Study on Energy Consumption Pattern Changes in Domestic Area and Role of Natural Refrigerants based Solar Air-Conditioners in Energy System

58

THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (ENGINEERING)
of
JADAVPUR UNIVERSITY

by

Rakesh Naskar

(Ph. D. ENROLMENT NUMBER: D-7/ISLM/94/18)

SCHOOL OF ENERGY STUDIES
JADAVPUR UNIVERSITY
KOLKATA-700032
INDIA

September 2023

INDEX NO: D-7/ISLM/94/18

1. Title of Thesis:

"Study on Energy Consumption Pattern Changes in Domestic Area and Role of Natural Refrigerants based Solar Air-Conditioners in Energy System"

2. Name, Designation, and Institution of the Supervisor:

Dr. Ratan Mandal
Professor and Director, School of Energy Studies,
Jadavpur University,
Kolkata-700032,
India

3. LIST OF PUBLICATIONS(JOURNAL):

A. Naskar R, Ghosh A & Mandal R: Design & New Development of Solar Air Conditioner. ***International Journal of Scientific Research in Multidisciplinary Studies (IJSRMS)***, 2018; 4(6):19-23. **ISSN No.: 2454-9312. (UGC Care listed Journal during publication time).**

B. Naskar R, Ghosh A & Mandal R: Advancement of Solar Refrigeration Technology and its Impact in Society**. *Science And Culture*,** 2019; 85(9–10): 323-330**, ISSN No.: 0036-8156. (SCI Indexed).**

C. Naskar R & Mandal R, "Energy Optimization of Natural Refrigerant-based Air-Conditioning System for a Sustainable Environment on the Basis of the Major Five Climatic Zones in India", ***Industrial Engineering Journal***. 2023; 52(5): 2. **ISSN: 0970-2555**. (**UGC CARE Group-1**).

D. Naskar R & Mandal R: Studies and Analysis on Feasibility of Two Different Natural Refrigerants Based Solar Powered Air-Conditioning System of One Ton Capacity. ***Journal of Nanomaterials & Energy***. *2023;* **(SCOPUS Indexed) Communicated***

E. Naskar R & Mandal R, "A Competitive study of all Natural refrigerants Implementation on 1.5-ton Domestic Air Conditioners using cool pack software", Industrial Engineering Journal. 2023; **Industrial Engineering Journal. September, 2023; 52(9): 1. ISSN: 0970-2555. (UGC CARE Group-1).**

4. LIST OF PATENTS: NIL

5. List of Presentation in National/ International/ Conferences

LIST OF PUBLICATIONS (Conference)

A. Naskar R, Ghosh A & Mandal R**:** Some Studies on energy conservation by use of Natural Refrigerants in Solar Thermal & Photovoltaic powered Air-conditioning and Refrigeration Systems. ***Proceedings of International Conference on Sustainable Water Resources Management under Changed Climate***. **2020.**

Title of the book: Water Resources: Current and Future Challenges and Research, Directions. ISBN No.: 978-8-19-410094-2. (Book Chapter)

B. Naskar R, Ghosh A & Mandal R**:** Integration Analysis on Impact of Using Natural Refrigerants in Solar powered Air-conditioning and Refrigeration Systems: An Overview**.** Proceedings of 1st **National Conference** on Innovations in Mechanical Engineering. December **2021**, Heritage Institute of Technology, Kolkata-700107, West Bengal, India.

STATEMENT OF ORIGINALITY

I, **Rakesh Naskar (Enrolment Number: D-7/ISLM/94/18)** registered on 27th December 2018, do hereby declare that this thesis entitled **"Study on Energy Consumption Pattern Changes in Domestic Area and Role of Natural Refrigerants based Solar Air-Conditioners in Energy System"**, includes a literature review and original research conducted by the undersigned candidate for a Ph.D. degree.

The collection and presentation of all the data included in this thesis complied with ethical and recognized academic norms. I attest that, in accordance with these guidelines and conduct, I have accurately referenced and made reference to any materials and conclusions that are not unique to this work.

Additionally, I certify that I reviewed this thesis in accordance with the "policy on anti-Plagiarism, Jadavpur University, 2019," and the **iThenticate software** found **05% of similarity**.

Rakesh Naskar.

Signature of Candidate:

Date: 27/09/2023

Certified By

Supervisor:

Ratan Mandal 27/9/2023

Director
School of Energy Studies
Jadavpur University
Kolkata -700032

Prof. (Dr.) Ratan Mandal
Professor & Director
School of Energy Studies
Jadavpur University, Kolkata-32

CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis entitled "**Study on Energy Consumption Pattern Changes in Domestic Area and Role of Natural Refrigerants based Solar Air-Conditioners in Energy System**", submitted by **Mr. Rakesh Naskar (Enrolment Number: D-7/ISLM/94/18)**, who registered his name on December 27, 2018, for the Ph.D. (Engineering) degree offered by Jadavpur University, is entirely based on his own work done under Prof. Ratan Mandal's supervision, and neither his thesis nor any portion of it has ever been submitted elsewhere for a degree, diploma, or other academic award.

Ratan Mandal ---------------------------------- Signature of the Supervisor
&
28/9/2023 ---------------------------------- Date with Official Seal

Director
School of Energy Studies
Jadavpur University
Kolkata -700032

DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby certify that the undersigned candidate completed his doctoral studies in energy science and technology during the academic year 2023–2024, and that this thesis contains both an analysis of the literature and original research. The sources from which the data in this document were gathered and presented all followed the standards of academic integrity.

I further affirm that I have correctly referenced and cited all data and conclusions that are not original to my work in accordance with these rules and conduct.

NAME: RAKESH NASKAR

Enrolment Number: D-7/ISLM/94/18

TITLE:

Study on Energy Consumption Pattern Changes in Domestic Area and Role of Natural Refrigerants based Solar Air-Conditioners in Energy System

SIGNATURE: Rakesh Naskar

DATE: 27/09/2023

ACKNOWLEDGEMENT

I must first express my gratitude to **Dr. Ratan Mandal**, my **research supervisor**, without whose assistance and diligent participation in each step of these trials, it wouldn't have been possible to finish this research work. I want to express my gratitude to you for your help and patience over the past around five years.

I express my sincere thanks and regards to **Prof. Tushar Jash** for their continuous encouragement, advice and help in this work.

I would like to remember and thank to research scholars of School of Energy Studies, who advise me in different ways to approach a research problem and possible methods and solutions.

I want to honour the **whole personnel at the School of Energy Studies department** and express my thanks to all of them.

A **RUSA** Project helps me a lot during my PhD thesis work providing the financial support and I would like to acknowledge and appreciate the RUSA cell at Jadavpur University for providing funding for the construction of the experimental facilities there. Some of these tasks cannot be done without this unit.

Additionally, I want to say thank you to **Dr. Asit Ghosh**, without whose supportive acceleration and contribution at first stage, this work would not have been possible. I want to express my gratitude to you for your help and patience over the past around five years.

I also like to thank my wife, **Mrs. Sonia Naskar**, for her unwavering mental support over these years, without which I could not have completed this thesis. I want to thank you for all of your steadfast support over the past four to five years and for being an inspiration to me.

Last but not least, I want to thank my parents and grandparents for educating me in both the arts and sciences, encouraging me to follow my hobbies, and believing in me despite my complaints and disappointments.

Rakesh Naskar
27/09/2023

Mr. Rakesh Naskar

Dedicated

To

My Parents& Guides

&

Wife
&
My beloved Daughters

LIST OF FIGURES AND TABLES

FIGURES

LIST OF TABLES

TABLES

NOMENCLATURE

Roman:	
h_{lv}	Latent heat of vaporization, (J kg^{-1})
c_r	Specific heat ratio ($=c_{p,1}/c_{p,3}$), dimensionless
c_v	Specific heat at constant volume, (J kg-1 K-1)
A	Area, m^2
c_p	Specific heat at constant pressure, (J kg^{-1} K^{-1})
h	Specific enthalpy, (J kg^{-1})
k	Isentropic exponent, dimensionless
L	Length, m
M	Mass, kg
MW	Molecular weight, (kg $kmol^{-1}$)
N	Number of moles, (mol)
p	Pressure, Pa
S	Density ratio ($=\rho_v/\rho_1$), dimensionless
t	Temperature, K
v	Specific volume, (m^3 kg^{-1})
V	Volume, m^3
x	Vapor quality, dimensionless
y	Void fraction, dimensionless
$\langle y \rangle$	Mean void fraction, dimensionless
Greek:	
A	Isothermal compressibility, (Pa^{-1})
b	Volumetric expansivity, K^{-1}
c	Mole fraction of refrigerant, dimensionless
f	Additional refrigerating effect, dimensionless
ε	Heat exchanger effectiveness, dimensionless
q	Refrigerant expansion factor, dimensionless
r	Refrigerant density, kg m^{-3}
Superscripts:	
COP	coefficient of performance
ex	exergy (kJ kg^{-1})
Ex	exergy rate of fluid (kW)
h	specific enthalpy (kJ kg^{-1})
ṁ	mass flow rate (kg s^{-1})
P	pressure (MPa)
q_{ev}	volumetric refrigeration capacity (kJ m^{-3})

Qc	heating capacity per unit of mass (kJ kg^{-1})
Qe	refrigerating capacity per unit of mass (kJ kg^{-1})
s	entropy (kJ kg^{-1} k^{-1})
t	refrigerant temperature (^{0}C)
T_0	the environmental temperature (K)
v	specific volume (m^3 kg^{-1})
Wc	specific work of compressor (kJ kg^{-1})
x	quality
Greeks' symbols:	
η_{ex}	exergetic efficiency
η_x	isentropic efficiency of compressor
γ_c	pressure ratio of compressor
Ø	refrigeration capacity ratio
Subscripts:	
a	air
ct	capillary tube
com	compressor
con	condenser
d	exergy destruction
eva	evaporator
f	freezer evaporator
r	refrigerator evaporator
s	sub-cooler
t	time
E	voltage (V)
h	specific enthalpy (J kg^{-1})
H	heat transfer coefficient (W m^{-2} K^{-1})
I	electrical current (A)
j	complex number indicator (–)
m	mass (kg)
$\dot{m}$	actual mass flow rate (kg s^{-1})
V	volume (m^3)
T	temperature (K)
Greek letters:	
β	temperature coefficient (K^{-1})
Δ	difference (–)
η_v	volumetric efficiency (–)
η_s	isentropic efficiency (–)
η_{ele}	electrical motor efficiency (–)
ρ	specific mass (kg m^{-3})

τ	torque (N m)
ϕ	gas mixing factor (–)
ω	compressor speed (rad s^{-1})
Abbreviations	
AHRI	air conditioning, heating, and refrigeration institute
ASHRAE	American society of heating, refrigerating, and air conditioning engineers
COP	coefficient of performance
HFC	hydro fluorocarbon
HVAC	heating, ventilation, and air-conditioning
WMO	world meteorological organization
ATEX	Atmospheres Exposable
ACHP	Air Conditioner and Heat Pump
HFC	Hydro fluorocarbon
ACL	Allowable Charge Limit
CR	compression ratio
HC	Hydrocarbon
HC	hydrocarbon
ODP	Ozone Depletion potential
GWP	global warming potential
ISO	International Organisation for Standardisation
LFL	Lower Flammability Limit
IEC	International Electro technical Commission
HSE	Health and Safety Executive (UK governmental safety regulator)
UCL	Upper Charge Limit
NSB	National Standardisation Body
TEAP	Technical and Economic Assessment Panel
IPCC	The Intergovernmental Panel on Climate Change

PREFACE

The present thesis entitled **"Study on Energy Consumption Pattern Changes in Domestic Area and Role of Natural Refrigerants based Solar Air-Conditioners in Energy System"** is submitted to the Faculty of Interdisciplinary Studies Law and Management (FISLM) for consideration of the degree of Doctor of Philosophy, under Faculty of Engineering and Technology, Jadavpur University, Kolkata. The research work presented here was carried out under supervision of Prof. Ratan Mandal at School of Energy Studies, Jadavpur University in between the period of December, 2018 to August 2023.

To the best of my knowledge, this work is original outside of the places where previous work is acknowledged and cited. This thesis has not been presented, nor will any substantially similar thesis be, for any other degree, diploma, or other qualification at any other University.

The present work dealt with natural refrigerants based solar air conditioner operates with complete solar thermal and photovoltaic power. Hopefully this work will help in future researchers in energy solution in some extent. As we know energy plays a very important role in everyday life. Apart from land, capital & labour, energy is a crucial component of a nation's economic development. The standard of living increases with per capita consumption of energy and it is increasing day by day. If a current rate of world consumption of fossil fuels continues unabated then due to the finite supply of fossil fuels, the world's reserves will be exhausted by the year 2050. Long-term concerns about the exhaustibility of fossil fuels contrast with the reliability and inevitability of renewable energy. Therefore, it is simple for humans to rely on renewable energy. The main benefit of these energies is that they do not emit any pollutants to the environment, unlike thermal power plants powered by coal, oil, or gas, which produce enormous amounts of flue gases like CO_2, NOx, and SOx, among other harmful substances. These energies are abundant in nature. Four criteria—availability, adaptation, acceptability, and affordability—control access to energy supplies. All of these needs might potentially be satisfied by solar energy. As a result, in nations with abundant sunlight, solar energy is the most promising source of energy. A solar cell is a type of electrical appliance that uses the photovoltaic effect to convert light energy directly into electricity. The main focus of the present work in the possibilities of using organic natural refrigerant in domestic air conditioning system. There are so many refrigerants but emphasis is given on selection of natural refrigerants due to low GWP and ODP for sustainable future. The detail studies are presented in the volume of four to six chapters.

Also, a new direction about application of Air conditioner on climatic Zone basis design is presented where a great potential on saving of Energy consumption is identified. All about the detail of aim and objective of this work are elaborated in chapter I.

While working on a Ph.D. is a lonely endeavour, but it is also not possible without others. As I mentioned, My PhD work was supervised by Prof. Ratan Mandal (Ph.D.Eng.), Professor at School of Energy Studies, Jadavpur University, whose continuous helps, encouragement, advice, guidance and his unparalleled in-depth knowledge in the present subject make it possible to complete this PhD work. I express my deepest gratitude to my philosopher, my teacher cum Guru Prof. Ratan Mandal. I am working as research scholar member at the same school of Jadavpur University and I feel very glad to express that I got every help from my departmental Professors as well as my university, unless it would become very difficult to complete this work. I express my sincere thanks and regards to Prof. Tushar Jash for their continuous encouragement, advice and help in this work.

I would like to remember and thank to research scholars of School of Energy Studies, who advise me in different ways to approach a research problem and possible methods and solutions.

I want to honour the whole personnel at the School of Energy Studies department and express my thanks to all of them.

A RUSA Project helps me a lot during my PhD thesis work providing the financial support and I would like to acknowledge and appreciate the RUSA cell at Jadavpur University for providing funding for the construction of the experimental facilities there. Some of these tasks cannot be done without this unit.

I will always be grateful to my parents and family for inspiring me to persevere through every challenge and put in more effort.

Finally, I'd like to express my gratitude to all of my instructors, family members, friends, seniors, and juniors, and other well-wishers for their unending kindness, support, and encouragement.

I want to thank them all again from the bottom of my heart. I imagine that you will all be delighted to have me back after this journey.

RAKESH NASKAR

ABSTRACT

In the present work, software based theoretical analysis is carried out along with some experimental work and presented in the form of thesis. This thesis presents sustainable and low-Power consumption drives to get environmental comfort. Air conditioning units are used as a low-carbon alternative. It can be possible in three ways: i.e., solar thermal, solar PV technologies, and application of natural refrigerants so that solar energy can be implemented as solar thermal technology to reduce compressor rating by superheating refrigerants when required and also by using electricity generated from the PV panel (Photo voltaic) and use of natural refrigerants (R290 & R600a), instead of synthetic refrigerants (R134a, R32, R22, and R152a). The detail aims and objectives are illustrated in the following section.

Aim and objective:

This research proposal will be ready to serve comfort with less power consumption using natural resources in Air conditioning units. Therefore, the main aim and objectives of the present work are enlisted as follows;

a) To make comprehensive review of energy consumption pattern changes in the domestic sector in India for adaptation air conditioning system
b) To develop a model of solar air conditioning operating units as a green energy application with least power consumption
c) To develop a unique approach for cooling using solar thermal and solar Photovoltaic power with natural organic refrigerants
d) To compare the compressor power consumption and COP of different cooling capacity Air conditioning system operated with various types of refrigerants (synthetic as well as natural/organic) to understand the feasibility and identifying the best suited refrigerant option considering environmental aspect and energy savings in concern using cool pack software & EES Software
e) To analyze and evaluate the performance of different natural refrigerants to make the best performance for a solar AC by Cool pack software
f) To propose a novel technique for the implementation of R600a natural refrigerants by introducing Solar thermal and
g) To analyze energy optimization and its application on solar air-conditioning systems based on five major climatic conditions in India.

Actually, air conditioning and the effect of load on air conditioning systems on energy consumption, and pattern of load changes are studied in detail, and try to develop renewable energy-based air

conditioning systems operated with natural refrigeration. The whole work is presented in the form of a thesis consists of the following sections.

The thesis is started with the major objective to create a model for solar air conditioning that runs throughout years long using green energy. The authors try to annualize a 20-year energy consumption pattern for solar air conditioning system in domestic sector and its impact on energy sector and environmental aspects. This thesis assessed and compared the effectiveness of various natural and synthetic refrigerants to provide the better performance in terms of energy saving and sustainable environment. Accordingly, the main objectives of the work are fixed and presented in Chapter-1.

Rigorous literature review was conducted in Chapter-2. The knowledge gap identified as normal AC is now available with high power usage. Inverter ACs can help to reduce power consumption. There are natural solar powered (DC) air conditioners with low power requirements; however they are not yet on the market. The focus is given on developing a natural solar powered (DC) air conditioner utilizing solar thermal technology to use the least amount of compressor power.

In Chapter-3 the authors made several assumptions for the study including data analysis on gathering demand information based on per capita income growth, weather information, and calculated hourly, monthly, and yearly solar radiation; calculating the cooling load to ascertain the type and quantity of cooling required. The components of the AC system can be developed and scaled using specific design conditions. The designed system should be optimized to use the least amount of energy possible. Performance assessment and economic analysis was done. The system's economic viability has been assessed. In order to be competitive in terms of price and thermal efficiency for household applications, the lifetime costs for solar cooling systems are evaluated. The results are examined, and potential solutions are identified.

In Chapter-4 a preliminary experimental setup employing R-290 as a natural refrigerant is set up on the roof of the School of Energy Studies building at Jadavpur University. Different solar AC with DC compressor setup components indicates indoor and outdoor units to observe solar thermal impact. The experimental result reveals significant changes of refrigerant pressure by introducing solar thermal energy at the compressor inlet to reduce compression energy consumption.

Software called CoolPack1.50 is used to conduct the current analysis and is discussed in Chapter-5. For developing, dimensioning, analysing, and optimizing refrigeration and air conditioning systems, a group of simulation software programs is available in whichCoolPack1.50 is chosen for the same. A 1

Ton capacity solar air conditioner is taken into account while analysing the system initially. It uses various synthetic as well as natural refrigerants as its working medium and runs on a vapour compression cycle powered by DC solar photovoltaic energy. The natural refrigerants R290 and R600a were chosen because they have no potential to deplete the ozone layer and very little GWP in comparison to other refrigerants currently in use. The various qualitative parameters of natural refrigerants show that R290 has a high Latent heat of vaporization at a lower boiling point temperature. While R718 and R123 cannot be chosen due to their high boiling point temperatures at atmospheric pressure, as well as R114 & R502 having high molar masses, R600a also has more or less comparable attributes to those of R290. As a result, it is determined that R290 and R600a are the best candidates for use as natural refrigerants in air conditioning and refrigeration systems. Reheating is also offered in order to maintain a realistic working cycle for R600a. The same analysis also carried out with other different cooling capacity (2 Ton, 3 Ton and 5 Ton) with R290 and R600a (with super heating and without superheating) which justified the result with similar pattern.

For the purpose of designing vapor compression cycle air conditioning systems with a capacity of 1 Ton and natural refrigerants (R 290 and R600a with 5 ^{0}C reheating), the authors took into account various climate zones in India which is discussed in Chapter-6. They then compared the compressor capacity and its full load power consumption based on various condenser temperatures in the various climate zones with respect to the readily available standard system for all locations. The evaporator temperature is held constant at 10°C, while the condenser temperature and humidity are changed according to the zone's maximum temperature and humidity in order to comprehend the techniques better. Since the compressor is the system's main power-consuming component, solely its power consumption is calculated here. The Cool Pack (Version 1.50) and EES Software are utilized for analysis. Summary, discussion and concluding remarks of the whole work is given in Chapter-7

The main conclusion of this thesis along with avenue of future work will be discussed in the following Chapter-8.

The authors of the current work provide guidance for the micro design of the air conditioning system based on various climatic conditions in India by downsizing all essential parts like the compressor, evaporator, and condenser for the best possible power consumption and financial aspect. The potential for energy savings is calculated using the CoolPack version 1.50 software, and the results are cross-checked with those from the EES Software Professional V9.478 version 11.319, which also show the same results. Here, the environmental behaviour of the natural refrigerant R290 is taken into account. The system's COP and compressor work, in particular, are approximated using comfortable climatic conditions like a temperature of 25°C and a 50% relative humidity. The results show that changing the evaporator and condenser temperatures in accordance with the various climatic zones may significantly reduce the energy consumed by the compressor. Specifically, 12.99% of the area is in a hot and dry climate zone, 41.73% is warm and humid, 44.36% is temperate, 54.41% is cold (sunny/cloudy), and 19.17% is in a composite climate zone. In order to have the best possible power usage, this effort emphasizes downsizing air conditioning system components, particularly the compressor system.

Using R600a refrigerant instead of refrigerant R290 has also huge energy-saving possibilities i.e., 12.97 % in a Hot and Dry Climate Zone; 40.89% in a Warm and Humid Climate Zone; 43.35% in a Temperate Climate Zone; 59.77% in a Cold (Sunny/ Cloudy) Climate Zone; 23.65% in Composite Climate Zone. From the present analysis, the authors suggested resizing compressor capacity based on the different climatic zone to achieve the best performance of the system with optimized energy consumption.

One of the major important points that due to application of R600a(with 5^0C superheat) we can able to save in compressor power consumption comparing with R290 on standard consideration(without superheating) is 6.24% extra whereas in case of superheating for both the cases, R600a shows better performance by reducing 5.28% compressor power consumption comparing with R290.

The output from the analysis considering different climatic zones author found possible decrease in compression capacity 27-40% indicated lower consumption of energy compared to the standard design. In case of R600a with 5 ^{0}C author obtained better results compared to R290. Further, using DC compressor can help to reduce energy consumption by 30%. This thesis also discusses on the use of solar thermal (superheating for R600a) and photovoltaic energy to power air conditioners in the future. Therefore, in this work the authors propose to save energy consumption by pre-size designing of domestic air conditioning system on the basis of different climatic zones of India.

LIST OF CONTENTS

SL. NO.	CONTENT	PAGE NO.

CHAPTER 1

Chapter 1

Aim and objective

Introduction:

A wide range of cooling solutions are available through solar Refrigeration/air conditioning, including electrical cooling systems powered by photovoltaic (PV) power and thermally driven cycles based on solar collectors.

While the use of all cooling systems is entirely dependent on the compression system, even though solar energy is time-dependent, solar cooling promises to save a significant amount of primary energy. As a result, it improves energy conservation and environmental protection.

This illustration of solar refrigeration illustrates a system in which cooling might also be accomplished using sun energy. The four main methods are solar thermal cooling with solar photovoltaic power (P-V-based), direct solar thermal cooling, mechanical solar thermal cooling, and electrical solar thermal cooling. Similar to conventional systems, the solar energy is converted into electrical energy in this P-V-based system before being used for refrigeration.

The second technique cools via a thermoelectric cooling process.

The third one assists in converting thermal energy into mechanical energy, which is needed to create the cooling effect. The last technique is a solar thermal refrigeration system, which uses collector tubes to directly heat and cool the refrigerants using solar collector energy rather than solar electric energy. India receives solar radiation of over 5000 trillion kWh per year, which is a significant amount higher than its annual energy needs [1].

Water heating applications using solar thermal technology has been also been discovered and are ready to be accepted in a variation of settings, including residential, commercial, and industrial use.

Under the category of "Air conditioning & refrigeration," solar cooling describes the use of solar radiation for various applications. The fact that the air conditioning and refrigeration load rises as ambient temperatures rise is pertinent and evident. India is a tropical nation, with lengthy summers with temperatures above 35 °C throughout practically the whole country [2].

Some sectors have set up a few cooling systems, but they haven't gained much traction because of the large losses and the small number of layers that provide products or solutions in this field. If access to air conditioning were taken into account, the value of these solar cooling and heating solutions may be greatly increased.

Thus, this thesis presents a low power consumption that tries to achieve environmental comfort. Air conditioning units are to be used as a low-carbon alternative and it can be only possible via three ways that is solar thermal, solar PV technology, and the application of natural refrigerants.

This thesis presents sustainable and low-power consumption drives to get environmental comfort. Air conditioning units considered for the present study are to be used as a low-carbon alternative. It can be possible in three ways by integration with: i.e. solar thermal, solar PV technologies, and application of natural refrigerants. Solar energy can be introduced as solar thermal technology to reduce compressor rating by superheating refrigerants when required and also by using electricity generated from the PV panel (Photo voltaic) and use of natural refrigerants (R290 & R600a), instead of synthetic refrigerants (R134a, R32, R22, and R152a).

1.1 Energy Consumption Pattern in the Domestic Sector:

Energy is one of the most fundamental components of our world and the primary prerequisite for economic growth additionally; it helps to reform society for nations everywhere.

The availability of the energy necessary for modern economic industries, including transportation infrastructure, information technology, building heating and cooling, domestic uses, etc., is a major factor in the economic growth and prosperity of the country.

A nation that wants to grow its economy and even wants to prove its living standard must secure an energy supply. High standard country consumes more than fourteen times as compared to least developed countries.

The overconsumption and overpopulation lead to the shortage of energy supply in the economy. The rise of consumption in petroleum and its product during the last two decades has increased incomparably and the stock of petroleum and other sources is fast depleting.

Renewable sources of energy are becoming the alternative support to human society. There are various types of renewable energy like solar wind oceanic biomass and others. We should encourage to use of non-conventional energy. By using non-conventional energy not only we can solve the problems but we can control environmental issues and maintain good public health. The impact of renewable energy on the global economy, politics, and ecology is significant. According to data, cooling and heating homes and commercial buildings account for 30–40% of energy use in nations with extreme heat and humidity [3].

Within a few lifespans the use of air conditioners has grown steadily both as household appliances and in other businesses. To provide a comfortable environment at home, solar power air conditioning has advanced recently and is now placed in all buildings. The research will now concentrate on how residential areas like rural, suburban, and urban should use energy. The solar air conditioner will be essential to our environment since, as we all know; the residential load is growing daily.

The details study and forecasting on adapting solar air conditioner systems in the context of West Bengal and in India will help to make the future planning of power consumption. However, in the current study, a laboratory-scale performance analysis of a direct current (DC) air conditioning system linked with a solar thermal system will be carried out.

Utilizing solar energy is crucial for addressing significant energy issues like the depletion of fossil fuels with rising energy demand, global warming, and power prices. As a result, this solar energy can be used for a variety of processes, including desalination, industrial heat processes, chemical processes, space heating, cooling, and refrigeration. Solar refrigeration systems are the choices for the demand for the areas especially for the high solar potential.

However, shifting to renewable energy will benefit the environment and other advantages that are not quantified in economic terms therefore the use of solar refrigeration/ cooling systems will be had to decrease electricity consumption.

Solar cooling will be the most crucial applications for renewable energy conversion systems and will be more favorable because cooling needs are greater during daytime when solar radiation is most abundant. Additionally, cooling is significantly more important in hotter temperatures than it is in cooler climates. Furthermore, because these areas typically have higher cooling and refrigeration needs, there is excellent compatibility between source supply and load demand.

In addition to using more energy, vapor compression air conditioning technology harms the environment because it uses hydrofluorocarbon (HCFC) and chlorofluorocarbon (CFC) refrigerants, which cause ozone depletion and the ensuing greenhouse effect. The absorption system is a viable choice for lowering the use of electricity and CFCs in the hunt for sustainable energy utilization technologies. By 2050, it is predicted that global carbon dioxide (CO_2) emissions will have fallen to 75% of their levels from the year 1985 if energy efficiency and renewable resources are broadly adopted [4].

There are generally three different types of solar cooling systems. A PV-type cooling system is the foremost of cooling system, which directly powers the cooling system using solar energy that is immediately transformed into electricity. The second kind is a solar thermal refrigeration system, which, as opposed to solar electric power, uses solar energy to directly heat the refrigerant using collection tubes. Combining thermal and solar applications has the potential to reduce compressor rating, making it the third category.

Solar Thermal AC (Solar Hybrid AC): It is a hybrid air conditioner that uses both grid electricity and some solar power, which can reduce grid electricity consumption by 60%, or 40% of the cost of electricity.

Solar PV AC: It is a completely solar-powered photovoltaic air conditioner with no need for grid power and no electricity costs. The current market value in India for a 1.5 Ton (1.5kW) capacity Solar

PV Air Conditioner with 100% Off-Grid Electricity from Solar Energy is approximately INR 3, 60,000 (includes Solar Panels with Back-up of 4 hrs.). This is the solar air conditioners current situation, which is difficult to handle. By utilizing solar energy and natural refrigerants, the current method of work adds another dimension for cost-effectiveness, with no negative effects on the environment, and with the least amount of power usage.

1.2 Indian Energy Scenario:

The renewable energy sector is predicted to maintain growing and achieve desired statistics in 2023, with financial flow, technological advancement, and government support through futuristic initiatives being the important elements driving growth.

The availability and exploitation of energy have influenced the course of human evolution. Energy has always been a development enabler, from the earliest periods when fire and animal power were employed to the present day when cleaner sustainable fuels and electricity are used for a number of reasons. In every business globally, energy is a crucial demand for everything from machinery to information and communications technologies. Essential functions including cooking, heating, cooling, lighting, transportation, and appliance operation are also included but not limited to. The current accord states that a major impediment to the advancement of human well-being on a worldwide basis is the lack of reliable and sustainable energy sources.

International action has agreed to limit emissions in response to growing concerns about how human-made greenhouse gases are affecting the climate on Earth. Renewable energy is being looked into as a clever approach to employ for tackling issues like poverty and global warming, with renewed promises. Making sure that everyone has access to reasonably priced, dependable, green, and the environmental impact of the energy sector is well understood, and modern energy services are reducing greenhouse gas emissions.

To perform a fair analysis and make the necessary course corrections on the way to sustainability, it is crucial to collect the energy statistics for a country's energy situation. However, not all energy can be statistically observed. Nature's sources of energy but does not directly impact mankind is not often measured and documented as part of energy statistics. A specialized area of statistics is energy statistics that widely covers both (i) the primary characteristics and activities of the energy industries and (ii) the process of obtaining, producing, transforming, distributing, storing, trading, and using energy products. The range of their influence has grown throughout time. Energy statistics are thought of as a flexible collection of knowledge. According to the definition of energy resources, they are "any non-renewable energy sources that have been found either as a solid, liquid, or gas in the crust of the earth, regardless of their inorganic or organic origins." Given pertinent technological, economic, and other factors, such as environmental considerations, energy reserves are among the resources that could be recovered and whose extraction is at least partially justified. According to this definition, the term "products" refers to all produced items and services, just like it does in economic statistics. Energy statistics are viewed as a versatile body of information. Energy resources are defined as "any non-renewable energy sources found in the earth's crust, whether they are solid, liquid, or gaseous, regardless of their origins (organic or inorganic)." Energy reserves are among the resources that could be recovered and whose extraction is at least partially justified in light of relevant technological, economic, and other variables, such as environmental concerns. Like in economic statistics, the term "products" is assumed to refer to all items as well as services that end product of production.

As a result of some energy products being converted into other energy products prior to usage, main and secondary energy products are separated. Energy products can be made from both non-renewable (coal, crude oil, etc.) and renewable (solar, biomass, etc.) sources. Energy statistics may not always provide a simple explanation for the universe's maximum number of energy products. For instance, various varieties of maize and corncobs are present. For example, (1) combusted directly to produce heat; (2) used in the production of ethanol as a biofuel, (3) consumed as food, or (4) thrown away as waste.

The International Recommendations on Energy Statistics (IRES), are frequently followed by nations when are defining about energy products. The United Nations Statistical Commission accepted IRES as a statistical standard and recommended additional countries adopt it at its 42ndsession (22-25 February, 2011). IRES offers a thorough methodological framework for gathering, collecting, and disseminating energy statistics regardless of the state of a country's statistical system. IRES provides a set of generally accepted recommendations that address all facets of the production of statistics, including the institutional and legal framework, fundamental ideas, classifications, and data sources, as well as data compilation techniques, energy balances, problems with data quality, and the dissemination of statistics.

Given India's current energy situation, it is clear that the country contains some of the world's richest coal reserves. As of 1st January, to 1st April, 2022, there were 361.41 billion tons of projected coal reserves, an increase of 9.28 billion tons at the same time compared to previous year. The total projected coal reserves have increased by 2.64% over the years 2020–21, in terms of percentage (Table 1.1). Odisha, Jharkhand, and Chhattisgarh are the top three states in India for coal deposits, making up over 69% of all coal reserves in the nation. Proven reserves, or those that can be extracted due to their economic viability, feasibility study, or level of geological exploration, make up over 52% of the country's total reserves, as shown. The estimated amount of lignite as of April 1, 2022, was 46.20 billion tons, an increase of 0.18 billion tons from the same time last year. The total estimated lignite reserves have increased by 0.39% throughout the years 2020 and 2021 in terms of percentage (Table 1.1A). The largest lignite reserves are in Tamil Nadu. Proven reserves make up less than 16% of the country's total

Lignite reserves, according to the graph. As of 1 April 2022, India's estimated crude oil reserves were 651.77 million tons, up from 591.92 million tons the year before. a rise of nearly 10% from the previous year. According to the geographic distribution of crude oil, the Western Offshore has the largest reserves (33%) followed by Assam (23%).

Table 1.1: State-wise Estimated Reserve Coal as of 1st April 2023

										(in Million Tonnes)
States/ UTs	Proved		Indicated		Inferred		Total		Distribution (%)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Andhra Pradesh	921	921	901	2,443	425	778	2,247	4,142	0.64	1.15
Arunachal Pradesh	31	31	40	40	19	19	90	90	0.03	0.02
Assam	465	465	57	55	3	3	525	522	0.15	0.14
Bihar	310	310	3,143	4,080	11	48	3,464	4,437	0.98	1.23
Chhattisgarh	31,562	32,053	40,425	40,701	1,437	1,437	73,424	74,192	20.85	20.53
Jharkhand	52,046	53,245	28,882	28,260	5,288	5,155	86,217	86,660	24.48	23.98
Madhya Pradesh	13,479	14,052	13,060	12,723	3,678	4,142	30,217	30,917	8.58	8.55
Maharashtra	7,770	7,984	3,320	3,390	1,847	1,847	12,936	13,221	3.67	3.66
Meghalaya	89	89	17	17	471	471	576	576	0.16	0.16
Nagaland	9	9	22	22	416	448	446	478	0.13	0.13
Odisha	43,326	48,573	35,222	34,080	6,330	5,452	84,878	88,105	24.10	24.38
Sikkim	0	0	58	58	43	43	101	101	0.03	0.03
Uttar Pradesh	884	884	178	178	0	0	1,062	1,062	0.30	0.29
West Bengal	15,199	17,234	13,296	12,859	4,597	3,779	33,092	33,871	9.40	9.37
Telangana	11,089	11,257	8,328	8,344	3,433	3,433	22,851	23,034	6.49	6.37
All India Total	**1,77,179**	**1,87,105**	**1,46,949**	**1,47,250**	**27,998**	**27,054**	**3,52,126**	**3,61,409**		
Distribution (%)	**50.32**	**51.77**	**41.73**	**40.74**	**7.95**	**7.49**	**100.00**	**100.00**		
Total may not tally due to rounding off										
Source: Office of Coal Controller, Ministry of Coal										

Table 1.1A: State-wise Estimated reserve Lignite as on 1st April, 2023

										(in Million Tonnes)
States/UTs	Proved		Indicated		Inferred		Total		Distribution (%)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Gujarat	1279	1279	284	284	1160	1160	2722	2722	6	6
Jammu & Kashmir	0	0	20	20	7	7	28	28	0	0
Kerala	0	0	0	0	10	10	10	10	0	0
Puducherry	0	0	406	406	11	11	417	417	1	1
Rajasthan	1169	1169	3030	3030	2151	2259	6349	6458	14	14
Tamil Nadu	4927	4927	21910	21981	9653	9653	36490	36561	79	79
West Bengal	0	0	1	1	3	3	4	4	0	0
All India	**7374**	**7374**	**25651**	**25722**	**12994**	**13102**	**46018**	**46198**	**100**	**100**
Distribution (%)	**16**	**16**	**56**	**56**	**28**	**28**	**100**	**100**		
Total may not tally due to rounding off										
Source: Office of Coal Controller, Ministry of Coal										

Natural gas reserves were expected to be 1138.67 billion cubic meters as of April 1, 2022. Western offshore has the highest natural gas reserves (29.6%), followed by Eastern offshore (23.6%) [5].

The production of renewable energy from a range of sources, such as wind, sun, biomass, small hydro, and bagasse cogeneration, has a sizable potential in India. The nation's capacity to produce renewable energy is anticipated to be 14,90,727 MW as by 31.03.2022. This includes the potential for

7,48,990 MW of solar power (50.24%), 6,95,509 MW of wind power (46.66%), 21,134 MW of small hydropower (1.42%), 17,538 MW of biomass power (1.18%), The waste-to-energy capacity of 2,556 MW and 5,000 MW of cogeneration using bagasse in sugar mills.

Rajasthan has the biggest proportion of roughly 18.2% (271219 MW) of the predicted potential for renewable energy as of 31.03.2022, according to the regional distribution. Gujarat comes in second place with 180215 MW, or 12.1% of the market. Following them are Karnataka and Maharashtra each have respective proportions of 10.3% and 11.2% (154162 and 166743 MW). In India, the potential for renewable energy is greater than 50% in these four (4) states [5].

