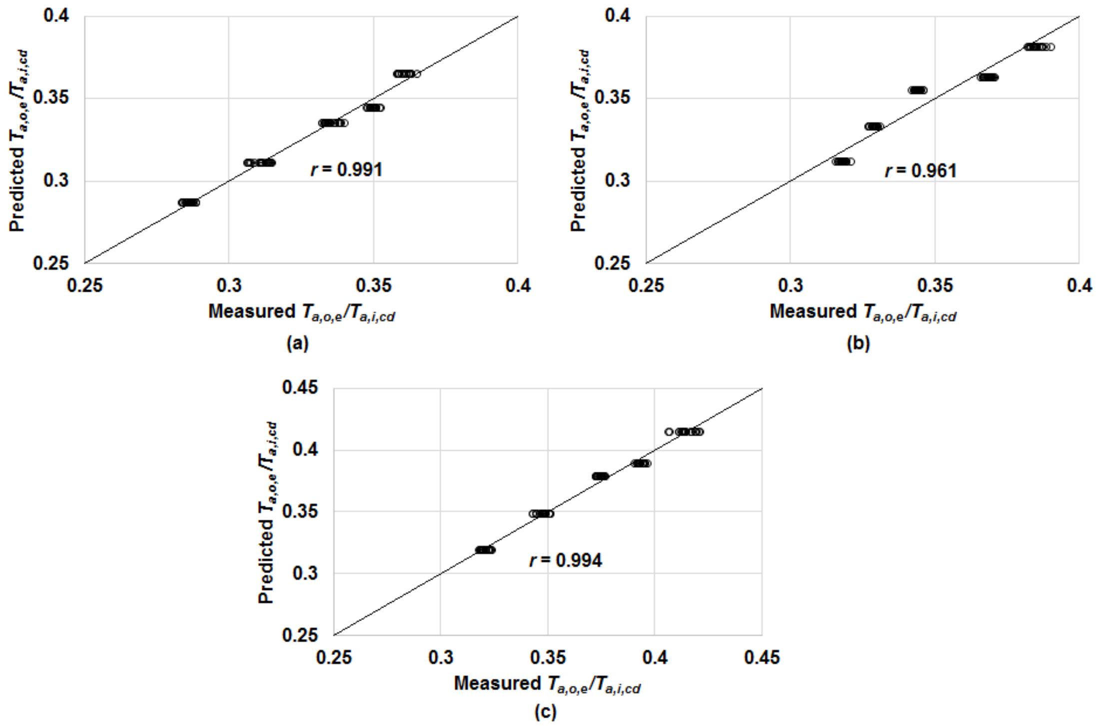


Figure 4.28 Predicted and measured $T_{a,o,e}/T_{a,i,cd}$ for $\phi_{a,i,e}$ = 50%. (a) $T_{a,i,e}/T_{a,i,cd}$ = 0.750, (b) $T_{a,i,e}/T_{a,i,cd}$ = 0.857, (c) $T_{a,i,e}/T_{a,i,cd}$ = 1.000

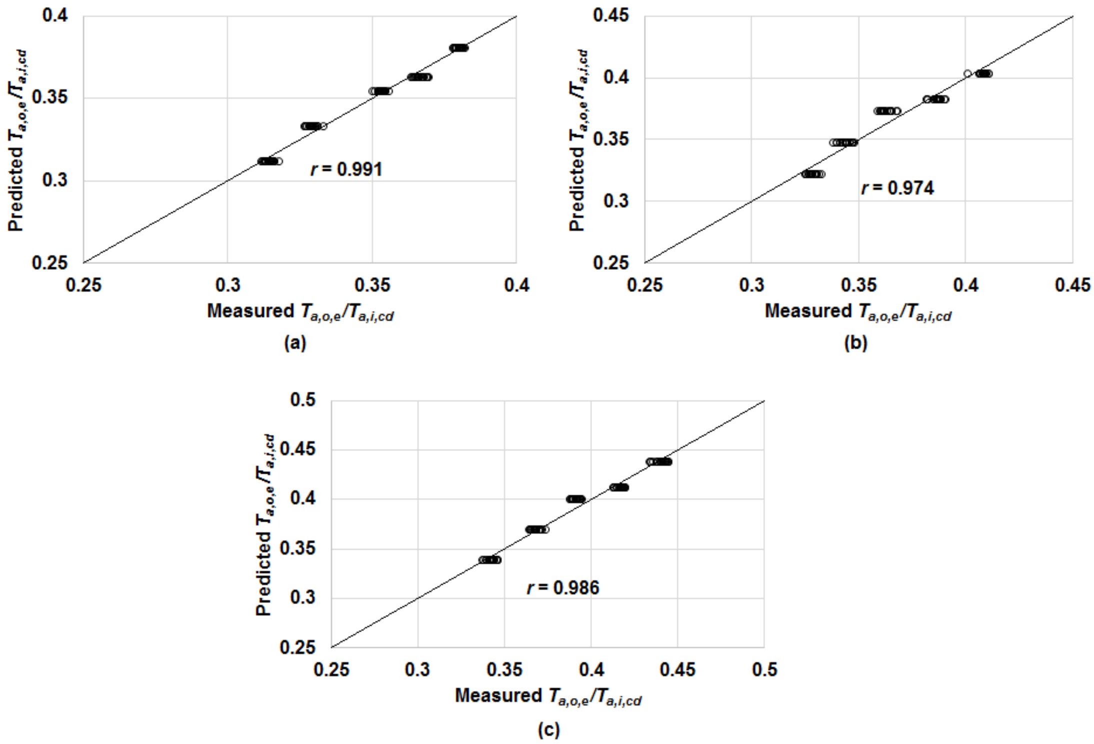


Figure 4.29 Predicted and measured $T_{a,o,e}/T_{a,i,cd}$ for $\phi_{a,i,e}$ = 60%. (a) $T_{a,i,e}/T_{a,i,cd}$ = 0.750, (b) $T_{a,i,e}/T_{a,i,cd}$ = 0.857, (c) $T_{a,i,e}/T_{a,i,cd}$ = 1.000

Meanwhile, linearization and curve fitting techniques with multiple variables as described by Rao (2002) are used for the refrigerant-side analysis to obtain the best fit to the set of experimental data for Equations (3.43)–(3.46). Tables 4.13–4.16 show the generated empirical correlations for W_c, $\dot{m}_r$, Q_e and Q_{cd}.

Table 4.13 Empirical correlation of compressor work

$\phi_{a,i,e}$ (%)	$\frac{T_{a,i,e}}{T_{a,i,cd}}$	$w_c = c_0 T_{cd}^{c_1} T_e^{c_2} N_c^{c_3}$				r
		c_0	c_1	c_2	c_3	
	0.750	0.9338	0.5672	-0.0784	0.2084	0.990
40	0.857	1.2941	0.3495	0.0988	0.2235	0.991
	1.000	21.8893	0.7041	-0.6772	-0.0988	0.987
	0.750	6.3230	0.2402	-0.1630	0.1599	0.994
50	0.857	29.5062	-0.3235	-0.0739	0.0032	0.997
	1.000	1.0719	0.9003	-0.2505	0.0814	0.997
	0.750	1.5920	0.1054	0.1928	0.2911	0.997
60	0.857	13.9113	-0.0241	-0.1023	0.1691	0.986
	1.000	4.5046	0.2070	-0.1426	0.2047	0.999

Table 4.14 Empirical correlation of refrigerant mass flow rate

$\phi_{a,i,e}$ (%)	$\frac{T_{a,i,e}}{T_{a,i,cd}}$	$\dot{m}_r = d_0 T_{cd}^{d_1} T_e^{d_2} N_c^{d_3}$				r
		d_0	d_1	d_2	d_3	
	0.750	6.6737E-8	1.4313	0.5725	0.6991	0.995
40	0.857	6.8178E-4	1.5011	-1.0257	-0.0183	0.991
	1.000	1.1683E-6	2.6458	-0.1052	0.0075	0.990
	0.750	1.7042E-8	1.7281	0.5834	0.7171	0.995
50	0.857	8.2408E-7	2.7492	-0.3060	0.0214	0.988
	1.000	6.5295E-5	1.4554	-0.4061	0.1288	0.986
	0.750	2.7902E-6	3.0042	-0.8734	-0.1030	0.987
60	0.857	5.2817E-4	1.6054	-0.9380	-0.0568	0.998
	1.000	9.2936E-5	1.4156	-0.5189	0.1349	0.987

Table 4.15 Empirical correlation of cooling capacity

$\phi_{a,i,e}$ (%)	$\dfrac{T_{a,i,e}}{T_{a,i,cd}}$	$q_e = e_0 T_{cd}^{e_1} T_e^{e_2} N_c^{e_3}$ e_0	e_1	e_2	e_3	r
	0.750	854.3150	-0.4369	0.0047	-0.0173	0.996
40	0.857	607.3468	-0.3449	0.0057	-0.0193	0.997
	1.000	374.9902	-0.3185	0.0820	0.0100	0.993
	0.750	716.4439	-0.3909	0.0089	-0.0192	0.996
50	0.857	786.1912	-0.4292	0.0122	-0.0133	0.998
	1.000	670.6182	-0.4141	0.0162	-0.0019	0.996
	0.750	961.6975	-0.5154	0.0404	-0.0055	0.998
60	0.857	1039.2972	-0.4678	-0.0129	-0.0223	0.999
	1.000	515.6870	-0.3452	0.0433	-0.0084	0.995

Table 4.16 Empirical correlation of heat rejected from condenser

$\phi_{a,i,e}$ (%)	$\dfrac{T_{a,i,e}}{T_{a,i,cd}}$	$q_{cd} = f_0 T_{cd}^{f_1} T_e^{f_2} N_c^{f_3}$ f_0	f_1	f_2	f_3	r
	0.750	351.5669	-0.2119	-0.0307	0.0250	0.951
40	0.857	296.3082	-0.2424	0.0338	0.0424	0.716
	1.000	456.6421	-0.1730	-0.0955	-0.0109	0.508
	0.750	426.4947	-0.2200	-0.0500	0.0117	0.969
50	0.857	707.5441	-0.3235	-0.0739	0.0032	0.968
	1.000	286.7182	-0.1510	-0.0316	0.0211	0.857
	0.750	381.8775	-0.4346	0.1039	0.0832	0.881
60	0.857	617.4512	-0.3797	-0.0139	0.0313	0.940
	1.000	326.5229	-0.2488	0.0048	0.0424	0.958

Figures 4.30–4.32 show the predicted w_c, $\dot{m}_r$, q_e, and q_{cd} at $\phi_{a,i,e}$ = 40% against the measured values for $T_{a,i,e}/T_{a,i,cd}$ = 0.750, 0.857, 1.000. Figures 4.33–4.35

show the predicted w_c, $\dot{m}_r$, q_e, and q_{cd} at $\phi_{a,i,e}$ = 50% against the measured values for $T_{a,i,e}/T_{a,i,cd}$ = 0.750, 0.857, 1.000. Figures 4.36–4.38 show the predicted w_c, $\dot{m}_r$, q_e, and q_{cd} at $\phi_{a,i,e}$ = 60% against the measured values for $T_{a,i,e}/T_{a,i,cd}$ = 0.750, 0.857, 1.000.

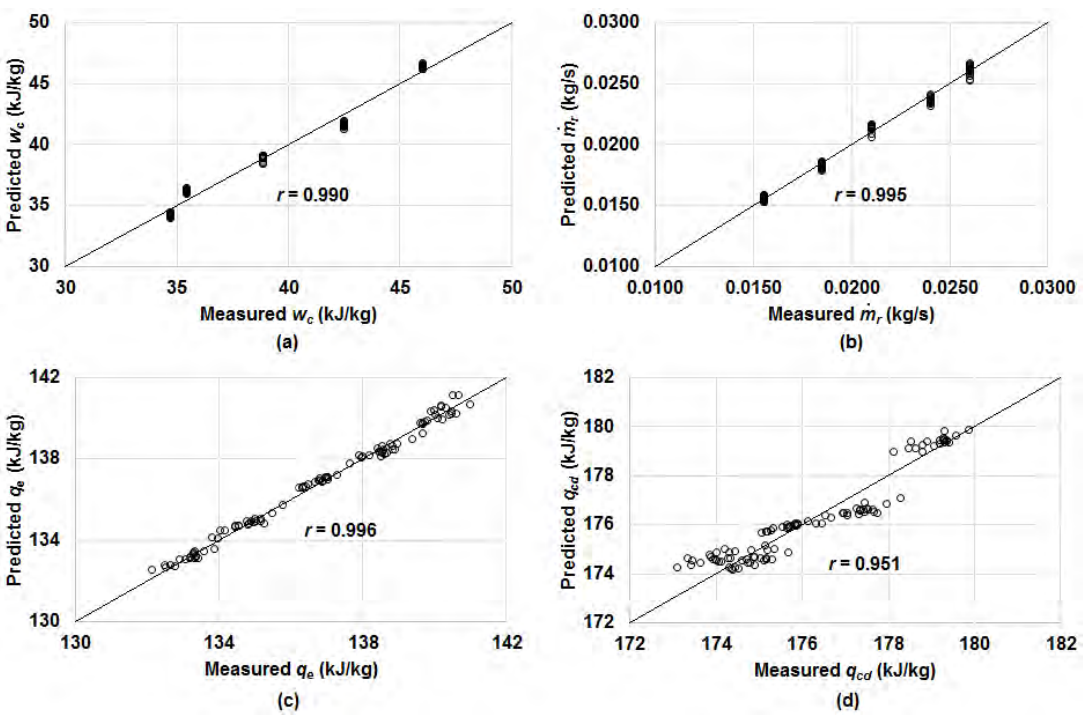


Figure 4.30 Predicted and measured values at $\phi_{a,i,e}$ = 40% and $T_{a,i,e}/T_{a,i,cd}$ = 0.750. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

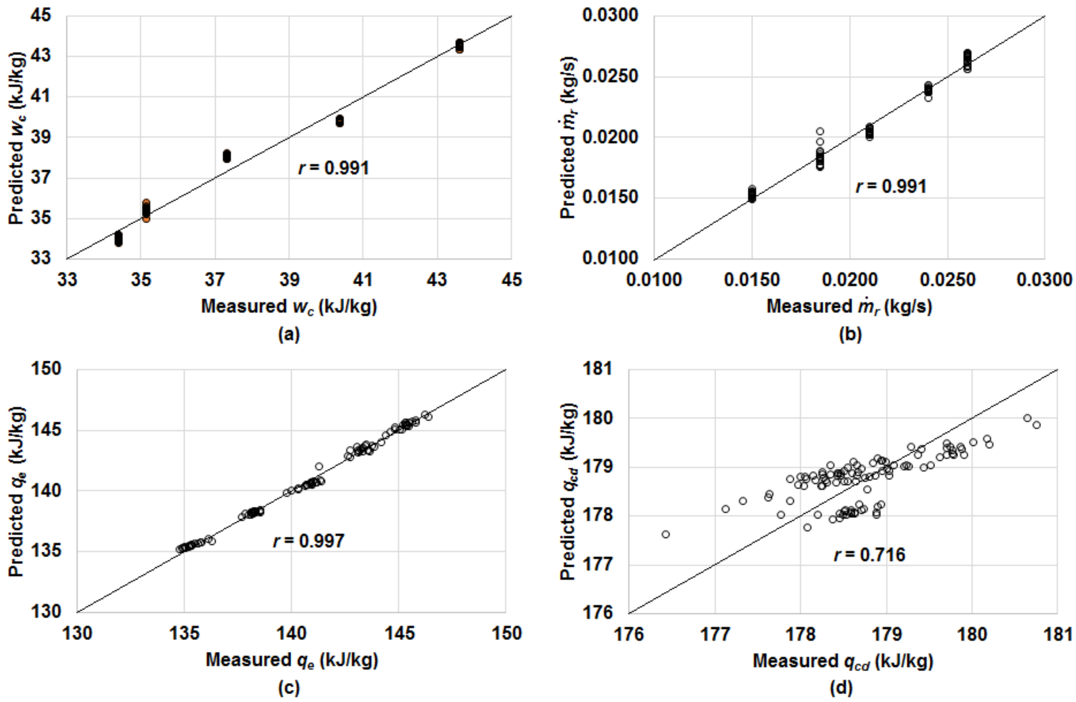


Figure 4.31 Predicted and measured values at $\phi_{a,i,e}$ = 40% and $T_{a,i,e}/T_{a,i,cd}$ = 0.857. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

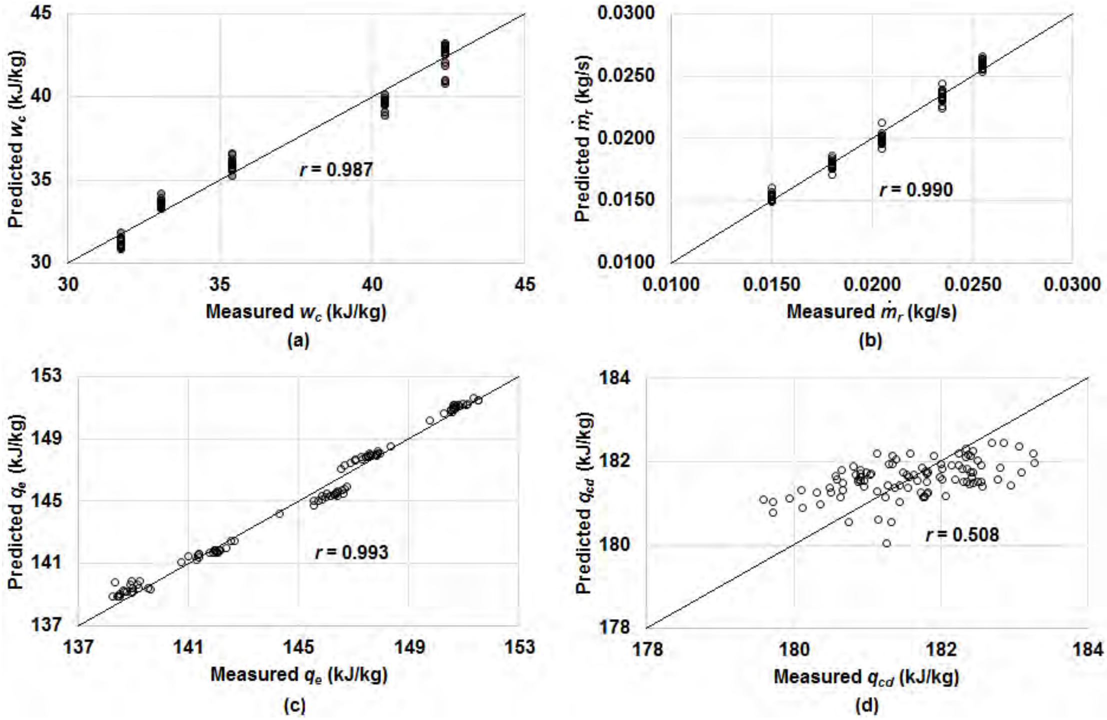


Figure 4.32 Predicted and measured values at $\phi_{a,i,e}$ = 40% and $T_{a,i,e}/T_{a,i,cd}$ = 1.000. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

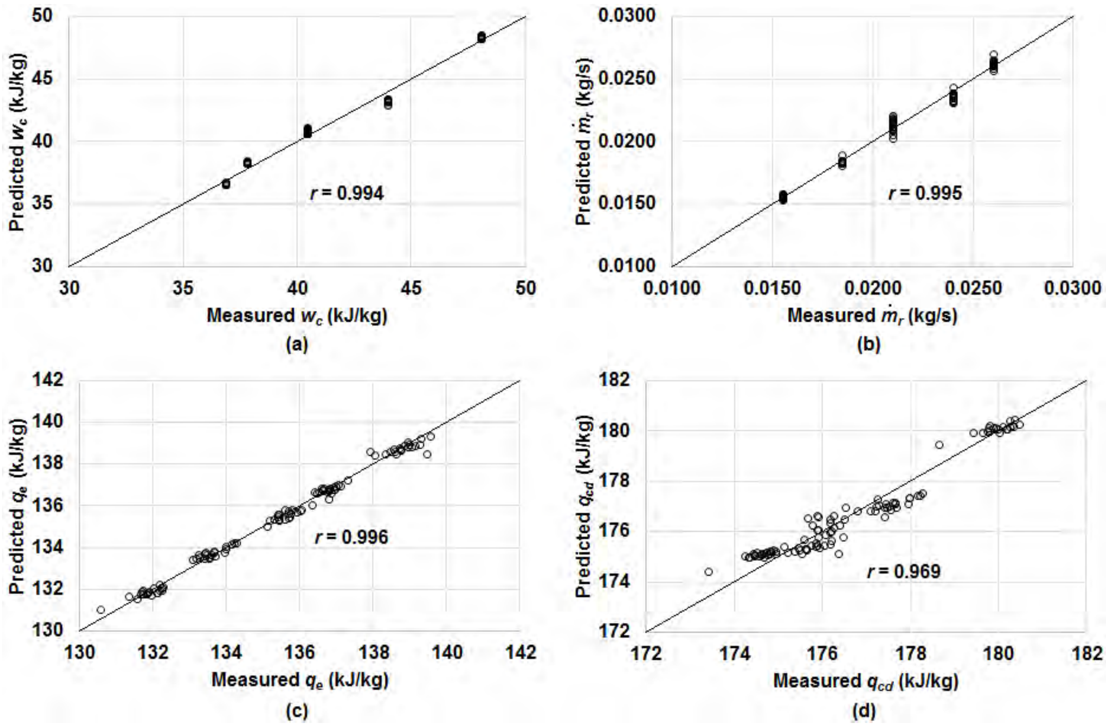


Figure 4.33 Predicted and measured values at $\phi_{a,i,e}$ = 50% and $T_{a,i,e}/T_{a,i,cd}$ = 0.750. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

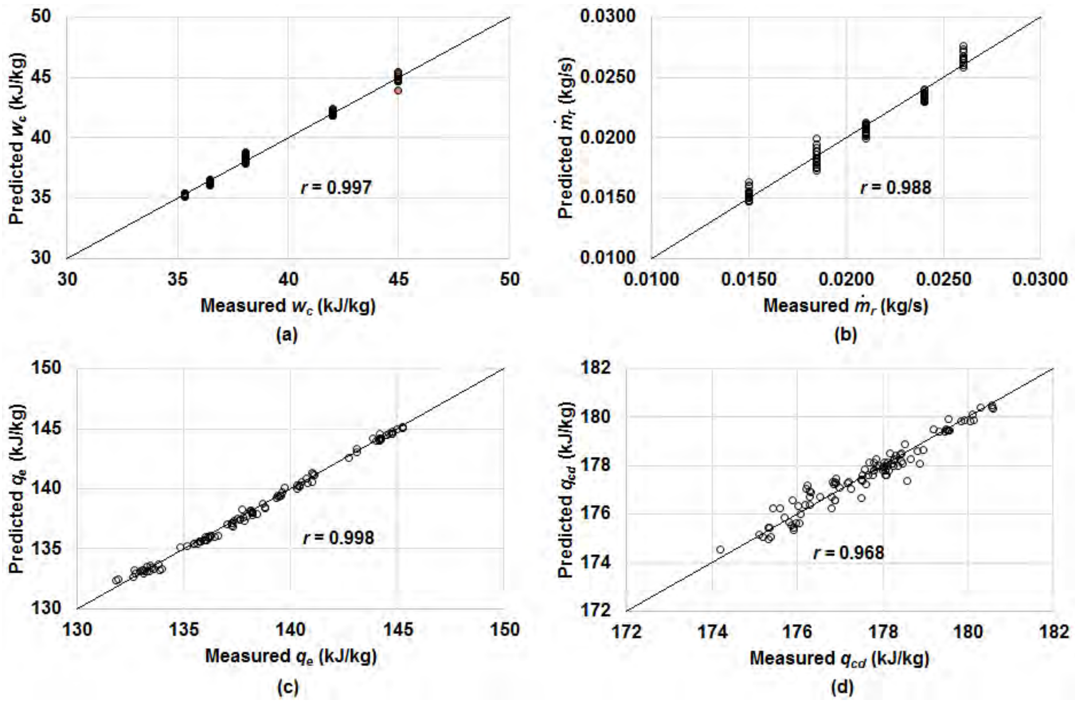


Figure 4.34 Predicted and measured values at $\phi_{a,i,e}$ = 50% and $T_{a,i,e}/T_{a,i,cd}$ = 0.857. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

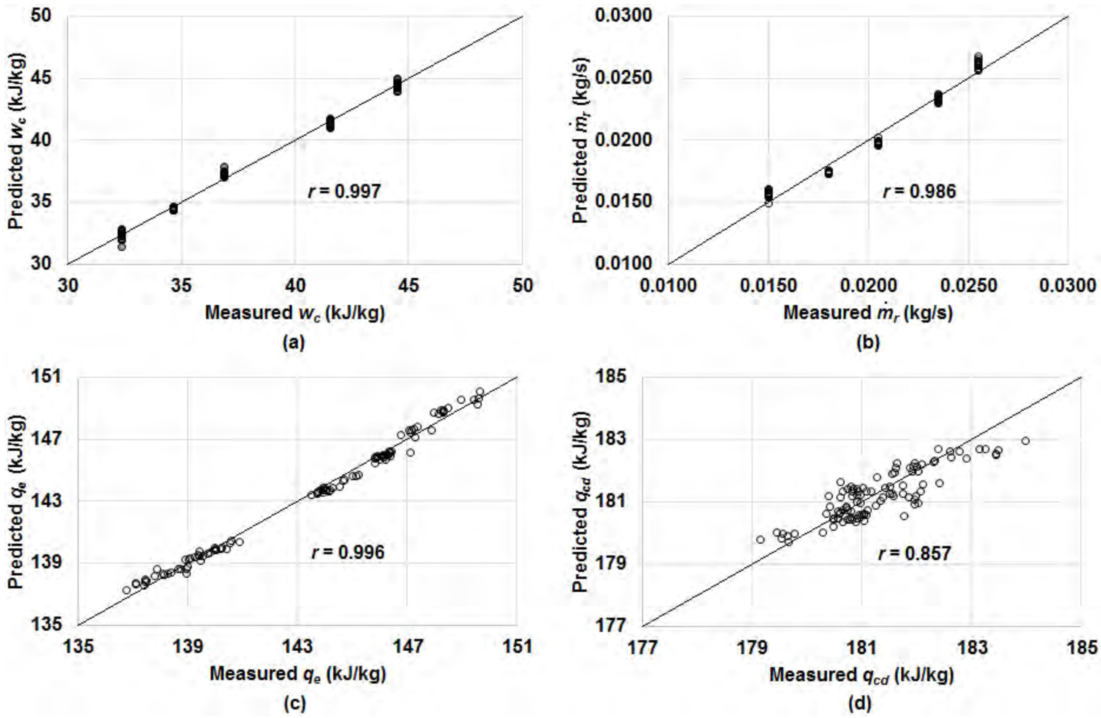


Figure 4.35 Predicted and measured values at $\phi_{a,i,e}$ = 50% and $T_{a,i,e}/T_{a,i,cd}$ = 1.000. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

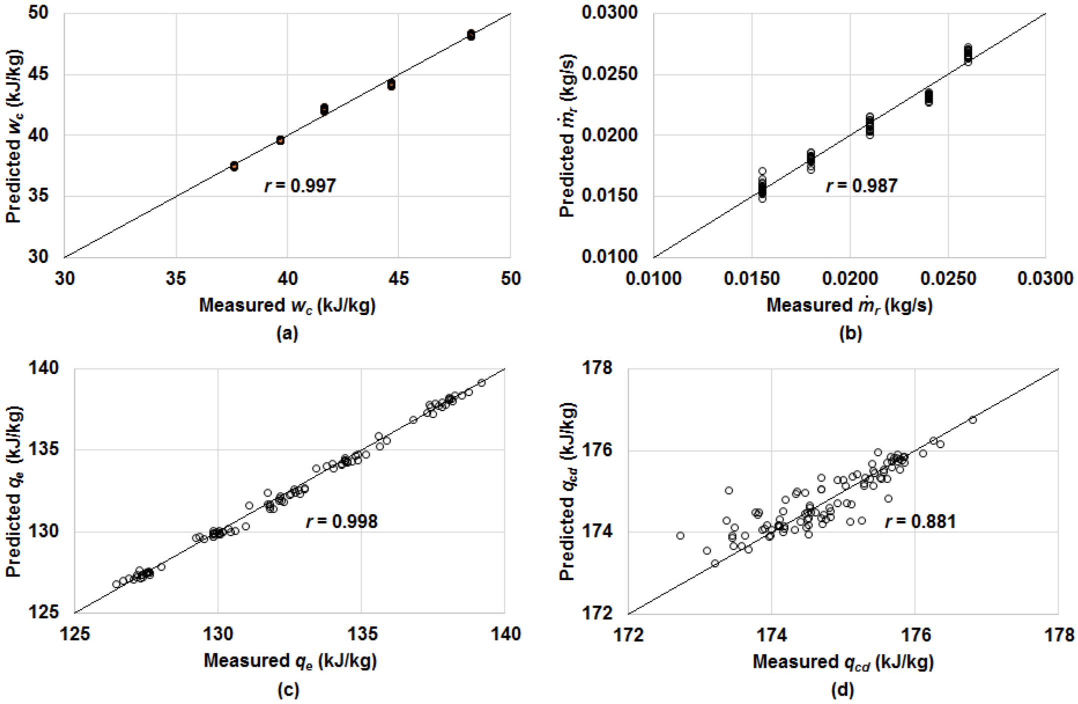


Figure 4.36 Predicted and measured values at $\phi_{a,i,e}$ = 60% and $T_{a,i,e}/T_{a,i,cd}$ = 0.750. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

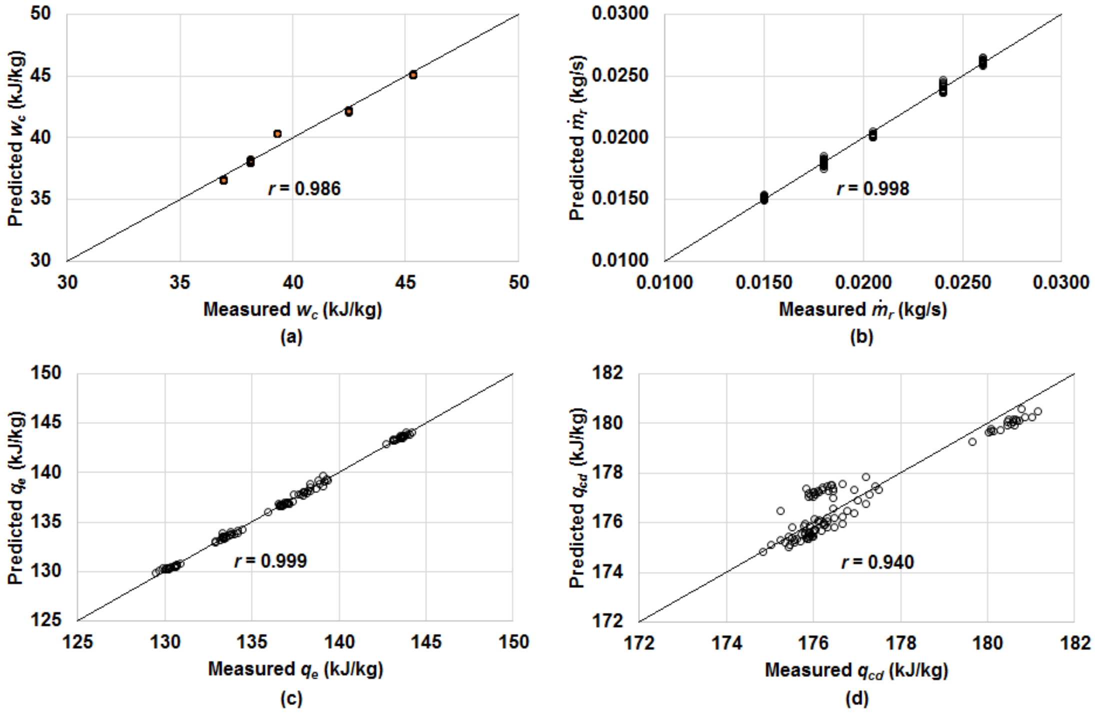


Figure 4.37 Predicted and measured values at $\phi_{a,i,e}$ = 60% and $T_{a,i,e}/T_{a,i,cd}$ = 0.857. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

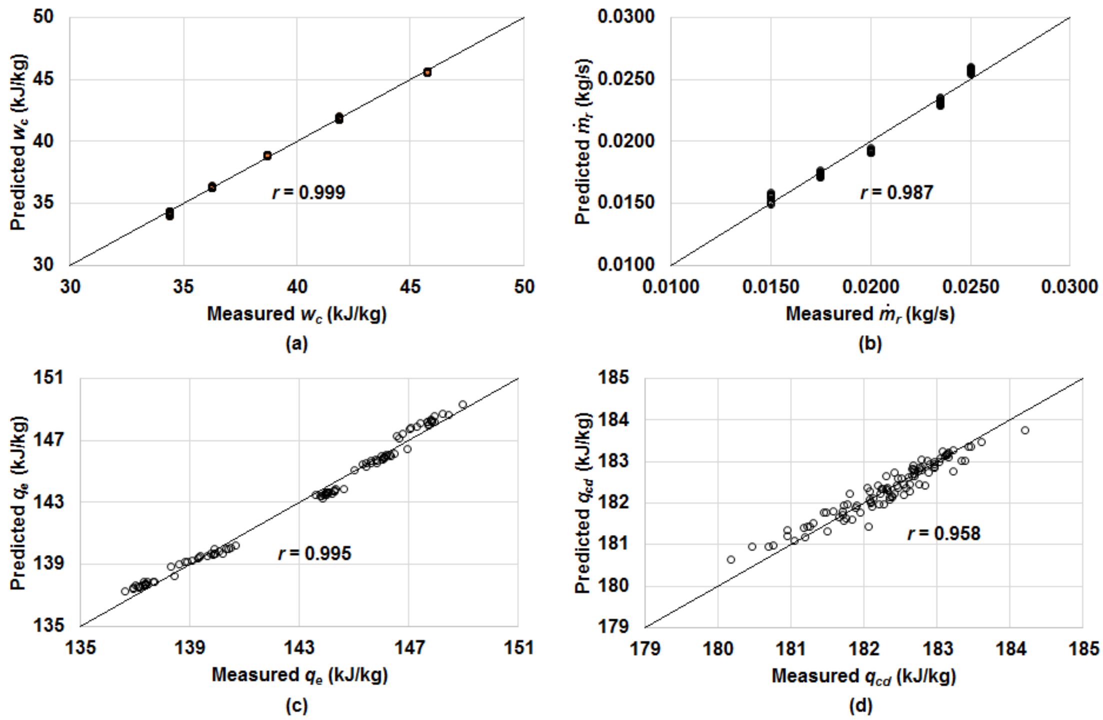


Figure 4.38 Predicted and measured values at $\phi_{a,i,e}$ = 60% and $T_{a,i,e}/T_{a,i,cd}$ = 1.000. (a) compressor work per unit mass of refrigerant, (b) refrigerant mass flow rate, (c) cooling capacity per unit mass of refrigerant, (d) heat rejection rate from condenser per unit mass of refrigerant

CHAPTER 5

RESULTS

5.1 Introduction

Experimental approach is the most effective method of investigating the effects of parametric changes on the thermal and energy performance of an AAC system. However, this approach is costly and time consuming; thus, a simulation program is another option. This tool is useful for identifying the effect of numerous parametric changes on the thermal and energy performance of the AAC system. The simulation approach is more practical because it does not incur too much of the cost and time associated with the actual modification required by the experimental approach.

This chapter demonstrates the application and results of cabin compartment thermal load and compartment-air conditioning models developed in Chapters 3 and 4 as a complete simulation tool of the AAC system for designers and researchers. The parametric study is divided into two sections, namely, cabin compartment thermal load and AAC system performance analyses. The selected parameters are vehicle surface color, occupant number, desired cabin air dry-bulb temperature, vehicle speed, fractional ventilation air intake (*XOA*) and evaporator air volumetric flow rate.

5.2 The Baseline Parameters

The baseline parameters for the base case simulation are presented in Table 5.1. The results serve as a basis for comparison with each parametric change.

Table 5.1 Baseline parameters

Parameters	Specifications
Vehicle speed	~ 90 km/h
Occupant	~ 1 driver and 3 passengers
Vehicle surface color (bodywork)	~ Black color
Evaporator air volumetric flow rate	~ 230 m^3/h
Desired cabin air-dry bulb temperature	~ 20ºC
Desired cabin air humidity ratio	~ 50% RH
Fractional ventilation air intake	~ 0
Travel duration and direction	~ 4 hours (11.00 am to 3.00 pm), heading East
Weather condition	~ Compressed Singapore weather data for typical day two (Mar/Apr) (Senawi, 1992)

The current Malaysia national speed limit for federal and state roads is 90 km/h. This speed is also allowed in expressways. Due to this reason, this speed is chosen as baseline condition. In addition, maximum comfort number of occupant in typical passenger vehicle, that is four (1 driver and 3 passengers) with black vehicle surface color that mostly available in any variant or model of typical passenger vehicles on road are also chosen as baseline condition. The average blower speed between minimum and maximum speeds, allowed by the motor blower (internal fan) of around 230 m^3/h is also selected for baseline condition.

The comfort air temperature and humidity inside the cabin compartment depend on activity and clothing of the occupants (Arora, 2009). By this reason, desired cabin air-dry bulb temperature and humidity ratio of 20ºC and 50% RH are considered appropriate for baseline condition. *XOA* is considered 0 for baseline condition because driving experiences noticed that most of the time, the AAC system is operated on air-circulation mode (*XOA* ~ 0) than fresh air mode (*XOA* ~ 1). Travel duration of 4 hours between 11.00 am to 3.00 pm with compressed Singapore weather data of typical day two (Mar/Apr), and assumption of traveling heading East are considered for baseline condition. It is because, these are the most critical operational hours and weather condition for AAC system due to high cooling capacity shall be supplied by the AAC system, as described in section 4.2.3. The selection of compressed Singapore weather data for this analysis is also described in section 4.2.3.

5.3 Cabin Compartment Thermal Load Analysis

The effects of selected parameters on the cabin cooling load as mentioned in Section 5.1 are investigated in this section. The selected parameters are changed one at a time in the runs, while the other parameters are held constant at the base values.

5.3.1 Effect of Vehicle Surface Color

Figure 5.1 shows the cabin cooling load variations with time for black and white surface colors of the vehicle. The effect of vehicle surface color on cabin cooling loads is significant between 11.00 am to 3.00 pm because of the solar radiation effect on the surface of the vehicle envelope. An object with black surface color absorbs all wavelengths of light and reflects none. The more light the object absorbs, the more heat absorbed since light is form of energy. On the other hand, an object with white surface color reflects all wavelengths of light and therefore absorb the least heat. As black surface colors absorb more heat than that white ones, higher sol-air temperature is created, which further intensifies heat in the cabin compartment during these hours. As a result, cabin cooling load increases because of the increased heat gain especially during the hours when the radiation intensity is high. In this analysis, changing from white to black surface color increases the cabin cooling load of around 142.31 W (5.03%), 158.64 W (5.32%), 157.02 W (5.33%), 140.11 W (4.89%) and 122.73 W (4.47%) for hours past midnight of 11.00, 12.00, 13.00, 14.00 and 15.00 respectively. On average, each hour past midnight from 11.00 to 15.00, the cabin cooling load increases by around 144.16 W (5.01%).

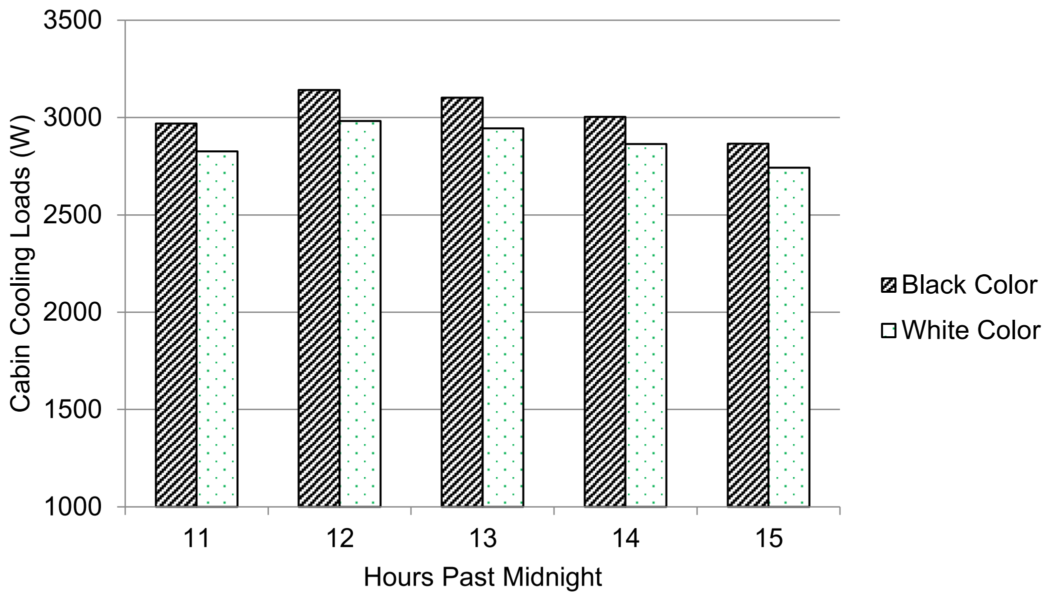


Figure 5.1 Effect of vehicle surface color on cabin cooling load

5.3.2 Effect of Occupant Number

Figure 5.2 shows the simulation results when the cabin is occupied by 1, 2, and 4 persons. Cabin cooling load generally increases with increased number of occupants considering that human beings generate sensible and latent heat loads. Thus, when more people occupy an enclosed space, i.e., a cabin compartment, more sensible and latent heats are generated inside that enclosed space, which results in the rise in the cabin cooling load. In this analysis, it is found that each additional passenger increases the cabin cooling load by 120 W at a cabin temperature of 20°C.

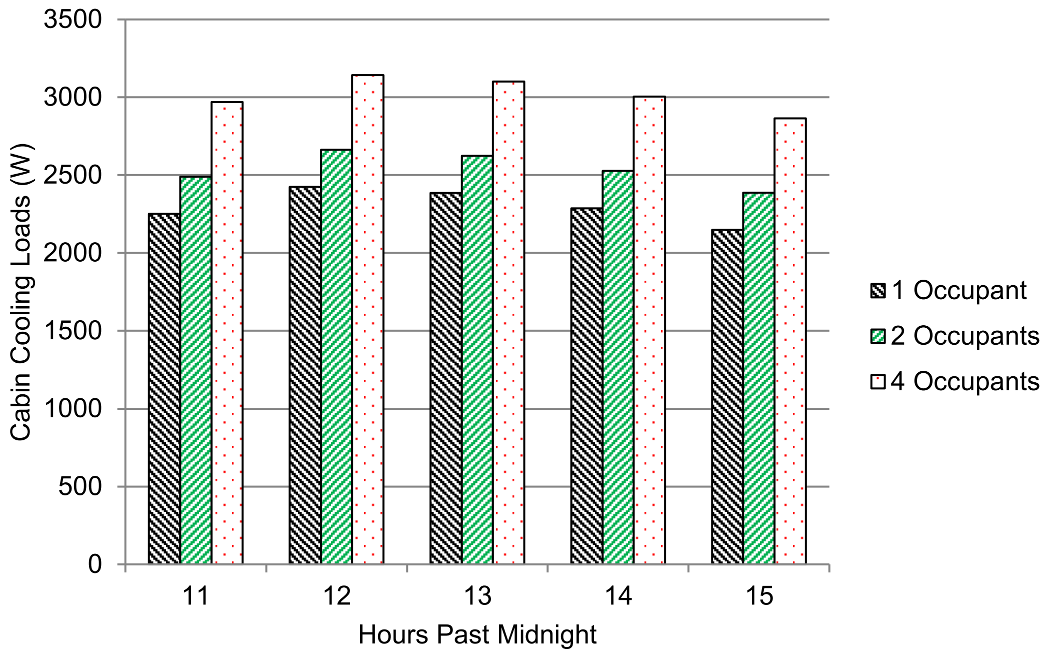


Figure 5.2 Effect of number of occupants on cabin cooling load

5.3.3 Effect of Desired Cabin Air-dry Bulb Temperature

Figure 5.3 illustrates the effect of desired cabin temperature on the cabin cooling loads over time. The result indicates that, the cabin cooling load increases when the desired cabin air-dry bulb temperature decreases. It is found that the decrement of desired cabin air-dry bulb temperature from 22 to 21°C and from 21 to 20°C increase the cabin cooling load by 111.05 W (3.98%) and 110.96 W (3.82%) respectively. On average, decrement of 1°C on desired cabin air-dry bulb temperature from 22 to 20°C increases the cabin cooling load by 111.01 W (3.90%)

In this study, heat transfer is steady-state and all instantaneous heat gains are equal to cooling loads as explained in section 3.3.1. Since heat gain released from occupants varies with air dry-bulb temperature of the conditioned space (Arora, 2009), for simplification, the instantaneous cooling load from occupants generated at air dry-bulb temperature of 24°C is assumed for all desired cabin temperatures. This may be accounted for by the extremely minimal variation in occupant total thermal load at air dry-bulb temperature ranging from 20°C to 35°C (Li and Sun, 2013).

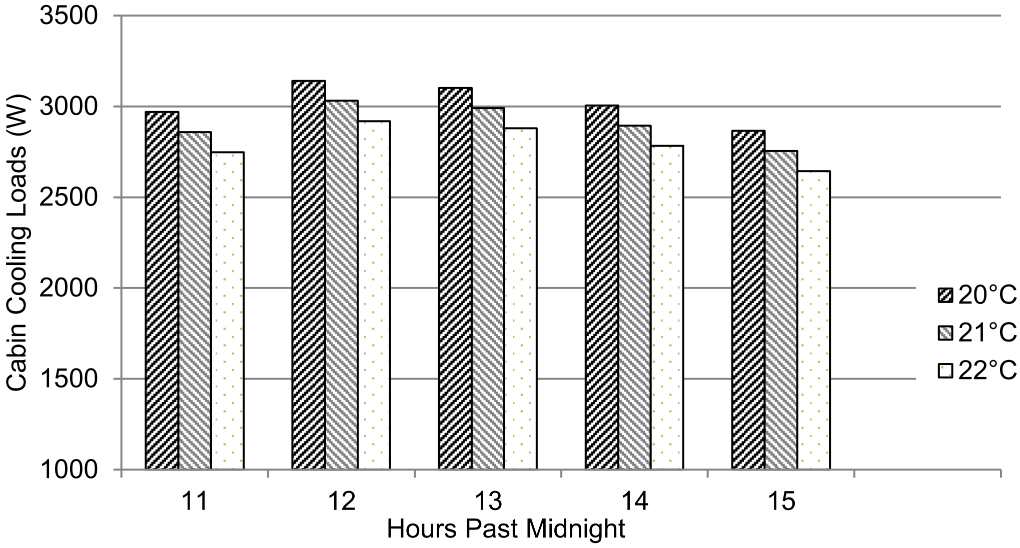


Figure 5.3 Effect of desired cabin temperature on cabin cooling load

5.3.4 Effect of Vehicle Speed

The effect of vehicle speed on cabin cooling load over time is shown in Figure 5.4. The convective heat transfer coefficient on the outside vehicle envelope is obtained from the empirical equation by Shahril *et al*. (2013). Increasing the vehicle speed increases the cabin cooling load because the outside surface convective heat transfer coefficient also increases with increased vehicle speed. As a result, more heat is convected to the passenger cabin space, thereby increasing the cooling load. However, Figure 5.4 clearly shows that the effect of vehicle speed on the cabin cooling load is not significant. The increment of vehicle speed from 70 to 90 $\mathrm{km/h}$ and from 90 to 110 $\mathrm{km/h}$ increase the cabin cooling load by 8.25 W (0.27%) and 6.18 W

(0.21%) respectively. On average, each increment of 20 km/h from 70 to 110 km/h, the cabin cooling load increases by around 7.22 W (0.24%) This result is consistent with the findings of Mohamed Kamar (2008).

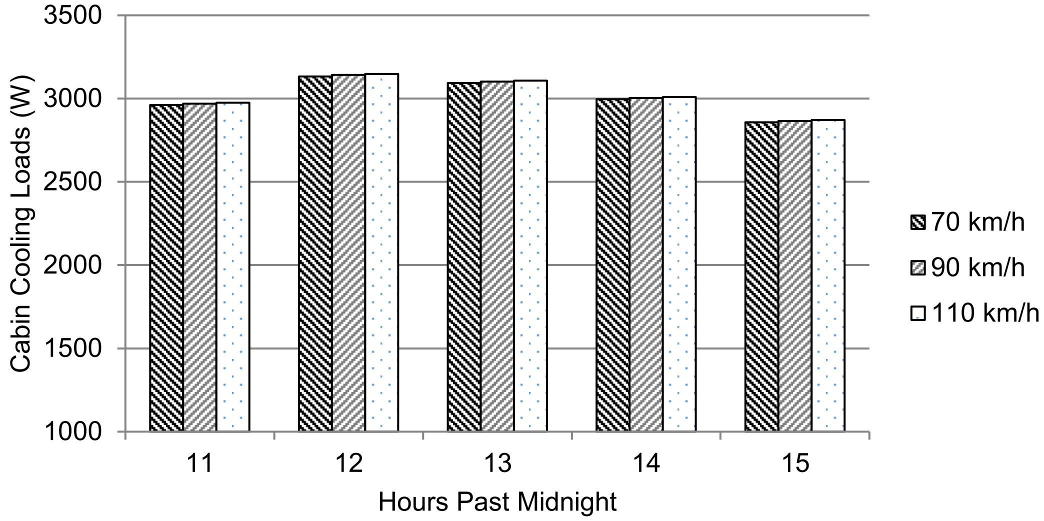


Figure 5.4 Effect of vehicle speed on cabin cooling load

5.4 Automotive Air-conditioning System Performance Analysis

The effects of vehicle surface color, v_{vhc}, XOA, and $\dot{V}_e$ on the Q_e, W_c, COP, $\dot{m}_r$, T_e, and T_{cd} of the AAC system are investigated in this section. The Matlab program, in Appendix L, was developed to solve five (5) simultaneous non-liner equations, namely, Equations (3.42) to (3.46). Again, the selected parameters are changed one at a time, whereas the other parameters are held constant at the base values.

5.4.1 Effect of Vehicle Surface Color

This section discusses the effects of vehicle surface color on Q_e, W_c, *COP*, $\dot{m}_r$, T_e, and T_{cd}. Results are shown in Figures 5.5 to 5.7. Vehicle surface color is determined by surface absorptivity. ASHRAE (2009) proposed surface absorptivity as 0.026 and 0.052 for white and black surface color, respectively. Surface absorptivity indicates a fraction of the absorbed solar radiation incident on the exterior surface of the vehicle. A higher surface absorptivity value denotes that a higher fraction of incident radiation is absorbed by the exterior surface of the vehicle envelope, resulting in the transfer of more absorbed heat to the cabin compartment. As a result, a higher cooling load for dark surface color than light surface color is recorded as in Section 5.2.1. Vehicles with dark surface colors consequently require a higher cooling capacity and compressor work compared to vehicles with light surface colors at the same time of the day. As a result, refrigerant mass flow rate rises with increasing compressor work. However, a dominant increase in compressor power, as opposed to a rise in cooling capacity, leads to the decrement of *COP*. On average, by changing from white to black surface color, the Q_e and W_c increase by around 139.84 W (5.01%) and 89.12 W (10.82%), respectively, whereas the *COP* decreases by 0.18 (5.53%).

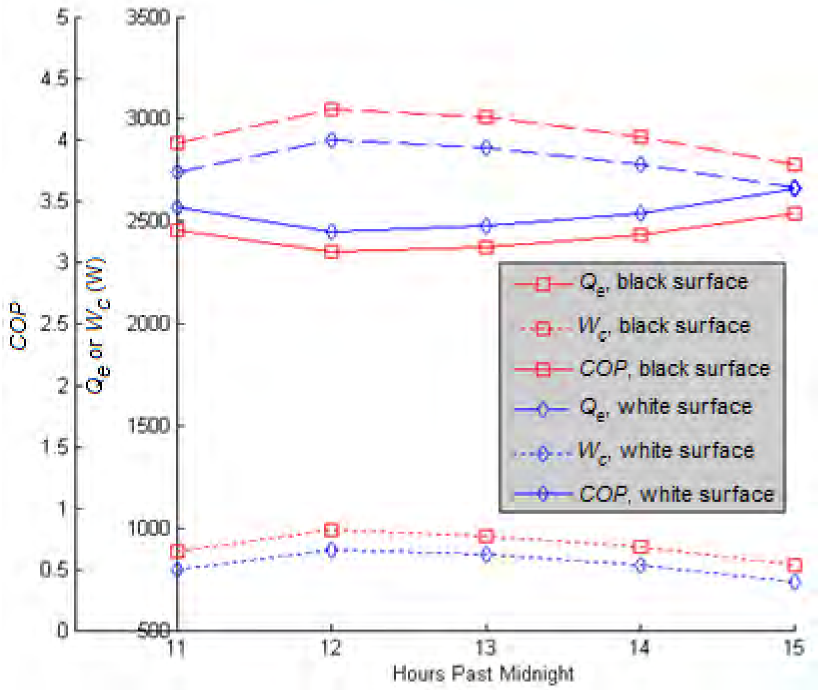


Figure 5.5 Effects of vehicle surface color on cooling capacity, compressor work and coefficient of performance

In addition, the T_e for vehicles with dark surface colors is always lower than that for vehicles with light surface colors at the same time of the day. The T_{cd} is almost identical between 12.00 nn and 13.00 pm. This shows that as a result of system energy balance, the system operates at a lower T_e for a higher Q_e. The T_{cd} is mainly influenced by the compressor discharged temperature because of its direct connection to the condenser coils using a refrigerant pipeline in the AAC circuit. Therefore, the higher the compressor discharged temperature is, the higher the T_{cd}, and vice versa. Given that the compressor discharged temperature is mainly influenced by the condenser ambient temperature (Wang *et al*., 2005), an almost identical value of T_{cd} between 11.00 am and 3.00 pm is expected. This expectation results from the maintained ambient temperature and v_{afc} between 11.00 am and 3.00 pm at 30ºC and 3.0 m/s, respectively, in this simulation.