To provide everyone in developing nations with contemporary, sustainable energy services, the world has committed to upgrading technology and expanding infrastructure (SDG Target 7. B). The necessity of the hour is to design energy systems that can meet the constantly evolving and new needs of developing economies. The need to convert to cleaner fuels and larger energy systems has been brought on by the increase in energy demand worldwide and in densely populated areas of Asia, particularly India. As a result, there has been a push in India to boost installed power generation capacity while reducing dependency on primary fossil fuels to meet these needs. The foundation of India's policy planning has been generating and providing dependable power at affordable costs sustainably by maximizing the utilization of various energy resources with cutting-edge environmentally friendly technologies. Additionally, the costs to the environment and public health associated with the usage of hydrocarbons push nations to implement energy-efficient and clean energy systems. Due to manufacturing losses and other reasons, not all potential can be transformed into capacity, Consequently, generation is not equal to overall capacity. Despite having the capacity to produce a certain amount of electricity over time, power plants do not produce electricity when they are offline (for maintenance or refueling).

1.2a. Alternative Energy in the Domestic Sector:

Due to their comparatively low cost, fossil fuels have traditionally been the primary energy source in the energy sector. But as our need for energy is expected to increase, we can no longer rely on depleting, polluting energy sources. On a local as well as a global scale, the last ten years have seen a significant movement in Favor of increasing our capacity for renewable energy.

Future energy requirements in our nation will be met by a variety of alternative energy sources, including solar power, onshore and offshore wind turbines, and hydroelectricity.

The biggest contributor to environmental harm is our reliance on natural gas and oil, which accounts for 1.7% of the increase in carbon dioxide gases in our atmosphere in the energy sector alone. To stop the additional effects of climate change on our world, alternative energy sources will be the key focus in the future. Global renewable power capacity reached 2,351 GW in 2019, according to IRENA's annual

Renewable Capacity Statistics [6]. The top three sources of alternative energy are as follows: Around half of the total, or 1,172 GW, is attributed to hydropower. With 564 GW, onshore and offshore wind energy is second. The combined capacity of solar photovoltaic and solar thermal electricity is somewhat smaller, at 480 GW.

By 2023, every industry is expected to increase its use of alternative energy sources. With a 30% market share, the power sector is the largest. As the world moves toward de-carbonization, electricity will replace other forms of transportation as the primary source of energy.

Transportation comes in lowest with only 3.8% of alternative energy sources, and heating comes in second with 12%.

In the info graphic below, Green Match demonstrates the breadth of alternative energy sources both now and in the future and offers a summary of investments and future expectations on our road toward a sustainable future.

Even more effective renewable energy technology and the reform of the electric utility sector are necessary for greater acceptance of alternative energy sources. Using technology like solar panels, heat pumps, and biomass boilers, it is possible to generate clean energy on a residential scale. We need to develop better energy storage systems to fully utilize energy that is mostly weather or time-dependent. Large-scale solar farms require a lot of land, thus expanding their use may not be the greatest solution, and by 2050, the population is projected to expand to 9.7 billion. A less environmental impact must be achieved, or more advanced technology like wind energy converters must be developed. In the UK, Currently, one of the most important alternative energy sources is wind energy, providing 4 million people with power. Due to expensive maintenance and its location in deep waters, offshore wind is still in its infancy. However, in the future, the oceans and deep waters will be more efficiently used to produce energy.

Due to their inability to reach high-altitude winds, present wind turbines have a weakness that limits their ability to use wind energy. With a considerably more promising reach of up to 500 meters, where the winds are stronger, future airborne technology might set the standard.

Solar energy sourced from space is one of the more expensive, early-stage concepts. The prototype is made up of photovoltaic cells that harness solar energy, optical reflectors, and a device that converts electrical energy into radio frequency. The energy is then sent back to Earth via an inbuilt antenna.

By utilizing the steady sunshine from space, this cutting-edge alternative energy source has the potential to completely supply the energy needs of our expanding population in the future.

For a hybrid energy system based mostly on renewable sources to operate well, storage of renewable energy is crucial. For alternative energy sources to be widely adopted, efficient battery storage is essential. Because solar photovoltaic systems require direct sunlight exposure, a significant amount of energy is lost or wasted because there are no built-in solar storage batteries.

Hydrogen will serve as a source of propulsion energy in the future. Currently, fossil fuels are used to produce the bulk. However, the production of hydrogen gas also uses excess alternative energy. There are several applications for hydrogen gas, including supplying it to the natural gas system and converting it to power using fuel cells. If we can find less expensive ways to deploy these alternative energy sources more generally, hydrogen may be employed extensively in the transportation sector.

Hydrogen is superior for distribution and storage since it has the highest mass density of any fuel. Because of its steady chemistry, it can store energy better than any other medium. Future hydrogen utilization will be conceivable with the construction of a supply and storage infrastructure. The building of an underground hydrogen storage system is required by future hydrogen plans so that extra wind energy, for example, can be electrolyzed into hydrogen.

1.2b. Alternative Energy and Infrastructure:

Only the infrastructure in place now is designed for fossil fuels. It would take years and a lot of resources to construct a new one. Off-grid systems based on alternative energy have recently been successful in supplying local or small grids to remote regions.

If the grid is fully decentralized, consumers will have the option to buy electricity back from the system and take charge of the needed and utilized energy. However, due to the enormous amount of transformation required, the UK is far from implementing true decentralization.

However, some companies, including UPS and some of the biggest retailers and supermarkets in the UK, might be seen as forerunners in the off-grid restructuring.

More jobs will become available in the sustainable energy sector when alternative energy is scaled up. All industries will need to experience growth and implementation, which will require extensive planning over many years.

We may start by stopping more future fossil fuel projects and establishing more strict emission targets to ensure a future with no additional climate emissions.

1.3 Energy Conservation Possibilities in Domestic Air Conditioning Systems:

Air conditioners are employed to remove heat from designated spaces known as controlled areas. Large buildings employ chill water plants, central air conditioning plants, and package units. Small units with a capacity of 1 to 2 tons are typically utilized in homes and offices.

The older window units are no longer in use, and split units are the most popular. The air inside a normally controlled space is circulated in a tight loop. There is a regulated space here. For tiny spaces like bedrooms, sitting rooms, cabins, laboratories, etc., air conditioning units are employed.

In a natural process, heat moves from higher to lower temperatures. However, in this instance, heat must be driven by some mechanism to move from a lower temperature location to a comparable higher temperature area. Refrigerant is circulated in a closed channel to achieve this. Prior to being delivered to the condenser, the refrigerant is compressed to a temperature above ambient, which removes heat from the area and causes the gas to condense into a liquid. When the liquid falls below room temperature, it is routed to the cooling coils of the evaporator where it can expand and relieve pressure.

Air from the room is blown over cooling coils by an air blower, where refrigerant converts heat from the air into gas while losing heat and chilling it.

The entire procedure is comparable to wiping water off the floor. The housekeeper spreads out the mop over the water. Water is absorbed by the mop, which is then removed and squeezed to release the water. This procedure is continuously repeated to transport water from the floor to the outside. The refrigerant in an air conditioner acts as a mop, absorbing and dissipating heat.

The following three motors consume the majority of the electricity used to operate an air conditioner.

1. The compressor motor:

The unit's largest capacity motor is this one. The motor runs sporadically in response to signals from the thermostat and uses the most energy when the air conditioner is running.

2. Motor for the condenser:

This motor propels a fan with three or four blades that pushes air through condenser coils to release as much refrigerant heat as feasible. This fan only activates when the compressor is operating.

3. Motor for an air fan:

A blower that circulates chilly air across the room is powered by this motor. The chamber is filled with comparatively hot air that has been forced to travel through an evaporator (cooling coils) and is then cooled. Until the air conditioner is turned on, this motor runs continually.

4. Other motor:

The louver may be moved by extremely tiny motors to distribute cold air as needed. These motors operate according to the operator's needs, although they barely use any energy.

The device that is crucial for regulating the desired temperature and that the operator may adjust is the thermostat. The electrical supply to the compressor and condenser fan is turned off when the room temperature drops below the preset level, and further cooling is put on hold. Power consumption is decreased as a result of these two motors being stopped. The compressor and condenser motors are then restarted when the room temperature exceeds the preset level.

The temperature setting on the thermostat is crucial for the efficient operation of air conditioners. A thermostat regulates when the compressor and condenser motors start and stop. The compressor and condenser have a prolonged-ON duration and a short turned OFF duration when the thermostat is set at a lower temperature.

The ON duration is shorter and the OFF period is longer when the thermostat is set at a higher temperature. The amount of time these main motors are working determines how much power the air conditioner uses. The compressor uses more energy the higher its Run/Rest ratio. According to estimates, increasing the temperature by 1^0C will reduce energy use by around 2.5%. The following paragraphs go through the ideal operating circumstances and prospects for energy conservation.

The ambient temperature is uncomfortably cold in both the hot zone and the cold zone. When the temperature is unusual, turning on the air conditioner will restore comfort. Depending on the user's metabolic rate, the comfort zone may be between 22 ^{0}C and 28 ^{0}C. Extremely low temperatures are uncomfortable and expensive to maintain. Therefore, it should be avoided. However, certain air conditioners do operate in frigid zones, as seen below;

A. Over Cooling in the AC Environment:

The coolness provided by the air conditioner when someone enters the room from a hot environment is noticeably insufficient. The body is actually at room temperature, together with its attire and accessories. The air conditioner could occasionally take a bit longer to remove all of this additional heat.

However, impatience and ignorance have minimized the amount of temperature setting. In actuality, cooling cannot be sped up by lowering the temperature setting; instead, it proceeds at its own pace by the unit's capabilities. The lower setting eventually leads to overcooling as it is maintained.

Some air conditioners have a function known as quick cooling mode. It is necessary to return to normal functioning after achieving quick cooling. The environment should be kept as consistent and comfortable as feasible.

B. Pre-Cooling:

Another option is to turn on the air conditioner in advance so that the room is already cool when you enter. This can be accomplished by giving the order to the watchmen, attendants, or assistants to turn on the air conditioner in advance of the arrival time.

Some air conditioners can be controlled remotely via mobile devices. This can be utilized for pre-cooling and advanced startup. However, caution should be exercised to avoid starting too far in advance since this could be a wasteful action.

The situation in the bedroom is almost identical. When I first entered the room, the cooling didn't seem to be working very well. As usual, the temperature setting is kept low to facilitate quick cooling.

Late at night, the temperature lowers, necessitating the usage of a blanket. In a train with air conditioning, a similar observation might be made. A few passengers first protested to the attendant about the lack of cooling, but by late hours, the majority of passengers were utilizing blankets.

Does it not seem absurd to spend money on overcooling while simultaneously shivering and using a blanket as protection?

By pre-cooling the bedroom and employing the sleep mode, which gradually raises the setting at late night, these situations can be resolved.

C. **Ignorance:**

Some people simply turn on the air conditioner, when necessary, not understands the importance or practical application of the temperature setting. As a result, the air conditioner operates at its lowest default setting.

It should be noted that the following Important Tip might be taken into account for better AC system performance: An increase in temperature from 22°C to 26°C leads to 10% energy savings. The temperature is frequently set at 18°C or 20°C. There could be a 20% energy savings if this was changed to 26°C or 28°C. Therefore, the most important piece of advice is to adjust your thermostat appropriately.

Other Energy Saving Tips are summarized as follows;

1. **During the Installation:**

Internal unit: To prevent airflow obstruction, the internal unit should be inserted. The top of the appliance should be used to draw air in. There should be enough room at the top, and there shouldn't be any ornamental hangings or other objects blocking the airflow. Air delivery from the bottom is cooled. Under the unit, there shouldn't be any obstructions to the airflow like a cabinet, curtain, etc. Any barrier can block airflow, which decreases cooling. Ultimately, the compressor must run for a long time and use more energy to reach a predetermined temperature. Additionally, the restriction in the air route increases the fan load, which uses more energy.

External unit: For unobstructed air flow, the external unit should also have a comparable setup. The back and top of the unit must have enough room. The location of the device should prevent it from being exposed to direct sunlight while it is operating. The maximum heat from the compressed refrigerant in the atmosphere must be rejected by the condenser unit. The unit is heated by direct sunlight, which may only partially condense. Since air conditioning is typically used at night and in the day, the external unit should face east. However, because of a practical restriction, it is on the west side, and it should have a shed to protect it from direct sunlight without obstructing air movement.

2. **Heat Ingress:**

When it's extremely hot outside, people use air conditioners. If the heat from outside enters the room, the machine must remove this extra heat to reach the desired temperature. The compressor runs longer and expends more energy as a result. Therefore, it is imperative to make every effort to reduce the quantity of heat that enters the space. If the room is on the top floor, heat from the sun is sent to the room through the patio via the Terrace. This can be avoided, or at least lessened, by painting the terrace with white glossy paint so that the sun's rays are reflected.

Alternately, white glassed tiles or mosaics with pieces can be installed on the terrace for a better and more long-lasting option. A shedding green net can also be set up about two feet above the terrace to block the sun's rays from reaching and scorching it. Insulation is provided by the air between the terrace and the net.

The room's ceiling may feature a fake ceiling composed of gypsum board or plaster of Paris as a heat insulator or insulation lining. Insulating air is trapped between the artificial ceiling and the ceiling above.

The afternoon light heats the space from Walls, where the west-facing wall of the room is located. This heat is transported throughout the space, increasing the air conditioners heat load. It is possible to paint the outside of the wall with glossy light-colored paint to reflect sunlight and reduce temperature. The interior of the wall can be lined with wood or insulation.

Sunray control film can be used to cover a west-facing window in a room with glass shutters. It will be best to have double glass (inside and outside) shutters since the trapped air will act as thermal insulation. Additionally, a cotton curtain in a light color on the window is beneficial. The air between the curtain and shutter acts as an insulator and reflects sunlight.

3. Intermix:

Care must be taken to prevent a mixture of the hot air outside and the chilly air inside the room. To prevent the flow of air, any vents and gaps in doors, windows, and partitions should be sealed. Typically, there is a gap between the floor and the bottom of the door. Fix the door seal strip, which is available at hardware stores. The window and door should be kept closed while the air conditioner is running. To avoid unintentional door openings, a door closer should be installed. An air curtain or automatic door control (open-close mechanism) can be installed where frequent entry and exit are anticipated. Where possible, an air buffer is a superior choice. Two doors—one leading into the room and the other leading outside—are on the intervening closet. Doors may have door closers and are interconnected so that they do not open simultaneously.

4. Words of Caution:

Approximately 6 to 8 hours are spent sleeping nonstop at this time. A person is not paying attention to any oddities in the space. Running the air conditioner on the lowest level without the sleep mode could result in excessive cooling during the final hours of the night. At cold temperatures, blood viscosity may be comparably higher, necessitating greater pressure for circulation. Additionally, oxygen is absorbed and carbon dioxide is exhaled as a result of breathing. The proportion of oxygen decreases and the fraction of carbon dioxide rises in completely sealed rooms. The last hour of the night may see the worst of the situation, which could be dangerous for anyone inside. To maintain the balance of oxygen and carbon dioxide by diffusion through it, an intentional slit must be supplied. For those who have breathing or heart issues, this is especially important. The car's windows and doors are hermetically sealed and lined with rubber. Compared to a room, an automobile has far less air volume. Up to 5 people may be present as opposed to 2 in a bedroom. Windows are closed and the air conditioner is set to the air circulation setting for improved cooling.

Passenger breathing affects the oxygen and carbon dioxide ratios over time. Despite the agreeable temperature and seating layout, passengers could feel exhausted. Therefore, it's imperative to convert the air circulation mode to the fresh air mode for one minute per hour when jogging a long distance.

5. Capacity of AC:

The following factors determine the capacity needed for an air conditioner:

- Airflow (size of the room)
- The total number of occupants (people in the space)
- Heat load (heat emitted from the room's technology)
- If the room is open to the kitchen, another room, or upstairs, the condition is similar: the desired cooling cannot be accomplished, the compressor runs continually without rest, and there is a danger of compressor failure.

6. Maintenance of AC:

Periodically cleaning internal unit air filters is recommended.

- To remove any deposits and clogging, a vacuum cleaner must blow reverse air through the condenser and evaporator coils.
- Any obstruction may limit airflow, reducing cooling and reducing heat transfer while extending compressor operation.
- Verify the gas pressure. If low, add gas.
- Search for gas leaks. Stop any leaks.

7. Avoid Waste By:

Occupancy sensors help prevents unnecessary air conditioning use when there is no one present.

- Do not use an iron or a hot plate or stove in a room with air conditioning. It suffers from two drawbacks.
- It increases energy usage by adding unneeded heat load.

Irons and hot plates use more energy because the air conditioner removes some of the heat they produce, while stoves use oxygen and release carbon dioxide in enclosed spaces.

The aforementioned actions are most helpful for energy conservation and lowering electricity costs. This will also indirectly reduce greenhouse gas emissions, which will eventually reduce global warming. In comparison to geysers and refrigerators, air conditioners are energy-intensive appliances. By putting the appropriate solutions from the above into practice, energy savings of up to 30% are attainable.

Now, as per regulation, air conditioners must have a star rating. The Bureau of Energy Efficiency (BEE) has regulatory jurisdiction. Energy Efficiency Ratio is related to the star rating. The EER and power usage are higher with higher star ratings. A high star rating could increase the cost.

There is an Eliminating method that waste energy is referred to as conservation of energy. Additionally, technology can be used to reduce waste and energy loss. One of our most valuable resources is energy. In the coming year, our energy usage may significantly grow. Energy consumption, according to power officials, might almost triple in the next 20 years. We could reduce our use by being energy-efficient. Conservation is necessary for all sectors, including transportation, residential, commercial, and industrial. Refrigeration and air conditioning consume up to 35% of all energy used in various systems.

The possibility of energy conservation varies based on the system's design, its mode of operation, its operational standards, how well it is maintained under control, how well it is monitored, and how competent the user is. The energy conservation in the ACR system was discussed utilizing the aforementioned factors in this research. Energy can be saved by putting maintenance plans into action, implementing controls, and replacing equipment. Not only should you use less energy, but you should also utilize it responsibly. Effective conservation measures taken today can contribute to ensuring adequate energy sources in the future.

1.4 Environmental Protection by Using Natural Refrigerants:

Systems for food preservation and ice production, climate control for human comfort and regulated environments, and support for industrial processes all employ refrigerants. These systems all play a key role in civilization. The "banked" refrigerant that is present in deployed equipment and the increased volume of refrigerant required for repair and maintenance lead to a proliferation in refrigerant production as the use of refrigeration and air conditioning systems grows along with global economies. Due to these two factors, there is a greater likelihood that refrigerant emissions will harm the environment. As the demand for refrigerants rises, so do the concerns of the world's civilizations regarding the consequences of the systems that employ them and the refrigerants on the environment. The Montreal Protocol provided the world with a once-in-a-lifetime opportunity to address the issue of stratospheric ozone depletion through the progressive abolition of the production and use of ozone-damaging refrigerants. Hydrofluorocarbons (HFCs) are the main alternatives to these refrigerants; however, they are greenhouse gases that have been linked to anthropogenic climate change. As a result, strategies for lowering greenhouse gas emissions are now being researched. People are looking for alternatives with a low Global Warming Potential (GWP), which has led to an increase in the popularity of natural refrigerants and are less likely to have other negative environmental effects. Natural refrigerants are those that are found in the environment naturally.

Examples of natural refrigerants include air, water, carbon dioxide, hydrocarbons, and ammonia. Despite various levels of use, a number of natural refrigerants have been in use on the market for many years. Natural refrigerants are better for the environment, but they are not without drawbacks. These include corrosion, toxicity, high pressures, flammability, and in certain circumstances, reduced operating efficiency. One must consider a number of factors, such as capital cost including operational maintenance cost, size and location of the equipment, operating pressures and temperatures, facility staff qualifications, and regional, governmental, and international laws when determining which refrigerant is best for a given application.

The American Society of Heating, Refrigerating, and Engineering (ASHRAE) has gained widespread recognition for its work in the fields of air conditioning and refrigeration and its members are particularly qualified to help progress natural refrigerants in the appropriate way because of their goal is to advance the heating, ventilation, refrigeration, and air conditioning arts and sciences to benefit humanity and create a sustainable planet.

A class of organic and inorganic materials collectively referred to as "natural refrigerants" can be employed in a range of applications for air conditioning and refrigeration systems, but they also bring several challenges and issues. As a result, depending on the compound, these refrigerants may or may not be used successfully. "Without human involvement, natural refrigerants are produced in nature's biological and chemical processes" is a helpful definition. Ammonia, water, carbon dioxide, natural hydrocarbons, and air are some of these substances, natural refrigerants have seen substantial growth in use in recent years in applications previously handled by fluorocarbons due to their benefits.

One of the main goals of current research is to solve safety problems by lowering the refrigerant charge in refrigeration systems for ammonia and hydrocarbons. By adopting design concepts Dry expansion evaporators and plate heat exchangers, both of which are now common in many applications, it is frequently possible to lower the necessary number of refrigerants in systems. Utilizing indirect refrigeration systems with supplementary coolants is another approach to reduce the refrigerant charge. Throughout these systems, the secondary coolants circulate throughout the occupied regions while the refrigerant is contained in the machine room. In addition to more conventional secondary coolants like brines of salt and glycols, new coolants have entered the market. CO_2 as a secondary coolant has shown particularly promising results. Due to the existence of a secondary working fluid, these solutions compromise the environmental advantages of lower refrigerant charge with decreased system operating efficiency. The necessity to progress the creation of system elements that may affordably achieve targeted performance with energy efficiency is another difficulty that many natural refrigerants face.

1.4a. Ammonia(R-717): R-717 Ammonia is the most significant natural refrigerant and has been used for a very long time and extensively in the processing and preservation of food and beverages as well as in an increasing number of supermarkets, gas stations, convenience stores, district cooling systems, HVAC chillers, process cooling, and air conditioning. There have been many variations in the sorts of refrigerants since the middle of the nineteenth century, but ammonia is special because it has been used continuously for 150 years. Ammonia has a zero GWP and Ozone Depletion Potential (ODP). It has outstanding thermodynamic characteristics, high heat transfer coefficients, and an inherent high refrigeration system energy performance. It is lighter than air when it is in a vapor condition. It is commonly available for a reasonable price and is easily recognized by scent or by several electrochemical and electronic sensors. Even though less than 2% of the ammonia that is generated commercially around the world is utilized as a refrigerant, ammonia is inexpensive because it is produced in such vast quantities for use as fertilizer. The main drawback of ammonia is that it becomes poisonous at higher quantities (i.e., 300 ppm or more); however, this danger is marginally diminished by the fact that people can detect it by its strong Odor even at lower doses (5 ppm).

According to ASHRAE Standard 34, ammonia has a "lower flammability" in the air and is incompatible with copper and copper alloys when its content is between 16% and 28% (by weight). Because of concerns about worker safety, ammonia refrigeration systems are governed by laws and norms in various countries. These do not necessarily provide additional obstacles because other refrigerants also require compliance with legal requirements, appropriate maintenance, and staff training. Furthermore, the enforcement of environmental laws, fees, and uncertainties surrounding the Kyoto Protocol hinder the use of fluorocarbon refrigerants in many nations. The risk associated with using ammonia is comparable to that associated with using the majority of other refrigerants if the rules and standards are put into practice and maintenance staff are given the proper training. From air conditioning to low-temperature applications, ammonia offers practical cooling across the temperature spectrum. Recently, various commercial and municipal buildings have installed air conditioning systems with ammonia chillers. Despite the fact that these appliances now cost more than chillers, that use fluorocarbons, with increased manufacturing volumes, the price disparity should decrease. It will be used in chillers, which are typically found in ice factories and smaller food processing and storage facilities, as well as factory-packaged refrigeration units. A compressor for ammonia that is semi-hermetic is already available. To lessen the chance of ammonia leakage, compact refrigeration units are manufactured completely factory-tested, sealed products. They can be provided with less than 50 kg of ammonia for every 1000 kW of cooling power. Last but not least, ammonia has been employed in large industrial systems that demand low temperatures (- 30^0C to -50^0C) in CO_2 cascade refrigeration systems. Absorption chillers using a mixture of ammonia and water are acceptable and affordable for some particular applications, particularly when utilizing waste heat in district cooling and combined cooling, heat, and power (CCHP) systems.

1.4b. Carbon dioxide (R-744): In the middle to end of the nineteenth century, carbon dioxide was also employed, notably on ships and in establishments like stores and theaters where the smell of ammonia was unwelcome. Carbon dioxide systems, however, declined in popularity as ammonia systems around the turn of the twentieth century became safer and more effective. By the 1950s, carbon dioxide was no longer used due to the development of fluorocarbons in the 1930s. Since the search for CFC-free alternatives began in the early 1990s, due to low toxicity, non-flammability, no possibility for ozone depletion, and a low risk of global warming have all been priorities for system designers. Since then, a range of vapor compression devices, from high-temperature heat pumps to low-temperature freezers have incorporated carbon dioxide. It has also been widely utilized as a secondary refrigerant, providing substantial efficiency gains over conventional systems using brine, glycol, or water. The pressure/temperature characteristic of carbon dioxide is one of the main differences between it and other refrigerants since compared to ammonia or R-404A systems, the pressures encountered are approximately ten times higher. Although it necessitates unique equipment designs, this high pressure has many benefits over other refrigerants. High pressure and high gas density allow for much more cooling power to be extracted from a given compressor. A greater mass flux in evaporators and suction pipes is made possible without compromising efficiency since it also causes extremely modest reductions in saturation temperature for a given pressure drop. Carbon dioxide systems work so well at these low temperatures (-3^0 to -50^0C) because of how noticeable this influence is at these low temperatures. Extremely strong system performance has been recorded in multi-chamber blast freezers and low-temperature plate freezers, where efficiency gains and it has been shown that the freezing time has decreased. Whenever the pressure exceeds the critical level (7.3773 MPa), carbon dioxide cannot condense. The very dense gas is cooled in these circumstances to achieve heat rejection that results in the temperature glide effect. For a variety of uses, this has been used with remarkable success in water-heating heat pumps, including home and industrial ones. These trans-critical heat pumps perform best when the incoming water, such as from the cold-water supply, is at a low temperature. Over a narrow temperature range, such as in central heating systems, they are less effective. Due to its high density and low critical point, carbon dioxide is an unusual fluid that is especially well suited for dissipating extremely high heat loads, such as those seen in trading rooms and blade servers used in information technology. It just so happens that the evaporation temperature needed for IT cooling to prevent dehumidification is 14^0 C, which is also the best temperature for transferring heat to carbon dioxide. R-

134a can only transmit heat about 1/6 as effectively as carbon dioxide at 140 C, while the ideal temperature for R-134a is 770 C. As a good substitute for automotive air conditioning, carbon dioxide is suggested. The German Automobile Industry has decided collectively to use by 2011, carbon dioxide for the upcoming mobile air conditioning technology, and this decision has been ratified by the German Association of the Automotive Industry (VDA 2007). Nowadays, supermarkets have a lot of trans-critical carbon dioxide systems. For roughly 90% of the year, carbon dioxide systems have a greater Coefficient of Performance (COP) than HFC systems. It is a desirable option for beverage cabinets and vending machines because of this. Carbon dioxide is frequently recovered from the waste streams of industrial processes and is normally of an industrial or scientific grade. It is anticipated that the inherent energy needed to capture, purify, liquefy, and transport carbon dioxide has a carbon equivalent of 1 kg CO_2eq per kg. In comparison, the manufacture of ammonia results in a carbon equivalent of 2-kilogram CO_2eq per kg, and the carbon equivalent of fluorocarbons is typically around 9 kg CO_2eq per kg.

1.4c. Hydrocarbons (HC): The components of hydrocarbon-based refrigerants of oil and natural gas are present in the natural world. Although very flammable, hydrocarbon refrigerants have outstanding environmental, thermodynamic, and thermo-physical qualities. Because of these reasons, halogens like less flammable substances include chlorine, bromine, and fluorine but can have an adverse impact on the ecosystem, have been added to some or all of the hydrogen atoms in hydrocarbons to create halocarbon refrigerants. The range of boiling points offered by hydrocarbon refrigerants makes them suitable for use in air conditioning and cryogenics. In the past, hydrocarbon refrigerants were mainly used in the petrochemical industry for process refrigeration and industrial chilling. The phase-out of CFCs has opened up new markets for hydrocarbon refrigerants. its use in halocarbon blends as a minor ingredient to enhance thermo-physical properties like oil miscibility, was one of its initial applications. Concerns about the environmental effects of halocarbon refrigerants have led to an increase in the commercial market for systems using hydrocarbon refrigerants during the past 10 years in European and Asian countries.

Examples of hydrocarbon-based refrigerants used in commercially accessible equipment include:

· Small-charge systems such as domestic refrigerators/portable air conditioners and freezers;

· Standalone commercial refrigeration equipment, such as ice-cream and beverage dispensers;

· In centralized indirect systems used for supermarket refrigeration, the primary refrigerant;

· Truck transport refrigeration systems;

· And chillers ranging from 1kW to 150kW (0.3 to 40 tons).

R-50 Methane

R-170 ethane

R260 Propene

R-600 Butane

Isobutane R-600a

R-1150 ethylene &

R-1270 Propylene

1.4d. Water (R-718): Water is another natural refrigerant that has recently gained popularity owing to its lack of toxicity and flammability, low cost, & abundance. Most frequently, lithium bromide is used as an absorbent and water as a refrigerant in lithium bromide-water (LiBR-H_2O) absorption chillers, which operate at high temperatures. Even an absorptive dual-effect cycle is difficult for absorption chillers because its COP (Coefficient of Performance) is only marginally above 1. Contrarily, centrifugal chillers with an electric motor have a COP of greater than 5. Water is used much less frequently in vapor compression refrigeration systems, but it does have one noteworthy quality: it has an excellent performance coefficient thanks to its thermo-physical qualities. R-718 systems have a variety of technological traits that, up until now, have prevented them from taking off in the market. First, it is challenging to maintain the functioning of water-based refrigeration systems free of impurities (air) due to the extremely low working pressures that are close to a near-perfect vacuum. Second, Due to the exceptionally low density of water vapor, compressors able to process extraordinarily high-volume flow rates are required. And finally, water can only be used for high-temperature refrigeration by its very nature. However, progress in the prototyping of the vapor compression-based R-718 systems is still being made, and this is enabling the introduction of large-sized chillers that may play a big role in the chiller and ice-water sectors.

1.4e. Other: In specialized industrial applications, refrigerants include air and some of its components in addition to carbon dioxide. Carbon dioxide is one of the most important selection criteria, along with pressure and efficiency. Indirect contact freezing of liquid nitrogen is not regarded as a natural refrigerant due to the high intrinsic energy needed to produce and move the liquid.

As stated in ASHRAE's Strategic Plan, enhancing environmentally and socially responsible construction practices is essential for preserving both society and the environment as a whole. This shift toward sustainability is aided by an increase in the safe and effective use of natural refrigerants, which also contributes to ASHRAE's status as a world authority in refrigeration and air conditioning.

1.5 Recent Development of the work:

Based on a review of the available literature from journal articles, this review offers a succinct description of the state of solar air conditioning technology at the moment.

This literature search aims to determine the most effective solar energy conversion systems for both summer and winter interior heating and cooling.

Since cooling accounts for 45% of household energy use, air conditioning is a desirable application for solar energy. Additionally, 10–20% of all electricity generated is used for air conditioning and refrigeration. [7] Peak radiation levels and peak demand for air conditioning and refrigeration make solar energy an attractive energy source.

Including non-commercial biomass, the total primary energy supply (TPES) for humanity in 2002 was 433 Ej, which is equal to 13.75 TW of continuous power use. According to the IEA's projections from 2004 (IEA), the TPES in 2030 will be around 688 Ej, or 21.8 TW of power. This contrasts with the 173,000 TW of solar radiation that the Earth intercepts, of which 120,000 TW strikes the planet's surface. The dominant energy source on the surface of our planet is therefore solar energy, which is 8,000 times more abundant than our main energy source. By 2030, it would be necessary to cover 0.6% of newly emerging regions with solar systems that are 10% net efficient to meet the predicted world energy needs.

Humanity's insatiable energy needs are thus increasing quickly, but the fossil fuel resources that primarily meet these needs are finite and are predicted to begin declining at a rate of 2 to 3 percent per year starting in 2016 (International Energy Agency). Humans always want to live in comfortable surroundings to counteract the oppressive effects of heat. Buildings and the commercial sector use about one-third of the world's energy, with HVAC systems being the most energy-hungry building energy component.

Between 2003–2004 and 2010–2011, there was a considerable 50% increase in electricity use. Therefore, the adoption of cooling systems that are aided by renewable energy can reduce reliance on fossil fuels and will be beneficial for achieving global energy and environmental policy. The most widely used renewable energy source for cooling is solar energy since it is easily accessible, intense, and corresponds with the peak cooling demand period.

Around the world, there are around 140 million m2 of solar thermal collectors in use, and more than 10 million m2 are added every year. Thus, the installed capacity is approaching 100 GW, which is greater than the electric power generated by wind worldwide. With one-third of the global installed capacity and a predominance of evacuated tubular collectors, China is the world's largest market. They presently have a surface area of more than 22 million m^2. Swimming pool heating is common practice in the US, Canada, and Australia, is the most widely used technique, using unglazed polycarbonate collectors with an installed capacity of 18GW. Europe and Japan each produce approximately 10 and 9 GW utilizing evacuated tube collectors and flat-plate collectors, respectively. Air collectors make up just 1% of the total and are almost universally used as a heat transfer fluid.

Germany, Greece, and Austria are the top three marketplaces in Europe. Cyprus has the biggest collector surface area per resident at 582 m2, greatly above Austria's 297 m^2, and the average for the EU at 33.7 m^2 (Eur Observ'ER 2005) [7].

Around 40% of the EU-15's yearly final energy demand and 33.33% of its greenhouse gas emissions are accounted for by the home and tertiary sectors in Europe. The residential sector accounts for two-thirds of them, with the remaining three quarters being made up of commercial buildings. About 70% of all energy used in buildings is consumed by the residential sector [7].

According to estimates, Greece's total annual energy usage for central air conditioning systems was 2909 GWh [7], compared to an estimated 371 KWh [3] per person. the widespread adoption of electrically powered,

Due to the energy generation or the leaking of cooling fluids, compression cooling equipment is to blame for a rise in greenhouse gas emissions, which intensifies the cycle of climate change. The latter is quite important, particularly in the case of public structures.

Direct use of solar thermal energy for cooling and dehumidification is possible. Adsorption chillers, desiccant systems that use solid or liquid desiccant, single- and double-effect absorption chillers are a few examples of cooling technologies. In Europe, there are about 45 solar air conditioners with a combined 19,000 m^2 solar collecting surface and 4.8 MW cooling capacity. California recently created a prototype indirect-direct evaporative chiller. An indirect-direct evaporative cooler prototype was recently made by engineers in California. The coefficient of performance, a measure of direct efficiency, ranges from about 12 to over 40 when the cooling power is divided by the fan power. Simulations for a home in various climate zones in California show 92 to 95% yearly energy savings for cooling. Although using liquid desiccants that can be heated by solar thermal energy could boost energy savings in humid climates, they would still be significantly lower. However, cost is a major barrier to solar air conditioning because compared to conventional electric vapor-compression systems, capital costs are much greater. The cost per unit Energy expenses increasesIf solar thermal collectors are utilized for both winter and summer for heating and cooling respectively.

It is possible to convert district heating and cooling systems to solar power and pair them with a thermal energy storage device. In Germany, eight district heating systems with solar assistance had been built by 2003. Under German conditions, 30 to 95% of the total yearly heating and hot water needs can be met, albeit at quite high costs (from 16 to 42 cents per kWh). The Netherlands, Austria, Sweden, Denmark, and other countries also have comparable systems. The biggest of these is in Denmark and has 1300 residences, a 70,000 m3 gravel pit for storage, and a 30% solar component [7].

In 2011, over 750 solar cooling systems, including those with a 20kW capacity, were installed globally. (2012) Mugnier and Jakob. Numerous huge installations have just been completed or are now being constructed. The system installed at the Lisbon, Portugal, headquarters of the CGD bank, which features a 1560 m^2 collector field and a 400-kW cooling capacity, as well as have cooling capacity of 1470 kW and collector field 3900 m^2 in the system installed in Singapore's United World College, which was finished in 2011. According to reports, this Singapore installation was finished using an energy services company (ESCO) strategy that shields the client from equipment or project costs by charging them for the resulting cooling capacity. Recent years have seen a major increase in the installation of small (20kW) solar cooling "kit" systems for residential usage, particularly in Spain, even though the economics of large systems have historically been more beneficial as a result of scale economies, demand, and equipment limitations in smaller capacities (Henning & Wiemken, 2007).

It is enticing to think about using solar power generation since cooling loads typically coincide with access to solar electricity, most buildings use cooling cycles for their space conditioning and, as a result, building cooling requirements almost exactly match solar incidence. The benefit of employing water or solutions of specific salts as working fluids in solar cooling systems is advantageous. They are both ecologically friendly and energy-efficient. To enhance the indoor air quality of any type of building, they can be utilized as standalone systems or in conjunction with traditional air conditioning. Utilizing "zero emission" technologies is the main goal to reduce energy consumption and CO_2 emissions.

A scenario like this is not the concentrating solar power (CSP) technology's absolute limit. By 2030, it is projected that 4,700 GW of new electricity capacity will have been installed globally, either as a replacement for current capacity or as extra capacity, according to the IEA (2003). According to the Greenpeace-ESTIA scenario, 630 GW might be generated by CSP plants by 2040. In sunny places, this would likely represent a sizable market share of electricity investments.

Many additional present or potential uses exist for concentrating solar systems in addition to providing power, such as direct heating and cooling.

Now considering previous discussions regarding the impact on the energy sector of a huge increasing in energy consumption on domestic air conditioning systems, alternative energy use possibilities, energy conservation opportunities, and possibilities of natural refrigerant use for the benefit of the environment, the author feels a rigorous study is required on Energy Consumption pattern changes in domestic area and Role of Natural Refrigerants based Solar Air-Conditioner in Energy System and energy optimization opportunities. The detailed aim and objective of the present work are discussed in the next section.

1.6 Aim and Objective of the Present Work:

The proposed research work will focus on how energy consumption pattern changes in domestic areas year by year in different regions in India. As we find domestic load is increasing day by day due to the incorporation of the air-conditioning system, solar air-conditioners play a vital role in the energy system.

Therefore, detailed studies, future projections, and forecasting on the adaptation of solar air-conditioning systems in this context will help in the future planning of power system expansion. Moreover, in this present study, a photovoltaic (PV) system coupled with a direct current (DC) air conditioning system as well as with a solar thermal system for a combined effect will be designed and its performance analysis will be done in the laboratory scale. System design and performance analysis based on different climatic zones of India also be carried out along with natural refrigerant, which will show the energy savings opportunities in the domestic air conditioning systems. Therefore, this research proposal will be ready to serve comfort with less power consumption using natural resources in Air conditioning units. As a result, the following are stated as the primary goals and objectives of the current work:

a) To make comprehensive review of energy consumption pattern changes in the domestic sector in India for adaptation air conditioning system
b) To develop a model of solar air conditioning operating units as a green energy application with least power consumption
c) To develop a unique approach for cooling using solar thermal and solar Photovoltaic power with natural organic refrigerants
d) To compare the compressor power consumption and COP of different cooling capacity Air conditioning system operated with various types of refrigerants (synthetic as well as natural/organic) to understand the feasibility and identifying the best suited refrigerant option considering environmental aspect and energy savings in concern using cool pack software & EES Software
e) To analyze and evaluate the performance of different natural refrigerants to make the best performance for a solar AC by Cool pack software
f) To propose a novel technique for the implementation of R600a natural refrigerants by introducing Solar thermal and
g) To analyze energy optimization and its application on solar air-conditioning systems based on five major climatic conditions in India.

Actually, air conditioning and the effect of load on air conditioning systems on energy consumption, and pattern of load changes are studied in detail, and try to develop renewable energy-based air conditioning systems operated with natural refrigeration. The whole work is presented in the form of a thesis consists of the following sections.

1.7 Scope of the Work:

All the work carried out as mentioned in the aim and objective section has been compiled in the form of a thesis coherently from Chapters 1-8.

Air conditioning and the effect of load on air conditioning systems on energy consumption, and the pattern of load changes are studied in detail and try to develop renewable energy-based air conditioning systems operated with natural refrigeration. The whole work is presented in the form of a thesis consisting of the following sections.

The thesis starts with the major objective of creating a model for solar air conditioning that runs for years using green energy. The authors try to annualize a 20-year energy consumption pattern for solar air conditioning systems in the domestic sector and its impact on the energy sector and environmental aspects. This thesis assessed and compared the effectiveness of various natural and synthetic refrigerants to provide better performance in terms of energy saving and a sustainable environment. Accordingly, the main objectives of the work are fixed and presented in Chapter 1.

A rigorous literature review was conducted in Chapter 2. The knowledge gap identified as normal AC is now available with high power usage. Inverter ACs can help to reduce power consumption. There are natural solar-powered (DC) air conditioners with low power requirements; however, they are not yet on the market. The focus is on developing a natural solar-powered (DC) air conditioner utilizing solar thermal technology to use the least amount of compressor power.

In Chapter 3 The study's authors made several assumptions, including data analysis on gathering demand information based on the growth in per capita income, weather information, and estimated hourly, monthly, and annual solar radiation; calculating the cooling load to determine the type and amount of cooling needed; and more. The components of the AC system can be developed and scaled using specific design conditions. The designed system should be optimized to use the least amount of energy possible. Performance assessment and economic analysis were done. The system's economic viability has been assessed. To be competitive in terms of price and thermal efficiency for household applications, the lifetime costs for solar cooling systems are evaluated. The results are examined, and potential solutions are identified.

In Chapter 4 a preliminary experimental setup employing R-290 as a natural refrigerant is set up on the roof of the School of Energy Studies building at Jadavpur University. Different solar AC with DC compressor setup components indicates indoor and outdoor units to observe solar thermal impact. The experimental result reveals significant changes in refrigerant pressure by introducing solar thermal energy at the compressor inlet to reduce compression energy consumption.

Software called CoolPack1.50 is used to conduct the current analysis and is discussed in Chapter-5. For developing, dimensioning, analysing, and optimizing refrigeration and air conditioning systems, a group of simulation software programs is available in whichCoolPack1.50 is chosen for the same. A 1

Ton capacity solar air conditioner is taken into account while analyzing the system initially. It uses various synthetic as well as natural refrigerants as its working medium and runs on a vapour compression cycle powered by DC solar photovoltaic energy. The natural refrigerants R290 and R600a were chosen because they have no potential to deplete the ozone layer and very little GWP in comparison to other refrigerants currently in use. The various qualitative parameters of natural refrigerants show that R290 has a high Latent heat of vaporization at a lower boiling point temperature. While R718 and R123 cannot be chosen due to their high boiling point temperatures at atmospheric pressure, as well as R114 & R502 having high molar masses, R600a also has more or less comparable attributes to those of R290. As a result, it is determined that R290 and R600a are the best candidates for use as natural refrigerants in air conditioning and refrigeration systems. Reheating is also offered in order to maintain a realistic working cycle for R600a. The same analysis also carried out with other different cooling capacity (2 Ton, 3 Ton and 5 Ton) with R290 and R600a (with super heating and without superheating) which justified the result with similar pattern.

For the purpose of designing vapor compression cycle air conditioning systems with a capacity of 1 Ton and natural refrigerants (R 290 and R600a with 5 ^{0}C reheating), the authors took into account various climate zones in India which is discussed in Chapter-6. They then compared the compressor capacity and its full load power consumption based on various condenser temperatures in the various climate zones with respect to the readily available standard system for all locations. The evaporator temperature is held constant at 10°C, while the condenser temperature and humidity are changed according to the zone's maximum temperature and humidity in order to comprehend the techniques better. Since the compressor is the system's main power-consuming component, solely its power consumption is calculated here. The Cool Pack (Version 1.50) and EES Software are utilized for analysis. Summary, discussion and concluding remarks of the whole work is given in Chapter-7

The main conclusion of this thesis along with avenue of future work will be discussed in the following Chapter-8.

1.8 Conclusion:

Present work deals with sustainable and low-power consumption drives to get environmental comfort. Air conditioning units considered for the present study are to be used as a low-carbon alternative. It can be possible in three ways by integration with: i.e., solar thermal, solar PV technologies, and application of natural refrigerants. Solar energy can be introduced as solar thermal technology to reduce compressor rating by superheating refrigerants when required and also by using electricity generated from the PV panel (Photo voltaic) and use of natural refrigerants (R290 & R600a), instead of synthetic refrigerants (R134a, R32, R22, and R152a). In this chapter, all the things related to the energy scenario, and energy consumption pattern changes in the domestic sector especially for more and more use of air conditioning systems which are increasing rapidly nowadays are discussed in detail. The energy savings opportunities and the use of alternative sources (solar energy) are identified to run the AC system. Environmental problems (ODP and GWP) of using synthetic refrigerants are discussed in detail and the alternative natural organic refrigerant. For energy optimization different climatic zone-based AC system design is also proposed. All these things to find the optimum solutions the detailed aim and scope of the work are presented here. Now it is required to understand more and more regarding the present research work carried out by various researchers on the above-discussed aim and objectives, a rigorous literature review is carried out to get in-depth knowledge on that regard that is presented in the next chapter.

References:

[1] https://en.wikipedia.org/wiki/Solar_power_in_India#:~:text=With%20about%20300%20clear%20and,5%20EWh%2Fyr).

[2] https://en.wikipedia.org/wiki/Climate_of_India

[3] Z.S. Lu, R.Z. Wang,(2014) "Experimental performance investigation of small solar air-conditioning systems with different kinds of collectors and chillers", Solar Energy,Volume 110, December 2014, Pages 7-14, https://doi.org/10.1016/j.solener.2014.08.044.

[4] https://www.iea.org/reports/global-energy-review-co2-emissions-in-2021-2.

[5] Chapter 1-Reserves and Potential for Generation: https://www.mospi.gov.in/sites/default/files/publication_reports/Energy_Statistics_2023/Chapter%201-Reserves%20and%20Potential%20for%20Generation.pdf

[6] Press Releases: https://www.irena.org/News/pressreleases/2019/Apr/Renewable-Energy-Now-Accounts-for-a-Third-of-Global-Power-Capacity#:~:text=Globally%2C%20total%20renewable%20energy%20generation,around%20half%20of%20the%20total.

[7] Press Release, 2005. http://eufores.org/uploads/media/GB_168_BD.pdf.

CHAPTER 2

Chapter 2

Literature Review

2.1 Introduction:

Generally, the Air conditioner operates in the summer season and the Sun radiation maximum availability is also during this period. This system also serves as a room warmer during the winter. No conventional power is required for the solar air conditioner for both sessions.

Solar Modules produce DC power and BLDC Air conditioners or DC power Air conditioners use DC power so no power conversion loss is associated with this to run a standard air conditioner. Using standard solar modules that produce active DC power will avoid adding an ineffective "inverter" that transforms solar DC into AC. Our solar air conditioners also employ 48V DC brushless fan motors for both the interior and outdoor versions. DC brushless fan motors operate with exceptionally low noise and can significantly cut energy usage. So, introduction of BLDC compressor in solar power air conditioner enabling the system to dynamically modify its capacity with least power consumption in response to circumstances. It can be able to operate in the forward direction for cooling in summer as well as heating for the winter season. The successful development and use of solar air conditioning technology in India will greatly benefit the country's efforts to create energy- and environmentally-friendly cooling and refrigeration systems. Additionally, they are probably going to give India a unique chance to take the lead in integrating some of these technologies for tropical nations, emerging nations, and eventually even more developed nations like Australia and South West America.

To design the AC system based on natural refrigerant and integrated with solar energy an enormous study is required to identify the gap in the knowledge and the problems behind it. Therefore, a huge study has been carried out on the domestic air conditioning system, which is carried out by various researchers.

2.2. Review of the Earlier works:

As per present trends, by 2050, the number of residential air conditioners will have tripled from where it is today. Therefore, more study is required to find the least amount of power, especially in (sub) tropical locations, are ultra-efficient air conditioners with incredibly low energy usage.

Present scenario of solar air conditioners worldwide:

Based on a review of the literature from journal publications, this review gives a concise overview of the state of solar air conditioning technology at the moment. This article will give readers a brief overview of the top methods for using solar energy to cool indoor spaces in the summer and heat indoor spaces in the winter by reversing the refrigerant flow. In this present situation, since cooling accounts for

45% of household energy use, air conditioning is a desirable application for solar energy. Furthermore, refrigeration and air conditioning use 10–20% of all electricity produced. Peak radiation levels and peak demand for air conditioning and refrigeration make solar energy an attractive energy source.

So, a thorough examination of the current system is required. T D J Prabha et al.,[1] compares refrigerants in a 1.5-ton capacity room air conditioning system using experimentation and simulation. R32, chosen for the safety group due to its 15-year atmospheric life and 4.9-year compressor life, is an efficient retrofit refrigerant. R32 offers the best cooling temperature under ambient conditions and has a high coefficient of performance compared to other refrigerants. Difluoromethane also shows better performance, making it a suitable retrofit refrigerant for the test rig.

Enyuan Gao et al.,[2] Describe the use of refrigerants and their replacement in Chinese cold chain equipment. Overall, compared to the air conditioning industry, the Chinese cold chain company replaces refrigerants more slowly. Future demonstrates the scale of the future and the need for policy and technological endeavours. The effectiveness, safety, and environmental friendliness of R717 alone or in combination with R744 are further discussed in this work. Supermarkets currently use controlled refrigerants like R22 and R404A for their freezers and display cabinets. So, finally, conclude that the Government initiative is very much necessary to promote such environmentally friendly systems in China [2].

Only a small increase in the coefficient of performance (COP) is possible by additional increases, according to a general study in cycle thermodynamics, as long as the refrigerant has a latent heat of around 10 (K) kJ/kg, and the concentration change is greater than l0%. Based on the limited information for a few chosen refrigerants and carbons, the Dubinin-Astakhov (D--A) equation is utilized to anticipate cycle COPS for activated charcoal in particular. among the refrigerants that are sub-atmospheric at -10 °C. The best COP is provided by methanol, which is also acceptable for use with acetonitrile, methylamine, and NO_2. The refrigerants ammonia, formaldehyde, and SO_2 that are above atmospheric pressure and -l0°C are appropriate. Methanol provides the best COP overall, with a single-stage cycle COP of 0.5 being possible.

When cooling is needed in certain regions of our planet where high amounts of insolation present and no dependable electrical source to power traditional systems, then solar cooling may be an effective alternative. The storage of vaccines and the preservation of food, particularly fish, are the most promising uses. Many refrigerators have been built and tested, and solar thermal refrigeration systems have been investigated for some time. In earlier research, intermittent absorption cycles, such those in ammonia-water machines, were the main focus by Exell et al. [3,4].

C S Choudhari & S N Sapali [5] investigate about the potential of adopting R290, a natural refrigerant as a replacement for R22 due to its superior environmental and thermo-physical properties. When compared to R22, R290 has lower parameters and a slightly lower coefficient of performance, according to a thermodynamic performance analysis. However, higher COP can be expected with designed systems. R290's environmental, thermo-physical, and energy-efficient characteristics make it a superior replacement for R22 in practical applications [5].

In Europe, the leading markets are Germany, Greece, and Austria for the application of air conditioning units using solar power. A major part of this paper is about solar thermal collector area requirements. Cyprus has the biggest collector surface area per resident at 582 m^2, greatly above Austria's 297 m^2 and the average for the EU at 33.7 m^2(EurObserv'ER 2005) [6].

Debasmita Bal et al.,[7] present in this paper that Humanity's endless energy needs are expanding quickly, but the fossil fuel resources that primarily provide these needs are finite and are expected to decline at a rate of 2 to 3 percent per year starting in 2016. To counter the oppressive impacts of heat, humans have a constant yearning for suitable living spaces. The use of energy in buildings and the business sector accounts for around one-third of global energy with HVAC and air conditioning systems among the energy-intensive building components. Between 2003–2004 and 2010–2011, the use of electricity rose by a notable 50%. As a result, less reliance on fossil fuels can be achieved by employing renewable energy for cooling. Solar energy is the most widely used renewable energy source for cooling because it is easily accessible with high intensity and occurs during the peak cooling demand time.

A major difference is not seen in current economic, environmental, and social trends in energy supply and consumption. Despite taking decisive action, carbon dioxide (CO_2) emissions related to energy will more than triple by 2050, raising worries. Though change is needed, It will require a revolution in energy, with the use of low-carbon energy technology being a key component. It will be necessary to deploy new transportation technologies, carbon capture and storage (CCS), nuclear power, and diverse renewable energy sources widely to satisfy our greenhouse gas (GHG) emission targets. Every significant economic sector and large nation must participate. Additionally, the effort must ensure that any investments made now do not force us to use subpar technologies in the long run. According to this plan, solar energy may create solar cooling account for1.5 EJ, which is nearly 17% of all cooling energy demand by 2050.Solar heating will account for 16.5 EJ, or more than 16% of the total energy required for low-temperature heating. In the upcoming energy revolution, solar heating and cooling will be crucial [8].

Zhang Xingjuan et al.,[9] approach a new solar air-conditioning system with a heat pump which is proposed to improve solar energy applications. The system has a 1.7 times higher cooling capacity at high sun radiation intensity and a 70% decrease at low radiation intensity. It reduces the need for high-efficiency solar collectors and has a higher COP and less power consumption. The system can maintain evaporation temperature by adjusting pump rotational speed and water tank height. The R600a refrigerant in the heat pump system has a higher COP and less power consumption compared to R134a HPS [9].

Among the various types of consumers, one of the biggest users of electricity is business buildings. About 30% of India's electricity is used for home and commercial purposes. In a normal air-conditioned structure, this takes between 50 and 60 percent of the total energy. The estimates from CII-GBC are as follows: Building heating and cooling accounts for around 50% of the overall energy usage in developed countries. Compared to electricity (20%) or transportation (31%) in Europe, and overall energy requirement for heating and cooling is higher (49%) according to EREC 2006. [10]. Primary energy in excess of 4.3 quads (4.54 billion GJ) are used by the $10 billion air conditioning market in the United States alone, practically all of it coming from non-renewable sources. [10].

Compression cooling equipment is caused by the widespread use of electrically powered transportation, a growth in greenhouse gas emissions from energy generation, or the loss of cooling fluids, which intensifies the climate change cycle. The latter is quite important, especially when it comes to public structures [11].

A mechanism called refrigeration is responsible for creating and maintaining temperatures that are lower than their surroundings. In this situation, heat must be extracted from the system and transported to a body whose temperature is lower than that of the chilled body or space. Mainly, the sun's energy is the heat source, and the same logic applies to the demand for maximum cooling. According to the IPCC Report 2019, Asia will be the driving force behind a more sustainable future in this region over the next two decades. In most Asian countries, buildings typically produce more than half of all national greenhouse gas emissions, and since the majority of that energy when utilized to cool or heat interior rooms, national carbon footprints have dramatically increased in recent decades as a result of the increased use of air conditioning brought on by improvements in human lifestyle and the enhancement of global warming potential (GWP) in season and climate [12].

Presently, in the air-conditioning system, the area of refrigerants used over the years past like Feon, Ammonia, Li-Br, etc. produce cooling, therefore maximum output can be obtained but the major disadvantages occur, greenhouse gas (GHG) emissions and the effect of global warming thereby hit a new horizon in 2018, despite scientific warnings and political commitments made the Paris Agreement followed by the Montreal Protocol. According to a UN report, in 2019 the World is heading for an average temp. rise by 2100, 3.20 Celsius temp., bringing more disastrous consequences of climate change. These problems can be cleared by opting for interior air-conditioning of thermoelectric modules. Thus, thermo-electric cooling is in other words known as “cooling technology” Thermo-electric coolers (TECs) have the benefits of high reliability, being compact, and having no mechanical moving parts in the working fluid. In addition, the surface tension of refrigerant flow influences heat transfer as well as phase change characteristics of the working fluid. In another aspect, thermoelectric power can be used for air conditioners' sensor power without any storage system.

Over the next two decades, Asia will contribute the most to the 40 percent increase in global energy consumption, with gasoline continuing to make up more than three-quarters of it (Fernando et al., 2008). More than half of all national greenhouse gas emissions for the majority of Asian countries are a result of the built environment, including its construction, upkeep, deconstruction, and demolition. (Caroon, 2010). It was anticipated that in tropical Asia, including India, China, Thailand, Japan, and Indonesia, where the climate is hot and humid, more than half of energy consumption is often related to cooling or heating interior spaces. As a result, the introduction of electronic air-conditioning has increased carbon emissions in recent decades severely (AC) (Li, 2010) [13].

Moreover, the cost of conventional electricity has gone beyond reproach day by day. The research paper argues sustainable and low-carbon drives for environmentally comfortable Air conditioning units which are used for carbon-free substitutes, this paper the proponents of a different strategy, a low-carbon establishment that is alienated in three ways: solar thermal and solar PV technologies and application of natural refrigerants so that solar energy can be implemented as: -

a. Solar thermal technology governance to reduce compressor rating;
b. Using electricity generation from the PV panel (Photo voltaic);
c. Use of natural refrigerants (R290, R600a & its blend variation)

Furthermore, water as a refrigerant (R718) and some other natural refrigerants (R744, R717, R600, R600a, and R290) are the key aspects instead of synthetic refrigerants (R134a, R12, R22, and R152a) based air conditioners have recognized the need for this hour as a safety standard and The Bureau of Indian Standards (BIS), holds superior for safety (flammability and toxicity), operating cost, refrigeration capacity, and coefficient of performance (COP) are to be comparatively ascertained to the World enhanced level around 75 percent by 2030 [14].

Examining the scope of rapid adaptation of the AC systems we carry these trajectories forward; their signification will be high by 2030. Population intensification throughout the world and Asia in particular; thus, the adaptation of AC in the social contexts, this paper argues an alternative less energy-intensive, climate control paradigm that the vision towards cooling will contribute to green refrigerant transition, more sustainable and advancing technology options [15].

The refrigerant in the earlier stage was used chlorofluorocarbon (CFC) which was the most commonly called Freon (R12). This refrigerant mostly functions with reciprocating compressors in household refrigeration equipment and automobile air conditioners. Since the 90s, the CFC was replaced with HCFC (R22). In India, over 50 to 60 percent of air conditioners still use HCFCs, which are only slightly preferable to CFCs because they include chlorine, which is bad for the environment [16].

Also, compared to refrigerant R12, refrigerant 22 has a smaller, less expensive compressor, and now many air conditioning applications previously handled by R22 refrigerant now go by R12. However, chlorine is removed from the refrigerants to the next generation creating another set of refrigerants called Hydro Fluor carbons (HFC). R134 and R410A are the brands. Despite having the potential to contribute to global warming, they are better than HCFC because they do not destroy the ozone layer. The majority of these emit significant amounts of greenhouse gases since they use refrigerants like R-134a, which has negative environmental effects. There is a lot of discussion nowadays about banning all environmentally harmful substances, and R-134a is unquestionably one of them [17].

Different manufacturers use varied inverter split AC condensers like copper, Aluminium, and alloy materials used as trade efficiency so that cost-benefit will be lower due to condenser technology being anti-corrosive thereby extending the life of AC. The next generation comes to cooling technology which has the significant movement over the last few years. The airflow maintains an even temp and increases comfort levels. This ventilation technology aids in maintaining a clean, evenly-cooled interior devoid of any strange freezing or warm patches. Therefore, with this perfectly constructed ventilation system, the food items stay fresh for a longer period [18].

Air quality is one of the main issues in large cities due to impending urbanization and technological advancement. Currently, air conditioners with sophisticated filters rid the air of all pollutants, bacteria, viruses, dust particles, and offensive Odors utilizing a perfect combination of multi-layer filters operating in unison [19].

However, There was no attempt made to increase the system's performance or efficiency or lower the cost of production; the creation of this research was only intended to demonstrate the refrigeration effect provided by solar energy and to gather practical experience, by using solar PV technology for input energy at the source and solar thermal technology as heat absorption and heat rejection both are taking place for thermo-electric conduction [20], which will serve as the basis for future research.

Bin-Juine Huang et al.,[21] examine and focusing on the effects of design choices on air conditioners' runtime fraction (RF) and probability of instantaneous operation (OPB).Solar air conditioning systems powered by standalone solar PV. Six air conditioners were constructed and tested outside. Their OPB values were larger than 0.98 at instantaneous solar irradiation and approached 1.0 at amounts of daily solar radiation greater than 13 MJ m^{-2} day^{-1} (rpL> 3). The design criterion "rpL" is the major factor influencing OPB and RF. The OPB curve is greater than 0.98 at instantaneous solar irradiation and approaches 0.80 at cloudy conditions. There is no discernible correlation between RF and OPB with top and tbL, despite the fact that the ranges for each of the six assessed systems are 0.42 to 1.1 hours and 0.89 to 2.18 hours [21].

Researchers presented this review article covering numerical analysis and experimental models of photovoltaic and thermal (PVT) collectors in addition to the types and parameters affecting the performance (solar PV and thermal). It has been determined that R290 R32, R600a, and R134a, correspondingly, are acceptable for air conditioning and refrigeration systems. Using mixes of hydrocarbons may also lessen the effect of flammability. Carbon dioxide is safe, naturally available, and an eco-friendly refrigerant with the best thermo-physical properties after ammonia. However, the disadvantage of it is a low critical point in high ambient climates [22].

Large-scale power generation from renewable sources requires vast areas of LAND which is a constraint for the present scenario. Thus, Liquid Solar Arrays aim at the rescue in this situation. Moreover, the main advantage of liquid solar PV is to utilize the sun’s rays to a much greater extent, mounted on water, the PV concentrators have added advantages of a greater cooling effect available from the water body as well as the benefit of using light and less light structure being on the water having protective feature of drowning the panels at times of cyclonic conditions, wind flow and lesser dust accumulation compared to ground-mounted ones. Even during the hot and humid conditions in Southeast Asian countries, the O&M cost will be carried out in addition which can be attributed to increased direct normal irradiation (DNI), and even while the atmosphere is exposed to global horizontal irradiation (GHI) in season and out of season. Particularly, large clouds and incessant rains during monsoon are mostly perceptible in the Indian sub-continent resulting in the lowest output [23].

In the refrigeration system, a blend of hydrocarbon refrigerants is a suitable replacement for hydro-fluorocarbon refrigerant since R134a has zero ODP and high GWP features and the blend of R-290 and R-600a has zero ODP and insignificant GWP characteristics. Using the blend of R-290 and R-600a instead of R-134a, the discharge of compressor temperature is decreased by 10.2% [24].

Environmental issues including greenhouse gas (GHG) emissions in residential and commercial buildings are also linked to modern refrigeration and air conditioning technology. Such emissions are directly caused at the source by refrigerant leaks and the use of fossil fuel-based electricity to operate the system [25].

Since India's per capita income quadrupled from Rs. 63.5 K to Rs. 125 lakhs in just seven years, air conditioning (AC) is no longer regarded as a luxury good, even though the price of the electricity required for maintenance is rising significantly. Accordingly, 15% of the world's population is expected to be able to use air conditioning to maintain a comfortable house temperature and high indoor air quality while using 20% of the world's energy [26].

Given the rising global temperature, air conditioning is increasingly becoming a human necessity in many areas. For instance, in 2015, the deadliest heat wave on record caused over 2,300 fatalities in India. Therefore, unless action is taken to lessen both the direct and indirect effects of AC consumption, the sharp rise in social demand for AC machines over the past few decades will result in increased climatic damage. In this essay, we will categorize the adoption of a new technological paradigm into two primary categories by the availability of energy: an effect on the environment due to improved energy efficiency. The technology of solar cooling [27] can be classified as follows;

(a) the system is driven by heat and work

- The Desiccant cooling cycle, the Adsorption refrigeration cycle, and the refrigeration cycle of the ejector;

(b) (Photovoltaic) system that generates electricity

- Stirling cycle for refrigeration, the cycle of vapour compression refrigeration, and cycle of thermoelectric refrigeration;

A fresh strategy for low-carbon technology:

The environment is considerably improved by the significant use of refrigerant in the refrigeration or refrigerator business. As a result, the benefit of employing this design is that it may be utilized as a standalone system with working fluids that are primarily non-toxic and environmentally friendly, like water or salt solution. Furthermore, both active and passive systems can offer the cooling process [28].

To implement solar lighting, at least four known technologies are used: -

Solar ejector cooling,

Vapour compression cycle cooling,

Absorption-based cooling,

Evaporative cooling

An important and expanding source of GHGs [29] is refrigeration. Reduced usage of refrigerants with high Global Warming Potential (GWP) is mandated by European Parliament Directive 517/2014. Due to its low GWP of less than 150 among hydrofluoric carbons, R152a appears to be a potential option. To establish it, flammability issues are the only ones that must be resolved. The utilization of CO_2 in the future seems promising, notably with the upgraded system that combines parallel compression also like cascade connection, sub-cooling, and Ejector devices [30, 31].

S. B. Riffat et al. [32] discuss the use of natural refrigerants as an alternative to synthetic new refrigerants (HFCs) in refrigeration and air-conditioning systems. It highlights the minimal environmental impact of natural refrigerants and the need for further research to understand their systems and cycles. The paper also discusses the potential of ammonia and hydrocarbons for further research, with a focus on low charge in large-capacity systems, higher efficiencies, and smaller system sizes for competitive absorption. It also highlights the need for research on water vapor compression cycles for high-temperature applications and more efficient rotary compressors and expanders.[32]

Due to its sustainability, solar energy is without a doubt the best source for low-temperature applications. This source is appealing due to its widespread accessibility, minimal environmental impact, and lack of recurring fuel costs [33].

Solar energy is used and is absorbed on a surface, which can heat the refrigeration system. The Peltier effect directly pumps heat using electricity. To prevent food contamination, freezers enable the storage of food, milk, fruit, vegetables, medicines like vaccinations, and other items [34].

To optimize the total entropy of the system and its surroundings in equilibrium, the temp minimization under constrained conditions is performed. To achieve the appropriate temperature range, this results in an increase in power consumption, which therefore necessitates the use of more PV cells and thermo-electrics [35].

Consequently, the system's overall price will go up. Additionally, it tries to address this issue by developing a thermoelectric refrigeration technology that is highly effective and affordable [36,37]. Additionally, efforts are being made to make the system more portable by utilizing solar PV which is smaller in size. Food items would be substantially more resistant to temperature variations using the LED (which consumes 20 times less electricity) in place of the GI bulb in this lighting arrangement. Thus, one of the enticing aspects of refrigeration technology is the necessity for cooling. With the aforementioned scope, we may conclude that even in middle- and low-income homes, air conditioners are increasingly seen as a necessary appliance [38].

Prasanta Kumar Bal [39] stated in his paper (2016) that comprehensive assessment of the possible regional climate changes over India. The highest temperature estimates from all six models for all of India indicated a rise in the range of 2.5^0C to 4.4^0C compared to present-day climate simulations by the end of the century. According to the IPCC report, such granular climate change data can be helpful for upcoming research to reduce the effect of climate change on extreme weather like floods and droughts, and develop a variety of climate change adaption options for society to limit temperature rise below 1.5^0C. Limitation of Temperature Rise and energy conservation are correlated which has been a major concern in India. One of the major concerns is domestic Electric power consumption by using Air conditioners.

Yanjie Li [40], explained in his paper (2021), explain how to assess the environmental advantages and costs of various air-conditioning technologies for the home market, and also a techno-economic assessment methodology is proposed. This case study demonstrates the modelling framework's capacity to derive trustworthy and understandable results from a holistic and methodical evaluation technique for communicating policy ideas. According to the study's overall evaluation, R32 is the greatest contender for reducing ASEAN's life cycle costs and greenhouse gas emissions. However, the ODP aspect of Natural Refrigerant should be preferred for future analysis.

Gustavo de [41] correlates AC and solar Power integration in his paper that an Economic Analysis of the Integration between Solar Photovoltaic Systems and Air Conditioning." In this study, the technical aspects of integrated solar photovoltaic energy consumption to complement air conditioning (AC) systems with solar power connected to the national grid are examined economically. This work may inspire building-integrated PV system development in addition to solar energy development. Last but not least, this study could be enhanced in the future by using actual HVAC data from a building whose electricity is produced by a PV solar plant.

I Dautetal.[42] focused on the planning and building of a photovoltaic (PV) system that combines PV panels, solar chargers, inverters, and batteries with a direct current (DC) air conditioning system. In locations without electricity, the air conditioning unit can alternatively be powered by solar energy. The approach taken is as follows: The values of solar radiation at the hourly, monthly, and annual scales were calculated, and a typical meteorological year (TMY) was constructed. A cooling load calculation was performed to estimate the type and amount of cooling required. The air conditioning system's ability to chill must be determined to create and implement the system with adequate electrical power available.

Arthur Heleno Pontes Antunes et al. [43] examine the HCFC-22 drop-in approach in a 5-ton refrigeration system, substituting halogenated substitutes for the original refrigerant, like the hydrocarbons HC-290 and HC-1270, HFC-438A, HFC-404A, HFC-410A, and HFC-32. The highest performance coefficient is seen in natural refrigerants, whereas hydrocarbons have the best environmental impact, according to the findings. The EEV/VSC combination is critical for matching a different refrigerant to the original vapor compression cycle. R1270 systems have the highest COP values, whereas R32 outperforms R410A in all application areas. The HCs system reduces electric energy use and imposes carbon levies.

J. Amanetal et al., [44] have worked on the possibility of home air conditioning using solar-powered ammonia water absorption chillers. This study's objective was to improve an absorption chiller's efficiency with low-temperature driving capabilities, such as solar thermal energy, that may be used for household air conditioning applications. Thermodynamic analysis is based on an ammonia-water absorption chiller with a 10-kW air-cooled solar thermal power source. The performance of this residential-scale cooling system has been evaluated using both energy and exergy assessments. According to the study, The generator (13%), condenser (11%), and absorber (63%) all experience the most energy loss.

Piotr Aet al. [45] the paper explores using evolutionary methods, to determine the thermodynamic performance limits of a vapour compression cycle. The optimal parameters are established, the trade-off between volumetric capacity and COP is confirmed, and the critical temperature of the refrigerant is emphasized as a crucial parameter. The study provides realistic benchmarks for refrigerant performance potentials.

Kai changetal. [46] Have worked in China on the improving the global solar hourly model and sun radiation for designing air conditioning systems. The solar radiation model mainly focuses on monthly or daily values. One of the key functions of buildings is air conditioning. To aid in the design of air conditioning systems, the frequency levels of 95% and 97.5% are used to construct two types of hourly solar radiation database for 17 locations.

Lawrence Drojetzki and Mieczyslaw Porowski [47] present in this article a method for choosing a supermarket's energy-efficient refrigeration system utilizing carbon dioxide and ammonia as natural refrigerants. The method uses a vector of constant parameters and decision variables to identify acceptable variants. The system is categorized into three types: classic CO_2 booster, 2nd generation CO_2 booster, 3rd generation CO_2 booster, and indirect expansion system with ammonia. The 3rd generation booster is optimal for humid continental climates. The method is universal and can be applied to other refrigeration system selection applications.

Lawrence Drojetzki and Mieczyslaw Porowski [48] have found that natural refrigerant-based energy-optimal refrigeration systems are most effective in supermarket applications. The study analyzed four systems, with the CASC_1 system chosen due to its large drop in COP in hot climates. The Cascade R744/R717 system, which combines ammonia and carbon dioxide, was also considered. The simulation results showed that load factor and mode of operation significantly influence the COP of the cooling systems. At outdoor temperatures of 33.5°C and 36.5°C, CASC_1 performs better than CASC_2 and CB_NH_3, and 50%, 4.7%, and 2.7% when temperature rises to 40°C. The proposed CASC_2 and CB_NH_3 systems achieve higher energy efficiencies under hot climate conditions and are simpler in design.

Bi Yuehongetal. [49] analysed solar absorption refrigeration and a three-phase energy system. Simulations of charging/discharging processes using MATLAB were used to develop based on the absorption principle about thermodynamic simulations of the process of charging and discharging.

Ali M. Baniyounes. Et al. [50] studied the solar air-conditioning system in central Queensland's subtropical climate, Australia. An electric vapour compression pump, for cooling is used with a 2.5 coefficient of performance (COP). According to the analysis of the proposed system where in the three chosen regions, 50 m^2 of solar thermal collectors and 1.8 m^3 of hot water storage can be installed to save 80% of the primary energy.

R. Opokuetal. [51] The study compares a DC and AC refrigerator powered by solar photovoltaic systems. Both maintain similar temperatures but have higher power consumption and surges. The DC refrigerator could reduce system installation costs by 18%. Converting a 92 L AC refrigerator to DC is technically feasible, but higher surge powers result in higher system costs.

D.C. Gao [52] explained the first overviews of three designs of typical desiccant air-conditioning (DAC) systems, their operational procedures, and the commonly used performance metrics. The study also provides a summary of the primary DAC system integration approaches. The study offers a current and thorough analysis of the use of desiccant air-conditioning (DAC) systems and their integration into system design to enhance performance. Their applications and performance advances have received detailed assessments.

A paper presented by Qudama Al-Yasiri et al. [53] talked about a broad review of SCACSs (solar air conditioning and cooling system) used in building applications. Consideration is given to the functioning and development features of the well-known SCACSs powered by solar thermal energy.
Several technical, operational, economic, and environmental parameters are considered when comparing solar thermal SCACSs. The examined literature is used to identify some research gaps, provide recommendations, and draw conclusions about how to better comprehend and develop this crucial study subject. A highly effective air conditioner with clever evaporative cooling and photovoltaic-powered ventilation is proposed by Zixu Yang et al. [54],
This consists of a photovoltaic panel, an evaporative condenser, an evaporative fresh air blower, and a high-efficiency air conditioner. The gas-injected vapor compression cycle used by the mechanical vapor compression system, along with relay cooling, enables it to function in harsh environments and at high temperatures. The goal of the field test is to examine the actual performance in the residence. Temperatures reached a high of 36.2 C during the field test, with an average of 25.6 C. The development of a very effective air conditioner with intelligent evaporative cooling ventilation and photovoltaics presented in this study. Some studies present the integration of a trans-critical radiative cooler acting as a sub-cooler and/or roof envelope in a carbon dioxide-based (CO_2 refrigerant based) air conditioning system [55].

An attempt is made to employ both natural refrigerant and natural sub-cooling while simultaneously reducing cooling demand through the roof envelope. the measured dependent parameters used in the numerical simulation, such as ambient temperature, wind speed, roof emissivity, and sun irradiation throughout the day. When in comparison to numerous experimental findings using a unique mechanical sub-cooler, the simulation result shows a comparable improving trend in COP. Global electricity usage has been increasing at a higher rate in recent years. Electricity is most commonly used in buildings, as well as in the increased need for appliances and air conditioners. Implementing energy efficiency measures and using renewable energy are two basic ways to reduce energy usage. Photovoltaics, in particular, have attracted a lot of attention [56].
The feasibility of a solar-powered cooling system for an office building from a technical, financial, and environmental perspective were thoroughly examined. HOMER software was used for the system's design, simulation, and optimization. In particular, the need for cooling is expected to increase dramatically in rising economies with hot climates, enhancing room air conditioners' effectiveness (RACs) could result in large energy and related emissions reductions. Researchers [57] have identified ‘‘best-in-class’’ high-efficiency RAC components and products to help accelerate efficiency

improvements. The results demonstrate that manufacturers frequently use widely accessible or standardized RAC designs for their production in an effort to reduce manufacturing costs.

There is an overview of several flow control techniques used in refrigeration systems which proposed here by the authors [58]. Refrigeration systems have received a lot of attention in recent decades to reduce their energy usage. Various refrigeration system control approaches have been developed. The theoretical underpinning of these strategies differs, and their performance is dependent on system operating conditions. The main challenges and recent improvements in their control strategies are discussed.

Passive cooling is a versatile method that can reduce energy requirements for a building's thermal comfort in a place like India, where there are many different climate zones [59]. The authors describe the findings of numerous research projects on buildings under various climatic conditions are cooled by evaporation, night time radiative cooling, and PCM-based free cooling. Additionally, to provide a full picture about the acquired empirical equations and correlations are combined to determine the vital design variables for the aforementioned passive cooling systems. As per current trends, the use of domestic air conditioners will have tripled. To achieve the goal of climate change, It is essential to consider an air conditioner with very low operational energy consumption, particularly in the (sub)tropical area. So, in this regard, some literature views are introduced here to understand the present research outcomes in that regard.

D. Sanchez et al.,[60] showed that the Kigali Amendment and European F-Gas Regulation No. 517/2014 have accelerated medium and high-GWP refrigerants being phased out, requiring environmentally friendly alternatives like hydrocarbons R600a, R290, and inorganic fluid R744. A study evaluates the behaviour of a commercial beverage cooler with six low-GWP alternatives to replace HFC R134a. Results show that R290 and R1270 hydrocarbons resulted in energy reductions of 27.5 and 26.3 percent, respectively, while HFC R152a and R600a have 13.7%, 3.9%, and 1.2% energy savings. However, HFO R1234yf penalizes energy consumption up to 4.1% due to higher electrical power consumption and compressor running time. All tested fluids perform more effectively when the process is pulled down, with Energy savings of 26.0% and 34.4%, respectively, are demonstrated by the hydrocarbons R1270 and R290.