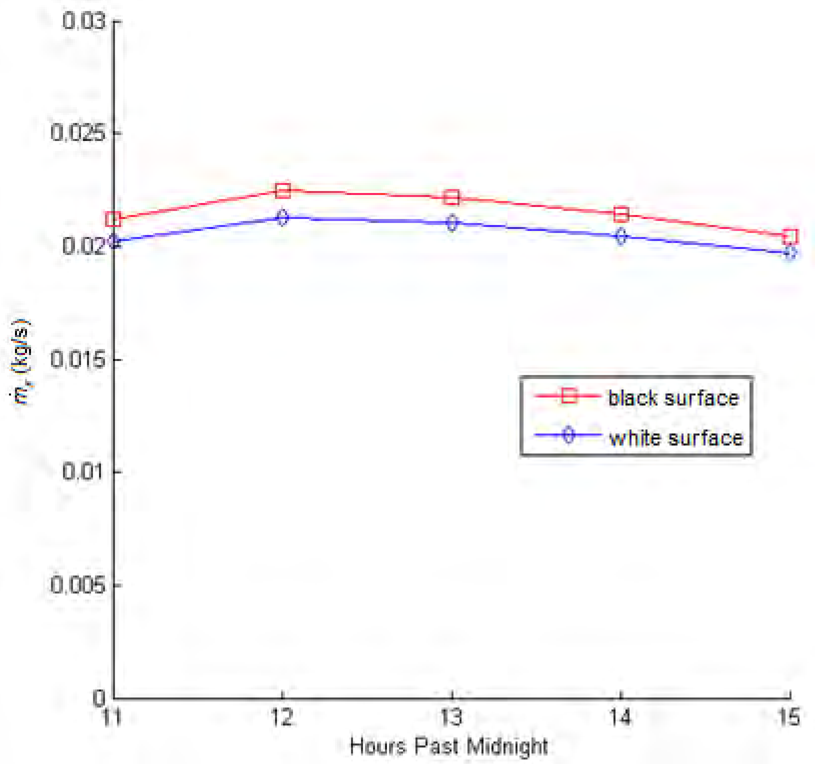


Figure 5.6 Effect of vehicle surface color on refrigerant mass flow rate

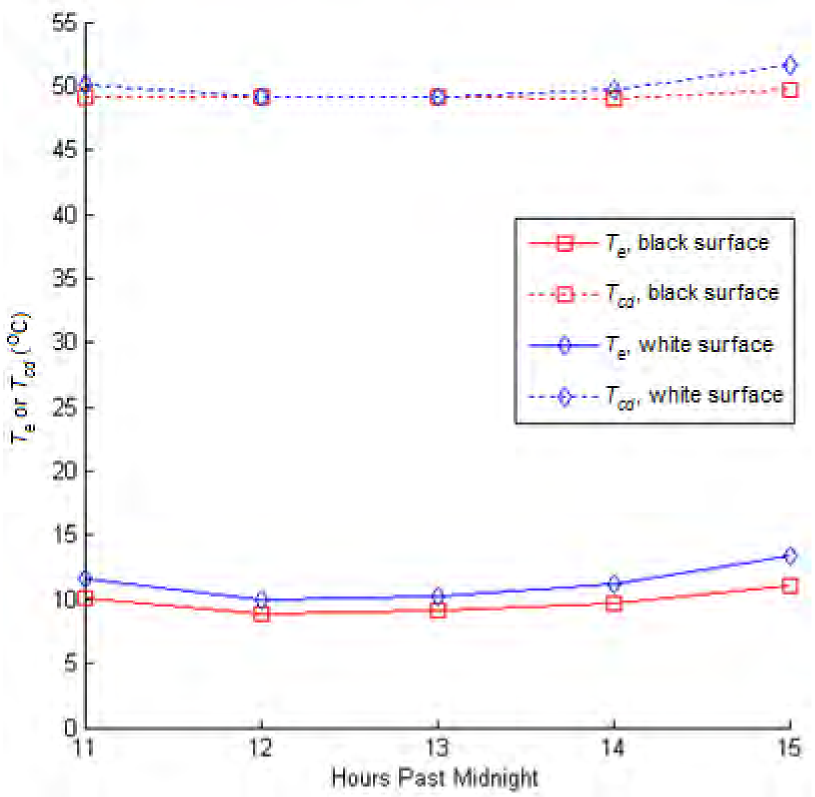


Figure 5.7 Effects of vehicle surface color on evaporating and condensing temperatures

5.4.2 Effect of Vehicle Speed

Vehicle speed is one of the most important vehicle operation variables that are highly dependent on driving conditions, i.e., city driving (typically low vehicle speed) or highway driving (typically high vehicle speed). Vehicle speed directly influences the AAC system performance. In this section, the effects of vehicle speed at 70, 90, and 110 km/h on Q_e, W_c, COP, $\dot{m}_r$, T_e , and T_{cd} are investigated. Results are shown in Figures 5.8–5.10.

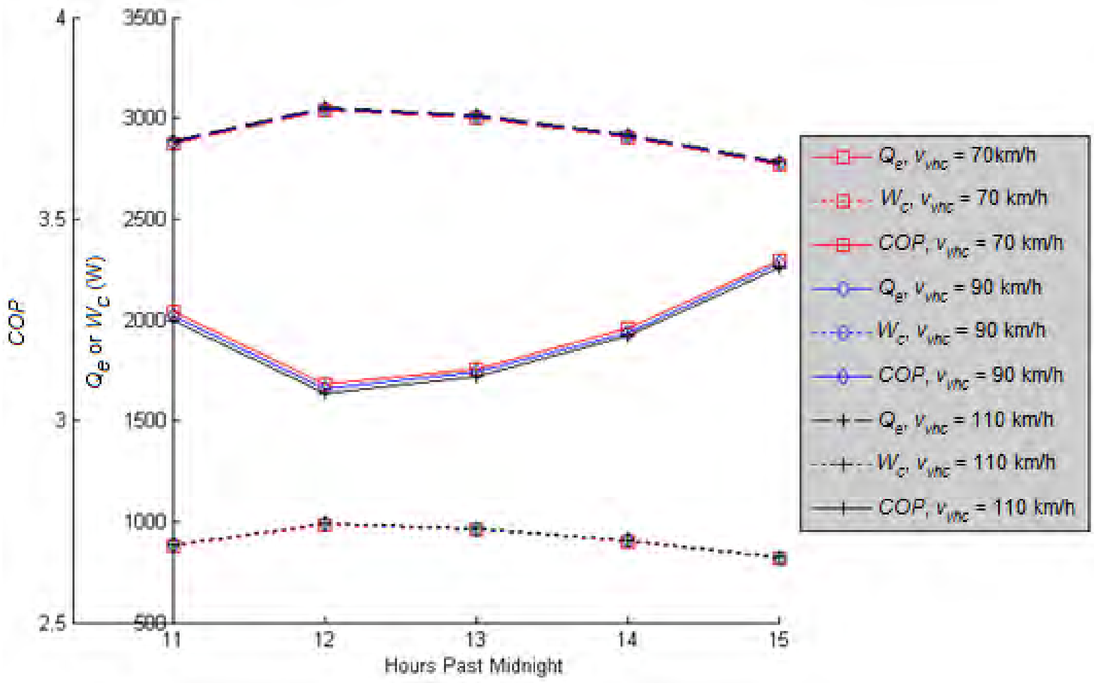


Figure 5.8 Effects of vehicle speed on cooling capacity, compressor work and coefficient of performance

The results obtained from the parametric study indicate that increasing the vehicle speed from 70 km/h to 110 km/h increases the Q_e and W_c; however, it reduces the COP as shown in Figure 5.8. This result is accounted for by the increase in vehicular cooling load with increasing vehicle speed, as discussed in Section 5.2.4. Increases in cooling load leads to increased Q_e. Therefore, the compressor has to rotate faster (considered in the simulation) for the AAC system to produce more Q_e.

Increasing the rotational speed of the compressor directly increases the W_c, which later results in a higher $\dot{m}_r$ (Figure 5.9). In addition, reduction in the T_e of the AAC system (Figure 5.10) occurred at higher Q_e, which confirms the possibility of a bigger temperature difference between cold refrigerant and hotter air. As a result, the higher cooling effect produced by the AAC system is available. Furthermore, the T_{cd} are tabulated in Figure 5.10 because of energy balance. Figures 5.8–5.10 show that the effects of vehicle speed on Q_e, W_c, COP, $\dot{m}_r$, T_e, and T_{cd} are not significant. On average, for each increment of 20 km/h, the Q_e and W_c increase by around 7.00 W (0.24%) and 4.39 W (0.48%), respectively, whereas the COP decreases by 0.1 (0.24%).

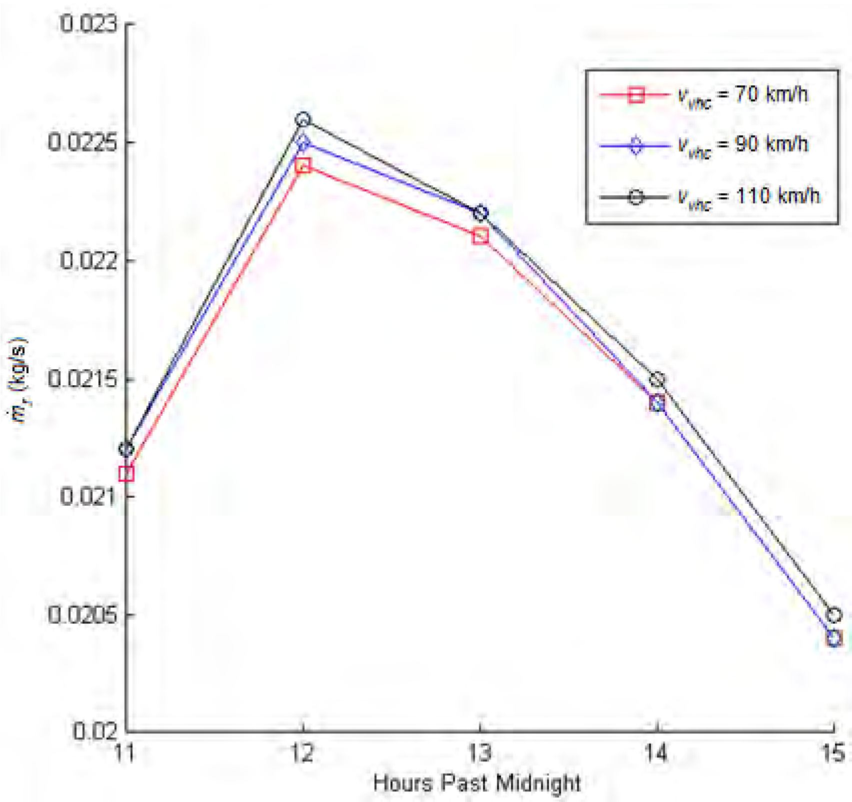


Figure 5.9 Effect of vehicle speed on refrigerant mass flow rate

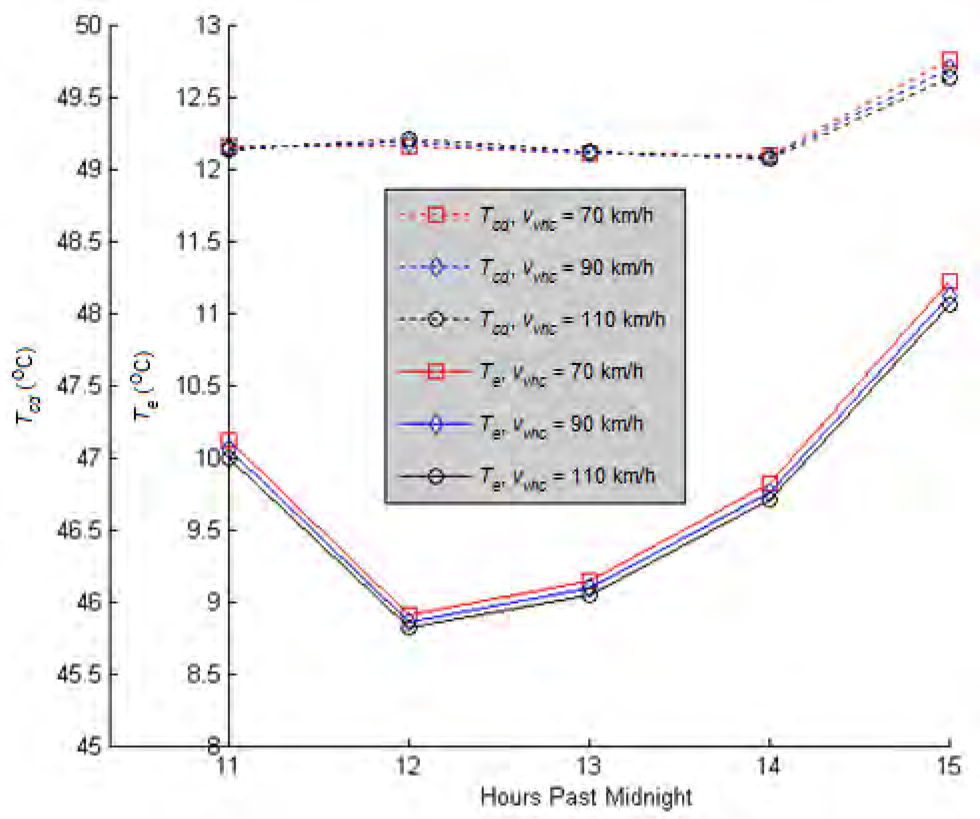


Figure 5.10 Effects of vehicle speed on evaporating and condensing temperatures

5.4.3 Effect of Fractional Ventilation Air Intake

XOA refers to ratio of outside air volumetric flow rate to supply evaporator air volumetric flow rate (supply of cold air to the cabin compartment); its value ranges from 0 for total re-circulation mode, to 1 for total outside fresh air mode (no recirculation of cabin air). Figure 5.11 shows the influences of different *XOA* values to the Q_e, W_c, and *COP* of the AAC system. Increasing *XOA* increases the cooling load as a more humid and hotter outside ambient air is introduced to the cabin compartment. As the air cabin temperature and relative humidity are fixed at the desired values of 20ºC and 50%, respectively, the AAC system responses by producing higher Q_e, which increases W_c as well. However, given that an increase in W_c is more significant than that in Q_e, the *COP* drops at a higher Q_e. On average, the Q_e and W_c increase for every 3% increment of *XOA* by 143.21 W (4.79%) and 55.75 W (5.93%), respectively, whereas the *COP* drops by 0.03 (1.06%). This finding shows that a small amount of fresh air load significantly affects Q_e and W_c, and that it plays an important role in system performance (*COP*).

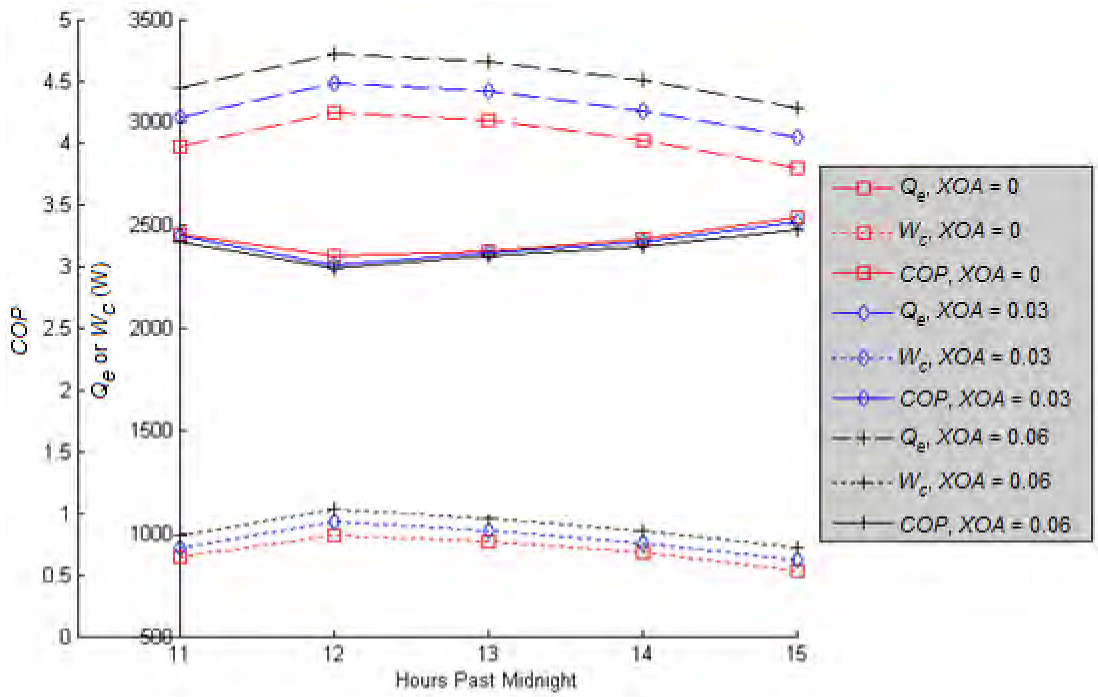


Figure 5.11 Effects of fractional ventilation air intake on cooling capacity, compressor work and coefficient of performance

The W_c increments increase $\dot{m}_r$ (Figure 5.12) and T_e (Figure 5.13). Increment in the T_e is caused by the larger amount of hotter ambient air outside (higher *XOA*) introduced to the cabin compartment by passing through an evaporator coil. Therefore, it has a direct effect on the evaporator and particularly on the T_e. As a result, higher *XOA* increases the evaporator coil surface temperature, which later increases the T_e and T_{cd} (Figure 5.13) in the entire AAC system.

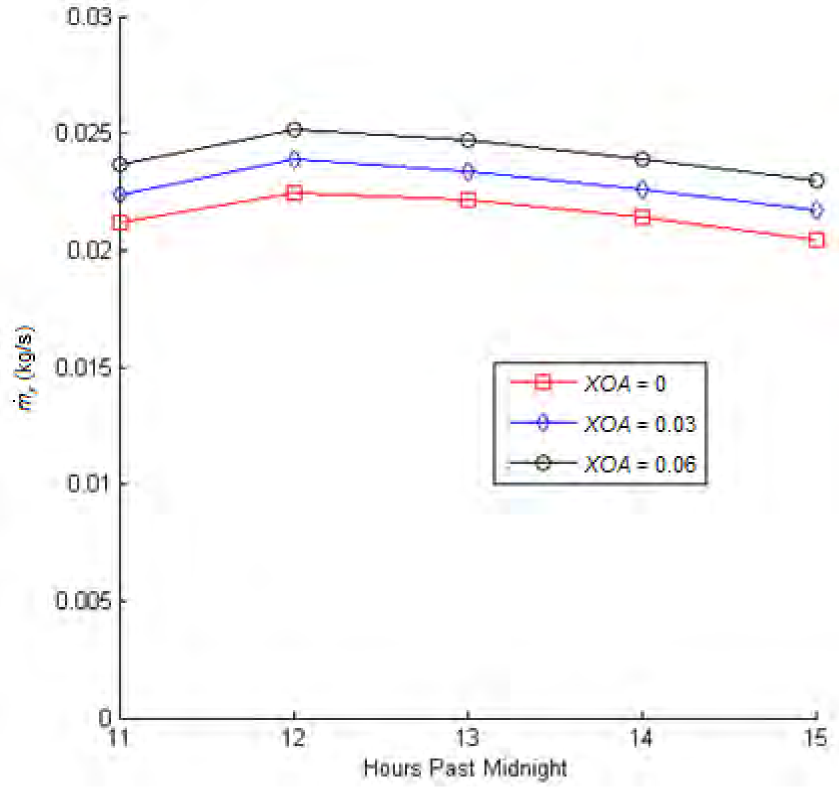


Figure 5.12 Effect of fractional ventilation air intake on refrigerant mass flow rate

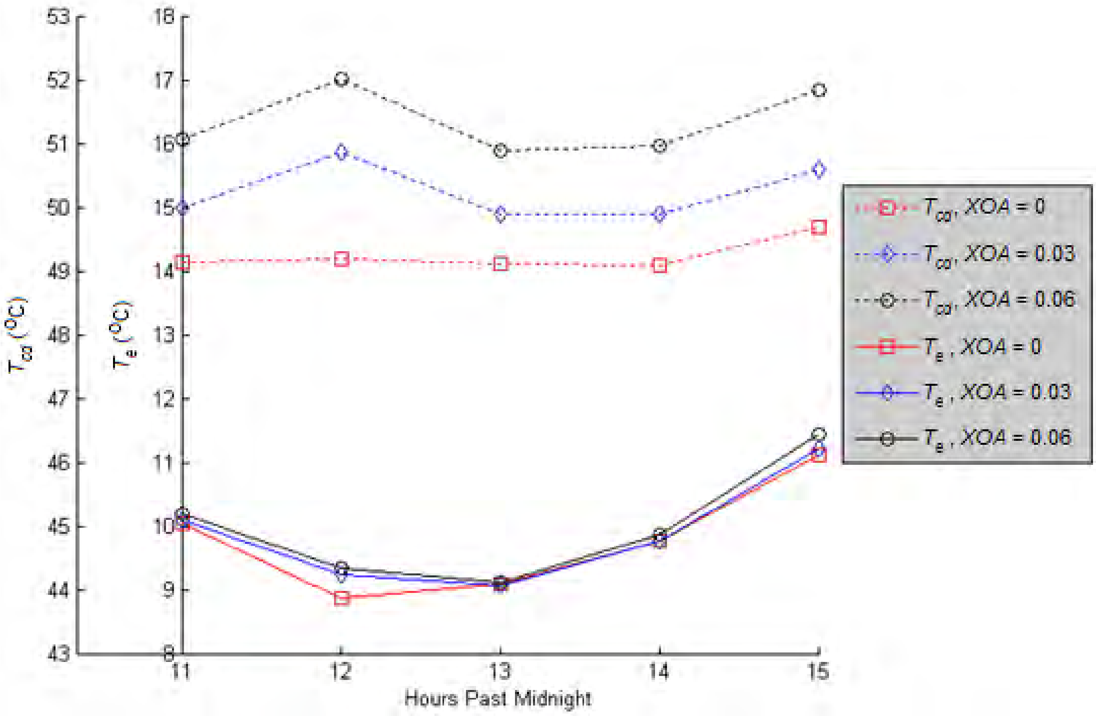


Figure 5.13 Effects of fractional ventilation air intake on evaporating and condensing temperatures

5.4.4 Effect of Evaporator Air Volumetric Flow Rate

This section studies the effects of $\dot{V}_e$ on Q_e, W_c, COP, $\dot{m}_r$, T_e, and T_{cd}. The Q_e depends on cabin compartment cooling load, thus, the $\dot{V}_e$ does not influence the Q_e (Figure 5.14) at any $\dot{V}_e$ variation. At constant Q_e, $\dot{V}_e$ is inversely proportional to W_c. Therefore, the W_c decreases when $\dot{V}_e$ increases, and vice versa. As a result, the decrement or increment of $\dot{V}_e$ significant impacts W_c and COP (Figure 5.14). Furthermore, the increment of $\dot{V}_e$ reduces the compressor work load (W_c) and increases the COP at the same cooling effect. On average, the increment of 10 m^3/h in $\dot{V}_e$ decreases the W_c at around 38.14 W (3.83%) and increases the COP at around 0.12 (3.98%).

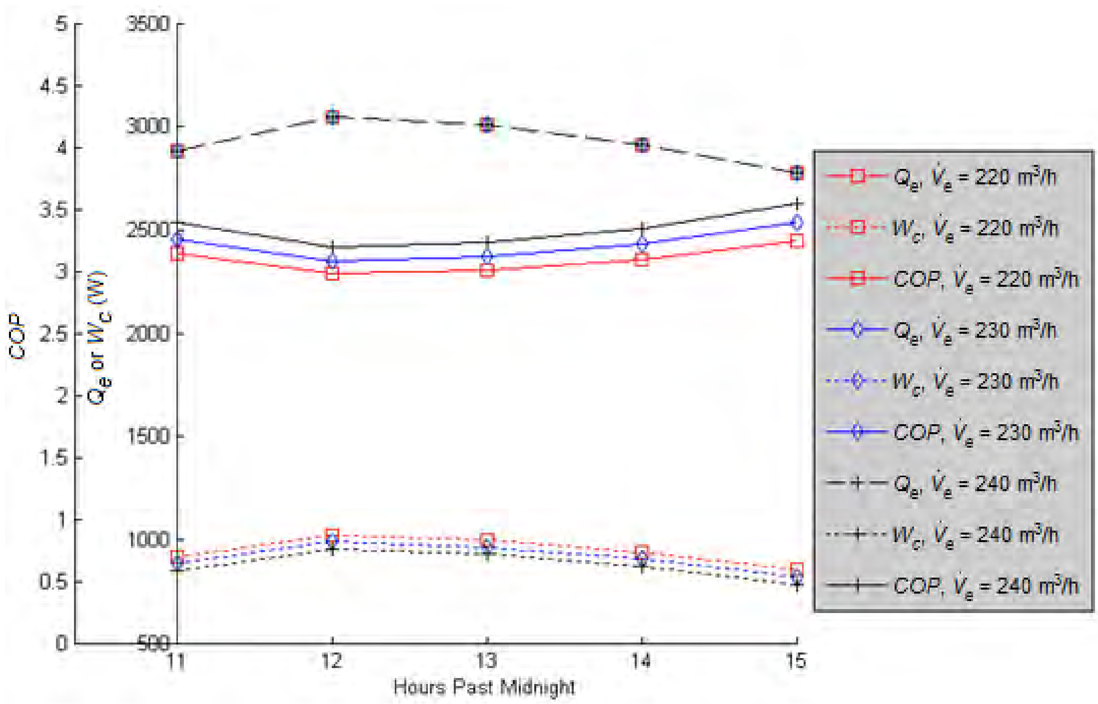


Figure 5.14 Effects of evaporator air volumetric flow rate on cooling capacity, compressor work and coefficient of performance

At constant $\dot{V}_e$, the $\dot{m}_r$ and T_e depend on Q_e, where a higher Q_e leads to increased $\dot{m}_r$ (Figure 5.15) and decreased T_e (Figure 5.16). In addition, the increment in $\dot{V}_e$ slightly causes a decrease in W_c (Figure 5.14) at the same cooling effect (constant Q_e), however, with an increase in $\dot{m}_r$ (Figure 5.15). Furthermore, higher T_e results in higher T_{cd} (Figure 5.16) in the entire AAC system.

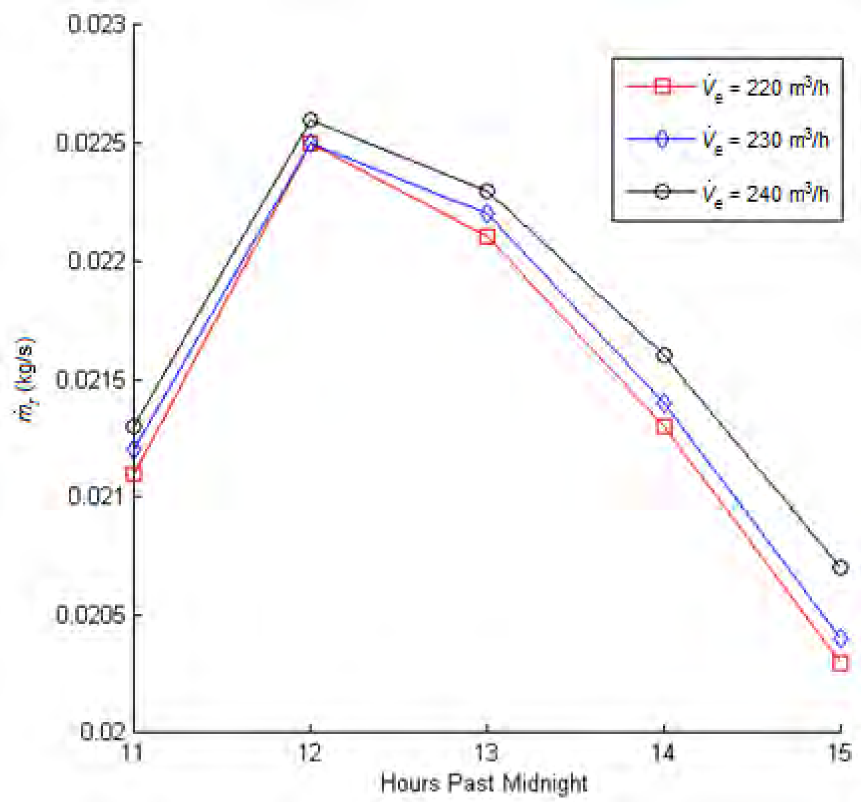


Figure 5.15 Effect of evaporator air volumetric flow rate on refrigerant mass flow rate

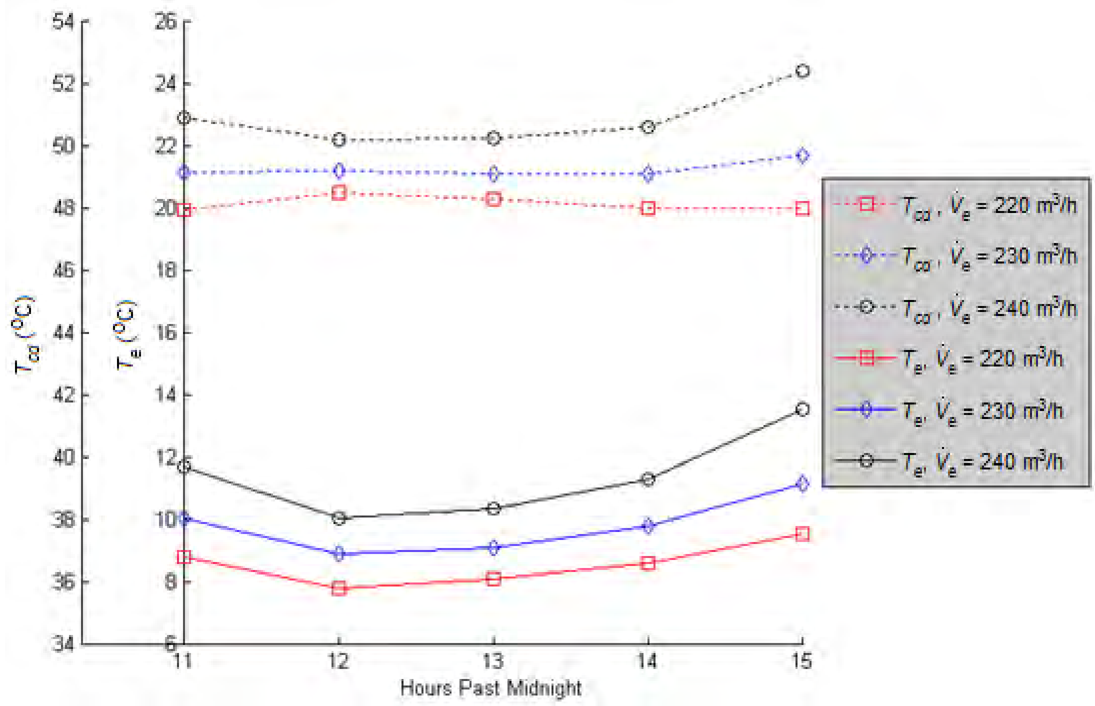


Figure 5.16 Effects of evaporator air volumetric flow rate on evaporating and condensing temperatures

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A semi-empirical AAC system simulation model to simulate the thermal and energy performances of an AAC system has been developed. The development consists of two major models, namely, a cabin compartment thermal load model, and a thermal and energy AAC system performance model. These models are linked via an evaporator-cabin compartment air-side model. By linking these models, we can evaluate the effects of ambient conditions, types and operation of the vehicles, and thermal and energy performances of the AAC system, i.e., Q_e, W_c, COP, $\dot{m}_r$, T_e, and T_{cd}.

Five empirical correlations (off-road air-side evaporator heat transfer correlation and refrigerant-side correlations of compressor work, refrigerant mass flow rate, cooling capacity, and heat rejected from the condenser) in order to link cabin compartment thermal load characteristic to the air and refrigerant sides of the AAC system were developed with good accuracies, were 89% of the total correlations have coefficient of determination, r of more than 0.950. A parametric study from 11.00 am to 3.00 pm reveals that on average,

a. changing from white to black surface color increases the cabin cooling load by 144.16 W (5.01%),

b. each additional passenger increases the cabin cooling load by 120 W,

c. decrement of each 1°C on desired cabin air-dry bulb temperature from 22 to 20°C increases the cabin cooling load by 111.01 W (3.90%),

d. each increment of 20 $\mathrm{km/h}$ in vehicle speed from 70 to 110 $\mathrm{km/h}$, the cabin cooling load increases by 7.22 W (0.24%),

e. the Q_e and W_c increase by around 139.84 W (5.01%) and 89.12 W (10.82%) respectively, whereas the *COP* decreases by 0.18 (5.53%) if the vehicle surface color changes from white to black,

f. each increment of 20 $\mathrm{km/h}$ in vehicle speed from 70 to 110 $\mathrm{km/h}$, the Q_e and W_c increase by around 7.00 W (0.24%) and 4.39 W (0.48%) respectively, whereas the *COP* decreases by 0.1 (0.24%),

g. the Q_e and W_c increase for every 3% increment of *XOA* by 143.21 W (4.79%) and 55.75 W (5.93%) respectively, whereas the *COP* drops by 0.03 (1.06%),

h. the increment of 10 $\mathrm{m^3/h}$ in $\dot{V}_e$ from 220 to 240 $\mathrm{m^3/h}$ decreases the W_c at around 38.14 W (3.83%) and increases the *COP* at around 0.12 (3.98%).

It was found that darker vehicle surface color, an increase in the number of occupants and vehicle speed, and lower cabin temperature tend to increase the cooling load. The vehicle speed does not significantly influence the cooling load profile. Darker surface color, higher vehicle speed, and increase in XOA require higher cooling capacities. As a result, refrigerant mass flow rate increases with compressor work, but the COP decreases. A dominant increase in compressor work, as opposed to an increase in cooling capacity, as well as a prominent decrease in cooling capacity rather than a decline in compressor work, decreases COP.

A lower evaporating temperature occurs at higher cooling capacities, except in the case of XOA. Introduction of hot outside air to the cabin compartment through an evaporator ductwork increases the cooling capacity, evaporator surface temperature, as well as evaporating temperature. Meanwhile, a lower evaporating temperature produces a lower condensing temperature as a result of system energy balance. In another aspect, the increment of evaporator air volumetric flow rate does not influence the cooling capacity, but helps to reduce the compressor work. Consequently, the COP increases with decrement of compressor work.

6.2 Contributions to the Field of Knowledge

This study contributes to thermal and energy AAC system performance evaluation. Utilizing the proposed model simulation can reduce the effort, time, and cost spent on developing AAC systems and vehicles. Therefore, designers and/or engineers are able to understand the best type of vehicles and AAC system operations that can enhance the overall performance of the vehicle, particularly an EV, in the most efficient way.

6.3 Recommendations for Future Work

The two most important aspects of this study are the development of empirical correlation and validation of the entire model simulation. The future research challenges are expanding the predictive ability and strengthening the validation of the AAC system performance simulation models. The following are recommendations toward enhancing the predictive ability and improving the validation of the simulation model.

a. *Minimum stable superheat* is one of the optional operational modes for EEV that can contribute to energy saving of the entire AAC system. During the experimental study, at higher compressor speed, the *minimum stable superheat operation* of EEV caused a continuous reduction in the valve opening of EEV. As a result, the system is cut off because of excessively high pressure (more than 14 bars of gauge pressure) at the refrigerant high-pressure side or excessively low pressure (less than 2 bars of gauge pressure) at the refrigerant low-pressure side. Consequently, the EEV is operated manually at 100% of valve openings. This type of fixed opening degree of EEV operation can be considered as the reference case for variable opening systems, i.e., *minimum stable superheat*. Thus, solutions are necessary for the EEV to work at the *minimum stable superheat* mode so that the performance simulation applies for this type of mode operation.

b. The empirical correlations developed from experimental data are model-specific. More extensive experimental work should be conducted to find a large number of correlations to cover various AAC systems to increase the usefulness of the simulation model.

c. In addition, extensive experimental work for varied operating conditions, i.e., low condenser air inlet temperature of below 30°C is proposed to represent the performance of the AAC system at low ambient temperatures, particularly at night.

d. Compared with the pure physics-based models, data-driven models are more accurate for the developed system. Pure physics models can be introduced to the developed model to increase the scope of the simulation model, so that it can cover varied AAC systems. However, the analyses will be more complex and could result in poor accuracy.

e. Extensive validation of the simulation model should be conducted to achieve more convincing predictive results. Validation through a road test is one of the best options. Therefore, the suitable compressor and refrigerant flow capacity controls should be developed. The complete AAC system can then be installed in an actual EV for road testing.

In short, these recommendations are not carried out in this study due to following constrains

a. Limitation of time dedicated to this study.

b. Limitation of the scope of this study as stated in Section 1.4.

c. Limitation of the experimental test rig, i.e., the condenser ductwork is unable to produce low condenser air inlet temperature of below 30^0C in order to represent the performance of the AAC system at low ambient temperatures, particularly at night.

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APPENDIX A

Compressed Singapore Weather Data for Six Typical Days (Senawi, 1998)

	Time of day (hours past midnight)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Typical day 1: frequency = 59 days(Jan/Feb)																								
T_o	24	24	24	24	24	24	24	25	27	28	29	29	29	29	29	28	28	27	26	25	25	25	25	25
T_{wb}	18	18	18	18	18	18	18	19	19	19	19	19	18	18	18	18	18	18	18	18	18	18	18	18
IDH	0	0	0	0	0	0	2	106	221	300	344	343	318	261	198	124	51	7	0	0	0	0	0	0
Idh	0	0	0	0	0	0	18	49	118	193	251	299	319	313	277	224	150	59	1	0	0	0	0	0
Typical day 2: frequency = 61 days(Mar/Apr)																								
T_o	26	25	25	25	25	25	25	26	28	29	30	30	30	30	30	29	28	28	27	26	26	26	26	26
T_{wb}	19	19	19	19	19	19	19	20	20	20	20	20	20	20	20	19	19	19	19	19	19	19	19	19
IDH	0	0	0	0	0	0	3	132	236	312	345	341	300	232	165	96	32	4	0	0	0	0	0	0
Idh	0	0	0	0	0	0	32	58	128	199	251	292	310	298	269	213	130	41	1	0	0	0	0	0
Typical day 3: frequency = 61 days(May/Jun)																								
T_o	26	26	26	26	25	25	26	27	29	29	30	30	30	30	30	29	29	28	27	27	27	27	26	26
T_{wb}	20	20	20	20	20	20	20	21	21	21	20	20	20	20	20	20	20	20	20	20	20	20	20	20
IDH	0	0	0	0	0	0	3	124	204	255	281	275	252	206	129	76	27	4	2	0	0	0	0	0
Idh	0	0	0	0	0	0	37	58	124	186	233	269	286	271	234	182	106	31	1	0	0	0	0	0
Typical day 4: frequency = 62 days(Jul/Aug)																								
T_o	26	26	26	26	25	25	26	27	28	29	29	29	30	29	29	29	29	28	27	27	27	26	26	26
T_{wb}	20	20	20	20	19	19	20	20	20	20	20	20	19	19	19	19	19	19	19	20	20	20	20	20
IDH	0	0	0	0	0	0	3	101	173	244	284	286	263	212	163	96	42	7	1	0	0	0	0	0
Idh	0	0	0	0	0	0	26	55	122	84	242	278	292	288	263	215	142	48	1	0	0	0	0	0
Typical day 5: frequency = 61 days(Sep/Oct)																								
T_o	26	25	25	25	25	25	27	27	28	28	29	30	30	29	29	29	28	27	27	27	26	26	26	26
T_{wb}	19	19	19	19	19	19	19	20	20	20	20	20	19	19	19	19	19	19	19	20	20	20	20	20
IDH	0	0	0	0	0	0	27	115	191	275	297	308	271	210	144	76	26	3	0	0	0	0	0	0
Idh	0	0	0	0	0	0	22	78	155	221	274	308	308	300	257	198	119	27	0	0	0	0	0	0
Typical day 6: frequency = 61 days(Nov/Dec)																								
T_o	25	25	24	24	24	24	25	26	27	28	28	29	29	28	28	28	27	26	26	25	25	25	25	25
T_{wb}	19	19	18	18	18	18	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
IDH	0	0	0	0	0	0	20	104	191	236	252	229	197	139	103	57	20	3	0	0	0	0	0	0
Idh	0	0	0	0	0	0	21	70	140	204	260	291	289	265	230	167	95	23	0	0	0	0	0	0

APPENDIX B

Analysis of Experimental Variables using Buckingham π -Theorem

1. Number of variable involved.

$T_{a,o,e} = f\left(N_c, v_{afc}, \dot{V}_e, \phi_{a,i,e}, T_{a,i,e}, T_{a,i,cd}\right)$. Therefore, 7 variables are involved.

2. Dimension of each variables

$T_{a,o,e}$ = [C]

N_c = $[T^{-1}]$

v_{afc} = $[LT^{-1}]$

$\dot{V}_e$ = $[L^3T^{-1}]$

$\phi_{a,i,e}$ = -

$T_{a,i,e}$ = [C]

$T_{a,i,cd}$ = [C]

3. Three (3) repeating variables.

N_c, v_{afc}, $T_{a,i,cd}$

4. Number of π.

With 3 repeating variables, number of π is 4 (7 – 3). Therefore,

$\pi_1 = f(\pi_2, \pi_3, \pi_4)$.

5. Formation of each π.

$\pi_1 = T_{a,o,e} \Big/ \left(N_c{}^A v_{afc}{}^B T_{a,i,cd}{}^C\right)$

$C = \left(T^{-1}\right)^A \left(LT^{-1}\right)^B (C)^C$

For T ; $0 = -A - B$; $A = -B$ ……(i)

C ; $1 = C$ ……(ii)

L ; $0 = B$ ……(iii)

Therefore, $\pi_1 = T_{a,o,e} / T_{a,i,cd}$

$$\pi_2 = \dot{V}_e \Big/ \left(N_c{}^A v_{afc}{}^B T_{a,i,cd}{}^C \right)$$

$$L^3T^{-1} = \left(T^{-1}\right)^A \left(LT^{-1}\right)^B (C)^C$$

For T ; $-1 = -A - B$; $A = 1 - B$ ……(i)

C ; $0 = C$ ……(ii)

L ; $3 = B$ ……(iii)

Therefore, $\pi_2 = \dot{V}_e \Big/ \left(N_c{}^{-2} v_{afc}{}^3 \right) = \dot{V}_e\, N_c{}^2 \Big/ v_{afc}{}^3$

$$\pi_3 = T_{a,i,e} \Big/ \left(N_c{}^A v_{afc}{}^B T_{a,i,cd}{}^C \right)$$

$$C = \left(T^{-1}\right)^A \left(LT^{-1}\right)^B (C)^C$$

For T ; $0 = -A - B$; $A = -B$ ……(i)

C ; $1 = C$ ……(ii)

L ; $0 = B$ ……(iii)

Therefore, $\pi_3 = T_{a,i,e} / T_{a,i,cd}$

$$\pi_4 = \phi_{a,i,e}$$

5. Final formation of π.

$$\pi_1 = f\left(\pi_2, \pi_3, \pi_4\right)$$

$$\frac{T_{a,o,e}}{T_{a,i,cd}} = f\left(\frac{\dot{V}_e\, N_c{}^2}{v_{afc}{}^3}, \frac{T_{a,i,e}}{T_{a,i,cd}}, \phi_{a,i,e} \right)$$

APPENDIX C

SIERRA06-0982Y3 Compressor Data Sheet (Masterflux, 2013b)

Cooling Capacity (150V) — BTU/hr (Watt)

	Evaporator Temperature													
RPM	-10°F	(-23°C)	10°F	(-12°C)	20°F	(-7°C)	30°F	(-1°C)	40°F	(4°C)	45°F	(7°C)	55°F	(13°C)
1800	1046	(306)	1955	(572)	2309	(676)	2725	(798)	3301	(967)	3680	(1078)	4678	(1370)
2300	1559	(457)	2690	(788)	3199	(937)	3798	(1112)	4586	(1343)	5081	(1488)	6334	(1855)
2800	1964	(575)	3318	(972)	3981	(1166)	4765	(1395)	5765	(1688)	6378	(1867)	7887	(2309)
3500	2392	(700)	4062	(1189)	4943	(1447)	5985	(1752)	7284	(2133)	8061	(2360)	9930	(2908)

Power Consumption (150V) — Watt | **Current (150V)** — Amp

	Evaporator Temperature (Watt)							Evaporator Temperature (Amp)						
RPM	-10°F	10°F	20°F	30°F	40°F	45°F	55°F	-10°F	10°F	20°F	30°F	40°F	45°F	55°F
1800	286	377	440	493	518	515	465	1.91	2.51	2.93	3.29	3.45	3.43	3.10
2300	399	461	520	573	604	606	572	2.66	3.08	3.46	3.82	4.03	4.04	3.82
2800	510	548	603	659	699	707	691	3.40	3.65	4.02	4.39	4.66	4.72	4.61
3500	664	675	730	793	849	868	880	4.42	4.50	4.86	5.29	5.66	5.79	5.87

Efficiency (150V) — BTU/hr/W (W/W)

	Evaporator Temperature													
RPM	-10°F	(-23°C)	10°F	(-12°C)	20°F	(-7°C)	30°F	(-1°C)	40°F	(4°C)	45°F	(7°C)	55°F	(13°C)
1800	3.65	(1.07)	5.19	(1.52)	5.24	(1.54)	5.53	(1.62)	6.37	(1.87)	7.15	(2.09)	10.05	(2.94)
2300	3.91	(1.14)	5.83	(1.71)	6.16	(1.80)	6.63	(1.94)	7.59	(2.22)	8.38	(2.45)	11.07	(3.24)
2800	3.85	(1.13)	6.06	(1.77)	6.60	(1.93)	7.23	(2.12)	8.25	(2.42)	9.02	(2.64)	11.41	(3.34)
3500	3.60	(1.06)	6.01	(1.76)	6.77	(1.98)	7.55	(2.21)	8.58	(2.51)	9.28	(2.72)	11.28	(3.30)

Cooling Capacity (300V) — BTU/hr (Watt)

	Evaporator Temperature													
RPM	-10°F	(-23°C)	10°F	(-12°C)	20°F	(-7°C)	30°F	(-1°C)	40°F	(4°C)	45°F	(7°C)	55°F	(13°C)
3700	2493	(730)	4254	(1245)	5197	(1522)	6313	(1849)	7698	(2254)	8522	(2495)	10494	(3073)
4500	2844	(833)	4969	(1455)	6164	(1805)	7578	(2219)	9307	(2725)	10320	(3022)	12704	(3720)
5300	3184	(932)	5677	(1662)	7126	(2087)	8839	(2588)	10913	(3195)	12116	(3548)	14915	(4367)
6500	3885	(1138)	6938	(2032)	8770	(2568)	10936	(3202)	13532	(3962)	15022	(4399)	18446	(5401)

Power Consumption (300V) — Watt | **Current (300V)** — Amp

	Evaporator Temperature (Watt)							Evaporator Temperature (Amp)						
RPM	-10°F	10°F	20°F	30°F	40°F	45°F	55°F	-10°F	10°F	20°F	30°F	40°F	45°F	55°F
3700	708	714	769	835	896	919	939	2.36	2.38	2.56	2.78	2.99	3.06	3.13
4500	890	879	940	1021	1106	1145	1204	2.97	2.93	3.13	3.40	3.69	3.82	4.01
5300	1085	1068	1140	1242	1357	1415	1518	3.62	3.56	3.80	4.14	4.52	4.72	5.06
6500	1417	1412	1511	1654	1825	1916	2096	4.72	4.71	5.04	5.51	6.08	6.39	6.99

Efficiency (300V) — BTU/hr/W (W/W)

	Evaporator Temperature													
RPM	-10°F	(-23°C)	10°F	(-12°C)	20°F	(-7°C)	30°F	(-1°C)	40°F	(4°C)	45°F	(7°C)	55°F	(13°C)
3700	3.52	(1.03)	5.96	(1.74)	6.76	(1.98)	7.56	(2.21)	8.59	(2.52)	9.27	(2.72)	11.17	(3.27)
4500	3.19	(0.94)	5.65	(1.66)	6.56	(1.92)	7.42	(2.17)	8.41	(2.46)	9.01	(2.64)	10.55	(3.09)
5300	2.93	(0.86)	5.31	(1.56)	6.25	(1.83)	7.12	(2.08)	8.04	(2.35)	8.56	(2.51)	9.82	(2.88)
6500	2.74	(0.80)	4.91	(1.44)	5.80	(1.70)	6.61	(1.94)	7.41	(2.17)	7.84	(2.30)	8.80	(2.58)

* all points are with 18.33°C (65°F) suction temperature, 8.33°C (15°F) subcooling, 55.4°C (130°F) condenser

APPENDIX D

Condenser Air Face Velocity Sample Data Measurements

(a) 10 Hz

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	0.91	0.61	0.99	0.99	0.79	0.58	0.62	0.97	0.58
20	1.07	0.44	0.89	1.01	0.46	0.91	0.71	0.97	0.55
30	0.91	0.96	1.13	1.12	0.70	0.84	0.85	1.02	0.71
40	0.99	0.70	1.03	1.00	0.78	1.21	0.52	0.97	0.66
50	0.95	0.77	1.07	1.05	0.56	1.25	0.58	0.99	0.77
60	0.93	0.75	0.99	0.85	0.91	1.00	0.36	1.01	0.71
70	0.92	0.77	1.08	1.05	0.34	1.16	0.59	0.84	0.64
80	1.04	0.77	1.05	1.02	0.71	1.06	0.56	1.03	0.37
90	0.87	0.81	1.02	1.03	0.77	1.10	0.68	0.99	0.44
100	0.94	0.78	1.08	1.00	0.63	1.20	0.69	1.05	0.57
110	0.95	0.98	1.04	1.07	0.59	0.35	0.66	1.03	0.59
120	0.92	0.59	0.99	1.12	0.26	0.79	0.62	1.06	0.59
130	0.84	0.78	0.97	0.99	0.65	1.01	0.55	0.92	0.34
140	0.95	0.91	1.04	1.11	0.66	0.84	0.57	1.04	0.39
150	0.85	0.56	1.08	1.06	0.54	0.72	0.51	1.00	0.37
160	0.98	0.83	1.06	1.07	0.42	1.09	0.93	1.07	0.59
170	0.89	0.82	1.05	1.11	0.68	1.04	0.66	1.09	0.58
180	1.02	0.73	1.06	1.09	0.61	1.19	0.52	0.92	0.81
190	0.93	0.80	0.89	1.12	0.76	1.19	0.42	1.03	0.68
200	0.87	0.91	1.04	1.02	0.73	1.12	0.47	1.00	0.47
210	0.89	0.72	1.00	0.93	0.71	0.80	0.59	1.04	0.50
220	0.89	0.71	1.02	1.04	0.29	1.02	0.74	1.02	0.53
230	0.87	0.81	1.03	1.13	0.62	0.79	0.57	0.77	0.51
240	0.86	0.73	1.00	1.08	0.56	0.99	0.74	1.04	0.45
250	0.96	0.45	1.05	1.04	0.71	0.93	0.84	0.98	0.59
260	0.91	0.83	1.08	0.74	0.96	1.07	0.59	1.04	0.45
270	0.89	0.81	1.06	0.98	0.77	0.65	0.61	1.02	0.53
280	0.92	0.92	1.05	0.99	0.77	0.88	0.57	0.95	0.54
290	1.08	0.53	1.06	0.82	0.65	1.12	0.50	1.02	0.50
300	0.78	0.78	0.98	0.84	0.56	1.12	0.66	1.04	0.59
Average	0.93	0.75	1.03	1.02	0.64	0.97	0.62	1.00	0.55

(b) 20 Hz

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	2.31	1.54	2.66	2.22	0.87	1.87	0.70	1.84	0.50
20	2.47	1.77	2.33	2.27	1.10	1.95	1.11	1.61	1.47
30	2.13	1.41	2.47	2.27	1.59	1.88	1.56	1.77	0.94
40	2.61	1.80	2.33	2.14	0.64	1.85	0.84	1.90	0.57
50	2.53	1.95	2.57	2.12	1.55	1.85	0.96	1.36	0.62
60	2.29	1.51	2.57	2.42	1.53	1.84	0.91	1.67	0.45
70	2.29	1.84	2.35	2.26	1.41	1.98	1.18	1.82	0.93
80	2.13	1.43	2.37	2.25	1.01	1.76	1.12	1.57	0.79
90	2.31	1.72	2.71	2.41	0.58	2.05	0.99	1.97	0.70
100	2.40	1.69	2.88	2.30	0.72	1.96	0.78	1.54	0.89
110	2.15	1.74	2.58	2.11	0.86	1.78	1.25	1.98	0.77
120	2.15	1.27	2.59	2.16	0.82	1.56	0.75	1.51	0.74
130	2.31	1.57	2.82	2.10	0.94	1.86	1.11	1.73	0.59
140	2.28	1.51	2.70	2.17	1.79	1.90	0.90	1.99	0.91
150	2.14	1.44	2.13	2.17	1.21	1.96	0.86	1.41	0.73
160	2.18	1.13	2.74	2.20	0.78	1.80	1.00	1.72	0.57
170	2.32	1.58	2.42	2.14	1.47	1.80	0.98	1.96	0.34
180	2.14	1.59	2.74	2.29	0.82	2.04	1.36	2.00	0.70
190	2.39	1.68	2.61	2.17	0.46	1.65	1.16	1.63	0.95
200	2.56	1.39	2.74	2.10	0.62	1.92	1.30	1.52	0.59
210	2.40	1.01	2.66	2.17	0.91	1.70	0.92	1.84	0.64
220	2.32	1.35	2.44	2.17	0.94	2.12	1.22	1.71	0.84
230	2.20	1.36	2.63	2.16	0.69	1.78	1.66	1.64	0.88
240	2.31	1.63	2.30	2.22	1.58	1.88	1.49	1.96	0.32
250	2.44	1.38	2.68	2.11	0.92	1.68	1.66	1.81	0.67
260	2.28	1.56	2.63	2.33	0.78	1.49	1.21	1.54	0.47
270	2.21	1.41	2.57	2.20	1.49	1.90	0.91	1.41	0.69
280	2.25	1.56	2.60	2.07	0.87	2.05	1.25	1.86	0.56
290	2.28	1.59	2.64	2.16	0.85	2.07	1.38	1.96	0.33
300	2.16	1.45	2.43	2.19	0.43	1.38	1.39	1.58	0.74
Average	2.30	1.53	2.56	2.20	1.01	1.84	1.13	1.73	0.70