Ali Al-Alili et al.,[61] examined a hybrid AC performance using desiccant wheels, enthalpy wheels, and vapour compression cycles. According to the findings, a hybrid air conditioner (AC) is more efficient than a solitary vapour compression cycle (VCC) for preserving comfortable interior conditions. A full hybrid solar air conditioner was simulated, using a condensing thermal/photovoltaic collector shows a system performance coefficient (COP) that is greater than one. The hybrid AC system is highly effective in maintaining indoor conditions within the comfort zone, with projected COP system values are achieved at higher than unity and are double those of normal solar air conditioners.

Yuhe Gao et al.,[62] presented a dynamic model of a PV direct-driven refrigeration system, incorporating the PV power-compressor coupling model that reflects the connection between speed, compressor load, and solar irradiation. The simulated results are consistent with the experimental results. The model is compared to the MPPT method and the compressor speed prediction (CSP) approach, indicating that The MPPT approach is more effective than the CSP approach. If the control model is effectively matched to the system, the discrepancy in total cooling capabilities can be minimized. Despite variations in sun irradiation, the MPPT approach produces higher cooling capacity and is more adaptable to temperature swings. The comparison outcomes offer numerical benchmarks for the distinction between the MPPT and CSP methodologies, and they can be utilized to evaluate PV direct-driven refrigeration systems with different types of control strategies. The results are predicted to provide a conceptual framework for creating and improving the PV direct-driven refrigeration system.

D. Sanchez et al.,[63] explained that directive 517/2014 by the European Parliament aims to cut the EU's usage of high-GWP greenhouse gases, affecting artificial refrigerants like R134a due to its high GWP100. This study aimed to identify new low-GWP alternatives for R134a in refrigeration and air conditioning. Five low-GWP R134a alternatives were tested and compared under identical operating conditions. The findings indicated that R290 (propane), while requiring a rise in power consumption, had the greatest outcomes in terms of COP and cooling capacity. R152a demonstrated a typical reduction in cooling capacity& compressor power consumption, with a small gain in COP between 1% to 4.8%. R1234yf, an HFO refrigerant, introduced a decrease in cooling capacity and increased power consumption, resulting in a 10% reduction in average COP. These findings suggest that with a considerable COP reduction, R1234yf is a viable direct drop-in replacement for R134a with also considering safety requirements for an A2L refrigerant. The hydrofluoric-olefin R1234ze (E) reduces power usage by 17.8% and 24.9%, respectively, and cooling capacity, indicating the need for a higher displacement compressor. The refrigerating plant's COP drops by 8.6%, making using it as a direct replacement is not recommended. R1234ze (E), R290 & R600a, are not ideal drop-ins due to their differing displacements, while R1234yf and R152a are potential replacements for R134a.

F.J. Aguilar, et al.,[64] did experimental work on a cooling system that is simultaneously powered by a grid and a photovoltaic installation conducted over a year to analyze the feasibility of using photovoltaic systems without batteries or regulators. The apparatus had a 3.52 kW nominal cooling capacity, and three 235 Wp photovoltaic panels were directly linked to it at 24 Vdc. The results showed an average EER of close to 15, with a nearly 65% of production comes from solar energy. Three PV panels and an inverter air conditioner linked to the grid were also examined as part of the study to determine how they would perform in actual use. The output temperature, load factor, and solar radiation all affect the system's performance. In Alicante, Spain, the solar contribution in cooling mode was 64.5% and the production factor was 65.1%. The analysis suggested several technological improvements to optimize performance, including adaptative mode control based on solar radiation availability and an optimization method based on an ECO operation mode. The aim was to maximize photovoltaic solar energy input and coincidence between demand and production curves.

Dariusz Butrymowicz et al.,[65] introduced that ejection refrigeration systems are becoming a popular alternative to compression devices in air-conditioning technologies, competing with absorption systems under low-motive heat sources. This paper investigates experimental investigations using isobutene as a working fluid under low motive vapour temperatures. The study confirms that ejection cycles can be effectively driven by low-temperature heat sources, making them competitive compared to absorption refrigeration systems. The study reveals a maximum mass entrainment ratio and higher motive vapour values result in higher ejector efficiency. The theoretical prediction of ejector performance under non-design conditions was experimentally confirmed, and there was good agreement between theoretical and actual data.

Mustafa Ozsipahi et al.,[66] evaluated the effect of the effect of R290/R600a refrigerant mixtures on adjustable-speed hermetic compressor performance in residential refrigeration. Four alternative R290/R600a mixture compositions are investigated, with R290 content ranging from 40-70% by mass weight. The study contrasts performance results with R600a, the baseline refrigerant. With the hermetic reciprocating compressor that was tested, 2100 rpm is the ideal compressor speed. The refrigeration cycle COP increases with evaporation and condensation temperature, depending on the refrigerant mixture's composition and operating circumstances, the refrigeration cycle COP is 10–20% higher than R600a. To find the hermetic compressors ideal operating speed at a set evaporation temperature, 28 tests were carried out. When employing 60% and 70% of the R290 mass fraction, the maximum COP was discovered at a compression ratio of 8.9. The study emphasizes the potential of R290/R600a combinations, but to account for this increase in energy efficiency, more effort must be put into creating heat exchangers.

Sergio Ledesma et al.,[67] used Artificial Intelligence (AI) to model a reciprocating compressor using multiple artificial neural networks. The ANN model was optimized to achieve high precision in modelling three energy parameters: power use, discharge temperature, and mass flow rate. Computer simulations showed the ANN model had the best accuracy for mass flow rate, whereas discharge temperature had the lowest accuracy. The proposed iterative algorithm involved measuring devices in the compressor to train and validate several ANNs. Each energy parameter was independently modelled using one ANN, analysingbehaviour without interactions. To prevent machine learning over-fitting, the hidden layer's number of neurons was increased. ANNs offer advantages such as creating a non-linear model that adapts to experimental tests and detects complex relationships between dependent and independent variables. By changing the hidden layer neurons, the ANN model's complexity can be changed. To study the energy behaviour of the compressor utilizing the refrigerant R134a; 3D graphs were made using ANN models.

Tingxun Li et al.,[68] in their paper investigate an R290 split-type air conditioners refrigerant mass distributions measured with liquid nitrogen. The findings can lead to safer products and safety precautions, as well as data for more theoretical research and simulation assessments. 60% of the charge is made up of refrigerant in heat exchangers under steady-state circumstances, and when powered off, most accumulates in the lower-temperature heat exchanger. The distribution of refrigerant in the condenser increases with increasing compressor speed, while the evaporator decreases in heating mode. The refrigerant mass in heat exchangers increases with increasing refrigerant charge, but the distribution ratio remains relatively constant. During start-up, the refrigerant flows out from lower heat exchangers into the compressor/accumulator and higher heat exchangers, gradually increasing to stable conditions after two minutes.

Cleison Henrique de Paula et al.,[69] in their paper presented an efficient geometric VCRS was made using a model, and various compressors' effectiveness in terms of the environment, energy use, and resources was evaluated. The optimization method was applied to reduce the VCRS's geometric structure to an optimal size. The system with R290 optimization performed better in terms of energy efficiency at -3°C for evaporation and 45°C for condensation and gas cooling. The refrigerant charge in the optimized systems was 102.4%, 126.9%, and 114.2% higher for the established thermodynamic condition. The exergy analysis revealed that the compressor caused the highest rate of energy destruction, accounting for 83.5%, 84.1%, 81.9%, and 66.3% of the total energy destruction. For evaporation temperatures of -3°C, the optimized systems had a higher refrigerant charge than the system using R290. The optimized systems fit the authors' description of the range when the findings were compared to those in the literature.

Guogeng He et al.,[70] investigated the flammability change of mixtures using hydrocarbons (HCs) and R134a as alternatives. It measures the flammability thresholds for the refrigerant mixtures R290/R134a, R600a/R134a, and R600a/R290, finding that R134a has a more significant flammability inhibition effect on R290 than R600a. The paper examines determining variables and calculation techniques for flammability limits in mixes with average MAPEs ranging from 0.62% to 2.94%. The refrigeration cycle of HCs/R134a mixtures is simulated, with COP, volume refrigeration capacity per unit, and condensation pressure having local maximums near the azeotropic point. To comprehend how temperature affects the flammability thresholds of HC refrigerants, more study is necessary.

Yunho Hwang et al.,[71] discussed solar cooling as a solution to climate change and reviewed recent advancements in solar thermally operated cooling technologies. Sunlight absorption cycle research looks into refrigerant pairings and system designs to maximize sunlight fraction and cycle operation. Computer models and experimental methods are used in ejector cycle research to study performance and important parameters. Solar thermal cooling systems, despite substantial research, have lower overall efficiency than vapour compression cycles. Improving efficiency is an important future research subject, and solar thermal cooling cycles must continue to develop to compete with electric vapor compression cycles, and they must employ long-term data to demonstrate their practicality. New liquid desiccants and improvements to cycle components are examples of liquid desiccant advancements. Sunlight absorption cycles have examined different system designs, increased sunlight percentage, and prolonged cycle operation during the night. Normalized collector area, heat storage, and absorption cycle averages.

Renato M. Lazzarin [72] stated that solar cooling technologies, including solar thermal-driven sorption and photovoltaic-driven compression chillers, are evaluated for efficiency and investment costs during sunny days. Double-effect absorption chillers with water and air cooling, single-effect absorption chillers, and other solar thermal systems are all examples, while PV systems use traditional compression chillers. The performance of FPC, ETC, and PTC systems was evaluated, and the best results were for double-effect chillers powered by ETC. PV systems showed favourable results, despite lower efficiency due to air-cooled and water-cooled chillers with high COP (EER). PV investment costs For daily 10 kWh cooling, solar cooling systems and absorption systems were comparable, with PV systems in the centre of thermal technologies. In contrast to earlier comparisons, this finding and anticipates future evolutions (2030) of PV systems due to lowering costs and improved efficiency.

Naci Kalkan et al.,[73] explored the integration of heat-driven cooling technologies with solar thermal energy, focusing on solar refrigeration systems, open and closed cooling cycles, and recent solar-thermal air conditioning installations. Solar thermal technology offers numerous advantages, including CO_2 emissions reduction, proven reliability, reduced heating and cooling bills, rapid growth, reduced dependency on imported fuels, and the preservation of rare natural sources. Currently, around 70 solar-assisted air conditioning systems have been established in Europe, with research and developments increasing rapidly in the last five years. Thermally driven chillers and desiccant cooling systems are expected to play a key role in achieving economic feasibility. To make solar-thermal air conditioning in buildings more affordable and a viable choice in the future for sunny climates, new development efforts are required. The project aims to reduce solar thermal air-cooling systems' environmental impact, as solar absorption systems are not suitable for domestic buildings due to investment expenses and the competition from other cooling methods. In this industry, innovation and optimization could make solar-thermal air conditioning more attractive and suitable for larger-scale integration.

Gang Yan et al., [74] introduced a vapour compression refrigeration cycle (MVRC) that has been modified using a R170/R290 zeotropic mixture for freezers. The system uses capillary tubes and two separators are used to accomplish partial condensation and flash separation, improving cycle performance. A mathematical model comparing MVRC and CVRC shows 12.7%, 32.6%, and 20% improvements in COP, volumetric cooling capacity, and exergy efficiency under specific conditions. The simulation's findings show that the MVRC outperforms the CVRC in terms of COP, volumetric cooling capacity, overall exergy efficiency, and total exergy destruction. However, A functional MVRC-based freezer prototype must be used for experimental research to confirm the performance enhancement potential.

Harrison M et al.,[75] explained that based on the CYCLE_D-HX model simulated a vapor-compression cycle for specified temperature profiles using experimental data from a compact heat pump testing device. R-410A, a high-pressure refrigerant, R-513A, R-450A, Tern-1, R-515B, and R-1234yf were the other tested refrigerants. R-134a, a medium-pressure refrigerant, was also examined. The model's predictions for both the basic cycle and the LLSL-HX cycle (which uses a liquid-line/suction-line heat exchanger) were off by COP and volumetric capacity by 0.3–3% and 0.5–5%, respectively. However, the model's predictions were usually in line with the actual data. The model was utilized to evaluate a system's refrigerant performance with improved evaporator and condenser circuitries.

R.Z. Wang et al.,[76] explained a universal method for evaluating photovoltaic air-conditioner (PVAC) performance using TRNSYS simulations. Results show that PVAC performance is highly influenced by the types of buildings and the climate. High summertime heat and daytime operations in commercial centres, office towers, and hospitals show higher SF and SCR. In order to maximize PV capacity and assess both energy and economic performance, a comprehensive evaluation indicator (CEI) is developed. The study focuses on four climate zones and four building types, revealing that climate conditions and building types significantly impact PVAC performance. The economic performance of PVAC depends on SCR and solar radiation, with higher SCR yields larger profits. For the purpose of maximizing PV capacity, a thorough evaluation indicator (CEI) is proposed, considering constraints such as installation area and investment capital.

Davide Del Col et al.,[77] explained Hydrocarbons Because of their favourable thermodynamic and transport qualities, hydrocarbons are appealing for use in heat pump, refrigeration, and air conditioning systems. Although tiny heat exchangers must be used with combustible refrigerants to reduce charge, propylene's condensation and flow boiling data inside a mini-channel are innovative. Propylene, with a GWP of 2, outperforms propane and R134a in terms of heat transfer performance. Heat transfer coefficients were measured during flow boiling at the temperature of saturation is 30 °C. The heat transfer coefficient is substantially influenced by heat flux but unaffected by mass velocity.

According to Jordan A et al.,[78] predicting here that the heat transfer for fluids with low global warming potential (GWP) is of major importance. This study examines the effectiveness of typical flow condensation correlations created for specific fluids. Propane and R600a data's heat transfer performance is most accurately predicted by the (Kim and Mudawar, 2013) correlation. The majority of analysed relationships were unable to forecast the CO_2 and ammonia heat transfer coefficient. The strongest predictors for synthetic refrigerants were Kim and Muda war (2013) and Cavallini et al. (2011). Since the present data on refrigerant condensation are outside the boundaries of the ranges considered, certain relationships have significant MAEs.

D. Colbourne et al.,[79] analysed the current industry and found that it is growing dissatisfaction with the stringent regulations on combustible refrigerants –especially class A3 -charge limits, within permissible limits. A3 refrigerants are seen to be preferable to other choices (like HFCs) for addressing the global warming issue. Clinical Laboratory (CL) requirements ought to be altered to reflect a more standardized method of calculating CL, and these revisions should apply to all horizontal/group and vertical standards. UCLs should be avoided in most (interior) contexts because they serve no use other than to confuse practitioners.

Stella Maia Rocha de Carvalho et al.,[80] stated that the hydrocarbon-mixed refrigerants were blended with an alternate flash tank with a vapour injection (FTVI) refrigeration cycle. The cycle was simulated and tuned for optimal COP using various refrigerant compositions. When compared to the usual vapor compression cycle, the introduction of an FTVI increased the COP from 4% to 36%. To determine whether an FTVI system is economically viable, an economic study should be performed. The best temperature glide matching in the evaporator was achieved by ethane/propane and propane/n-butane mixtures. Because of their composition, zeotropic mixed refrigerants enable improved temperature glide compatibility with heat exchange fluids.

Christian J.L. Hermes [81] presented an evaluation of the potential use of an exchange of heat from liquid to suction in order to reduce the refrigerant charge in vapour compression refrigeration cycles. The evaporation pressure, which rises for R717 and R22 and decreases for R134a, 290, and 600a, affects how much refrigerant is dissolved in oil. Charge reductions of up to 15% were observed for LBP and 5% for HBP applications. By 2050, residential air conditioner usage is expected to triple based on present patterns. In order to achieve Climate change's objective, particularly in the (sub) tropical region, it is important to research an incredibly energy-effective air conditioner with very little operational energy consumption. Therefore, in this regard, several literary perspectives are introduced, and then a detailed explanation of the present work's perspective follows.

2.3 Gap of the Knowledge:

A detailed discussion of the study on this Solar application-based air conditioner and refrigeration field conducted by several researchers is presented above. From the above discussion it is found that normal AC exists with huge power consumption presently and the tendency to use AC systems in the domestic sector is increasing day by day. Inverter AC with a five-star rating is already introduced in the market which helps to reduce power consumption, but the cost of the system is high. Therefore, it needs to find some optimization techniques and processes in the design stage so that the power consumption can be reduced. Work regarding the use of natural refrigerant along with solar energy-driven systems is found limited. Therefore, rigorous research work is needed in that regard for its real-time applications for the benefit of society.

2.4 Synopsys of the present work:

Since the last decade, the use of air conditioners as residential appliances and in the industry has grown. Progress in solar-powered air conditioning has increased in recent years; now, an If we want to have acceptable interior comfort inside the building, air conditioning equipment is almost always required.

The proposed research work will focus on how energy consumption pattern changes in domestic areas year by year in different regions. As we find domestic load is increasing day by day due to the incorporation of air-conditioning systems, solar air-conditioners may play a vital role in energy conservation and management of the energy system.

Therefore, detailed studies, future projections, and forecasting on the adaptation of solar air-conditioning systems will help in the future planning of power system expansion. Moreover, in this present study a photovoltaic (PV) system drive air conditioning system including solar thermal will be designed and its performance analysis will be done on a laboratory scale. Therefore, in the present work, a laboratory-scale domestic air conditioner is considered with a 1.5 Ton capacity and it would be operated on natural refrigerant (R290) and run with solar PV power. Further solar thermal energy can also be used for preheating the refrigerant to some extent at the suction of the compressor for increasing refrigerant pressure at that point for reduction of the compressor work. The theoretical analysis to find the energy-saving potential and possibilities of superheating with solar thermal energy can also be analysed with the help of software (Cool Pack, EES, etc.) while using natural refrigerants (R290, R600a, etc.). A comparative performance study also be carried out considering other various types of refrigerants (synthetic as well as organic) to find the best possible ways of using organic natural refrigerant keeping in mind the adverse effects (ODP and GWP) of synthetic refrigerants. The energy optimization criteria are also kept in mind in that study.

The authors of the current work guide the Micro design of the air conditioning system based on various climatic conditions in India by downsizing all essential parts like the compressor, evaporator, and condenser for the best possible power consumption and financial aspect. The potential for energy savings will be calculated using the Cool Pack version 1.50 software and the results also will be cross-checked and validated with those from the EES Software Professional V9.478 version 11.319 as well as experimental results. Here, the environmental behaviour of the natural refrigerant R290 is taken into account. The system's COP and compressor work, in particular, are approximated using comfortable climatic conditions like a temperature of 25°C and a 50% relative humidity. Finally, the energy conservation opportunities will be estimated by changing the evaporator and condenser temperatures by the various climatic zones, and that may significantly reduce the energy consumed by the compressor. Here shown Air conditioner normal operating cycle and solar thermal operated Air conditioner operating cycle in figure 2.1

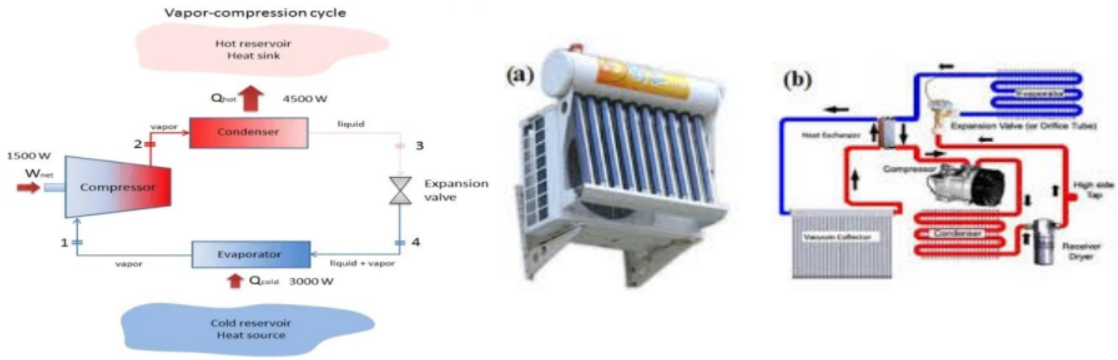


Figure 2.1 AC &Solar AC Operation Cycle

2.5 Conclusion:

Climate change nowadays is a global concern and a mounting threat to our well-being all over the world. In India, particularly in the northern region, temperature exceeds to 50 degrees Celsius mark. Since the last two decades, the Temperature of summer months in India has broken all the previous records of rising temperatures. India will be the World's third largest energy-consuming country by the year 2030, keeping behind the European countries, thanks to rising income and improving standard of living. With the increasing demand for home appliances, India's Air Conditioner market needs to grow more units, as 9.7 million units are projected to be introduced by the end of the 2023 fiscal year. Subsequently, the amount of electricity used by residences is expected to increase from 8TWh in 2010 to 239 TWh by 2030 due to the installation of air conditioning machines.

Such Increasing demand for electricity has a significant impact on the Indian power sector and there is an urgent need for new power plants. We have already seen that 40% of the energy consumed for domestic purposes could be saved by introducing solar power-based Green (with natural refrigerants) Air conditioners which will be cost-effective as well as efficient. This power transform to a potential energy saving of 118TWh at bus-bar or a peak demand saving of 60GW by 2030. This energy saving is possible through the implementation of Solar power-based Air conditioners with natural refrigerants. Natural refrigerants are used mainly to reduce Global warming potential (GWP) at the same time. The use of solar energy in recent years has had an alarming result in global warming and its depletion of the ozone layer. So, effective natural refrigerants are the best alternative to face zero ozone depletion potential (ODP) in place of higher ODP base synthetic refrigerants.

Tropical countries like ours have an abundant source of solar radiation. It increases ambient temperature and we have to use the Air conditioner to reduce excess heat to make room ambient temperature in a comfortable zone. So, we can use solar photovoltaic power to run Air conditioners for domestic and industrial purposes and maintain the Solar Energy Ecosystem by judiciously using solar radiation.

The whole system would be operated on Solar Power (DC) with natural refrigerant for vapour compression-based domestic scale air conditioning systems and for implementing the technique, more theoretical analysis is needed to have the energy optimization in this regard. Therefore, in the present work, software-based theoretical analysis is carried out along with some experimental work and presented in the form of a thesis. Most of the research work reported in this regard is discussed and summarized in detail to understand the gap in the knowledge presented in the present chapter. Accordingly, the work plan and synopsis of the present author are also discussed here. Solar Refrigeration Technology Advancement and its effect on Society is elaborately studied and presented in the next chapter.

References:

[1] T D J Prabha, Dr. V Rambabu, "Experimental investigation on the performance of air conditioner using R32 Refrigerant", (Jul. - Aug. 2015) IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE). e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 12, Issue 4 Ver. V, PP 139-144. DOI: 10.9790/1684-1245139144.

[2] Enyuan Gao, Qi Cui, Huaqian Jing, Zhiyuan Zhang, Xiaosong Zhang, "A review of application status and replacement progress of refrigerants in the Chinese cold chain industry", (2021) International Journal of Refrigeration. https://doi.org/10.1016/j.ijrefrig.2021.03.025.

[3] H. B. ExeI1 and S. Kornsakoo. Design and testing of a solar-powered refrigerator. Asian Institute of Technology Research Report No. 126.

[4] R. H. B. ExeIl. S. Kornsakoo. and S. Oeapipatanakul. A village-size solar refrigerator. Asian Institute of Technology Research Report No. 172.

[5] C S Choudhari, S N Sapali, "Performance Investigation of Natural Refrigerant R290 as a Substitute to R22 in Refrigeration Systems", (2017) Energy Procedia 109, 346 – 352.

https://doi.org/10.1016/j.egypro.2017.03.084.

[6] Cédric Philibert, 'THE PRESENT AND FUTURE USE OF SOLAR THERMAL ENERGY AS A PRIMARY SOURCE OF ENERGY' International Energy Agency, Paris, France.

[7] Debasmita Bal, S.L. Soni, Dilip Sharma, 'Healing global warming with Solar Air conditioning: a review', (2014) IJSRET, ISSN:2278-0882, 1EERET-2014.

[8] IEA Renewable Energy Division in 2012, International Energy Agency (IEA) Secretariat, 9 rue de la Fédération,75739 Paris Cedex 15, France, *www.iea.org.*

[9] Zhang Xingjuan, Song Bojie, Bai Qingyuan, Yang Chunxin, "Performance analysis on a new type of solar air conditioning system", (2013) Energy and Buildings 60, 280–285. https://doi.org/10.1016/j.enbuild.2013.01.018.

[10] A.Vaidyanathan, 'White paper on Solar Thermal Technologies' www.cleantechconsultants.in

[11] C. Koroneos, E. Nanaki, G. Xydis, Solar Air-conditioning Systems Impact on the Built Environment – A, Thermodynamic Approach, (2009) 45th ISOCARP Congress 2009.

[12] BIS (1916), National Building Code of India. Available at: http://bis.org.in/sf/nbc.htm (Accessed: 5 Sept. 2018)

[13] H. Lee, Thermo-electrics- Design and Materials, (2016) John Wiley and Sons.

[14] X.Q. Zhai, R. Z. Wang, J.Y. Wu, Y.J.Dai and Q. Ma, " *Design and performance of a solar-powered air-conditioning system in a green building",* (2008)Journal of Applied Energy, Vol.85, pp 297-311. https://doi.org/10.1016/j.apenergy.2007.07.016.

[15] H. Lee, Thermal Design: Heat Sinks, Thermo-electrics, Heat Pipes, Compact Heat Exchangers, and Solar Cells, (2010) Hoboken: John Wiley & Sons, Inc.

[16] Abas, N.; Kalair, A.R.; Khan, N.; Haider, A.; Saleem, Z.; Saleem, M.S. Natural and synthetic Refrigerants, global warming, A review. (2018) Renew. Sustain. Energy Rev. , 90, 557–569. [Google Scholar] [Cross Ref]

[17] C. Vinning, "An inconvenient truth about thermoelectrics," (2009) *Nature Materials,* vol. 8, no.2, pp. 83-85.http://dx.doi.org/10.1038/nmat2361.

[18] Shekarchan M, Zarifi F, Moghavvemi M, Motasemi F, Mahlia TMI, Energy, Exergy, Environmental and economic analysis based on heat recovery and preheating technique, (2013) Energy convers Manage; 71:51-61.

[19] Latest Air conditioner Technology in India: Review, (2019).
available at https://www.bijlibachao.com/air-conditioner-ac/latest-air-conditioner-technologies-india-review-2.html. (www.googlegate.com.)

[20] Harby K, Hydrocarbon and their mixtures as alternatives to environmental unfriendly halogenated refrigerants: An updated overview.(2017) *Renewable and Sustainable Energy Reviews*, 73, 1247-1264.

[21] Bin-Juine Huang, Tung-Fu Hou, Po-Chien Hsu, Tse-Han Lin, Yan-Tze Chen, Chi-Wen Chen, Kang Li, K.Y. Lee, "Design of direct solar PV driven air conditioner", Renewable Energy 88 (2016) 95-101. http://dx.doi.org/10.1016/j.renene.2015.11.026.

[22] Mani, Pooja Iyer, "Design, Modeling and Simulation of a Thermoelectric Cooling System (TEC)" (2016).*Master's Theses*.749.available at: http://scholarworks.wmich.edu/masters_theses/749.

[23] Roy, S. Mukherjee S. and Chakravorty M. submitted at the *International Conference on Impact of Changing Energy Mix in the Power Sector* (ICIEMPS- 2019), (2019) The Institute of Engineers (India), WBSC, 23-24 Nov.

[24] Ramesh Rohan Patil and C. N. Nataraj, Comparative Analysis of Different Refrigerants, (June 2016) IJIRSET, Vol. 5, Issue 6.

[25] N.S.S.O., Statistical Data, Govt. of India, 2014.

[26] R. Ciconkov, Refrigerants. There is still no vision for sustainable solutions. (2018) Int. J. Refrig., **86**, 441–448. [Google Scholar] [CrossRef],.

[27] Yogesh Musale, Satyawant Patil, Bhakti Chougule, Amruta Kulkarni and Ashish S. Utage, "Recent Developments in Solar Refrigeration Technology - A Review", (March 2016) International Journal of Current Engineering and Technology, Special Issue-4, E-ISSN 2277 – 4106, P-ISSN 2347 – 5161. DOI:10.14741/Ijcet/22774106/Spl.4.2016.17.

[28] R. K. Bansal, Fluid Mechanics& Hydraulic Machine, (2010) Laxmi Pub(P) Ltd., New Delhi.

[29] H. Liu, Evaluation of a seasonal storage system of solar energy for house heating using different absorption couples [J], Energy Conversion and Management **52**, 2427–2436,(2011).

[30] K.M. Tsamos; Y.T. Ge, I. Santosa; S.A. Tassou; G. Bianchi; Z. Mylona, Energy analysis of alternative CO_2 refrigeration system configurations for retail food applications in moderate and warm climates. Energy Convers. Manag., **150**, 822–829. [Google Scholar] [CrossRef], (2017).

[31] P.Gullo; B. Elmegaard; G. Cortella, "Energy and environmental performance assessment of R744 booster supermarket refrigeration systems operating in warm climates",(2016) Int. J. Refrigeration, **64**, 61–79. [Google Scholar] [CrossRef][Green Version].

[32] S. B. Riffat, C. F. Afonso, A. C. Oliveira and D. A. Reay, "Natural Refrigerants for Refrigeration and Air-Conditioning Systems", (1997) Applied Thermal Engineering, Vol. 17, No. I, pp. 3342.

[33] A Text Book of Fluid Mechanics- Rajput, S. Chand & Co. (2013).

[34] Gaurav Gupta, Gaurav Gattani, Jerin Samuel, Rakshit Ratan and Shivank Bhardwaj, "Unconventional Energy Harness: A Review on Developments of Solar Power based Multipurpose Refrigerator", (April 2016) International Journal of Engineering Technology Science and Research (IJETSR), ISSN 2394 – 3386, Vol. 3, Issue 4.

[35] SurithNivas, Vishnu Vardhan, Raam Kumar, Ramya. Sai Prasad, "Photo-voltaic Driven Dual Purpose Thermoelectric Refrigerator for Rural India". (June- 2018) International Journal of Advancements in Research & Technology, Volume 2, Issue 6.

[36] J. Sea bright; Presentation to Refrigerants Naturally in Brussels, Belgium during June 2004. Available at: http://www.refrigrant naturally.com/ speech.pdf **123**, Jan. 2007.

[37] Proposed amendment to Montreal Protocol submitted by Canada, Maxico and United State of America UNEP, (2013). Available at https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol.

[38] Latest Air –conditioning Technology in India—Review, (2019) Journal paper on future of Air-conditioning for Builders.

[39] Prasanta Kumar Bal, Andimuthu Ramachandran, Kandasamy Palanivelu, Perumal Thirumurugan, Rajadurai Geetha, and Bhaski Bhaskaran (2016) "Climate Change Projections over India by a Downscaling Approach Using PRECIS," The Korean Meteorological Society and Springer 2016, Asia-Pac. J. Atmos. Sci., 52(4), 353-369, 2016, DOI:10.1007/s13143-016-0004-1, pISSN 1976-7633 / eISSN 1976-7951.

[40] Yanjie Li, Victor Nian, Hailong Li, Shengchun Liu, Yabo Wang, " A life cycle analysis techno-economic assessment framework for evaluating future technology pathways – The residential air-conditioning example", (2021) Applied Energy 291, 116750, Science Direct.

[41] Gustavo de, Novaes Pires Leite, FrancieleWeschenfelder, Alex Mauricio, Araujo,Alvaro Antonio Villa Ochoaa, Newton da Franca PrestreloNetoa, Andrea Kraj, "An economic analysis of the integration between air-conditioning and solar photovoltaic systems", (2019) Energy Conversion and Management 185, 836–849, Science Direct.

[42] I. Dauta, M. Adzriea, M. Irwantoa, P. Ibrahima, M. Fitraa, "Solar Powered Air Conditioning System", (2013) Energy Procedia 36 444 – 453. doi: 10.1016/j.egypro.2013.07.050.

[43] Arthur Heleno Pontes Antunes, Enio Pedone Bandarra Filho, "Experimental investigation on the performance and global environmental impact of a refrigeration system retrofitted with alternative refrigerants", (2016) International Journal of Refrigeration 70, 119–127.

[44] J. Aman, D.S.-K. Ting, P. Henshaw, "Residential solar air conditioning: Energy and exergy analyses of an ammonia–water absorption cooling system",(2014) Applied Thermal Engineering 62, 424-432.

[45] Piotr A. Domanski, J. Steven Brown, Jaehyeok Heo, Janusz Wojtusiak, Mark O. McLinden, “A thermodynamic analysis of refrigerants: Performance limits of the vapor compression cycle”, (2014) International Journal of Refrigeration 38, 71-79.

[46] Saurav Dubey, Sunil Chamoli and Ravi Kumar, ‘Indian Scenario of Solar Energy and its Application in Cooling Systems: A Review’,(2013) International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 6, Number 4, pp. 571-578.

[47] Lawrence Drojetzki and Mieczysław Porowski, “The problem of selecting an energy-optimal cooling system using natural refrigerants in a supermarket application in a humid continental and Mediterranean climate conditions”, (2022) International Journal of Refrigeration 136, 184–208.

[48] Lawrence Drojetzki and Mieczyslaw Porowski, “Outdoor Climate as a Decision Variable in the Selection of an Energy-Optimal Refrigeration System Based on Natural Refrigerants for a Supermarket”, (2023) Energies, 16, 3375.https://doi.org/10.3390/en16083375

[49] Bi Yuehong, ZangGaoli, QinLifeng, LiHongyan, Wang Hongyan, (1 December 2019) Energy and buildings, volume 204, ,109456, DOI: 10.1016/j.enbuild.2019.109456

[50] Baniyounes, Ali M. &Ghadi, Yazeed Yasin & Rasul, M.G. & Khan, M.M.K., (2013). "An overview of solar assisted air conditioning in Queensland's subtropical regions, Australia," Renewable and Sustainable Energy Reviews, Elsevier, vol. 26(C), pages 781-804. DOI: 10.1016/j.rser.2013.05.053.

[51] R. Opoku, S. Anane, I.A. Edwin, M.S. Adaramola, R. Seidu, “Comparative techno-economic assessment of a converted DC refrigerator and a conventional AC refrigerator both powered by solar PV”, (2016) International Journal of Refrigeration 72, 1–11.

[52] D.C. Gao, Y.J. Sun, Z. Ma, H. Ren, “ A review on integration and design of desiccant air-conditioning systems for overall performance improvements”, (2021) Renewable and Sustainable Energy Reviews 141, 110809, Science Direct.

[53] Qudama Al-Yasiri, Márta Szabó, MüslümArıc, “A review on solar-powered cooling and air-conditioning systems for building applications”, (2022) Energy Reports 8, 2888–2907, Science Direct.

[54] Zixu Yang, Youlin Zhang, Hansong Xiao, Rong Zhuang, Xiangfei Liang, Mengdi Cui, Xin Li, Jiaan Zhao, Qi Yuan, Ruiqi Yang, Baolong Wang, Wenxing Shi, “Comprehensive test of ultra-efficient air conditioner with smart evaporative cooling ventilation and photovoltaic”, (2022) Energy Conversion and Management 254, 115267, Science Direct.

[55] Jay Prakash Bijarniya, Jahar Sarkar, Pralay Maiti, “Performance improvement of CO_2 air conditioner by integrating photonic radiative cooler as sub-cooler or/and roof envelope, (2022) Energy Conversion and Management 251, 115019, Science Direct.

[56] Aziz Haffafa, FatihaLakdjaa, DjaffarOul, Abdeslamc and Rachid Meziane, “Solar energy for air conditioning of an office building in a case study: Techno-economic feasibility assessment”,(December 2021) ELSEVIER, Renewable Energy Focus, Volume 39.

[57] Nihar Shah, Won Young Park, Chao Ding, “Trends in best-in-class energy-efficient technologies for room air conditioners”, (2021) Energy Reports 7, 3162–3170, Science Direct.

[58] B. Saleh, and Ayman A. Aly, “Flow Control Methods in Refrigeration Systems: A Review”, INTERNATIONAL JOURNAL OF CONTROL, AUTOMATION AND SYSTEMS VOL.4 NO.1 January 2015. ISSN 2165-8277 (Print) ISSN 2165-8285 (Online).

[59] Karthik Panchabikesan, KumaresanVellaisamy, Velraj Ramalingam, “Passive cooling potential in buildings under various climatic conditions in India”. (2017) Renewable and Sustainable Energy Reviews 78, 1236–1252, Science Direct.

[60] D. S´anchez, A. Andreu-N´acher, D. Calleja-Anta, R. Llopis, R. Cabel, “Energy impact evaluation of different low-GWP alternatives to replace R134a in a beverage cooler. Experimental analysis and optimization for the pure refrigerants R152a, R1234yf, R290, R1270, R600a and R744”, (2022) Energy Conversion and Management 256, 115388.
https://doi.org/10.1016/j.enconman.2022.115388

[61] Ali Al-Alili, Yunho Hwang, Reinhard Radermacher, “A hybrid solar air conditioner: Experimental Investigation”, (2014) International Journal of Refrigeration 39, 117-124.
http://dx.doi.org/10.1016/j.ijrefrig.2013.10.006

[62] Yuhe Gao, Jie Ji, Kedong Han, Feng Zhang, "Comparative analysis on performance of PV direct-driven refrigeration system under two control methods", (2021) International Journal of Refrigeration 127, 21-33.https://doi.org/10.1016/j.ijrefrig.2021.03.003

[63] D. Sánchez, R. Cabello, R. Llopis, I. Arauzo, J. Catalán-Gil, E. Torrella, "Energy performance evaluation of R1234yf, R1234ze(E), R600a, R290 and R152a as low-GWP R134a alternatives", (2017) International Journal of Refrigeration 74, 269–282.http://dx.doi.org/10.1016/j.ijrefrig.2016.09.020

[64] F.J. Aguilar, S. Aledo, P.V. Quiles, "Experimental analysis of an air conditioner powered by photovoltaic energy and supported by the grid", (2017) Applied Thermal Engineering 123, 486–497. http://dx.doi.org/10.1016/j.applthermaleng.2017.05.123.

[65] Dariusz Butrymowicz, Kamil Smierciew, Jarosław Karwacki, Jerzy Gagan, "Experimental investigations of low-temperature driven ejection refrigeration cycle operating with isobutane", (2014) International Journal of Refrigeration 39, 196-209.