(c) 30 Hz

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	3.29	1.91	3.60	2.58	1.98	2.44	1.16	2.18	1.17
20	3.38	1.63	3.45	2.63	1.21	2.57	1.18	2.52	1.66
30	3.26	1.81	3.47	2.17	1.55	2.46	1.13	2.58	1.54
40	3.38	2.12	3.51	2.56	1.91	2.46	1.02	2.42	0.98
50	3.36	1.27	3.57	2.15	1.86	2.48	1.09	2.49	0.95
60	3.72	2.19	3.49	2.64	1.41	2.72	1.13	2.86	1.19
70	4.41	1.73	3.43	2.66	1.17	2.66	0.87	2.05	1.24
80	3.42	1.64	3.46	2.33	1.59	2.28	1.56	2.20	1.32
90	3.51	1.07	3.60	2.47	1.19	2.25	1.39	2.76	1.59
100	3.29	1.56	3.43	2.33	1.90	2.90	0.82	2.28	1.05
110	3.48	1.35	3.57	2.57	1.25	2.79	1.14	2.05	1.15
120	3.29	1.81	3.70	2.57	1.36	2.74	1.05	2.89	1.04
130	3.33	1.62	3.25	2.35	1.99	2.58	1.17	2.03	1.33
140	3.40	1.63	3.68	2.37	1.85	2.68	1.04	2.34	1.57
150	3.52	1.60	3.37	2.71	1.44	2.67	0.95	2.29	1.42
160	3.53	1.63	3.47	2.88	1.69	2.59	1.06	2.33	1.09
170	3.50	1.77	3.58	2.58	1.64	2.67	1.13	2.24	1.36
180	3.58	2.14	3.54	2.59	1.99	2.51	1.26	2.54	0.89
190	3.36	2.02	3.30	2.82	1.79	2.88	1.08	2.10	1.00
200	3.57	1.85	3.44	2.70	1.41	3.03	1.01	2.28	0.55
210	3.20	2.45	3.56	2.13	1.60	2.61	0.86	2.20	1.07
220	3.53	1.47	3.29	2.74	1.72	2.76	0.90	2.31	0.93
230	3.46	1.69	3.48	2.42	1.29	2.45	1.14	2.24	1.22
240	3.12	1.65	3.64	2.74	1.18	2.73	1.04	2.92	1.14
250	3.63	1.86	3.63	2.61	1.92	2.76	1.01	2.35	1.16
260	3.45	1.71	3.43	2.74	1.20	2.39	1.34	2.68	0.84
270	3.48	1.81	3.41	2.66	1.88	2.89	1.09	2.42	0.73
280	3.41	2.13	3.47	2.44	1.33	2.75	1.12	2.19	1.39
290	3.49	1.52	3.73	2.63	2.01	2.53	1.23	2.29	1.24
300	3.38	1.78	3.56	2.30	1.25	2.70	0.99	2.47	1.00
Average	3.46	1.75	3.50	2.54	1.59	2.63	1.10	2.38	1.16

(d) 40 Hz

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	4.12	3.38	4.51	4.16	3.16	4.12	2.57	3.22	1.15
20	4.71	3.05	4.94	3.98	3.12	4.12	2.24	3.44	1.75
30	5.02	3.28	4.66	4.01	3.34	3.93	2.27	3.53	1.81
40	4.90	3.71	4.97	4.03	3.46	4.07	2.12	3.41	1.39
50	4.98	3.36	4.78	4.10	2.98	3.93	2.20	3.23	1.02
60	4.75	3.60	4.89	3.98	2.90	3.77	2.68	3.50	1.05
70	4.90	3.13	4.78	4.11	2.78	4.24	1.99	3.22	1.44
80	4.74	3.22	4.71	4.13	3.14	3.99	3.12	3.25	1.97
90	4.54	3.70	4.48	4.12	3.17	3.86	1.84	3.33	1.89
100	4.70	3.31	4.50	4.00	2.90	3.99	2.79	3.29	1.88
110	4.47	3.36	4.83	4.18	2.81	4.19	2.53	3.25	1.75
120	4.82	3.06	4.74	3.93	3.07	4.24	2.46	3.53	1.25
130	4.63	3.01	4.84	4.12	2.82	4.37	2.35	3.40	1.29
140	4.63	3.12	4.85	4.27	3.12	4.15	2.22	3.17	1.71
150	4.85	2.96	4.63	4.28	2.95	4.03	2.98	3.33	1.77
160	4.73	3.04	4.65	4.17	2.45	3.85	3.25	3.46	1.71
170	4.56	3.49	4.98	4.29	2.82	3.99	2.29	3.44	1.45
180	4.72	3.28	4.74	4.13	2.65	4.01	1.84	3.35	1.45
190	4.49	3.41	4.83	3.87	2.28	4.37	2.39	3.37	1.76
200	4.50	3.11	4.81	3.93	2.99	4.15	2.74	3.43	1.94
210	4.53	3.30	4.67	3.95	2.55	4.03	2.59	3.33	1.22
220	4.84	3.43	4.67	4.04	1.93	3.85	1.64	3.25	1.46
230	4.95	3.03	4.56	4.17	2.99	3.99	2.45	3.30	1.24
240	4.96	3.21	4.45	4.27	2.29	4.01	2.07	3.13	1.20
250	4.72	3.18	4.64	4.14	2.76	4.37	2.89	3.29	1.22
260	4.70	3.14	4.82	4.18	2.64	4.09	1.98	3.29	1.39
270	4.42	2.91	4.71	4.18	2.49	4.05	1.50	3.46	1.46
280	4.93	3.38	4.55	4.21	2.86	4.09	3.13	3.23	1.81
290	4.80	3.06	4.79	4.07	2.87	3.47	2.27	3.21	1.98
300	4.71	3.12	4.82	4.17	2.88	3.69	2.15	3.29	1.38
Average	4.71	3.24	4.73	4.11	2.84	4.03	2.38	3.33	1.53

(e) 50 Hz

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	6.20	3.79	6.29	5.50	3.56	5.15	3.16	4.17	2.18
20	5.58	3.51	5.91	4.42	4.61	5.35	3.71	4.13	2.10
30	5.97	3.23	6.07	4.90	4.25	5.28	3.21	4.03	2.44
40	6.34	3.23	5.98	5.17	4.17	5.35	3.36	4.12	1.85
50	5.82	4.26	5.85	5.00	3.98	5.25	3.38	3.94	1.60
60	6.29	3.52	6.27	4.66	3.93	5.20	2.61	4.18	2.26
70	5.93	3.60	6.11	5.45	4.44	5.34	3.52	4.10	1.97
80	6.32	3.53	6.17	4.65	3.46	5.36	3.25	4.16	2.11
90	6.21	3.40	6.25	4.62	4.36	5.28	3.32	4.01	2.55
100	6.20	3.80	6.00	4.80	4.13	5.23	3.47	4.09	1.93
110	5.83	4.42	5.98	5.08	3.44	5.36	3.03	4.20	1.96
120	6.31	3.58	6.17	5.21	3.98	5.22	3.36	4.14	1.84
130	6.19	3.76	6.23	4.94	4.13	5.40	3.60	4.05	1.88
140	6.17	3.88	6.13	5.02	4.05	5.31	2.79	4.05	1.49
150	6.00	4.18	6.23	5.16	4.09	5.32	4.09	4.11	2.53
160	5.94	3.91	6.08	4.84	4.40	5.28	3.92	4.09	3.05
170	6.72	4.08	6.36	4.24	4.17	5.27	3.02	4.02	1.78
180	5.88	3.34	6.07	4.91	3.92	5.29	3.89	4.19	1.71
190	5.94	3.67	5.98	4.58	4.16	5.25	4.04	4.17	2.81
200	5.98	3.59	5.81	4.83	4.49	5.21	3.21	4.14	2.39
210	6.51	3.16	6.33	4.76	4.04	5.33	3.16	4.04	2.22
220	5.98	3.72	6.18	4.86	4.25	5.23	3.30	4.01	1.71
230	6.33	3.59	6.25	4.93	4.59	5.25	4.01	4.09	2.18
240	5.84	4.01	6.23	4.76	3.61	5.20	4.70	4.11	3.07
250	5.85	3.68	6.08	4.50	3.71	5.11	3.56	4.23	2.13
260	5.70	3.37	6.25	4.04	4.02	5.40	3.81	4.11	2.88
270	5.65	3.29	6.31	5.08	4.22	5.33	3.80	4.08	2.29
280	5.86	4.05	6.15	5.28	3.83	5.29	3.18	4.17	1.86
290	5.90	4.18	6.26	5.22	4.80	5.15	3.10	4.02	1.89
300	5.14	3.84	6.06	4.91	4.65	5.32	3.67	4.21	2.38
Average	6.02	3.71	6.13	4.88	4.11	5.28	3.47	4.11	2.17

APPENDIX E

Evaporator Air Velocity Sample Data Measurements

(a) 24% of input energy

t (s)	**Measuring points**								
	A	B	C	D	E	F	G	H	I
10	1.71	0.40	1.77	1.96	1.60	1.95	1.80	1.22	1.52
20	1.75	0.38	1.73	1.97	1.65	1.96	1.78	1.24	1.52
30	1.75	0.32	1.76	2.00	1.64	1.99	1.76	1.25	1.50
40	1.73	0.29	1.78	2.00	1.66	1.98	1.80	1.27	1.49
50	1.77	0.55	1.74	1.98	1.65	1.97	1.81	1.21	1.51
60	1.73	0.30	1.78	1.97	1.60	1.95	1.80	1.26	1.53
70	1.75	0.30	1.79	2.00	1.64	1.98	1.80	1.28	1.49
80	1.74	0.31	1.81	1.97	1.62	1.94	1.80	1.27	1.51
90	1.79	0.29	1.29	2.01	1.63	1.98	1.78	1.25	1.53
100	1.74	0.33	1.77	2.01	1.62	1.99	1.79	1.23	1.52
110	1.71	0.36	1.91	2.00	1.60	1.95	1.78	1.25	1.51
120	1.71	0.32	1.82	1.99	1.62	1.98	1.82	1.28	1.51
130	1.74	0.28	1.78	1.97	1.63	1.95	1.79	1.24	1.51
140	1.72	0.37	1.78	2.02	1.63	1.94	1.77	1.27	1.51
150	1.76	0.34	1.75	2.02	1.61	1.97	1.79	1.28	1.53
160	1.71	0.30	1.78	2.01	1.66	1.96	1.81	1.24	1.54
170	1.74	0.37	1.76	2.00	1.62	1.96	1.80	1.26	1.50
180	1.74	0.31	1.78	2.02	1.61	1.91	1.81	1.26	1.49
190	1.70	0.29	1.79	2.00	1.61	1.95	1.84	1.24	1.51
200	1.75	0.39	1.80	1.98	1.63	1.96	1.81	1.27	1.52
210	1.73	0.35	1.81	2.02	1.63	2.00	1.80	1.25	1.51
220	1.76	0.41	1.78	2.03	1.66	1.97	1.78	1.25	1.52
230	1.72	0.27	1.79	2.02	1.62	1.97	1.79	1.25	1.51
240	1.75	0.32	1.75	2.05	1.56	1.95	1.75	1.25	1.54
250	1.73	0.28	1.78	2.01	1.62	1.99	1.81	1.24	1.51
260	1.74	0.30	1.75	2.01	1.62	1.96	1.79	1.22	1.53
270	1.72	0.28	1.80	2.00	1.60	1.93	1.77	1.26	1.53
280	1.74	0.31	1.75	1.98	1.60	1.94	1.82	1.25	1.53
290	1.77	0.52	1.79	1.98	1.60	2.02	1.80	1.25	1.53
300	1.75	0.54	1.76	2.01	1.61	1.96	1.78	1.27	1.54
Average	1.74	0.35	1.76	2.00	1.62	1.96	1.79	1.25	1.52

(b) 35% of input energy

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	2.62	0.52	2.37	3.03	2.30	2.97	2.69	1.96	2.33
20	2.56	0.80	2.40	3.06	2.31	3.02	2.74	1.94	2.34
30	2.55	0.72	2.36	3.05	2.32	2.93	2.70	1.93	2.36
40	2.60	0.64	2.46	3.06	2.31	2.93	2.71	1.90	2.37
50	2.50	0.76	2.44	3.05	2.28	2.93	2.65	1.94	2.34
60	2.56	0.74	2.40	3.03	2.27	2.99	2.68	1.92	2.33
70	2.56	0.65	2.37	3.01	2.28	2.92	2.64	1.96	2.37
80	2.53	0.68	2.44	2.99	2.28	2.91	2.66	1.95	2.39
90	2.55	0.65	2.42	3.05	2.31	2.95	2.67	1.94	2.36
100	2.55	0.60	2.39	3.04	2.32	2.90	2.66	1.91	2.38
110	2.58	0.55	2.40	3.03	2.31	2.91	2.67	1.92	2.35
120	2.56	0.59	2.43	3.00	2.24	2.92	2.67	1.98	2.36
130	2.55	0.66	2.39	3.09	2.29	2.89	2.65	1.92	2.35
140	2.58	0.48	2.45	2.97	2.26	2.91	2.65	1.91	2.36
150	2.56	0.67	2.43	3.06	2.30	2.87	2.65	1.92	2.35
160	2.56	0.58	2.44	3.05	2.28	2.90	2.66	1.95	2.34
170	2.53	0.58	2.40	3.00	2.29	2.89	2.63	1.97	2.34
180	2.54	0.66	2.44	3.03	2.34	2.95	2.67	1.97	2.36
190	2.57	0.58	2.40	3.00	2.32	2.94	2.63	1.97	2.33
200	2.54	0.63	2.40	3.01	2.31	2.88	2.66	1.94	2.33
210	2.56	0.53	2.41	3.05	2.26	3.00	2.65	1.94	2.36
220	2.53	0.70	2.43	3.01	2.31	2.84	2.62	1.95	2.34
230	2.54	0.61	2.50	3.05	2.26	2.90	2.66	1.97	2.34
240	2.56	0.78	2.33	3.02	2.25	2.85	2.66	1.96	2.33
250	2.55	0.63	2.40	3.07	2.29	2.85	2.67	1.95	2.33
260	2.53	0.69	2.42	3.02	2.26	2.87	2.63	1.96	2.36
270	2.51	0.51	2.41	3.00	2.29	2.89	2.66	1.95	2.38
280	2.52	0.83	2.40	3.03	2.27	2.86	2.65	1.96	2.35
290	2.53	0.46	2.41	3.00	2.29	2.92	2.63	1.94	2.34
300	2.52	0.57	2.41	3.00	2.28	2.91	2.66	1.96	2.35
Average	2.55	0.64	2.41	3.03	2.29	2.91	2.66	1.94	2.35

(c) 47% of input energy

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	3.35	1.39	2.97	4.03	2.85	3.65	3.51	2.52	3.16
20	3.31	0.83	3.00	3.98	2.86	3.70	3.49	2.52	3.12
30	3.35	1.07	2.96	3.99	2.89	3.64	3.43	2.50	3.16
40	3.36	0.97	2.92	4.02	2.90	3.65	3.46	2.53	3.15
50	3.31	1.15	3.04	4.01	2.92	3.71	3.51	2.46	3.17
60	3.37	0.96	3.01	4.00	2.92	3.69	3.46	2.57	3.15
70	3.31	1.16	2.98	4.04	2.90	3.66	3.50	2.47	3.18
80	3.30	1.53	2.99	4.03	2.86	3.64	3.47	2.55	3.07
90	3.32	0.73	3.00	3.94	2.89	3.71	3.48	2.52	3.12
100	3.27	0.67	2.95	3.96	2.81	3.61	3.48	2.53	3.14
110	3.33	0.75	2.94	3.99	2.87	3.67	3.50	2.54	3.13
120	3.31	0.86	2.96	4.04	2.88	3.60	3.45	2.51	3.14
130	3.32	1.30	3.00	4.00	2.90	3.65	3.49	2.56	3.09
140	3.30	1.01	3.02	3.96	2.90	3.63	3.50	2.55	3.14
150	3.31	1.29	2.93	3.99	2.90	3.75	3.49	2.52	3.15
160	3.27	1.22	2.96	3.94	2.89	3.72	3.52	2.55	3.16
170	3.36	1.13	3.09	3.98	2.85	3.63	3.51	2.55	3.17
180	3.32	1.01	3.03	3.97	2.93	3.69	3.50	2.58	3.13
190	3.31	1.21	3.00	3.99	2.87	3.63	3.47	2.57	3.17
200	3.31	0.76	2.95	4.00	2.89	3.64	3.51	2.54	3.12
210	3.33	0.89	3.09	3.98	2.84	3.59	3.53	2.55	3.13
220	3.30	0.81	2.97	3.99	2.83	3.65	3.48	2.54	3.15
230	3.29	0.80	2.98	4.01	2.83	3.67	3.46	2.55	3.11
240	3.30	0.73	2.99	3.99	2.90	3.57	3.53	2.55	3.17
250	3.30	0.63	3.00	4.00	2.84	3.64	3.51	2.51	3.15
260	3.32	0.60	2.91	3.99	2.85	3.66	3.50	2.52	3.14
270	3.26	0.94	2.98	3.98	2.87	3.66	3.47	2.53	3.14
280	3.28	1.04	2.97	3.94	2.86	3.75	3.46	2.53	3.18
290	3.35	1.21	3.00	4.03	2.87	3.62	3.45	2.55	3.14
300	3.32	1.28	3.00	4.03	2.90	3.63	3.49	2.53	3.17
Average	3.31	1.00	2.99	3.99	2.88	3.66	3.49	2.53	3.14

(d) 59% of input energy

t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	4.04	1.27	3.58	4.94	3.45	4.25	4.26	3.05	3.84
20	4.00	2.01	3.53	4.94	3.55	4.29	4.26	3.08	3.86
30	4.01	1.49	3.49	4.97	3.44	4.31	4.22	3.05	3.86
40	3.99	1.40	3.57	4.95	3.45	4.35	4.25	3.08	3.97
50	4.04	1.60	3.50	4.96	3.47	4.36	4.26	3.14	3.91
60	4.07	1.59	3.52	4.94	3.51	4.27	4.24	3.09	3.90
70	4.09	2.01	3.50	4.99	3.61	4.32	4.25	3.10	3.89
80	4.00	1.93	3.55	4.98	3.53	4.17	4.22	3.04	3.91
90	4.02	1.73	3.51	4.98	3.53	4.27	4.27	3.11	4.00
100	4.05	1.99	3.54	4.93	3.55	4.27	4.23	3.06	3.94
110	4.07	2.49	3.51	4.98	3.56	4.28	4.28	3.08	3.91
120	4.06	2.49	3.49	4.89	3.49	4.30	4.27	3.09	3.90
130	4.00	2.30	3.48	4.96	3.51	4.35	4.27	3.11	3.97
140	4.13	1.66	3.51	4.94	3.60	4.33	4.25	3.08	3.93
150	4.07	1.77	3.46	4.92	3.58	4.34	4.27	3.05	3.92
160	4.18	2.00	3.51	4.97	3.46	4.31	4.26	3.09	3.88
170	4.03	1.82	3.48	4.98	3.54	4.34	4.24	3.07	3.94
180	4.13	1.48	3.54	4.98	3.55	4.28	4.21	3.07	3.93
190	4.17	1.24	3.58	4.92	3.50	4.37	4.24	3.11	3.92
200	4.13	1.37	3.58	4.95	3.56	4.29	4.26	3.09	3.91
210	4.08	1.28	3.57	4.99	3.39	4.29	4.27	3.10	3.94
220	4.06	1.79	3.53	4.96	3.51	4.28	4.27	3.08	3.87
230	4.16	1.30	3.52	4.89	3.50	4.33	4.26	3.09	3.88
240	4.15	2.46	3.56	4.92	3.55	4.26	4.25	3.03	3.95
250	4.10	2.03	3.72	4.91	3.45	4.18	4.29	3.12	3.95
260	4.15	1.39	3.49	4.96	3.52	4.38	4.29	3.14	3.93
270	4.08	1.65	3.51	5.01	3.52	4.34	4.24	3.06	4.00
280	4.07	1.99	3.57	4.96	3.40	4.32	4.27	3.09	3.93
290	4.10	1.66	3.54	4.99	3.52	4.27	4.32	3.11	3.98
300	4.08	1.83	3.50	4.98	3.49	4.32	4.25	3.06	3.90
Average	4.08	1.77	3.53	4.95	3.51	4.30	4.26	3.08	3.92

(e) 71% of input energy

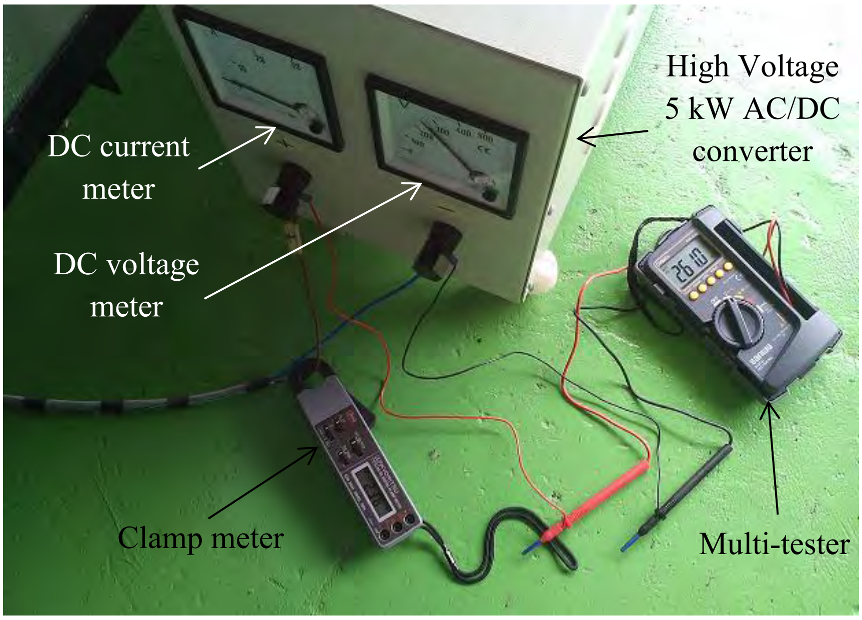
t (s)	Measuring points								
	A	B	C	D	E	F	G	H	I
10	4.79	2.98	3.96	5.95	3.94	4.93	4.96	3.64	4.70
20	4.67	2.13	4.03	5.67	4.08	4.96	4.99	3.62	4.60
30	4.81	2.00	3.95	5.72	3.94	4.67	4.98	3.61	4.64
40	4.74	1.67	4.02	5.70	3.93	4.82	5.01	3.57	4.54
50	4.78	2.22	3.98	5.69	3.85	4.90	5.03	3.58	4.61
60	4.85	2.95	4.01	5.74	3.94	4.88	4.95	3.60	4.67
70	4.76	2.61	4.05	5.72	4.05	4.79	4.93	3.58	4.65
80	4.71	1.92	3.98	5.53	3.87	4.89	4.93	3.59	4.66
90	4.80	2.32	3.94	5.71	4.01	4.92	5.00	3.57	4.74
100	4.72	2.17	3.97	5.68	4.08	5.05	4.95	3.61	4.65
110	4.71	2.48	4.03	5.67	3.96	4.99	4.99	3.57	4.70
120	4.82	1.77	4.07	5.63	4.13	4.98	4.97	3.64	4.66
130	4.86	1.62	4.03	5.52	3.80	4.89	4.98	3.62	4.61
140	4.71	2.22	4.00	5.67	4.07	4.77	5.00	3.61	4.64
150	4.76	2.37	4.04	5.40	3.94	4.69	4.96	3.59	4.59
160	4.74	1.67	4.11	5.72	3.90	4.80	4.98	3.64	4.60
170	4.74	2.24	3.99	5.81	3.87	4.84	5.00	3.60	4.66
180	4.79	1.97	4.01	5.74	3.93	4.90	4.97	3.60	4.62
190	4.79	2.69	4.06	5.73	4.10	4.99	5.00	3.61	4.68
200	4.83	1.94	4.01	5.74	4.03	4.89	5.00	3.61	4.66
210	4.80	1.87	3.97	5.85	3.74	4.96	4.96	3.59	4.68
220	4.74	2.04	4.06	5.73	3.84	4.99	5.02	3.62	4.72
230	4.76	2.60	4.00	5.69	3.81	4.84	4.95	3.61	4.63
240	4.76	1.86	3.94	5.57	4.03	4.90	4.98	3.62	4.64
250	4.73	1.96	4.00	5.65	4.11	4.80	5.03	3.61	4.67
260	4.79	2.50	4.05	5.75	3.93	4.53	4.95	3.65	4.64
270	4.75	2.50	4.02	5.74	4.10	4.93	5.02	3.62	4.72
280	4.79	2.22	3.97	5.71	4.00	4.87	5.01	3.65	4.65
290	4.72	2.00	3.96	5.71	3.82	4.94	4.97	3.60	4.60
300	4.79	2.30	4.00	5.60	3.98	4.70	4.96	3.63	4.69
Average	4.77	2.19	4.01	5.69	3.96	4.87	4.98	3.61	4.65

APPENDIX F

Calibration Process of Pressure Transducer using Standard Pressure Gauge

APPENDIX G

High-Voltage AC/DC Converter with Calibration Process of Direct Current and Voltage Meters



APPENDIX H

Standard Industry Practice of Charge Determination for Typical Passenger Car

APPENDIX I

Thermal and Energy Automotive Air-conditioning System Performance Experimental Measured Sample Data

1. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.14	12.22	12.12	4.31	12.86	46.60	12.26	15.5	269	2.0	13.87	14.02	13.49	14.36	14.02	14.18	14.07
2	4.24	12.25	12.15	4.41	12.96	46.59	12.36	15.5	269	2.0	14.01	14.27	13.60	14.32	13.85	14.41	14.16
3	4.14	12.43	12.28	4.43	13.08	47.04	12.28	15.5	269	2.0	13.85	14.00	13.78	14.39	13.92	14.31	14.19
4	4.19	12.42	12.27	4.33	13.15	46.99	12.36	15.5	269	2.0	13.85	13.96	13.74	14.38	13.86	14.32	14.21
5	4.19	12.42	12.32	4.33	13.21	47.15	12.21	15.5	269	2.0	13.96	14.18	13.78	14.32	13.92	14.43	14.17
6	4.21	12.51	12.34	4.33	13.24	47.20	12.24	15.5	269	2.0	13.89	14.17	13.71	14.31	13.88	14.39	14.11
7	4.09	12.53	12.41	4.31	13.26	47.33	12.26	15.5	269	2.0	13.92	14.13	13.69	14.44	13.82	14.33	14.07
8	4.07	12.57	12.45	4.26	13.35	47.57	12.36	15.5	269	2.0	13.84	14.26	13.74	14.29	13.93	14.23	14.03
9	4.07	12.54	12.37	4.24	13.60	47.32	12.09	15.5	269	2.0	13.98	14.14	13.70	14.19	13.95	14.44	14.01
10	4.14	12.46	12.33	4.28	13.62	47.18	12.09	15.5	269	2.0	13.67	14.14	13.73	14.21	13.97	14.4	13.99
11	4.11	12.45	12.25	4.31	13.66	46.92	12.07	15.5	269	2.0	14.06	14.08	13.62	14.13	13.77	14.24	14.06
12	4.14	12.49	12.42	4.33	13.64	47.45	12.05	15.5	269	2.0	13.88	14.28	13.6	14.10	13.75	14.31	14.05
13	4.07	12.48	12.36	4.28	13.68	47.26	12.05	15.5	269	2.0	13.77	14.18	13.56	14.11	13.82	14.23	14.03
14	4.11	12.56	12.36	4.33	13.67	47.26	12.10	15.5	269	2.0	13.81	14.20	13.56	14.17	14.01	14.23	14.15
15	4.19	12.59	12.47	4.34	13.57	47.62	12.22	15.5	269	2.0	13.98	14.17	13.83	14.26	14.06	14.25	14.42
16	4.16	12.56	12.46	4.31	13.56	47.59	12.26	15.5	269	2.0	13.98	14.24	13.95	14.30	14.02	14.25	14.32
17	4.16	12.59	12.49	4.36	13.67	47.69	12.24	15.5	269	2.0	14.09	14.11	13.91	14.37	13.98	14.35	14.09
18	4.21	12.66	12.47	4.41	13.68	47.63	12.28	15.5	269	2.0	13.83	14.16	13.88	14.32	13.87	14.09	13.95
19	4.24	12.58	12.46	4.40	13.54	47.06	12.27	15.5	269	2.0	13.95	14.19	13.89	14.24	13.94	14.07	13.83
20	4.11	12.61	12.44	4.30	13.80	47.52	12.17	15.5	269	2.0	13.88	14.22	13.7	14.27	13.97	14.35	14.15
$\bar{x}$	4.15	12.50	12.36	4.33	13.44	47.25	12.21	15.5	269	2.0	13.90	14.16	13.72	14.27	13.92	14.29	14.10
σ	0.05	0.11	0.11	0.05	0.28	0.32	0.10	0.0	0	0.0	0.10	0.09	0.13	0.10	0.09	0.10	0.13

2. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.94	12.75	12.60	4.16	12.62	48.03	11.72	18.5	243	2.7	13.13	13.40	12.88	13.34	13.18	13.54	13.19
2	3.99	12.78	12.76	4.14	12.63	48.52	11.73	18.5	243	2.7	13.05	13.42	12.95	13.41	12.99	13.52	13.18
3	3.97	12.75	12.60	4.14	12.67	48.14	11.77	18.5	243	2.7	13.01	13.44	12.89	13.43	13.06	13.58	13.32
4	3.92	12.76	12.64	4.09	12.86	48.15	11.86	18.5	243	2.7	13.07	13.45	12.91	13.57	13.10	13.58	13.46
5	3.90	12.75	12.68	4.14	12.76	48.39	11.86	18.5	243	2.7	13.11	13.40	12.90	13.53	13.01	13.57	13.41
6	3.97	12.76	12.74	4.12	12.77	48.57	11.87	18.5	243	2.7	13.04	13.47	12.93	13.66	13.11	13.56	13.36
7	3.90	12.75	12.61	4.14	12.79	48.06	11.89	18.5	243	2.7	13.21	13.35	12.91	13.54	13.10	13.57	13.43
8	4.02	12.77	12.67	4.12	12.81	48.24	11.91	18.5	243	2.7	13.07	13.54	12.99	13.42	13.09	13.61	13.48
9	3.90	12.83	12.49	4.16	12.90	47.67	12.00	18.5	243	2.7	13.33	13.60	13.01	13.43	13.15	13.69	13.34
10	3.87	12.81	12.68	4.09	12.95	48.29	12.05	18.5	243	2.7	13.16	13.74	12.97	13.47	13.03	13.70	13.57
11	3.97	12.82	12.74	4.26	12.96	48.37	12.06	18.5	243	2.7	13.34	13.73	12.85	13.56	13.06	13.64	13.52
12	4.02	12.82	12.86	4.21	12.97	48.82	12.08	18.5	243	2.7	13.23	13.56	12.83	13.24	13.07	13.73	13.58
13	3.90	12.86	12.74	4.09	13.11	48.45	12.11	18.5	243	2.7	13.26	13.46	12.88	13.52	13.19	13.75	13.46
14	3.92	12.89	12.74	4.19	13.13	48.46	12.13	18.5	243	2.7	13.34	13.53	12.95	13.49	13.13	13.67	13.58
15	4.07	12.88	12.79	4.14	13.13	48.62	12.13	18.5	243	2.7	13.33	13.45	12.87	13.41	13.18	13.74	13.60
16	4.04	12.86	12.76	4.29	13.13	48.53	12.13	18.5	243	2.7	13.27	13.47	12.90	13.43	13.26	13.69	13.49
17	3.94	12.86	12.73	4.16	13.09	48.44	12.09	18.5	243	2.7	13.39	13.43	12.83	13.32	13.28	13.70	13.33
18	3.99	12.86	12.71	4.19	13.08	48.37	12.08	18.5	243	2.7	13.31	13.51	12.90	13.55	13.09	13.66	13.43
19	3.87	12.88	12.68	4.09	12.98	48.28	12.08	18.5	243	2.7	13.40	13.49	12.97	13.48	13.00	13.75	13.53
20	3.90	12.76	12.56	4.12	12.95	47.90	12.05	18.5	243	2.7	13.24	13.51	13.07	13.34	13.12	13.42	13.24
$\bar{x}$	3.95	12.81	12.69	4.15	12.91	48.32	11.98	18.5	243	2.7	13.21	13.50	12.92	13.46	13.11	13.63	13.43
σ	0.06	0.05	0.09	0.05	0.17	0.27	0.14	0.0	0	0.0	0.13	0.10	0.06	0.10	0.08	0.09	0.13

3. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.88	13.02	12.85	4.07	11.80	48.79	10.95	21.0	240	3.4	12.46	12.52	12.32	12.64	12.31	12.71	12.50
2	3.76	13.03	12.69	4.05	11.78	48.00	10.93	21.0	240	3.4	12.37	12.59	12.35	12.69	12.21	12.72	12.43
3	3.90	13.04	12.99	4.12	11.77	49.23	10.91	21.0	240	3.4	12.38	12.53	12.33	12.67	12.28	12.65	12.32
4	3.85	13.03	12.86	4.20	11.78	48.93	10.90	21.0	240	3.4	12.32	12.52	12.34	12.68	12.29	12.52	12.44
5	3.88	13.05	12.95	4.10	11.79	49.21	10.91	21.0	240	3.4	12.39	12.51	12.36	12.62	12.34	12.68	12.51
6	3.90	13.03	12.96	4.12	11.87	49.24	10.89	21.0	240	3.4	12.32	12.48	12.29	12.61	12.36	12.58	12.47
7	3.85	13.02	12.85	4.00	11.76	48.81	10.88	21.0	240	3.4	12.32	12.47	12.24	12.59	12.28	12.57	12.49
8	3.88	13.01	12.98	4.10	11.80	49.20	10.90	21.0	240	3.4	12.46	12.45	12.21	12.53	12.27	12.43	12.39
9	3.83	13.01	12.86	4.10	11.76	48.82	10.88	21.0	240	3.4	12.45	12.48	12.28	12.46	12.31	12.61	12.47
10	3.85	13.01	12.92	3.98	11.75	49.18	10.88	21.0	240	3.4	12.40	12.47	12.38	12.50	12.30	12.59	12.42
11	3.80	12.99	12.82	4.05	11.77	48.70	10.86	21.0	240	3.4	12.51	12.51	12.32	12.54	12.39	12.54	12.44
12	3.90	12.98	12.86	4.07	11.74	48.83	10.85	21.0	240	3.4	12.44	12.46	12.35	12.50	12.29	12.65	12.39
13	3.83	13.00	12.86	4.10	11.76	48.82	10.86	21.0	240	3.4	12.47	12.43	12.26	12.68	12.33	12.66	12.43
14	3.88	12.99	12.92	4.02	11.85	49.01	10.84	21.0	240	3.4	12.55	12.45	12.36	12.56	12.25	12.51	12.41
15	3.88	12.99	12.94	4.07	11.75	49.09	10.81	21.0	240	3.4	12.39	12.45	12.38	12.52	12.34	12.77	12.40
16	3.78	13.00	12.88	4.10	11.74	48.90	10.85	21.0	240	3.4	12.37	12.48	12.28	12.59	12.35	12.72	12.43
17	3.78	13.00	12.88	4.00	11.73	49.00	10.81	21.0	240	3.4	12.38	12.53	12.25	12.60	12.33	12.54	12.45
18	3.80	13.00	12.93	4.02	11.75	48.96	10.81	21.0	240	3.4	12.36	12.46	12.35	12.53	12.27	12.69	12.46
19	3.90	13.02	12.50	4.12	11.78	47.70	10.83	21.0	240	3.4	12.46	12.46	12.32	12.51	12.24	12.60	12.40
20	3.85	12.99	12.90	4.17	11.79	48.96	10.96	21.0	240	3.4	12.36	12.45	12.29	12.61	12.30	12.76	12.36
$\bar{x}$	3.85	13.01	12.87	4.08	11.78	48.87	10.88	21.0	240	3.4	12.41	12.49	12.31	12.58	12.30	12.63	12.43
σ	0.04	0.02	0.11	0.06	0.04	0.39	0.04	0.0	0	0.0	0.06	0.04	0.05	0.07	0.04	0.09	0.05

4. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

Independent variables (Measured variables)																	
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.61	13.46	13.36	3.95	10.90	50.35	9.45	24.0	255	4.0	11.31	11.42	11.40	11.51	11.50	11.78	11.44
2	3.63	13.44	13.29	3.85	10.95	50.13	9.46	24.0	255	4.0	11.34	11.60	11.26	11.58	11.37	11.78	11.47
3	3.53	13.43	13.53	3.83	10.93	50.25	9.46	24.0	255	4.0	11.47	11.73	11.30	11.58	11.28	11.39	11.47
4	3.58	13.42	13.37	3.95	10.92	50.39	9.45	24.0	255	4.0	11.37	11.54	11.36	11.31	11.30	11.84	11.37
5	3.63	13.44	13.39	3.73	10.84	50.53	9.44	24.0	255	4.0	11.27	11.85	11.23	11.62	11.38	11.91	11.56
6	3.61	13.46	13.29	3.83	11.04	50.13	9.52	24.0	255	4.0	11.30	11.46	11.25	11.41	11.42	11.43	11.46
7	3.51	13.45	13.54	3.83	11.00	50.89	9.49	24.0	255	4.0	11.26	11.36	11.12	11.78	11.32	11.50	11.42
8	3.56	13.45	13.19	3.85	11.01	49.83	9.52	24.0	255	4.0	11.34	11.46	11.29	11.71	11.51	11.67	11.48
9	3.61	13.46	13.36	3.80	11.01	50.34	9.53	24.0	255	4.0	11.26	11.68	11.30	11.77	11.49	11.63	11.58
10	3.56	13.46	13.29	3.85	11.02	50.13	9.55	24.0	255	4.0	11.43	11.47	11.41	11.87	11.46	11.64	11.65
11	3.66	13.46	13.07	3.90	11.05	49.49	9.53	24.0	255	4.0	11.32	11.75	11.28	11.66	11.39	11.65	11.55
12	3.63	13.48	13.26	3.88	11.04	50.04	9.55	24.0	255	4.0	11.40	11.66	11.13	11.75	11.39	11.73	11.47
13	3.61	13.48	13.53	3.83	11.07	50.85	9.56	24.0	255	4.0	11.36	11.78	11.20	11.91	11.36	11.81	11.44
14	3.66	13.47	13.40	3.92	11.10	50.56	9.58	24.0	255	4.0	11.33	11.73	11.31	11.67	11.38	11.80	11.39
15	3.56	13.47	13.32	3.83	11.10	50.22	9.57	24.0	255	4.0	11.35	11.85	11.41	11.76	11.24	11.83	11.41
16	3.58	13.45	13.26	3.90	11.09	50.06	9.57	24.0	255	4.0	11.35	11.46	11.33	11.81	11.38	11.87	11.47
17	3.63	13.47	13.37	3.83	11.11	50.37	9.58	24.0	255	4.0	11.41	11.52	11.27	11.71	11.26	11.74	11.66
18	3.56	13.47	13.32	3.80	11.12	50.32	9.58	24.0	255	4.0	11.48	11.66	11.23	11.84	11.28	11.68	11.42
19	3.48	13.46	13.32	3.85	11.23	50.24	9.59	24.0	255	4.0	11.41	11.35	11.34	11.46	11.36	11.74	11.51
20	3.53	13.47	13.30	3.80	11.15	50.16	9.61	24.0	255	4.0	11.43	11.42	11.29	11.33	11.34	11.74	11.57
$\bar{x}$	3.59	13.46	13.34	3.85	11.03	50.26	9.53	24.0	255	4.0	11.36	11.59	11.29	11.65	11.37	11.71	11.49
σ	0.05	0.02	0.11	0.05	0.09	0.31	0.05	0.0	0	0.0	0.07	0.16	0.08	0.17	0.08	0.14	0.08

5. $\phi_{a,i,e} = 40\%$, $\frac{\dot{V}_e N_c^2}{v_{afc}^3} = 22.92$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.04	13.51	13.39	3.38	8.79	50.43	6.79	26.0	260	4.6	10.83	11.20	10.79	11.19	10.81	11.34	10.92
2	3.21	13.53	13.41	3.48	8.79	50.51	6.79	26.0	260	4.6	10.80	11.24	10.71	11.23	10.92	11.25	11.06
3	3.18	13.61	13.42	3.43	9.00	50.52	7.00	26.0	260	4.6	10.82	10.84	10.84	10.96	10.73	11.21	11.10
4	3.23	13.61	13.54	3.50	9.00	50.87	7.00	26.0	260	4.6	10.86	11.28	10.80	11.23	10.89	11.34	11.03
5	3.18	13.60	13.50	3.45	9.01	50.75	7.01	26.0	260	4.6	10.98	11.16	10.94	11.35	10.87	11.16	11.15
6	3.28	13.69	13.44	3.50	9.07	50.58	73.26.07	26.0	260	4.6	10.92	10.95	10.90	11.14	10.97	11.15	10.93
7	3.16	13.67	13.52	3.40	9.20	50.83	7.10	26.0	260	4.6	10.82	11.18	10.79	11.28	10.70	11.25	11.02
8	3.23	13.67	13.59	3.45	9.20	51.15	7.10	26.0	260	4.6	10.94	11.04	10.80	11.29	11.08	11.24	10.99
9	3.28	13.69	13.69	3.52	9.08	51.33	7.08	26.0	260	4.6	10.91	10.90	10.88	11.09	11.06	11.19	10.92
10	3.26	13.69	13.62	3.50	9.08	51.13	7.08	26.0	260	4.6	10.98	11.00	11.00	11.15	10.80	11.22	11.04
11	3.13	13.78	13.65	3.52	9.19	51.21	7.19	26.0	260	4.6	11.10	10.94	10.97	11.29	11.16	11.32	10.94
12	3.21	13.71	13.54	3.77	9.17	50.89	7.17	26.0	260	4.6	10.92	11.08	10.88	11.26	10.89	11.23	10.84
13	3.18	13.67	13.49	3.45	9.13	50.83	7.13	26.0	260	4.6	10.81	10.96	10.79	11.27	10.71	11.13	11.01
14	3.26	13.65	13.45	3.48	9.11	50.62	7.11	26.0	260	4.6	10.94	11.01	10.69	11.28	10.76	11.24	11.03
15	3.23	13.64	13.47	3.48	9.11	50.68	7.11	26.0	260	4.6	10.90	11.07	10.83	11.21	10.97	11.10	11.11
16	3.13	13.64	13.51	3.40	9.18	50.81	7.08	26.0	260	4.6	11.15	10.89	10.73	11.31	11.13	11.26	11.03
17	3.16	13.66	13.49	3.43	9.07	50.73	7.07	26.0	260	4.6	10.93	11.13	10.79	11.37	10.75	11.20	10.93
18	3.21	13.66	13.64	3.16	9.07	51.18	6.70	26.0	260	4.6	10.91	11.12	10.81	11.28	10.88	11.21	11.07
19	3.13	13.65	13.50	3.48	9.07	50.78	7.07	26.0	260	4.6	10.89	10.97	10.88	11.26	10.81	11.19	10.99
20	3.21	13.66	13.58	3.48	9.06	50.99	7.06	26.0	260	4.6	10.84	11.24	10.87	11.31	10.85	11.14	10.85
$\bar{x}$	3.20	13.65	13.52	3.46	9.07	50.84	7.04	26.0	260	4.6	10.91	11.06	10.83	11.24	10.89	11.22	11.00
σ	0.06	0.06	0.08	0.11	0.11	0.26	0.13	0.0	0	0.0	0.09	0.13	0.08	0.10	0.14	0.07	0.08

6. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	**Independent variables (Measured variables)**																
	Refrigerant side								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.90	11.01	10.94	4.07	10.82	42.58	10.42	15.0	258	2.0	12.85	12.75	12.90	13.06	12.67	12.85	13.02
2	3.85	11.04	11.01	4.10	10.60	42.83	10.20	15.0	258	2.0	12.74	13.07	13.02	13.18	12.65	13.12	12.94
3	3.95	11.06	11.01	4.14	10.61	42.81	10.21	15.0	258	2.0	12.81	13.12	12.94	13.07	12.65	13.11	12.98
4	3.88	11.03	10.93	4.10	10.58	42.54	10.18	15.0	258	2.0	12.96	13.21	13.08	13.08	12.77	13.17	12.98
5	3.92	11.04	10.92	4.05	10.60	42.48	10.20	15.0	258	2.0	13.12	12.97	12.65	13.15	12.88	12.92	13.08
6	4.02	11.03	10.88	4.17	10.61	42.35	10.21	15.0	258	2.0	13.17	12.79	12.67	13.12	12.44	12.82	13.13
7	3.85	11.03	11.00	4.10	10.61	42.78	10.21	15.0	258	2.0	13.13	12.78	12.77	13.07	12.69	12.74	13.05
8	3.97	11.15	11.05	4.10	10.69	42.94	10.29	15.0	258	2.0	13.14	12.76	13.00	13.06	12.90	12.83	12.95
9	3.83	10.97	10.87	4.02	10.55	42.33	10.15	15.0	258	2.0	12.79	12.60	12.68	13.07	13.02	12.94	12.89
10	3.80	10.94	10.76	4.12	10.39	41.92	10.09	15.0	258	2.0	12.75	12.73	12.65	13.14	13.05	13.11	12.90
11	3.92	10.91	10.71	4.10	10.35	41.75	10.05	15.0	258	2.0	12.66	12.93	12.76	13.02	13.05	13.00	12.84
12	3.95	10.92	10.97	4.05	10.41	42.66	10.01	15.0	258	2.0	12.84	13.17	12.85	12.96	12.86	13.03	12.81
13	3.90	10.93	10.81	4.02	10.38	42.11	9.98	15.0	258	2.0	12.64	12.97	12.75	12.96	12.97	12.80	12.80
14	3.85	10.99	10.91	4.07	10.39	42.46	9.99	15.0	258	2.0	12.72	13.00	12.70	12.89	13.04	12.91	12.72
15	3.92	10.95	10.86	4.05	10.40	42.30	10.00	15.0	258	2.0	12.60	13.17	12.72	12.94	13.02	13.05	12.75
16	3.97	10.97	10.87	4.12	10.40	42.31	10.00	15.0	258	2.0	12.72	13.20	12.74	12.93	12.93	13.04	12.70
17	3.88	10.99	10.84	4.05	10.30	42.21	10.00	15.0	258	2.0	12.61	13.04	12.72	12.92	13.02	12.87	12.73
18	3.85	10.99	10.91	4.10	10.30	42.46	10.00	15.0	258	2.0	12.81	13.18	12.83	12.96	12.97	13.15	12.87
19	3.90	11.02	10.92	4.00	10.42	42.51	10.02	15.0	258	2.0	13.01	13.01	12.71	12.97	13.09	12.95	12.66
20	3.85	11.07	11.12	4.00	10.48	43.19	10.08	15.0	258	2.0	13.10	12.97	12.83	12.94	12.99	12.95	12.99
$\bar{x}$	3.90	11.00	10.91	4.08	10.49	42.48	10.11	15.0	258	2.0	12.86	12.97	12.80	13.02	12.88	12.97	12.89
σ	0.06	0.06	0.10	0.05	0.14	0.34	0.12	0.0	0	0.0	0.19	0.18	0.13	0.09	0.18	0.13	0.14

7. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Independent variables (Measured variables)																
	Refrigerant side								Compressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.70	11.35	11.18	4.02	9.73	43.40	9.03	18.5	250	2.6	12.08	12.69	11.89	12.43	11.95	12.54	12.39
2	3.68	11.31	11.28	3.90	9.93	43.72	8.98	18.5	250	2.6	11.71	12.41	12.29	12.28	11.78	12.59	12.22
3	3.65	11.35	11.27	3.78	9.38	43.71	8.68	18.5	250	2.6	12.06	12.63	11.93	12.43	12.18	12.57	12.47
4	3.71	11.29	11.21	3.95	9.44	43.51	8.74	18.5	250	2.6	11.93	12.54	11.67	12.27	12.14	12.21	12.27
5	3.85	11.37	11.27	4.09	9.56	43.70	8.86	18.5	250	2.6	11.90	12.61	11.86	12.57	11.98	12.86	12.12
6	3.65	11.40	11.30	3.87	9.59	43.80	8.89	18.5	250	2.6	12.01	12.48	11.81	12.47	12.01	12.84	12.08
7	3.70	11.35	11.11	3.90	9.74	43.16	9.04	18.5	250	2.6	12.18	12.65	11.86	12.54	11.87	12.78	12.15
8	3.71	11.41	11.31	3.85	9.93	43.82	9.13	18.5	250	2.6	12.22	12.70	11.96	12.64	12.07	12.87	12.17
9	3.73	11.28	11.21	3.92	10.09	43.51	9.09	18.5	250	2.6	11.99	12.12	11.94	12.63	11.73	12.88	12.49
10	3.56	11.36	11.29	3.87	9.78	43.77	8.98	18.5	250	2.6	11.76	12.48	12.31	12.50	11.89	12.94	12.55
11	3.60	11.48	11.41	3.75	9.62	44.19	8.92	18.5	250	2.6	12.00	12.71	11.77	12.82	11.68	12.85	12.26
12	3.51	11.42	11.38	3.60	9.06	44.08	8.36	18.5	250	2.6	11.84	12.53	11.60	12.75	11.54	12.82	12.39
13	3.60	11.36	11.24	3.73	9.56	43.59	7.86	18.5	250	2.6	12.04	12.69	11.80	12.41	11.98	12.73	12.48
14	3.75	11.32	11.17	3.85	9.17	43.45	8.47	18.5	250	2.6	11.74	12.23	11.67	12.56	11.51	12.65	12.59
15	3.75	11.26	11.17	3.87	9.40	43.35	8.70	18.5	250	2.6	11.90	12.48	11.78	12.57	11.67	12.79	12.52
16	3.78	11.27	11.15	3.85	9.45	43.28	8.75	18.5	250	2.6	12.07	12.55	11.72	12.55	11.66	12.80	12.34
17	3.68	11.28	11.23	3.92	9.49	43.58	8.79	18.5	250	2.6	12.08	12.65	11.72	12.47	11.80	12.84	12.05
18	3.73	11.36	11.24	3.95	9.52	43.59	8.82	18.5	250	2.6	12.03	12.77	11.73	12.73	11.71	12.88	12.12
19	3.63	11.44	11.32	3.85	9.62	43.89	8.92	18.5	250	2.6	12.18	12.16	11.84	12.37	11.99	12.60	12.20
20	3.73	11.52	11.64	3.92	9.65	44.93	8.95	18.5	250	2.6	12.12	12.34	11.81	12.48	11.93	12.61	12.22
$\bar{x}$	3.69	11.36	11.27	3.87	9.59	43.70	8.80	18.5	250	2.6	11.99	12.52	11.85	12.52	11.85	12.73	12.30
σ	0.08	0.07	0.12	0.11	0.25	0.39	0.29	0.0	0	0.0	0.15	0.19	0.18	0.14	0.19	0.17	0.17

8. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.40	11.91	11.79	3.59	9.32	45.43	8.40	21.0	245	3.2	11.43	11.74	11.27	11.83	11.45	11.86	11.37
2	3.43	11.94	11.77	3.51	9.31	45.36	8.32	21.0	245	3.2	11.38	11.71	11.48	12.00	11.42	11.77	11.58
3	3.48	11.94	11.79	3.68	9.33	45.42	8.42	21.0	245	3.2	11.35	11.63	11.21	11.92	11.48	11.67	11.72
4	3.43	11.93	11.86	3.56	9.26	45.65	8.39	21.0	245	3.2	11.37	11.55	11.35	12.05	11.42	12.05	11.93
5	3.46	11.93	11.83	3.68	9.29	45.55	8.39	21.0	245	3.2	11.39	11.49	11.25	11.67	11.53	12.05	11.83
6	3.39	11.91	11.77	3.65	9.29	45.38	8.40	21.0	245	3.2	11.49	11.53	11.21	11.60	11.48	12.02	11.55
7	3.46	11.91	11.79	3.65	9.29	45.43	8.39	21.0	245	3.2	11.67	11.79	11.31	11.66	11.68	11.81	11.49
8	3.48	11.91	11.83	3.78	9.27	45.56	8.47	21.0	245	3.2	11.46	11.53	11.39	11.84	11.56	11.82	11.48
9	3.43	11.91	11.81	3.61	9.33	45.50	8.36	21.0	245	3.2	11.70	11.70	11.27	11.85	11.74	11.79	11.63
10	3.48	11.91	11.96	3.63	9.28	46.00	8.38	21.0	245	3.2	11.55	11.46	11.29	11.86	11.58	11.77	11.70
11	3.36	11.93	11.83	3.65	9.28	45.57	8.39	21.0	245	3.2	11.72	11.51	11.80	11.82	11.74	11.81	11.69
12	3.45	11.94	11.84	3.59	9.29	45.60	8.28	21.0	245	3.2	11.64	11.62	11.46	11.95	11.56	11.89	11.49
13	3.41	11.94	11.94	3.58	9.30	45.94	8.38	21.0	245	3.2	11.52	11.74	11.75	12.04	11.48	12.02	11.51
14	3.51	11.92	11.75	3.68	9.30	45.29	8.46	21.0	245	3.2	11.47	11.84	11.86	11.87	11.51	12.06	11.65
15	3.41	11.92	11.73	3.51	9.28	45.24	8.38	21.0	245	3.2	11.40	12.01	11.40	11.69	11.32	11.90	11.64
16	3.45	11.92	12.02	3.52	9.28	46.19	8.38	21.0	245	3.2	11.40	11.90	11.26	11.73	11.39	11.96	11.68
17	3.48	11.91	11.79	3.68	9.27	45.45	8.38	21.0	245	3.2	11.58	11.79	11.38	11.77	11.38	12.11	11.58
18	3.46	11.91	11.91	3.65	9.30	45.84	8.37	21.0	245	3.2	11.37	12.02	11.37	11.78	11.45	11.90	11.49
19	3.34	11.90	11.75	3.46	9.26	45.32	8.39	21.0	245	3.2	11.56	11.99	11.40	11.80	11.54	11.96	11.31
20	3.46	11.91	11.83	3.70	9.30	45.57	8.49	21.0	245	3.2	11.54	11.50	11.31	11.84	11.55	11.92	11.30
$\bar{x}$	3.44	11.92	11.83	3.62	9.29	45.56	8.39	21.0	245	3.2	11.50	11.70	11.40	11.83	11.51	11.91	11.58
σ	0.04	0.01	0.08	0.08	0.02	0.25	0.05	0.0	0	0.0	0.12	0.18	0.19	0.12	0.11	0.12	0.16

9. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.29	12.40	12.30	3.51	8.85	47.17	7.75	24.0	255	3.8	11.35	11.41	11.16	11.23	10.76	11.14	11.01
2	3.24	12.48	12.36	3.48	8.69	47.36	7.59	24.0	255	3.8	10.92	11.07	11.07	11.48	10.70	11.30	11.01
3	3.31	12.42	12.33	3.46	8.72	47.17	7.60	24.0	255	3.8	11.20	11.23	11.06	11.20	10.73	11.34	11.36
4	3.24	12.46	12.34	3.48	8.67	47.21	7.60	24.0	255	3.8	11.10	11.18	10.96	11.41	10.69	11.42	11.27
5	3.26	12.47	12.44	3.51	8.70	47.53	7.57	24.0	255	3.8	11.36	11.36	10.83	11.42	10.55	11.62	11.37
6	3.29	12.45	12.33	3.56	8.70	47.19	7.60	24.0	255	3.8	11.39	11.26	10.54	11.31	10.43	11.47	11.42
7	3.24	12.41	12.31	3.44	8.62	47.11	7.52	24.0	255	3.8	11.27	11.28	11.07	11.19	10.76	11.34	11.16
8	3.22	12.43	12.28	3.41	8.63	47.02	7.53	24.0	255	3.8	11.05	11.14	10.23	11.28	10.56	11.35	11.08
9	3.29	12.43	12.31	3.53	8.63	47.10	7.53	24.0	255	3.8	11.07	11.32	10.37	11.37	10.57	11.41	11.17
10	3.26	12.37	12.29	3.46	8.51	47.06	7.41	24.0	255	3.8	11.21	11.09	10.37	11.12	10.64	11.27	11.22
11	3.17	12.35	12.28	3.44	8.49	47.03	7.39	24.0	255	3.8	11.07	11.23	10.48	11.32	10.88	11.25	11.02
12	3.24	12.48	12.36	3.44	8.71	47.27	7.61	24.0	255	3.8	11.20	11.38	10.65	11.58	10.84	11.45	11.26
13	3.22	12.47	12.35	3.44	8.69	47.25	7.59	24.0	255	3.8	11.14	11.52	10.74	11.50	10.78	11.53	11.21
14	3.26	12.48	12.35	3.51	8.66	47.23	7.56	24.0	255	3.8	11.47	11.26	10.56	11.45	10.79	11.33	11.24
15	3.22	12.51	12.39	3.46	8.69	47.34	7.59	24.0	255	3.8	11.38	11.23	10.71	11.32	10.81	11.30	11.30
16	3.29	12.49	12.34	3.44	8.68	47.22	7.58	24.0	255	3.8	11.27	11.24	10.76	11.29	10.90	11.39	11.28
17	3.36	12.48	12.36	3.51	8.69	47.27	7.59	24.0	255	3.8	11.36	11.43	10.78	11.32	10.83	11.51	11.25
18	3.22	12.45	12.28	3.44	8.68	47.02	7.58	24.0	255	3.8	11.14	11.20	10.78	11.54	10.89	11.31	11.31
19	3.24	12.43	12.33	3.53	8.69	47.19	7.53	24.0	255	3.8	11.04	11.35	10.88	11.42	10.69	11.50	11.34
20	3.12	12.44	12.34	3.44	8.63	47.20	7.53	24.0	255	3.8	10.69	11.10	10.81	11.57	10.60	11.22	11.35
$\bar{x}$	3.25	12.45	12.33	3.47	8.67	47.20	7.56	24.0	255	3.8	11.18	11.26	10.74	11.37	10.72	11.37	11.23
σ	0.05	0.04	0.04	0.04	0.07	0.13	0.07	0.0	0	0.0	0.19	0.12	0.26	0.13	0.13	0.12	0.12

10. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.18	13.12	12.95	3.38	8.15	49.10	7.25	26.0	252	4.5	10.50	10.32	10.21	11.04	10.49	10.67	10.67
2	3.16	13.07	12.95	3.36	8.18	49.11	7.28	26.0	252	4.5	10.35	10.68	10.25	10.62	10.18	10.89	10.59
3	3.21	13.05	12.90	3.36	8.23	48.95	7.33	26.0	252	4.5	10.39	10.85	10.06	10.80	10.43	10.74	10.69
4	3.16	13.03	12.89	3.26	8.19	48.94	7.39	26.0	252	4.5	10.23	10.84	9.93	10.92	10.12	10.77	10.60
5	3.11	13.00	12.80	3.31	8.04	48.64	7.34	26.0	252	4.5	10.46	11.07	10.07	11.05	10.01	10.66	10.69
6	3.21	13.00	12.88	3.38	8.22	48.87	7.32	26.0	252	4.5	10.84	10.92	10.11	11.02	10.31	10.75	10.68
7	3.11	12.95	12.81	3.36	8.05	48.67	7.25	26.0	252	4.5	10.73	11.05	10.18	11.06	10.15	10.73	10.61
8	3.09	12.86	12.71	3.33	7.92	48.38	7.12	26.0	252	4.5	10.71	10.94	10.00	11.00	10.32	10.64	10.36
9	2.94	12.92	12.75	3.33	7.87	48.50	7.07	26.0	252	4.5	10.65	10.74	10.29	10.43	10.46	10.68	10.56
10	3.14	12.97	12.84	3.31	8.00	48.77	7.10	26.0	252	4.5	10.57	10.73	10.19	10.65	10.41	10.70	10.53
11	3.11	13.00	12.88	3.33	8.01	48.88	7.11	26.0	252	4.5	10.85	10.76	10.17	10.69	10.17	11.09	10.65
12	3.06	12.96	12.84	3.40	7.98	48.78	7.08	26.0	252	4.5	10.44	10.68	10.16	10.50	10.38	11.01	10.66
13	3.16	12.98	12.96	3.38	8.08	49.13	7.08	26.0	252	4.5	10.56	10.37	10.11	10.52	10.13	10.72	10.39
14	3.09	13.00	12.92	3.38	7.99	49.03	7.09	26.0	252	4.5	10.39	10.38	10.15	10.52	10.29	10.81	10.24
15	3.11	13.04	12.89	3.36	8.02	48.92	7.12	26.0	252	4.5	10.43	10.43	10.16	10.47	10.20	10.60	10.37
16	3.16	13.07	12.97	3.38	8.12	49.18	7.12	26.0	252	4.5	10.68	10.58	10.16	10.49	10.21	11.08	10.53
17	3.14	13.11	12.99	3.36	8.05	49.24	7.15	26.0	252	4.5	10.43	10.47	10.11	10.56	10.11	10.92	10.64
18	3.11	13.06	12.91	3.36	8.06	48.99	7.06	26.0	252	4.5	10.32	10.84	9.96	10.38	10.55	10.96	10.40
19	3.16	13.08	12.96	3.36	8.18	49.13	7.08	26.0	252	4.5	10.55	10.47	9.98	10.43	10.41	11.01	10.67
20	3.04	13.08	12.93	3.21	8.11	49.04	7.11	26.0	252	4.5	10.58	10.43	10.02	10.41	10.31	11.03	10.57
$\bar{x}$	3.12	13.02	12.89	3.35	8.07	48.91	7.17	26.0	252	4.5	10.53	10.68	10.11	10.68	10.28	10.82	10.56
σ	0.06	0.07	0.08	0.05	0.10	0.23	0.11	0.0	0	0.0	0.17	0.23	0.10	0.25	0.15	0.16	0.13

11. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.68	9.87	9.80	4.04	9.11	38.44	8.61	15.0	238	2.0	11.61	11.44	11.29	11.62	11.43	11.91	11.31
2	3.53	9.85	9.73	3.82	9.20	38.19	8.60	15.0	238	2.0	11.58	11.46	11.29	11.57	11.45	11.83	11.35
3	3.75	9.86	9.79	3.92	9.19	38.40	8.59	15.0	238	2.0	11.54	11.37	11.24	11.55	11.45	11.82	11.29
4	3.58	9.83	9.79	3.73	9.17	38.39	8.57	15.0	238	2.0	11.47	11.60	11.04	11.47	11.38	11.66	11.23
5	3.65	9.84	9.82	3.70	9.14	38.42	8.54	15.0	238	2.0	11.41	11.38	11.16	11.51	11.27	11.75	11.30
6	3.70	9.82	9.67	3.73	9.10	37.95	8.50	15.0	238	2.0	11.44	11.54	11.35	11.49	11.40	11.90	11.22
7	3.63	9.82	9.72	3.77	8.98	38.15	8.38	15.0	238	2.0	11.20	11.81	11.25	11.56	11.18	11.87	11.36
8	3.70	9.85	9.80	3.85	8.99	38.44	8.39	15.0	238	2.0	11.32	11.53	11.05	11.39	11.26	11.65	11.55
9	3.65	9.85	9.95	3.75	8.89	38.99	8.39	15.0	238	2.0	11.28	11.50	11.08	11.62	11.35	11.71	11.50
10	3.68	9.83	9.71	3.85	8.89	38.12	8.39	15.0	238	2.0	11.49	11.48	11.13	11.60	11.41	11.55	11.51
11	3.75	9.81	9.76	3.75	8.99	38.29	8.39	15.0	238	2.0	11.38	11.53	11.22	11.70	11.24	11.53	11.56
12	3.65	9.87	9.80	3.77	9.01	38.44	8.42	15.0	238	2.0	11.27	11.53	11.11	11.81	11.22	11.72	11.76
13	3.68	9.87	9.79	3.73	9.02	38.41	8.42	15.0	238	2.0	11.32	11.61	11.10	11.69	11.33	11.74	11.71
14	3.63	9.85	9.80	3.73	8.92	38.46	8.42	15.0	238	2.0	11.37	11.73	11.18	11.48	11.26	11.52	11.57
15	3.68	9.88	9.86	3.87	9.02	38.66	8.42	15.0	238	2.0	11.34	11.67	11.13	11.52	11.39	11.70	11.53
16	3.71	9.87	9.77	3.69	9.02	38.31	8.42	15.0	238	2.0	11.45	11.74	11.20	11.56	11.24	11.80	11.55
17	3.63	9.90	9.83	3.75	8.95	38.55	8.49	15.0	238	2.0	11.39	11.94	11.25	11.59	11.29	11.72	11.42
18	3.60	9.91	9.86	3.68	9.09	38.65	8.49	15.0	238	2.0	11.48	11.30	11.35	11.46	11.34	11.87	11.48
19	3.55	9.91	9.72	3.73	9.12	38.11	8.52	15.0	238	2.0	11.30	11.47	11.22	11.58	11.28	11.77	11.47
20	3.73	9.92	9.94	3.80	9.15	38.32	8.52	15.0	238	2.0	11.42	11.40	11.33	11.55	11.42	11.86	11.53
$\bar{x}$	3.66	9.86	9.80	3.78	9.05	38.38	8.47	15.0	238	2.0	11.40	11.55	11.20	11.57	11.33	11.74	11.46
σ	0.06	0.03	0.07	0.09	0.10	0.23	0.08	0.0	0	0.0	0.11	0.16	0.10	0.09	0.08	0.12	0.15

12. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

Independent variables (Measured variables)																	
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.55	10.47	10.35	3.63	8.64	40.47	7.94	18.0	248	2.4	11.13	11.34	10.72	11.31	11.00	11.46	11.08
2	3.53	10.47	10.45	3.70	8.62	40.84	7.92	18.0	248	2.4	11.14	11.42	10.60	11.26	11.05	11.49	11.10
3	3.48	10.46	10.43	3.63	8.61	40.76	7.91	18.0	248	2.4	11.08	11.42	10.59	11.54	11.06	11.38	11.11
4	3.53	10.47	10.37	3.75	8.56	40.54	7.86	18.0	248	2.4	11.06	11.40	10.71	11.29	10.97	11.58	11.13
5	3.60	10.49	10.37	3.68	8.56	40.54	7.86	18.0	248	2.4	10.99	11.47	10.78	11.27	10.97	11.45	11.04
6	3.58	10.49	10.44	3.80	8.53	40.81	7.83	18.0	248	2.4	10.94	11.40	10.65	11.16	11.00	11.49	11.09
7	3.50	10.47	10.35	3.68	8.56	40.49	7.86	18.0	248	2.4	10.84	11.54	10.62	11.22	11.04	11.41	11.06
8	3.55	10.45	10.28	3.68	8.55	40.22	7.85	18.0	248	2.4	11.14	11.42	10.85	11.26	11.06	11.67	11.27
9	3.58	10.46	10.48	3.65	8.52	40.96	7.82	18.0	248	2.4	11.24	11.22	10.78	11.28	11.04	11.58	11.44
10	3.53	10.46	10.36	3.68	8.50	40.51	7.82	18.0	248	2.4	11.14	11.26	10.71	11.40	11.15	11.46	11.32
11	3.55	10.47	10.32	3.70	8.52	40.37	7.82	18.0	248	2.4	11.29	11.29	10.83	11.31	10.94	11.33	11.17
12	3.63	10.46	10.38	3.72	8.52	40.60	7.82	18.0	248	2.4	11.32	11.28	10.86	11.34	10.93	11.51	11.36
13	3.46	10.44	10.32	3.72	8.50	40.38	7.80	18.0	248	2.4	11.22	11.22	10.74	11.20	10.92	11.43	11.24
14	3.48	10.43	10.31	3.65	8.49	40.34	7.79	18.0	248	2.4	11.17	11.17	10.81	11.21	10.88	11.45	11.28
15	3.50	10.43	10.28	3.72	8.49	40.28	7.79	18.0	248	2.4	11.05	11.16	10.84	11.18	10.95	11.48	11.36
16	3.58	10.41	10.16	3.63	8.46	39.80	7.76	18.0	248	2.4	11.15	11.21	10.97	11.15	10.83	11.52	11.36
17	3.60	10.42	10.30	3.77	8.46	40.31	7.76	18.0	248	2.4	11.29	11.17	10.96	11.30	10.88	11.36	11.10
18	3.50	10.43	10.28	3.63	8.50	40.23	7.76	18.0	248	2.4	10.91	11.16	10.93	11.32	10.78	11.42	11.23
19	3.55	10.49	10.56	3.70	8.50	41.08	7.75	18.0	248	2.4	11.11	11.31	10.56	11.30	10.65	11.33	11.17
20	3.53	10.46	10.33	3.68	8.46	40.42	7.76	18.0	248	2.4	11.07	11.49	10.65	11.23	10.77	11.34	11.18
$\bar{x}$	3.54	10.46	10.36	3.69	8.53	40.50	7.82	18.0	248	2.4	11.11	11.32	10.76	11.28	10.94	11.46	11.20
σ	0.05	0.02	0.09	0.05	0.05	0.29	0.06	0.0	0	0.0	0.13	0.12	0.12	0.09	0.12	0.09	0.12

13. $\phi_{a,i,e} = 40\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								Compressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.33	10.87	10.78	3.50	7.82	42.01	7.07	20.5	242	3.0	10.64	10.79	10.09	10.66	10.31	10.86	10.67
2	3.24	10.86	10.77	3.26	7.81	42.09	7.07	20.5	242	3.0	10.62	10.84	10.04	10.52	10.26	10.90	10.70
3	3.31	10.88	10.76	3.48	7.81	41.93	7.10	20.5	242	3.0	10.68	10.85	10.13	10.73	10.03	10.90	10.76
4	3.21	10.90	10.85	3.50	7.85	42.26	7.11	20.5	242	3.0	10.74	10.65	10.11	10.69	10.05	11.12	10.74
5	3.26	10.88	10.69	3.38	7.89	41.70	7.09	20.5	242	3.0	10.65	10.49	10.21	10.88	10.37	11.02	10.86
6	3.26	10.87	10.75	3.46	7.88	41.90	7.06	20.5	242	3.0	10.62	10.45	10.28	10.78	10.30	11.12	10.87
7	3.19	10.86	10.74	3.26	7.98	41.86	7.06	20.5	242	3.0	10.62	10.51	10.15	10.56	10.39	10.80	10.52
8	3.24	10.81	10.74	3.46	7.94	41.87	6.99	20.5	242	3.0	10.68	10.39	10.20	10.71	10.22	10.82	10.64
9	3.31	10.82	10.72	3.43	7.92	41.79	6.97	20.5	242	3.0	10.65	10.48	10.17	10.74	10.12	10.85	10.69
10	3.26	10.83	10.88	3.50	7.88	42.38	6.97	20.5	242	3.0	10.77	10.54	9.98	10.66	10.08	10.99	10.65
11	3.28	10.95	10.85	3.50	7.93	42.26	7.05	20.5	242	3.0	10.48	10.95	10.07	10.52	10.27	10.88	10.65
12	3.26	10.98	10.79	3.48	7.96	42.03	7.09	20.5	242	3.0	10.56	10.82	10.12	10.80	10.37	11.00	10.80
13	3.28	11.02	10.73	3.58	8.24	41.82	7.24	20.5	242	3.0	10.27	10.74	10.16	10.40	10.56	10.96	10.50
14	3.21	10.93	10.76	3.55	8.08	42.05	7.18	20.5	242	3.0	10.29	10.92	10.36	10.52	10.48	10.84	10.39
15	3.31	10.78	10.61	3.46	7.74	41.41	7.06	20.5	242	3.0	10.66	10.65	10.26	10.63	10.25	11.06	10.71
16	3.38	10.87	10.82	3.58	7.83	42.14	6.99	20.5	242	3.0	10.59	10.91	10.22	10.64	10.46	11.02	10.60
17	3.36	10.85	11.07	3.43	7.84	43.01	7.04	20.5	242	3.0	10.60	10.71	10.25	10.37	10.32	10.95	10.70
18	3.28	10.83	10.68	3.53	7.84	41.75	7.11	20.5	242	3.0	10.66	10.85	10.22	10.91	10.70	10.92	10.49
19	3.33	10.84	10.69	3.50	7.87	41.69	7.03	20.5	242	3.0	10.74	10.79	10.36	10.86	10.37	11.01	10.56
20	3.28	10.85	10.75	3.60	7.85	41.92	7.02	20.5	242	3.0	10.85	10.73	10.15	10.75	10.28	11.09	10.70
$\bar{x}$	3.28	10.87	10.77	3.47	7.90	41.99	7.07	20.5	242	3.0	10.62	10.70	10.18	10.67	10.31	10.96	10.66
σ	0.05	0.06	0.09	0.09	0.11	0.33	0.07	0.0	0	0.0	0.14	0.17	0.10	0.15	0.17	0.10	0.12

14. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.16	11.62	11.52	3.33	7.41	44.55	6.31	23.5	250	3.8	10.17	10.15	10.07	10.08	10.27	10.00	10.08
2	3.19	11.66	11.56	3.38	7.33	44.68	6.33	23.5	250	3.8	10.23	10.14	9.94	10.37	10.00	10.22	9.93
3	3.09	11.55	11.46	3.21	7.44	44.34	6.24	23.5	250	3.8	10.02	10.13	9.71	10.04	10.01	10.34	10.13
4	3.11	11.52	11.40	3.36	7.31	44.14	6.21	23.5	250	3.8	10.20	9.82	9.85	10.18	9.90	10.08	10.01
5	3.14	11.48	11.43	3.36	7.49	44.23	6.29	23.5	250	3.8	9.99	9.88	9.95	10.52	9.88	9.94	9.98
6	3.16	11.44	11.37	3.31	7.45	44.14	6.25	23.5	250	3.8	10.11	9.72	9.98	10.12	10.11	10.08	9.96
7	3.11	11.58	11.55	3.38	7.46	44.64	6.26	23.5	250	3.8	10.03	10.02	9.80	10.40	9.84	10.41	10.01
8	3.04	11.59	11.45	3.33	7.45	44.30	6.25	23.5	250	3.8	10.00	10.26	9.92	10.20	9.65	10.20	10.08
9	3.21	11.59	11.51	3.36	7.50	44.49	6.30	23.5	250	3.8	9.98	10.36	10.01	10.23	10.01	10.31	10.07
10	3.16	11.57	11.42	3.36	7.48	44.20	6.28	23.5	250	3.8	9.85	10.17	9.84	10.07	10.16	10.18	9.99
11	3.06	11.58	11.43	3.33	7.50	44.25	6.30	23.5	250	3.8	9.78	10.17	9.98	10.25	9.50	9.93	10.08
12	3.19	11.58	11.53	3.36	7.52	44.56	6.32	23.5	250	3.8	9.60	10.27	9.87	9.88	9.71	10.18	10.16
13	3.09	11.53	11.39	3.36	7.58	44.11	6.28	23.5	250	3.8	9.72	9.88	9.86	9.91	10.01	10.42	9.86
14	3.11	11.52	11.42	3.26	7.57	44.22	6.27	23.5	250	3.8	9.96	10.01	10.05	9.82	9.76	10.37	9.89
15	3.14	11.52	11.32	3.46	7.50	43.86	6.40	23.5	250	3.8	10.27	9.67	9.91	10.06	9.57	10.50	9.97
16	3.09	11.49	11.69	3.36	7.47	45.12	6.37	23.5	250	3.8	9.93	10.95	10.01	9.80	10.16	10.49	9.79
17	3.11	11.61	11.58	3.31	7.53	44.74	6.23	23.5	250	3.8	9.96	9.80	9.91	9.93	10.08	10.36	10.08
18	3.09	11.53	11.45	3.26	7.55	44.32	6.25	23.5	250	3.8	10.16	9.74	9.94	9.84	10.05	10.37	10.04
19	3.11	11.49	11.27	3.36	7.32	43.71	6.32	23.5	250	3.8	9.97	9.84	10.10	9.83	10.20	10.04	9.67
20	3.14	11.49	11.44	3.33	7.34	44.27	6.24	23.5	250	3.8	9.81	9.95	10.07	10.08	10.10	9.92	9.72
$\bar{x}$	3.13	11.55	11.46	3.34	7.46	44.34	6.29	23.5	250	3.8	9.99	10.05	9.94	10.08	9.95	10.22	9.98
σ	0.04	0.06	0.10	0.05	0.08	0.32	0.05	0.0	0	0.0	0.18	0.29	0.10	0.21	0.22	0.19	0.13

15. $\phi_{a,i,e} = 40\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								Com- pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	2.98	11.99	11.84	3.25	6.27	45.61	5.47	25.5	235	4.6	9.27	9.22	8.75	9.26	8.97	9.96	8.91
2	3.01	11.98	11.91	3.30	6.26	45.92	5.56	25.5	235	4.6	9.07	9.17	8.79	9.25	8.85	9.61	9.28
3	3.06	11.97	11.89	3.25	6.24	45.75	5.44	25.5	235	4.6	9.15	9.28	8.84	9.36	9.09	9.31	9.14
4	3.01	11.96	11.82	3.35	6.25	45.52	5.65	25.5	235	4.6	8.96	9.33	8.86	9.57	9.06	9.93	9.29
5	3.08	12.10	12.02	3.35	6.47	46.17	5.47	25.5	235	4.6	8.74	9.16	9.11	9.38	8.69	9.45	9.13
6	3.01	12.09	12.02	3.28	6.50	46.18	5.50	25.5	235	4.6	8.82	9.20	9.15	9.48	9.05	9.65	9.23
7	3.06	12.06	11.99	3.28	6.46	46.09	5.46	25.5	235	4.6	9.19	9.35	8.94	9.18	8.82	9.30	9.12
8	2.69	12.07	12.10	3.38	6.49	46.44	5.99	25.5	235	4.6	9.09	9.39	9.07	9.27	9.10	9.64	9.34
9	2.94	12.10	11.98	3.38	6.61	46.04	5.91	25.5	235	4.6	9.16	9.27	9.92	9.20	9.11	9.45	9.13
10	3.03	12.09	12.02	3.35	6.60	46.17	5.50	25.5	235	4.6	9.02	9.22	9.15	9.51	9.14	9.27	8.82
11	3.13	12.06	11.99	3.38	6.61	46.10	5.90	25.5	235	4.6	8.81	9.10	8.83	9.53	8.87	9.78	9.13
12	3.03	12.02	11.89	3.28	6.45	45.78	5.45	25.5	235	4.6	8.91	9.32	9.09	9.43	9.09	9.72	8.86
13	3.03	12.02	11.85	3.35	6.42	45.64	5.62	25.5	235	4.6	9.26	9.25	8.89	9.42	9.06	9.69	8.75
14	2.94	11.99	11.84	3.35	6.49	45.59	5.49	25.5	235	4.6	8.92	9.11	9.11	9.62	9.11	9.44	8.91
15	3.03	12.00	11.95	3.35	6.45	45.97	5.54	25.5	235	4.6	8.85	9.34	8.73	9.52	8.82	9.71	9.18
16	2.98	12.01	11.94	3.28	6.48	45.92	5.48	25.5	235	4.6	8.95	9.12	8.95	9.79	9.05	9.90	8.95
17	3.06	12.05	11.98	3.33	6.50	46.05	5.50	25.5	235	4.6	9.12	9.25	8.78	9.43	9.06	9.65	9.09
18	2.79	12.02	11.90	3.33	6.53	45.80	5.54	25.5	235	4.6	9.22	9.17	8.71	9.15	9.18	9.71	9.16
19	3.11	12.06	11.87	3.23	6.53	45.69	5.53	25.5	235	4.6	9.16	9.37	8.82	9.57	9.14	9.51	9.17
20	2.86	12.05	11.93	3.33	6.66	45.89	5.56	25.5	235	4.6	9.22	9.19	8.99	9.64	8.99	9.64	8.98
$\bar{x}$	2.99	12.03	11.94	3.32	6.46	45.92	5.58	25.5	235	4.6	9.04	9.24	8.97	9.43	9.01	9.62	9.08
σ	0.11	0.04	0.08	0.05	0.12	0.24	0.16	0.0	0	0.0	0.16	0.09	0.27	0.17	0.13	0.20	0.17

16. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Independent variables (Measured variables)																
	Refrigerant side								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.17	12.75	12.63	4.39	13.96	48.11	12.56	15.5	260	2.2	14.26	14.77	14.07	14.7	14.39	14.8	14.48
2	4.19	12.76	12.64	4.39	13.96	48.17	12.56	15.5	260	2.2	14.22	14.8	14.03	14.68	14.37	14.82	14.49
3	4.26	12.79	12.64	4.39	13.85	48.16	12.55	15.5	260	2.2	14.09	14.86	14	14.73	14.34	14.81	14.46
4	4.19	12.77	12.67	4.39	13.86	48.35	12.56	15.5	260	2.2	13.96	14.81	14.97	14.67	14.3	14.83	14.39
5	4.31	12.80	12.60	4.48	13.87	48.02	12.57	15.5	260	2.2	14.03	14.79	13.97	14.66	14.31	14.85	14.48
6	4.19	12.77	12.72	4.34	13.08	48.42	12.58	15.5	260	2.2	14.09	14.76	14.08	14.79	14.33	14.82	14.62
7	4.29	12.80	12.63	4.36	13.98	48.12	12.58	15.5	260	2.2	14.06	14.75	14.05	15.1	14.32	14.8	14.46
8	4.29	12.76	12.68	4.44	13.99	48.29	12.59	15.5	260	2.2	14.02	14.75	14.08	14.87	14.32	14.84	14.44
9	4.19	12.80	12.73	4.39	14.00	48.52	12.60	15.5	260	2.2	13.85	14.73	13.98	14.94	14.33	14.8	14.4
10	4.31	12.81	12.52	4.22	13.99	47.87	12.59	15.5	260	2.2	13.8	14.76	14.03	14.76	14.36	14.84	14.26
11	4.31	12.79	12.69	4.46	13.97	48.40	12.58	15.5	260	2.2	13.82	14.71	14.04	14.68	14.39	14.85	14.37
12	4.22	12.73	12.70	4.36	13.92	48.34	12.58	15.5	260	2.2	13.78	14.7	14.01	14.75	14.33	14.86	14.43
13	4.22	12.78	12.73	4.34	13.98	48.53	12.58	15.5	260	2.2	13.75	14.71	13.96	14.71	14.27	14.84	14.35
14	4.19	12.78	12.63	4.39	13.97	48.24	12.57	15.5	260	2.2	13.67	14.72	13.91	14.66	14.25	14.85	14.32
15	4.26	12.79	12.69	4.41	13.95	48.40	12.55	15.5	260	2.2	13.77	14.71	13.97	14.72	14.28	14.87	14.37
16	4.29	12.75	12.66	4.51	13.85	48.30	12.55	15.5	260	2.2	13.57	14.72	13.94	14.69	14.29	14.83	14.25
17	4.26	12.78	12.51	4.39	13.94	47.75	12.54	15.5	260	2.2	13.61	14.68	13.84	14.72	14.3	14.79	14.23
18	4.22	12.81	12.66	4.39	13.93	48.21	12.53	15.5	260	2.2	13.68	14.66	13.93	14.69	14.27	14.73	14.35
19	4.31	12.78	12.78	4.44	13.82	48.58	12.52	15.5	260	2.2	13.58	14.67	13.87	14.68	14.3	14.77	14.35
20	4.29	12.75	12.75	4.44	13.94	48.51	12.54	15.5	260	2.2	13.52	14.69	13.88	14.7	14.36	14.8	14.41
$\bar{x}$	4.25	12.78	12.66	4.40	13.89	48.26	12.56	15.5	260	2.2	13.86	14.74	14.03	14.75	14.32	14.82	14.40
σ	0.05	0.02	0.07	0.06	0.20	0.22	0.02	0.0	0	0.0	0.22	0.05	0.23	0.11	0.04	0.03	0.09

17. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^2}{v_{afc}^3} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.14	13.20	13.03	3.77	13.58	49.36	12.08	18.5	250	2.8	13.87	14.34	13.85	14.43	13.61	14.52	14.17
2	4.14	13.21	13.07	4.24	13.59	49.47	12.09	18.5	250	2.8	13.74	14.36	13.61	14.43	13.53	14.54	14.09
3	4.02	13.21	13.11	4.26	13.59	49.71	12.09	18.5	250	2.8	14.01	14.34	13.68	14.36	13.51	14.54	14.11
4	4.12	13.23	13.09	4.31	13.58	49.54	12.08	18.5	250	2.8	13.88	14.32	13.52	14.44	13.58	14.56	14.10
5	4.19	13.24	13.09	3.92	13.53	49.54	12.08	18.5	250	2.8	14.00	14.39	13.39	14.53	13.53	14.53	14.13
6	4.07	13.22	13.10	4.19	13.56	49.56	12.06	18.5	250	2.8	13.93	14.37	13.46	14.49	13.53	14.54	14.13
7	4.19	13.19	13.14	4.19	13.55	49.68	12.05	18.5	250	2.8	13.89	14.34	13.37	14.49	13.55	14.52	14.09
8	4.04	13.20	13.05	4.14	13.46	49.43	12.06	18.5	250	2.8	13.98	14.32	13.27	14.52	13.47	14.51	14.08
9	4.14	13.24	13.14	4.16	13.55	49.69	12.05	18.5	250	2.8	13.78	14.33	13.47	14.43	13.39	14.53	14.06
10	4.17	13.20	13.10	4.29	13.54	49.58	12.04	18.5	250	2.8	14.02	14.34	13.25	14.44	13.38	14.51	14.12
11	4.19	13.18	13.08	4.29	13.54	49.50	12.04	18.5	250	2.8	13.79	14.35	13.05	14.47	13.42	14.54	14.12
12	4.09	13.21	13.09	4.14	13.64	49.55	12.04	18.5	250	2.8	13.80	14.32	13.91	14.44	13.35	14.56	14.08
13	4.17	13.21	13.09	4.26	13.64	49.64	12.04	18.5	250	2.8	13.95	14.44	14.04	14.49	13.37	14.57	14.10
14	4.07	13.19	13.09	4.26	13.54	49.63	12.04	18.5	250	2.8	13.84	14.43	13.33	14.43	13.43	14.57	14.06
15	4.04	13.20	13.39	4.19	13.53	50.45	12.03	18.5	250	2.8	13.87	14.42	13.32	14.35	13.46	14.52	14.02
16	4.14	13.22	13.15	4.19	13.53	49.71	12.03	18.5	250	2.8	13.79	14.38	13.30	14.44	13.43	14.53	13.99
17	4.12	13.20	13.05	4.21	13.54	49.42	12.04	18.5	250	2.8	13.87	14.40	13.24	14.48	13.61	14.55	14.02
18	4.12	13.23	13.10	4.21	13.57	49.56	12.04	18.5	250	2.8	13.89	14.39	13.60	14.49	13.45	14.55	14.15
19	4.17	13.20	12.96	4.14	13.56	49.15	12.06	18.5	250	2.8	13.85	14.42	13.57	14.48	13.44	14.56	14.12
20	4.07	13.21	13.13	4.46	13.55	49.67	12.05	18.5	250	2.8	13.90	14.40	13.26	14.47	13.39	14.57	14.10
$\bar{x}$	4.12	13.21	13.10	4.19	13.56	49.59	12.05	18.5	250	2.8	13.88	14.37	13.47	14.46	13.47	14.54	14.09
σ	0.05	0.02	0.08	0.14	0.04	0.24	0.02	0.0	0	0.0	0.08	0.04	0.25	0.05	0.08	0.02	0.04

18. $\phi_{a,i,e} = 50\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.93	13.41	13.26	4.29	12.67	50.05	11.16	18.5	250	3.4	13.49	13.84	12.91	13.62	13.29	13.91	13.83
2	4.00	13.31	13.19	4.02	12.62	49.85	11.11	18.5	250	3.4	13.45	13.79	12.92	13.68	13.09	13.99	13.53
3	3.95	13.30	13.18	4.17	12.54	49.80	11.02	18.5	250	3.4	13.43	13.7	12.85	13.64	13.05	13.93	13.17
4	3.98	13.29	13.19	4.37	12.45	49.83	10.92	18.5	250	3.4	13.34	13.59	12.71	13.56	13.22	13.76	13.69
5	3.88	13.19	13.12	4.12	12.19	49.62	10.37	18.5	250	3.4	13.93	13.06	12.91	13.42	13.23	13.31	13.31
6	3.95	13.15	12.96	4.20	12.38	49.14	10.40	18.5	250	3.4	13.95	13.12	12.73	13.45	13.22	13.37	13.66
7	4.00	13.25	13.27	4.17	12.36	50.08	10.45	18.5	250	3.4	13.98	13.18	12.72	13.5	13.24	13.5	13.1
8	4.02	13.35	13.20	4.22	12.29	49.86	10.52	18.5	250	3.4	13.13	13.24	13.16	13.62	13.25	13.61	13.06
9	4.00	13.36	13.19	4.24	12.21	49.83	10.61	18.5	250	3.4	13.16	13.28	13.01	13.67	13.28	13.53	13.15
10	3.90	13.43	13.06	4.17	12.27	49.46	10.66	18.5	250	3.4	13.19	13.32	13.08	13.67	13.27	13.56	13.23
11	4.00	13.35	13.13	4.22	12.31	49.66	10.70	18.5	250	3.4	13.18	13.39	13.09	13.75	13.14	13.74	13.13
12	3.93	13.43	13.28	4.17	12.34	50.10	10.75	18.5	250	3.4	13.25	13.47	13.13	13.8	13.08	13.75	13.25
13	3.93	13.47	13.27	4.17	12.43	49.70	10.84	18.5	250	3.4	13.19	13.53	13.18	13.82	13.18	13.74	13.58
14	3.95	13.67	13.57	4.22	12.67	50.01	11.12	18.5	250	3.4	13.4	13.69	13.07	13.92	13.25	13.9	13.63
15	3.98	13.42	13.30	4.22	12.74	50.17	11.28	18.5	250	3.4	13.59	13.83	12.91	13.89	13.38	13.98	13.74
16	3.93	13.38	13.28	4.20	12.66	50.11	11.20	18.5	250	3.4	13.5	13.71	12.93	13.99	13.3	13.9	13.41
17	3.90	13.36	13.39	4.20	12.60	50.43	11.15	18.5	250	3.4	13.41	13.66	12.84	13.94	13.2	13.83	13.13
18	4.02	13.37	13.25	4.22	12.55	50.01	11.09	18.5	250	3.4	13.34	13.73	13.09	13.86	13.13	13.82	13.82
19	3.93	13.27	13.27	4.17	12.45	50.09	10.98	18.5	250	3.4	13.24	13.38	13.02	13.74	13.16	13.7	13.32
20	3.98	13.23	13.16	4.20	12.31	49.74	10.81	18.5	250	3.4	13.06	13.28	13.08	13.58	13.24	13.55	13.49
$\bar{x}$	3.96	13.35	13.22	4.20	12.45	49.88	10.86	18.5	250	3.4	13.41	13.49	12.97	13.71	13.21	13.72	13.41
σ	0.04	0.11	0.12	0.07	0.17	0.28	0.29	0.0	0	0.0	0.27	0.25	0.15	0.16	0.08	0.20	0.26

19. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Independent variables (Measured variables)																
	Refrigerant side								Compressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.78	13.71	13.61	4.00	11.52	51.09	9.97	24.0	240	4.4	12.17	12.54	11.51	12.5	12.04	12.94	12.47
2	3.78	13.71	13.45	4.03	11.51	50.71	9.46	24.0	240	4.4	12.13	12.51	11.47	12.64	12.03	12.91	12.39
3	3.78	13.71	13.44	4.03	11.50	50.59	9.45	24.0	240	4.4	12.17	12.65	11.39	12.58	12.04	12.83	12.35
4	3.69	13.71	13.64	4.35	11.56	51.18	9.42	24.0	240	4.4	12.21	12.63	11.34	12.58	12.09	12.78	12.30
5	3.81	13.70	13.41	3.93	11.57	50.51	9.40	24.0	240	4.4	12.29	12.66	11.35	12.57	12.17	12.77	12.44
6	3.71	13.68	13.63	4.00	11.55	51.10	9.34	24.0	240	4.4	12.34	12.65	11.42	12.6	12.37	12.76	12.47
7	3.74	13.70	13.51	3.98	11.55	50.81	9.38	24.0	240	4.4	12.51	12.6	11.55	12.667	12.52	12.74	12.67
8	3.78	13.72	13.64	4.03	11.57	51.19	9.38	24.0	240	4.4	12.49	12.65	11.61	12.68	12.39	12.79	12.62
9	3.69	13.76	13.66	4.00	11.52	51.24	9.43	24.0	240	4.4	12.38	12.74	11.71	12.9	12.43	12.78	12.75
10	3.76	13.74	13.43	4.00	11.47	50.57	9.48	24.0	240	4.4	12.11	12.82	11.81	12.78	12.19	12.74	12.68
11	3.81	13.75	13.58	4.03	11.48	50.99	9.48	24.0	240	4.4	12.2	12.87	11.9	12.83	12.4	13.01	12.6
12	3.74	13.76	13.61	4.05	11.49	51.09	9.51	24.0	240	4.4	12.29	12.95	12.02	12.92	11.78	12.81	12.65
13	3.74	13.77	13.67	3.96	11.50	51.28	9.52	24.0	240	4.4	12.07	12.79	12.02	12.87	11.78	13.01	12.59
14	3.78	13.75	13.65	4.00	11.52	51.30	9.51	24.0	240	4.4	12.12	12.88	12.02	12.91	11.86	13.08	12.53
15	3.64	13.71	13.59	3.96	11.53	51.15	9.50	24.0	240	4.4	12.41	12.86	12.07	12.93	12.16	13.03	12.5
16	3.61	13.70	13.67	4.00	11.51	51.28	9.48	24.0	240	4.4	12.47	12.85	12.08	12.95	12.2	13.02	12.53
17	3.83	13.71	13.62	4.10	11.53	51.12	9.48	24.0	240	4.4	12.35	12.83	12.06	13.05	12.28	13.04	12.56
18	3.76	13.71	13.56	3.96	11.51	50.95	9.47	24.0	240	4.4	12.3	12.88	12.09	13.01	12.27	13	12.6
19	3.61	13.71	13.54	4.00	11.48	51.00	9.47	24.0	240	4.4	12.18	12.84	12.11	12.96	12.14	13.04	12.66
20	3.71	13.72	13.57	3.93	11.44	50.99	9.47	24.0	240	4.4	12.32	12.8	12.15	12.95	12.33	13.02	12.68
$\bar{x}$	3.74	13.72	13.57	4.02	11.52	51.01	9.48	24.0	240	4.4	12.28	12.75	11.78	12.79	12.17	12.91	12.55
σ	0.06	0.02	0.08	0.09	0.03	0.25	0.13	0.0	0	0.0	0.13	0.13	0.30	0.17	0.21	0.12	0.12

20. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.33	13.90	13.68	3.50	9.40	51.31	6.88	26.0	250	5.0	11.57	11.74	10.45	12.02	11.33	11.72	11.50
2	3.35	13.90	13.80	3.57	9.54	51.66	6.95	26.0	250	5.0	11.15	11.90	10.69	11.97	11.54	11.79	11.59
3	3.28	13.88	13.80	3.50	9.61	51.64	7.00	26.0	250	5.0	11.35	11.82	10.48	11.25	11.54	11.83	11.69
4	3.30	13.89	13.89	3.55	9.52	51.90	6.96	26.0	250	5.0	11.22	11.79	10.84	11.85	11.72	11.91	11.68
5	3.40	13.89	13.77	3.60	9.39	51.57	6.98	26.0	250	5.0	11.52	11.89	10.87	11.60	11.55	11.99	11.38
6	3.28	13.87	13.75	3.50	9.47	51.51	7.01	26.0	250	5.0	11.63	11.85	10.73	11.73	11.41	11.77	11.44
7	3.26	13.84	13.75	3.52	9.52	51.52	7.00	26.0	250	5.0	11.80	11.84	11.13	12.01	11.11	11.68	11.40
8	3.35	13.86	13.78	3.50	9.46	51.70	7.02	26.0	250	5.0	11.63	11.77	10.37	11.65	11.12	11.74	11.46
9	3.38	13.90	13.75	3.55	9.26	51.51	6.96	26.0	250	5.0	11.14	11.20	10.96	11.95	11.40	11.75	11.65
10	3.28	13.90	14.07	3.48	9.30	52.44	6.99	26.0	250	5.0	11.17	11.53	11.07	12.01	11.33	11.92	11.78
11	3.30	13.90	13.78	3.52	9.34	51.68	7.00	26.0	250	5.0	11.43	11.66	11.07	12.03	11.26	11.88	11.71
12	3.38	13.88	13.66	3.62	9.29	51.23	7.00	26.0	250	5.0	11.04	11.81	10.83	11.99	11.31	11.82	11.67
13	3.30	13.87	13.78	3.52	9.32	51.59	6.98	26.0	250	5.0	10.90	11.71	11.37	11.94	11.31	11.73	11.69
14	3.20	13.87	13.80	3.52	9.41	51.64	7.00	26.0	250	5.0	10.86	11.78	11.05	11.60	11.37	11.65	11.75
15	3.30	13.86	13.71	3.52	9.37	51.38	7.02	26.0	250	5.0	10.96	11.82	10.96	12.00	11.35	11.70	11.76
16	3.40	13.91	13.84	3.55	9.36	51.77	7.02	26.0	250	5.0	11.60	11.97	10.79	11.77	10.96	11.76	11.69
17	3.35	13.91	13.72	3.52	9.34	51.41	7.06	26.0	250	5.0	11.57	11.55	10.84	11.82	11.01	11.82	11.59
18	3.18	13.90	13.83	3.60	9.34	51.74	7.06	26.0	250	5.0	11.54	11.85	10.68	11.85	10.91	11.67	11.39
19	3.28	13.88	13.78	3.55	9.31	51.59	7.04	26.0	250	5.0	11.32	11.78	10.78	11.77	10.89	11.76	11.44
20	3.26	13.86	13.69	3.48	9.36	51.33	7.03	26.0	250	5.0	11.31	11.75	10.74	11.89	10.89	11.80	11.49
$\bar{x}$	3.31	13.88	13.78	3.53	9.40	51.60	7.00	26.0	250	5.0	11.34	11.75	10.84	11.84	11.27	11.78	11.59
σ	0.06	0.02	0.09	0.04	0.10	0.26	0.04	0.0	0	0.0	0.27	0.17	0.24	0.20	0.24	0.09	0.14

21. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

	Independent variables (Measured variables)																
No	**Refrigerant side**								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.92	11.33	11.11	4.14	11.59	43.16	10.49	15.0	265	2.0	13.81	13.59	12.98	13.39	13.25	13.90	13.75
2	3.95	11.35	11.30	4.12	11.63	43.81	10.53	15.0	265	2.0	13.49	13.57	13.18	13.31	13.30	14.00	13.56
3	3.95	11.34	11.29	4.14	11.55	43.78	10.55	15.0	265	2.0	13.76	13.64	13.20	13.25	13.34	13.97	13.52
4	3.97	11.33	11.21	4.04	11.66	43.49	10.56	15.0	265	2.0	13.02	13.79	13.13	13.34	13.28	13.94	13.61
5	3.97	11.30	11.20	4.09	11.72	43.47	10.52	15.0	265	2.0	13.51	13.50	13.06	13.62	13.21	13.87	13.49
6	4.02	11.29	11.29	4.07	11.69	43.78	10.49	15.0	265	2.0	13.25	13.96	13.03	13.97	13.18	13.90	13.42
7	3.95	11.29	11.32	4.17	11.65	43.86	10.45	15.0	265	2.0	13.71	13.26	13.98	14.05	13.12	13.82	13.39
8	4.04	11.31	11.12	4.19	11.64	43.18	10.44	15.0	265	2.0	13.78	13.27	13.01	13.82	13.08	13.87	13.36
9	4.00	11.33	11.33	4.14	11.65	43.90	10.45	15.0	265	2.0	13.45	13.47	12.98	13.86	13.11	13.85	13.26
10	4.00	11.33	11.18	4.19	11.65	43.38	10.45	15.0	265	2.0	13.40	13.54	12.99	13.80	13.11	13.88	13.36
11	4.02	11.33	11.09	4.12	11.69	43.07	10.49	15.0	265	2.0	13.55	13.36	13.03	13.81	13.08	13.91	13.33
12	4.00	11.30	11.10	4.14	11.70	43.11	10.50	15.0	265	2.0	13.37	13.47	13.13	13.85	13.11	13.73	13.49
13	4.02	11.30	11.21	4.17	11.70	43.50	10.50	15.0	265	2.0	13.10	13.42	12.96	13.94	13.12	13.64	13.59
14	4.17	11.33	11.21	4.07	11.69	43.49	10.49	15.0	265	2.0	13.24	13.40	12.98	13.80	13.12	13.65	13.45
15	4.04	11.37	11.22	4.22	11.70	43.53	10.50	15.0	265	2.0	13.21	13.54	12.82	13.68	13.04	13.79	13.46
16	4.14	11.42	11.29	4.22	11.71	43.78	10.51	15.0	265	2.0	13.40	13.53	12.85	13.24	13.11	13.84	13.65
17	4.00	11.50	11.31	4.12	11.64	43.81	10.55	15.0	265	2.0	13.14	13.52	12.87	13.82	13.22	13.94	13.60
18	4.12	11.59	11.47	4.16	11.85	44.39	10.65	15.0	265	2.0	13.25	13.85	12.94	13.88	13.21	14.05	13.68
19	4.04	11.68	11.53	4.14	11.93	44.59	10.73	15.0	265	2.0	13.29	13.66	13.02	13.96	13.32	13.80	13.72
20	4.02	11.82	11.64	4.21	12.03	44.93	10.83	15.0	265	2.0	13.01	13.81	13.11	14.07	13.45	13.85	13.82
$\bar{x}$	4.02	11.39	11.27	4.14	11.70	43.70	10.53	15.0	265	2.0	13.39	13.56	13.06	13.72	13.19	13.86	13.53
σ	0.06	0.15	0.14	0.05	0.11	0.49	0.10	0.0	0	0.0	0.25	0.19	0.24	0.27	0.11	0.10	0.15

22. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^2}{v_{afc}^3} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.82	12.13	11.99	3.99	10.99	46.10	10.14	18.5	270	2.5	12.79	13.02	12.57	13.09	12.61	13.05	12.86
2	3.77	12.21	12.06	3.92	11.02	46.33	10.22	18.5	270	2.5	12.82	13.08	12.54	13.08	12.54	13.08	12.91
3	3.92	12.26	12.09	3.92	11.10	46.52	10.30	18.5	270	2.5	12.79	13.01	12.60	13.03	12.65	13.04	12.84
4	3.84	12.33	12.57	3.92	11.08	47.95	10.38	18.5	270	2.5	12.84	13.06	12.46	12.98	12.82	13.04	12.88
5	3.80	12.41	12.26	4.02	11.26	47.04	10.46	18.5	270	2.5	12.91	13.08	12.51	12.94	12.91	13.01	13.04
6	3.75	12.43	12.28	3.92	11.34	47.14	10.54	18.5	270	2.5	12.81	12.98	12.56	13.01	12.85	13.02	13.08
7	3.80	12.45	12.33	4.02	11.42	47.17	10.22	18.5	270	2.5	13.03	12.95	12.60	13.04	12.83	13.06	13.02
8	3.80	12.43	12.13	3.99	11.47	46.56	10.37	18.5	270	2.5	12.99	12.91	12.66	13.05	12.98	13.02	13.01
9	3.85	12.41	12.28	4.17	11.50	47.03	10.40	18.5	270	2.5	12.95	12.97	12.70	13.01	12.81	13.08	13.07
10	3.77	12.38	12.01	3.89	11.51	46.16	10.41	18.5	270	2.5	13.02	12.91	12.76	13.10	13.02	13.08	12.99
11	3.82	12.33	12.28	4.11	11.52	47.03	10.42	18.5	270	2.5	13.08	12.94	12.79	13.05	12.84	13.01	13.07
12	3.85	12.29	12.44	4.07	11.49	47.52	10.39	18.5	270	2.5	12.99	13.04	12.82	13.00	12.85	13.05	12.92
13	3.95	12.25	12.20	3.68	11.46	46.76	10.36	18.5	270	2.5	12.92	12.86	12.97	13.02	12.71	12.92	13.06
14	3.87	12.19	12.07	4.04	11.41	46.35	10.31	18.5	270	2.5	12.93	12.85	12.87	13.07	12.56	12.98	12.97
15	3.80	12.14	12.09	4.04	11.34	46.42	10.24	18.5	270	2.5	12.72	12.79	12.81	12.92	12.57	13.02	12.92
16	3.82	12.08	12.01	3.90	11.35	46.15	10.15	18.5	270	2.5	12.79	12.87	12.72	12.94	12.58	13.10	12.94
17	3.92	12.04	11.85	4.17	11.14	45.62	10.04	18.5	270	2.5	12.85	12.94	12.71	13.03	12.64	13.04	12.96
18	3.87	11.98	11.93	4.12	11.05	45.91	10.16	18.5	270	2.5	12.95	12.88	12.68	13.05	12.83	13.04	12.94
19	3.90	11.94	11.84	4.04	10.97	45.60	10.23	18.5	270	2.5	12.96	12.84	12.58	13.06	13.07	13.07	12.92
20	3.90	11.91	11.83	4.07	10.90	45.57	10.40	18.5	270	2.5	12.83	12.89	12.62	13.03	13.03	13.04	12.96
$\bar{x}$	3.84	12.23	12.13	4.00	11.27	46.55	10.31	18.5	270	2.5	12.90	12.94	12.68	13.03	12.79	13.04	12.97
σ	0.06	0.17	0.20	0.11	0.21	0.65	0.13	0.0	0	0.0	0.10	0.08	0.13	0.05	0.17	0.04	0.07

23. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.53	12.49	12.35	3.78	10.20	47.24	8.96	21.0	250	3.2	12.16	11.92	11.92	12.22	11.89	12.12	11.97
2	3.70	12.53	12.41	3.73	10.28	47.42	9.01	21.0	250	3.2	11.97	12.12	11.91	12.18	12.09	12.13	12.00
3	3.60	12.58	12.46	3.73	10.29	47.58	9.04	21.0	250	3.2	11.87	12.06	11.84	12.02	11.93	12.17	11.87
4	3.58	12.63	12.51	3.82	10.27	47.85	9.07	21.0	250	3.2	11.91	12.03	12.05	12.11	12.04	12.15	12.02
5	3.65	12.70	12.43	3.82	10.35	47.50	9.15	21.0	250	3.2	11.96	12.07	11.84	12.18	12.12	12.29	11.97
6	3.63	12.88	12.76	3.82	10.96	48.54	9.66	21.0	250	3.2	12.04	12.12	12.23	12.14	11.96	12.22	11.94
7	3.78	12.86	12.71	3.75	10.90	48.39	9.64	21.0	250	3.2	11.93	12.14	12.11	12.24	11.86	12.26	12.05
8	3.63	12.86	12.64	3.75	10.94	48.15	9.64	21.0	250	3.2	11.97	12.25	12.14	12.11	11.72	12.22	11.94
9	3.53	12.84	12.77	3.80	10.75	48.56	9.56	21.0	250	3.2	12.03	12.08	11.91	12.06	11.88	12.08	12.02
10	3.60	12.79	12.70	3.80	10.56	48.35	9.47	21.0	250	3.2	12.01	12.12	11.95	12.04	11.93	12.21	11.98
11	3.58	12.77	12.70	3.75	10.53	48.35	9.45	21.0	250	3.2	12.03	12.25	11.88	12.07	11.85	12.18	11.83
12	3.58	12.72	12.62	3.63	10.46	48.09	9.37	21.0	250	3.2	11.98	12.13	11.86	12.18	11.82	12.16	11.99
13	3.53	12.71	12.51	3.73	10.39	47.74	9.31	21.0	250	3.2	11.95	12.15	11.96	12.02	11.89	12.26	11.88
14	3.56	12.66	12.54	3.70	10.36	47.86	9.24	21.0	250	3.2	11.89	12.06	11.85	12.08	11.96	12.19	11.90
15	3.65	12.65	12.58	3.75	10.30	47.95	9.21	21.0	250	3.2	11.87	12.11	11.92	12.13	11.99	12.11	11.90
16	3.60	12.60	12.46	3.73	10.32	47.59	9.19	21.0	250	3.2	11.89	12.16	11.93	12.03	11.74	12.18	12.01
17	3.48	12.56	12.44	3.68	10.31	47.63	9.15	21.0	250	3.2	11.91	12.14	11.96	12.07	11.85	12.24	12.15
18	3.63	12.51	12.29	3.70	10.36	47.17	9.14	21.0	250	3.2	11.95	12.05	11.99	12.15	11.84	12.25	12.04
19	3.70	12.50	12.41	3.78	10.27	47.44	9.10	21.0	250	3.2	11.91	12.21	12.03	12.22	11.85	12.19	12.06
20	3.63	12.49	12.62	3.85	10.32	48.10	9.10	21.0	250	3.2	12.05	12.03	12.09	12.20	11.93	12.22	12.15
$\bar{x}$	3.61	12.67	12.55	3.76	10.46	47.87	9.27	21.0	250	3.2	11.96	12.11	11.97	12.12	11.91	12.19	11.98
σ	0.07	0.13	0.14	0.05	0.24	0.43	0.23	0.0	0	0.0	0.07	0.08	0.11	0.07	0.10	0.06	0.09

24. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

	Independent variables (Measured variables)																
No	**Refrigerant side**								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.51	12.94	12.86	3.70	9.70	48.95	7.36	24.0	246	4.1	11.45	11.41	11.23	11.60	11.49	11.63	11.54
2	3.56	12.95	12.76	3.63	9.69	48.62	7.38	24.0	246	4.1	11.51	11.45	11.26	11.87	11.27	11.64	11.69
3	3.44	12.96	12.86	3.70	9.73	48.89	7.40	24.0	246	4.1	11.53	11.46	11.36	11.52	11.33	11.67	11.63
4	3.51	12.97	12.87	3.73	9.78	48.97	7.45	24.0	246	4.1	11.43	11.65	11.23	11.43	11.16	11.66	11.58
5	3.46	12.99	12.89	3.70	9.72	48.92	7.48	24.0	246	4.1	11.53	11.62	11.27	11.70	11.25	11.67	11.47
6	3.53	13.02	12.80	3.70	9.73	48.64	7.51	24.0	246	4.1	11.46	11.64	11.26	11.75	11.49	11.73	11.49
7	3.51	13.03	12.91	3.70	9.74	48.98	7.53	24.0	246	4.1	11.37	11.67	11.22	11.68	11.31	11.74	11.56
8	3.63	13.06	13.03	3.73	9.70	49.36	7.59	24.0	246	4.1	11.45	11.48	11.25	11.65	11.35	11.73	11.66
9	3.51	13.07	13.02	3.68	9.65	49.33	7.60	24.0	246	4.1	11.42	11.54	11.40	11.72	11.39	11.76	11.55
10	3.56	13.06	12.82	3.80	9.68	48.71	7.60	24.0	246	4.1	11.48	11.58	11.45	11.79	11.48	11.74	11.57
11	3.46	13.04	12.87	3.70	9.71	48.87	7.61	24.0	246	4.1	11.38	11.62	11.39	11.73	11.40	11.76	11.52
12	3.46	13.03	12.98	3.68	9.65	49.19	7.63	24.0	246	4.1	11.32	11.66	11.36	11.63	11.35	11.75	11.58
13	3.48	12.98	12.93	3.88	9.61	49.15	7.62	24.0	246	4.1	11.37	11.51	11.35	11.68	11.44	11.66	11.42
14	3.41	12.59	12.75	3.68	9.64	48.66	7.57	24.0	246	4.1	11.44	11.64	11.39	11.71	11.45	11.79	11.52
15	3.39	12.92	12.77	3.63	9.62	48.56	7.55	24.0	246	4.1	11.47	11.54	11.27	11.62	11.32	11.63	11.39
16	3.53	12.90	12.78	3.68	9.66	48.58	7.54	24.0	246	4.1	11.38	11.70	11.37	11.64	11.31	11.58	11.48
17	3.44	12.86	12.81	3.68	9.65	48.77	7.51	24.0	246	4.1	11.21	11.59	11.24	11.58	11.41	11.45	11.58
18	3.44	13.01	12.89	3.68	9.66	48.91	7.56	24.0	246	4.1	11.39	11.67	11.23	11.67	11.57	11.52	11.38
19	3.41	12.98	12.96	3.66	9.59	49.14	7.54	24.0	246	4.1	11.42	11.68	11.24	11.69	11.55	11.56	11.49
20	3.46	12.97	12.90	3.63	9.53	48.95	7.55	24.0	246	4.1	11.47	11.58	11.27	11.61	11.43	11.61	11.53
$\bar{x}$	3.49	12.96	12.87	3.70	9.67	48.91	7.53	24.0	246	4.1	11.42	11.58	11.30	11.66	11.39	11.66	11.53
σ	0.06	0.10	0.08	0.06	0.06	0.24	0.08	0.0	0	0.0	0.08	0.09	0.07	0.09	0.10	0.09	0.08

25. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.33	13.41	13.36	3.53	8.48	50.30	6.65	26.0	260	4.5	11.16	11.06	11.1	11.24	11.24	11.5	11.06
2	3.36	13.43	13.26	3.60	8.43	50.05	6.65	26.0	260	4.5	11.1	11.01	11.08	11.22	11.25	11.27	11.03
3	3.43	13.43	13.34	3.55	8.40	50.30	6.65	26.0	260	4.5	11.13	10.94	11.06	11.21	11.08	11.21	11.08
4	3.33	13.44	13.58	3.55	8.38	51.02	6.64	26.0	260	4.5	11.19	11.04	11.03	11.21	10.73	11.16	11.13
5	3.14	13.45	13.32	3.55	8.36	50.34	6.68	26.0	260	4.5	11.16	11.05	10.92	11.27	11.88	11.28	11.07
6	3.26	13.46	13.19	3.70	8.32	49.83	6.67	26.0	260	4.5	11.14	11.24	10.98	11.26	10.86	11.54	11.09
7	3.21	13.46	13.36	3.50	8.43	50.34	6.69	26.0	260	4.5	11.07	11.18	11.08	11.17	11.14	11.56	11.04
8	3.36	13.42	13.23	3.58	8.41	49.97	6.66	26.0	260	4.5	11.15	11.14	11.02	11.16	11.04	11.33	11.06
9	3.28	13.46	13.34	3.50	8.43	50.30	6.71	26.0	260	4.5	11.18	11.16	11.1	11.25	10.92	11.58	11.16
10	3.21	13.51	13.43	3.50	8.63	50.56	6.74	26.0	260	4.5	11.04	11.24	11.05	11.18	11.12	11.36	11.14
11	3.28	13.50	13.43	3.50	8.49	50.57	6.75	26.0	260	4.5	11.13	11.28	10.93	11.1	11.01	11.37	11.16
12	3.33	13.46	13.56	3.60	8.33	50.94	6.70	26.0	260	4.5	11.19	11.2	11.06	11.16	11.04	11.48	11.04
13	3.01	13.46	13.34	3.45	8.47	50.29	6.67	26.0	260	4.5	11.12	11.23	10.98	11.19	10.94	11.3	10.96
14	3.33	13.48	13.36	3.58	8.44	50.35	6.69	26.0	260	4.5	11.04	11.21	11.04	11.23	11.12	11.29	11.05
15	3.23	13.52	13.38	3.62	8.53	50.42	6.74	26.0	260	4.5	11.07	11.25	11.08	11.27	11.29	11.26	11.1
16	3.23	13.52	13.52	3.65	8.66	50.84	6.78	26.0	260	4.5	11.08	11.28	11.06	11.26	11.04	11.34	11.04
17	3.31	13.51	13.34	3.65	8.98	50.28	7.04	26.0	260	4.5	11.15	11.19	11.01	11.14	10.95	11.25	10.96
18	3.04	13.40	13.30	3.58	8.42	50.16	6.45	26.0	260	4.5	11.16	11.14	11.08	11.15	11.02	11.29	11.06
19	3.26	13.36	13.26	3.45	8.38	50.06	6.41	26.0	260	4.5	11.13	11.07	10.92	11.19	11.06	11.44	11.08
20	3.28	13.39	13.37	3.62	8.25	50.37	6.52	26.0	260	4.5	11.15	11.15	11.06	11.13	11.18	11.49	11.16
$\bar{x}$	3.26	13.45	13.36	3.56	8.46	50.37	6.67	26.0	260	4.5	11.13	11.15	11.03	11.20	11.10	11.37	11.07
σ	0.10	0.05	0.10	0.07	0.16	0.30	0.13	0.0	0	0.0	0.05	0.10	0.06	0.05	0.23	0.12	0.06

26. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

	Independent variables (Measured variables)																
No	**Refrigerant side**								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.75	10.09	10.04	3.95	9.46	39.36	8.61	15.0	243	2.0	11.81	12.34	12.16	12.62	11.36	12.88	12.20
2	3.73	10.09	10.02	3.87	9.42	39.28	8.60	15.0	243	2.0	11.87	12.31	12.16	12.60	11.42	12.94	12.17
3	3.78	10.21	10.13	3.90	9.01	39.66	8.52	15.0	243	2.0	12.18	12.34	12.00	12.67	12.28	12.51	12.59
4	3.78	10.24	10.17	4.02	9.04	39.81	8.56	15.0	243	2.0	12.19	12.42	11.95	12.72	12.27	12.46	12.46
5	3.80	10.26	10.04	3.90	9.06	39.34	8.60	15.0	243	2.0	12.19	12.46	12.01	12.76	12.28	12.58	12.55
6	3.80	10.28	10.16	3.80	9.08	39.79	8.63	15.0	243	2.0	12.13	12.55	11.89	12.85	12.11	12.37	12.34
7	3.78	10.30	10.20	4.00	9.09	39.94	8.65	15.0	243	2.0	12.18	12.67	11.81	12.80	12.50	12.55	12.29
8	3.75	10.31	10.19	4.07	9.10	39.89	8.66	15.0	243	2.0	12.31	12.58	11.90	12.68	12.49	12.53	12.40
9	3.48	10.29	10.10	3.95	9.14	39.57	8.72	15.0	243	2.0	12.25	12.48	11.97	12.75	12.47	12.46	12.38
10	3.82	10.30	10.17	3.95	9.09	39.81	8.75	15.0	243	2.0	12.10	12.53	11.99	12.58	12.46	12.57	12.38
11	3.87	10.33	10.20	3.95	9.11	39.92	8.77	15.0	243	2.0	12.16	12.46	11.96	12.67	12.50	12.34	12.50
12	3.53	10.45	10.40	4.02	9.25	40.67	8.92	15.0	243	2.0	12.35	12.71	12.07	12.63	12.74	12.74	12.62
13	3.85	10.48	10.41	4.02	9.29	40.68	8.94	15.0	243	2.0	12.43	12.72	11.94	12.61	12.74	12.63	12.70
14	3.82	10.51	10.41	4.00	9.31	40.68	9.00	15.0	243	2.0	12.44	12.71	12.13	12.72	12.03	12.76	12.61
15	3.85	10.54	10.47	4.00	9.34	40.91	9.04	15.0	243	2.0	12.50	12.80	12.00	12.63	12.66	12.69	12.69
16	3.60	10.54	10.50	4.07	9.37	41.03	9.07	15.0	243	2.0	12.63	12.80	12.01	12.66	12.69	12.64	12.70
17	3.82	10.55	10.38	3.92	9.38	40.57	9.10	15.0	243	2.0	12.79	12.79	11.94	12.79	12.68	12.56	12.74
18	3.80	10.54	10.44	3.92	9.41	40.79	9.10	15.0	243	2.0	11.93	12.79	12.08	12.81	12.72	12.68	12.42
19	3.85	10.52	10.40	4.36	9.43	40.64	9.14	15.0	243	2.0	11.76	12.47	12.00	12.73	12.07	12.83	12.42
20	3.80	9.95	11.67	4.00	9.37	39.11	9.14	15.0	243	2.0	12.46	12.19	11.91	12.61	12.52	12.40	12.59
$\bar{x}$	3.76	10.34	10.32	3.98	9.24	40.07	8.83	15.0	243	2.0	12.23	12.56	11.99	12.69	12.35	12.61	12.49
σ	0.11	0.17	0.35	0.11	0.16	0.61	0.22	0.0	0	0.0	0.27	0.19	0.09	0.08	0.40	0.17	0.17

27. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.65	10.80	10.70	3.87	9.08	41.73	8.33	18.0	260	2.4	11.85	11.94	11.59	11.99	11.52	12.13	11.91
2	3.58	10.76	10.64	3.85	9.10	41.51	8.35	18.0	260	2.4	11.81	11.87	11.71	11.92	11.33	12.16	11.81
3	3.58	10.73	10.66	3.90	9.14	41.58	8.33	18.0	260	2.4	11.67	11.90	11.82	12.07	11.43	12.26	11.80
4	3.63	10.77	10.67	3.80	9.16	41.61	8.37	18.0	260	2.4	11.58	12.21	11.14	11.91	11.83	12.06	11.73
5	3.68	10.79	10.70	3.85	9.22	41.71	8.35	18.0	260	2.4	11.65	11.91	11.35	12.12	11.56	12.14	11.90
6	3.60	10.85	10.70	3.85	9.30	41.74	8.40	18.0	260	2.4	11.78	11.89	11.40	12.15	11.79	12.23	11.95
7	3.60	10.87	10.73	3.82	9.30	41.85	8.41	18.0	260	2.4	11.62	11.81	11.37	12.04	11.63	12.25	11.81
8	3.58	10.90	10.78	3.85	9.30	42.00	8.44	18.0	260	2.4	11.60	11.72	11.24	11.97	11.61	12.18	11.87
9	3.55	10.79	10.69	3.46	9.34	41.70	8.45	18.0	260	2.4	11.57	12.16	11.63	12.01	11.82	12.16	11.89
10	3.63	10.75	10.63	3.85	9.27	41.49	8.40	18.0	260	2.4	11.67	11.66	11.56	12.14	11.70	12.02	11.78
11	3.72	10.75	10.68	3.75	9.26	41.67	8.36	18.0	260	2.4	11.75	11.92	11.51	12.11	11.94	12.26	11.64
12	3.63	10.77	10.64	3.80	9.27	41.52	8.35	18.0	260	2.4	11.54	12.01	11.68	12.05	11.80	12.24	11.66
13	3.70	10.78	10.71	3.82	9.26	41.75	8.37	18.0	260	2.4	11.67	11.86	11.63	12.18	11.45	12.14	11.70
14	3.70	10.80	10.63	3.92	9.34	41.47	8.39	18.0	260	2.4	11.64	11.68	11.49	12.16	11.60	12.36	11.63
15	3.63	10.81	10.64	3.77	9.33	41.63	8.40	18.0	260	2.4	11.58	11.82	11.61	11.94	11.59	12.29	11.66
16	3.68	10.81	10.69	3.92	9.39	41.70	8.40	18.0	260	2.4	11.55	12.01	11.76	11.82	11.58	12.21	11.75
17	3.65	10.73	10.66	3.72	9.38	41.60	8.39	18.0	260	2.4	11.60	11.65	11.52	11.98	11.84	12.19	11.87
18	3.41	10.81	10.64	3.80	9.43	41.51	8.43	18.0	260	2.4	11.63	11.70	11.48	12.14	11.81	12.08	11.81
19	3.65	10.82	10.70	3.75	9.38	41.72	8.42	18.0	260	2.4	11.46	12.26	11.42	12.11	11.75	12.28	11.78
20	3.55	10.75	10.73	3.65	9.41	41.85	8.41	18.0	260	2.4	11.73	12.06	11.69	12.04	11.88	12.31	11.71
$\bar{x}$	3.62	10.79	10.68	3.80	9.28	41.67	8.39	18.0	260	2.4	11.65	11.90	11.53	12.04	11.67	12.20	11.78
σ	0.07	0.04	0.04	0.10	0.10	0.14	0.04	0.0	0	0.0	0.10	0.18	0.17	0.10	0.17	0.09	0.10

28. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

	Independent variables (Measured variables)																
No	**Refrigerant side**								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.41	11.11	10.96	3.65	8.41	42.15	7.06	20.5	252	3.0	11.22	10.98	11.28	11.21	11.16	11.32	11.07
2	3.46	11.05	11.22	3.65	8.35	43.02	7.09	20.5	252	3.0	11.33	11.03	11.08	11.38	11.08	11.24	11.18
3	3.43	11.08	10.99	3.65	8.35	42.23	7.13	20.5	252	3.0	11.16	11.12	11.05	11.27	11.14	11.31	11.11
4	3.46	11.12	11.04	3.63	8.44	42.42	7.18	20.5	252	3.0	11.09	11.06	11.13	11.41	10.90	11.42	11.26
5	3.43	11.13	11.05	3.63	8.38	42.46	7.18	20.5	252	3.0	11.15	10.82	10.98	11.49	11.44	11.49	11.39
6	3.41	11.16	10.99	3.58	8.51	42.26	7.25	20.5	252	3.0	11.09	11.13	10.84	11.55	11.25	11.58	11.37
7	3.38	11.21	11.21	3.60	8.53	43.00	7.34	20.5	252	3.0	10.99	11.42	10.73	11.32	11.02	11.64	11.35
8	3.46	11.24	11.20	3.60	8.55	42.95	7.39	20.5	252	3.0	11.05	11.31	10.93	11.26	10.98	11.57	11.13
9	3.53	11.25	11.20	3.63	8.58	42.95	7.40	20.5	252	3.0	11.19	11.28	10.98	11.26	11.13	11.56	11.17
10	3.56	11.26	11.17	3.58	8.56	42.84	7.41	20.5	252	3.0	11.40	11.29	10.83	11.20	11.32	11.52	11.30
11	3.51	11.29	11.22	3.63	8.56	43.02	7.45	20.5	252	3.0	11.47	11.23	10.97	11.30	10.99	11.54	11.57
12	3.36	11.31	11.21	3.53	8.53	42.99	7.48	20.5	252	3.0	11.33	11.25	10.87	11.11	11.16	11.45	11.53
13	3.34	11.32	11.15	3.58	8.53	42.80	7.50	20.5	252	3.0	11.16	11.33	10.93	11.15	11.53	11.49	11.37
14	3.51	11.33	11.18	3.65	8.53	42.88	7.48	20.5	252	3.0	11.27	11.46	11.03	11.29	11.54	11.40	11.12
15	3.43	11.33	11.21	3.68	8.56	42.98	7.48	20.5	252	3.0	11.42	11.62	11.15	11.16	10.71	11.39	11.18
16	3.46	11.33	11.21	3.63	8.53	42.99	7.48	20.5	252	3.0	10.94	11.58	11.03	11.23	10.84	11.45	11.25
17	3.48	11.33	11.24	3.70	8.52	43.22	7.50	20.5	252	3.0	11.03	11.68	11.00	11.12	10.92	11.41	11.29
18	3.46	11.33	11.26	3.68	8.61	43.18	7.56	20.5	252	3.0	11.23	11.62	10.94	11.16	10.81	11.55	11.40
19	3.43	11.32	11.17	3.68	8.63	42.87	7.56	20.5	252	3.0	11.22	11.59	11.04	11.34	11.10	11.45	11.26
20	3.41	11.32	11.25	3.63	8.63	43.13	7.58	20.5	252	3.0	11.34	11.46	11.23	11.05	10.92	11.58	11.07
$\bar{x}$	3.45	11.24	11.16	3.63	8.51	42.82	7.38	20.5	252	3.0	11.20	11.31	11.00	11.26	11.10	11.47	11.27
σ	0.06	0.10	0.09	0.04	0.09	0.33	0.17	0.0	0	0.0	0.15	0.24	0.13	0.13	0.23	0.10	0.14

29. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

	Independent variables (Measured variables)																
No	**Refrigerant side**								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.38	12.04	11.87	3.60	7.88	45.70	6.50	23.5	244	4.0	10.39	10.59	9.91	10.24	10.17	10.70	10.48
2	3.41	12.05	12.00	3.55	8.08	46.13	6.64	23.5	244	4.0	10.30	10.48	10.01	10.28	10.09	10.50	10.34
3	3.31	11.97	11.95	3.55	8.11	45.96	6.61	23.5	244	4.0	10.29	10.68	10.00	10.18	10.27	10.69	10.27
4	3.26	11.94	11.84	3.50	7.97	45.58	6.54	23.5	244	4.0	10.30	10.36	9.98	10.99	10.35	10.67	10.25
5	3.33	11.90	11.70	3.46	8.03	45.13	6.50	23.5	244	4.0	10.48	10.46	10.13	10.98	10.22	10.30	10.15
6	3.33	11.99	11.91	3.55	7.88	45.83	6.42	23.5	244	4.0	10.46	10.56	10.31	10.27	10.13	10.59	10.64
7	3.21	12.02	11.85	3.48	7.95	45.64	6.59	23.5	244	4.0	10.33	10.67	10.49	10.56	10.49	10.61	10.57
8	3.38	12.11	12.02	3.55	8.27	46.19	6.86	23.5	244	4.0	10.21	10.87	10.16	10.23	10.56	10.68	10.46
9	3.43	12.09	12.01	3.63	8.37	46.15	6.86	23.5	244	4.0	10.19	11.00	10.19	10.88	10.42	10.76	10.29
10	3.33	12.06	11.99	3.48	8.19	46.08	6.82	23.5	244	4.0	10.29	10.78	10.20	10.92	10.38	10.63	10.55
11	3.31	12.05	11.96	3.55	8.32	46.00	6.84	23.5	244	4.0	10.18	10.58	10.14	10.18	10.31	10.35	10.23
12	3.36	12.00	11.93	3.58	8.46	45.89	6.77	23.5	244	4.0	10.40	10.68	10.00	10.14	10.39	10.87	10.77
13	3.26	11.99	11.84	3.50	8.47	45.61	6.74	23.5	244	4.0	10.30	10.50	10.21	10.30	10.45	10.71	10.83
14	3.33	11.98	11.90	3.50	8.26	45.78	6.65	23.5	244	4.0	10.26	10.33	10.03	10.44	10.40	10.69	10.93
15	3.36	11.97	11.75	3.48	8.36	45.30	6.62	23.5	244	4.0	10.33	10.48	10.07	10.24	10.39	10.63	10.25
16	3.31	11.97	11.82	3.50	8.23	45.52	6.57	23.5	244	4.0	10.23	10.26	10.12	11.04	10.29	10.79	10.55
17	3.33	11.94	11.84	3.50	8.14	45.60	6.51	23.5	244	4.0	10.44	10.28	10.31	10.93	10.13	10.89	10.11
18	3.24	11.93	11.71	3.43	8.13	45.16	6.44	23.5	244	4.0	10.34	10.48	10.12	10.82	10.23	11.06	10.32
19	3.36	11.93	11.79	3.46	7.97	45.44	6.36	23.5	244	4.0	10.53	10.41	10.25	10.75	10.42	10.90	10.44
20	3.26	11.95	11.78	3.48	8.04	45.50	6.30	23.5	244	4.0	10.23	10.65	10.01	10.65	10.11	11.09	10.34
$\bar{x}$	3.32	11.99	11.87	3.52	8.16	45.71	6.61	23.5	244	4.0	10.32	10.56	10.13	10.55	10.31	10.71	10.44
σ	0.06	0.06	0.10	0.05	0.18	0.32	0.17	0.0	0	0.0	0.10	0.19	0.14	0.33	0.14	0.20	0.23

30. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								Compressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.11	12.22	12.14	3.40	7.28	46.58	5.95	25.5	258	4.4	9.57	9.73	9.66	9.60	9.46	9.81	9.65
2	3.18	12.22	12.15	3.40	7.36	46.62	5.92	25.5	258	4.4	9.67	9.86	9.56	9.54	9.46	9.63	9.55
3	3.23	12.23	12.33	3.50	7.40	47.19	5.96	25.5	258	4.4	9.30	9.48	9.38	9.51	9.81	9.55	9.78
4	3.13	12.22	12.08	3.52	7.41	46.38	6.00	25.5	258	4.4	9.36	9.46	9.46	10.02	9.87	9.72	9.45
5	3.08	12.16	11.94	3.43	7.44	45.94	5.98	25.5	258	4.4	9.62	9.33	9.53	9.71	9.51	9.65	9.68
6	3.18	12.16	12.07	3.45	7.61	46.35	6.00	25.5	258	4.4	9.51	9.28	9.64	9.47	9.48	9.86	9.65
7	3.16	12.20	12.05	3.43	7.69	46.27	6.10	25.5	258	4.4	9.55	9.64	9.40	9.45	9.47	9.85	9.71
8	2.94	12.25	12.15	3.48	7.59	46.61	6.04	25.5	258	4.4	9.43	9.45	9.47	10.05	9.32	9.98	9.47
9	3.21	12.24	12.17	3.48	7.56	46.67	6.07	25.5	258	4.4	9.42	9.87	9.30	9.46	9.67	9.60	9.84
10	3.28	12.23	12.08	3.50	7.02	46.38	5.97	25.5	258	4.4	9.85	9.77	9.38	10.09	9.39	9.62	9.53
11	3.08	12.23	12.09	3.48	7.67	46.42	6.13	25.5	258	4.4	9.80	9.67	9.32	9.67	9.73	9.85	9.80
12	3.16	12.25	12.37	3.16	7.68	47.29	6.18	25.5	258	4.4	9.50	9.86	9.67	9.87	9.58	9.56	9.92
13	3.26	12.25	12.20	3.50	7.51	46.77	6.16	25.5	258	4.4	9.60	9.31	9.52	9.66	9.48	9.90	9.81
14	3.18	12.27	12.14	3.43	7.61	46.57	6.18	25.5	258	4.4	9.44	9.97	9.46	9.74	9.61	10.00	9.58
15	3.18	12.31	12.22	3.35	7.18	46.94	6.11	25.5	258	4.4	9.63	9.58	9.55	9.63	9.40	9.72	9.46
16	3.11	12.32	12.30	3.35	7.24	47.10	6.13	25.5	258	4.4	9.54	9.72	9.64	10.09	9.47	9.91	9.51
17	3.16	12.33	12.29	3.48	7.36	47.04	6.15	25.5	258	4.4	9.57	9.78	9.76	9.78	9.48	10.04	9.69
18	3.23	12.31	12.45	3.52	7.62	47.56	6.20	25.5	258	4.4	9.32	9.54	9.52	9.68	9.40	10.16	9.53
19	3.30	12.31	12.31	3.50	7.47	47.13	6.15	25.5	258	4.4	9.45	9.32	9.42	9.59	9.71	10.03	9.66
20	3.16	12.32	12.22	3.35	7.34	46.83	6.11	25.5	258	4.4	9.78	9.88	9.40	9.64	9.87	10.01	9.42
$\bar{x}$	3.17	12.25	12.19	3.44	7.45	46.73	6.07	25.5	258	4.4	9.55	9.63	9.50	9.71	9.56	9.82	9.63
σ	0.08	0.05	0.12	0.09	0.18	0.40	0.09	0.0	0	0.0	0.15	0.22	0.13	0.21	0.16	0.18	0.15

31. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.36	12.86	12.74	4.61	14.26	48.48	13.16	15.5	265	2.2	15.10	15.07	14.80	15.62	14.86	15.72	15.18
2	4.34	12.89	12.82	4.56	14.24	48.71	13.14	15.5	265	2.2	15.10	14.97	14.75	15.65	14.89	15.67	15.05
3	4.44	12.91	12.74	4.56	14.20	48.48	13.10	15.5	265	2.2	15.17	15.06	14.69	15.64	14.92	15.66	15.12
4	4.39	12.95	13.07	4.54	14.18	49.49	13.08	15.5	265	2.2	15.15	15.05	14.70	15.57	14.90	15.67	14.92
5	4.44	12.98	13.30	4.61	14.18	50.17	13.08	15.5	265	2.2	14.99	15.09	14.70	15.60	14.84	15.69	14.82
6	4.41	12.94	12.79	4.49	14.17	48.62	13.07	15.5	265	2.2	14.99	15.05	14.72	15.53	14.85	15.63	14.91
7	4.36	12.96	12.98	4.46	14.19	49.21	13.09	15.5	265	2.2	14.99	15.01	14.76	15.60	14.86	15.61	14.98
8	4.56	12.92	12.89	4.56	14.22	48.84	13.10	15.5	265	2.2	15.00	15.01	14.77	15.57	14.86	15.64	15.08
9	4.32	12.95	12.99	4.49	14.32	49.24	13.12	15.5	265	2.2	14.94	15.12	14.83	15.60	14.89	15.71	14.93
10	4.36	12.97	12.90	4.61	14.33	48.97	13.13	15.5	265	2.2	14.85	15.16	14.94	15.68	14.96	15.67	15.01
11	4.39	12.90	12.83	4.54	14.20	48.92	13.13	15.5	265	2.2	15.00	15.14	15.06	15.58	14.97	15.69	15.18
12	4.34	12.94	12.82	4.66	14.23	48.87	13.14	15.5	265	2.2	14.90	15.16	15.00	15.56	14.93	15.73	15.02
13	4.44	13.01	12.57	4.61	14.33	47.94	13.13	15.5	265	2.2	15.04	15.19	14.97	15.67	14.92	15.75	15.06
14	4.49	12.96	13.16	4.63	14.28	48.97	13.14	15.5	265	2.2	14.91	15.14	14.98	15.50	14.97	15.75	15.07
15	4.36	12.93	12.64	4.58	14.30	48.34	13.16	15.5	265	2.2	15.02	15.28	15.01	15.58	14.94	15.80	15.15
16	4.51	12.95	12.85	4.63	14.28	48.83	13.18	15.5	265	2.2	14.98	15.18	14.94	15.67	15.06	15.84	15.24
17	4.41	12.91	12.79	4.58	14.25	48.62	13.18	15.5	265	2.2	14.80	15.12	14.85	15.56	15.10	15.80	15.15
18	4.44	12.90	12.80	4.61	14.30	48.65	13.20	15.5	265	2.2	14.73	15.15	14.90	15.66	15.14	15.82	15.05
19	4.44	12.94	12.85	4.66	14.28	48.79	13.17	15.5	265	2.2	14.78	15.22	14.97	15.60	15.17	15.83	14.87
20	4.49	12.94	12.77	4.58	14.30	48.57	13.20	15.5	265	2.2	14.74	15.24	15.02	15.59	15.14	15.84	14.98
$\bar{x}$	4.41	12.94	12.87	4.58	14.25	48.84	13.14	15.5	265	2.2	14.96	15.12	14.87	15.60	14.96	15.73	15.04
σ	0.06	0.03	0.17	0.05	0.05	0.46	0.04	0.0	0	0.0	0.13	0.08	0.12	0.05	0.11	0.07	0.11

32. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c{}^2}{v_{afc}{}^3} = 9.67$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

	Independent variables (Measured variables)																
No	**Refrigerant side**								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.18	13.68	13.51	4.35	14.00	50.80	12.70	18.0	238	3.0	14.70	14.37	14.09	14.91	14.35	15.03	14.70
2	4.28	13.64	13.51	4.45	13.98	50.79	12.69	18.0	238	3.0	14.94	14.30	14.13	14.88	14.46	15.06	14.68
3	4.20	13.62	13.38	4.42	13.95	50.42	12.68	18.0	238	3.0	14.72	14.51	14.06	14.83	14.81	15.07	14.64
4	4.28	13.70	13.65	4.50	13.70	51.20	12.65	18.0	238	3.0	14.60	15.33	14.05	14.57	14.59	15.01	14.54
5	4.23	13.66	13.56	4.40	13.66	50.95	12.66	18.0	238	3.0	14.21	14.62	14.38	14.60	14.74	15.13	14.58
6	4.25	13.60	13.30	4.50	13.95	50.16	12.65	18.0	238	3.0	14.52	14.75	14.33	14.75	14.72	15.12	14.57
7	4.13	13.67	13.59	4.42	13.93	51.02	12.63	18.0	238	3.0	14.72	14.52	14.18	14.67	14.54	15.16	14.69
8	4.25	13.70	13.58	4.50	13.80	51.01	12.60	18.0	238	3.0	13.98	14.06	14.66	15.07	14.68	14.97	14.40
9	4.18	13.74	13.62	4.42	13.84	51.11	12.60	18.0	238	3.0	14.18	14.23	14.58	15.06	14.60	14.97	14.44
10	4.13	13.76	13.62	4.40	13.81	51.07	12.61	18.0	238	3.0	14.59	14.54	14.42	15.12	14.50	15.00	14.48
11	4.40	13.77	13.72	4.45	13.84	51.42	12.62	18.0	238	3.0	14.28	15.16	14.53	15.09	14.48	15.12	14.47
12	4.23	13.72	13.52	4.47	13.82	50.82	12.62	18.0	238	3.0	14.10	14.65	14.66	15.10	14.74	15.05	14.72
13	4.20	13.68	13.68	4.42	13.89	51.42	12.63	18.0	238	3.0	14.11	14.63	14.69	14.97	14.69	15.06	14.75
14	4.20	13.77	13.65	4.18	13.86	51.21	12.66	18.0	238	3.0	14.29	14.54	14.68	14.97	14.74	15.11	14.75
15	4.25	13.64	13.57	4.50	13.88	51.06	12.68	18.0	238	3.0	14.85	14.53	14.62	14.99	14.72	15.14	14.75
16	4.23	13.75	13.58	4.37	13.85	51.07	12.69	18.0	238	3.0	14.83	14.51	14.68	15.01	14.62	15.13	14.67
17	4.32	13.77	13.68	4.32	13.79	51.30	12.70	18.0	238	3.0	14.93	14.72	14.62	14.89	14.09	15.39	14.52
18	4.18	13.75	13.67	4.37	13.90	51.27	12.70	18.0	238	3.0	14.24	14.98	14.70	14.73	14.43	15.14	14.66
19	4.20	13.73	13.61	4.42	13.88	51.10	12.69	18.0	238	3.0	14.76	14.91	14.36	14.97	14.64	15.03	14.79
20	4.23	13.81	13.61	4.45	13.89	51.09	12.69	18.0	238	3.0	14.72	15.01	14.16	14.93	14.69	15.05	14.88
$\bar{x}$	4.23	13.71	13.58	4.42	13.86	51.01	12.66	18.0	238	3.0	14.51	14.64	14.43	14.91	14.59	15.09	14.63
σ	0.06	0.06	0.10	0.08	0.09	0.31	0.04	0.0	0	0.0	0.31	0.31	0.24	0.17	0.17	0.09	0.13

33. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

	Independent variables (Measured variables)																
No	**Refrigerant side**								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.13	14.16	13.97	4.28	12.76	52.05	11.18	21.0	246	3.5	14.10	14.21	13.95	14.46	13.98	14.65	14.02
2	4.01	14.26	14.17	4.18	13.01	52.61	11.45	21.0	246	3.5	14.01	14.38	14.05	14.45	14.14	14.37	14.18
3	4.04	14.19	14.05	4.18	13.02	52.38	11.47	21.0	246	3.5	14.03	14.27	13.98	14.48	14.12	14.21	14.07
4	4.11	14.17	14.08	4.23	13.02	52.52	11.48	21.0	246	3.5	13.98	14.36	13.90	14.46	14.08	14.50	13.94
5	4.06	14.02	13.92	4.21	13.04	51.99	11.44	21.0	246	3.5	13.53	14.17	14.02	14.47	14.05	14.49	14.16
6	4.08	13.99	13.91	4.18	12.02	51.96	11.43	21.0	246	3.5	14.14	13.98	13.86	14.39	14.01	14.05	14.10
7	4.08	13.95	13.82	4.23	13.00	51.72	11.41	21.0	246	3.5	13.91	14.03	13.93	14.33	14.00	14.45	14.20
8	4.01	14.22	14.12	4.25	12.95	51.91	11.15	21.0	246	3.5	13.93	14.43	13.87	14.14	13.87	14.64	13.94
9	4.11	14.16	14.07	4.23	12.96	52.43	11.17	21.0	246	3.5	14.39	14.41	13.91	14.26	13.85	14.52	14.00
10	3.94	14.25	14.15	4.13	12.99	52.65	11.20	21.0	246	3.5	14.19	14.42	13.88	14.19	13.87	14.42	14.00
11	4.16	14.02	13.97	4.35	13.03	52.16	11.25	21.0	246	3.5	14.10	14.33	13.98	14.26	13.94	14.45	13.95
12	4.21	13.92	13.82	4.35	12.97	51.71	11.16	21.0	246	3.5	13.91	14.22	13.91	14.19	13.89	14.63	13.84
13	4.06	14.10	14.00	4.28	12.94	52.24	11.08	21.0	246	3.5	14.01	13.96	13.87	14.23	14.10	14.69	13.88
14	4.01	14.18	14.15	4.23	13.07	52.65	11.21	21.0	246	3.5	13.83	14.07	13.95	14.28	13.86	14.27	13.97
15	4.04	14.20	14.10	4.16	12.10	52.50	11.24	21.0	246	3.5	13.97	14.12	14.03	14.33	14.01	14.62	13.91
16	3.99	14.08	14.04	4.08	13.01	52.35	11.26	21.0	246	3.5	14.18	14.11	14.01	14.43	13.94	14.36	14.08
17	4.11	13.93	13.86	4.21	13.04	51.83	11.28	21.0	246	3.5	13.81	14.09	13.98	14.38	13.99	14.54	14.03
18	4.06	13.87	13.83	4.35	12.99	51.74	11.24	21.0	246	3.5	14.24	14.04	13.91	14.30	13.94	14.28	13.84
19	4.08	14.00	14.03	4.30	12.90	52.00	11.15	21.0	246	3.5	13.84	13.94	13.83	14.40	13.81	14.13	14.06
20	4.11	14.05	13.95	4.25	12.95	51.95	11.28	21.0	246	3.5	14.08	14.34	13.7	14.36	14.04	14.32	14.18
$\bar{x}$	4.07	14.09	14.00	4.23	12.89	52.17	11.28	21.0	246	3.5	14.01	14.19	13.93	14.34	13.97	14.43	14.02
σ	0.06	0.12	0.11	0.07	0.29	0.32	0.12	0.0	0	0.0	0.19	0.16	0.08	0.10	0.10	0.18	0.11

34. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.88	14.63	14.48	4.08	12.21	53.61	10.72	24.0	268	4.0	13.18	12.90	13.09	13.59	12.90	13.80	13.31
2	4.00	14.62	14.53	4.05	12.16	53.76	10.71	24.0	268	4.0	13.18	12.89	12.95	13.23	12.85	13.54	13.40
3	3.83	14.58	14.51	4.08	12.15	53.67	10.65	24.0	268	4.0	13.16	13.06	12.76	13.45	13.00	13.66	13.34
4	3.71	14.55	14.33	4.05	12.20	53.17	10.64	24.0	268	4.0	13.18	13.01	12.63	13.53	13.31	13.72	13.11
5	3.98	14.58	14.50	4.10	12.05	53.67	10.62	24.0	268	4.0	13.11	13.00	12.71	13.40	13.19	13.51	13.31
6	3.95	14.55	14.42	4.15	12.09	53.43	10.67	24.0	268	4.0	13.52	13.29	12.65	13.39	13.38	13.77	13.27
7	3.88	14.57	14.45	4.10	12.06	53.52	10.65	24.0	268	4.0	13.08	12.99	12.84	13.49	13.27	13.74	13.12
8	3.90	14.55	14.45	4.12	12.21	53.51	10.73	24.0	268	4.0	13.17	13.20	12.77	13.68	13.35	12.88	12.99
9	3.90	14.58	14.46	4.17	12.18	53.53	10.74	24.0	268	4.0	13.13	13.36	12.91	13.61	12.92	12.94	13.13
10	3.86	14.56	14.44	4.15	12.29	53.49	10.73	24.0	268	4.0	12.98	13.44	12.66	13.43	12.84	13.59	13.09
11	3.88	14.57	14.48	4.12	12.40	53.59	10.76	24.0	268	4.0	12.88	13.36	12.88	13.53	13.23	13.67	13.18
12	3.93	14.57	14.55	4.12	12.31	53.80	10.73	24.0	268	4.0	12.80	13.08	12.81	13.47	12.97	13.77	13.33
13	3.88	14.58	14.38	4.05	12.27	53.31	10.69	24.0	268	4.0	12.70	12.96	12.73	13.35	12.93	13.87	13.22
14	3.83	14.60	14.50	4.12	12.33	53.60	10.70	24.0	268	4.0	12.91	13.44	12.83	13.59	12.72	14.03	12.94
15	3.90	14.57	14.38	4.10	12.37	53.47	10.63	24.0	268	4.0	12.84	13.15	12.56	13.20	13.15	13.45	13.14
16	3.83	14.61	14.46	4.03	12.12	53.63	10.52	24.0	268	4.0	12.81	13.30	12.63	13.66	12.90	13.38	13.29
17	3.90	14.59	14.42	4.15	12.18	53.43	10.50	24.0	268	4.0	12.88	13.40	12.72	13.55	12.78	13.45	13.36
18	3.93	14.53	14.40	4.03	12.12	53.36	10.52	24.0	268	4.0	12.76	13.16	12.95	13.63	13.15	13.55	13.49
19	3.81	14.54	14.39	4.03	12.20	53.35	10.46	24.0	268	4.0	12.79	13.45	12.59	13.40	12.65	13.70	13.06
20	3.78	13.48	14.57	4.08	12.25	53.33	10.46	24.0	268	4.0	12.87	13.05	12.68	13.55	12.88	13.62	12.97
$\bar{x}$	3.88	14.52	14.46	4.09	12.21	53.51	10.64	24.0	268	4.0	13.00	13.17	12.77	13.49	13.02	13.58	13.20
σ	0.07	0.25	0.06	0.04	0.10	0.16	0.10	0.0	0	0.0	0.21	0.19	0.14	0.13	0.22	0.28	0.15

35. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

Independent variables (Measured variables)																	
No	Refrigerant side								Compressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.61	15.07	15.00	3.85	11.01	55.03	9.51	26.0	285	4.4	12.63	12.66	12.09	12.97	12.57	12.86	12.86
2	3.63	15.06	14.91	3.88	11.04	54.80	9.54	26.0	285	4.4	12.41	12.53	12.08	12.88	12.48	12.93	12.81
3	3.66	15.06	15.14	3.92	11.06	55.43	9.56	26.0	285	4.4	12.64	12.44	11.92	12.98	12.71	12.83	13.02
4	3.68	15.05	15.07	3.95	11.05	55.25	9.55	26.0	285	4.4	12.59	12.66	12.15	13.02	12.54	12.98	12.81
5	3.58	15.04	14.92	3.83	11.03	54.82	9.53	26.0	285	4.4	12.67	12.75	12.04	12.97	12.66	12.65	12.66
6	3.61	15.05	14.93	3.80	11.03	54.84	9.53	26.0	285	4.4	12.56	12.65	11.72	12.88	12.84	12.66	12.61
7	3.63	15.04	14.92	3.88	11.02	54.82	9.52	26.0	285	4.4	12.27	12.47	12.03	13.02	12.81	13.20	12.60
8	3.61	15.06	14.81	3.80	11.05	54.53	9.53	26.0	285	4.4	12.47	12.77	12.00	12.71	12.24	13.11	12.53
9	3.63	15.04	14.99	3.90	11.09	54.93	9.53	26.0	285	4.4	12.41	12.82	11.80	12.60	12.31	13.20	12.80
10	3.53	15.01	14.94	3.88	11.01	54.89	9.51	26.0	285	4.4	12.27	12.68	12.27	12.79	12.22	13.32	12.47
11	3.75	15.00	14.87	3.83	10.89	54.69	9.49	26.0	285	4.4	12.38	12.77	12.19	12.30	12.40	13.11	12.32
12	3.61	15.02	14.87	3.88	11.03	54.79	9.47	26.0	285	4.4	12.38	12.69	12.16	12.71	12.33	13.18	12.27
13	3.63	15.10	15.00	3.83	11.10	55.12	9.48	26.0	285	4.4	12.54	12.96	12.19	12.78	12.96	13.32	12.47
14	3.70	15.04	14.94	3.90	10.98	54.88	9.48	26.0	285	4.4	12.49	12.64	12.22	12.82	12.80	13.16	12.51
15	3.68	15.05	14.98	3.78	10.95	55.06	9.45	26.0	285	4.4	12.24	13.19	12.34	12.72	12.34	13.03	12.58
16	3.61	15.04	14.95	3.88	10.92	54.89	9.42	26.0	285	4.4	12.49	12.72	12.18	12.88	12.70	13.04	12.38
17	3.63	15.03	14.88	3.88	10.92	54.71	9.42	26.0	285	4.4	12.60	12.69	12.21	12.86	12.59	12.86	12.39
18	3.58	15.07	14.97	3.90	11.03	55.03	9.41	26.0	285	4.4	12.41	12.59	12.48	12.96	12.45	12.74	12.21
19	3.56	15.04	14.97	3.85	10.95	54.95	9.35	26.0	285	4.4	12.51	12.53	12.25	12.88	12.56	13.16	12.39
20	3.66	15.06	14.91	3.90	10.99	54.97	9.36	26.0	285	4.4	12.57	12.65	11.86	12.76	12.37	12.94	12.45
$\bar{x}$	3.63	15.05	14.95	3.87	11.01	54.92	9.48	26.0	285	4.4	12.48	12.69	12.11	12.82	12.54	13.01	12.56
σ	0.05	0.02	0.07	0.04	0.06	0.20	0.06	0.0	0	0.0	0.13	0.17	0.19	0.17	0.21	0.20	0.22

36. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.02	11.53	11.46	4.00	12.53	44.34	11.33	15.0	252	2.2	14.15	14.68	13.99	14.45	14.19	14.41	14.06
2	4.05	11.54	11.41	4.22	12.46	44.16	11.56	15.0	252	2.2	14.13	14.47	12.65	14.35	14.01	14.58	14.11
3	4.14	11.56	11.46	4.29	12.48	44.36	11.58	15.0	252	2.2	14.05	14.32	13.80	14.22	14.30	14.67	13.99
4	4.10	11.56	11.44	4.27	12.49	44.29	11.59	15.0	252	2.2	14.07	14.35	14.20	14.12	14.42	14.77	13.99
5	4.24	11.57	11.39	4.34	12.49	44.10	11.59	15.0	252	2.2	14.08	14.26	13.69	14.30	14.42	14.62	14.15
6	4.19	11.58	11.48	4.36	12.51	44.41	11.61	15.0	252	2.2	14.11	14.38	14.01	14.32	14.31	14.70	14.11
7	4.10	11.60	11.48	4.22	12.51	44.40	11.61	15.0	252	2.2	14.04	14.31	14.00	14.42	14.25	14.85	14.19
8	4.14	11.99	11.87	4.27	12.49	44.41	11.59	15.0	252	2.2	14.11	14.43	13.91	14.32	14.28	14.72	13.96
9	4.12	11.59	11.47	4.22	12.50	44.38	11.60	15.0	252	2.2	14.15	14.55	13.81	14.23	13.98	14.89	13.94
10	4.19	11.62	11.67	4.34	12.52	44.95	11.62	15.0	252	2.2	14.20	14.48	14.05	14.40	14.13	14.76	14.11
11	4.17	11.61	11.56	4.32	12.53	44.67	11.63	15.0	252	2.2	14.22	14.39	13.89	14.38	13.87	14.78	14.05
12	4.22	11.58	11.46	4.27	12.51	44.35	11.61	15.0	252	2.2	14.23	14.43	13.89	14.54	13.97	14.71	14.23
13	4.07	11.60	11.51	4.22	12.50	44.50	11.60	15.0	252	2.2	14.20	14.68	13.55	14.27	14.00	14.61	14.20
14	4.17	11.58	11.56	4.27	12.49	44.68	11.59	15.0	252	2.2	14.20	14.30	13.86	14.35	13.93	14.69	14.51
15	4.22	11.59	11.54	4.46	12.51	44.61	11.61	15.0	252	2.2	14.20	14.35	13.83	14.35	14.09	14.67	14.44
16	4.14	11.63	11.58	4.34	12.52	44.62	11.62	15.0	252	2.2	14.15	14.31	13.88	14.20	14.54	14.69	13.94
17	4.12	11.57	11.50	4.27	12.51	44.47	11.61	15.0	252	2.2	14.19	14.32	13.88	14.66	14.72	14.75	13.89
18	4.17	11.56	11.46	4.32	12.50	44.35	11.60	15.0	252	2.2	14.14	14.27	14.12	14.62	14.59	14.53	14.09
19	4.12	11.58	11.51	4.32	12.48	44.52	11.58	15.0	252	2.2	14.17	14.25	13.93	14.39	14.59	14.47	14.13
20	4.17	11.57	11.57	4.36	12.48	44.70	11.58	15.0	252	2.2	14.17	14.29	13.98	14.39	14.54	14.45	14.02
$\bar{x}$	4.14	11.60	11.52	4.28	12.50	44.46	11.59	15.0	252	2.2	14.15	14.39	13.85	14.36	14.26	14.67	14.11
σ	0.06	0.09	0.11	0.09	0.02	0.20	0.06	0.0	0	0.0	0.06	0.13	0.32	0.13	0.26	0.13	0.16

37. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.13	12.71	12.63	4.30	12.01	48.21	10.81	18.0	245	2.8	13.45	13.44	12.50	14.31	13.14	14.16	13.82
2	4.03	12.78	12.61	4.20	12.09	48.17	10.89	18.0	245	2.8	13.43	13.47	13.59	14.06	13.50	14.05	13.69
3	4.03	12.45	12.38	4.15	11.49	47.45	10.29	18.0	245	2.8	13.18	13.28	13.39	13.28	12.86	14.28	13.44
4	3.98	12.68	12.56	4.20	11.81	48.01	10.61	18.0	245	2.8	12.80	13.36	13.37	13.58	13.06	14.13	13.48
5	4.10	12.42	12.22	4.20	11.48	46.84	10.28	18.0	245	2.8	14.08	13.31	13.02	13.47	13.36	14.04	13.44
6	4.05	12.48	12.33	4.20	11.65	47.19	10.35	18.0	245	2.8	13.54	13.41	12.57	13.54	13.42	14.02	13.43
7	3.98	12.64	12.50	4.27	11.75	47.70	10.55	18.0	245	2.8	13.45	13.53	13.25	13.68	13.39	14.06	13.55
8	4.03	12.79	12.65	4.25	11.98	48.18	10.78	18.0	245	2.8	13.40	13.92	13.11	13.73	13.34	14.29	13.54
9	4.00	12.81	12.57	4.15	12.03	47.93	10.83	18.0	245	2.8	13.57	14.05	12.87	13.90	13.46	14.41	13.60
10	3.93	12.79	12.67	4.18	12.08	48.26	10.88	18.0	245	2.8	13.32	14.08	12.97	13.70	13.50	13.96	13.58
11	3.98	12.76	12.61	4.18	12.12	48.06	10.92	18.0	245	2.8	13.50	13.92	13.05	13.84	13.49	14.01	13.58
12	4.05	12.71	12.59	4.18	12.10	48.01	10.90	18.0	245	2.8	13.75	13.80	12.67	13.92	13.32	14.15	13.63
13	3.98	12.68	12.56	4.13	12.11	47.90	10.91	18.0	245	2.8	13.72	13.61	12.90	13.88	13.23	14.03	13.58
14	3.91	12.60	12.50	4.13	11.96	47.73	10.86	18.0	245	2.8	13.49	13.63	13.95	13.78	13.16	13.49	13.52
15	4.03	12.58	12.31	4.18	12.04	47.11	10.84	18.0	245	2.8	13.28	13.39	13.44	13.73	13.48	14.23	13.65
16	3.88	12.57	12.45	4.05	12.02	47.54	10.82	18.0	245	2.8	13.42	13.59	13.42	13.54	13.22	14.14	13.62
17	4.00	12.52	12.59	4.15	11.98	48.01	10.78	18.0	245	2.8	13.67	13.60	13.37	13.82	12.98	14.20	13.55
18	3.98	12.49	12.35	4.13	11.93	47.26	10.73	18.0	245	2.8	13.54	13.58	13.26	14.00	12.93	13.82	13.63
19	3.96	12.49	12.42	4.08	11.89	47.46	10.69	18.0	245	2.8	13.64	13.52	13.43	14.01	12.87	14.24	13.65
20	4.00	12.44	12.29	4.03	11.80	47.06	10.60	18.0	245	2.8	13.17	13.53	13.48	13.62	12.79	14.30	13.68
$\bar{x}$	4.00	12.62	12.49	4.17	11.92	47.70	10.72	18.0	245	2.8	13.47	13.60	13.18	13.77	13.23	14.10	13.58
σ	0.06	0.13	0.14	0.07	0.20	0.44	0.21	0.0	0	0.0	0.26	0.24	0.36	0.24	0.24	0.20	0.10

38. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 11.74$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.71	12.86	12.76	3.93	10.71	48.62	9.64	20.5	252	3.2	12.71	13.14	12.49	13.08	12.51	12.72	12.78
2	3.73	12.88	12.81	3.88	10.69	48.60	9.62	20.5	252	3.2	12.51	13.02	12.47	13.18	12.63	12.75	12.82
3	3.73	12.90	12.95	3.85	10.65	49.04	9.61	20.5	252	3.2	12.29	13.03	12.16	12.72	12.49	12.91	12.73
4	3.76	12.85	12.75	3.83	10.66	48.49	9.60	20.5	252	3.2	12.90	12.75	12.49	13.02	12.86	13.19	12.89
5	3.71	12.86	12.79	3.90	10.70	48.58	9.60	20.5	252	3.2	12.90	12.88	12.52	12.99	13.00	13.02	12.85
6	3.76	12.85	12.71	3.98	10.67	48.37	9.60	20.5	252	3.2	12.58	12.69	12.19	12.43	12.96	12.72	12.92
7	3.73	12.88	12.78	4.00	10.65	48.47	9.61	20.5	252	3.2	12.70	12.82	12.46	12.94	12.43	12.73	13.34
8	3.78	12.84	12.76	3.90	10.66	48.53	9.62	20.5	252	3.2	12.55	13.12	12.41	13.21	12.67	13.11	12.59
9	3.63	12.82	12.74	3.85	10.71	48.46	9.60	20.5	252	3.2	12.53	12.76	12.51	12.93	12.50	12.97	12.55
10	3.73	12.85	12.75	3.98	10.67	48.42	9.62	20.5	252	3.2	12.69	12.91	12.50	13.21	12.50	12.95	12.56
11	3.66	12.82	12.67	3.85	10.70	48.26	9.60	20.5	252	3.2	12.70	12.75	12.53	13.07	12.23	12.99	12.54
12	3.90	12.88	12.78	3.83	10.72	48.41	9.63	20.5	252	3.2	12.42	12.82	12.30	13.16	12.29	13.02	12.43
13	3.76	12.94	12.90	3.88	10.77	48.64	9.62	20.5	252	3.2	12.40	12.97	12.35	13.19	12.15	12.95	12.47
14	3.73	12.82	12.70	3.90	10.67	48.35	9.57	20.5	252	3.2	12.59	13.04	12.52	13.26	12.21	12.93	12.51
15	3.66	12.83	12.71	3.88	10.68	48.46	9.59	20.5	252	3.2	12.68	13.05	12.45	12.68	12.22	12.95	12.49
16	3.73	12.91	12.79	3.85	10.70	48.31	9.56	20.5	252	3.2	12.93	12.85	12.29	12.77	13.11	12.81	12.58
17	3.76	12.85	12.71	3.88	10.76	48.30	9.53	20.5	252	3.2	12.21	12.72	12.20	12.44	12.51	12.91	13.40
18	3.73	12.83	12.76	3.83	10.77	48.52	9.54	20.5	252	3.2	12.61	12.79	12.20	12.37	12.27	12.77	13.12
19	3.68	12.89	12.69	3.73	10.77	48.40	9.55	20.5	252	3.2	12.70	12.71	11.81	12.48	12.46	12.70	13.06
20	3.78	12.84	12.77	3.80	10.76	48.52	9.54	20.5	252	3.2	12.66	12.60	12.29	12.55	12.47	13.06	13.01
$\bar{x}$	3.73	12.86	12.76	3.88	10.70	48.49	9.59	20.5	252	3.2	12.61	12.87	12.36	12.88	12.52	12.91	12.78
σ	0.06	0.03	0.07	0.06	0.04	0.17	0.03	0.0	0	0.0	0.19	0.16	0.18	0.30	0.28	0.14	0.29

39. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.61	13.59	13.52	3.78	10.59	50.82	8.59	24.0	255	4.0	12.19	12.28	11.67	12.34	11.71	12.66	12.23
2	3.56	13.57	13.55	3.71	10.58	50.92	8.58	24.0	255	4.0	11.85	12.33	11.22	12.60	11.54	12.95	12.11
3	3.61	13.58	13.53	3.66	10.57	50.86	8.57	24.0	255	4.0	12.19	12.45	11.24	12.85	11.88	12.84	11.83
4	3.68	13.51	13.49	3.75	10.55	50.74	8.65	24.0	255	4.0	12.11	12.42	11.48	12.60	11.57	12.49	11.87
5	3.58	13.60	13.53	3.71	10.62	50.84	8.62	24.0	255	4.0	12.32	12.06	11.76	12.51	12.04	12.60	11.97
6	3.54	13.57	13.40	3.78	10.58	50.46	8.58	24.0	255	4.0	11.98	12.07	11.47	12.38	12.16	12.39	11.99
7	3.58	13.53	13.43	3.73	10.54	50.66	8.54	24.0	255	4.0	11.80	12.19	11.62	12.69	12.30	12.22	11.90
8	3.61	13.50	13.33	3.78	10.47	50.27	8.47	24.0	255	4.0	11.58	12.01	12.33	12.83	11.83	12.72	11.86
9	3.80	13.48	13.40	3.78	10.45	50.48	8.41	24.0	255	4.0	11.71	12.66	11.30	12.55	11.70	12.77	11.80
10	3.58	13.52	13.47	3.73	10.41	50.77	8.41	24.0	255	4.0	11.56	12.45	11.29	12.59	11.64	12.54	11.81
11	3.63	13.50	13.42	3.85	10.52	50.52	8.42	24.0	255	4.0	11.77	12.40	11.04	12.36	11.74	12.73	11.82
12	3.56	13.49	13.30	3.66	10.48	50.18	8.38	24.0	255	4.0	11.73	12.11	11.03	12.31	11.69	12.80	11.87
13	3.66	13.51	13.37	3.73	10.40	50.37	8.55	24.0	255	4.0	11.82	12.11	10.92	12.38	11.69	12.61	11.96
14	3.61	13.59	13.50	3.78	10.48	50.77	8.38	24.0	255	4.0	11.79	11.93	10.84	12.41	11.90	12.31	11.89
15	3.51	13.56	13.44	3.68	10.53	50.59	8.43	24.0	255	4.0	11.82	12.29	11.05	12.59	11.92	12.47	11.98
16	3.51	13.57	13.57	3.66	10.48	50.96	8.39	24.0	255	4.0	11.61	12.08	11.08	12.45	12.02	12.85	12.05
17	3.56	13.57	13.57	3.75	10.49	50.98	8.66	24.0	255	4.0	11.78	12.07	11.09	12.35	12.00	12.76	12.06
18	3.61	13.58	13.58	3.80	10.54	51.09	8.53	24.0	255	4.0	11.76	12.04	11.26	12.02	12.00	12.69	12.03
19	3.53	13.59	13.62	3.68	10.49	51.21	8.40	24.0	255	4.0	12.49	12.34	10.95	12.25	11.86	12.87	12.12
20	3.56	13.58	13.43	3.71	10.48	50.57	8.48	24.0	255	4.0	12.12	12.23	11.21	12.22	11.68	12.33	12.21
$\bar{x}$	3.59	13.55	13.47	3.74	10.51	50.70	8.50	24.0	255	4.0	11.90	12.23	11.29	12.46	11.84	12.63	11.97
σ	0.07	0.04	0.09	0.05	0.06	0.27	0.10	0.0	0	0.0	0.26	0.19	0.35	0.20	0.20	0.21	0.13

40. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\;3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

Independent variables (Measured variables)

No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.43	14.21	14.03	3.72	9.65	52.32	7.95	26.0	262	4.5	11.66	11.32	11.20	11.77	11.44	11.97	11.50
2	3.53	14.21	14.11	3.72	9.67	52.55	7.97	26.0	262	4.5	11.83	11.73	11.25	11.64	11.57	11.88	11.68
3	3.5	14.22	14.12	3.75	9.72	52.57	8.02	26.0	262	4.5	11.27	11.65	11.19	11.29	11.34	12.13	11.70
4	3.46	14.25	14.05	3.7	9.72	52.38	8.02	26.0	262	4.5	11.44	11.83	11.24	11.45	11.35	12.10	11.76
5	3.58	14.24	14.14	3.72	9.76	52.63	8.06	26.0	262	4.5	11.34	11.55	11.38	11.81	11.59	12.40	11.40
6	3.41	14.25	14.1	3.7	9.79	52.52	8.09	26.0	262	4.5	11.58	11.49	11.26	11.61	11.23	11.79	11.31
7	3.38	14.22	14.1	3.65	9.78	52.51	8.08	26.0	262	4.5	11.09	11.28	11.48	11.83	11.21	11.61	11.38
8	3.46	14.21	14.14	3.68	9.75	52.63	8.05	26.0	262	4.5	11.19	11.82	11.16	11.72	11.55	11.69	11.40
9	3.58	14.28	14.26	3.65	9.77	52.77	8.07	26.0	262	4.5	11.23	11.43	11.04	11.57	11.39	12.02	11.19
10	3.48	14.23	14.13	3.68	9.8	52.59	8.10	26.0	262	4.5	11.90	11.19	11.17	11.44	11.00	12.55	11.84
11	3.50	14.22	13.97	3.72	9.78	52.15	8.08	26.0	262	4.5	11.34	11.60	10.80	11.84	11.28	12.03	11.23
12	3.53	14.25	14.3	3.68	9.79	52.99	8.09	26.0	262	4.5	11.26	11.22	11.26	11.68	11.48	12.13	11.44
13	3.41	14.21	14.09	3.63	9.77	52.49	8.07	26.0	262	4.5	11.02	11.01	11.41	11.70	11.41	12.61	11.41
14	3.48	14.28	14.1	3.72	9.76	52.30	8.06	26.0	262	4.5	11.18	11.61	11.50	11.50	11.48	12.35	11.11
15	3.50	14.25	14.13	3.68	9.76	52.46	8.06	26.0	262	4.5	11.33	11.26	11.35	11.14	11.26	11.87	11.89
16	3.46	14.19	14.04	3.58	9.77	52.34	8.07	26.0	262	4.5	11.63	11.18	11.01	11.93	11.95	12.09	11.26
17	3.48	14.31	14.17	3.75	9.8	52.36	8.10	26.0	262	4.5	11.24	11.60	11.21	11.26	11.75	11.70	11.32
18	3.50	14.28	14.26	3.72	9.75	52.69	8.07	26.0	262	4.5	11.32	11.69	11.07	11.48	11.35	11.84	11.71
19	3.43	14.24	14.22	3.68	9.78	52.69	8.08	26.0	262	4.5	11.46	11.88	10.98	11.71	11.24	11.82	11.57
20	3.53	14.27	14.15	3.7	9.8	52.39	8.08	26.0	262	4.5	11.63	11.77	10.70	11.59	11.87	11.93	11.53
$\bar{x}$	3.48	14.24	14.13	3.69	9.76	52.52	8.06	26.0	262	4.5	11.40	11.51	11.18	11.60	11.44	12.03	11.48
σ	0.05	0.03	0.08	0.04	0.04	0.19	0.04	0.0	0	0.0	0.24	0.25	0.21	0.21	0.23	0.28	0.22

41. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^2}{v_{afc}^3} = 4.96$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								Compressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	4.00	10.53	10.40	4.03	10.37	40.66	9.47	15.0	258	2.0	13.02	13.17	12.86	13.56	12.51	13.37	12.83
2	3.97	10.49	10.37	4.14	10.23	40.55	9.43	15.0	258	2.0	13.03	12.79	12.58	13.39	12.85	13.39	13.08
3	4.05	10.48	10.41	3.95	10.31	40.71	9.41	15.0	258	2.0	13.36	13.08	12.73	13.27	13.15	13.50	13.08
4	3.95	10.49	10.39	4.05	10.32	40.61	9.42	15.0	258	2.0	13.51	13.35	12.65	13.44	13.09	13.40	12.93
5	3.90	10.47	10.37	4.02	10.33	40.65	9.43	15.0	258	2.0	13.02	13.57	12.67	13.31	13.04	13.37	12.93
6	4.00	10.45	10.38	4.05	10.23	40.59	9.33	15.0	258	2.0	13.23	13.01	12.59	13.32	12.80	13.31	12.68
7	3.92	10.47	10.39	4.05	10.25	40.62	9.35	15.0	258	2.0	12.95	12.99	12.66	13.35	12.92	13.30	12.85
8	3.97	10.52	10.42	4.10	10.56	40.74	9.66	15.0	258	2.0	13.06	13.57	12.84	13.51	13.15	13.61	13.20
9	4.02	10.64	10.54	4.10	10.59	41.16	9.79	15.0	258	2.0	13.31	13.46	12.76	13.49	13.22	13.69	13.25
10	4.00	10.69	10.64	4.12	10.76	41.50	9.86	15.0	258	2.0	13.06	13.38	12.84	13.54	13.14	13.89	13.47
11	4.02	10.70	10.53	4.10	10.79	41.14	9.89	15.0	258	2.0	13.32	12.54	12.94	13.74	13.04	13.80	13.30
12	3.88	10.72	10.72	3.92	10.77	41.81	9.97	15.0	258	2.0	13.07	13.28	12.99	13.39	13.26	13.79	13.09
13	4.05	10.57	10.38	4.14	10.98	40.58	10.08	15.0	258	2.0	13.24	13.00	12.91	13.26	13.22	13.33	13.79
14	4.10	10.52	10.40	4.29	10.91	40.65	10.01	15.0	258	2.0	13.45	13.13	12.85	13.55	13.27	13.21	13.55
15	4.02	10.45	10.23	4.19	10.85	40.05	9.95	15.0	258	2.0	13.34	13.48	13.06	13.33	13.44	13.05	13.27
16	3.92	10.45	10.38	4.07	10.83	40.58	9.93	15.0	258	2.0	12.18	13.72	12.91	13.47	13.43	13.04	13.48
17	4.05	10.66	10.54	4.05	10.63	41.16	9.73	15.0	258	2.0	12.78	13.56	12.89	13.61	12.95	13.81	13.31
18	4.00	10.65	10.65	4.12	10.60	41.55	9.70	15.0	258	2.0	12.82	13.36	12.89	13.65	12.92	13.77	13.11
19	3.88	10.62	10.48	4.14	10.51	40.95	9.61	15.0	258	2.0	12.82	13.61	12.55	13.54	12.78	13.58	13.12
20	3.90	10.53	10.45	4.05	10.40	40.83	9.50	15.0	258	2.0	13.17	12.98	12.84	13.32	13.00	13.51	12.89
$\bar{x}$	3.98	10.56	10.45	4.08	10.56	40.85	9.68	15.0	258	2.0	13.09	13.25	12.80	13.45	13.06	13.49	13.16
σ	0.06	0.09	0.12	0.08	0.25	0.42	0.25	0.0	0	0.0	0.30	0.31	0.14	0.14	0.23	0.25	0.28

42. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^2}{v_{afc}^3} = 9.67$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.81	10.80	10.71	3.93	10.17	41.89	8.93	17.5	254	2.5	12.62	12.48	11.99	12.61	11.92	13.07	12.33
2	3.71	10.83	10.61	3.90	10.18	41.55	8.87	17.5	254	2.5	12.76	12.52	11.72	13.03	12.11	12.88	13.07
3	3.73	10.83	10.69	3.93	10.20	41.84	8.89	17.5	254	2.5	12.81	12.67	11.75	12.88	12.14	12.90	12.36
4	3.78	10.85	10.72	4.00	10.19	41.94	8.92	17.5	254	2.5	12.58	12.84	11.59	12.65	12.06	13.06	12.99
5	3.83	10.84	10.72	3.83	10.19	41.96	8.92	17.5	254	2.5	12.61	12.60	11.57	12.63	12.14	12.82	12.69
6	3.78	10.87	10.94	3.98	10.23	42.74	8.96	17.5	254	2.5	12.81	12.77	11.62	13.32	11.95	12.77	12.69
7	3.78	10.87	10.85	3.86	10.31	42.40	9.04	17.5	254	2.5	12.52	12.91	11.35	13.29	11.92	13.03	12.24
8	3.76	10.86	10.88	3.95	10.27	42.53	8.95	17.5	254	2.5	12.65	13.04	11.68	13.21	12.26	13.16	12.06
9	3.86	10.88	10.83	4.03	10.24	42.32	8.89	17.5	254	2.5	12.48	12.33	11.78	12.93	12.01	12.91	12.26
10	3.73	10.88	10.78	3.98	10.26	42.15	8.91	17.5	254	2.5	12.32	12.41	11.48	13.37	12.38	13.12	12.66
11	3.76	10.89	10.77	3.95	10.34	42.13	8.98	17.5	254	2.5	12.50	12.59	11.64	13.22	12.11	13.23	12.85
12	3.83	10.87	10.79	3.90	10.34	42.20	8.98	17.5	254	2.5	12.54	12.54	11.27	13.18	12.27	13.33	12.61
13	3.81	10.89	10.72	3.90	10.40	41.94	9.03	17.5	254	2.5	12.47	12.21	11.58	12.55	11.92	13.60	12.49
14	3.86	10.91	10.83	4.03	10.48	42.35	9.11	17.5	254	2.5	12.55	12.44	11.73	12.99	12.24	13.12	12.66
15	3.78	10.90	10.76	3.95	10.37	42.08	8.99	17.5	254	2.5	12.73	12.62	11.44	12.54	12.38	12.90	12.23
16	3.73	10.85	10.75	3.83	10.35	42.02	9.00	17.5	254	2.5	12.81	12.67	11.58	12.65	12.51	13.03	12.52
17	3.78	10.90	10.78	3.93	10.45	42.16	9.09	17.5	254	2.5	12.47	12.33	11.66	12.88	12.12	13.40	12.69
18	3.83	10.90	10.80	3.95	10.42	42.24	8.99	17.5	254	2.5	12.78	12.55	11.79	13.21	11.94	13.18	12.27
19	3.76	10.91	10.83	3.98	10.41	42.35	8.93	17.5	254	2.5	13.01	12.51	11.82	13.34	11.52	13.15	12.53
20	3.90	10.94	10.87	4.05	10.46	42.48	9.03	17.5	254	2.5	12.61	12.30	11.89	13.50	12.07	13.06	12.50
$\bar{x}$	3.79	10.87	10.78	3.94	10.31	42.16	8.97	17.5	254	2.5	12.63	12.57	11.65	13.00	12.10	13.09	12.54
σ	0.05	0.03	0.08	0.06	0.10	0.28	0.07	0.0	0	0.0	0.16	0.21	0.18	0.31	0.22	0.20	0.26

43. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								**Com-pressor**		**Air side**						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.60	11.41	11.26	3.78	9.92	43.33	8.61	20.0	258	3.0	11.93	11.85	10.99	12.13	11.61	12.27	11.93
2	3.48	11.42	11.39	3.73	9.93	43.86	8.62	20.0	258	3.0	11.96	11.67	10.68	12.01	11.51	12.16	11.83
3	3.60	11.43	11.38	3.82	9.96	43.72	8.65	20.0	258	3.0	11.71	11.57	10.81	11.82	12.25	12.26	11.86
4	3.65	11.41	11.31	3.75	9.97	43.51	8.65	20.0	258	3.0	11.77	11.43	10.72	11.71	11.94	12.37	11.60
5	3.58	11.44	11.34	3.75	9.97	43.61	8.62	20.0	258	3.0	11.72	11.65	11.17	11.91	11.69	12.35	11.92
6	3.56	11.44	11.36	3.80	9.99	43.66	8.63	20.0	258	3.0	11.90	11.73	10.79	11.85	11.53	12.22	11.84
7	3.58	11.40	11.35	3.85	9.98	43.73	8.63	20.0	258	3.0	11.91	11.48	10.96	11.93	11.44	12.24	11.82
8	3.60	11.42	11.28	3.73	9.99	43.40	8.65	20.0	258	3.0	11.77	11.52	11.14	11.73	11.53	12.27	11.81
9	3.63	11.43	11.31	3.78	9.99	43.49	8.64	20.0	258	3.0	11.90	11.93	11.06	12.11	11.72	12.34	11.86
10	3.53	11.42	11.34	3.73	10.02	43.60	8.67	20.0	258	3.0	11.64	11.74	10.99	11.73	11.84	12.17	11.88
11	3.58	11.37	11.25	3.75	10.00	43.45	8.64	20.0	258	3.0	11.65	11.86	11.40	12.22	11.23	12.11	11.97
12	3.60	11.43	11.35	3.70	9.98	43.52	8.63	20.0	258	3.0	11.69	11.51	10.94	12.32	11.19	11.98	11.91
13	3.58	11.44	11.37	3.75	10.00	43.69	8.65	20.0	258	3.0	11.85	11.01	11.01	12.28	11.75	12.11	11.84
14	3.70	11.43	11.36	3.73	9.98	43.67	8.63	20.0	258	3.0	11.67	12.12	11.27	11.79	11.71	12.14	12.11
15	3.48	11.40	11.26	3.75	9.89	43.31	8.64	20.0	258	3.0	11.89	11.84	11.14	11.22	11.65	12.20	11.96
16	3.53	11.41	11.36	3.68	9.86	43.66	8.62	20.0	258	3.0	11.94	12.26	11.51	11.44	11.50	12.54	11.82
17	3.58	11.41	11.31	3.73	9.87	43.49	8.63	20.0	258	3.0	11.99	11.99	11.07	11.68	11.93	12.23	11.92
18	3.60	11.43	11.33	3.73	10.00	43.56	8.66	20.0	258	3.0	11.90	12.19	10.77	11.75	11.46	12.48	11.85
19	3.63	11.44	11.32	3.90	9.97	43.52	8.63	20.0	258	3.0	12.21	12.15	11.21	11.71	11.34	12.28	11.73
20	3.56	11.38	11.26	3.70	10.01	43.48	8.68	20.0	258	3.0	11.82	11.94	10.88	11.84	12.17	12.19	11.69
$\bar{x}$	3.58	11.42	11.32	3.76	9.96	43.56	8.64	20.0	258	3.0	11.84	11.77	11.03	11.86	11.65	12.25	11.86
σ	0.05	0.02	0.04	0.05	0.05	0.14	0.02	0.0	0	0.0	0.14	0.31	0.22	0.27	0.28	0.13	0.11

44. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

	Independent variables (Measured variables)																
No	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.44	12.18	11.98	3.63	9.15	46.06	7.45	23.5	246	4.0	10.73	11.30	11.20	10.93	11.05	11.33	11.27
2	3.39	12.14	11.97	3.53	8.94	45.69	7.34	23.5	246	4.0	10.92	11.29	10.94	11.24	10.53	11.64	10.77
3	3.48	12.03	12.03	3.58	8.96	46.23	7.36	23.5	246	4.0	10.96	11.12	12.09	11.31	10.03	11.64	10.87
4	3.41	12.13	12.03	3.58	8.96	45.88	7.36	23.5	246	4.0	10.65	11.49	11.13	11.53	10.62	11.44	10.98
5	3.44	12.22	12.17	3.68	8.94	46.01	7.34	23.5	246	4.0	10.77	11.35	10.66	11.37	10.90	11.34	11.07
6	3.36	12.11	12.09	3.53	8.92	46.09	7.32	23.5	246	4.0	10.97	11.33	10.77	11.21	10.74	11.70	11.10
7	3.41	12.09	11.90	3.56	8.91	45.46	7.31	23.5	246	4.0	10.97	10.88	10.42	11.21	10.72	11.49	11.03
8	3.56	12.07	11.97	3.48	8.86	45.68	7.26	23.5	246	4.0	11.05	11.03	10.55	10.81	10.83	11.24	11.07
9	3.39	12.23	12.13	3.53	8.80	45.56	7.20	23.5	246	4.0	11.15	11.23	10.32	10.94	10.32	11.57	11.18
10	3.46	12.31	12.21	3.61	9.25	46.78	7.65	23.5	246	4.0	11.22	11.24	10.55	11.11	10.75	11.47	11.48
11	3.48	12.31	12.31	3.63	9.27	47.10	7.67	23.5	246	4.0	10.69	11.39	10.34	11.79	11.00	11.41	11.34
12	3.46	12.29	12.20	3.68	9.27	46.75	7.67	23.5	246	4.0	10.52	10.91	10.69	11.09	11.06	11.62	11.41
13	3.24	12.26	12.04	3.56	9.23	46.26	7.63	23.5	246	4.0	10.99	11.32	10.84	11.41	11.24	11.44	11.20
14	3.41	12.25	12.08	3.68	9.32	46.39	7.62	23.5	246	4.0	10.84	11.36	10.36	11.16	11.02	11.34	11.25
15	3.44	12.23	12.13	3.66	9.32	46.54	7.62	23.5	246	4.0	10.74	11.30	10.42	11.24	10.99	11.24	11.32
16	3.53	12.18	12.04	3.66	9.18	46.25	7.48	23.5	246	4.0	10.71	11.15	10.14	10.81	10.98	11.66	11.39
17	3.51	12.15	12.20	3.66	9.11	46.76	7.51	23.5	246	4.0	10.82	11.03	10.54	11.49	10.56	11.71	11.16
18	3.36	12.12	11.99	3.56	9.04	46.08	7.44	23.5	246	4.0	10.90	11.44	10.42	11.04	10.64	11.37	11.16
19	3.44	12.16	12.21	3.56	8.93	46.46	7.33	23.5	246	4.0	10.77	11.26	10.57	10.69	11.23	11.45	11.32
20	3.39	11.98	11.86	3.53	8.86	45.68	7.26	23.5	246	4.0	11.00	11.04	10.53	10.86	10.97	11.39	10.99
$\bar{x}$	3.43	12.17	12.08	3.59	9.06	46.19	7.44	23.5	246	4.0	10.87	11.22	10.67	11.16	10.81	11.47	11.17
σ	0.07	0.09	0.12	0.06	0.17	0.45	0.15	0.0	0	0.0	0.18	0.17	0.43	0.28	0.30	0.15	0.19

45. $\phi_{a,i,e} = 50\%$, $\frac{\dot{V}_e N_c^{\;2}}{v_{afc}^{\;3}} = 22.92$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Independent variables (Measured variables)																
	Refrigerant side								Com-pressor		Air side						
	P_1	P_2	P_3	P_4	T_1	T_3	T_4	$\dot{m}_r$	V	I	T_A	T_C	T_E	T_F	T_G	T_H	T_I
1	3.24	12.55	12.41	3.46	8.12	47.43	7.22	25.0	260	4.4	10.69	10.31	9.85	10.18	10.54	10.83	10.37
2	3.28	12.50	12.53	3.48	8.07	47.81	7.17	25.0	260	4.4	10.53	10.41	9.56	10.74	10.17	10.76	10.53
3	3.19	12.51	12.19	3.46	7.98	46.74	7.08	25.0	260	4.4	10.44	10.24	9.73	10.71	10.20	10.85	10.64
4	3.26	12.55	12.41	3.46	8.08	47.44	7.18	25.0	260	4.4	10.63	10.39	9.82	10.20	10.11	10.97	10.23
5	3.31	12.59	12.47	3.46	8.15	47.63	7.25	25.0	260	4.4	10.03	10.47	9.90	10.63	10.36	10.37	10.13
6	3.33	12.59	12.42	3.50	8.07	47.47	7.17	25.0	260	4.4	10.02	10.17	10.02	10.79	10.30	11.02	9.58
7	3.26	12.58	12.51	3.50	8.19	47.74	7.29	25.0	260	4.4	10.53	10.58	9.81	10.15	10.18	10.68	10.31
8	3.21	12.56	12.46	3.43	8.04	47.59	7.14	25.0	260	4.4	9.95	9.91	9.90	10.37	10.25	10.79	10.01
9	3.28	12.55	12.40	3.55	8.13	47.39	7.23	25.0	260	4.4	10.82	10.42	9.81	10.39	10.27	10.62	9.85
10	3.24	12.51	12.44	3.41	8.10	47.54	7.20	25.0	260	4.4	10.51	10.53	10.03	9.99	10.14	10.63	10.29
11	3.31	12.52	12.35	3.41	8.08	47.24	7.18	25.0	260	4.4	10.41	10.31	9.93	10.61	10.08	10.29	10.33
12	3.26	12.49	12.44	3.48	8.03	47.52	7.13	25.0	260	4.4	10.73	10.27	9.76	10.12	10.08	10.53	10.38
13	3.26	12.46	12.32	3.36	8.00	47.14	7.10	25.0	260	4.4	9.95	10.26	9.80	9.92	10.07	10.36	10.55
14	3.24	12.47	12.32	3.48	8.01	47.16	7.11	25.0	260	4.4	10.25	10.39	9.92	9.83	10.29	10.38	10.36
15	3.26	12.47	12.38	3.46	8.00	47.33	7.10	25.0	260	4.4	10.18	10.08	10.00	10.07	10.00	10.19	10.69
16	3.24	12.48	12.38	3.46	7.98	47.35	7.08	25.0	260	4.4	10.29	10.28	9.62	10.41	10.26	10.72	10.53
17	3.26	12.49	12.37	3.46	7.99	47.31	7.09	25.0	260	4.4	10.32	10.11	10.08	10.58	10.34	10.69	10.24
18	3.28	12.48	12.39	3.50	8.09	47.36	7.19	25.0	260	4.4	10.28	10.11	9.94	10.78	10.26	10.82	10.26
19	3.31	12.45	12.36	3.50	8.01	47.29	7.21	25.0	260	4.4	10.47	10.80	10.10	10.90	9.84	10.53	10.24
20	3.24	12.50	12.33	3.53	7.96	47.03	7.16	25.0	260	4.4	10.62	10.14	9.77	10.55	10.28	10.34	10.35
$\bar{x}$	3.26	12.52	12.39	3.47	8.05	47.38	7.16	25.0	260	4.4	10.38	10.31	9.87	10.40	10.20	10.62	10.29
σ	0.03	0.04	0.08	0.04	0.06	0.25	0.06	0.0	0	0.0	0.26	0.20	0.14	0.32	0.15	0.24	0.26

APPENDIX J

Thermal and Energy Automotive Air-conditioning System Performance Experimental Calculated Sample Data

1. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.03	441.74	266.38	266.38	63.94	14.03	34.71	538	140.65	2180.08	175.36	2718.08	4.05
2	406.86	441.57	266.37	266.37	63.84	14.11	34.71	538	140.49	2177.60	175.20	2715.60	4.05
3	407.23	441.94	267.06	267.06	64.48	14.09	34.71	538	140.17	2172.64	174.88	2710.64	4.04
4	407.17	441.88	266.98	266.98	64.41	14.07	34.71	538	140.19	2172.95	174.90	2710.95	4.04
5	407.22	441.93	267.22	267.22	64.45	14.13	34.71	538	140.00	2170.00	174.71	2708.00	4.03
6	407.20	441.91	267.30	267.30	64.58	14.09	34.71	538	139.90	2168.45	174.61	2706.45	4.03
7	407.53	442.24	267.50	267.50	64.91	14.08	34.71	538	140.03	2170.47	174.74	2708.47	4.03
8	407.67	442.38	267.87	267.87	65.11	14.07	34.71	538	139.80	2166.90	174.51	2704.90	4.03
9	407.90	442.61	267.49	267.49	65.26	14.08	34.71	538	140.41	2176.36	175.12	2714.36	4.05
10	407.74	442.45	267.27	267.27	64.99	14.04	34.71	538	140.47	2177.29	175.18	2715.29	4.05
11	407.85	442.56	266.87	266.87	65.07	14.02	34.71	538	140.98	2185.19	175.69	2723.19	4.06
12	407.76	442.47	267.68	267.68	65.05	14.02	34.71	538	140.08	2171.24	174.79	2709.24	4.04
13	407.98	442.69	267.39	267.39	65.24	13.98	34.71	538	140.59	2179.15	175.30	2717.15	4.05
14	407.86	442.57	267.39	267.39	65.26	14.04	34.71	538	140.47	2177.29	175.18	2715.29	4.05
15	407.56	442.27	267.95	267.95	65.04	14.17	34.71	538	139.61	2163.96	174.32	2701.96	4.02
16	407.63	442.34	267.90	267.90	65.05	14.19	34.71	538	139.73	2165.82	174.44	2703.82	4.03
17	407.73	442.44	268.05	268.05	65.19	14.16	34.71	538	139.68	2165.04	174.39	2703.04	4.02
18	407.61	442.32	267.96	267.96	65.20	14.05	34.71	538	139.65	2164.58	174.36	2702.58	4.02
19	407.40	442.11	267.08	267.08	64.88	14.06	34.71	538	140.32	2174.96	175.03	2712.96	4.04
20	407.99	442.70	267.79	267.79	65.46	14.10	34.71	538	140.20	2173.10	174.91	2711.10	4.04
μ'_A (%)								0.00		2.81			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.04			1.90
μ'_E at 95% confi-dence level (%)								2.44		6.08			3.80

2. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.33	442.79	268.58	268.58	65.77	13.22	35.46	656	138.75	2566.88	174.21	3222.88	3.91
2	407.21	442.67	269.33	269.33	65.72	13.19	35.46	656	137.88	2550.78	173.34	3206.78	3.89
3	407.30	442.76	268.75	268.75	65.75	13.22	35.46	656	138.55	2563.18	174.01	3219.18	3.91
4	407.60	443.06	268.76	268.76	66.03	13.28	35.46	656	138.84	2568.54	174.30	3224.54	3.92
5	407.56	443.02	269.13	269.13	65.98	13.25	35.46	656	138.43	2560.96	173.89	3216.96	3.90
6	407.39	442.85	269.41	269.41	65.84	13.28	35.46	656	137.98	2552.63	173.44	3208.63	3.89
7	407.59	443.05	268.62	268.62	66.01	13.28	35.46	656	138.97	2570.95	174.43	3226.95	3.92
8	407.30	442.76	268.90	268.90	65.78	13.29	35.46	656	138.40	2560.40	173.86	3216.40	3.90
9	407.69	443.15	268.02	268.02	66.23	13.34	35.46	656	139.67	2583.90	175.13	3239.90	3.94
10	407.81	443.27	268.98	268.98	66.30	13.35	35.46	656	138.83	2568.36	174.29	3224.36	3.92
11	407.57	443.03	269.10	269.10	66.11	13.36	35.46	656	138.47	2561.70	173.93	3217.70	3.91
12	407.44	442.90	269.79	269.79	65.99	13.29	35.46	656	137.65	2546.53	173.11	3202.53	3.88
13	407.88	443.34	269.22	269.22	66.45	13.33	35.46	656	138.66	2565.21	174.12	3221.21	3.91
14	407.85	443.31	269.24	269.24	66.47	13.36	35.46	656	138.61	2564.29	174.07	3220.29	3.91
15	407.46	442.92	269.49	269.49	66.11	13.34	35.46	656	137.97	2552.45	173.43	3208.45	3.89
16	407.54	443.00	269.35	269.35	66.14	13.33	35.46	656	138.19	2556.52	173.65	3212.52	3.90
17	407.76	443.22	269.21	269.21	66.34	13.30	35.46	656	138.55	2563.18	174.01	3219.18	3.91
18	407.63	443.09	269.10	269.10	66.22	13.32	35.46	656	138.53	2562.81	173.99	3218.81	3.91
19	407.84	443.30	268.96	268.96	66.45	13.35	35.46	656	138.88	2569.28	174.34	3225.28	3.92
20	407.74	443.20	268.38	268.38	66.16	13.26	35.46	656	139.36	2578.16	174.82	3234.16	3.93
μ'_A (%)								0.00		3.98			0.16
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.14			1.91
μ'_E at 95% confidence level (%)								2.44		8.28			3.82

3. $\phi_{a,i,e} = 40\%$, $\frac{\dot{V}_e N_c{}^2}{v_{afc}{}^3} = 11.74$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.72	445.58	269.75	269.75	68.72	12.50	38.86	816	136.97	2876.37	175.83	3692.37	3.52
2	407.02	445.88	268.53	268.53	69.00	12.48	38.86	816	138.49	2908.29	177.35	3724.29	3.56
3	406.64	445.50	270.43	270.43	68.68	12.45	38.86	816	136.21	2860.41	175.07	3676.41	3.51
4	406.78	445.64	269.97	269.97	68.79	12.45	38.86	816	136.81	2873.01	175.67	3689.01	3.52
5	406.71	445.57	270.40	270.40	68.76	12.49	38.86	816	136.31	2862.51	175.17	3678.51	3.51
6	406.74	445.60	270.44	270.44	68.75	12.45	38.86	816	136.30	2862.30	175.16	3678.30	3.51
7	406.76	445.62	269.78	269.78	68.75	12.43	38.86	816	136.98	2876.58	175.84	3692.58	3.53
8	406.72	445.58	270.38	270.38	68.70	12.40	38.86	816	136.34	2863.14	175.20	3679.14	3.51
9	406.82	445.68	269.79	269.79	68.79	12.44	38.86	816	137.03	2877.63	175.89	3693.63	3.53
10	406.76	445.62	270.35	270.35	68.74	12.44	38.86	816	136.41	2864.61	175.27	3680.61	3.51
11	406.90	445.76	269.61	269.61	68.83	12.47	38.86	816	137.29	2883.09	176.15	3699.09	3.53
12	406.61	445.47	269.81	269.81	68.55	12.45	38.86	816	136.80	2872.80	175.66	3688.80	3.52
13	406.82	445.68	269.79	269.79	68.78	12.47	38.86	816	137.03	2877.63	175.89	3693.63	3.53
14	406.77	445.63	270.09	270.09	68.71	12.45	38.86	816	136.68	2870.28	175.54	3686.28	3.52
15	406.68	445.54	270.21	270.21	68.63	12.47	38.86	816	136.47	2865.87	175.33	3681.87	3.51
16	406.93	445.79	269.92	269.92	68.87	12.46	38.86	816	137.01	2877.21	175.87	3693.21	3.53
17	406.92	445.78	270.07	270.07	68.87	12.44	38.86	816	136.85	2873.85	175.71	3689.85	3.52
18	406.89	445.75	270.01	270.01	68.84	12.45	38.86	816	136.88	2874.48	175.74	3690.48	3.52
19	406.65	445.51	268.07	268.07	68.66	12.43	38.86	816	138.58	2910.18	177.44	3726.18	3.57
20	406.79	445.65	270.01	270.01	68.73	12.45	38.86	816	136.78	2872.38	175.64	3688.38	3.52
μ'_A (%)								0.00		5.53			0.19
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		5.65			1.91
μ'_E at 95% confi-dence level (%)								2.44		11.30			3.82

4. $\phi_{a,i,e} = 40\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.60	449.10	272.16	272.16	72.57	11.48	42.50	1020	134.44	3226.56	176.94	4246.56	3.16
2	406.59	449.09	271.82	271.82	72.53	11.48	42.50	1020	134.77	3234.48	177.27	4254.48	3.17
3	406.83	449.33	272.00	272.00	72.73	11.47	42.50	1020	134.83	3235.92	177.33	4255.92	3.17
4	406.69	449.19	272.23	272.23	72.59	11.44	42.50	1020	134.46	3227.04	176.96	4247.04	3.16
5	406.49	448.99	272.45	272.45	72.44	11.54	42.50	1020	134.04	3216.96	176.54	4236.96	3.15
6	406.73	449.23	271.82	271.82	72.68	11.40	42.50	1020	134.91	3237.84	177.41	4257.84	3.17
7	406.95	449.45	273.00	273.00	72.87	11.39	42.50	1020	133.95	3214.80	176.45	4234.80	3.15
8	406.83	449.33	271.36	271.36	72.76	11.50	42.50	1020	135.47	3251.28	177.97	4271.28	3.19
9	406.70	449.20	272.15	272.15	72.66	11.53	42.50	1020	134.55	3229.20	177.05	4249.20	3.17
10	406.84	449.34	271.82	271.82	72.78	11.57	42.50	1020	135.02	3240.48	177.52	4260.48	3.18
11	406.61	449.11	270.83	270.83	72.58	11.51	42.50	1020	135.78	3258.72	178.28	4278.72	3.19
12	406.67	449.17	271.68	271.68	72.66	11.50	42.50	1020	134.99	3239.76	177.49	4259.76	3.18
13	406.75	449.25	272.94	272.94	72.73	11.54	42.50	1020	133.81	3211.44	176.31	4231.44	3.15
14	406.65	449.15	272.49	272.49	72.63	11.51	42.50	1020	134.16	3219.84	176.66	4239.84	3.16
15	406.91	449.41	271.96	271.96	72.86	11.54	42.50	1020	134.95	3238.80	177.45	4258.80	3.18
16	406.85	449.35	271.71	271.71	72.78	11.52	42.50	1020	135.14	3243.36	177.64	4263.36	3.18
17	406.74	449.24	272.19	272.19	72.71	11.51	42.50	1020	134.55	3229.20	177.05	4249.20	3.17
18	406.93	449.43	272.12	272.12	72.88	11.51	42.50	1020	134.81	3235.44	177.31	4255.44	3.17
19	407.23	449.73	271.99	271.99	73.13	11.46	42.50	1020	135.24	3245.76	177.74	4265.76	3.18
20	407.03	449.53	271.87	271.87	72.97	11.45	42.50	1020	135.16	3243.84	177.66	4263.84	3.18
μ'_A (%)								0.00		4.83			0.15
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.97			1.91
μ'_E at 95% confi-dence level (%)								2.44		9.94			3.82

5. $\phi_{a,i,e} = 40\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.16	452.16	272.29	272.29	75.39	10.98	46.00	1196	133.87	3480.62	179.87	4676.62	2.91
2	405.72	451.72	272.41	272.41	75.03	11.00	46.00	1196	133.31	3466.06	179.31	4662.06	2.90
3	405.99	451.99	272.43	272.43	75.39	10.91	46.00	1196	133.56	3472.56	179.56	4668.56	2.90
4	405.86	451.86	272.97	272.97	75.27	11.03	46.00	1196	132.89	3455.14	178.89	4651.14	2.89
5	405.99	451.99	272.79	272.79	75.37	11.07	46.00	1196	133.20	3463.20	179.20	4659.20	2.90
6	405.79	451.79	272.52	272.52	75.33	10.98	46.00	1196	133.27	3465.02	179.27	4661.02	2.90
7	406.22	452.22	272.91	272.91	75.69	10.98	46.00	1196	133.31	3466.06	179.31	4662.06	2.90
8	406.04	452.04	273.41	273.41	75.52	11.03	46.00	1196	132.63	3448.38	178.63	4644.38	2.88
9	405.8	451.8	273.69	273.69	75.34	10.98	46.00	1196	132.11	3434.86	178.11	4630.86	2.87
10	405.85	451.85	273.38	273.38	75.38	11.01	46.00	1196	132.47	3444.22	178.47	4640.22	2.88
11	406.28	452.28	273.50	273.50	75.90	11.09	46.00	1196	132.78	3452.28	178.78	4648.28	2.89
12	406.06	452.06	273.00	273.00	75.60	10.99	46.00	1196	133.06	3459.56	179.06	4655.56	2.89
13	406.1	452.10	272.91	272.91	75.58	10.93	46.00	1196	133.19	3462.94	179.19	4658.94	2.90
14	405.88	451.88	272.58	272.58	75.35	10.97	46.00	1196	133.30	3465.80	179.30	4661.80	2.90
15	405.96	451.96	272.68	272.68	75.41	11.01	46.00	1196	133.28	3465.28	179.28	4661.28	2.90
16	406.28	452.28	272.88	272.88	75.70	11.05	46.00	1196	133.40	3468.40	179.40	4664.40	2.90
17	406.1	452.1	272.75	272.75	75.56	10.99	46.00	1196	133.35	3467.10	179.35	4663.10	2.90
18	405.97	451.97	273.46	273.46	75.45	11.02	46.00	1196	132.51	3445.26	178.51	4641.26	2.88
19	406.18	452.18	272.83	272.83	75.62	10.98	46.00	1196	133.35	3467.10	179.35	4663.10	2.90
20	405.96	451.96	273.16	273.16	75.44	10.99	46.00	1196	132.80	3452.80	178.80	4648.80	2.89
μ'_A (%)								0.00		4.18			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.34			1.90
μ'_E at 95% confi-dence level (%)								2.44		8.68			3.80

6. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.76	440.16	260.28	260.28	60.44	12.91	34.40	516	145.48	2182.20	179.88	2698.20	4.23
2	405.69	440.09	260.66	260.66	60.43	12.99	34.40	516	145.03	2175.45	179.43	2691.45	4.22
3	405.43	439.83	260.62	260.62	60.22	12.99	34.40	516	144.81	2172.15	179.21	2688.15	4.21
4	405.59	439.99	260.22	260.22	60.32	13.07	34.40	516	145.37	2180.55	179.77	2696.55	4.23
5	405.50	439.90	260.13	260.13	60.25	13.00	34.40	516	145.37	2180.55	179.77	2696.55	4.23
6	405.24	439.64	259.93	259.93	59.99	12.91	34.40	516	145.31	2179.65	179.71	2695.65	4.22
7	405.70	440.10	260.58	260.58	60.42	12.93	34.40	516	145.12	2176.80	179.52	2692.80	4.22
8	405.45	439.85	260.82	260.82	60.39	13.00	34.40	516	144.63	2169.45	179.03	2685.45	4.20
9	405.70	440.10	259.90	259.90	60.32	12.89	34.40	516	145.80	2187.00	180.20	2703.00	4.24
10	405.63	440.03	259.28	259.28	60.20	12.93	34.40	516	146.35	2195.25	180.75	2711.25	4.25
11	405.27	439.67	259.03	259.03	59.81	12.93	34.40	516	146.24	2193.60	180.64	2709.60	4.25
12	405.24	439.64	260.40	260.40	59.80	12.97	34.40	516	144.84	2172.60	179.24	2688.60	4.21
13	405.35	439.75	259.57	259.57	59.92	12.88	34.40	516	145.78	2186.70	180.18	2702.70	4.24
14	405.49	439.89	260.10	260.10	60.16	12.89	34.40	516	145.39	2180.85	179.79	2696.85	4.23
15	405.32	439.72	259.86	259.86	59.93	12.93	34.40	516	145.46	2181.90	179.86	2697.90	4.23
16	405.18	439.58	259.87	259.87	59.83	12.93	34.40	516	145.31	2179.65	179.71	2695.65	4.22
17	405.33	439.73	259.72	259.72	60.01	12.88	34.40	516	145.61	2184.15	180.01	2700.15	4.23
18	405.41	439.81	260.10	260.10	60.08	13.00	34.40	516	145.31	2179.65	179.71	2695.65	4.22
19	405.39	439.79	260.17	260.17	60.11	12.96	34.40	516	145.22	2178.30	179.62	2694.30	4.22
20	405.58	439.98	261.20	261.20	60.38	13.01	34.40	516	144.38	2165.70	178.78	2681.70	4.20
μ'_A (%)								0.00		3.48			0.15
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.67			1.91
μ'_E at 95% confi-dence level (%)								2.44		7.34			3.82

7. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.29	440.43	261.52	261.52	61.27	12.25	35.14	650	143.77	2659.75	178.91	3309.75	4.09
2	405.52	440.66	262.00	262.00	61.42	12.16	35.14	650	143.52	2655.12	178.66	3305.12	4.08
3	405.10	440.24	261.98	261.98	61.10	12.30	35.14	650	143.12	2647.72	178.26	3297.72	4.07
4	404.99	440.13	261.68	261.68	60.89	12.13	35.14	650	143.31	2651.24	178.45	3301.24	4.08
5	404.72	439.86	261.97	261.97	60.78	12.23	35.14	650	142.75	2640.88	177.89	3290.88	4.06
6	405.29	440.43	262.12	262.12	61.36	12.21	35.14	650	143.17	2648.65	178.31	3298.65	4.07
7	405.30	440.44	261.15	261.15	61.28	12.25	35.14	650	144.15	2666.78	179.29	3316.78	4.10
8	405.44	440.58	262.15	262.15	61.51	12.34	35.14	650	143.29	2650.87	178.43	3300.87	4.08
9	405.54	440.68	261.68	261.68	61.38	12.21	35.14	650	143.86	2661.41	179.00	3311.41	4.09
10	405.70	440.84	262.08	262.08	61.67	12.32	35.14	650	143.62	2656.97	178.76	3306.97	4.09
11	405.45	440.59	262.71	262.71	61.64	12.25	35.14	650	142.74	2640.69	177.88	3290.69	4.06
12	405.18	440.32	262.54	262.54	61.29	12.16	35.14	650	142.64	2638.84	177.78	3288.84	4.06
13	405.40	440.54	261.80	261.80	61.39	12.27	35.14	650	143.60	2656.60	178.74	3306.60	4.09
14	404.63	439.77	261.59	261.59	60.61	12.09	35.14	650	143.04	2646.24	178.18	3296.24	4.07
15	404.85	439.99	261.44	261.44	60.71	12.20	35.14	650	143.41	2653.09	178.55	3303.09	4.08
16	404.81	439.95	261.33	261.33	60.69	12.20	35.14	650	143.48	2654.38	178.62	3304.38	4.08
17	405.12	440.26	261.79	261.79	61.00	12.19	35.14	650	143.33	2651.61	178.47	3301.61	4.08
18	405.01	440.15	261.80	261.80	61.03	12.23	35.14	650	143.21	2649.39	178.35	3299.39	4.08
19	405.37	440.51	262.26	262.26	61.50	12.17	35.14	650	143.11	2647.54	178.25	3297.54	4.07
20	405.13	440.27	263.83	263.83	61.42	12.19	35.14	650	141.30	2614.05	176.44	3264.05	4.02
μ'_A (%)								0.00		4.75			0.19
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.89			1.91
μ'_E at 95% confi-dence level (%)								2.44		9.78			3.82

8. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.70	443.03	264.60	264.60	64.60	11.56	37.33	784	141.10	2963.10	178.43	3747.10	3.78
2	405.62	442.95	264.49	264.49	64.58	11.62	37.33	784	141.13	2963.73	178.46	3747.73	3.78
3	405.50	442.83	264.58	264.58	64.47	11.57	37.33	784	140.92	2959.32	178.25	3743.32	3.77
4	405.57	442.90	264.93	264.93	64.52	11.66	37.33	784	140.64	2953.44	177.97	3737.44	3.77
5	405.52	442.85	264.78	264.78	64.47	11.59	37.33	784	140.74	2955.54	178.07	3739.54	3.77
6	405.70	443.03	264.52	264.52	64.60	11.55	37.33	784	141.18	2964.78	178.51	3748.78	3.78
7	405.52	442.85	264.60	264.60	64.44	11.63	37.33	784	140.92	2959.32	178.25	3743.32	3.77
8	405.45	442.78	264.79	264.79	64.37	11.58	37.33	784	140.66	2953.86	177.99	3737.86	3.77
9	405.63	442.96	264.70	264.70	64.54	11.67	37.33	784	140.93	2959.53	178.26	3743.53	3.77
10	405.46	442.79	265.46	265.46	64.38	11.60	37.33	784	140.00	2940.00	177.33	3724.00	3.75
11	405.77	443.10	264.81	264.81	64.70	11.74	37.33	784	140.96	2960.16	178.29	3744.16	3.78
12	405.55	442.88	264.85	264.85	64.51	11.66	37.33	784	140.70	2954.70	178.03	3738.70	3.77
13	405.66	442.99	265.37	265.37	64.61	11.72	37.33	784	140.29	2946.09	177.62	3730.09	3.76
14	405.40	442.73	264.38	264.38	64.34	11.75	37.33	784	141.02	2961.42	178.35	3745.42	3.78
15	405.64	442.97	264.31	264.31	64.56	11.61	37.33	784	141.33	2967.93	178.66	3751.93	3.79
16	405.54	442.87	265.75	265.75	64.47	11.61	37.33	784	139.79	2935.59	177.12	3719.59	3.74
17	405.45	442.78	264.63	264.63	64.37	11.64	37.33	784	140.82	2957.22	178.15	3741.22	3.77
18	405.53	442.86	265.22	265.22	64.45	11.62	37.33	784	140.31	2946.51	177.64	3730.51	3.76
19	405.81	443.14	264.43	264.43	64.68	11.65	37.33	784	141.38	2968.98	178.71	3752.98	3.79
20	405.53	442.86	264.81	264.81	64.45	11.56	37.33	784	140.72	2955.12	178.05	3739.12	3.77
μ'_A (%)								0.00		3.60			0.13
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.78			1.90
μ'_E at 95% confi-dence level (%)								2.44		7.56			3.80

9. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.57	445.95	267.26	267.26	68.05	11.16	40.38	969	138.31	3319.44	178.69	4288.44	3.43
2	405.55	445.93	267.55	267.55	68.16	11.07	40.38	969	138.00	3312.00	178.38	4281.00	3.42
3	405.40	445.78	267.25	267.25	67.93	11.16	40.38	969	138.15	3315.60	178.53	4284.60	3.42
4	405.53	445.91	267.32	267.32	68.11	11.14	40.38	969	138.21	3317.04	178.59	4286.04	3.42
5	405.51	445.89	267.81	267.81	68.11	11.20	40.38	969	137.70	3304.80	178.08	4273.80	3.41
6	405.43	445.81	267.29	267.29	68.01	11.10	40.38	969	138.14	3315.36	178.52	4284.36	3.42
7	405.49	445.87	267.16	267.16	68.00	11.15	40.38	969	138.33	3319.92	178.71	4288.92	3.43
8	405.55	445.93	267.03	267.03	68.08	10.93	40.38	969	138.52	3324.48	178.90	4293.48	3.43
9	405.37	445.75	267.15	267.15	67.92	11.02	40.38	969	138.22	3317.28	178.60	4286.28	3.42
10	405.34	445.72	267.09	267.09	67.80	10.98	40.38	969	138.25	3318.00	178.63	4287.00	3.42
11	405.55	445.93	267.04	267.04	67.96	11.02	40.38	969	138.51	3324.24	178.89	4293.24	3.43
12	405.57	445.95	267.41	267.41	68.18	11.18	40.38	969	138.16	3315.84	178.54	4284.84	3.42
13	405.60	445.98	267.38	267.38	68.19	11.18	40.38	969	138.22	3317.28	178.60	4286.28	3.42
14	405.47	445.85	267.35	267.35	68.09	11.15	40.38	969	138.12	3314.88	178.50	4283.88	3.42
15	405.60	445.98	267.52	267.52	68.26	11.14	40.38	969	138.08	3313.92	178.46	4282.92	3.42
16	405.41	445.79	267.33	267.33	68.05	11.16	40.38	969	138.08	3313.92	178.46	4282.92	3.42
17	405.24	445.62	267.41	267.41	67.88	11.20	40.38	969	137.83	3307.92	178.21	4276.92	3.41
18	405.59	445.97	267.03	267.03	68.15	11.16	40.38	969	138.56	3325.44	178.94	4294.44	3.43
19	405.55	445.93	267.29	267.29	68.08	11.16	40.38	969	138.26	3318.24	178.64	4287.24	3.42
20	405.81	446.19	267.30	267.30	68.34	11.04	40.38	969	138.51	3324.24	178.89	4293.24	3.43
μ'_A (%)								0.00		2.06			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		2.36			1.90
μ'_E at 95% confi-dence level (%)								2.44		5.72			3.80

10. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.22	448.84	270.23	270.23	71.81	10.54	43.62	1134	134.99	3509.74	178.61	4643.74	3.10
2	405.30	448.92	270.24	270.24	71.80	10.48	43.62	1134	135.06	3511.56	178.68	4645.56	3.10
3	405.22	448.84	269.99	269.99	71.70	10.54	43.62	1134	135.23	3515.98	178.85	4649.98	3.10
4	405.31	448.93	269.98	269.98	71.75	10.44	43.62	1134	135.33	3518.58	178.95	4652.58	3.10
5	405.31	448.93	269.52	269.52	71.70	10.53	43.62	1134	135.79	3530.54	179.41	4664.54	3.11
6	405.21	448.83	269.87	269.87	71.61	10.63	43.62	1134	135.34	3518.84	178.96	4652.84	3.10
7	405.31	448.93	269.56	269.56	71.63	10.61	43.62	1134	135.75	3529.50	179.37	4663.50	3.11
8	405.25	448.87	269.12	269.12	71.43	10.53	43.62	1134	136.13	3539.38	179.75	4673.38	3.12
9	405.59	449.21	269.30	269.30	71.83	10.53	43.62	1134	136.29	3543.54	179.91	4677.54	3.12
10	405.19	448.81	269.72	269.72	71.55	10.52	43.62	1134	135.47	3522.22	179.09	4656.22	3.11
11	405.28	448.90	269.89	269.89	71.68	10.59	43.62	1134	135.39	3520.14	179.01	4654.14	3.10
12	405.38	449.00	269.73	269.73	71.71	10.52	43.62	1134	135.65	3526.90	179.27	4660.90	3.11
13	405.21	448.83	270.27	270.27	71.58	10.38	43.62	1134	134.94	3508.44	178.56	4642.44	3.09
14	405.31	448.93	270.12	270.12	71.70	10.37	43.62	1134	135.19	3514.94	178.81	4648.94	3.10
15	405.29	448.91	269.95	269.95	71.75	10.36	43.62	1134	135.34	3518.84	178.96	4652.84	3.10
16	405.25	448.87	270.35	270.35	71.76	10.50	43.62	1134	134.90	3507.40	178.52	4641.40	3.09
17	405.24	448.86	270.44	270.44	71.81	10.43	43.62	1134	134.80	3504.80	178.42	4638.80	3.09
18	405.32	448.94	270.06	270.06	71.81	10.46	43.62	1134	135.26	3516.76	178.88	4650.76	3.10
19	405.30	448.92	270.27	270.27	71.82	10.48	43.62	1134	135.03	3510.78	178.65	4644.78	3.10
20	405.55	449.17	270.13	270.13	72.04	10.45	43.62	1134	135.42	3520.92	179.04	4654.92	3.10
μ'_A (%)								0.00		3.89			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.06			1.90
μ'_E at 95% confi- dence level (%)								2.44		8.12			3.80

11. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.77	436.50	254.09	254.09	55.01	11.54	31.73	476	150.68	2260.20	182.41	2736.20	4.75
2	405.25	436.98	253.71	253.71	55.43	11.53	31.73	476	151.54	2273.10	183.27	2749.10	4.78
3	404.65	436.38	254.03	254.03	54.88	11.49	31.73	476	150.62	2259.30	182.35	2735.30	4.75
4	405.09	436.82	254.01	254.01	55.24	11.43	31.73	476	151.08	2266.20	182.81	2742.20	4.76
5	404.88	436.61	254.06	254.06	55.06	11.42	31.73	476	150.82	2262.30	182.55	2738.30	4.75
6	404.70	436.43	253.36	253.36	54.86	11.50	31.73	476	151.34	2270.10	183.07	2746.10	4.77
7	404.78	436.51	253.65	253.65	54.93	11.48	31.73	476	151.13	2266.95	182.86	2742.95	4.76
8	404.60	436.33	254.09	254.09	54.82	11.41	31.73	476	150.51	2257.65	182.24	2733.65	4.74
9	404.65	436.38	254.90	254.90	54.86	11.45	31.73	476	149.75	2246.25	181.48	2722.25	4.72
10	404.57	436.30	253.61	253.61	54.75	11.48	31.73	476	150.96	2264.40	182.69	2740.40	4.76
11	404.47	436.20	253.86	253.86	54.62	11.48	31.73	476	150.61	2259.15	182.34	2735.15	4.75
12	404.76	436.49	254.09	254.09	55.00	11.50	31.73	476	150.67	2260.05	182.40	2736.05	4.75
13	404.69	436.42	254.04	254.04	54.94	11.51	31.73	476	150.65	2259.75	182.38	2735.75	4.75
14	404.73	436.46	254.12	254.12	54.94	11.47	31.73	476	150.61	2259.15	182.34	2735.15	4.75
15	404.69	436.42	254.41	254.41	54.95	11.49	31.73	476	150.28	2254.20	182.01	2730.20	4.74
16	404.60	436.33	253.89	253.89	54.85	11.52	31.73	476	150.71	2260.65	182.44	2736.65	4.75
17	404.76	436.49	254.25	254.25	55.06	11.54	31.73	476	150.51	2257.65	182.24	2733.65	4.74
18	404.96	436.69	254.40	254.40	55.26	11.49	31.73	476	150.56	2258.40	182.29	2734.40	4.74
19	405.13	436.86	253.60	253.60	55.42	11.46	31.73	476	151.53	2272.95	183.26	2748.95	4.78
20	404.67	436.40	253.90	253.90	55.01	11.52	31.73	476	150.77	2261.55	182.50	2737.55	4.75
μ'_A (%)								0.00		2.95			0.14
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.17			1.91
μ'_E at 95% confi-dence level (%)								2.44		6.34			3.82

12. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.69	437.75	257.11	257.11	57.26	11.12	33.06	595	147.58	2656.44	180.64	3251.44	4.46
2	404.72	437.78	257.66	257.66	57.29	11.12	33.06	595	147.06	2647.08	180.12	3242.08	4.45
3	404.85	437.91	257.54	257.54	57.39	11.14	33.06	595	147.31	2651.58	180.37	3246.58	4.46
4	404.67	437.73	257.22	257.22	57.24	11.13	33.06	595	147.45	2654.10	180.51	3249.10	4.46
5	404.48	437.54	257.22	257.22	57.10	11.11	33.06	595	147.26	2650.68	180.32	3245.68	4.45
6	404.50	437.56	257.62	257.62	57.12	11.08	33.06	595	146.88	2643.84	179.94	3238.84	4.44
7	404.75	437.81	257.14	257.14	57.31	11.08	33.06	595	147.61	2656.98	180.67	3251.98	4.47
8	404.60	437.66	256.74	256.74	57.14	11.21	33.06	595	147.86	2661.48	180.92	3256.48	4.47
9	404.50	437.56	257.84	257.84	57.06	11.20	33.06	595	146.66	2639.88	179.72	3234.88	4.44
10	404.61	437.67	257.17	257.17	57.17	11.18	33.06	595	147.44	2653.92	180.50	3248.92	4.46
11	404.58	437.64	256.96	256.96	57.15	11.15	33.06	595	147.62	2657.16	180.68	3252.16	4.47
12	404.36	437.42	257.31	257.31	56.93	11.21	33.06	595	147.05	2646.90	180.11	3241.90	4.45
13	404.80	437.86	256.98	256.98	57.31	11.12	33.06	595	147.82	2660.76	180.88	3255.76	4.47
14	404.74	437.80	256.92	256.92	57.23	11.12	33.06	595	147.82	2660.76	180.88	3255.76	4.47
15	404.68	437.74	256.83	256.83	57.18	11.12	33.06	595	147.85	2661.30	180.91	3256.30	4.47
16	404.44	437.50	256.11	256.11	56.92	11.15	33.06	595	148.33	2669.94	181.39	3264.94	4.49
17	404.39	437.45	256.87	256.87	56.89	11.14	33.06	595	147.52	2655.36	180.58	3250.36	4.46
18	404.69	437.75	256.75	256.75	57.19	11.08	33.06	595	147.94	2662.92	181.00	3257.92	4.48
19	404.56	437.62	258.02	258.02	57.17	11.03	33.06	595	146.54	2637.72	179.60	3232.72	4.43
20	404.58	437.64	257.04	257.04	57.14	11.08	33.06	595	147.54	2655.72	180.60	3250.72	4.46
μ'_A (%)								0.00		3.51			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.69			1.90
μ'_E at 95% confi-dence level (%)								2.44		7.38			3.80

13. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.53	439.94	258.67	258.67	59.99	10.56	35.41	726	145.86	2990.13	181.27	3716.13	4.12
2	404.76	440.17	258.79	258.79	60.19	10.54	35.41	726	145.97	2992.39	181.38	3718.39	4.12
3	404.57	439.98	258.55	258.55	60.05	10.57	35.41	726	146.02	2993.41	181.43	3719.41	4.12
4	404.87	440.28	259.04	259.04	60.36	10.57	35.41	726	145.83	2989.52	181.24	3715.52	4.12
5	404.78	440.19	258.20	258.20	60.24	10.63	35.41	726	146.58	3004.89	181.99	3730.89	4.14
6	404.77	440.18	258.50	258.50	60.22	10.62	35.41	726	146.27	2998.54	181.68	3724.54	4.13
7	405.04	440.45	258.44	258.44	60.45	10.50	35.41	726	146.60	3005.30	182.01	3731.30	4.14
8	404.88	440.29	258.46	258.46	60.22	10.52	35.41	726	146.42	3001.61	181.83	3727.61	4.13
9	404.67	440.08	258.34	258.34	60.04	10.52	35.41	726	146.33	2999.77	181.74	3725.77	4.13
10	404.77	440.18	259.22	259.22	60.15	10.51	35.41	726	145.55	2983.78	180.96	3709.78	4.11
11	404.76	440.17	259.04	259.04	60.35	10.53	35.41	726	145.72	2987.26	4.11	3713.26	4.11
12	404.84	440.25	258.70	258.70	60.47	10.62	35.41	726	146.14	2995.87	4.13	3721.87	4.13
13	405.04	440.45	258.38	258.38	60.73	10.50	35.41	726	146.66	3006.53	4.14	3732.53	4.14
14	405.08	440.49	258.73	258.73	60.61	10.54	35.41	726	146.35	3000.18	4.13	3726.18	4.13
15	404.51	439.92	257.77	257.77	59.82	10.59	35.41	726	146.74	3008.17	4.14	3734.17	4.14
16	404.40	439.81	258.86	258.86	59.87	10.62	35.41	726	145.54	2983.57	4.11	3709.57	4.11
17	404.47	439.88	260.17	260.17	59.90	10.55	35.41	726	144.30	2958.15	4.07	3684.15	4.07
18	404.68	440.09	258.28	258.28	60.07	10.67	35.41	726	146.40	3001.20	4.13	3727.20	4.13
19	404.57	439.98	258.19	258.19	59.98	10.66	35.41	726	146.38	3000.79	4.13	3726.79	4.13
20	404.69	440.10	258.53	258.53	60.11	10.63	35.41	726	146.16	2996.28	4.13	3722.28	4.13
μ'_A (%)								0.00		4.62			0.17
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.76			1.91
μ'_E at 95% confi-dence level (%)								2.44		9.52			3.82

14. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.61	445.04	263.26	263.26	65.97	10.14	40.43	950	141.35	3321.73	181.78	4271.73	3.50
2	404.46	444.89	263.45	263.45	65.89	10.12	40.43	950	141.01	3313.74	181.44	4263.74	3.49
3	404.82	445.25	262.94	262.94	66.05	10.05	40.43	950	141.88	3334.18	182.31	4284.18	3.51
4	404.65	445.08	262.64	262.64	65.84	10.01	40.43	950	142.01	3337.24	182.44	4287.24	3.51
5	404.73	445.16	262.77	262.77	65.85	10.03	40.43	950	141.96	3336.06	182.39	4286.06	3.51
6	404.64	445.07	262.64	262.64	65.70	10.03	40.43	950	142.00	3337.00	182.43	4287.00	3.51
7	404.79	445.22	263.39	263.39	66.07	10.06	40.43	950	141.40	3322.90	181.83	4272.90	3.50
8	404.96	445.39	262.88	262.88	66.24	10.04	40.43	950	142.08	3338.88	182.51	4288.88	3.51
9	404.56	444.99	263.17	263.17	65.87	10.14	40.43	950	141.39	3322.67	181.82	4272.67	3.50
10	404.67	445.10	262.73	262.73	65.94	10.04	40.43	950	141.94	3335.59	182.37	4285.59	3.51
11	404.95	445.38	262.80	262.80	66.22	9.96	40.43	950	142.15	3340.53	182.58	4290.53	3.52
12	404.63	445.06	263.27	263.27	65.92	9.95	40.43	950	141.36	3321.96	181.79	4271.96	3.50
13	404.95	445.38	262.59	262.59	66.14	9.95	40.43	950	142.36	3345.46	182.79	4295.46	3.52
14	404.88	445.31	262.76	262.76	66.06	9.98	40.43	950	142.12	3339.82	182.55	4289.82	3.52
15	404.74	445.17	262.21	262.21	65.93	9.99	40.43	950	142.53	3349.46	182.96	4299.46	3.53
16	404.85	445.28	264.12	264.12	65.98	10.16	40.43	950	140.73	3307.16	181.16	4257.16	3.48
17	404.85	445.28	263.55	263.55	66.17	10.02	40.43	950	141.30	3320.55	181.73	4270.55	3.50
18	404.92	445.35	262.91	262.91	66.11	10.03	40.43	950	142.01	3337.24	182.44	4287.24	3.51
19	404.66	445.09	261.98	261.98	65.80	9.97	40.43	950	142.68	3352.98	183.11	4302.98	3.53
20	404.60	445.03	262.83	262.83	65.75	9.97	40.43	950	141.77	3331.60	182.20	4281.60	3.51
μ'_A (%)								0.00		4.60			0.15
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.74			1.91
μ'_E at 95% confi-dence level (%)								2.44		9.48			3.82

15. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.06	446.45	264.87	264.87	67.86	9.15	42.39	1081	139.19	3549.35	181.58	4630.35	3.28
2	403.98	446.37	265.34	265.34	67.77	9.12	42.39	1081	138.64	3535.32	181.03	4616.32	3.27
3	403.82	446.21	265.08	265.08	67.61	9.15	42.39	1081	138.74	3537.87	181.13	4618.87	3.27
4	403.97	446.36	264.73	264.73	67.73	9.24	42.39	1081	139.24	3550.62	181.63	4631.62	3.28
5	403.98	446.37	265.72	265.72	67.96	9.06	42.39	1081	138.26	3525.63	180.65	4606.63	3.26
6	404.19	446.58	265.74	265.74	68.14	9.20	42.39	1081	138.45	3530.48	180.84	4611.48	3.27
7	404.02	446.41	265.60	265.60	67.94	9.11	42.39	1081	138.42	3529.71	180.81	4610.71	3.27
8	405.01	447.40	266.14	266.14	68.86	9.25	42.39	1081	138.87	3541.19	181.26	4622.19	3.28
9	404.47	446.86	265.53	265.53	68.41	9.31	42.39	1081	138.94	3542.97	181.33	4623.97	3.28
10	404.23	446.62	265.72	265.72	68.18	9.14	42.39	1081	138.51	3532.01	180.90	4613.01	3.27
11	403.97	446.36	265.62	265.62	67.89	9.11	42.39	1081	138.35	3527.93	180.74	4608.93	3.26
12	404.09	446.48	265.13	265.13	67.94	9.17	42.39	1081	138.96	3543.48	181.35	4624.48	3.28
13	404.07	446.46	264.92	264.92	67.92	9.16	42.39	1081	139.15	3548.33	181.54	4629.33	3.28
14	404.36	446.75	264.84	264.84	68.14	9.15	42.39	1081	139.52	3557.76	181.91	4638.76	3.29
15	404.09	446.48	265.42	265.42	67.91	9.12	42.39	1081	138.67	3536.09	181.06	4617.09	3.27
16	404.25	446.64	265.34	265.34	68.07	9.20	42.39	1081	138.91	3542.21	181.30	4623.21	3.28
17	404.06	446.45	265.54	265.54	67.96	9.16	42.39	1081	138.52	3532.26	180.91	4613.26	3.27
18	404.79	447.18	265.16	265.16	68.58	9.16	42.39	1081	139.63	3560.57	182.02	4641.57	3.29
19	403.95	446.34	264.99	264.99	67.87	9.22	42.39	1081	138.96	3543.48	181.35	4624.48	3.28
20	404.72	447.11	265.30	265.30	68.56	9.20	42.39	1081	139.42	3555.21	181.81	4636.21	3.29
μ'_A (%)								0.00		3.82			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.99			1.90
μ'_E at 95% confi-dence level (%)								2.44		7.98			3.80

16. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.98	444.88	268.70	268.70	67.65	14.52	36.90	572	139.28	2158.84	176.18	2730.84	3.77
2	407.93	444.83	268.79	268.79	67.62	14.51	36.90	572	139.14	2156.67	176.04	2728.67	3.77
3	407.64	444.54	268.78	268.78	67.41	14.49	36.90	572	138.86	2152.33	175.76	2724.33	3.76
4	407.83	444.73	269.07	269.07	67.55	14.61	36.90	572	138.76	2150.78	175.66	2722.78	3.76
5	407.53	444.43	268.56	268.56	67.33	14.46	36.90	572	138.97	2154.04	175.87	2726.04	3.77
6	407.10	444.00	269.18	269.18	66.89	14.52	36.90	572	137.92	2137.76	174.82	2709.76	3.74
7	407.69	444.59	268.71	268.71	67.47	14.52	36.90	572	138.98	2154.19	175.88	2726.19	3.77
8	407.70	444.60	268.98	268.98	67.42	14.49	36.90	572	138.72	2150.16	175.62	2722.16	3.76
9	407.97	444.87	269.33	269.33	67.72	14.45	36.90	572	138.64	2148.92	175.54	2720.92	3.76
10	407.64	444.54	268.33	268.33	67.44	14.42	36.90	572	139.31	2159.31	176.21	2731.31	3.78
11	407.62	444.52	269.15	269.15	67.39	14.43	36.90	572	138.47	2146.29	175.37	2718.29	3.75
12	407.81	444.71	269.05	269.05	67.47	14.42	36.90	572	138.76	2150.78	175.66	2722.78	3.76
13	407.87	444.77	268.41	268.41	67.60	14.39	36.90	572	139.46	2161.63	176.36	2733.63	3.78
14	407.94	444.84	268.90	268.90	67.67	14.35	36.90	572	139.04	2155.12	175.94	2727.12	3.77
15	407.74	444.64	269.15	269.15	67.50	14.40	36.90	572	138.59	2148.15	175.49	2720.15	3.76
16	407.56	444.46	268.99	268.99	67.27	14.34	36.90	572	138.57	2147.84	175.47	2719.84	3.75
17	407.73	444.63	268.15	268.15	67.48	14.32	36.90	572	139.58	2163.49	176.48	2735.49	3.78
18	407.82	444.72	268.85	268.85	67.61	14.35	36.90	572	138.97	2154.04	175.87	2726.04	3.77
19	407.48	444.38	269.42	269.42	67.25	14.33	36.90	572	138.06	2139.93	174.96	2711.93	3.74
20	407.65	444.55	269.32	269.32	67.36	14.35	36.90	572	138.33	2144.12	175.23	2716.12	3.75
μ'_A (%)								0.00		3.24			0.14
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.44			1.91
μ'_E at 95% confi-dence level (%)								2.44		6.88			3.82

17. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.70	445.54	270.63	270.63	68.97	14.08	3.61	700	137.07	2535.80	174.91	3235.80	3.62
2	407.71	445.55	270.80	270.80	69.00	14.00	3.62	700	136.91	2532.84	174.75	3232.84	3.62
3	408.02	445.86	271.17	271.17	69.27	14.04	3.61	700	136.85	2531.73	174.69	3231.73	3.62
4	407.75	445.59	270.91	270.91	69.06	14.02	3.62	700	136.84	2531.54	174.68	3231.54	3.62
5	407.52	445.36	270.91	270.91	68.87	14.03	3.58	700	136.61	2527.29	174.45	3227.29	3.61
6	407.87	445.71	270.94	270.94	69.16	14.02	3.61	700	136.93	2533.21	174.77	3233.21	3.62
7	407.54	445.38	271.12	271.12	68.81	13.99	3.62	700	136.42	2523.77	174.26	3223.77	3.61
8	407.85	445.69	270.74	270.74	69.11	13.97	3.62	700	137.11	2536.54	174.95	3236.54	3.62
9	407.67	445.51	271.14	271.14	69.01	13.95	3.63	700	136.53	2525.81	174.37	3225.81	3.61
10	407.59	445.43	270.97	270.97	68.87	13.96	3.61	700	136.62	2527.47	174.46	3227.47	3.61
11	407.53	445.37	270.85	270.85	68.79	13.91	3.61	700	136.68	2528.58	174.52	3228.58	3.61
12	407.89	445.73	270.92	270.92	69.16	14.03	3.62	700	136.97	2533.95	174.81	3233.95	3.62
13	407.68	445.52	271.06	271.06	68.97	14.10	3.61	700	136.62	2527.47	174.46	3227.47	3.61
14	407.85	445.69	271.05	271.05	69.09	13.96	3.62	700	136.80	2530.80	174.64	3230.80	3.62
15	407.91	445.75	272.32	272.32	69.16	13.95	3.58	700	135.59	2508.42	173.43	3208.42	3.58
16	407.66	445.50	271.17	271.17	68.97	13.93	3.61	700	136.49	2525.07	174.33	3225.07	3.61
17	407.72	445.56	270.72	270.72	68.99	13.98	3.62	700	137.00	2534.50	174.84	3234.50	3.62
18	407.74	445.58	270.94	270.94	69.06	14.03	3.62	700	136.80	2530.80	174.64	3230.80	3.62
19	407.61	445.45	270.30	270.30	68.89	14.02	3.63	700	137.31	2540.24	175.15	3240.24	3.63
20	407.86	445.70	271.11	271.11	69.13	13.96	3.61	700	136.75	2529.88	174.59	3229.88	3.61
μ'_A (%)								0.00		2.90			0.11
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.12			1.90
μ'_E at 95% confi-dence level (%)								2.44		6.24			3.80

18. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.40	447.88	271.70	271.70	71.40	13.54	40.48	850	135.70	2849.70	176.18	3699.70	3.35
2	407.17	447.65	271.39	271.39	71.03	13.47	40.48	850	135.78	2851.38	176.26	3701.38	3.35
3	407.23	447.71	271.31	271.31	71.07	13.38	40.48	850	135.92	2854.32	176.40	3704.32	3.36
4	407.06	447.54	271.36	271.36	70.90	13.40	40.48	850	135.70	2849.70	176.18	3699.70	3.35
5	407.08	447.56	271.03	271.03	70.77	13.32	40.48	850	136.05	2857.05	176.53	3707.05	3.36
6	407.08	447.56	270.29	270.29	70.70	13.36	40.48	850	136.79	2872.59	177.27	3722.59	3.38
7	406.93	447.41	271.74	271.74	70.73	13.32	40.48	850	135.19	2838.99	175.67	3688.99	3.34
8	406.81	447.29	271.40	271.40	70.77	13.30	40.48	850	135.41	2843.61	175.89	3693.61	3.35
9	406.79	447.27	271.36	271.36	70.77	13.30	40.48	850	135.43	2844.03	175.91	3694.03	3.35
10	407.11	447.59	270.78	270.78	71.17	13.33	40.48	850	136.33	2862.93	176.81	3712.93	3.37
11	406.88	447.36	271.09	271.09	70.84	13.34	40.48	850	135.79	2851.59	176.27	3701.59	3.35
12	407.09	447.57	271.78	271.78	71.15	13.38	40.48	850	135.31	2841.51	175.79	3691.51	3.34
13	407.18	447.66	271.15	271.15	71.29	13.45	40.48	850	136.03	2856.63	176.51	3706.63	3.36
14	407.35	447.83	271.62	271.62	71.76	13.54	40.48	850	135.73	2850.33	176.21	3700.33	3.35
15	407.33	447.81	271.88	271.88	71.35	13.60	40.48	850	135.45	2844.45	175.93	3694.45	3.35
16	407.39	447.87	271.79	271.79	71.34	13.52	40.48	850	135.60	2847.60	176.08	3697.60	3.35
17	407.41	447.89	272.29	272.29	71.33	13.41	40.48	850	135.12	2837.52	175.60	3687.52	3.34
18	407.05	447.53	271.64	271.64	71.02	13.53	40.48	850	135.41	2843.61	175.89	3693.61	3.35
19	407.20	447.68	271.76	271.76	71.00	13.36	40.48	850	135.44	2844.24	175.92	3694.24	3.35
20	406.93	447.41	271.22	271.22	70.69	13.33	40.48	850	135.71	2849.91	176.19	3699.91	3.35
μ'_A (%)								0.00		3.50			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.68			1.90
μ'_E at 95% confidence level (%)								2.44		7.36			3.80

19. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.73	450.73	273.32	273.32	74.41	12.28	44.00	1056	133.41	3201.84	177.41	4257.84	3.03
2	406.72	450.72	272.73	272.73	74.40	12.27	44.00	1056	133.99	3215.76	177.99	4271.76	3.05
3	406.71	450.71	272.54	272.54	74.39	12.26	44.00	1056	134.17	3220.08	178.17	4276.08	3.05
4	407.00	451.00	273.46	273.46	74.65	12.25	44.00	1056	133.54	3204.96	177.54	4260.96	3.04
5	406.69	450.69	272.41	272.41	74.36	12.30	44.00	1056	134.28	3222.72	178.28	4278.72	3.05
6	406.94	450.94	273.33	273.33	74.55	12.35	44.00	1056	133.61	3206.64	177.61	4262.64	3.04
7	406.86	450.86	272.88	272.88	74.51	12.45	44.00	1056	133.98	3215.52	177.98	4271.52	3.05
8	406.77	450.77	273.47	273.47	74.46	12.44	44.00	1056	133.30	3199.20	177.30	4255.20	3.03
9	406.96	450.96	273.55	273.55	74.69	12.51	44.00	1056	133.41	3201.84	177.41	4257.84	3.03
10	406.73	450.73	272.51	272.51	74.45	12.43	44.00	1056	134.22	3221.28	178.22	4277.28	3.05
11	406.61	450.61	273.16	273.16	74.36	12.52	44.00	1056	133.45	3202.80	177.45	4258.80	3.03
12	406.80	450.80	273.32	273.32	74.55	12.46	44.00	1056	133.48	3203.52	177.48	4259.52	3.03
13	406.81	450.81	273.61	273.61	74.57	12.42	44.00	1056	133.20	3196.80	177.20	4252.80	3.03
14	406.73	450.73	273.64	273.64	74.47	12.45	44.00	1056	133.09	3194.16	177.09	4250.16	3.02
15	407.10	451.10	273.41	273.41	74.74	12.54	44.00	1056	133.69	3208.56	177.69	4264.56	3.04
16	407.16	451.16	273.61	273.61	74.78	12.57	44.00	1056	133.55	3205.20	177.55	4261.20	3.04
17	406.60	450.60	273.36	273.36	74.29	12.57	44.00	1056	133.24	3197.76	177.24	4253.76	3.03
18	406.77	450.77	273.10	273.10	74.45	12.57	44.00	1056	133.67	3208.08	177.67	4264.08	3.04
19	407.13	451.13	273.18	273.18	74.77	12.54	44.00	1056	133.95	3214.80	177.95	4270.80	3.04
20	406.83	450.83	273.16	273.16	74.51	12.59	44.00	1056	133.67	3208.08	177.67	4264.08	3.04
μ'_A (%)								0.00		3.31			0.10
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.50			1.90
μ'_E at 95% confidence level (%)								2.44		7.00			3.80

20. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.96	454.04	273.66	273.66	77.66	11.43	48.08	1250	132.30	3439.80	180.38	4689.80	2.75
2	406.03	454.11	274.21	274.21	77.72	11.48	48.08	1250	131.82	3427.32	179.90	4677.32	2.74
3	406.28	454.36	274.17	274.17	77.92	11.39	48.08	1250	132.11	3434.86	180.19	4684.86	2.75
4	406.15	454.23	274.58	274.58	77.82	11.54	48.08	1250	131.57	3420.82	179.65	4670.82	2.74
5	405.77	453.85	274.06	274.06	77.47	11.51	48.08	1250	131.71	3424.46	179.79	4674.46	2.74
6	406.15	454.23	273.97	273.97	77.79	11.47	48.08	1250	132.18	3436.68	180.26	4686.68	2.75
7	406.25	454.33	273.99	273.99	77.83	11.53	48.08	1250	132.26	3438.76	180.34	4688.76	2.75
8	405.96	454.04	274.27	274.27	77.60	11.35	48.08	1250	131.69	3423.94	179.77	4673.94	2.74
9	405.70	453.78	273.97	273.97	77.43	11.41	48.08	1250	131.73	3424.98	179.81	4674.98	2.74
10	406.00	454.08	275.43	275.43	77.70	11.51	48.08	1250	130.57	3394.82	178.65	4644.82	2.72
11	405.98	454.06	274.24	274.24	77.68	11.54	48.08	1250	131.74	3425.24	179.82	4675.24	2.74
12	405.73	453.81	273.53	273.53	77.42	11.45	48.08	1250	132.20	3437.20	180.28	4687.20	2.75
13	405.96	454.04	274.10	274.10	77.62	11.49	48.08	1250	131.86	3428.36	179.94	4678.36	2.74
14	406.30	454.38	274.17	274.17	77.92	11.41	48.08	1250	132.13	3435.38	180.21	4685.38	2.75
15	406.01	454.09	273.77	273.77	77.65	11.47	48.08	1250	132.24	3438.24	180.32	4688.24	2.75
16	405.74	453.82	274.38	274.38	77.48	11.46	48.08	1250	131.36	3415.36	179.44	4665.36	2.73
17	405.85	453.93	273.81	273.81	77.58	11.42	48.08	1250	132.04	3433.04	180.12	4683.04	2.75
18	406.29	454.37	274.33	274.33	77.96	11.37	48.08	1250	131.96	3430.96	180.04	4680.96	2.74
19	406.01	454.09	274.10	274.10	77.68	11.35	48.08	1250	131.91	3429.66	179.99	4679.66	2.74
20	406.10	454.18	273.69	273.69	77.73	11.36	48.08	1250	132.41	3442.66	180.49	4692.66	2.75
μ'_A (%)								0.00		4.11			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.27			1.90
μ'_E at 95% confi-dence level (%)								2.44		8.54			3.80

21. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.42	441.75	261.15	261.15	61.22	13.54	35.33	530	145.27	2179.05	180.60	2709.05	4.11
2	406.38	441.71	262.14	262.14	61.22	13.51	35.33	530	144.24	2163.60	179.57	2693.60	4.08
3	406.31	441.64	262.09	262.09	61.13	13.55	35.33	530	144.22	2163.30	179.55	2693.30	4.08
4	406.36	441.69	261.65	261.65	61.15	13.46	35.33	530	144.71	2170.65	180.04	2700.65	4.10
5	406.41	441.74	261.62	261.62	61.16	13.48	35.33	530	144.79	2171.85	180.12	2701.85	4.10
6	406.25	441.58	262.09	262.09	60.98	13.54	35.33	530	144.16	2162.40	179.49	2692.40	4.08
7	406.40	441.73	262.21	262.21	61.13	13.66	35.33	530	144.19	2162.85	179.52	2692.85	4.08
8	406.15	441.48	261.18	261.18	60.92	13.47	35.33	530	144.97	2174.55	180.30	2704.55	4.10
9	406.27	441.60	262.27	262.27	61.07	13.44	35.33	530	144.00	2160.00	179.33	2690.00	4.08
10	406.27	441.60	261.49	261.49	61.07	13.45	35.33	530	144.78	2171.70	180.11	2701.70	4.10
11	406.25	441.58	261.02	261.02	61.05	13.45	35.33	530	145.23	2178.45	180.56	2708.45	4.11
12	406.31	441.64	261.08	261.08	61.06	13.47	35.33	530	145.23	2178.45	180.56	2708.45	4.11
13	406.26	441.59	261.67	261.67	61.01	13.41	35.33	530	144.59	2168.85	179.92	2698.85	4.09
14	405.85	441.18	261.65	261.65	60.65	13.40	35.33	530	144.20	2163.00	179.53	2693.00	4.08
15	406.21	441.54	261.71	261.71	61.28	13.37	35.33	530	144.50	2167.50	179.83	2697.50	4.09
16	405.95	441.28	262.09	262.09	60.90	13.39	35.33	530	143.86	2157.90	179.19	2687.90	4.07
17	406.26	441.59	262.14	262.14	61.35	13.45	35.33	530	144.12	2161.80	179.45	2691.80	4.08
18	406.13	441.46	263.01	263.01	61.37	13.56	35.33	530	143.12	2146.80	178.45	2676.80	4.05
19	406.42	441.75	263.32	263.32	61.81	13.55	35.33	530	143.10	2146.50	178.43	2676.50	4.05
20	406.57	441.90	263.83	263.83	62.19	13.60	35.33	530	142.74	2141.10	178.07	2671.10	4.04
μ'_A (%)								0.00		5.10			0.22
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		5.23			1.91
μ'_E at 95% confi-dence level (%)								2.44		10.46			3.82

22. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.13	442.62	265.62	265.62	64.59	12.84	36.49	675	140.51	2599.44	177.00	3274.44	3.85
2	406.29	442.78	265.97	265.97	64.87	12.84	36.49	675	140.32	2595.92	176.81	3270.92	3.85
3	405.97	442.46	266.26	266.26	64.66	12.83	36.49	675	139.71	2584.64	176.20	3259.64	3.83
4	406.16	442.65	268.45	268.45	64.95	12.85	36.49	675	137.71	2547.64	174.20	3222.64	3.77
5	406.43	442.92	267.06	267.06	65.33	12.90	36.49	675	139.37	2578.35	175.86	3253.35	3.82
6	406.64	443.13	267.21	267.21	65.55	12.89	36.49	675	139.43	2579.46	175.92	3254.46	3.82
7	406.58	443.07	267.25	267.25	65.53	12.92	36.49	675	139.33	2577.61	175.82	3252.61	3.82
8	406.63	443.12	266.32	266.32	65.54	12.94	36.49	675	140.31	2595.74	176.80	3270.74	3.85
9	406.52	443.01	267.04	267.04	65.41	12.93	36.49	675	139.48	2580.38	175.97	3255.38	3.82
10	406.74	443.23	265.71	265.71	65.56	12.97	36.49	675	141.03	2609.06	177.52	3284.06	3.87
11	406.62	443.11	267.04	267.04	65.37	12.96	36.49	675	139.58	2582.23	176.07	3257.23	3.83
12	406.51	443.00	267.79	267.79	65.20	12.94	36.49	675	138.72	2566.32	175.21	3241.32	3.80
13	406.22	442.71	266.63	266.63	64.87	12.92	36.49	675	139.59	2582.42	176.08	3257.42	3.83
14	406.39	442.88	266.00	266.00	64.93	12.88	36.49	675	140.39	2597.22	176.88	3272.22	3.85
15	406.51	443.00	266.11	266.11	64.95	12.81	36.49	675	140.40	2597.40	176.89	3272.40	3.85
16	406.46	442.95	265.69	265.69	64.81	12.83	36.49	675	140.77	2604.25	177.26	3279.25	3.86
17	406.00	442.49	264.89	264.89	64.32	12.87	36.49	675	141.11	2610.54	177.60	3285.54	3.87
18	406.05	442.54	265.33	265.33	64.27	12.90	36.49	675	140.72	2603.32	177.21	3278.32	3.86
19	405.90	442.39	264.85	264.85	64.06	12.92	36.49	675	141.05	2609.43	177.54	3284.43	3.87
20	405.83	442.32	264.81	264.81	63.95	12.90	36.49	675	141.02	2608.87	177.51	3283.87	3.86
μ'_A (%)								0.00		7.23			0.28
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		7.32			1.92
μ'_E at 95% confidence level (%)								2.44		14.64			3.84

23. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.17	444.27	267.36	267.36	66.68	12.04	38.10	800	138.81	2915.01	176.91	3715.01	3.64
2	405.79	443.89	267.64	267.64	66.40	12.07	38.10	800	138.15	2901.15	176.25	3701.15	3.63
3	406.07	444.17	267.88	267.88	66.74	11.97	38.10	800	138.19	2901.99	176.29	3701.99	3.63
4	406.10	444.20	268.30	268.30	66.84	12.06	38.10	800	137.80	2893.80	175.90	3693.80	3.62
5	405.99	444.09	267.76	267.76	66.86	12.06	38.10	800	138.23	2902.83	176.33	3702.83	3.63
6	406.60	444.70	269.36	269.36	67.70	12.10	38.10	800	137.24	2882.04	175.34	3682.04	3.60
7	406.15	444.25	269.13	269.13	67.27	12.09	38.10	800	137.02	2877.42	175.12	3677.42	3.60
8	406.58	444.68	268.76	268.76	67.65	12.05	38.10	800	137.82	2894.22	175.92	3694.22	3.62
9	406.67	444.77	269.39	269.39	67.70	12.02	38.10	800	137.28	2882.88	175.38	3682.88	3.60
10	406.31	444.41	269.07	269.07	67.29	12.04	38.10	800	137.24	2882.04	175.34	3682.04	3.60
11	406.34	444.44	269.07	269.07	67.29	12.02	38.10	800	137.27	2882.67	175.37	3682.67	3.60
12	406.27	444.37	268.67	268.67	67.14	12.02	38.10	800	137.60	2889.60	175.70	3689.60	3.61
13	406.34	444.44	268.13	268.13	67.19	12.02	38.10	800	138.21	2902.41	176.31	3702.41	3.63
14	406.23	444.33	268.31	268.31	67.01	11.99	38.10	800	137.92	2896.32	176.02	3696.32	3.62
15	405.94	444.04	268.45	268.45	66.73	12.01	38.10	800	137.49	2887.29	175.59	3687.29	3.61
16	406.09	444.19	267.90	267.90	66.79	11.99	38.10	800	138.19	2901.99	176.29	3701.99	3.63
17	406.40	444.50	267.96	267.96	67.00	12.05	38.10	800	138.44	2907.24	176.54	3707.24	3.63
18	406.05	444.15	267.26	267.26	66.60	12.04	38.10	800	138.79	2914.59	176.89	3714.59	3.64
19	405.78	443.88	267.67	267.67	66.34	12.07	38.10	800	138.11	2900.31	176.21	3700.31	3.63
20	406.01	444.11	268.68	268.68	66.53	12.10	38.10	800	137.33	2883.93	175.43	3683.93	3.60
μ'_A (%)								0.00		4.64			0.16
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.78			1.91
μ'_E at 95% confi-dence level (%)								2.44		9.56			3.82

24. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.76	447.80	270.00	270.00	70.59	11.48	42.04	1009	135.76	3258.24	177.80	4267.24	3.23
2	405.62	447.66	269.49	269.49	70.48	11.53	42.04	1009	136.13	3267.12	178.17	4276.12	3.24
3	405.97	448.01	269.90	269.90	70.81	11.50	42.04	1009	136.07	3265.68	178.11	4274.68	3.24
4	405.83	447.87	270.03	270.03	70.70	11.45	42.04	1009	135.80	3259.20	177.84	4268.20	3.23
5	405.91	447.95	269.95	269.95	70.80	11.50	42.04	1009	135.96	3263.04	178.00	4272.04	3.23
6	405.74	447.78	269.52	269.52	70.70	11.54	42.04	1009	136.22	3269.28	178.26	4278.28	3.24
7	405.80	447.84	270.04	270.04	70.77	11.50	42.04	1009	135.76	3258.24	177.80	4267.24	3.23
8	405.44	447.48	270.63	270.63	70.49	11.51	42.04	1009	134.81	3235.44	176.85	4244.44	3.21
9	405.72	447.76	270.58	270.58	70.76	11.54	42.04	1009	135.14	3243.36	177.18	4252.36	3.21
10	405.61	447.65	269.62	269.62	70.64	11.59	42.04	1009	135.99	3263.76	178.03	4272.76	3.23
11	405.90	447.94	269.87	269.87	70.87	11.54	42.04	1009	136.03	3264.72	178.07	4273.72	3.24
12	405.85	447.89	270.37	270.37	70.81	11.52	42.04	1009	135.48	3251.52	177.52	4260.52	3.22
13	405.76	447.80	270.31	270.31	70.65	11.49	42.04	1009	135.45	3250.80	177.49	4259.80	3.22
14	405.97	448.01	269.55	269.55	70.23	11.56	42.04	1009	136.42	3274.08	178.46	4283.08	3.24
15	406.00	448.04	269.39	269.39	70.78	11.46	42.04	1009	136.61	3278.64	178.65	4287.64	3.25
16	405.67	447.71	269.42	269.42	70.45	11.50	42.04	1009	136.25	3270.00	178.29	4279.00	3.24
17	405.90	447.94	269.72	269.72	70.59	11.44	42.04	1009	136.18	3268.32	178.22	4277.32	3.24
18	405.91	447.95	269.93	269.93	70.83	11.50	42.04	1009	135.98	3263.52	178.02	4272.52	3.23
19	405.92	447.96	270.29	270.29	70.80	11.52	42.04	1009	135.63	3255.12	177.67	4264.12	3.23
20	405.74	447.78	269.99	269.99	70.62	11.50	42.04	1009	135.75	3258.00	177.79	4267.00	3.23
μ'_A (%)								0.00		4.01			0.13
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.17			1.90
μ'_E at 95% confi-dence level (%)								2.44		8.34			3.80

25. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.13	450.13	272.09	272.09	73.42	11.18	45.00	1170	133.04	3459.04	178.04	4629.04	2.96
2	405.00	450.00	271.70	271.70	73.33	11.13	45.00	1170	133.30	3465.80	178.30	4635.80	2.96
3	404.79	449.79	272.09	272.09	73.14	11.09	45.00	1170	132.70	3450.20	177.70	4620.20	2.95
4	405.04	450.04	273.21	273.21	73.38	11.05	45.00	1170	131.83	3427.58	176.83	4597.58	2.93
5	405.51	450.51	272.15	272.15	73.82	11.23	45.00	1170	133.36	3467.36	178.36	4637.36	2.96
6	405.17	450.17	271.36	271.36	73.53	11.13	45.00	1170	133.81	3479.06	178.81	4649.06	2.97
7	405.40	450.40	272.15	272.15	73.73	11.16	45.00	1170	133.25	3464.50	178.25	4634.50	2.96
8	404.98	449.98	271.57	271.57	73.30	11.11	45.00	1170	133.41	3468.66	178.41	4638.66	2.96
9	405.21	450.21	272.09	272.09	73.56	11.17	45.00	1170	133.12	3461.12	178.12	4631.12	2.96
10	405.58	450.58	272.49	272.49	73.97	11.14	45.00	1170	133.09	3460.34	178.09	4630.34	2.96
11	405.27	450.27	272.51	272.51	73.68	11.12	45.00	1170	132.76	3451.76	177.76	4621.76	2.95
12	404.99	449.99	273.08	273.08	73.37	11.15	45.00	1170	131.91	3429.66	176.91	4599.66	2.93
13	405.95	450.95	272.07	272.07	74.23	11.08	45.00	1170	133.88	3480.88	178.88	4650.88	2.98
14	405.09	450.09	272.16	272.16	73.49	11.12	45.00	1170	132.93	3456.18	177.93	4626.18	2.95
15	405.43	450.43	272.27	272.27	73.85	11.18	45.00	1170	133.16	3462.16	178.16	4632.16	2.96
16	405.55	450.55	272.93	272.93	73.96	11.14	45.00	1170	132.62	3448.12	177.62	4618.12	2.95
17	405.63	450.63	272.05	272.05	74.02	11.08	45.00	1170	133.58	3473.08	178.58	4643.08	2.97
18	405.83	450.83	271.87	271.87	74.03	11.11	45.00	1170	133.96	3482.96	178.96	4652.96	2.98
19	405.22	450.22	271.71	271.71	73.42	11.11	45.00	1170	133.51	3471.26	178.51	4641.26	2.97
20	405.05	450.05	272.19	272.19	73.31	11.17	45.00	1170	132.86	3454.36	177.86	4624.36	2.95
μ'_A (%)								0.00		5.60			0.16
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		5.72			1.91
μ'_E at 95% confi-dence level (%)								2.44		11.44			3.82

26. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	**Dependant variables (Calculated variables)**													
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.90	437.30	255.45	255.45	56.16	12.20	32.40	486	149.45	2241.75	181.85	2727.75	4.61
2	404.92	437.32	255.33	255.33	56.18	12.21	32.40	486	149.59	2243.85	181.99	2729.85	4.62
3	404.40	436.80	255.90	255.9	55.91	12.39	32.40	486	148.50	2227.50	180.90	2713.50	4.58
4	404.43	436.83	256.12	256.12	55.99	12.37	32.40	486	148.31	2224.65	180.71	2710.65	4.58
5	404.40	436.80	255.42	255.42	56.00	12.42	32.40	486	148.98	2234.70	181.38	2720.70	4.60
6	404.41	436.81	256.09	256.09	56.04	12.34	32.40	486	148.32	2224.80	180.72	2710.80	4.58
7	404.48	436.88	256.32	256.32	56.14	12.42	32.40	486	148.16	2222.40	180.56	2708.40	4.57
8	404.57	436.97	256.24	256.24	56.24	12.44	32.40	486	148.33	2224.95	180.73	2710.95	4.58
9	405.33	437.73	255.77	255.77	56.92	12.42	32.40	486	149.56	2243.40	181.96	2729.40	4.62
10	404.37	436.77	256.12	256.12	56.04	12.40	32.40	486	148.25	2223.75	180.65	2709.75	4.58
11	404.25	436.65	256.29	256.29	55.98	12.40	32.40	486	147.96	2219.40	180.36	2705.40	4.57
12	405.30	437.70	257.41	257.41	57.18	12.57	32.40	486	147.89	2218.35	180.29	2704.35	4.56
13	404.47	436.87	257.42	257.42	56.46	12.56	32.40	486	147.05	2205.75	179.45	2691.75	4.54
14	404.57	436.97	257.42	257.42	56.60	12.50	32.40	486	147.15	2207.25	179.55	2693.25	4.54
15	404.52	436.92	257.77	257.77	56.61	12.59	32.40	486	146.75	2201.25	179.15	2687.25	4.53
16	405.22	437.62	257.95	257.95	57.26	12.62	32.40	486	147.27	2209.05	179.67	2695.05	4.55
17	404.64	437.04	257.26	257.26	56.74	12.64	32.40	486	147.38	2210.70	179.78	2696.70	4.55
18	404.72	437.12	257.59	257.59	56.80	12.51	32.40	486	147.13	2206.95	179.53	2692.95	4.54
19	404.60	437.00	257.36	257.36	56.65	12.33	32.40	486	147.24	2208.60	179.64	2694.60	4.54
20	404.68	437.08	255.05	255.05	55.70	12.41	32.40	486	149.63	2244.45	182.03	2730.45	4.62
μ'_A (%)								0.00		6.60			0.30
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		6.70			1.92
μ'_E at 95% confi-dence level (%)								2.44		13.40			3.84

27. $\phi_{a,i,e} = 50\%$, $\frac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 9.67$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.82	439.49	259.00	259.00	59.46	11.83	34.67	624	145.82	2624.76	180.49	3248.76	4.21
2	405.03	439.70	258.67	258.67	59.58	11.78	34.67	624	146.36	2634.48	181.03	3258.48	4.22
3	405.06	439.73	258.77	258.77	59.56	11.83	34.67	624	146.29	2633.22	180.96	3257.22	4.22
4	404.95	439.62	258.82	258.82	59.52	11.75	34.67	624	146.13	2630.34	180.80	3254.34	4.22
5	404.87	439.54	258.97	258.97	59.48	11.77	34.67	624	145.90	2626.20	180.57	3250.20	4.21
6	405.16	439.83	259.01	259.01	59.86	11.86	34.67	624	146.15	2630.70	180.82	3254.70	4.22
7	405.16	439.83	259.18	259.18	59.89	11.76	34.67	624	145.98	2627.64	180.65	3251.64	4.21
8	405.21	439.88	259.40	259.40	59.99	11.71	34.67	624	145.81	2624.58	180.48	3248.58	4.21
9	405.33	440.00	258.95	258.95	59.91	11.87	34.67	624	146.38	2634.84	181.05	3258.84	4.22
10	405.05	439.72	258.64	258.64	59.58	11.77	34.67	624	146.41	2635.38	181.08	3259.38	4.22
11	404.80	439.47	258.91	258.91	59.35	11.85	34.67	624	145.89	2626.02	180.56	3250.02	4.21
12	405.05	439.72	258.68	258.68	59.62	11.83	34.67	624	146.37	2634.66	181.04	3258.66	4.22
13	404.85	439.52	259.03	259.03	59.45	11.78	34.67	624	145.82	2624.76	180.49	3248.76	4.21
14	404.93	439.60	258.61	258.61	59.56	11.76	34.67	624	146.32	2633.76	180.99	3257.76	4.22
15	405.10	439.77	258.85	258.85	59.73	11.76	34.67	624	146.25	2632.50	180.92	3256.50	4.22
16	405.03	439.70	258.95	258.95	59.67	11.79	34.67	624	146.08	2629.44	180.75	3253.44	4.21
17	405.10	439.77	258.80	258.80	59.59	11.79	34.67	624	146.30	2633.40	180.97	3257.40	4.22
18	405.78	440.45	258.67	258.67	60.37	11.79	34.67	624	147.11	2647.98	181.78	3271.98	4.24
19	405.10	439.77	258.98	258.98	59.75	11.83	34.67	624	146.12	2630.16	180.79	3254.16	4.22
20	405.39	440.06	259.18	259.18	59.90	11.90	34.67	624	146.21	2631.78	180.88	3255.78	4.22
μ'_A (%)								0.00		2.34			0.09
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		2.61			1.90
μ'_E at 95% confi-dence level (%)								2.44		5.22			3.80

28. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.85	441.73	259.63	259.63	62.06	11.19	36.88	756	145.22	2977.01	182.10	3733.01	3.94
2	404.66	441.54	260.94	260.94	61.79	11.20	36.88	756	143.72	2946.26	180.60	3702.26	3.90
3	404.74	441.62	259.75	259.75	61.91	11.17	36.88	756	144.99	2972.30	181.87	3728.30	3.93
4	404.74	441.62	260.03	260.03	61.98	11.18	36.88	756	144.71	2966.56	181.59	3722.56	3.92
5	404.77	441.65	260.09	260.09	62.02	11.26	36.88	756	144.68	2965.94	181.56	3721.94	3.92
6	404.94	441.82	259.79	259.79	62.23	11.25	36.88	756	145.15	2975.58	182.03	3731.58	3.94
7	405.04	441.92	260.91	260.91	62.41	11.19	36.88	756	144.13	2954.67	181.01	3710.67	3.91
8	404.85	441.73	260.83	260.83	62.28	11.17	36.88	756	144.02	2952.41	180.90	3708.41	3.91
9	404.69	441.57	260.83	260.83	62.15	11.22	36.88	756	143.86	2949.13	180.74	3705.13	3.90
10	404.59	441.47	260.67	260.67	62.08	11.27	36.88	756	143.92	2950.36	180.80	3706.36	3.90
11	404.72	441.60	260.94	260.94	62.25	11.29	36.88	756	143.78	2947.49	180.66	3703.49	3.90
12	405.09	441.97	260.89	260.89	62.62	11.24	36.88	756	144.20	2956.10	181.08	3712.10	3.91
13	405.15	442.03	260.61	260.61	62.70	11.29	36.88	756	144.54	2963.07	181.42	3719.07	3.92
14	404.69	441.57	260.73	260.73	62.29	11.31	36.88	756	143.96	2951.18	180.84	3707.18	3.90
15	404.93	441.81	260.88	260.88	62.51	11.23	36.88	756	144.05	2953.03	180.93	3709.03	3.91
16	404.83	441.71	260.89	260.89	62.42	11.18	36.88	756	143.94	2950.77	180.82	3706.77	3.90
17	404.76	441.64	261.24	261.24	62.35	11.20	36.88	756	143.52	2942.16	180.40	3698.16	3.89
18	404.90	441.78	261.18	261.18	62.48	11.23	36.88	756	143.72	2946.26	180.60	3702.26	3.90
19	405.00	441.88	260.71	260.71	62.56	11.28	36.88	756	144.29	2957.95	181.17	3713.95	3.91
20	405.05	441.93	261.10	261.10	62.60	11.24	36.88	756	143.95	2950.98	180.83	3706.98	3.90
μ'_A (%)								0.00		4.20			0.15
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.35			1.91
μ'_E at 95% confi-dence level (%)								2.44		8.70			3.82

29. $\phi_{a,i,e} = 50\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.45	445.98	265.01	265.01	67.51	10.35	41.53	976	139.44	3276.84	180.97	4252.84	3.36
2	404.55	446.08	265.66	265.66	67.62	10.28	41.53	976	138.89	3263.92	180.42	4239.92	3.34
3	404.84	446.37	265.40	265.40	67.76	10.33	41.53	976	139.44	3276.84	180.97	4252.84	3.36
4	404.85	446.38	264.82	264.82	67.72	10.40	41.53	976	140.03	3290.71	181.56	4266.71	3.37
5	404.72	446.25	264.14	264.14	67.53	10.39	41.53	976	140.58	3303.63	182.11	4279.63	3.38
6	404.58	446.11	265.21	265.21	67.55	10.43	41.53	976	139.37	3275.20	180.90	4251.20	3.36
7	404.96	446.49	264.92	264.92	67.95	10.54	41.53	976	140.04	3290.94	181.57	4266.94	3.37
8	404.80	446.33	265.75	265.75	67.94	10.45	41.53	976	139.05	3267.68	180.58	4243.68	3.35
9	404.76	446.29	265.69	265.69	67.87	10.52	41.53	976	139.07	3268.15	180.60	4244.15	3.35
10	404.86	446.39	265.59	265.59	67.92	10.53	41.53	976	139.27	3272.85	180.80	4248.85	3.35
11	405.03	446.56	265.46	265.46	68.06	10.29	41.53	976	139.57	3279.90	181.10	4255.90	3.36
12	405.03	446.56	265.30	265.30	67.98	10.46	41.53	976	139.73	3283.66	181.26	4259.66	3.36
13	405.30	446.83	264.87	264.87	68.21	10.47	41.53	976	140.43	3300.11	181.96	4276.11	3.38
14	404.93	446.46	265.13	265.13	67.85	10.44	41.53	976	139.80	3285.30	181.33	4261.30	3.37
15	404.94	446.47	264.40	264.40	67.85	10.34	41.53	976	140.54	3302.69	182.07	4278.69	3.38
16	404.95	446.48	264.73	264.73	67.86	10.46	41.53	976	140.22	3295.17	181.75	4271.17	3.38
17	404.82	446.35	264.85	264.85	67.69	10.43	41.53	976	139.97	3289.30	181.50	4265.30	3.37
18	405.05	446.58	264.18	264.18	67.88	10.46	41.53	976	140.87	3310.45	182.40	4286.45	3.39
19	404.58	446.11	264.61	264.61	67.45	10.52	41.53	976	139.97	3289.30	181.50	4265.30	3.37
20	404.91	446.44	264.70	264.70	67.79	10.41	41.53	976	140.21	3294.94	181.74	4270.94	3.38
μ'_A (%)								0.00		5.11			0.16
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		5.24			1.91
μ'_E at 95% confi-dence level (%)								2.44		10.48			3.82

30. $\phi_{a,i,e} = 50\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	404.62	449.13	266.35	266.35	70.68	9.63	44.51	1135	138.27	3525.89	182.78	4660.89	3.11
2	404.51	449.02	266.41	266.41	70.58	9.60	44.51	1135	138.10	3521.55	182.61	4656.55	3.10
3	404.41	448.92	267.29	267.29	70.50	9.54	44.51	1135	137.12	3496.56	181.63	4631.56	3.08
4	404.69	449.20	266.05	266.05	70.75	9.61	44.51	1135	138.64	3535.32	183.15	4670.32	3.11
5	404.85	449.36	265.37	265.37	70.80	9.57	44.51	1135	139.48	3556.74	183.99	4691.74	3.13
6	404.74	449.25	266.00	266.00	70.70	9.55	44.51	1135	138.74	3537.87	183.25	4672.87	3.12
7	404.86	449.37	265.88	265.88	70.87	9.57	44.51	1135	138.98	3543.99	183.49	4678.99	3.12
8	405.34	449.85	266.40	266.40	71.39	9.56	44.51	1135	138.94	3542.97	183.45	4677.97	3.12
9	404.61	449.12	266.49	266.49	70.70	9.58	44.51	1135	138.12	3522.06	182.63	4657.06	3.10
10	403.94	448.45	266.05	266.05	70.07	9.64	44.51	1135	137.89	3516.20	182.40	4651.20	3.10
11	405.05	449.56	266.11	266.11	71.09	9.68	44.51	1135	138.94	3542.97	183.45	4677.97	3.12
12	404.85	449.36	267.44	267.44	70.94	9.70	44.51	1135	137.41	3503.96	181.92	4638.96	3.09
13	404.43	448.94	266.64	266.64	70.55	9.60	44.51	1135	137.79	3513.65	182.30	4648.65	3.10
14	404.74	449.25	266.34	266.34	70.87	9.66	44.51	1135	138.40	3529.20	182.91	4664.20	3.11
15	404.35	448.86	266.90	266.90	70.57	9.55	44.51	1135	137.45	3504.98	181.96	4639.98	3.09
16	404.59	449.10	267.15	267.15	70.81	9.67	44.51	1135	137.44	3504.72	181.95	4639.72	3.09
17	404.56	449.07	267.06	267.06	70.80	9.71	44.51	1135	137.50	3506.25	182.01	4641.25	3.09
18	404.61	449.12	267.85	267.85	70.81	9.56	44.51	1135	136.76	3487.38	181.27	4622.38	3.07
19	404.29	448.80	267.19	267.19	70.52	9.58	44.51	1135	137.10	3496.05	181.61	4631.05	3.08
20	404.55	449.06	266.73	266.73	70.77	9.70	44.51	1135	137.82	3514.41	182.33	4649.41	3.10
μ'_A (%)								0.00		7.15			0.21
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		7.24			1.91
μ'_E at 95% confi-dence level (%)								2.44		14.48			3.82

31. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.77	445.38	269.27	269.27	68.28	15.21	37.61	583	138.50	2146.75	176.11	2729.75	3.68
2	407.80	445.41	269.62	269.62	68.36	15.17	37.61	583	138.18	2141.79	175.79	2724.79	3.67
3	407.50	445.11	269.27	269.27	68.12	15.20	37.61	583	138.23	2142.57	175.84	2725.57	3.68
4	407.61	445.22	270.83	270.83	68.28	15.16	37.61	583	136.78	2120.09	174.39	2703.09	3.64
5	407.48	445.09	271.88	271.88	68.21	15.12	37.61	583	135.60	2101.80	173.21	2684.80	3.61
6	407.55	445.16	269.49	269.49	68.21	15.12	37.61	583	138.06	2139.93	175.67	2722.93	3.67
7	407.70	445.31	270.40	270.40	68.38	15.13	37.61	583	137.30	2128.15	174.91	2711.15	3.65
8	407.20	444.81	269.82	269.82	67.87	15.15	37.61	583	137.38	2129.39	174.99	2712.39	3.65
9	407.93	445.54	270.44	270.44	68.57	15.16	37.61	583	137.49	2131.10	175.10	2714.10	3.66
10	407.83	445.44	270.03	270.03	68.51	15.20	37.61	583	137.80	2135.90	175.41	2718.90	3.66
11	407.63	445.24	269.95	269.95	68.22	15.26	37.61	583	137.68	2134.04	175.29	2717.04	3.66
12	407.79	445.40	269.87	269.87	68.43	15.21	37.61	583	137.92	2137.76	175.53	2720.76	3.67
13	407.62	445.23	268.44	268.44	68.39	15.25	37.61	583	139.18	2157.29	176.79	2740.29	3.70
14	407.44	445.05	270.02	270.02	68.15	15.21	37.61	583	137.42	2130.01	175.03	2713.01	3.65
15	407.80	445.41	269.06	269.06	68.42	15.27	37.61	583	138.74	2150.47	176.35	2733.47	3.69
16	407.39	445.00	269.81	269.81	68.08	15.29	37.61	583	137.58	2132.49	175.19	2715.49	3.66
17	407.63	445.24	269.49	269.49	68.24	15.21	37.61	583	138.14	2141.17	175.75	2724.17	3.67
18	407.59	445.20	269.53	269.53	68.18	15.22	37.61	583	138.06	2139.93	175.67	2722.93	3.67
19	407.57	445.18	269.75	269.75	68.23	15.23	37.61	583	137.82	2136.21	175.43	2719.21	3.66
20	407.46	445.07	269.41	269.41	68.13	15.24	37.61	583	138.05	2139.78	175.66	2722.78	3.67
μ'_A (%)								0.00		5.59			0.23
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		5.71			1.92
μ'_E at 95% confi-dence level (%)								2.44		11.42			3.84

32. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.99	447.66	272.86	272.86	71.62	14.56	39.67	714	135.13	2432.34	174.80	3146.34	3.41
2	407.71	447.38	272.85	272.85	71.31	14.61	39.67	714	134.86	2427.48	174.53	3141.48	3.40
3	407.89	447.56	272.27	272.27	71.44	14.64	39.67	714	135.62	2441.16	175.29	3155.16	3.42
4	407.45	447.12	273.49	273.49	71.17	14.64	39.67	714	133.96	2411.28	173.63	3125.28	3.38
5	407.54	447.21	273.10	273.10	71.19	14.59	39.67	714	134.44	2419.92	174.11	3133.92	3.39
6	407.76	447.43	271.87	271.87	71.29	14.66	39.67	714	135.89	2446.02	175.56	3160.02	3.43
7	408.06	447.73	273.21	273.21	71.67	14.61	39.67	714	134.85	2427.30	174.52	3141.30	3.40
8	407.62	447.29	273.19	273.19	71.33	14.53	39.67	714	134.43	2419.74	174.10	3133.74	3.39
9	407.84	447.51	273.35	273.35	71.58	14.56	39.67	714	134.49	2420.82	174.16	3134.82	3.39
10	407.94	447.61	273.28	273.28	71.70	14.64	39.67	714	134.66	2423.88	174.33	3137.88	3.39
11	407.26	446.93	273.83	273.83	71.12	14.70	39.67	714	133.43	2401.74	173.10	3115.74	3.36
12	407.69	447.36	272.89	272.89	71.42	14.70	39.67	714	134.80	2426.40	174.47	3140.40	3.40
13	407.84	447.51	273.83	273.83	71.49	14.68	39.67	714	134.01	2412.18	173.68	3126.18	3.38
14	407.81	447.48	273.50	273.50	71.60	14.71	39.67	714	134.31	2417.58	173.98	3131.58	3.39
15	407.70	447.37	273.27	273.27	71.30	14.78	39.67	714	134.43	2419.74	174.10	3133.74	3.39
16	407.72	447.39	273.29	273.29	71.49	14.76	39.67	714	134.43	2419.74	174.10	3133.74	3.39
17	407.43	447.10	273.64	273.64	71.27	14.71	39.67	714	133.79	2408.22	173.46	3122.22	3.37
18	407.90	447.57	273.60	273.60	71.65	14.68	39.67	714	134.30	2417.40	173.97	3131.40	3.39
19	407.83	447.50	273.33	273.33	71.56	14.76	39.67	714	134.50	2421.00	174.17	3135.00	3.39
20	407.76	447.43	273.32	273.32	70.79	14.75	39.67	714	134.44	2419.92	174.11	3133.92	3.39
μ'_A (%)								0.00		4.67			0.17
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.81			1.91
μ'_E at 95% confidence level (%)								2.44		9.62			3.82

33. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.96	448.63	274.81	274.81	73.23	14.19	41.67	861	132.15	2775.15	173.82	3650.15	3.17
2	407.51	449.18	275.69	275.69	73.87	14.23	41.67	861	131.82	2768.22	173.49	3643.22	3.16
3	407.44	449.11	275.33	275.33	73.70	14.17	41.67	861	132.11	2774.31	173.78	3649.31	3.17
4	407.26	448.93	275.55	275.55	73.51	14.17	41.67	861	131.71	2765.91	173.38	3640.91	3.16
5	407.41	449.08	274.72	274.72	73.41	14.12	41.67	861	132.69	2786.49	174.36	3661.49	3.18
6	406.40	448.07	274.67	274.67	72.47	14.09	41.67	861	131.73	2766.33	173.40	3641.33	3.16
7	407.32	448.99	274.30	274.30	73.22	14.12	41.67	861	133.02	2793.42	174.69	3668.42	3.19
8	407.45	449.12	274.59	274.59	73.76	14.11	41.67	861	132.86	2790.06	174.53	3665.06	3.19
9	407.20	448.87	275.41	275.41	73.44	14.19	41.67	861	131.79	2767.59	173.46	3642.59	3.16
10	407.67	449.34	275.76	275.76	74.00	14.14	41.67	861	131.91	2770.11	173.58	3645.11	3.17
11	407.13	448.80	274.99	274.99	73.16	14.14	41.67	861	132.14	2774.94	173.81	3649.94	3.17
12	406.95	448.62	274.28	274.28	72.85	14.08	41.67	861	132.67	2786.07	174.34	3661.07	3.18
13	407.31	448.98	275.11	275.11	73.45	14.10	41.67	861	132.20	2776.20	173.87	3651.20	3.17
14	407.56	449.23	275.76	275.76	73.79	14.04	41.67	861	131.80	2767.80	173.47	3642.80	3.16
15	406.58	448.25	275.52	275.52	72.96	14.14	41.67	861	131.06	2752.26	172.73	3627.26	3.15
16	407.56	449.23	275.29	275.29	73.64	14.16	41.67	861	132.27	2777.67	173.94	3652.67	3.17
17	407.27	448.94	274.47	274.47	73.15	14.11	41.67	861	132.80	2788.80	174.47	3663.80	3.19
18	407.36	449.03	274.33	274.33	73.14	14.08	41.67	861	133.03	2793.63	174.70	3668.63	3.19
19	407.22	448.89	274.73	274.73	73.21	14.00	41.67	861	132.49	2782.29	174.16	3657.29	3.18
20	407.19	448.86	274.66	274.66	73.26	14.14	41.67	861	132.53	2783.13	174.20	3658.13	3.18
μ'_A (%)								0.00		4.62			0.16
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.76			1.91
μ'_E at 95% confi-dence level (%)								2.44		9.52			3.82

34. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.10	451.77	277.27	277.27	76.72	13.24	44.67	1072	129.83	3115.92	174.50	4187.92	2.91
2	406.74	451.41	277.50	277.50	76.38	13.15	44.67	1072	129.24	3101.76	173.91	4173.76	2.89
3	407.18	451.85	277.36	277.36	76.71	13.19	44.67	1072	129.82	3115.68	174.49	4187.68	2.91
4	407.53	452.20	276.57	276.57	76.98	13.20	44.67	1072	130.96	3143.04	175.63	4215.04	2.93
5	406.69	451.36	277.36	277.36	76.28	13.17	44.67	1072	129.33	3103.92	174.00	4175.92	2.90
6	406.81	451.48	276.98	276.98	76.34	13.32	44.67	1072	129.83	3115.92	174.50	4187.92	2.91
7	406.96	451.63	277.12	277.12	76.50	13.21	44.67	1072	129.84	3116.16	174.51	4188.16	2.91
8	407.05	451.72	277.11	277.11	76.55	13.16	44.67	1072	129.94	3118.56	174.61	4190.56	2.91
9	407.02	451.69	277.14	277.14	76.57	13.15	44.67	1072	129.88	3117.12	174.55	4189.12	2.91
10	407.23	451.90	277.08	277.08	76.73	13.13	44.67	1072	130.15	3123.60	174.82	4195.60	2.91
11	407.28	451.95	277.23	277.23	76.78	13.24	44.67	1072	130.05	3121.20	174.72	4193.20	2.91
12	407.07	451.74	277.57	277.57	76.60	13.16	44.67	1072	129.50	3108.00	174.17	4180.00	2.90
13	407.16	451.83	276.79	276.79	76.69	13.09	44.67	1072	130.37	3128.88	175.04	4200.88	2.92
14	407.34	452.01	277.25	277.25	76.88	13.18	44.67	1072	130.09	3122.16	174.76	4194.16	2.91
15	407.20	451.87	277.05	277.05	76.71	13.06	44.67	1072	130.15	3123.60	174.82	4195.60	2.91
16	407.15	451.82	277.30	277.30	76.73	13.12	44.67	1072	129.85	3116.40	174.52	4188.40	2.91
17	407.02	451.69	276.98	276.98	76.58	13.15	44.67	1072	130.04	3120.96	174.71	4192.96	2.91
18	406.89	451.56	276.87	276.87	76.38	13.23	44.67	1072	130.02	3120.48	174.69	4192.48	2.91
19	407.28	451.95	276.86	276.86	76.74	13.06	44.67	1072	130.42	3130.08	175.09	4202.08	2.92
20	407.40	452.07	276.82	276.82	75.27	13.07	44.67	1072	130.58	3133.92	175.25	4205.92	2.92
μ'_A (%)								0.00		3.86			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.03			1.90
μ'_E at 95% confidence level (%)								2.44		8.06			3.80

35. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.70	454.93	279.51	279.51	80.28	12.64	48.23	1254	127.19	3306.94	175.42	4560.94	2.64
2	406.67	454.90	279.15	279.15	80.24	12.56	48.23	1254	127.52	3315.52	175.75	4569.52	2.64
3	406.61	454.84	280.15	280.15	80.18	12.63	48.23	1254	126.46	3287.96	174.69	4541.96	2.62
4	406.55	454.78	279.86	279.86	80.12	12.65	48.23	1254	126.69	3293.94	174.92	4547.94	2.63
5	406.79	455.02	279.18	279.18	80.31	12.61	48.23	1254	127.61	3317.86	175.84	4571.86	2.65
6	406.72	454.95	279.21	279.21	80.27	12.54	48.23	1254	127.51	3315.26	175.74	4569.26	2.64
7	406.66	454.89	279.18	279.18	80.20	12.59	48.23	1254	127.48	3314.48	175.71	4568.48	2.64
8	406.74	454.97	278.72	278.72	80.30	12.50	48.23	1254	128.02	3328.52	176.25	4582.52	2.65
9	406.72	454.95	279.35	279.35	80.25	12.52	48.23	1254	127.37	3311.62	175.60	4565.62	2.64
10	406.91	455.14	279.29	279.29	80.38	12.53	48.23	1254	127.62	3318.12	175.85	4572.12	2.65
11	406.22	454.45	278.97	278.97	79.75	12.46	48.23	1254	127.25	3308.50	175.48	4562.50	2.64
12	406.72	454.95	279.13	279.13	80.22	12.49	48.23	1254	127.59	3317.34	175.82	4571.34	2.65
13	406.73	454.96	279.66	279.66	80.35	12.71	48.23	1254	127.07	3303.82	175.30	4557.82	2.63
14	406.44	454.67	279.27	279.27	80.00	12.63	48.23	1254	127.17	3306.42	175.40	4560.42	2.64
15	406.46	454.69	279.56	279.56	80.04	12.59	48.23	1254	126.90	3299.40	175.13	4553.40	2.63
16	406.62	454.85	279.29	279.29	80.16	12.59	48.23	1254	127.33	3310.58	175.56	4564.58	2.64
17	406.56	454.79	279.00	279.00	80.10	12.57	48.23	1254	127.56	3316.56	175.79	4570.56	2.64
18	406.79	455.02	279.51	279.51	80.36	12.52	48.23	1254	127.28	3309.28	175.51	4563.28	2.64
19	406.77	455.00	279.39	279.39	80.30	12.58	48.23	1254	127.38	3311.88	175.61	4565.88	2.64
20	406.55	454.78	279.42	279.42	80.13	12.48	48.23	1254	127.13	3305.38	175.36	4559.38	2.64
μ'_A (%)								0.00		2.81			0.10
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.04			1.90
μ'_E at 95% confi-dence level (%)								2.44		6.08			3.80

36. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	407.03	443.96	262.94	262.94	64.83	14.31	36.93	554	144.09	2161.35	181.02	2715.35	3.90
2	406.89	443.82	262.67	262.67	64.71	14.03	36.93	554	144.22	2163.30	181.15	2717.30	3.90
3	406.67	443.60	262.97	262.97	64.54	14.22	36.93	554	143.70	2155.50	180.63	2709.50	3.89
4	406.79	443.72	262.86	262.86	64.65	14.31	36.93	554	143.93	2158.95	180.86	2712.95	3.90
5	406.41	443.34	262.57	262.57	64.32	14.24	36.93	554	143.84	2157.60	180.77	2711.60	3.89
6	406.57	443.50	263.05	263.05	64.48	14.31	36.93	554	143.52	2152.80	180.45	2706.80	3.89
7	406.81	443.74	263.03	263.03	64.74	14.31	36.93	554	143.78	2156.70	180.71	2710.70	3.89
8	406.68	443.61	263.03	263.03	65.26	14.27	36.93	554	143.65	2154.75	180.58	2708.75	3.89
9	406.74	443.67	263.00	263.00	64.66	14.24	36.93	554	143.74	2156.10	180.67	2710.10	3.89
10	406.58	443.51	263.86	263.86	64.56	14.33	36.93	554	142.72	2140.80	179.65	2694.80	3.86
11	406.64	443.57	263.44	263.44	64.60	14.24	36.93	554	143.20	2148.00	180.13	2702.00	3.88
12	406.49	443.42	262.95	262.95	64.41	14.30	36.93	554	143.54	2153.10	180.47	2707.10	3.89
13	406.87	443.80	263.18	263.18	64.79	14.23	36.93	554	143.69	2155.35	180.62	2709.35	3.89
14	406.60	443.53	263.45	263.45	64.51	14.28	36.93	554	143.15	2147.25	180.08	2701.25	3.88
15	406.49	443.42	263.35	263.35	64.43	14.29	36.93	554	143.14	2147.10	180.07	2701.10	3.88
16	406.71	443.64	263.36	263.36	64.69	14.27	36.93	554	143.35	2150.25	180.28	2704.25	3.88
17	406.75	443.68	263.14	263.14	64.63	14.37	36.93	554	143.61	2154.15	180.54	2708.15	3.89
18	406.61	443.54	262.95	262.95	64.49	14.38	36.93	554	143.66	2154.90	180.59	2708.90	3.89
19	406.72	443.65	263.21	263.21	64.62	14.31	36.93	554	143.51	2152.65	180.44	2706.65	3.89
20	406.59	443.52	263.49	263.49	64.49	14.30	36.93	554	143.10	2146.50	180.03	2700.50	3.87
μ'_A (%)								0.00		2.63			0.11
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		2.87			1.90
μ'_E at 95% confi-dence level (%)								2.44		5.77			3.80

37. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 9.67$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.26	444.37	268.85	268.85	67.13	13.49	38.11	686	137.41	2473.38	38.11	3159.38	3.61
2	406.60	444.71	268.79	268.79	67.55	13.66	38.11	686	137.81	2480.58	38.11	3166.58	3.62
3	406.04	444.15	267.69	267.69	66.51	13.35	38.11	686	138.35	2490.30	38.11	3176.30	3.63
4	406.47	444.58	268.55	268.55	67.27	13.36	38.11	686	137.92	2482.56	38.11	3168.56	3.62
5	405.84	443.95	266.75	266.75	66.28	13.51	38.11	686	139.09	2503.62	38.11	3189.62	3.65
6	406.13	444.24	267.29	267.29	66.64	13.38	38.11	686	138.84	2499.12	38.11	3185.12	3.64
7	406.41	444.52	268.07	268.07	67.15	13.53	38.11	686	138.34	2490.12	38.11	3176.12	3.63
8	406.49	444.60	268.81	268.81	67.47	13.58	38.11	686	137.68	2478.24	38.11	3164.24	3.61
9	406.62	444.73	268.42	268.42	67.62	13.65	38.11	686	138.20	2487.60	38.11	3173.60	3.63
10	406.85	444.96	268.93	268.93	67.79	13.55	38.11	686	137.92	2482.56	38.11	3168.56	3.62
11	406.76	444.87	268.62	268.62	67.66	13.60	38.11	686	138.14	2486.52	38.11	3172.52	3.62
12	406.55	444.66	268.55	268.55	67.39	13.56	38.11	686	138.00	2484.00	38.11	3170.00	3.62
13	406.75	444.86	268.38	268.38	67.52	13.53	38.11	686	138.37	2490.66	38.11	3176.66	3.63
14	406.79	444.90	268.11	268.11	67.43	13.58	38.11	686	138.68	2496.24	38.11	3182.24	3.64
15	406.55	444.66	267.16	267.16	67.18	13.57	38.11	686	139.39	2509.02	38.11	3195.02	3.66
16	406.93	445.04	267.82	267.82	67.51	13.54	38.11	686	139.11	2503.98	38.11	3189.98	3.65
17	406.57	444.68	268.55	268.55	67.10	13.56	38.11	686	138.02	2484.36	38.11	3170.36	3.62
18	406.58	444.69	267.39	267.39	67.06	13.51	38.11	686	139.19	2505.42	38.11	3191.42	3.65
19	406.60	444.71	267.70	267.70	67.08	13.59	38.11	686	138.90	2500.20	38.11	3186.20	3.64
20	406.41	444.52	267.09	267.09	66.82	13.47	38.11	686	139.32	2507.76	38.11	3193.76	3.66
μ'_A (%)								0.00		4.77			0.18
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.91			1.91
μ'_E at 95% confi-dence level (%)								2.44		9.82			3.82

38. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 11.74$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	**Dependant variables (Calculated variables)**												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.16	445.48	269.49	269.49	68.37	12.78	39.32	806	136.67	2801.74	175.99	3607.74	3.48
2	406.09	445.41	269.45	269.45	68.34	12.77	39.32	806	136.64	2801.12	175.96	3607.12	3.48
3	406.05	445.37	270.13	270.13	68.34	12.61	39.32	806	135.92	2786.36	175.24	3592.36	3.46
4	405.98	445.30	269.28	269.28	68.19	12.87	39.32	806	136.70	2802.35	176.02	3608.35	3.48
5	406.15	445.47	269.42	269.42	68.36	12.89	39.32	806	136.73	2802.97	176.05	3608.97	3.48
6	405.99	445.31	269.10	269.10	68.20	12.65	39.32	806	136.89	2806.25	176.21	3612.25	3.48
7	406.05	445.37	269.25	269.25	68.30	12.78	39.32	806	136.80	2804.40	176.12	3610.40	3.48
8	405.93	445.25	269.35	269.35	68.13	12.80	39.32	806	136.58	2799.89	175.90	3605.89	3.47
9	406.37	445.69	269.24	269.24	68.50	12.68	39.32	806	137.13	2811.17	176.45	3617.17	3.49
10	406.07	445.39	269.18	269.18	68.27	12.75	39.32	806	136.89	2806.25	176.21	3612.25	3.48
11	406.28	445.60	268.93	268.93	68.41	12.68	39.32	806	137.35	2815.68	176.67	3621.68	3.49
12	405.67	444.99	269.16	269.16	67.96	12.62	39.32	806	136.51	2798.46	175.83	3604.46	3.47
13	406.09	445.41	269.51	269.51	68.44	12.62	39.32	806	136.58	2799.89	175.90	3605.89	3.47
14	406.07	445.39	269.07	269.07	68.23	12.71	39.32	806	137.00	2808.50	176.32	3614.50	3.48
15	406.27	445.59	269.24	269.24	68.42	12.64	39.32	806	137.03	2809.12	176.35	3615.12	3.49
16	406.10	445.42	269.00	269.00	68.40	12.77	39.32	806	137.10	2810.55	176.42	3616.55	3.49
17	406.08	445.40	268.99	268.99	68.28	12.62	39.32	806	137.09	2810.35	176.41	3616.35	3.49
18	406.16	445.48	269.33	269.33	68.32	12.59	39.32	806	136.83	2805.02	176.15	3611.02	3.48
19	406.30	445.62	269.15	269.15	68.55	12.56	39.32	806	137.15	2811.58	176.47	3617.58	3.49
20	406.02	445.34	269.33	269.33	68.21	12.66	39.32	806	136.69	2802.15	176.01	3608.15	3.48
μ'_A (%)								0.00		2.69			0.09
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		2.93			1.90
μ'_E at 95% confi-dence level (%)								2.44		5.83			3.80

39. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 17.36$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	406.31	448.81	272.89	272.89	72.51	12.14	42.50	1020	133.42	3202.08	175.92	4222.08	3.14
2	406.44	448.94	273.05	273.05	72.59	12.04	42.50	1020	133.39	3201.36	175.89	4221.36	3.14
3	406.30	448.80	272.96	272.96	72.48	12.14	42.50	1020	133.34	3200.16	175.84	4220.16	3.14
4	406.09	448.59	272.77	272.77	72.19	12.05	42.50	1020	133.32	3199.68	175.82	4219.68	3.14
5	406.42	448.92	272.93	272.93	72.62	12.17	42.50	1020	133.49	3203.76	175.99	4223.76	3.14
6	406.49	448.99	272.33	272.33	72.64	12.05	42.50	1020	134.16	3219.84	176.66	4239.84	3.16
7	406.35	448.85	272.65	272.65	72.45	12.10	42.50	1020	133.70	3208.80	176.20	4228.80	3.15
8	406.20	448.70	272.04	272.04	72.27	12.15	42.50	1020	134.16	3219.84	176.66	4239.84	3.16
9	405.68	448.18	272.37	272.37	71.77	12.03	42.50	1020	133.31	3199.44	175.81	4219.44	3.14
10	406.23	448.73	272.82	272.82	72.33	11.95	42.50	1020	133.41	3201.84	175.91	4221.84	3.14
11	406.20	448.70	272.43	272.43	72.27	11.94	42.50	1020	133.77	3210.48	176.27	4230.48	3.15
12	406.34	448.84	271.90	271.90	72.38	11.89	42.50	1020	134.44	3226.56	176.94	4246.56	3.16
13	406.01	448.51	272.19	272.19	72.12	11.89	42.50	1020	133.82	3211.68	176.32	4231.68	3.15
14	406.21	448.71	272.82	272.82	72.42	11.84	42.50	1020	133.39	3201.36	175.89	4221.36	3.14
15	406.52	449.02	272.54	272.54	72.65	11.99	42.50	1020	133.98	3215.52	176.48	4235.52	3.15
16	406.47	448.97	273.11	273.11	72.62	11.98	42.50	1020	133.36	3200.64	175.86	4220.64	3.14
17	406.35	448.85	273.14	273.14	72.51	11.98	42.50	1020	133.21	3197.04	175.71	4217.04	3.13
18	406.27	448.77	273.32	273.32	72.46	11.95	42.50	1020	132.95	3190.80	175.45	4210.80	3.13
19	406.43	448.93	273.50	273.50	72.62	12.09	42.50	1020	132.93	3190.32	175.43	4210.32	3.13
20	406.34	448.84	272.51	272.51	72.52	11.98	42.50	1020	133.83	3211.92	176.33	4231.92	3.15
μ'_A (%)								0.00		3.82			0.12
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.99			1.90
μ'_E at 95% confi-dence level (%)								2.44		4.98			3.80

40. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.857$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.93	451.28	275.24	275.24	75.65	11.53	45.35	1179	130.69	3397.94	176.04	4576.94	2.88
2	405.68	451.03	275.60	275.60	75.43	11.63	45.35	1179	130.08	3382.08	175.43	4561.08	2.87
3	405.81	451.16	275.63	275.63	75.56	11.48	45.35	1179	130.18	3384.68	175.53	4563.68	2.87
4	405.91	451.26	275.33	275.33	75.70	11.56	45.35	1179	130.58	3395.08	175.93	4574.08	2.88
5	405.63	450.98	275.72	275.72	75.43	11.60	45.35	1179	129.91	3377.66	175.26	4556.66	2.86
6	406.10	451.45	275.55	275.55	75.86	11.44	45.35	1179	130.55	3394.30	175.90	4573.30	2.88
7	406.17	451.52	275.54	275.54	75.88	11.39	45.35	1179	130.63	3396.38	175.98	4575.38	2.88
8	405.94	451.29	275.72	275.72	75.66	11.48	45.35	1179	130.22	3385.72	175.57	4564.72	2.87
9	405.64	450.99	275.94	275.94	75.50	11.37	45.35	1179	129.70	3372.20	175.05	4551.20	2.86
10	405.93	451.28	275.66	275.66	75.68	11.55	45.35	1179	130.27	3387.02	175.62	4566.02	2.87
11	405.86	451.21	274.97	274.97	75.61	11.40	45.35	1179	130.89	3403.14	176.24	4582.14	2.89
12	405.79	451.14	276.29	276.29	75.59	11.47	45.35	1179	129.50	3367.00	174.85	4546.00	2.86
13	406.09	451.44	275.50	275.50	75.80	11.47	45.35	1179	130.59	3395.34	175.94	4574.34	2.88
14	405.90	451.25	275.20	275.20	75.73	11.49	45.35	1179	130.70	3398.20	176.05	4577.20	2.88
15	405.84	451.19	275.46	275.46	75.63	11.43	45.35	1179	130.38	3389.88	175.73	4568.88	2.88
16	405.96	451.31	275.27	275.27	75.65	11.55	45.35	1179	130.69	3397.94	176.04	4576.94	2.88
17	405.93	451.28	275.29	275.29	75.80	11.43	45.35	1179	130.64	3396.64	175.99	4575.64	2.88
18	405.83	451.18	275.81	275.81	75.67	11.47	45.35	1179	130.02	3380.52	175.37	4559.52	2.87
19	406.04	451.39	275.82	275.82	75.80	11.49	45.35	1179	130.22	3385.72	175.57	4564.72	2.87
20	405.80	451.15	275.34	275.34	75.63	11.55	45.35	1179	130.46	3391.96	175.81	4570.96	2.88
μ'_A (%)								0.00		3.67			0.11
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.85			1.90
μ'_E at 95% confidence level (%)								2.44		7.70			3.80

41. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.07	439.47	257.39	257.39	58.97	13.07	34.40	516	147.68	2215.20	182.08	2731.20	4.29
2	405.02	439.42	257.23	257.23	58.85	13.03	34.40	516	147.79	2216.85	182.19	2732.85	4.30
3	404.88	439.28	257.47	257.47	58.70	13.19	34.40	516	147.41	2211.15	181.81	2727.15	4.29
4	405.16	439.56	257.32	257.32	58.98	13.22	34.40	516	147.84	2217.60	182.24	2733.60	4.30
5	405.3	439.70	257.38	257.38	59.08	13.15	34.40	516	147.92	2218.80	182.32	2734.80	4.30
6	404.94	439.34	257.29	257.29	58.71	13.01	34.40	516	147.65	2214.75	182.05	2730.75	4.29
7	405.18	439.58	257.33	257.33	58.97	13.03	34.40	516	147.85	2217.75	182.25	2733.75	4.30
8	405.33	439.73	257.51	257.51	59.19	13.30	34.40	516	147.82	2217.30	182.22	2733.30	4.30
9	405.22	439.62	258.14	258.14	59.30	13.33	34.40	516	147.08	2206.20	181.48	2722.20	4.28
10	405.43	439.83	258.65	258.65	59.58	13.34	34.40	516	146.78	2201.70	181.18	2717.70	4.27
11	405.41	439.81	258.11	258.11	59.58	13.25	34.40	516	147.30	2209.50	181.70	2725.50	4.28
12	405.77	440.17	259.12	259.12	59.95	13.29	34.40	516	146.65	2199.75	181.05	2715.75	4.26
13	405.51	439.91	257.28	257.28	59.45	13.28	34.40	516	148.23	2223.45	182.63	2739.45	4.31
14	405.3	439.70	257.38	257.38	59.17	13.32	34.40	516	147.92	2218.80	182.32	2734.80	4.30
15	405.46	439.86	256.48	256.48	59.20	13.33	34.40	516	148.98	2234.70	183.38	2750.70	4.33
16	405.72	440.12	257.28	257.28	59.44	13.21	34.40	516	148.44	2226.60	182.84	2742.60	4.32
17	405.18	439.58	258.14	258.14	59.30	13.28	34.40	516	147.04	2205.60	181.44	2721.60	4.27
18	405.28	439.68	258.73	258.73	59.37	13.23	34.40	516	146.55	2198.25	180.95	2714.25	4.26
19	405.53	439.93	257.83	257.83	59.55	13.15	34.40	516	147.70	2215.50	182.10	2731.50	4.29
20	405.37	439.77	257.65	257.65	59.25	13.12	34.40	516	147.72	2215.80	182.12	2731.80	4.29
μ'_A (%)								0.00		4.27			0.19
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		4.42			1.91
μ'_E at 95% confi-dence level (%)								2.44		8.84			3.82

42. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 9.67$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.40	441.69	259.24	259.24	61.50	12.44	36.29	635	146.16	2557.80	182.45	3192.80	4.03
2	405.67	441.96	258.73	258.73	61.81	12.58	36.29	635	146.94	2571.45	183.23	3206.45	4.05
3	405.64	441.93	259.17	259.17	61.78	12.51	36.29	635	146.47	2563.23	182.76	3198.23	4.04
4	405.50	441.79	259.32	259.32	61.68	12.53	36.29	635	146.18	2558.15	182.47	3193.15	4.03
5	405.36	441.65	259.35	259.35	61.53	12.44	36.29	635	146.01	2555.18	182.30	3190.18	4.02
6	405.53	441.82	260.52	260.52	61.74	12.56	36.29	635	145.01	2537.68	181.30	3172.68	4.00
7	405.61	441.90	260.01	260.01	61.82	12.45	36.29	635	145.60	2548.00	181.89	3183.00	4.01
8	405.62	441.91	260.20	260.20	61.81	12.58	36.29	635	145.42	2544.85	181.71	3179.85	4.01
9	405.33	441.62	259.89	259.89	61.57	12.39	36.29	635	145.44	2545.20	181.73	3180.20	4.01
10	405.69	441.98	259.63	259.63	61.91	12.52	36.29	635	146.06	2556.05	182.35	3191.05	4.03
11	405.69	441.98	259.60	259.60	61.93	12.57	36.29	635	146.09	2556.58	182.38	3191.58	4.03
12	405.50	441.79	259.71	259.71	61.72	12.51	36.29	635	145.79	2551.33	182.08	3186.33	4.02
13	405.61	441.90	259.32	259.32	61.85	12.38	36.29	635	146.29	2560.08	182.58	3195.08	4.03
14	405.55	441.84	259.93	259.93	61.83	12.53	36.29	635	145.62	2548.35	181.91	3183.35	4.01
15	405.66	441.95	259.53	259.53	61.92	12.41	36.29	635	146.13	2557.28	182.42	3192.28	4.03
16	405.78	442.07	259.44	259.44	61.94	12.54	36.29	635	146.34	2560.95	182.63	3195.95	4.03
17	405.74	442.03	259.65	259.65	61.99	12.49	36.29	635	146.09	2556.58	182.38	3191.58	4.03
18	405.58	441.87	259.77	259.77	61.84	12.52	36.29	635	145.81	2551.68	182.10	3186.68	4.02
19	405.75	442.04	259.93	259.93	62.02	12.54	36.29	635	145.82	2551.85	182.11	3186.85	4.02
20	405.42	441.71	260.13	260.13	61.76	12.56	36.29	635	145.29	2542.58	181.58	3177.58	4.00
μ'_A (%)								0.00		3.48			0.14
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.67			1.91
μ'_E at 95% confi-dence level (%)								2.44		7.34			3.82

43. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 11.74$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.73	444.43	261.41	261.41	65.06	11.79	38.70	774	144.32	2886.40	183.02	3660.40	3.73
2	406.05	444.75	262.21	262.21	65.38	11.66	38.70	774	143.84	2876.80	182.54	3650.80	3.72
3	405.76	444.46	262.00	262.00	65.12	11.74	38.70	774	143.76	2875.20	182.46	3649.20	3.71
4	405.64	444.34	261.68	261.68	64.98	11.63	38.70	774	143.96	2879.20	182.66	3653.20	3.72
5	405.82	444.52	261.83	261.83	65.20	11.76	38.70	774	143.99	2879.80	182.69	3653.80	3.72
6	405.90	444.60	261.91	261.91	65.27	11.67	38.70	774	143.99	2879.80	182.69	3653.80	3.72
7	405.83	444.53	262.02	262.02	65.14	11.66	38.70	774	143.81	2876.20	182.51	3650.20	3.72
8	405.79	444.49	261.52	261.52	65.14	11.67	38.70	774	144.27	2885.40	182.97	3659.40	3.73
9	405.71	444.41	261.65	261.65	65.08	11.82	38.70	774	144.06	2881.20	182.76	3655.20	3.72
10	406.00	444.70	261.82	261.82	65.33	11.70	38.70	774	144.18	2883.60	182.88	3657.60	3.73
11	405.85	444.55	261.59	261.59	65.11	11.76	38.70	774	144.26	2885.20	182.96	3659.20	3.73
12	405.78	444.48	261.70	261.70	65.14	11.62	38.70	774	144.08	2881.60	182.78	3655.60	3.72
13	405.85	444.55	261.95	261.95	65.22	11.68	38.70	774	143.90	2878.00	182.60	3652.00	3.72
14	405.52	444.22	261.92	261.92	64.90	11.82	38.70	774	143.60	2872.00	182.30	3646.00	3.71
15	406.01	444.71	261.38	261.38	65.31	11.69	38.70	774	144.63	2892.60	183.33	3666.60	3.74
16	405.86	444.56	261.91	261.91	65.18	11.84	38.70	774	143.95	2879.00	182.65	3653.00	3.72
17	405.73	444.43	261.65	261.65	65.06	11.82	38.70	774	144.08	2881.60	182.78	3655.60	3.72
18	405.80	444.50	261.76	261.76	65.16	11.74	38.70	774	144.04	2880.80	182.74	3654.80	3.72
19	405.69	444.39	261.70	261.70	65.08	11.79	38.70	774	143.99	2879.80	182.69	3653.80	3.72
20	405.91	444.61	261.64	261.64	65.18	11.78	38.70	774	144.27	2885.40	182.97	3659.40	3.73
μ'_A (%)								0.00		1.92			0.07
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		2.24			1.90
μ'_E at 95% confi-dence level (%)								2.44		4.48			3.80

44. $\phi_{a,i,e} = 60\%$, $\frac{\dot{V}_e N_c^{\ 2}}{v_{afc}^{\ 3}} = 17.36$ and $\frac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)												
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.44	447.31	265.56	265.56	68.95	11.12	41.87	984	139.88	3287.18	181.75	4271.18	3.34
2	405.39	447.26	264.99	264.99	68.84	11.03	41.87	984	140.40	3299.40	182.27	4283.40	3.35
3	405.17	447.04	265.82	265.82	68.47	11.15	41.87	984	139.35	3274.73	181.22	4258.73	3.33
4	405.35	447.22	265.28	265.28	68.79	11.11	41.87	984	140.07	3291.65	181.94	4275.65	3.35
5	405.25	447.12	265.47	265.47	68.84	11.05	41.87	984	139.78	3284.83	181.65	4268.83	3.34
6	405.45	447.32	265.60	265.60	68.85	11.10	41.87	984	139.85	3286.48	181.72	4270.48	3.34
7	405.31	447.18	264.64	264.64	68.69	10.94	41.87	984	140.67	3305.75	182.54	4289.75	3.36
8	404.86	446.73	264.97	264.97	68.24	10.94	41.87	984	139.89	3287.42	181.76	4271.42	3.34
9	405.26	447.13	264.78	264.78	68.86	10.93	41.87	984	140.48	3301.28	182.35	4285.28	3.35
10	405.48	447.35	266.66	266.66	69.19	11.10	41.87	984	138.82	3262.27	180.69	4246.27	3.32
11	405.45	447.32	267.15	267.15	69.16	11.11	41.87	984	138.30	3250.05	180.17	4234.05	3.30
12	405.50	447.37	266.61	266.61	69.18	11.03	41.87	984	138.89	3263.92	180.76	4247.92	3.32
13	406.04	447.91	265.86	265.86	69.63	11.20	41.87	984	140.18	3294.23	182.05	4278.23	3.35
14	405.68	447.55	266.06	266.06	69.28	11.03	41.87	984	139.62	3281.07	181.49	4265.07	3.33
15	405.60	447.47	266.29	266.29	69.18	11.02	41.87	984	139.31	3273.79	181.18	4257.79	3.33
16	405.23	447.10	265.85	265.85	68.76	10.95	41.87	984	139.38	3275.43	181.25	4259.43	3.33
17	405.22	447.09	266.63	266.63	68.70	11.01	41.87	984	138.59	3256.87	180.46	4240.87	3.31
18	405.55	447.42	265.59	265.59	68.96	10.98	41.87	984	139.96	3289.06	181.83	4273.06	3.34
19	405.24	447.11	266.16	266.16	68.74	11.04	41.87	984	139.08	3268.38	180.95	4252.38	3.32
20	405.31	447.18	264.98	264.98	68.52	10.96	41.87	984	140.33	3297.76	182.20	4281.76	3.35
μ'_A (%)								0.00		6.06			0.19
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		6.17			1.91
μ'_E at 95% confi-dence level (%)								2.44		12.34			3.82

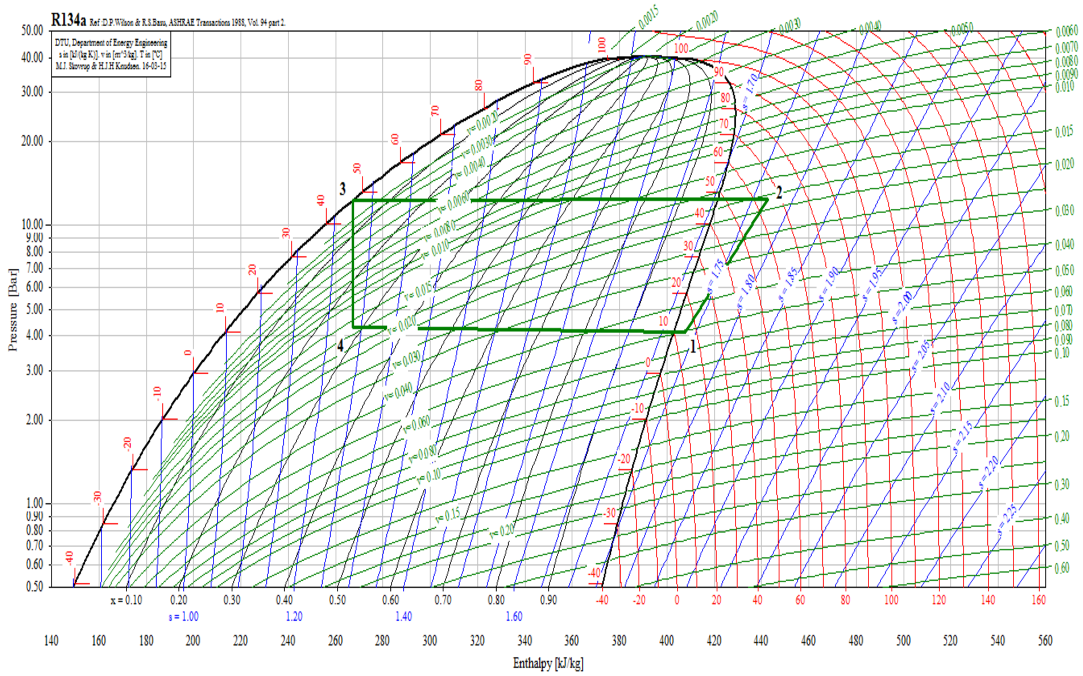
45. $\phi_{a,i,e} = 60\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 1.000$

No	Dependant variables (Calculated variables)													
	h_1	h_2	h_3	h_4	T_2	$T_{a,o,e}$	w_c	W_c	q_e	Q_e	q_{cd}	Q_{cd}	COP
1	405.04	450.80	267.65	267.65	72.72	10.38	45.76	1144	137.39	3434.75	183.15	4578.75	3.00
2	404.89	450.65	268.24	268.24	72.50	10.35	45.76	1144	136.65	3416.25	182.41	4560.25	2.99
3	405.04	450.80	266.60	266.60	72.66	10.37	45.76	1144	138.44	3461.00	184.20	4605.00	3.03
4	404.95	450.71	267.67	267.67	72.64	10.30	45.76	1144	137.28	3432.00	183.04	4576.00	3.00
5	404.88	450.64	267.96	267.96	72.63	10.25	45.76	1144	136.92	3423.00	182.68	4567.00	2.99
6	404.75	450.51	267.72	267.72	72.51	10.23	45.76	1144	137.03	3425.75	182.79	4569.75	2.99
7	405.05	450.81	268.13	268.13	72.77	10.30	45.76	1144	136.92	3423.00	182.68	4567.00	2.99
8	405.04	450.80	267.90	267.90	72.73	10.14	45.76	1144	137.14	3428.50	182.90	4572.50	3.00
9	404.94	450.70	267.59	267.59	72.63	10.29	45.76	1144	137.35	3433.75	183.11	4577.75	3.00
10	405.02	450.78	267.82	267.82	72.64	10.28	45.76	1144	137.20	3430.00	182.96	4574.00	3.00
11	404.82	450.58	267.36	267.36	72.47	10.26	45.76	1144	137.46	3436.50	183.22	4580.50	3.00
12	404.90	450.66	267.79	267.79	72.50	10.25	45.76	1144	137.11	3427.75	182.87	4571.75	3.00
13	404.88	450.64	267.21	267.21	72.43	10.11	45.76	1144	137.67	3441.75	183.43	4585.75	3.01
14	404.94	450.70	267.24	267.24	72.50	10.19	45.76	1144	137.70	3442.50	183.46	4586.50	3.01
15	404.88	450.64	267.50	267.50	72.45	10.17	45.76	1144	137.38	3434.50	183.14	4578.50	3.00
16	404.91	450.67	267.53	267.53	72.49	10.27	45.76	1144	137.38	3434.50	183.14	4578.50	3.00
17	404.87	450.63	267.47	267.47	72.47	10.32	45.76	1144	137.40	3435.00	183.16	4579.00	3.00
18	404.91	450.67	267.55	267.55	72.49	10.32	45.76	1144	137.36	3434.00	183.12	4578.00	3.00
19	404.75	450.51	267.44	267.44	72.30	10.37	45.76	1144	137.31	3432.75	183.07	4576.75	3.00
20	404.89	450.65	267.04	267.04	72.50	10.28	45.76	1144	137.85	3446.25	183.61	4590.25	3.01
μ'_A (%)								0.00		3.65			0.11
μ'_B (%)								1.22		1.15			1.90
μ'_C (%)								1.22		3.83			1.90
μ'_E at 95% confi-dence level (%)								2.44		7.66			3.80

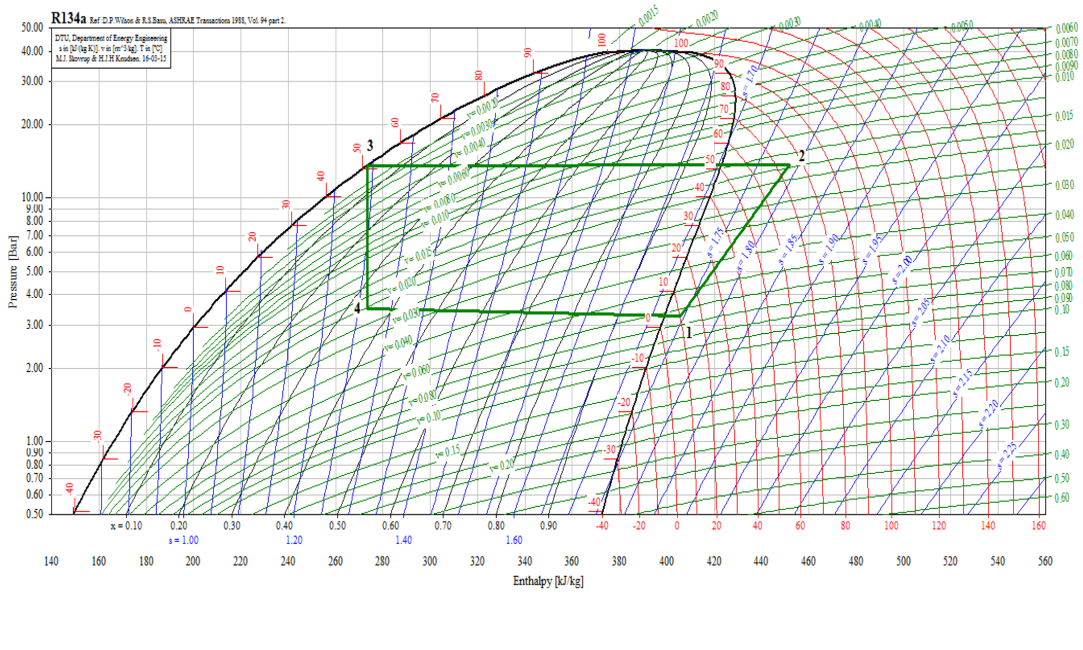
APPENDIX K

Sample *p-h* Diagram

1. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 4.96$, $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$ and sampling no. 10



2. $\phi_{a,i,e} = 40\%$, $\dfrac{\dot{V}_e N_c^{\,2}}{v_{afc}^{\,3}} = 22.92$ and $\dfrac{T_{a,i,e}}{T_{a,i,cd}} = 0.750$ and sampling no. 10



APPENDIX L

Sample of Matlab Program to Solve the Five Simultaneous Non-liner Equations

```
% THIS IS A PROGRAM TO SOLVE THE FIVE SIMULTANEOUS NONLINEAR EQUATIONS.
% IT SEARCHES THE WHOLE RANGE OF Te AND Tcd PROVIDED BY THE USER.
% VARIABLES OF Nc AND Qe ARE GIVEN.

clear all
clc
close all

% FIRST - SEARCH WHOLE DOMAIN STAGE
% =================================
Nc = 3453;
Qe = 2.779;
RangeTcd = [30 70];
RangeTe = [2 15];
delta = 0.05;
Accuracy = 0.001;

ii = 1; % counter
Fmin1 = 0.01; Fmin2 = 0.01;% initial value
for Tcd = RangeTcd(1):delta:RangeTcd(2)
    for Te = RangeTe(1):delta:RangeTe(2)
        Wc = 6.3230*Nc^0.1599*Tcd^0.2402*Te^(-0.1630);
        mr = 1.7042*10^(-8)*Nc^0.7171*Tcd^1.7281*Te^0.5834;
        %Qe = mr*(716.4439*Nc^(-0.0192)*Tcd^(-0.3909)*Te^(0.0089));
        F1  =  mr*(716.4439*Nc^(-0.0192)*Tcd^(-0.3909)*Te^(0.0089))  -
Qe;
        Qe1 = mr*(716.4439*Nc^(-0.0192)*Tcd^(-0.3909)*Te^(0.0089));
        Qcd1 = 426.4947*Nc^0.0117*Tcd^(-0.2200)*Te^(-0.0500);
        Qcd2 = Wc + Qe1/mr;
        F2 = Qcd1 - Qcd2;

        if abs(F2)< Fmin2 && abs(F1)< Fmin1
            Fmin2 = abs(F2);
            Fmin1 = abs(F1);
            TCD = Tcd;
            TE = Te;
        end
    end
end
disp('First Round')
TCD
TE
%% SECOND - REFINE STAGE
%  =====================
del = delta*6; % From previous delta
RangeTcd = [(TCD - del) (TCD + del)];
RangeTe = [(TE - del) (TE + del)];
delta = 0.001;
Accuracy = 0.0001;

ii = 1; % counter
Fmin1 = 0.01; Fmin2 = 0.01;% initial value
for Tcd = RangeTcd(1):delta:RangeTcd(2)
    for Te = RangeTe(1):delta:RangeTe(2)
        Wc = 6.3230*Nc^0.1599*Tcd^0.2402*Te^(-0.1630);
```

```
        mr = 1.7042*10^(-8)*Nc^0.7171*Tcd^1.7281*Te^0.5834;
        %Qe = mr*(716.4439*Nc^(-0.0192)*Tcd^(-0.3909)*Te^(0.0089));
        F1  =  mr*(716.4439*Nc^(-0.0192)*Tcd^(-0.3909)*Te^(0.0089))  -
Qe;
        Qe1 = mr*(716.4439*Nc^(-0.0192)*Tcd^(-0.3909)*Te^(0.0089));
        Qcd1 = 426.4947*Nc^0.0117*Tcd^(-0.2200)*Te^(-0.0500);
        Qcd2 = Wc + Qe1/mr;
        F2 = Qcd1 - Qcd2;

        if abs(F2)< Fmin2 && abs(F1)< Fmin1
            Fmin2 = abs(F2);
            Fmin1 = abs(F1);
            TCD = Tcd;
            TE = Te;
        end
    end
end
disp('Second Round')
TCD
TE
% CHECK VALUES
Tcd = TCD; Te = TE;
Wc = 6.3230*Nc^0.1599*Tcd^0.2402*Te^(-0.1630)
mr = 1.7042*10^(-8)*Nc^0.7171*Tcd^1.7281*Te^0.5834
Qe1 = mr*(716.4439*Nc^(-0.0192)*Tcd^(-0.3909)*Te^(0.0089))
Qcd1 = 426.4947*Nc^0.0117*Tcd^(-0.2200)*Te^(-0.0500)
Qcd2 = Wc + Qe1/mr
```

APPENDIX M
List of Publications

a. Journals

1. **Sukri, M. F.**, Musa, M. N., Sumeru, K and Sodiya, S. (2014). A Simple Method on Equipment Selection Methodology of Vapor Compression Refrigerant Electric Vehicle Air-Conditioning System. *Journal of Advanced Manufacturing Technology*. 8(2), 39- 49.
2. **Sukri, M. F.**, Musa M. N., Senawi, M. Y. and Nasution, H. (2015). Achieving a Better Energy-Efficient Automotive Air-Conditioning System: A Review of Potential Technologies and Strategies for Vapor Compression Refrigeration Cycle. *Energy Efficiency*. 8, 1201–1229 **(Indexed in ISI WoS, 2014 Impact Factor: 1.060, Q3)**.
3. **Sukri, M. F.**, Musa M. N. & Senawi, M. Y. and Nasution, H. (2016). Modeling and Parametric Study of Cooling Loads Characteristics for Automotive Air-Conditioning System. *Applied Mechanics and Materials.* 819, 189-201.
4. **Sukri, M. F.**, Musa M. N., Sumeru, K., Senawi, M. Y. and Nasution, H. (2016). Simulation of Vehicle Cooling Loads at Different Orientations. *Heat Transfer Research*. 47(4), 343-357 **(Indexed in ISI WoS, 2015 Impact Factor: 0.930, Q3)**.
5. **Sukri, M. F.** and Musa M. N. (2016). A review on an automobile air conditioning system: current thermal and energy performance studies, approaches and findings. *Renewable and Sustainable Energy Reviews*. ***Status: Submitted to Journal*** **(Indexed in ISI WoS, 2015 Impact Factor: 6.798, Q1)**.

b. Conferences

1. **Sukri, M. F.**, Musa, M. N., Senawi, M. Y. and Nasution, H. (2014). Modeling and Parametric Study of Cooling Loads Characteristics for Automotive Air-Conditioning System. *7th IMAT (International Meeting of Advances in Thermofluids)*. 26 -27 November. Kuala Lumpur, Malaysia.
2. **Sukri, M. F.**, Musa, M. N., Senawi, M. Y. and Nasution, H. (2015) Experimental Investigation of an Automobile Air-Conditioning System using Integrated Brushless Direct Current Motor Rotary Compressor, *3rd International Conference on Mechanical Engineering Research 2015 (3rd ICMER2015)*. 18 – 19 August. Kuantan, Pahang.