[66] Mustafa Ozsipahi, Haluk Anil Kose, HusnuKerpicci, Hasan Gunes, "Experimental study of R290/R600a mixtures in vapor compression refrigeration system", (2022) International Journal of Refrigeration 133, 247–258. https://doi.org/10.1016/j.ijrefrig.2021.10.004

[67] Sergio Ledesma, J.M. Belman-Flores, J.M. Barroso-Maldonado, "Analysis and modeling of a variable speed reciprocating compressor using ANN, (2015) International Journal of Refrigeration 59, 190–197. http://dx.doi.org/10.1016/j.ijrefrig.2015.08.009

[68] Tingxun Li, Jian Lu, Lei Chen, Dongcai He, Xiaozhou Qiu, Hongyao Li, Zhen Li, "Measurement of refrigerant mass distribution within a R290 split air conditioner", (2015) International Journal of Refrigeration 57, 163–172. http://dx.doi.org/10.1016/j.ijrefrig.2015.05.012.

[69] Cleison Henrique de Paula, Willian Moreira Duarte, Thiago Torres Martins Rocha, Raphael Nunes de Oliveira, Antônio Augusto Torres Maia, "Optimal design and environmental, energy and exergy analysis of a vapor compression refrigeration system using R290, R1234yf, and R744 as alternatives to replace R134a", (2020) International Journal of Refrigeration 113, 10–20. https://doi.org/10.1016/j.ijrefrig.2020.01.012.

[70] Dehua Cai, Zian Hao, Hao Xu, Guogeng He, “Research on flammability of R290/R134a, R600a/R134a and R600a/R290 refrigerant mixtures”, (2022) International Journal of Refrigeration 137, 53–61. https://doi.org/10.1016/j.ijrefrig.2022.02.015.

[71] Ali Al-Alili, Yunho Hwang, Reinhard Radermacher, “Review of solar thermal air conditioning Technologies”, (2014) International Journal of Refrigeration 39, 4-22. http://dx.doi.org/10.1016/j.ijrefrig.2013.11.028.

[72] Renato M. Lazzarin, “Solar cooling: PV or thermal? A thermodynamic and economical analysis”, (2014) International Journal of Refrigeration 39, 38-47. http://dx.doi.org/10.1016/j.ijrefrig.2013.05.012.

[73] Naci Kalkan, E.A. Young, Ahmet Celiktas, “Solar thermal air conditioning technology reducing the footprint of solar thermal air conditioning”, (2012) Renewable and Sustainable Energy Reviews 16, 6352–6383. http://dx.doi.org/10.1016/j.rser.2012.07.014.

[74] Qi Chen, Le Zhou, Gang Yan, Jianlin Yu, “Theoretical investigation on the performance of a modified refrigeration cycle with R170/R290 for freezers application”, (2019) International Journal of Refrigeration 104, 282–290. https://doi.org/10.1016/j.ijrefrig.2019.05.037.

[75] Harrison M. Skye, Piotr A. Domanski, Riccardo Brignoli, Sanghun Lee, Heunghee Bae, “Validation of and Optimization with a Vapor Compression Cycle Model Accounting for Refrigerant Thermodynamic and Transport Properties: With Focus on Low-GWP Refrigerants for Air-Conditioning”, (2022) International Journal of Refrigeration 11. https://doi.org/10.1016/j.ijrefrig.2022.11.014.

[76] B.Y. Zhao, Y. Li, R.Z. Wang, Z.G. Zhao, R.A Taylor, “A universal method for performance evaluation of solar photovoltaic air conditioner”, (2018) Solar Energy 172, 58–68, https://doi.org/10.1016/j.solener.2018.05.029.

[77] Davide Del Col, Marco Azzolin, Stefano Bortolin, Arianna Berto, Experimental results and design procedures for minichannel condensers and evaporators using propylene, (2017) International Journal of Refrigeration 83, 23–38, https://doi.org/10.1016/j.ijrefrig.2017.07.012.

[78] Jordan A. Morrow, Ryan A. Huber, Kashif Nawaz, Melanie M. Derby, “Flow condensation heat transfer performance of natural and emerging synthetic refrigerants”, (2021) International journal of refrigeration 132, 293–321. https://doi.org/10.1016/j.ijrefrig.2021.09.014

[79] D. Colbourne, K.O. Suen, T.-X. Li, I. Vince, A. Vonsild, “General framework for revising class A3 refrigerant charge limits –a discussion”, (2020) International Journal of Refrigeration, 117, 209–217. https://doi.org/10.1016/j.ijrefrig.2020.04.024.

[80] Stella Maia Rocha de Carvalho, Luiz Henrique Parolin Massuchetto, Raiza Barcelos Corrêa do Nascimento, Hugo Valença de Araújo, José Vicente Hallak D’Angelo, “Optimization of a vapor injection refrigeration cycle using hydrocarbon mixed refrigerants”, (2018) International Journal of Refrigeration 98, 109–119. https://doi.org/10.1016/j.ijrefrig.2018.10.008.

[81] Christian J.L. Hermes, “Refrigerant charge reduction in vapor compression refrigeration cycles via liquid-to-suction heat exchange”, (2015) International Journal of Refrigeration 52, 93- 99. http://dx.doi.org/10.1016/j.ijrefrig.2014.12.014.

CHAPTER 3

Chapter 3

Advancement of Solar Refrigeration Technology and its Impact on Society

3.1 Introduction:

Environmental problems including greenhouse gas (GHG) emissions in homes and businesses are linked to modern refrigeration and air conditioning systems. Through refrigerant leakage and the use of electricity generated from fossil fuels to operate the systems, these emissions at source directly contribute to climate change. Although the cost of electricity needed for maintenance is progressively increasing, India's per capita income [1] quadrupled in just seven years, rising from Rs. 63.5 K to Rs. 1.25 Cr, air conditioning (AC) is no longer considered a luxury good. Accordingly, 15% of the global population is thought to have access to refrigeration or a refrigerator, which provides a pleasant indoor temperature and great indoor air quality at 20% of the global energy cost [2]. Due to the rising global temperature, AC is gradually turning into a humanitarian requirement in many areas. For instance, in 2015, the deadliest heat wave on record caused over 2,300 fatalities in India. Thus, unless action is taken to limit the direct and indirect effects of AC consumption, the sharp rise in society demand for AC equipment over the past few decades will worsen the state of the environment. In this paper, our goal is to categorize the adoption of new technological paradigms into two primary groupings based on the energy supply, with the goal of reducing climate change through improved energy efficiency. In a nutshell, solar cooling technology [3] updates as follows:

3.1aHeat- and work-driven system

- Desiccant cooling cycle,
- Cycle of adsorption refrigeration,
- Ejector refrigeration cycle, and
- Absorption refrigeration cycle;

3.1b Electricity (photovoltaic) driven system

- Thermo-electric refrigeration cycle,
- Stirling refrigeration cycle, and
- vapor compression refrigeration cycle

3.1c a fresh strategy for low-carbon technology

- Significant usage in refrigeration or refrigeration systems, of refrigerant sector that contributes significantly to long-term ecological improvement.

3.2 Design of Development scenario of Solar Refrigeration Technology:

The system for thermal refrigeration, which is powered by fossil fuels, emits significant amounts of greenhouse gases with an average efficiency of roughly 35%. This analysis focuses on developments in solar refrigeration, where Li-Br and water were the ideal combination for absorbing the refrigeration process. Additionally, refrigerant water (H2O) has no ozone-depleting potential (ODP) and an extremely low GWP. In light of this, various researchers have proposed two types of solar-powered air-conditioning and cooling systems:

A. Photovoltaic (PV) conversion;

B. Photo-thermal conversion

Similar to that, we choose here to combine the aforementioned two techniques (Fig. 3.1) utilizing a green absorbent that is marketed as being cost-effective. When compared to thermal cooling, the photovoltaic cooling percentage has a standard deviation of 12 percent higher.

As a result, the benefit of employing this design is that it may be utilized as a standalone system with working fluids that are primarily non-toxic and environmentally friendly, like water or salt solution. Furthermore, both active and passive systems can offer the cooling process.4. To achieve solar cooling, at least four recognized technologies are used: -

- Vapor compression,
- absorption-based cooling,
- evaporation cooling,
- solar ejector cooling

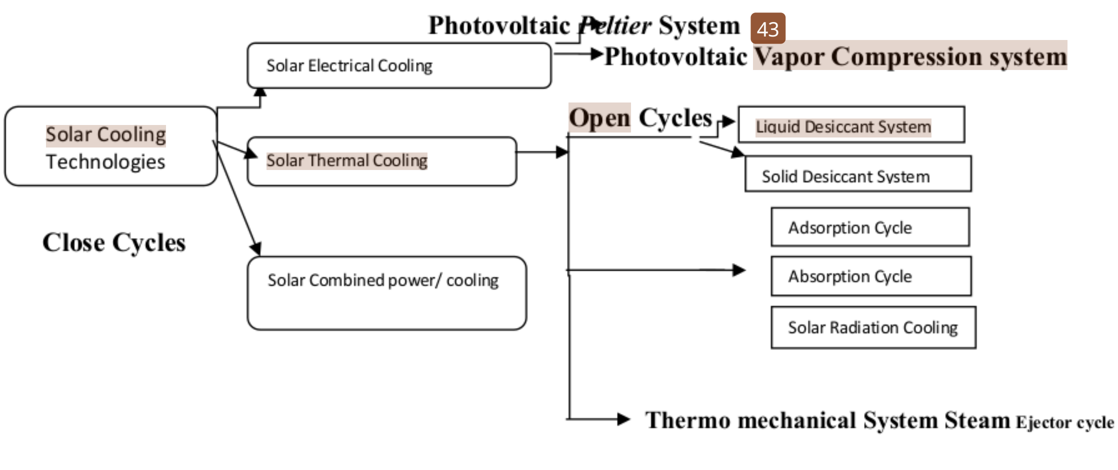


Figure 3.1: Solar Thermal Cooling Technology

Illustration: According to the Peltier system or effect, heat is absorbed into one end of a thermoelectric material and released from the other end as a result of a current flowing through the material. The thermoelectric cooler (TEC) used in solar thermoelectric cooling, also known as cooling technology (Fig. 3.2), has the advantages of high undependability, compact size and the absence of mechanical moving parts, light weight, and the lack of working fluid. When refrigeration is used, heat is removed from the area to drop its temperature below that of its surroundings. As a result, the Peltier effect, or thermoelectric cooling, prefers the gas compression cycle or the vapor compression cycle. As compression refrigeration's capacity increases, its co-efficient of performance (COP) declines. Therefore, it is necessary to design a low-capacity refrigerator to minimize noise, thereby optimizing the sensitivity. Hence, Solar based thermoelectric refrigerators (TERs) are a good option for chilling pharmaceutical items and applications involving food preservation.

In principle, solar power may therefore, be generated from these energy sources with outstanding efficiency because the max. possible efficiency, i. e., Carnot efficiency,

$$\eta = 1 - \frac{Tout}{Tin}$$

increases with T_{in} where T_{out} is the output temp.

3.2a Vapor compression refrigeration

The benefit of this system is that it collects heat from the area to be cooled and then releases it external to the system. Here, A solar collector collects solar energy, and transferred to the dc compressor using mechanical power. In addition to consuming energy, this method [3] has several detrimental effects on the environment. Because they use hydrofluorocarbons (HCFC) or chlorofluorocarbons (CFC) as refrigerants, they contribute to ozone loss and the greenhouse impact. The absorption system is a viable choice to reduce the consumption of power and CFCs while looking for sustainable energy utilization methods. Solar energy and system waste heat can be used to run absorption cooling devices to conserve energy.

3.2bAbsorption cooling

Solar energy is gradually absorbed through the collector, evaporator, and condenser during the daytime hour. As a result of the absorbent's release of absorbed water as a result of the collector's heating from the sun and the condenser's low pressure, water vapor is produced. The collector cools down over night and is ready to take in more water vapor in the morning. The temperature of the cooling chamber decreases because evaporation uses thermal energy [4]. In this manner, the absorption process enables nighttime cooling of the chilling chamber. To maintain the machine's cooling capacity during the day, the absorbent is rejuvenated utilizing sun radiation. LiBr-H_2O is occasionally used as an absorbent in the back [8, 10], which raises the possibility of crystallization and makes air cooling difficult. Ammonia is also occasionally used.

3.2c Evaporative air-cooling

Indirect air cooling, direct air cooling, and combinations of these three types of cooling with other methods are included. Devices for indirect evaporative cooling [8,9] cause the direct evaporation of water from a component of a water spray into the atmosphere. Environmental thermal energy is extracted by evaporation, which accounts for the drop in temperature. Furthermore, water evaporation could make the air more humid. When using indirect evaporative cooling methods, water evaporates into what is referred to as a heat exchanger, which cools the air that is passing through an air stream. Although sun energy is not necessary for evaporative cooling devices themselves, it can be used to heat the surface of a water-filled pan to speed up the evaporation process.

3.2d Solar ejector cooling (SEC)

This alternative technique is unquestionably effective under load and possesses a high coefficient of performance (COP). Here, As a refrigerant, water is used since it is safe and has strong heat conductivity. Additionally, it serves as a heat transfer fluid, enabling the design of a 'open' system between the solar collector, SEC, and chilled water delivery system without the need for hydraulic separation. The purpose of this project is to exchange experimental information for altering operating conditions and to analyze economic factors and potential system efficiency.

Solar-powered Ejector Cooling (SEC) has only been explored up to this point. Despite having a modest nominal COP value, the SEC is evaluated in operation because to its straightforward design and assembly [6]. The operation of the SEC is made possible by the use of ordinary refrigerators. Flat plate collectors (shown in Fig. 3.2) can supply heat at a low temperature.

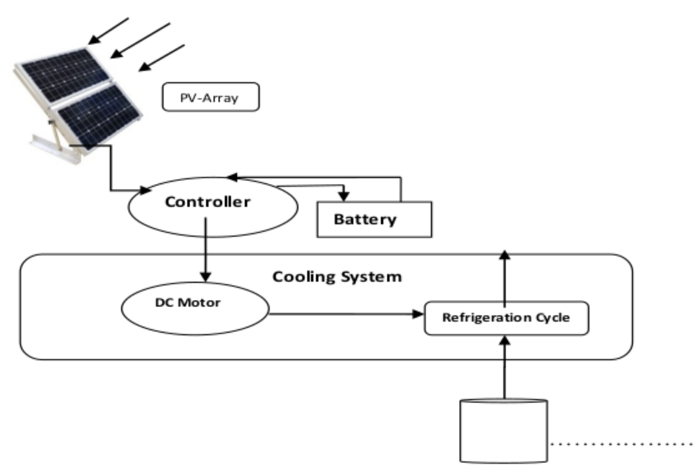


Figure 3.2: A PV-powered refrigerator's symmetrical configuration for a far-off village

A schematic of a "refrigeration" system is shown in Fig. 3.2. In order for the new system [6,7] to operate with solar at the source and optionally with conventional sources, when necessary, solar combined power/cooling will be added to the existing system.

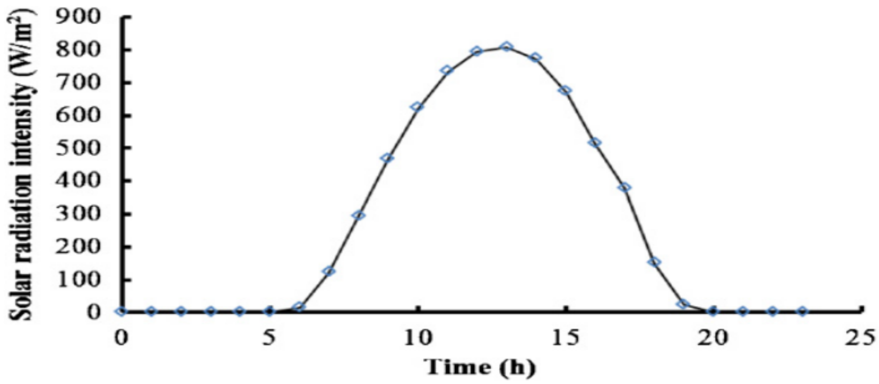


Figure 3.3: Variation of daily solar radiation intensities

According to the most recent research, thermal refrigeration powered by fossil fuels produces a significant amount of greenhouse gas emissions and has an average efficiency of around 35% [9]. However, the solar-powered refrigerator, which uses water (H_2O) as a refrigerant, has a negligible chance of contributing to global warming and no ozone depletion. Therefore, solar-powered refrigerator systems will have the best chance of being adopted by rural communities like Jhapandanga in Burdwan, Kaikhali in 24 Parganas (S), and Kutilpara village in Dankuni coal complex area under Hooghly, where there has been a long absence of a traditional grid system. The most abundant source of energy in India is solar energy, which has an average solar isolation of 5.5 KW/m^2/day over nearly 60% of the nation. Here, some sort of work must be done to generate mechanical work, often done by using regular electricity or other methods, in order to satisfy the second rule of thermodynamics. Conviction, conduction, and radiation have all been used as three of the fundamental heat transfer operations [10] during the process. Solar radiation and module temperature are the main determinants of a PV module's current-voltage and power-voltage parameters. [11].

3.2 Methodology:

The following is the basis of the strategies:

a. ***Data Analysis***: gathering data on demand based on growth in per capita income, meteorological data, and hourly, monthly, and annual solar radiation processing;

b. ***Cooling load calculation***: determining the type of cooling and the amount of cooling required;

c. ***Design and sizing of the AC system***: It is possible to size the system's components using a few design conditions;

d. ***Optimization of the system***: System design must be adjusted with the use of the least expensive energy in mind;

e. ***Performance evaluation and economic analysis***: It will be determined whether the system is economically viable. Calculating the lifecycle expenses of a solar cooling system and assessing its affordability and thermal effectiveness for domestic use;

f. ***Analysis of the outcome and a potential remedy***: The outcomes will be looked at, and a potential solution will be found. There will be a risk to the potential for enhancing technological effectiveness. Also investigated were ways to improve field research and development (R&D).

Use and abuse of types of inorganic sample as Refrigerant:

i) Ammonia is often a safe and effective refrigerant used in refrigeration and heat pumps. This is unusual compared to the risk that society perceives as being posed by ammonia, which has a very unsettling odor. Ammonia is the best refrigerant available, and it has outstanding thermodynamic properties that are also beneficial to the environment. On the other hand, the breakdown of natural compounds into ammonia (NH3), which is the recirculation of nitrogen, is essential for all life. However, anhydrous ammonia is employed as a refrigerant [12].

ii) The most effective solution for present global demands is refrigeration based on carbon dioxide. CO_2 is safe and non-hazardous and has a significantly lower Global Warming Potential (GWP) than hydro-fluorocarbon (HFC) when used in our air conditioners and coolers [13]. Due to the fact that they do not harm the ozone layer, they are superior to hydro color fluoro carbon (HCFC).

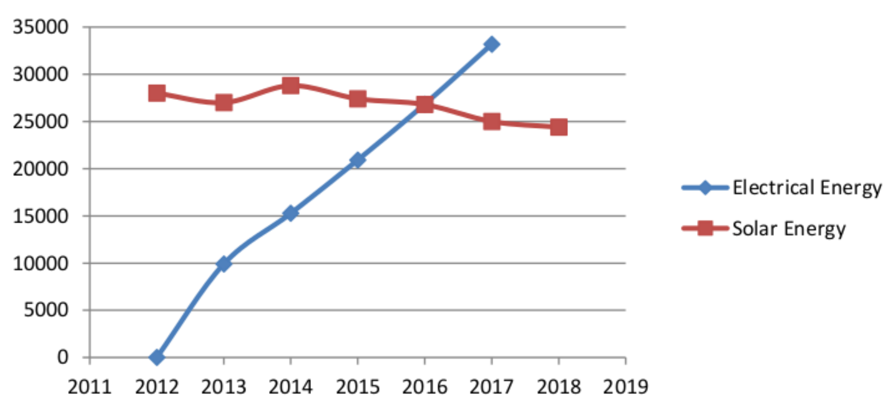


Figure 3.4: Cost comparison of Solar & Electrical energy Refrigeration

N.B.: The opportunity to use solar energy is expanding day by day, whilst the cost of conventional electrical energy has been skyrocketing.

3.4 Phasing out harmful HFCs:

An important and expanding source [15] of GHGs is refrigeration. Reduced usage of refrigerants with high Global Warming Potential (GWP) is required by European Parliament Directive 517/2014. Because R152a has a low GWP of less than 150, it appears to be a potential option among hydrofluoric carbons. To establish it, just the flammability issues need to be resolved. With the redesigned system's parallel compression, sub-cooling, and Ejector devices, using CO_2 appears to be a promising future option [18, 19]. The use of low-carbon technology to replace HFCs in refrigeration systems had not yet been demonstrated to have a positive influence on the climate in 2010, hence new methods of refrigeration starting in 2015 were not yet in use. With this focus on sustainability and the necessary innovation dynamics, we were able to observe new technological standards in the refrigeration and freeze segment of the commercial market, which significantly improved the ecological quality of the various foods in the retail sector. The current investigations demonstrate excellent performance and good compatibility with the installed systems. Consequently, a more in-depth analysis of this working fluid is necessary. This study provides an in-depth examining a cooling system, employing R152a in order to determine its functionality and cooling capacity under different operational circumstances. The design of a regression model for the system performance prediction and the evaluation of the numerous operating scenarios are what make this investigation distinctive.

A back aluminum condenser is sometimes preferred over a front aluminum condenser because it is less expensive, but it corrodes more quickly and is more difficult to fix. It becomes necessary to switch to a copper condenser over time. The dynamics of the inverter follow next, which requires a compressor to alter the power's magnitude. With this technique, the compressor is continually running but uses different amounts of electricity depending on the thermostat settings and the temperature of the entering air. Thus, the R-410 refrigerant is environmentally benign. Additionally, R-410A can be used, which is more energy-absorbing and energy-releasing than standard refrigerant and also reducing compressors' risk factor.

3.5 Efficiency Analysis:

The development of a more affordable and energy-efficient thermoelectric refrigeration system based on solar power that can store vaccines at temperatures between 2 and 8^0 C is proposed

(a) Load estimation

Total rated wattage: Prated = q ×Prated … … … (1)

Energy demand : Prated ×H … … … (2)

Load demand: Ed (Ah) $= \frac{Ed}{\eta \times V}$ (Ah) … … … (3)

Corrected load: EC (Ah) = Ed (Ah) / η … … … (4)

(b) Battery sizing

Battery capacity: $= \frac{EC}{(DOD)\times\eta}(Ah)xDc$ … … … (5)

. © Performance Indicators:

Collector Area … … … … … $5m^2$

Electrical capacity (based on 1000 W/m^2 incident solar radiation) ……… 750W

Heating capacity (based on 1000 W/m^2 incident solar radiation)……… 2000W

Cooling capacity (based on 1000 W/m^2 incident solar radiation)………… 750 W

PV module efficiency (1000W/m^2 incident solar radiation)……………… ≥ 40%

System cooling efficiency (overall 1000 W/m^2 incident solar radiation) … ≥ 15%

3.6 Economic and social impact:

Fresh produce trade volume in developing countries has increased as a result of sustained consumer demand for new fruits and vegetables in industrialized nations. As a result, there are now more jobs in both the rural and urban areas, more small farms are expanding, and the revenue gaps between farms of various sizes have decreased. Countries like ours are increasingly in demand for items with high value as they become wealthy. In developing nations, the impact of income increase on consumption is more evident. The report thus shows a bright future in the ensuing decades. Only modern cooling technology [20] that evenly distributes air through multi-directional vents makes this possible. With the aforementioned planned airflow, food items are thus kept fresher for longer.

3.7 Environmental Impact:

According to current research, a solar panel generates solar energy that is then stored in an underground reservoir before being pumped to an overhead water tank to change kinetic energy into potential energy. Solar radiation will activate a micro-hydel machine with high pressure to generate electricity, which will also be a cost-effective refrigerant mix and convert water into electricity. Additionally, employing ammonia is more energy-efficient, leak-free, and better for the environment.

Refrigerant characteristics, inverter and compressor usage in clean and environmentally acceptable absorbent materials are all possible in nature. The amount of solar radiation needed and the amount available are virtually synchronized. But when the amount of solar radiation fluctuates or even disappears completely at night, it is crucial for the solar refrigeration cycles to be able to operate continuously. Dennis suggested a workaround that involved installing a cold storage interior in place of the solar cooling system, which is unable to offer refrigeration at night [12]. Henrik reasoned that keeping a portion of the regenerating solution might be useful [13] and the refrigerant separately to lessen the effects during brief periods of gloomy weather. With cutting-edge energy storage technology, Xu unveiled a brand-new solar-powered absorption refrigeration (SPAR) system, initial chemical transformation into the working fluid's potential, followed by systemic storage, solar radiation energy was first converted. The proposed technology is capable of resolving the issue of the nonconformity [1]4 between solar radiation and cooling needs. For a long-term energy storage system, Liu suggested a novel idea. The analytic function of the solar system absorbs and stores solar energy in the summer, while the adsorption system releases heat in the winter [15,21].

Table 3.1: Per capita National Income Growth

Financial Year	Annual Growth (%)	Remarks
2013-14	11.9	India's per capita income will cross $1800 where China's is over $ 8,000
2014-15	11.5	
2015-16	9.5	
2016-17	9.3	
2017-18	9.6	Per capita income is double in seven years from Rs. 63.5 K to Rs. 1.25 Lacs.
2018-19	8.6	
2019-20	11.1	

(NSSO data, G.O.I, 2018)

It depicts from Table 3.1. The high per capita national income indicates a gradual improvement in the life happiness index (LHI). Because of this, there is a growing need for comforts like air conditioning and refrigeration. In instance, the Middle East, China, and Brazil, which may have hot and humid climates, are developing countries where this problem is prevalent. These countries' gross domestic products (GDP) are rising as well, which is increasing the demand for air conditioning among millions of people who can afford it. According to projections, the global AC energy consumption would increase by 2.5 times by 2050 as a result of the need for air conditioning in non-OECD nations [25].

Table 3.2: Mean Daily Sunshine Hours in Metro Cities

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Thiruvananthapuram	9.0	9.3	9.3	8.4	8.1	7.5	7.0	7.7	7.9	8.1	8.2	9.1
Bangalore	9.4	10.4	10.1	10.1	9.5	8.3	7.5	7.2	7.5	8.3	8.6	8.8
Chennai	9.3	10.3	9.8	10.3	10.1	9.3	8.9	8.7	8.9	7.6	8.3	8.2
Hyderabad	9.9	10.2	9.4	10.4	10.5	9.3	7.9	7.8	8.3	8.9	9.8	9.4
Mumbai	10.0	10.3	10.3	10.3	9.9	8.7	6.0	6.2	8.0	9.3	10.2	9.7
Kolkata	8.4	9.0	8.1	8.8	9.1	8.5	7.3	7.0	7.4	8.4	8.8	7.9
Ahmadabad	10.0	10.7	10.1	11.2	11.4	10.0	7.6	6.9	8.6	10.1	10.1	9.7
Varanasi	8.9	8.6	8.4	9.0	9.0	8.9	6.2	8.2	8.3	8.2	8.0	7.4
New Delhi	8.7	8.7	9.0	9.7	9.7	9.4	8.4	7.8	8.6	9.6	9.7	8.1
Patna	6.5	8.2	8.1	8.7	8.6	6.4	4.2	4.5	5.0	7.1	7.3	6.4

(**Source**: MNRE, Govt. of India)

Table 3.2. Shows the degree of solar isolation from various major metropolises, with Patna being somewhat low and Thiruvananthapuram in South India being somewhat high. For remote areas like Ahmadabad, Varanasi, Mumbai, Hyderabad, Chennai, etc., the provision for employing solar-powered refrigeration equipment will be advantageous. As a demonstrable technological advantage, this study will have a significant social influence in such locations.

Table 3.3: Data Analysis Solar Refrigerator versus Conventional Refrigerator

REVENUE AND EXPENSES

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Yr. »	**(0)**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Initial System Cost for Refrigerator (Rs.)	30,950	Running Cost					
Running Cost for conventional Refrigerator(Rs.)		4,818	5,083	5,363	5658	5970	6299
Cumulative Running Cost (Rs.)		4,818	9901	15,264	20,922	6,892	33,191
Payback Cost (Rs.)	(-)	26,132	21,049	15,686	10,028	4,058	2,241

Note: Calculation of Payback Cost of Solar Refrigeration System

Table 3.4: Consumption, Emission, and RF, as well as a comparison between RF and CO_2 and an increase in RF with the use of HFCs in the baseline scenario and integration

Scenario	**Consumption in 2013-2050 ($GtCO_2$ eq.)**	**Emission in 2013-2050 ($GtCO_2$ eq.)**	**RF in 2050 ($W\ m^{-2}$)**	**Years of CO_2, RF increase equal to HFC RF change 2050**	
				IPCC /SRES CO_2 Scenario	**IPCC 550 ppm CO_2 stabilization scenario**
Total base line Scenario range	146-231	110-170	0.25 - 0.40	6-13	11-18
Reduction from Global ban mobile AC EU style regulation*	7-10	6-8	0.017-0.40	0.4-0.8	0.8.-1.1
Reduction from Global mitigation freezes from 2014/2024^{-1}	69-118	45-72	0.12-0.20	3-7	5-9
Freeze & 2% $Yr.^{-1}$	91-148	59-97	0.15-0.25	3-9	7-11

From 2014/2024[2]					
Freeze & 4% $Yr.^{-1}$ From 2014/2024	106-171	70-118	0.18-0.30	4-10	8-13

3.8 Conclusion:

Solar energy is without a doubt the best source for low-temperature applications from a sustainability standpoint [22]. This source is appealing due to its wide availability, minimal impact on the environment, and lack of continuous fuel costs [23]. Solar energy is used and is absorbed on a surface, which has the capacity to heat the refrigeration system. Electricity is used to directly pump heat through the Pilfer effect. In order to prevent food contamination, freezers enable the preservation of vegetables, fruits, milk, and pharmaceuticals like vaccinations. As a result, the temp minimization [24] under constrained conditions is carried out in a manner that maximizes the total entropy of the system and its surroundings in equilibrium. As a result, the system's overall cost rises. This increases power consumption, which calls for more PV cells and thermo-electrics to achieve the appropriate temperature range [25]. It also attempts to address this issue by developing an affordable technique for thermoelectric refrigeration that is highly efficient [26,27]. Additionally, in an effort to make the system more portable, efforts are being undertaken to lower the size of the solar PV used. Food items would be significantly more resistant to temperature swings as a result of this lighting setup since the LED (which uses 20 times less electricity) can be used in place of the GI bulb and emit 10 times less heat [28]. Thus, one of the enticing aspects of refrigeration technology is the necessity for cooling. With the aforementioned scope, we may draw the conclusion that even in middle- and low-income homes, air conditioners are increasingly seen as a necessary appliance.

References:

[1] N.S.S.O., Statistical Data, Govt. of India, 2014

[2] R. Ciconkov, Refrigerants. There is still no vision for sustainable solutions. Int. J. Refrig., **86**, 441–448. [Google Scholar] [CrossRef], 2018.

[3] Yogesh Musale, Satyawan tPalit et al: Recent Developments in Solar Refrigeration Technology - A Review, International Journal of Current Khanna Publishing, New Delhi.

[4] R. K. Bansal, Fluid Mechanics& Hydraulic Machine, (Laxmi Pub(P) Ltd., New Delhi,2010).

[5] G. D. Rai, Non-conventional source of Energy (4^{th} Ed.), Khanna Publishing, New Delhi, (2008).

[5] R. S. Khurmi, A Text Book of Refrigeration and Air conditioning (New Asia Pub.2012),

[6] M. Izquierdo, M. Venegas, P. Rodriguez, A. Lecnona Crystallization as a limit to develop solar air-cooled Li-Br Absorption System using low grade heat Solar Energy Materials and Solar Cells, *Lett.***81**, 205-16, (2004).

[7] R. Saravenan, M.P. Marya, Experimental Analysis of a bubble pump operated H_2O—LiBr Vapor Absorption cooler, Appl. Therm. Eng., *Lett.***23**, 2383-2387(2003).

[8] IJSRET 2015: IEERET- 2014 Conference Proceeding, 3-4 Nov 2014.

[9] Ravi Sankar Raman et al, International Journal of Mechanical Auto & Prod. Engg., Vol. 2(1), 2012.

[10] R. Ali, G. El, Operational results of an intermittent absorption cooling unit, International Journal of Energy Research, **26**, 825–835, (2002).

[11] M. Dennis, K. Garzoli, Use of variable geometry ejector with cold store to achieve high solar fraction for solar cooling, International Journal of Refrigeration, **34**, 1626–1632, (2010).

[12] B. Henrik, Absorption process for heating cooling and energy storage – an historical survey, Energy Research **5**, 43–59. (1981)

[13] S.M. Xu, X.D. Huang, R. Dub, An investigation of the solar powered absorption refrigeration system with advanced energy storage technology, Solar Energy **85**, 1794–1804, (2011).

[14] H. Liu, Evaluation of a seasonal storage system of solar energy for house heating using different absorption couples [J], Energy Conversion and Management **52**, 2427–2436,(2011).

[15] A. Mani, Solar Refrigeration: Current status and Future trends- Refrigeration & Air conditioning Lab., Department of Mechanical Engineering, I.I.T. Madras, Chennai.

[16] W.F. Stoeker and J.W. Jones, *Refrigeration and Air conditioning,* International Edition, McGraHill, Singapore, (1982).

[17] K.M. Tsamos; Y.T. Ge, ; I. Santosa; S.A. Tassou ; G. Bianchi; Z. Mylona, Energy analysis of alternative CO_2 refrigeration system configurations for retail food applications in moderate and warm climates. Energy Convers. Manag., **150**, 822–829. [Google Scholar] [CrossRef], (2017).

[18] P.Gullo; B. Elmegaard; G. Cortella, Energy and environmental performance assessment of R744 booster supermarket refrigeration systems operating in warm climates. Int. J. Refrig., **64**, 61–79. [Google Scholar] [CrossRef][Green Version], (2016).

[19] P.J. Wilbar and C.E. Matchel, Solar Absorption and Air conditioning Alternatives, *Solar Energy,***17**, 193-199, (1975).

[20] International Journal for research in Applied Sc. &Engg. Tech. (IJRASET), Vol. 3, Issue X, (Oct. 2015).

[21] Yogesh Musale et al; Recent Development in Solar Refrigeration Tech.—A Review, Mech Engg. Dept., MIT College of Engineering, Kottnud, Pune, India.

[22] A Text Book of Fluid Mechanics- Rajput, S. Chand & Co. (2013)

[23] Gourav Gupta et al, International Journal of Engineering Technology Science and Research (IJETSR), available at www.ijetsr.com, Vol. 3, Issue 4, April 2016.

[24] SurithNivas , Vishnu Vardhan , Raam Kumar , Ramya. Sai Prasad, "Photo-voltaic Driven Dual Purpose Thermoelectric Refrigerator for Rural India". International Journal of Advancements in Research & Technology, Volume 2, Issue 6, June- 2018.

[25] J. Sea bright; Presentation to Refrigerants Naturally in Brussels, Belgium during June 2004. Available at: http://www.refrigrant naturally.com/ speech.pdf **123**, Jan. 2007.

[26] Proposed amendment to Montreal Protocol submitted by Canada, Maxico and United State of America UNEP, (2013).

[27] Latest Air –conditioning Technology in India—Review, Journal paper on future of Air-conditioning for Builders (2019).

CHAPTER 4

Chapter 4

Studies on Energy Conservation and Thermal Comfort Using Natural Refrigerants in Solar Thermal & Solar Photovoltaic Powered Air-Conditioning and Refrigeration Systems

4.1 Introduction:

The application of Air-Conditioner due to more and more society modernization increases at home appliances as well as in industries from the last decade. In recent years, the term ‘thermal comfort’ comes to an issue of person to person based on that they provide the characteristics and properties of the system and working medium required for optimal performance. The Montreal Protocol (1987) stressed to give on bring down of ozone depletion substance that contributes to the radioactive forcing to climate change from the environment [1] while technological change in the production sector like refrigeration and air-conditioner need to phase down CFC, HCF and carbon dioxide for reducing temperature change; human comfort was taken as vital initiative for scientists and engineers to explore suitable replacements for alternate energy connection as well as use of natural refrigerants. However, no scope for extensive laboratory tests and field data are yet to be collected at the present scenario, still has provided a few statistical data to define a specified percentage of occupants will find thermally comfortable. In the paper, the maximum experimental data are not at present considered under our purview. The proposed research work will focus on how energy consumption pattern changes in domestic areas in three different regions i.e. rural, suburban and urban areas. Moreover, the fact finds that domestic load has been increasing day by day due to increase of demand of air-conditioning system [2]. The mobility, transportation cost, water are at present main pillars to post fossil fuel based electricity. Naturally, solar air-conditioner may play a vital role on energy system as well as environment. In the context, detailed study, future projection and forecasting on adaptation of solar air-conditioning system in West Bengal will help in future planning of solar powered Refrigeration and air-conditioning system expansion. Moreover, the present study investigated an air conditioning system that runs on direct current (DC) that is combined with a solar thermal and photovoltaic (PV) system. The system is created, and a lab-scale investigation of its performance is conducted. The load pattern and the photovoltaic power output pattern are closely aligned because the electric power demand peaks spatially during the daytime in the summer. The following data have been statistically collected for theoretical analysis: a. Air Temperature; b. Rainfall pattern and c. Relative Humidity.

It is important to note that June in India was the wettest month in the previous 12 years, with 18% above-average rainfall (Fig. 4.1), as a result of the monsoon's punctual beginning and quick advance across the nation. The result thus, appears momentarily change of weather takes place but hot climax will further develop due to mismatch ventilation format (Source: IMD, Mousum, and June, 2020). Thus, for the sake of comfort, Refrigeration or A.C. will substitute to use as emergency products.

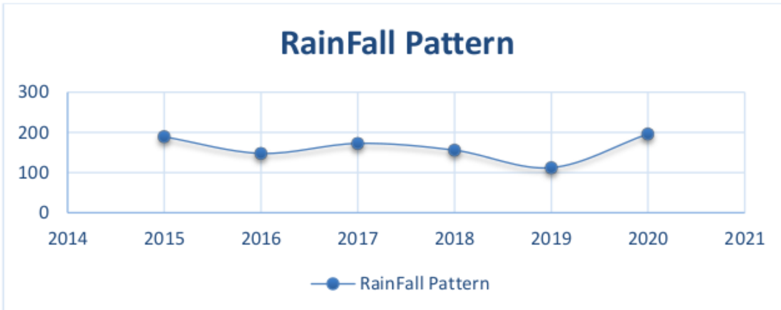


Figure 4.1: Variation of Annual Rainfall in India (Source: IMD, Mousum, and June, 2020)

The context above helps to understand why there is a rising need for air conditioning as a result of climate change and global warming. The conventional electric power is supplied mainly from burning of fossil fuels; naturally GHG emission will continuously worsen effect of global warming. In turn, the demand of Air Conditioner will find no alternative but to increase of demand-side supply-chain option. In view of the fact, subtropical cities like us connection with Refrigeration/AC is essential provision for buildings to meet this challenge of discomfort. More strictly, the simultaneous adjustment of temperature, humidity, air filtration, and current distribution is known as air conditioning. The air quality needs to be in line with the general need for air conditioning in the room [13]. The aim at using solar energy (both PV and thermal) is the most suitable system for installation of building and residential areas. This system is the most common, globally acceptable, easy operation and preferred type of thermally driven technology. It is well reliable as absorption cooling, capacity control, long life span and low maintenance profile. In a nutshell, the current system of work is built on the use of solar thermal energy (heat) to produce thermally driven refrigeration processes. At the same time photovoltaic solar energy conversion by the principle of photovoltaic effect, the generations of free electrons using sun light on flat plate solar cell are used to generate electricity. The complete set up is depicted in the following section below.

4.2 Literature Review:

There had been initiated several studies on substitution of refrigerants uses in years together for distinguishing as alternate refrigerants for improving art-of-sustainable design technology, economic stability and living environment for well-beings. Once upon a time, Abuzahra [3] demonstrated the performance of window type AC unit while replacing R-22 refrigerant with methane (CH_4). During observation, it was concluded that methane gas was not at all satisfactory replacement due to compressor overheating problems. Purkayastha and Bansal [4] investigated that the replacement of R-22 in heat pumps by a refrigerant composed of a combination of propane and LPG. The result showed that COP with Propane (R-290) and LPG mixture is better than R-290 use alone but with a small loss of condenser capacity. In a separate experiment, Hammad and Tarawnah [5] used a mixture of Butane and Propane at different ratio at the same Laboratory set-up. In that experiment 90% propane gives off the same pressure as R-22 while having a greater coefficient of performance but 60 per cent propane mixture gives same COP with lower pressure. Thus, the result indicates that the increase percentage of propane will decrease the capacity of compressor work.

Jung [6] studied on thermodynamics performance of two HCs in their purest form and seven combinations of other compounds likes propane (R-290), propylene (R-1270), HCF (152a) and R-170 etc. in a design of residential unit. The results included that COPs of those refrigerants were slightly higher than that of R-22 except R-1270 which was only 0.7% lower than that of R-22. A series of researcher's has studied solar cooling system using absorption refrigeration cycle stated by Bong et.al. [7], Duffy et. al. [8] and Zhai et. al. [9]. Another group, like Kunio et. al. [10], Habib et. al. [11] works on cooling systems using solar photovoltaic power-based technology. The main problems faced by them are; initially at high cost, low system performance and availability of solar irradiation only in day time operation. However, some enhancements to the primary solar cooling system parts have been investigated to improve performance while paying less upfront. These creative experiments impressed the most to perform solar powered AC units using as eco-friendly refrigerant. Further, in this study, parameters like: refrigeration effect; cooling capacity; COP; refrigerants' heat rejection and mass flow rate were optimized. The functions of evaporation temperature and condensation temperature were used to describe each of these factors.

Earlier, already mentioned about *Montreal Protocol* and discussed in brief about technology transfer on climate change perspective. Thereafter, *Kyoto Protocol* further phased out the changes of refrigerants used. In the context, we focused on Mukesh K. Agarwal [12] paper wherein it mentioned that refrigerant (heat from lower to higher temperature reservoir) has its own thermo-physical property. Refrigerants used in view of these like R-11 and R-12 are toxic in nature. In case of ammonia (R-717) is flammable.

Gaurav Gupta in his paper mentioned [13] that due to high global warming potential HFC as refrigerants phased down from 2015. Thus, the researchers' redundant or made adverse comments for the usage of R-134a, R-152a as refrigerants with various blending proportion. The above-mentioned historical perspectives of this brief review work confirmed that our decision of use of solar powered and solar thermal energy as supply-chain side thus effect, COP of natural refrigerant, R-290 as the present stage and finally, in the long-term basis, using mixture of blending of R-290 and R-600a and their comparative studies will undergo for future work.

4.3 Methodology:

The conceptual frame-work of both theoretical and experimental studies was developed step-wise as research methodology of this paper. In this present work some physical measures like building simulation, comfort model parameters analysis have been carried out. The environmental factors that are linked with individual feelings of air temperature, thermal comfort, radiant temperature, humidity and air velocity etc. are to be taken into an account. Moreover, exchange of heat with the air by convection and with the surrounding surfaces by radiation. The air temperature is very pertinent to thermal comfort since the process of heat loss from the human body [14]. The reducing effect of radiant temperature is used to record by a room thermometer surrounded by a bright metallic shield. Alternatively, sensor may be used to reduce relative effect of radiation. Field studies for adaptive comfort: Parallel to laboratory studies, there has been aimed at recording thermal comfort for using different refrigerants system in the real world. This field studies are conducted in the 'normal setting of daily life' instead of experimental set-up. This type of study, however, has disadvantages and pitfalls.

The advent of air-conditioning system in laboratory scale has brought a new dimension as shown in the photographic views in Fig.4.2. to the usage of this system which consists of two main parts:

- ***Indoor compartment*** contains solar cooling coils, blower and an air filter utilization to control the indoor environment in the building. This has led to a considerable reduction in the usage of room air-conditioners and central air-conditioning systems in the very hot days.
- ***Outdoor compartment*** which consists of compressor, condenser associated with expansion valve or capillary tubing to indoor units.

Different component of the present experimental set-up based on vapor compression cycle-based air conditioning system indicating the indoor and outdoor units are depicted in Fig.4.3.

According to *energy conservation law,* Indoor unit cooling as well as outdoor unit heating occur tremendous effect in global warming due to condensation of heat at the outdoor atmosphere. If solar thermal energy in refrigerant absorbs and thus utilizes as latent heat for cooling purpose then such effect in global warming does not apprehend in any case [15]. As all the renewable energy sources originate entirely from the sun, the roof-top floor of our school is free and abandon solar radiation is available at any location on the surface. The maximum irradiance of sunlight on Earth is about 1000 watt/m^2. Thus, the side location for experimental set-up takes place there. On the other side, Indoor unit will be developed where the presence of evaporator and thin copper tube as a heat exchanger will be set up as a new model. Evaporator in that case, will operate as motor-pump-set in forward direction wherein refrigerant gas will flow through thin copper tube not through the evaporator in reverse direction of motor. This illustrates the radical effect of a novel way that makes it simple to calculate Solar AC ratings from tiny units to large units, representing them in terms of kW rather than TON, which is not adequately defined publicly.

A sample test, Propane (R-290) as green refrigerant is used repeatedly so as to emphasize the high-efficiency, low-cost production mode products will be coped out. But due to unavoidable position, University climax is not normal to record a couple set of data from the present air conditioner -- utilize the same closed-circuit system's compression, condensation, expansion, and evaporation cycle. At room temperature Refrigerant liquid has been injected to the evaporator tube from compressor. The indoor warm air pushes through air filter by motor blower. As a result, due to the extremely low pressure that exists in the evaporation tube, warm air is forced through it and heat is absorbed by the refrigerant liquid. Ultimately, the air swiftly cools; the evaporator coil's extremely cold surface is where the moisture in the air condenses. Condensate that results is discharged into a drip pan. Through ducts, the air returns to the location.

The refrigerant's temperature increases as a result of absorbing heat from the interior air, causing it to boil and transform into extremely hot vapor. As a result, its temperature is close to 50°F. The refrigerant exits the evaporator and travels through the capillary tube thanks to the solar-powered system. A solar evacuated tube collector is the next thing it goes through. Before the refrigerant enters the compressor, the solar collector "pre-heats" it. The refrigerant is then forced into a compressor powered by solar DC energy, which raises its pressure before driving it into a condenser. Even on a scorching summer day, the compressor works to raise the gas pressure, which raises the temperature by around 170°F, allowing the refrigerant to release its energy into the surrounding air. The super-hot refrigerant gas then switches over compressor to the condenser coil and the gas becomes liquids releasing heat to the surroundings. That's happen with the help of a fan, the condenser unit's condenser coil, drawing outside air into the unit. As a result, Cooling of the refrigerant starts and return (condense) into liquid form, entering the expansion valve (of the capillary tube variety). As the liquid exits the expansion valve, the valve restricts its flow and causes a decrease in pressure. The cycle repeats as a result of the refrigerant's frequent pressure reductions, which intensifies the very cold sensation.

Moreover, in winter, DC compressor set will operate in reverse direction by a commutation switch and this pump will work as a heat pump through the same unit but indoor unit construction based on new methodology which will operate by 2 in 1 way valve operation.

The schematic-diagrams of solar air-conditioning system are presented below: -

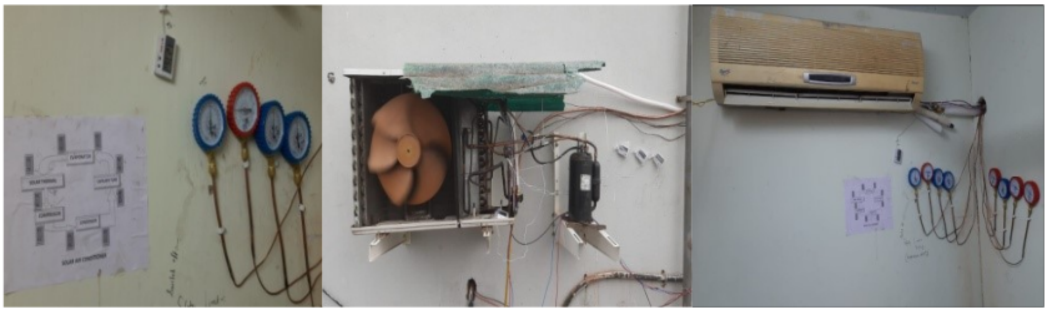


Figure 4.2: Experimental Set-up depicts at roof-top building of School of Energy Studies. Premises, Jadavpur University at initial stage by using R-290 as natural refrigerant.

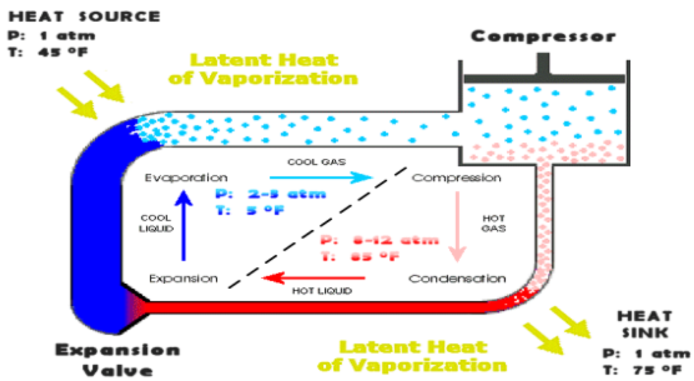


Figure 4.3: Different components of Solar AC with DC compressor set up indicating indoor and outdoor units

4.4 Results and discussions:

Glass generally uses, the major building set-ups as transparent material, provides the most direct route for entry of solar radiation for natural visualization. Therefore, the proper estimation of heat gain through glass is imperative [17]. Further, the glass is opaque to radiations from sources of surface temperature much greater than room temperature. The percentage of incidence radiations transmitted through glass depends on the angle of incidence (shown in Fig.4.4). Thus, ceramic materials hold to utilize as beneficial factor for natural ventilation inside the buildings.

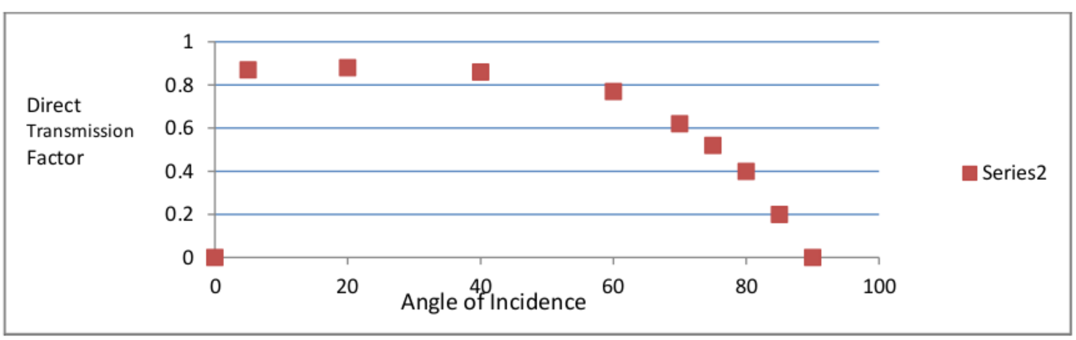


Figure 4.4: Solar Heat Gain through Glass

4.4a Comfort Analysis:

The amount of heat absorbed by the glass pans as a result of the sun's direct beams that depending on the glass's properties and its absorption behavior. The heat absorption coefficient of common glass is extremely low. During heat absorption; the temperature of glass gets raised. Thus, comfort potential goes below the average [18]. In this case, heat flows in conduction through the glass to both of its surfaces. After it, the heat is rapidly convected and reflected out which depends internal and external surface film coefficients of heat transfer h_i and h_0.

Let, the inside (INTERNAL) temp. = t_i;

Outside (EXTERNAL) temp. = t_0;

Inside surface co-efficient of heat transfer = h_i;

Outside surface co-efficient of heat transfer = h_0;

Assuming that glass thickness is small and therefore glass temperature t_g is constant throughout,; therefore heat gain to glass = heat loss from the glass;

Taking into consideration with heat absorption co-efficient = $\propto$ and t_g as glass temp, we have,

$$\propto I_\beta = (t_g - t_0)h_0 + (t_g - t_i)h_i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where, $I_\beta$is the direct solar radiation on the plane at an angle β with the horizontal plane surface, $\beta = 0$ and at vertical to the plane surface $\beta = 90^0$. Let us assume, I_β as I_d , for direct radiation as the tilt angle is not under consideration.

$$\text{Thus, } \propto I_d = (t_g - t_0)\, h_0 + (t_g - t_i)\, h_i \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

$$= t_g(h_0 + h_i) - (h_0 t_0 + h_i t_i)$$

$$\text{Thus, } \boldsymbol{t_g} = \frac{\propto Id + (h0t0 + hi\, ti)}{h0 + hi} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

This is known as comfort factor [19] which may be analyzed by the equation (3) if all terms in Equation (3)'s right side, hold good which correspond to data, temperature and comfort indices are plotted in Fig.4.5. Rough Sketch for ceramic material attached building and heat load from outer to interior of the building is as shown in Fig.4.6.

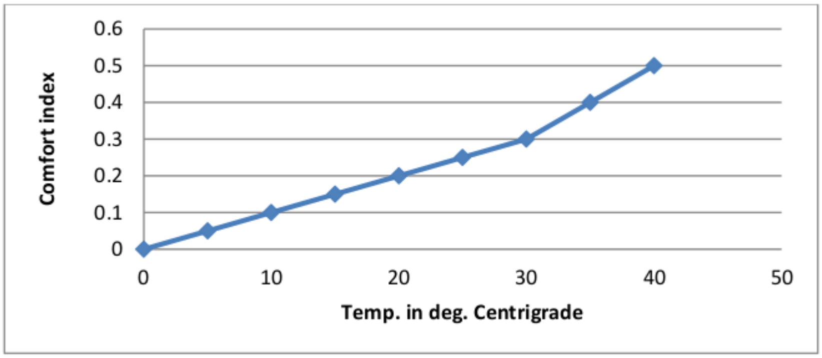


Figure 4.5: Comfort Index –vs- Temp variation

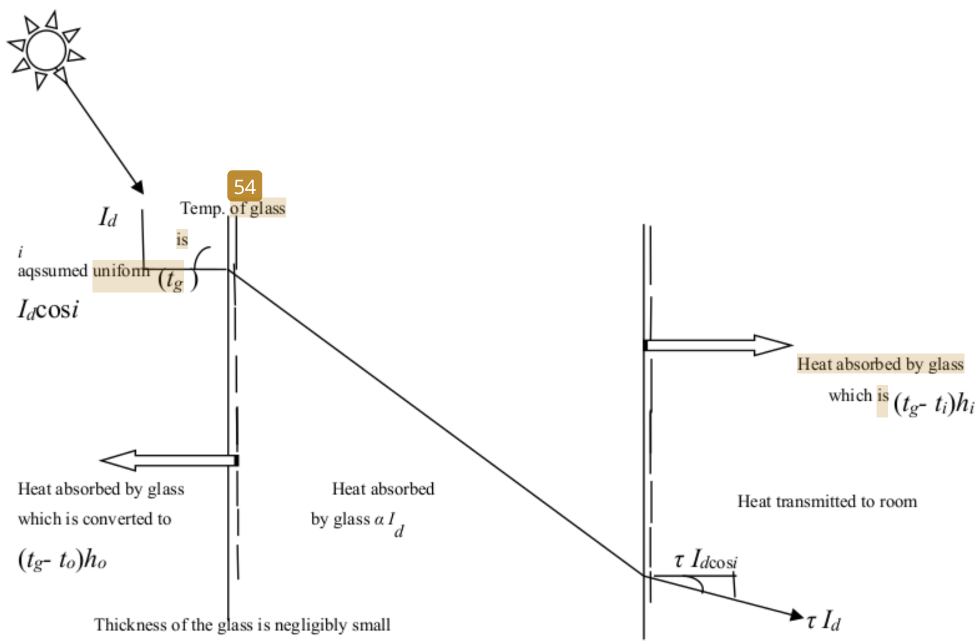


Figure 4.6: Illustration of building survey and Heat Load

Most of the people (90%) assume comfortable when air temperature is between 18-22^{0}C and the % sat is between 40-65%. Thus, this numerical analysis is regarded as comfort zone [20].

4.5 Use of Primary and Secondary Refrigerants:

When a new renovative approach may be considered owing to the environmental constraint and thermodynamic efficiency due to system design, safety and less operation cost the selection of refrigerant would be essential for the purpose. In principle, any fluid can be used as refrigerant. However, for the sake of easy vapor compression refrigeration system, mainly a few refrigerants will be focused here [21]. While liquids used to move thermal energy from one place to another are referred to as secondary refrigerants, those that are directly employed in vapor compression and vapor absorption at refrigeration systems are known as primary refrigerant. Already once more mentioned about Montreal protocol, Ozone depletion potential (ODP) of refrigerants should be restricted to zero while those having non-zero potential will be phased out. Thus, A1 to A3 and B1 to B3 are the six safety groups that ASHRAE assigned to refrigerants. The least dangerous refrigerants are those in Group A1 (such as R11, R12, R22, R134a, R744, and R718), while the most dangerous ones are those in Group B3 (such as R1140). Organic refrigerants Unsaturated hydrocarbons such as propane (R290), n-butane (R600), iso-butane (R600a), and butane Hydrocarbons: R1150 and C3 H8 may avoid the potential for ozone depletion and global warming, respectively [22].

In the present experimental work some preliminary data has been collected to understand the performance of the system. It has operated using natural refrigerant as R 290 with solar heating system to increase the temperature of vapor to some extent at the inlet of the compressor for reducing pressure difference across the compressor as well as power consumption. To evaluate the system performance some thermocouples and pressure gauge were installed (Fig.4.7.) and fixed in a protected walling area. Their locations are described and the points of measured temperatures and pressure are shown in Table 4.1. It is found that there is considerable amount temperature and presure increase at the inlet of the compressure without scrificing the comfort level (Temp & Humidity) in the indoor area and it helps to reduce the enegy consumption of solar PV driven DC compressor. The detailed experimentation is now being hampared due to the present COVIT 19 pandemic situation. All other aspects related to the energy consumption, comfortness, optimum temperature at compressure inlet, heating arrangement, blending of other refrigerant would be performed while normal situation will resume.

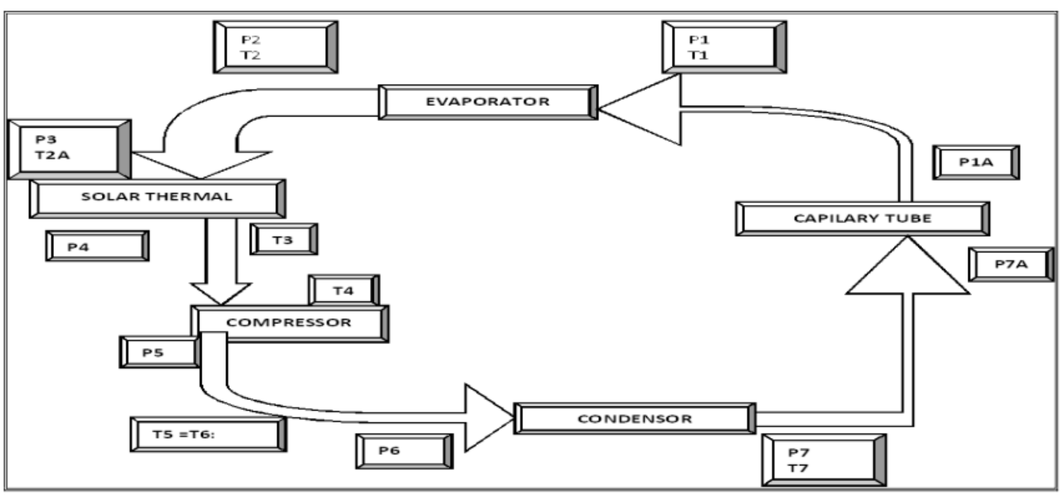


Figure 4.7: Schematic diagram of the Experimental set up indicating different points of Temperature and Pressure sensor.

Table 4.1: Temperature Vs Pressure Data with performance of the present set-up using R290 as refrigerant with solar thermal heating application for a day as dated: 12/03/2020.

	Date: 12/03/2020	Temperature ^{0}C	Pressure PSI1	Temperature ^{0}C	Pressure PSI2	Temperature ^{0}C	Pressure PSI3	Temperature ^{0}C	Pressure PSI4
1	EVAPORATOR INLET (T1, P1)	25.4	60	26.1	60	24.9	80	25.2	80
2	EVAPORATOR OUTLET (T2, P2)	25	64	26.4	60	24.2	67	25	66
2 A	SOLAR THERMAL INLET (T2A, P3)	25	60	26.4	50	24.2	55	25	60
3	SOLAR THERMAL OULET (T3, P4)	26.6	58	27.4	50	26.4	60	26.8	60
4	COMPRESSOR INLET (T4, P4)	28.4	58	27.4	50	28.5	60	28.9	60
5	COMPRESSOR OUTLET (T5, P5)	45.2	190	40.1	170	44.1	180	46.6	185
6	CONDENSOR INLET (T5=T6, P5=P6)	45.2	190	40.1	170	44.1	180	46.6	185
7	CONDENSOR OUTLET (T7, P7)	33.1	80	32.3	72.5	32.9	82.5	33.9	82.5
7 A	CAPILARY TUBE INLET (T7, P7A)	33.1	80	32.3	72.5	32.9	82.5	33.9	82.5
1 A	CAPILARY TUBE OUTLET (T1, P1)	25.4	60	26.1	60	24.9	80	25.2	80
1	…………………………								
		Room Temperature:23°C		Room Temperature:28°C		Room Temperature:21°C		Room Temperature:22°C	
		Ambient Tempaerature:30.5^O C		Ambient Tempaerature:31^O C		Ambient Tempaerature:32^O C		Ambient Temperature: 32^O C	
		Solar Radiation: 780 w/m^2		Solar Radiation: 722 w/m^2		Solar Radiation: 655 w/m^2		Solar Radiation: 420 w/m^2	
		Time: 1:30 pm		Time: 2:15 pm		Time: 2:40 pm		Time: 3:00 pm	
		At 2nd half of the day weather was not so good because of lad later rain was falling. Performance was found better in first half of the day.							

4.6 Social Impacts:

Design and innovation for social requirements depends on new social structures and models. It should satisfy social demands and develop both which advances social relationships. Murray et. al. [23] explained that existing social structures would not be able to address certain difficult problems like chronic diseases, climate change, or other challenges. However, Hillgren et. al. [24]elaborate that Progressively, a rising number of organizations—including business executives, philanthropic groups, and politicians—came to see the value of social innovation. Additionally, they search for novel, socially innovative solutions. As temperature change causes high volumetric efficiency and low power consumption, thereby relation between enthalpy and entropy of vaporization of selected fluid is important to consider. Moreover, to encourage and support sustainable behavior, the designer wants to find a product with attributes that are more available than functional [25, 26]. Even though they may not be aware of it, individuals generally lack concern for preserving the environment. In this case, it might be necessary to motivate people using a motivational intervention to uphold the standard and alter the environment. The foot-in-door strategy, which pushes people to pursue higher goals, was proposed by McCalley et al. [27. However, toxicity of the fluid used in refrigeration and air conditioning system is the one of major problem for sustainable mankind and it can be minimized. This is the reason for using mixture of two or more compounds as refrigerants for comfortable solution in the refrigeration system [28].

4.7 Conclusion:

The advantage of Solar Air Conditioners is an innovative measure to reduce the application of electricity for public or commercial gadgets which install for social modernization inside home-lets as well as modernization of the system in offices. Instead of paying an exorbitant tariff to operate those air conditioners with traditional electricity, this innovation provides for lower maintenance costs because it is powered by solar technology. This technology will undoubtedly become the most affordable option for lowering the temperature at a concerned location. Another significant advantage is that to run the capillary tubes, Solar thermal collectors are collected the sun's thermal energy and uses to perform the environment conditioning system. In comparison, the conventional air condition operating throughout the hottest day results high power grid demand, during its peak usage causes a significant drop in power outages and blackouts and increase CFC or greenhouse gas emissions.

There are some grid-independent solar hybrid air conditioners available in the market. These are excellent combination allowing both cooling and heating units without compromising the carbon footprint [29]. Even so, this system's DC-only variant might work throughout the day. Cloud cover will also have an impact on its effectiveness. In that situation, batteries are needed for it to work, even during the day. Realistically, this apartment could be used as a standalone studio or office. Only a significant investment in battery storage will allow this device to function properly at night. Unarguably, people can attribute convenient living as they render a lot of comfort particularly in warmer days, opting for these are sure to be cutting down fees in their energy charges [30]. Solar panels, like some other devices exposed to the sun will eventually deteriorate. Besides weather conditions, there are also other outside factors that can lead to the destruction of these electricity generating devices [31]. Therefore, proper care may provide and monitor for solar panels once for a while but to function well.

References:

[1] Ye Jason, Stephen Seidal and S.O. Anderson (Oct. 2015), Technological Change in the Production Sector under the Montreal Protocol, Available at: Centre for Climate and Energy Solutions, www. c2es.org

[2] Yao, R., Baizhan Li and Jing Liu (2009) - A Theoretical Adaptive Model of Thermal Comfort. in Building and Environment 44(10):2089-2096.

[3] Abuzahra, Hilal (1994). Performance of Methane Gas as a Refrigerant for small air-conditioning units. M.Sc. Thesis, Department of Mechanical Engineer, University of Jordon.

[4] Purkayastha, B. and Bansal. P.K. (1998). An Experimental Study of HC290 and a commercial liquefied petroleum gas (LPG) mix as suitable replacements for HCFC 22. International Journal of Refrigeration, Vol., No.1, 3-17,1998.

[5] Hammad, M. and Tarawnah, R (2000). Hydrocarbon refrigerants performance in air conditioning units. Proceedings of the 4th IIR-GastavLorentzen conference non-natural working fluids, Purdue University, USA, 167-176.90, 2000.

[6] Jung, Ki (2006). Thermodynamic Performance of HCF-22 alternative refrigerants for residential Air conditioning applications, Journal of Energy and Buildings,39: 675-680.

[7] Bong, T. Y., NG, K.C. and Tay A.O (1987). Performance study of a solar-powered air-conditioning system, Solar Energy, 39: 173-182.

[8] Duffy J.A. and Beckman W (1991). Solar Engineering for Thermal Process, John Wiley, New York.

[9] Zhai, X.Q., Wang, R. Z., Wu, J.Y., Dai, Y.J. and Ma. Q. (2008), Design and Performance of a solar powered air-conditioning system in a green building, Journal of Applied Energy,85: 297-313.

[10] Kunio Tanaka, Yasuhiro Makino, EtsuoSakoguchi, Akio Takeoka and Yukinori Kuwano, Residential Solar-Powered Air Conditioner, Periodicals of Electrical Engineering, Japan, 114:3, 123-133.

[11] Habib Choauki and Baccar (2006), Dynamic modeling and simulation of a new air-conditioning prototype solar energy, Journal Renewable Energy, 32: 200-215.

[12] Agarwal. K., Mukhesh and Matani. G. Ashok (2012). Evaluation of Vapour Compression Refrigeration System using different Refrigerants, IJEIT, 2 (4), 39-43.

[13] Gupta, Gaurav and Agarwal bani, Alka June 2015), Performance analysis of air-cooled water cooler by using Eco-friendlyrefrigerants as a possible substitute of R-134a, IJESRT, 4(6), 279-291.

[14] Koli, S.A., Koli, A.T. and Patil H.V. (2017). Design and experimental analysis of Solar air conditioner, International Research Journal of Engineering and Technology (IRJET), : 4(7), Available at www. irjet.net

[15] Carlucci and Salvatore (2013). Thermal comfort Assessment of Buildings, London, U. K.; Springer, DOI: 10.1007/ 978-88-470-5238-3_3.

[16] Goulding et al. (1992).112, Nicol. (2008),1. Thermal Environmental conditions for Human Occupancy, google.com

[17] Wang, K. Shan (2001). Handbook of Air conditioning and refrigeration, McGraw- Hill.2nd Ed. 2001.

[18] Henry, F. Wong NH. (2004), Thermal comfort for natural ventilated houses in Indonesia, Egergy and building; 36(7): 614-626.

[19] Refrigeration and Air-conditioning (2000)- P.L. Ballancy, Khanna Publishers, New Delhi, 16th Ed., 1077: 608-671.

[20] Iyar, V.A.- Aiur conditioning Principal and Concept (2014), Mechanical Engineering Department, KGP, IIT, available at: www.nptel.ac.in

[21] Sangeethsreeni (2019)- History of Refrigeration—Development of Refrigerants and Compressor, Lesson 2, 803: 2 (ME)., IIT, KGP.

[22] ASHRAE Hand Book- 4 (2019), Available at: www.ashrae.org

[23] Murray, R., Caulier-Grice, J., andMulgan, G., (2010), TheOpenBookofSocial Innovation, Young Foundation, NESTA, London.

[24] Hillegen, P.A., Seravalli, A. and Emilson, A. (2011), Prototyping and Infrastructuring in Design for Social Innovation, Co-design, 7(3-4), 169-183.

[25] Srivastava, J., and Shu, L. H., (2012), Designing Products to Encourage Conservation: Applying the Discretization Principle, Leveraging Technology for a Sustainable World, Springer, Berlin, Heidelberg,569–574.

[26] Steg, L., and Vlek, C., (2009), Encouraging Pro-Environmental Behaviour: An Integrative Review and Research Agenda, J. Environ. Psychol., 29(3),309–317.

[27] McCalley, L.T., DeVries, P.W., and Midden, C.J.,2011, Consumer Response to Product-Integrated Energy Feedback: Behavior, Goal Level Shifts, and Energy Conservation, Environ. Behav., 43(4), 525–545.

[28] A Text Book of Refrigeration and Air-conditioning, updated Ed. (2006), R. S. Khurmi and J.K. Jai, S.

[29] Chand & Co., New Delhi, Available at: www. Engineering Books Pdf.com

[30] Low Energy Cooling: A Guide to the Practical Application of Passive Cooling and cooling energy conservation measures (1986)- Donald W. Abrams, Van Nostrand Reinhold, U K, Available at: www. amazon.com

[31] FeriadiH., Wong NH. (2004), Thermal comfort for Natural ventilated houses in Indonesia, Energy and Building, 36(7): 614-626.

[32] Kunio T., Yashuhiro M., Etsuo S., Akio T. and Yukinori K. (1994), Residential Solar-powered Air Conditioners, Periodicals of Electrical Engineering, Japan, 114(3), 123-133.

CHAPTER 5

Chapter 5

Analysis on Feasibility of Two Different Natural Refrigerants based Solar Powered Domestic Air-Conditioning Systems

4.3 Introduction:

Refrigeration is a process that deals with the production and control of temperature below that of the surrounding. Here, heat is removed from the system and transferred to another body to keep the space cool. Mainly, sunlight is the main source of heat, and sometimes to beat the excess heat there is a need for refrigeration. As per IPCC Report 2019, Asia will emerge as a torch bearer to reuse sustainable energy within two decades. Over 50% of greenhouse gas (GHG) emissions originate from the great majority of Asian nations, and about half of that energy is typically used for heating or cooling interior space. Thus, due to improvements in human lifestyle and global warming, the stipulated increase in air conditioning has caused a further increase of 20 percent in load throughout the session, and as a result, in recent decades has seen a sharp growth in the country's carbon footprint [1]. Moreover, the cost of conventional electricity has gone beyond reach. This paper argues about sustainable and low-carbon drives for Air conditioning units and states the use of low-carbon Air conditioning units as an alternative method for environmental comfort. This low-carbon establishment can be alienated in three ways: (i) Solar thermal technology governance to reduce compressor rating by introducing superheating whenever required; (ii) Using electricity generation from the PV panel (Photo voltaic); (iii) Use of natural refrigerants (R290& R600a). Moreover, water as a refrigerant (R718) and some other natural refrigerants (R744, R717, R600a, and R290) are recognized as the need for our safety measures whereas synthetic refrigerants (R134a, R32, R22, and R152a) are becoming obsolete. The Bureau of Indian Standards (BIS), holds superior for safety (flammability and toxicity), operating cost, refrigeration capacity, and coefficient of performance (COP) are to be comparatively ascertained to the World enhanced level of around 75 percent by 2030 [2].

The Paris Agreement and Montreal Protocol in 2018 had already alarmed us providing scientific warming and political commitment to control the situation. According to a UN report 2019, the average temperature of the world will rise by 3.2 ^{0}Celsius in the 21st century and a more disastrous situation will arise unless we check it. The problems are also aggravated due to uses for interior air-conditioning units. In the coming decades, more than 75% of the energy used in Asia, which will consume 40% of the world's energy, will be derived from fossil fuels [3]. Majority of the Asian countries are responsible for 50 percent of all greenhouse gas emissions [3, 4] through construction, destruction, and demolition process. It was observed that throughout tropical Asia, including India, China, Thailand, Japan, and Indonesia, etc., the cooling or heating of interior areas accounts for more or less half of energy usage. As a result, the rise of carbon emissions severely through the development of electronic air conditioning (AC) in recent years (Li, 2010) [4]. Nowadays, AC is no longer a luxury good, but it is a cross-section requirement and an essential building block for economic growth. Different businesses, including those in the transportation, cold-chain, residential, and commercial building sectors, heavily rely on cooling. As a result, the demand for cooling in the selectors in near future is due to the optimum economic growth of the country. Needless to say that energy demand will rise in health, productivity, and another field by around 75 percent by 2030, (IEA, 2012) [2]. There is rapid adaptation of AC systems and their higher demand by 2030 throughout the world, particularly in Asia. This paper presents the use of AC with an alternative less energy-intensive, climate control paradigm. It is a vision to transit towards green refrigerants which increase sustainability and an option for advanced technology options [5]. Chlorofluorocarbon (CFC) was used in the name of Freon (R12) in the initial stage of the history of refrigeration technology. It is primarily used in domestic refrigeration appliances, compressors, and in automotive air conditioners. Since the 90s', the CFC was replaced by HCFC (R22). Roughly, 50 to 60 percent of the Air conditioners in India till now use HCFC, which was marginally better than CFCs as it has less ozone depletion potential and less global warmingbut contained Chlorine which is harmful to the environment [6]. Moreover, a smaller low-cost compressor can be used in refrigerant R 22 than refrigerant R12. In the meanwhile, another set of refrigerants called Hydro Fluor carbons (HFC) appeared as the next generation refrigerant another brand name R410A and R134 and it thus does not contain chlorine. They are better than HCFC since they do not damage the ozone layer, despite the fact that they have the potential to contribute to global warming. As a result of the release of a significant greenhouse gas, the ecology is adversely affected by certain of these refrigerants, such as R-134a. There is currently a lot of discussion about the need to outlaw all environmentally harmful substances, including synthetic refrigerants like R-134a [7].

Different manufacturers are using varying inverters and split AC condensers like copper, Aluminum, and alloys materials to promote trade efficiency, to lower the cost-benefit by us in anti-corrosive condensing technology. The next generation AC will bring a cooling technology in which airflow will maintain an even temperature and increase the comfort level. The airflow system maintains an evenly chilled interior free of strange frozen or heated patches. This ventilation systems design helps the stored food items stay fresh for a longer time [8]. Air quality is one of the main issues in large cities due to impending urbanization and technological advancement. Currently, air conditioners with sophisticated filters use a flawless configuration of multi-layer filters operating in unison to purge the air of all pollutants, bacteria, viruses, dust particles, and offensive odors. The mixture of blends of R290 and R32, or those of R600a with R134a happens to use as a refrigerant to reduce flammability when used in mixtures. Carbon dioxide is a safe, naturally available, eco-friendly refrigerant with the best thermo-physical properties after ammonia. However, disadvantage of it is a low critical point in high ambient climates [9-13]. Moreover, the design and development of Solar Power Air conditioning system are discussed in brief for better understanding of the advancement of technology and better usefulness towards society [14, 15].

In the present work authors have considered DC power operated different capacity domestic air conditioning system with two different natural refrigerants (R290 and R600). The performance parameters and power consumption pattern have been analyzed with the help of CoolPack1.50 software and compared with the existing conventional refrigerants. It is also checked the requirement of reheating at inlet of compressor for maintaining suitable state and pressure of the working refrigerant for reliable system operation with optimum co-efficient of performance (COP).The whole work is carried out for various capacities (1 Ton, 2 Ton, 3 Ton and 5 Ton capacity) of the domestic compression refrigeration-based air conditioning systems. The results and outcomes of the software is also validated with some experimental results with the existing air conditioning system to ensure the authenticity of the other results obtained for present work.

5.2 Methodology:

The present analysis is carried out by using CoolPack1.50 software EES software. Designing, dimensioning, evaluating, and optimizing refrigeration and air conditioning systems can be done with the help of the simulation tools in the CoolPack collection. The overview of both the software are given in the following sub-sections. While analyzing the system the capacity of Solar Air Conditioner is considered as 1 Ton, 2 Ton, 3 Ton and 5 Ton capacities, operate in vapor compression cycle with DC Solar Photovoltaic power and natural refrigerants as working medium. The natural refrigerants R290 and R600a were selected because, in comparison to other refrigerants now in use, they have relatively little as indicated in Tables 5.1 and 5.2, there is no ozone depletion potential (ODP) and no global warming potential (GWP) Various characteristics parameters of natural refrigerants are listed in Table 5.3 which indicates high Latent heat of vaporization at boiling point of R290 with lower Boiling point Temperature. R600a also have more or less similar properties as compared to R290 whereas R718 and R123 cannot be selected due to its high Boiling point Temperature at atmospheric pressure, also R114 & R502 have high molar mass. Therefore, R290 and R600a are discovered to be the most qualified candidates for use as natural refrigerants in the operation of air conditioning and refrigeration. Now considering all parameters of these refrigerants the various performance parameters i.e., evaporator heat removal, Qe [kW], condenser heat removal, Qc [kW], Compressor work, W [kW], and Co-efficient of Performance (COP) are estimated keeping fixed evaporator temperature (Te) as 10 °C and condenser temperature (Tc) as 50 °C. Reheating is also provided for keeping the operating cycle under realistic zone of operation.

Table 5.1: Existing Refrigerants ODP & GWP

Existing Refrigerant	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)
R-11 Trichlorofluoromethane	1.0	4000
R-12 Dichlorodifluoromethane	1.0	2400
R-22 Chlorodifluoromethane	0.05	1700
R-410A	0	2088
R-134a Tetrafluoroethane	0	1300
R-32 Difluoromethane	0	650

Table 5.2: Natural Refrigerants ODP & GWP

Natural Refrigerants	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)
R290 (Propane)	0	3
R600a (Iso-butane)	0	3
R-114 Dichlorotetrafluoroethane	1.0	3.9
R-123 Dichlorotrifluoroethane	0.02	0.02
R-502 (48.8% R-22, 51.2% R-115)	0.283	4.1
R-717 Ammonia - NH_3	0	0
R-718 Water - H20	0	
R-744 Carbon Dioxide - CO_2		1*

Table 5.3: Natural Refrigerants selection parameters

Natural Refrigerants	Boiling point Temperature at atmospheric pressure 14.7 psi, 1 bar abs (^{0}C)	Critical Point Temperature (^{0}C)	Latent heat of vaporization at boiling point (kJ/kg)	Specific heat of liquid at 25°C (KJ/Kg°C)	Specific Volume (Cu.Ft./lb.)	Molar Mass (g mol−1)
Condition	Should be low value	Better to be high value	Towards high value	Towards low value	Should be low value	Towards low value
R290	-42.2	97	425.60	2.6704	0.0728	44.0956
R600a	-11.8	135	362.60	2.38	0.0725	58.12
R-114	3.56	145.68	25.1163	0.9085	0.0275	170.921
R-123	27.8	184	170.2	0.9427	0.0291	152.931
R-502	-45.6	80.2	32.0564	0.8527	0.0286	111.6278
R-717	-33.3	133	1371.2	3.7503	0.0680	17.0303
R-718	99.9743	373.946	2260	85.1781	0.016066	18.0153

The following equations 5.1 to 5.6corresponding P-H diagram (Figure 5.1) taken for the performance analysis using both the software are given below as follows;

Heat absorbed in the evaporator

$Qe = \dot{m}\ (he\mathbf{1} - he\mathbf{4})$------------------5.1

Where, Qe = heat absorbed by evaporator,

he_1= enthalpy of vapour at exit of evaporator (kJ/kg) and

he_4 = enthalpy of a cooled refrigerant entering in to evaporator (kJ/kg)

ṁ = mass flow rate (kg s^{-1})

Compressor Work

$Wc = \dot{m}\ (hc2 - hc1)$------------------5.2

Where, Wc= Compression Work input in kW,

hc_2= enthalpy of vapourat the exit of compressor (kJ/kg) and

hc_1= enthalpy of vapour entering in to compressor in kJ/kg.

Coefficient of Performance

$COP = \frac{\dot{m}\ (he1 - he4)}{\dot{m}\ (hc2 - hc1)}$-----------------------5.3

Where,

COP= coefficient of performance,

Qe= heat of evaporator in kJ/kg and

Wc= Compressor work done in kJ/kg,

ṁ = mass flow rate of the refrigerant in kg/s.

Refrigerating Effect

$R.E. = (COP * Wc)$------------------5.4

Where,

R.E. = Refrigerating Effect, COP= coefficient of performance, **Wc** = compressor work done on the working fluid.

Heat rejected by condenser

$hcondensor = \dot{m}\ (hc2 - hc3)$--------5.5

Where,

$hcondensor$ = heat of condenser,

hc_2= enthalpy of vapour entering condenser in kJ/kg and

hc_3=enthalpy of sub cooled refrigerant exiting condenser in kJ/kg.

Refrigerant mass flow rate

The mass flow rate of a refrigeration system is determined by dividing the refrigerating effect by the enthalpy changes in the evaporator presented by equation in below;

Mass flow rate(ṁ)

$$\dot{m} = \frac{\text{Cooling load in kW}}{(\mathbf{he}1-\mathbf{he}4)} \quad \text{-----------------}5.6$$

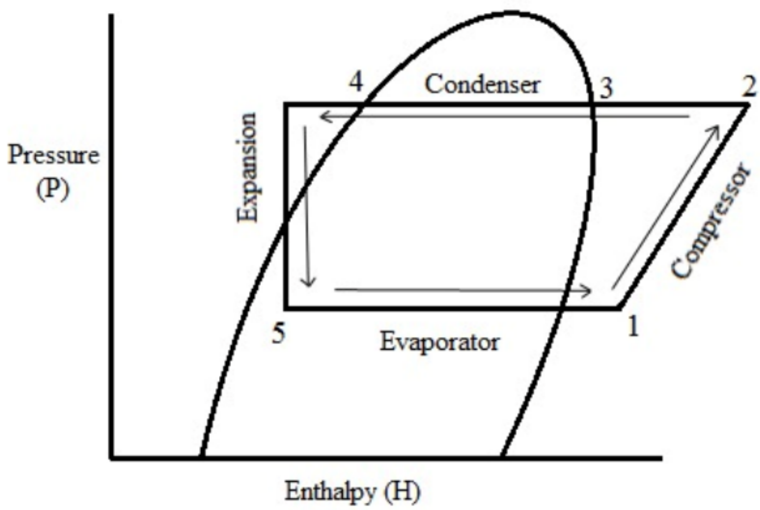


Figure 5.1: P-H Diagram of Vapour compression cycle

Further theCoolPack1.50 software is validated with some experimental results. The experiment is carried out for the Voltas make 1.5 Ton capacity domestic air conditioning system operating with R32 refrigerant as shown in Figure 5.2.

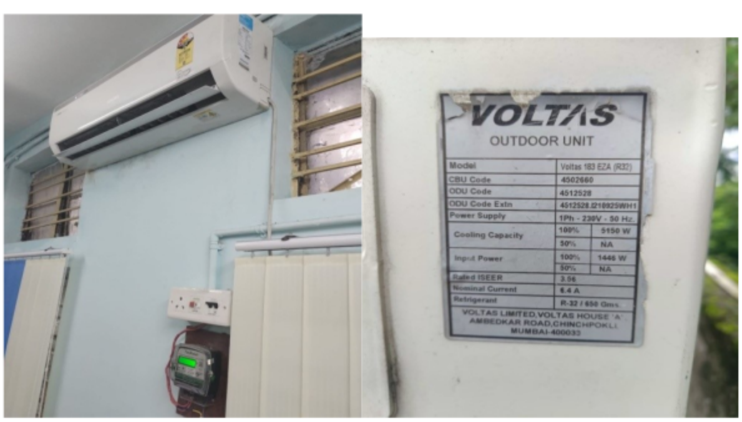


Figure 5.2: Photograph of Voltas Make 1.5 Ton capacity AC systems with its specification

A sample programming for EES software is given in the form of table 5.4 as follows, where refrigerant R600a is taken for 2 Ton capacity Air Conditioning system.

Table 5.4: Programming for obtaining Performance parameter of 2 Ton capacity R600a based Air Conditioning System:

```
TR=2
Te=10
Tc= 50
T=Te
Te=10
X=1
H1= Enthalpy (R600a, T=T,x=x)
s = Entropy (R600a, T=T,x=x)
S2=S1
P_sat=P_sat (R600a, T=T)
T= Tc
Tc=50
P2=Pc
H2=Enthalpy (R600a, s=S2=P2)
T2=Temperature (R600a, P=P2, s=S2)
H3=Enthalpy (R600a, T=T3, x=x3)
X3=0
T3=Tc
H4= H3
Qe= h1- h4
Wc= h2-h1
COP = Qc/Wc
ṁ= (R*3.517)/Qe
Qc= h2-h3
Qc_dot= ṁ * Qc
```

5.2.1 CoolPack 1.50 Version:

For developing, dimensioning, evaluating, and optimizing refrigeration systems, use the simulation tools in CoolPack 1.50. Six categories, each represented by a tab in the Toolbar above, are used to categorize the simulation programs in CoolPack.By selecting the Toolbar tab for that category and then selecting the icons in the Toolbar that represent each program, it may see a list of all the programs in that category. The project's goal was to create a simulation model that could be applied to refrigeration system energy optimization. Refrigeration technicians, engineers, students, and anybody else who has an impact on the current and future energy usage of refrigeration systems would use these models.

The following simulation goals are covered by the CoolPack programs:

•Calculations of refrigerant qualities (property plots, thermo-physical and thermodynamic data, and refrigerant comparisons)

•Analysis of the refrigeration cycle, such as a comparison of one- and two-stage cycles

•Component sizes for air conditioning systems are calculated using general dimensioning principles

•Calculating operating conditions in a system with known components is known as system simulation

•System operation review, efficiency assessment, and recommendations for lowering energy consumption

•Calculations of system components and component efficiency

•Transient simulation of item cooling, for example, to assess cooling down times

It has made every effort to make the programs in CoolPack as reliable, fault-free, pertinent, and user-friendly as possible [13].

5.2.2 EES Software Professional V9.478 (Version 11.319):

Engineering Equation Solver, also known as "EES," is a universal equation-solving tool that can numerically resolve countless connected algebraic nonlinearity, and differential equations. Equations involving integrals and differentials can also be solved using the application, optimisation be carried out and uncertainty analyses given, carry out conversion of units, verification of unit consistency, linear and non-linear regression, and produce graphs of publication-quality. A key component of EES is a very accurate database for thermodynamic and transport properties that is provided for hundreds of compounds in a way that enables equation-solving capacity.

5.2.3 Software validation:

Both the software's are used for analysis purpose in the present work and compared the results to establish the authenticity of the outcomes [14]. As it mentioned the author also tried to validate the outcomes from the software with the published results as well as some experimental results corresponds to the existing AC system with R32 refrigerants.

As the CoolPack 1.50 software have not any option to run with R32 refrigerant, the author first validates the experimental result with the results of EES software and then the results of EES software are compared and validated for CoolPack 1.50 software.

The percentage of compressor power consumption is calculated for the existing Voltas make 1.5 Ton capacity domestic AC at rated condition as follows;

Existing System capacity: 1.5-ton 3-star AC (Compressor fixed speed)

Rated Cooling Capacity= 5150Watt & Total rated Power consumption= 1446 Watt

Rated Input Power for Compressor= 1400 Watt (As per AC datasheet and Compressor Specification for R32)

Where, Rated AC Power consumption 2000 Watt with Rated overall COP = 3.562

But the present study is based on the energy consumption by the compressor. Therefore, it needs to find the percentage share of compressor power consumption in the AC system.

So, other power consumption for blower and sensor circuits and Outdoor unit fan except compressor at rated condition = (2000-1400) Watt= 600 Watt, i.e., 30%

Therefore, percentage of Compressor power consumption over total power consumption= (1400/2000) *100= 70%

Table 5.5: Comparison on Compressor performance based on Experimental Data with EES software simulation results for 1.5 Ton 3star AC unit at stable condition

Date of Experiment	Minimum Evaporator Temperature (°C)	Maximum Condenser Temperature (°C)	COP of Compressor (70% of total power)	Simulated C.O.P By EES Software	Error (%)	Simulated Compressor Power Consumption (W)	Experimental Compressor Power Consumption (W)	Error (%)	Experimental Total Power Consumption
11/08/23	7.8	49.2	5.167	5.075	1.78%	1015	996.8	1.83%	1424
14/08/23	7.6	50.4	5.159	4.848	6.03%	1062	998.2	6.39%	1426
14/08/23	7.9	51.3	5.138	4.751	7.53%	1084	1002.4	8.14%	1432
16/08/23	7.4	49.8	5.116	4.913	3.97%	1048	1006.6	4.11%	1438
17/08/23	7.7	50.1	5.174	4.911	5.08%	1049	995.4	5.38%	1422

For validation of EES software results are compared with the experimental results at stable operating condition that are presented as Compressor performance in Table 5.5 and find error over COP and Compressor power consumption, which always came below 10%.

In the present work analysis on compressor performance are carried out using both the software, CoolPack as well as EES and author find the similar results. Therefore, it can be concluded that CoolPack software is also be validated with experimental results.

Further the results of CoolPack software are compared with the results of another published paper "Performance Investigation of Natural Refrigerant R290 as a Substitute to R22 in Refrigeration Systems", on Elsevier, Science Direct, Energy Procedia 109 (2017) 346 – 352, where, performance parameters are obtained under the specified operating state of 45°C for condensing and 10°C for evaporation using REFPROP9.0 SOFTWARE with super heat 10 K and sub cool 5 K as in Table 5.6.

Table 5.6: Compressor performance based on data published using REFPROP 9.0 [16, 17]

Refrigerant	Pressure ratio	Discharge temperature (°C)	Refrigeration effect (kJ/kg)	Compressor work (kJ/kg)	COP	Power per TR (kW/ TR)	Refrigerant mass flow rate per TR (Kg/s)
R22	2.70	68.49	166.15	25.95	6.39	0.5496	0.0211
R290	2.55	57.56	294.84	46.23	6.37	0.5519	0.0119

And these data are verified by Cool Pack Software analysis data as in Table 5.7. This study demonstrates that the needed refrigerant mass flow rate for R290 is 43.6% less than that for R22 whereas CoolPack result indicates as 43.9%that's more or less same.

[(.0211-.0119)/.0211] *100=43.6 % where, R22 Mass flow rate=0.02107003 kg/s and R290 Mass flow rate= 0.01181840 kg/s for the case of Table 5.6. In the other way considering mass flow rate of R290 over R22 for the case of CoolPack as in Table 5.7, the variation of mass flow rate is {(0.02107003-0.01181840)/ 0.02107003} *100= 43.9%]

Table 5.7: Compressor performance based on analysis in CoolPack 1.50 software

Refrigerant	Pressure ratio	Discharge temperature (°C)	Refrigeration effect (kJ/kg)	Compressor work (kJ/kg)	COP	Power per TR (kW/ TR)	Refrigerant mass flow rate per TR (Kg/s)
R22	2.540	68.49	166.77	24.35	6.85	0.513	0.0210
R290	2.409	57.56	297.84	43.412	6.86	0.513	0.0118

And in both analysis Changes in COP between two refrigerants are negligible. A lower pressure ratio is preferred since it will boost the volumetric and isentropic efficiency, which will affect the system's COP and mass flow rate of the refrigerant. Compared to R22, R290 provides a somewhat lower pressure ratio.

Table 5.8: Compressor performance based on analysis in EES software

Refrigerant	Pressure ratio	Discharge temperature (°C)	Refrigeration effect (kJ/kg)	Compressor work (kJ/kg)	COP	Power per TR (kW/ TR)	Refrigerant mass flow rate per TR (Kg/s)
R22	2.540	59.76	152	22.98	6.615	0.5317	0.02314
R290	2.421	48.38	263	40.87	6.435	0.5465	0.01337

Similarly, in EES Software (Table 5.8), discharge pressure of both refrigerants shows lower value than REFPROP 9.0 Software whereas, changes in refrigerant mass flow rate became lower for R290 thanR22 by almost same as 43.9%.

Therefore, from the above discussion it can be concluded that both the results from CoolPack 1.50 and EES software are well validated with experimental results as well as with other published results. Now the compressor performance for domestic air conditioner system operating with natural refrigerant (R290, R600a) for various capacity (1 Ton, 2 Ton, 3 Ton and 5 Ton) are analysed and compared by both the software (CoolPack and EES) for energy optimization along with its feasibility study. The subsequent section contains the study's findings.

5.3 Results and Discussion:

The results found after the analysis considering fixed evaporator temperature (Te) as 10 °C and condenser temperature (Tc) as 50 °C without reheating arrangement for various kinds of Obsolete, Existing and Natural Refrigerants that the compressor power consumption and COP for refrigerant R290 and R600a are comparable and sometimes shows the better results in case of natural refrigerants for 1 Ton capacity as shown in Table 5.9 and Table 5.10. The same results are also represented graphically in Fig.5.3.

Table 5.9: Existing Synthetic Refrigerants Performance

Obsoleted & Existing Refrigerants Characteristics for 1TON Capacity	R-11	R-12	R-22	R-410A	R-134a
Te [°C]	10^0C	10^0C	10^0C	10^0C	10^0C
Tc [°C]	50^0C	50^0C	50^0C	50^0C	50^0C
Qe [kW]	3.516	3.516	3.516	3.516	3.516
Qc [kW]	4.077	4.133	4.144	4.239	4.152
Qe [kJ/kg]	150.442	106.816	145.590	136.231	131.469
Qc [kJ/kg]	174.447	125.560	171.605	164.257	155.243
COP	6.27	5.70	5.60	4.86	5.53
W [kJ/kg]	24.005	18.745	26.015	28.026	23.774
Pressure Ratio	3.875	2.881	2.853	2.804	3.178
W [kW]	0.561	0.617	0.628	0.723	0.636

Table 5.10: Natural Refrigerants Performance Analysis in 1TON AC

Future Natural Refrigerants Characteristics for 1TON System	**R290**	**R600a**	R-114	R-123	R-502	R-717	R-718
Te [°C]	10^0C	10^0C	10^0C	10^0C	10^0C	10^0C	10^0C
Tc [°C]	50^0C	50^0C	50^0C	50^0C	50^0C	50^0C	50^0C
Qe [kW]	3.516	3.516	3.516	3.516	3.516	3.516	3.516
Qc [kW]	4.163	4.131	4.143	4.093	4.209	4.102	4.133
Qe [kJ/kg]	249.983	248.361	92.887	136.623	89.369	1035.704	2309.730
Qc [kJ/kg]	295.988	291.809	109.450	159.062	106.985	1208.437	2715.247
COP	5.43	5.72	5.61	6.09	5.07	6.00	5.70
W [kJ/kg]	46.005	43.448	16.563	22.439	17.616	172.733	405.517
Pressure Ratio	2.705	3.118	3.486	4.200	2.718	3.306	10.060
W [kW]	0.647	0.615	0.627	0.577	0.693	0.586	0.617

Table 5.9 shows that the highest refrigeration effects are observed as 150.442[kJ/kg] in case of Synthetic Refrigerant R -11 but it becomes obsolete due to its higher value of GWP. So, R-410A and R-134a are our moderate selections for optimized refrigerants effect at their COP standards.

Author's main focus in table 5.10 is to understand the performance of natural refrigerants over 1TON AC against the same evaporator and condenser temperatures. It is found that R290 shows the 2nd lowest Power Consumption W [kW] whereas R502 shows lowest Power Consumption W [kW]. But R502 is a blending refrigerant which is not economic due to its high maintenance cost. On the other hand, R-717 & R-718 need extremely high compressor power and is not suitable for standard refrigeration effects.

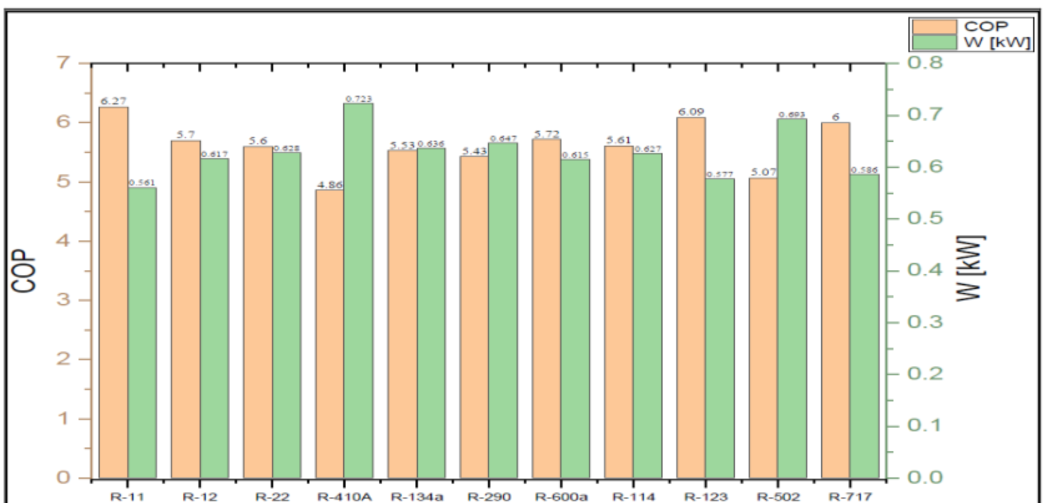


Fig. 1: Obsoleted, Existing & Future Refrigerants COP & W[kW] comparative study for 1TON AC System

Figure 5.3: Comparative Performance Study for Obsolete, Existing& Future Refrigerants COP &Compressor Work (W) in kW for 1 Ton AC System

In addition, the same analyses are carried out for other capacities (2 Ton, 3 Ton and 5 Ton) along with 1 Ton capacity and the outcomes are found that there is no change in COP (as same as shown in Figure 5.3). The variations in compressor power consumption are also obtained that's are compared and summarized as graphically represented in Figure 5.4.

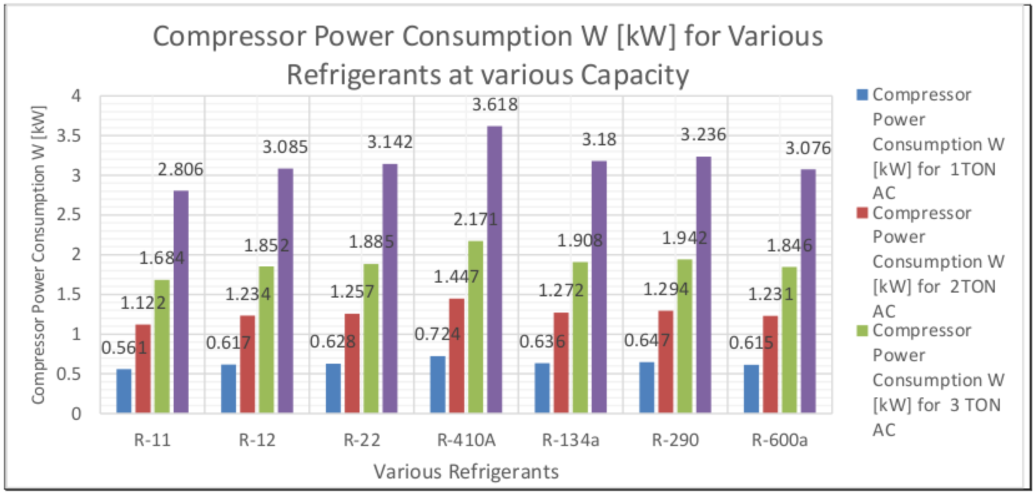


Figure 5.4: Comparisons on compressor power consumption for AC operating with different types of refrigerants for capacity of 1Ton, 2 Ton, 3 Ton, & 5 Ton

The effect of superheating at the inlet of the compressor for various capacity are also be checked, which is proposed to be done with the help of solar thermal energy. Initially the work is carried out for 1 Ton capacity system for all kinds of refrigerant as shown the outcomes in Table 5.11.After that the same analysis are carried out for other capacities (2 Ton, 3 Ton and 5 Ton) along with 1 Ton capacity considering only two natural refrigerants (R290 and R600a). The superheat temperatures are also kept as 5^0C, 10^0C and 15^0C. The variations of COP and compressor power consumption are shown in Fig. 5.5 and Fig. 5.6.

Table 5.11: The compressor performance of various natural refrigerants with 5^0C superheating by using solar thermal energy for 1 Ton capacity

Natural Refrigerants Characteristics for 1TON System when Superheat at 5^0C	R290	R600a	R-114	R-123	R-502	R-717
Te [°C]	10^0C	10^0C	10^0C	10^0C	10^0C	10^0C
Tc [°C]	50^0C	50^0C	50^0C	50^0C	50^0C	50^0C
Qe [kW]	3.516	3.516	3.516	3.516	3.516	3.516
Qc [kW]	4.159	4.125	4.133	4.091	4.203	4.109
Qe [kJ/kg]	259.425	256.788	96.395	140.064	93.278	1049.622
Qc [kJ/kg]	306.878	301.255	113.321	162.954	111.515	1226.677
COP	5.47	5.77	5.69	6.12	5.11	5.93
W [kJ/kg]	47.453	44.467	16.926	22.890	18.237	177.054
Pressure Ratio	2.705	3.118	3.486	4.200	2.718	3.306
W [kW]	0.643	0.609	0.617	0.575	0.687	0.593

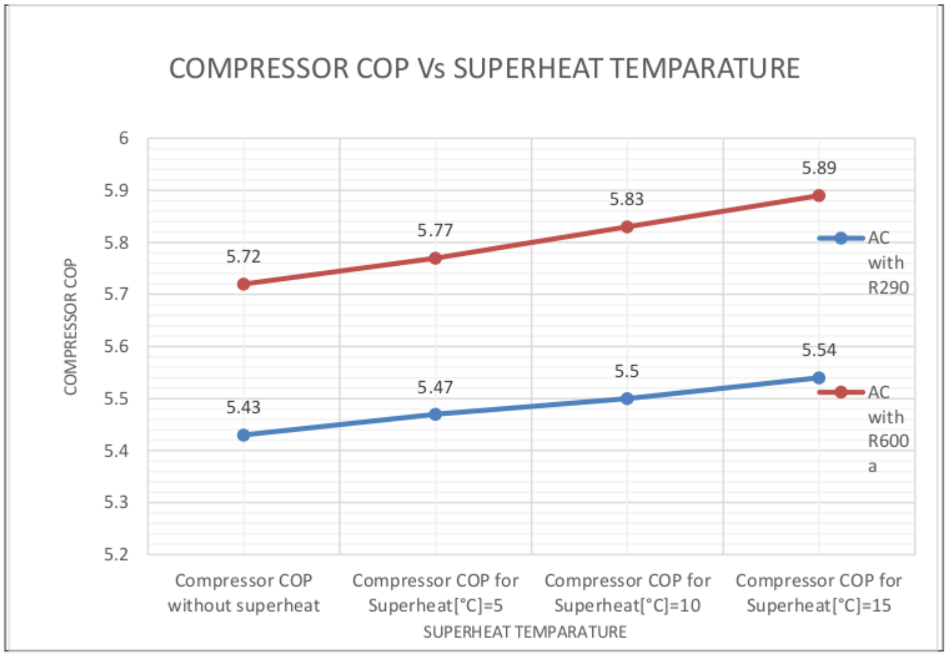


Figure 5.5: Variation of compressor COP on degree of superheat at compressor inlet for refrigerants R290 and R600a

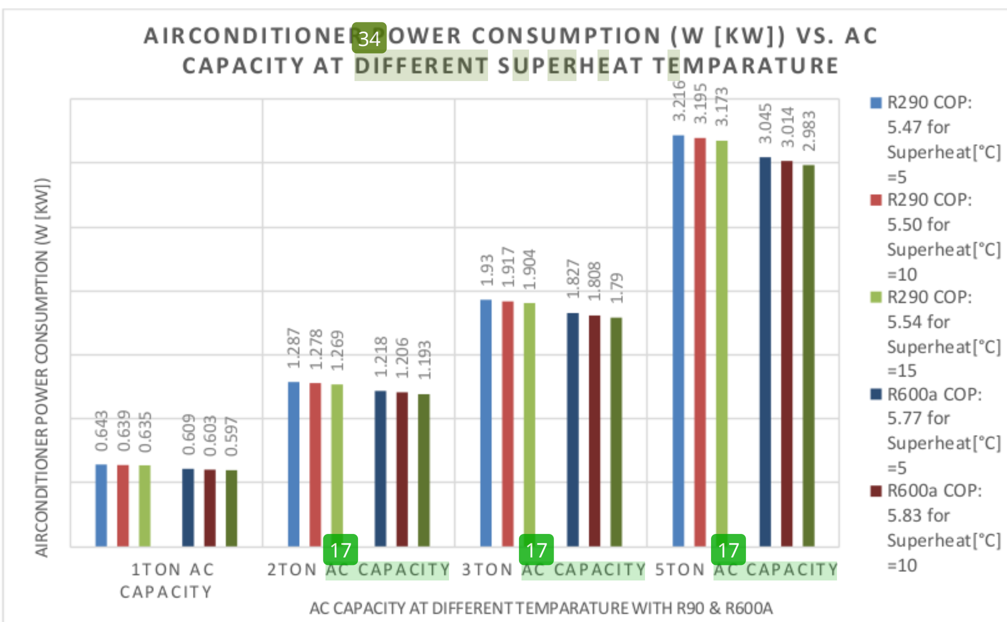


Figure 5.6: Compressor Power Consumption (W [kW]) for different AC Capacity at different superheat temperature for refrigerants R290 and R600a

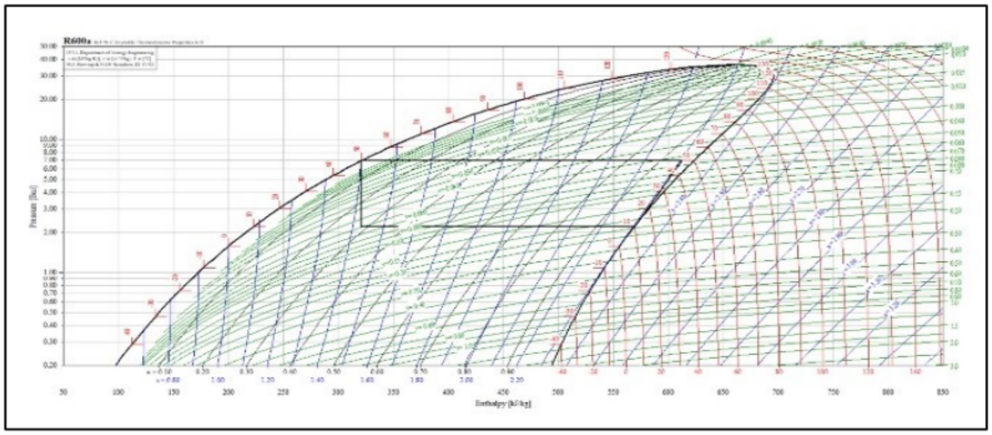


Figure. 5.7: P-H diagram for showing working cycle using R600a for 1Ton AC

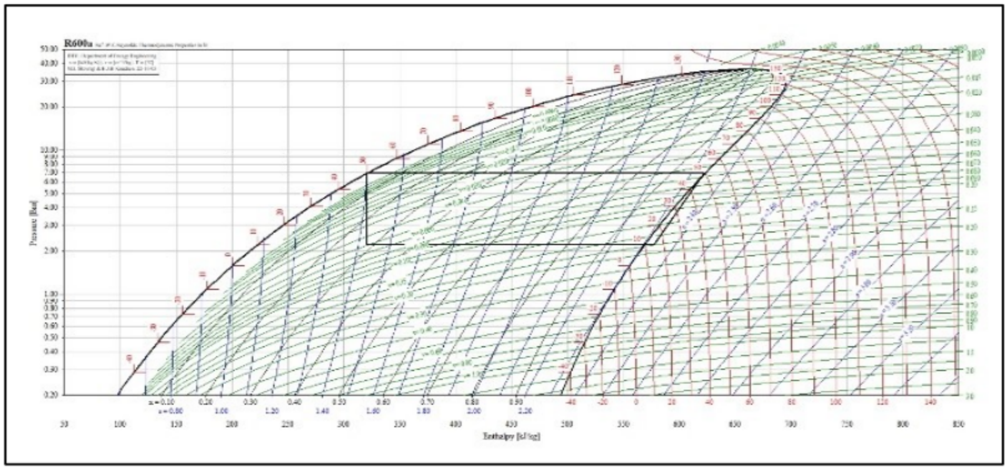


Figure. 5.8: P-H diagram for showing the working cycle using R600a for 1Ton AC with 5^{0}C superheat

Refrigerants R600a shows less power consumption (0.615 kW) than R290 (0.647kW), but the problem of using R600a without reheating at exit of evaporator, is not possible because of its mixed phase as shown in PH diagram (Fig. 5.7). This problem can be resolved by adding heat to the refrigerant medium in between evaporator outlet and suction of the compressor to make refrigerant dry and superheat. Therefore, the analysis is made introducing superheating of the refrigerants and found at least 5°C superheat of R600a indicates better results with respect to power consumption and COP of the system. Also it resolves the problems of mixed phasing at the suction of compressor that observed in gaseous phase as shown in PH diagram (Fig. 5.8).

It has been observed that R600a has the highest COP and highest Refrigerant effect with the exception of R-717, for different capacity domestic air conditioner system at 5^{0}C superheating condition. So, from all the above analysis it can be concluded that the next generation Natural refrigerant will be R600a and the system have to redesign as per working cycle shown in the

P-H diagram and Solar thermal heating will help to get the best performance with the lowest power consumption using R600a.

From power consumption point of view, there are different losses in induction motors such as temperature. A three-phase induction motor has an efficiency of about 74%, while a single-phase motor runs at 64%. In the other hands due to the fact that the secondary magnetic field is produced by permanent magnets rather than copper windings, the DC motor is 30% more efficient than AC motors. Now considering compressor work consumption as 640 W, the motor power input in case of single phase induction motor will be approximately 1000 W corresponding to 1 Ton AC system. Whereas by using DC motors there will be around 30% reduction of power consumption (770W) and easily can be powered by solar photovoltaic system. Again, it is observed that R290 has the lowest mass flow rate except Ammonia, but ammonia is toxic and not suitable for the vapor compression cycle due to the highest compressor work i.e. 177 kJ/kg .

Therefore, from the above analysis it is observed that R290 is the best acceptable Refrigerant for domestic air conditioning system from energy, reliability and environment point of view and R600a also shows best performance solar thermal energy is introduced for superheating of 5^0C at the suction of compressor. In Table 5.6., where comparisons of natural refrigerants are shown indicates highest cooling capacity for R-290.In other hand the mixed refrigerants; R-114 & R-502have the smallest cooling capacity because of its lower compression work.

5.4 Conclusion:

Present chapter redirected toward the precise analysis of various refrigerants based on vapor compression type domestic air-conditioning system considering various capacities (1 Ton, 2 Ton, 3 Ton and 5 Ton). Emphasize is given on replacement of all synthesized refrigerants to natural refrigerants because of their environment friendly behavior. The whole comparative analysis are carried out in the CoolPack software and EES software platform and identified that natural refrigerants R290 and R600a shows the promising results in terms of evaporator heat removal, Qe [kW], condenser heat removal, Qc [kW], Compressor work, W [kW], and Co-efficient of Performance (COP), keeping fixed evaporator temperature (Te) as 10 °C and condenser temperature (Tc) as 50 °C. It is also found the superheating of refrigerant at inlet of compressor improves the COP with decrease power consumption that is proposed to be done with the help of solar thermal energy. In case of refrigerant R600a, it is required superheating at least by 5^0C at the suction of compressor for keeping the operating cycle under realistic zone of operation. As it is found the compressor work consumption of 640 W for R290 based 1 Ton vapor compression cycle air-conditioning system, the motor power input in case of single-phase induction motor will be approximately 1000 W. Whereas by using DC motors there will be around 30% reduction of power consumption (770W) and easily can be powered by solar photovoltaic system (DC). Therefore, the present work shows the possibilities of reliable operation with optimized power consumption by introducing solar thermal (required for R600a) and solar photovoltaic power (DC) application for natural refrigerants R290 and R600a that will help towards sustainable environment.

References:

[1] BIS (1916), National Building Code of India. Available at: http (Accessed: 5 Sept.2018)

[2] X.Q. Zhai, R. Z. Wang, J.Y. Wu, Y.J. Dai, and Q. Ma, "Design and performance of a solar-powered air conditioning system in a green building", Journal of Applied Energy, Vol.85, pp 297-313, 2008.

[3] R. Kholsa, (2018). Plugging in Energy Demand in Indian Residence Philadelphia: Kleinman Centre for Energy Policy

[4] H. Lee, Thermo-electrics- Design and Materials, John Wiley and Sons, 2016.

[5] H. Lee, Thermal Design: Heat Sinks, Thermo-electrics, Heat Pipes, Compact Heat Exchangers, and Solar Cells, Hoboken: John Wiley & Sons, Inc., 2010.

[6] Abas, N.; Kalair, A.R.; Khan, N.; Haider, A.; Saleem, Z.; Saleem, M.S. Natural and synthetic Refrigerants, global warming, A review. Renew. Sustain. Energy Rev. 2018, 90, 557–569.

[7] C. Vinning, "An inconvenient truth about thermoelectrics," Nature Materials, vol. 8, no.2, pp. 83-85, 2009.

[8] Shekarchian M, Zarifi F, Moghavvemi M, Motasemi F, Mahlia TMI, Energy, Exergy, Environmental and economic analysis based on heat recovery and preheating technique, Energy Conversion, and Management, Volume 71, July 2013, Pages 51-61.

[9] Harby K 2017, Hydrocarbon and their mixtures as alternatives to environmentally unfriendly halogenated refrigerants: An updated overview. Renewable and Sustainable Energy Reviews, 73, 1247-1264.

[10] Yu C. C. and Teng T P 2014 Retrofit assessment of refrigeration using hydrocarbon refrigerants. Applied Thermal Engineering 66(1), 507-518.

[11] Ullah K. R., Saidur R., Ping H.W., Akikur R.K., and Shuvo N.H., A review of solar-thermal refrigeration and cooling Methods.

[12] Stanford A. Klein, Ph. D, Fellow ASHRAE, and Dougas T. Reindi, Ph.D., Solar Refrigeration, 2005, American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. ASHRAE, Journal, Vol47, No.9, September 2005.

[13] Mani, PoojaIyer, "Design, Modeling, and Simulation of a Thermoelectric Cooling System

(TEC)" (2016), Master's Theses. 749.

[14] Naskar, R., Ghosh,A., Mandal, R., Design & New Development of Solar Air Conditioner, at International Journal of Scientific Research in Multidisciplinary Studies (IJSRMS),Vol.4, Issue.6, pp.19-23, June (2018) E-ISSN: 2454-9312, Reg. No.24143/IND/CE/2012, UGC SL. NO.-45841.

[15] Naskar, R., Ghosh,A., Mandal, R., Advancement Of Solar Refrigeration Technology And Its Impact In Society, at Journal of SCIENCE AND CULTURE, VOL. 85, NOS. 9–10, September-October, 2019.

[16] T D J Prabha, Dr. V Rambabu, “Experimental investigation on the performance of air conditioner using R32 Refrigerant”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 12(4) Ver. V (Jul. - Aug. 2015), PP 139-144.

[17] C S Choudhari, S N Sapali, “Performance Investigation of Natural Refrigerant R290 as a Substitute to R22 in Refrigeration Systems”, Energy Procedia 109 (2017) 346 – 352.

CHAPTER 6

Chapter 6

Energy Optimization of Natural Refrigerant-Based Air Conditioning System for A Sustainable Environment on The Basis of The Major Five Climatic Zones in India

6.1 Introduction:

Refrigeration is a system that has to deal with the production and control of temperature below that of the surrounding. Herein, heat must be removed from the system and transferred to another body whose temperature is below that of the refrigerated body, or the space needs to be cooled. Mainly, Sunlight is the heat source, and for the same reason that refrigeration must be at its highest level. Over the coming two decades, according to the IPCC Report 2019, Asian countries account for 50% of national greenhouse gas emissions due to air conditioner use, which has increased significantly in recent decades. The cost of conventional electricity is increasing at an exponential rate, and domestic applications of air conditioners are expected to increase rapidly by three times by 2050. It attempted to examine various optimization strategies with a focus on the sub-tropical region to achieve the goal of climate change and presents the directions toward a highly effective air conditioner that uses very little energy during operation. Further, the restriction of temperature rise and energy efficiency is correlated by author Prasanta Kumar Bal [1]. This is a major concern in India and stated that one of the major concerns is domestic Electric power consumption by using only for the Air conditioner. A techno-economic assessment framework for life cycle analysis is proposed by Yanjie Li [2]. The authors show a case study of alternative air-conditioning technologies for the residential sector and evaluated the costs and environmental benefits. They create a modelling framework that can generate accurate and understandable outcomes using a systemic and systematic assessment method. R32 is the greatest contender, according to this study's overall assessment, for reducing greenhouse gas emissions while also having lower life cycle costs. But the ODP aspect of Natural Refrigerants should be preferred for future analysis and it is not natural refrigerants. Integration of PV systems with air-conditioning able to motivate not just solar energy developers but also focuses on incorporating solar power into buildings. Future improvements to the integrated system could be made using actual HVAC data from a building that is powered by a PV solar plant which stated by Gustavo de et.al.[3].

The planning and building of a photovoltaic (PV) system that combines PV panels, solar chargers, inverters, and batteries with a direct current (DC) air conditioning system is reported by I. Daut et.al. [4]. Calculations of the hourly, monthly, and annual levels of solar radiation were made using a typical meteorological year (TMY). To assess the kind of cooling and the amount of cooling required, cooling load calculations were made. F.J. Aguilar. al. [5] reported numerous options and the possibility of using photovoltaic systems instead of batteries or regulators to power air conditioning equipment. In this instance, the production factor was 65.1%, from May to October; the solar contribution obtained in cooling mode was 64.5%. Solar radiation estimation for the site is one of the major aspects of the proper design of the solar-powered air-conditioning system. Saurav Dubey et.al.[6] considered the solar radiation models that mainly focused on monthly or daily values. For the purpose of designing air conditioning systems, they have created 96.5% and 97.5% of the frequency levels of two different types of hourly solar radiation datasets for 17 sites presented by Zixu Yang et. al. [7] proposed a highly effective air conditioner with a solar system and clever evaporative cooling ventilation. Natural refrigerant and natural sub-cooling are used to reduce cooling load through the roof envelope, with a similar improvement in COP compared to a mechanical sub-cooler. The simulation result with a dedicated mechanical sub-cooler was explained by Jay Prakash Bijarniya, et.al.[8]. Rapid increases in global electricity usage make renewable energy sources and energy efficiency techniques are required. Photovoltaics have drawn a lot of interest, and HOMER software was used to optimize an office building's solar PV-powered air conditioning system shown by Aziz Haffafa et.al. [9]. A significant amount of energy and emissions savings can be achieved by introducing improved and energy-efficient air conditioners (RACs), particularly in emerging economies. Nihar Shah et.al.[10] have studied and identified 'best-in-class RAC components and designs for RACs that are easily accessible or standardized for manufacture in the context of synthetic refrigerants. In this Last decade, refrigerant systems have received a lot of attention in attempt to reduce their energy usage. Different refrigeration system control strategies were created. Depending on system operating conditions, these methods differ in their theoretical basis and performance analysis directed by B. Saleh et.al.[11]. Researchers have developed various technologies for passive cooling, including phase change materials (PCM), night-time radiative cooling, and evaporative cooling to reduce energy demands in India-based free cooling by considering solar thermal technology. Equations and correlations have been developed to determine various critical design parameters. [12].

The present analysis is carried out by using Cool Pack 1.50 software as well as a practical environmental database, which presents a comprehensive assessment of different operating temperature conditions per different climatic zones in India. Here, refrigerant operating temperatures are considered according to the climatic zones to have the optimum performance of the air conditioning system. Refrigeration or air-conditioning units are mainly required during the summer season. Tropical countries like India have an abundant source of solar radiation which is very much suitable to utilize solar power. Considering India is divided into five major climatic zones. This paper emphasizes on application of R290 as the natural refrigerant and the operating parameters are optimized to have higher COP based on the different climatic zones of India. Also, the present work argues sustainable and low power consumption to provide higher COP if the same capacity with the same refrigerant operates at different working temperatures as per different climatic zone. Here, an air conditioning system with 1 Ton capacity is considered for design purposes, and its compressor capacity is optimized based on the different climatic zone. Further, the results obtained are compared with the results from EES software.

6.2 Methodology:

In the present work, the authors considered a different climatic zone of India for designing the purpose of vapour compression cycle Air Conditioning Systems of Capacity of 1 ton with natural refrigerants (R 290) and compared the compressor capacity and its full load power consumption based on different condenser temperature in the different climatic zone with respect to the available standard system for all location. While comparing the system performance the evaporator temperature is kept at 10^{o}C and condenser temperature and humidity are varied as per the available maximum temperature and humidity of that zone. A generalized flow chart is provided in Fig.7.1. For a better understanding of the methodologies. Here only compressor power consumption is estimated as it is the major power-consuming unit of the system. For analysis purposes, CoolPack (Version 1.50) Software [13] is used. The details of the Indian climatic zone are discussed in subsequent sections.

6.2.1 Indian Climatic Zone

47

The whole of India is classified into five major climatic zones with consideration of the temporal and spatial distributions of temperature and rainfall patterns. India may be classified into 65 **five climate zones** i.e., **Warm and humid, temperate, cloudy and cold, and hot and dry and composite zone**, where most Indian states belong to more than one climatic zone with few states lying in the single climatic zone. This division of climatic zones is based on **temperature and humidity [1].** For estimation of maximum air conditioning power consumption with respect to standard 1-ton capacity air conditioning, system the properties of air in the different zone are considered and given in the tabular form in Table 7.2. Also, it is shown the amount of moisture and heat needs to be removed to maintain the comfort condition (25^0C & RH 50%) of the room.

Table 6.1: Climatic zones based on temperature and humidity in India

CLIMATE ZONE	SUMMER MIDDAY (HIGH)	MEAN RELATIVE HUMIDITY	HIGHEST VALUE CONSIDERATION	REMARKS
HOT AND DRY	40 to 45	Very Low 25-40%	45^0C & RH 40%	Main aim 25^0C at RH 50%
WARM AND HUMID	30 to 35	High 70 to 90%	35^0C & RH 90%	Main aim 25^0C at RH 50%
TEMPERATE	30 to 34	High 60 to 85%	34^0C & RH 85%	Main aim 25^0C at RH 50%
COLD (SUNNY/CLOUDY)	17 to 24 /20 to 30	Low:10-50% /High: 70-80%	30^0C & RH 80%	Main aim 25^0C at RH 50%
COMPOSITE	32 to 43	Variable Dry Periods=20-50% Wet Periods= 50-95%	43^0C & RH 95%	Main aim 25^0C at RH 50%

[Ref.: https://www.firstgreen.co/climate-zone-map-of-india/]

Table 6.2: Air properties based on Maximum Temperature and Humidity of different climatic zone

Highest temperature and humidity Consider (each zone)	Hot and dry zone 45^0C & RH 40%	Warm and humid zone 35^0C & RH 90%	Temperate zone 34^0C & RH 85%	Cold (Sunny/ Cloudy) 30^0C & RH 80%	Composite zone 43^0C & RH 95%	**25^0C & RH 50%**	Remarks
property	value	value	value	value	value	**value**	Air Properties in Each Zone are Separately shown to make it a comfort zone by proper design of the air conditioning unit.
Dry-bulb temperature in °C	45.0000	35.0000	34.3000	30.0000	43.2000	**25.0000**	
The wet-bulb temperature in °C	32.0710	33.5280	32.0350	27.1310	42.4540	**17.8900**	
Dew point temperature in °C	28.6820	33.1930	31.4770	26.2190	42.3430	**13.8900**	
Relative humidity in%	40.9000	90.4000	85.3000	80.2000	95.6000	**50.0000**	
moisture content in kg H_2O / kg DA	0.0243	0.0316	0.0286	0.0210	0.0526	**0.0099**	
Comfort moisture in kg H2O / kg DA	0.0099	0.0099	0.0099	0.0099	0.0099	**0.0099**	
Moisture removal in kg H2O / kg DA	0.0144	0.0217	0.0187	0.0111	0.0427	**0**	
humid volume in m^3 / kg DA	0.9355	0.9162	0.9100	0.8869	0.9704	**0.8580**	
specific enthalpy in kJ/kg DA	108.0200	116.1800	107.8300	83.8030	179.1100	**50.3200**	
Comfort-specific enthalpy in kJ/kg DA	50.3200	50.3200	50.3200	50.3200	50.3200	**50.3200**	
Heat removal from the room in kJ/kg DA	57.7000	65.8600	57.5100	33.4830	128.7900	**0.0000**	

The natural Refrigerant base solar air conditioner working principle is shown by an algorithm as follows;

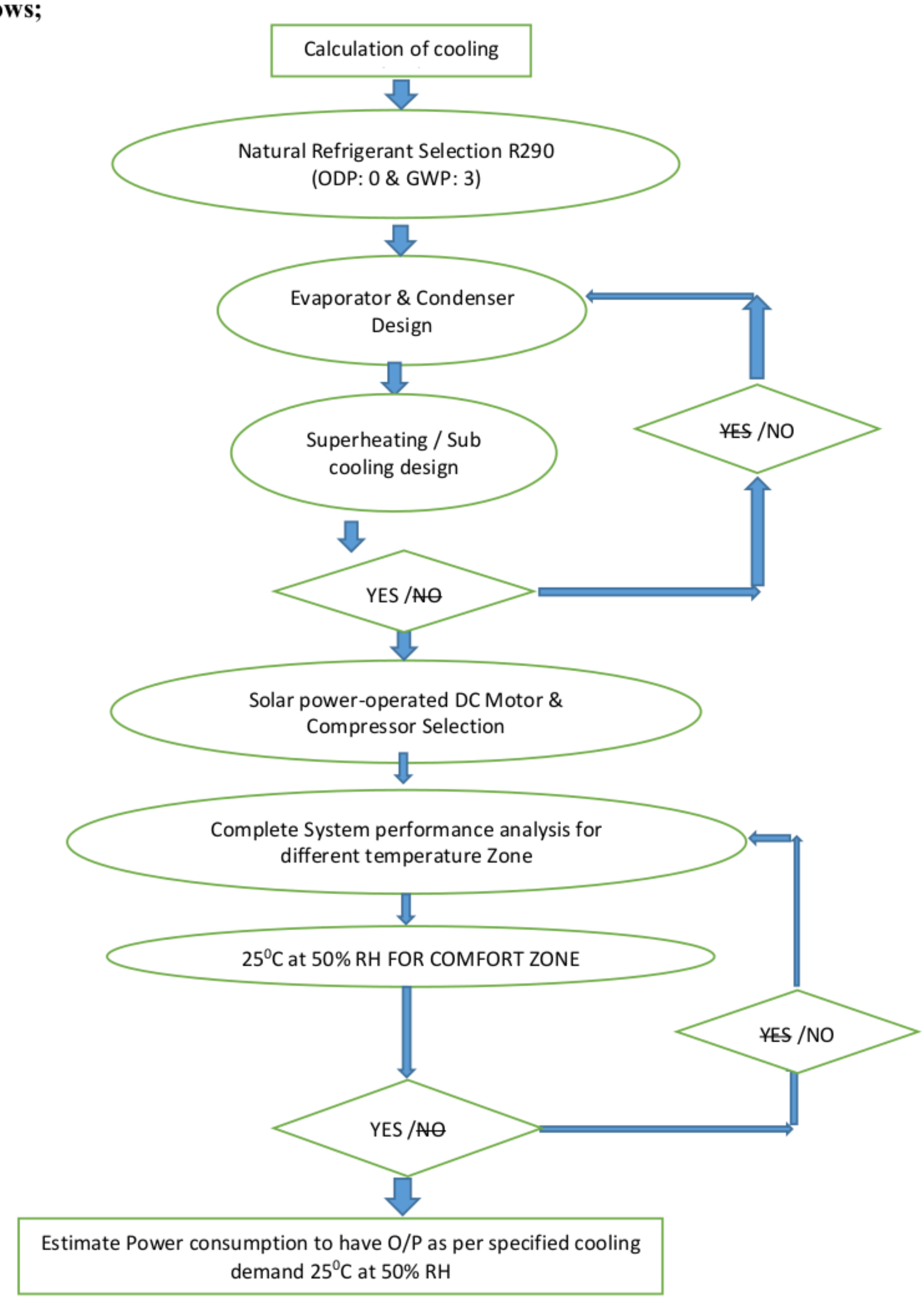


Figure 6.1: Methods of Air-conditioning process for estimating power consumption for different climate zone as shown by a flow chart

6.2.2. Natural Refrigerant:

Very effective natural refrigerant liquid Propane (R- 290) is taken as a sample test for consideration of next-generation refrigerant for promising cooling capacity in spite of its inflammability (consideration of dilution effect with respect to ignition point). While other refrigerants have a GWP of 675+, the R290 refrigerant has the lowest global warming potential (GWP) of only "3" and the ozone depletion potential (ODP) of zero. With a critical point exceeding 96°C and a wide temperature range, R290 is suitable for use with seawater condensers. Since it has a triple point of -188 °C, it can be used for both chilled water and supply cooling. As with ammonia, the pressure range is comparable. At a temperature of -10°C for evaporation, the absolute pressure is approximately 3,4 bar; at a temperature of 25°C for condensation, the absolute pressure is around 10 bar. The latent heat values are quite good. At -10 °C, the enthalpy will be around 380 kJ/kg. Propane is a versatile material that may be utilized in a variety of ways, including as fuel and an effective refrigerant. Having thermodynamic characteristics similar to those of synthetic gases like R-22 and R134a. The sole drawback is that it is moderately flammable [14].

6.3 Results and Discussion

The present work emphasizes on application of Air-conditioning systems considering various climatic zones in India and it is shown as major 5 different categories as per the P-H diagram. Initially, an attempt has been made to understand the effect of variation of condenser temperature (Tc) keeping evaporator temperature (Te) constant. In that regards temperature of the evaporator (Te) is kept at 10^0C and the temperature of the condenser (Tc) is varied from 35^0C to 50^0C based on the different zone. The condenser temperature for each zone is kept at 5^0C more than the maximum temperature for that said zone. The output as evaporator heat removal, Qe [kW], condenser heat removal, Qc [kW], Compressor work, W [kW], and Co-efficient of Performance (COP) is estimated. Also, the variation of compressor work (W [kW]) with respect to condenser temperature (Tc [°C]) and the variation of COP with respect to compressor work (W [kW]) are shown in figure2 & 3 on the basis of estimation. It indicates a huge variation in compressor work and COP of the system. It is to mention that the authors ensured the phase of refrigerants (R290) across the compression stage should be in the gaseous phase while selecting the possible temperature ranges for the evaporator studying with the P-H diagram.

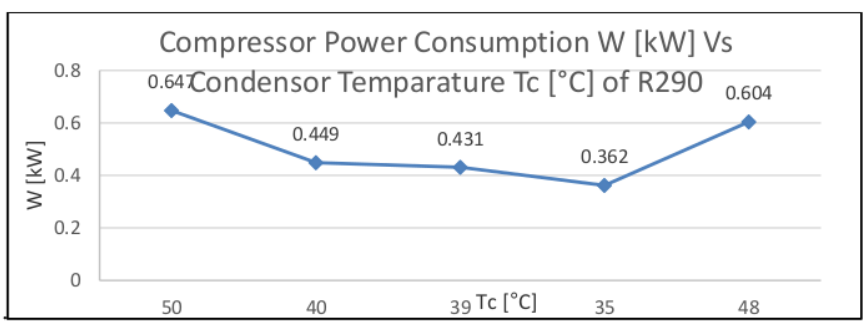


Figure 6.2: Compressor Power Consumption W [kW] Vs Condenser Temperature Tc [°C] of R290

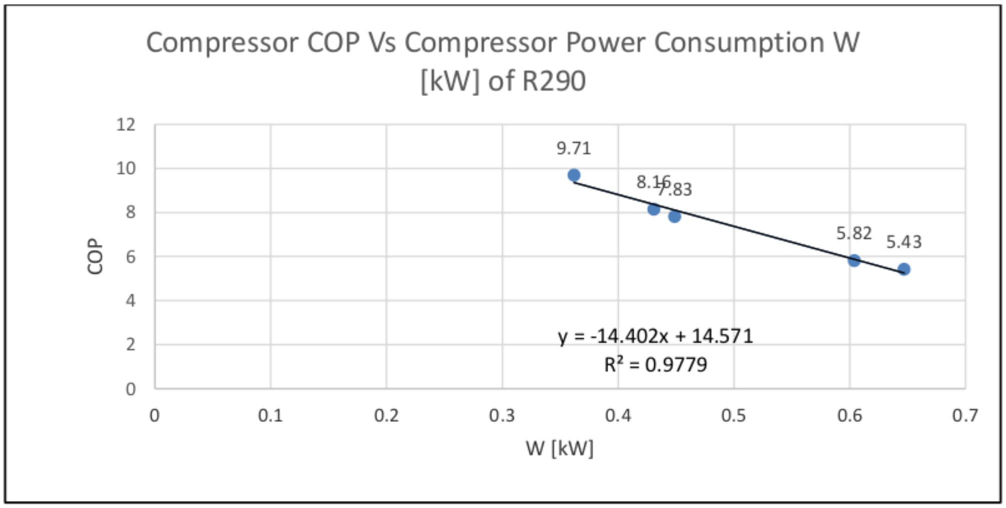


Figure 6.3: Compressor COP Vs Compressor Power Consumption W [kW] of R290

Similarly, the effects on the variation of evaporator temperature (Te) are performed keeping condenser temperature (Tc) constant. In that regard, condenser temperature (Tc) is kept at 50^{0}C and evaporator temperature (Te) is varied from 0^{0}C to 20^{0}C based on possibilities in the air-conditioning system keeping in mind the indoor comfort climatic condition and the output as evaporator heat removal, Qe [kW], condenser heat removal, Qc [kW], Compressor work, W [kW], and Coefficient of Performance (COP) is estimated. Also, the variation of compressor work (W [kW]) with respect to condenser temperature (Tc [°C]) and the variation of COP with respect to compressor work (W [kW]) are shown in Figures4 & 5 on the basis of estimation by cool Pack software. It also indicates huge power saving opportunities on compressor work and improvements of COP of the system by proper tuning of expansion valve based on environmental conditions.

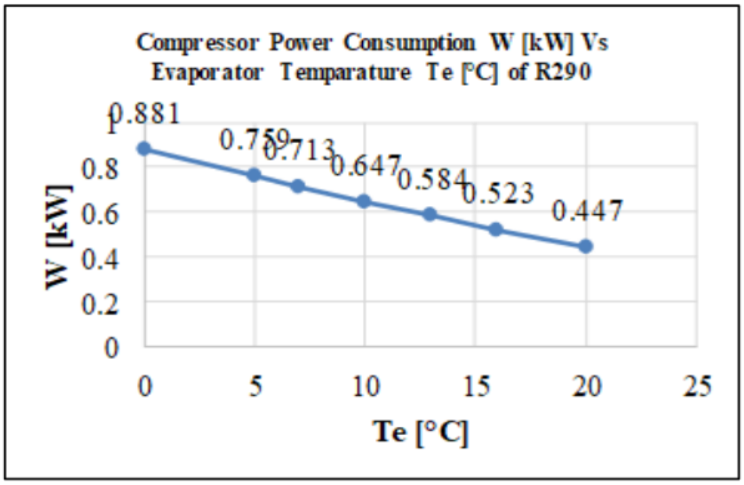


Figure 6.4: Compressor Power Consumption W [kW] Vs Evaporator Temperature Te [°C] of R290

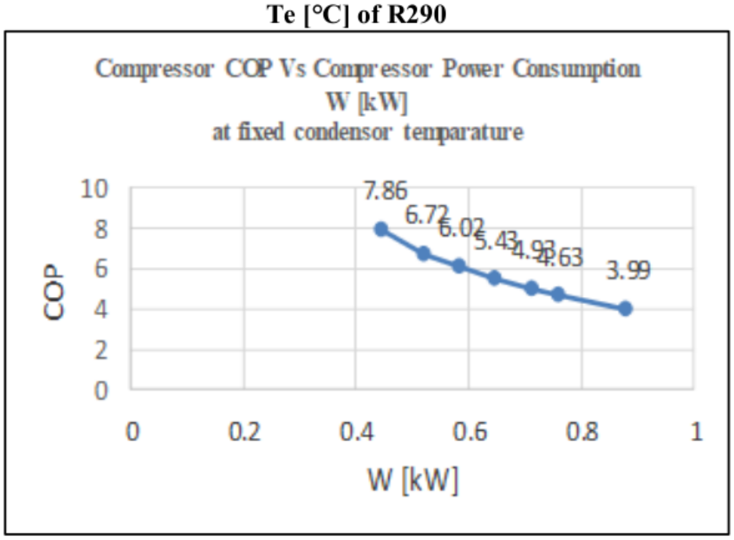


Figure 6.5: Compressor COP Vs Compressor Power Consumption W [kW] at fixed condenser temperature

From the above discussion, it is found that the lowest condenser temperature shows the lowest compressor power consumption and gives it the highest COP. So, from these results, it is clear that a considerable amount of energy can be saved by selecting proper refrigerant working temperature zone-wise compared to a common design of a wide range of temperature control.

Further, the analysis is carried out based on five climatic zones as mentioned earlier, and compared the result with standard design considerations as the evaporator temperature is 10^0C and the condenser temperature is 50^0C. Now the dew point temperature is taken as 14 ^{0}C as a reference as comfort condition (25^0C & RH 50%) for each climatic zone. Also, condenser temperatures (Tc) are kept at 5^0C more than the maximum environment temperature of that zone. All the performance parameters i.e., compressor work, COP, etc. are calculated with the variation evaporator temperature keeping condenser temperature constant for each zone. All the results are shown in tabular form in Table 6.3. The maximum possible energy-saving possibilities with respect to full load conditions of the standard system are estimated and mentioned in the remarks column of each table. It shows huge energy-saving possibilities i.e., 12.99 % in a Hot and Dry Climate Zone; 41.73% in a Warm and Humid Climate Zone; 44.36% in a Temperate Climate Zone; 54.41% in a Cold (Sunny/ Cloudy) Climate Zone; 19.17% in Composite Climate Zone. From the present analysis, the authors suggested resizing compressor capacity based on the different climatic zone to achieve the best performance of the system with optimized energy consumption.

Table 6.3: Estimated performance parameters for Different Climate Zones using R290

.	Present standard Design	Case 1 Hot and Dry Climate Zone (45^0C & RH 40%) MAX.	Case 2 Warm and Humid Climate Zone (35^0C & RH 90%) MAX	Case 3 Temperate Climate Zone (34^0C & RH 85%) MAX	Case 4 Cold (Sunny/ Cloudy) Climate Zone (30^0C & RH 80%) MAX	Case 5 Composite Climate Zone (43^0C & RH 95%) MAX
Te [°C]	10^0C	14^0C	14^0C	14^0C	14^0C	14^0C
Tc [°C]	50^0C	50^0C	40^0C	39^0C	35^0C	48^0C
Qe [kW]	3.516	3.516	3.516	3.516	3.516	3.516
Qc [kW]	4.163	4.079	3.893	3.876	3.811	4.039
Qe [kJ/kg]	249.983	254.074	283.047	285.871	297.051	259.986
Qc [kJ/kg]	295.988	294.782	313.418	315.168	321.979	298.685
COP	5.43	6.24	9.32	9.76	11.92	6.72
W [kJ/kg]	46.005	40.708	30.372	29.298	24.928	38.699
W [kW]	0.647	0.563	0.377	0.360	0.295	0.523
REMARKS	As per present standard design across all over India for 1 TON Airconditioning capacity	As per Zone-wise AC selection Case 1, will be more suitable and the power saving per ton from the present standard unit is (0.647-0.563) = 0.084 kW unit. i.e. 12.99 % Unit saving on existing AC unit.	As per Zone-wise AC selection Case 2, will be more suitable and the power saving per ton from the present standard unit is (0.647-0.377) = 0.270 kW unit. i.e. 41.73 % Unit save on existing AC unit.	As per Zone-wise AC selection Case 3, will be more suitable and the power saving per ton from the present standard unit is (0.647-0.360) = 0.287 kW unit. i.e. 44.36 % Unit save on existing AC unit.	As per Zone-wise AC selection Case 4, will be more suitable and the power saving per ton from the present standard unit is (0.647-0.295) = 0.352 kW unit. i.e. 54.41 % Unit save on existing AC unit.	As per Zone-wise AC selection Case 5, will be more suitable and the power saving per ton from the present standard unit is (0.647-0.523) = 0.124 kW unit. i.e. 19.17 % Unit save on existing AC unit.

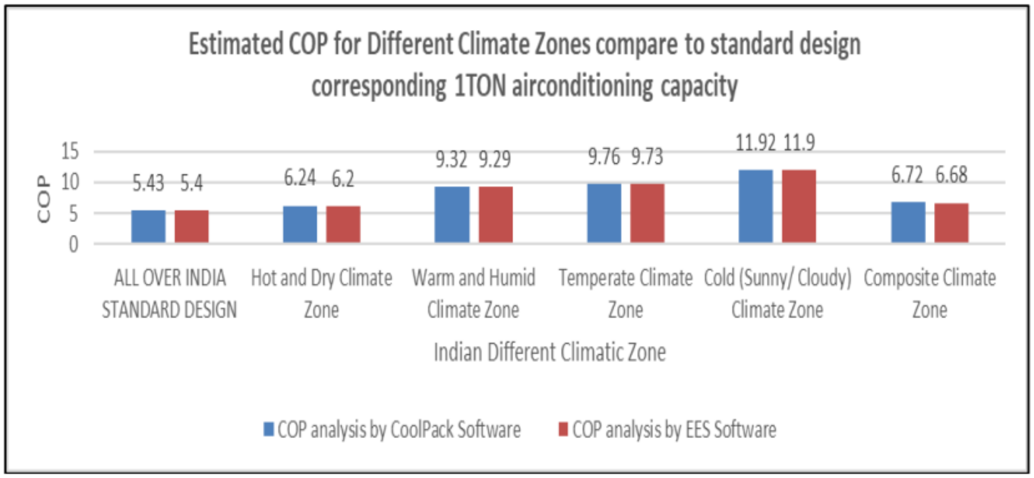


Figure 6.6: Estimated COP for Different Climatic Zones compare to standard design corresponding1TON air-conditioning capacity by EES & Cool Pack Software's

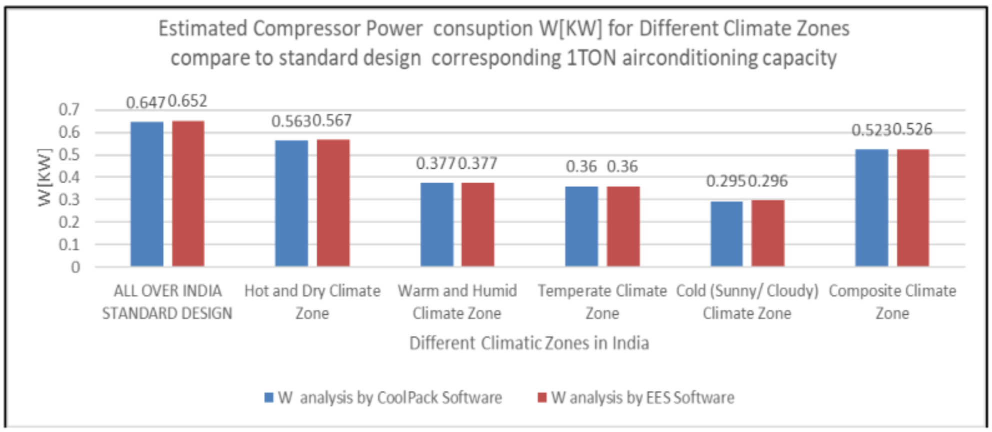


Figure 6.7: Estimated Compressor Power consumption W [kW] for Different Climate Zones compare to standard design corresponding to 1TON air-conditioning capacity

As we have seen in previous chapter that R600a is more superior than R290 from Better COP and Least power consumption point of view at its own standard with one consideration that R600a must requirement minimum 5 ^{0}C for compressor better performance.

So, again we have estimated COP and compressor power consumption for Different Climatic Zones compare to standard design corresponding 1TON air-conditioning capacity by using R600a and here COP and compressor power consumption saving shown in term of percentage value over standard design consideration. In table 6.4 details analysis using R600a with 5^{0}C superheating is shown.

It shows that using R600a has also huge energy-saving possibilities i.e., 12.97 % in a Hot and Dry Climate Zone; 40.89% in a Warm and Humid Climate Zone; 43.35% in a Temperate Climate Zone; 59.77% in a Cold (Sunny/ Cloudy) Climate Zone; 23.65% in Composite

Climate Zone. From the present analysis, the authors suggested resizing of compressor capacity based on the different climatic zone to achieve the best performance of the system with optimized energy consumption.

One of the major important points that due to application of R600a we can able to save on compressor power consumption over R290 with standard consideration is 6.24% extra when R290 are in normal operating condition and observes 5.28% more saving when R290 (with 5^0C Superheating) are in same working condition with R600a. This analysis is done only with CoolPack software which is already validated by us, presented in previous chapter.

Table 6.4: Estimated performance parameters for Different Climate Zones by using R600a with 5^0 Superheating

R600a Analysis	**Present standard Design**	**Case 1 Hot and Dry Climate Zone (45^0C & RH 40%) MAX.**	**Case 2 Warm and Humid Climate Zone (35^0C & RH 90%) MAX**	**Case 3 Temperate Climate Zone (34^0C & RH 85%) MAX**	**Case 4 Cold (Sunny/ Cloudy) Climate Zone (30^0C & RH 80%) MAX**	**Case 5 Composite Climate Zone (43^0C & RH 95%) MAX**
Te [°C]	10^0C	**14^0C**	14^0C	**14^0C**	**14^0C**	14^0C
Tc [°C]	50^0C	**50^0C**	**40^0C**	**39^0C**	**35^0C**	**48^0C**
Qe [kW]	3.516	**3.516**	**3.516**	**3.516**	**3.516**	**3.516**
Qc [kW]	4.125	**4.046**	**3.876**	**3.861**	**3.799**	**4.010**
Qe [kJ/kg]	256.788	**262.358**	**287.972**	**290.489**	**300.473**	**267.561**
Qc [kJ/kg]	301.255	**301.897**	**317.481**	**318.955**	**324.698**	**305.151**
COP	5.77	**6.64**	**9.76**	**10.20**	**12.40**	**7.12**
W [kJ/kg]	44.467	**39.539**	**29.509**	**28.467**	**24.224**	**37.590**
W [kW]	**0.609**	**0.530**	**0.360**	**0.345**	**0.283**	**0.494**
REMARKS	As per present standard design across all over India for 1 TON Airconditioning capacity	As per Zone-wise AC selection Case 1, will be more suitable and the power saving per ton from the present standard unit is (**0.609**-0.530) = 0.079 kW unit. i.e. **12.97 % Unit saving on existing AC unit.**	As per Zone-wise AC selection Case 2, will be more suitable and the power saving per ton from the present standard unit is (**0.609**-0.360) = 0.249 kW unit. i.e. **40.89 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 3, will be more suitable and the power saving per ton from the present standard unit is (**0.609**-0.345) = 0.264 kW unit. i.e. **43.35 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 4, will be more suitable and the power saving per ton from the present standard unit is (**0.609**-0.283) = 0.326 kW unit. i.e. **59.77 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 5, will be more suitable and the power saving per ton from the present standard unit is (**0.609**-0.494) = 0.153 kW unit. i.e. **23.65 % Unit save on existing AC unit.**

Table 6.5: Summarize performance parameters for Different Climate Zones by using R290 & R600a with 5^0 Superheating

with 5^0 C superheating	Present standard design		Case 1 Hot and Dry Climate Zone (45^0 C & RH 40%) MAX.		Case 2 Warm and Humid Climate Zone (35^0 C & RH 90%) MAX		Case 3 Temperate Climate Zone (34^0 C & RH 85%) MAX		Case 4 Cold (Sunny/ Cloudy) Climate Zone (30^0 C & RH 80%) MAX		Case 5 Composite Climate Zone (43^0 C & RH 95%) MAX	
	COP	W [kW]	COP	W [kW]	COP	W [kW]	COP	W [kW]	COP	W [kW]	COP	W [kW]
R290	5.47	**0.643**	**6.28**	**0.560**	**9.34**	**0.376**	**9.78**	**0.359**	**11.93**	**0.294**	**6.75**	**0.520**
R600a	5.77	**0.609**	**6.64**	**0.530**	**9.76**	**0.360**	**10.20**	**0.345**	**12.4**	**0.283**	**7.12**	**0.494**

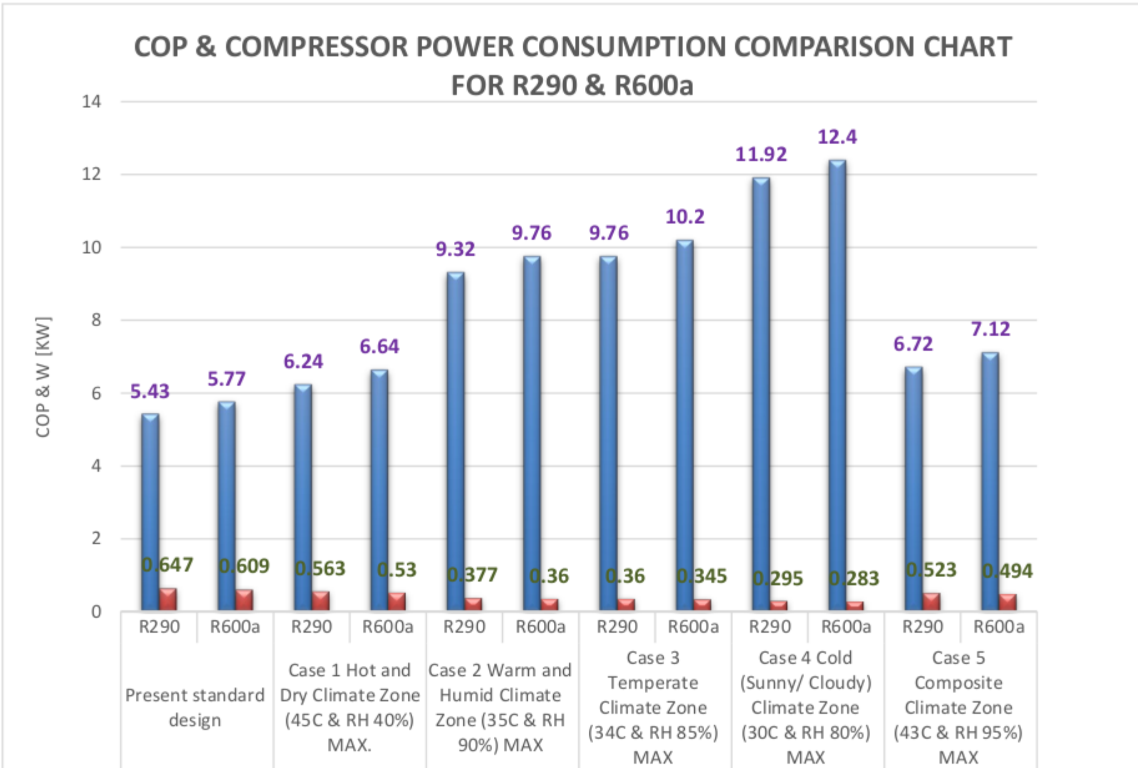
Table 6.5 indicates the detailed comparison on COP and Compressor power consumption for both refrigerants at same condition.

Table 6.6: Estimated performance parameters using 5^0C superheating R290 & R600a for Different Climate Zones:

Refrigerant analysis at different zone with 5^0C superheating	Present standard Design With R290	Present standard Design with R600a with 5^0C superheating with R600a	Case 1 Hot and Dry Climate Zone (45^0C & RH 40%) MAX. With R290	Case 1 Hot and Dry Climate Zone (45^0C & RH 40%) MAX. with R600a	Case 2 Warm and Humid Climate Zone (35^0C & RH 90%) MAX With R290	Case 2 Warm and Humid Climate Zone (35^0C & RH 90%) MAX with 5^0C superheating with R600a	Case 3 Temperate Climate Zone (34^0C & RH 85%) MAX With R290	Case 3 Temperate Climate Zone (34^0C & RH 85%) MAX with 5^0C superheating with R600a	Case 4 Cold (Sunny/ Cloudy) Climate Zone (30^0C & RH 80%) MAX With R290	Case 4 Cold (Sunny/ Cloudy) Climate Zone (30^0C & RH 80%) MAX with 5^0C superheating with R600a	Case 5 Composite Climate Zone (43^0C & RH 95%) MAX With R290	Case 5 Composite Climate Zone (43^0C & RH 95%) MAX with 5^0C superheating with R600a
Te [°C]	10^0C	10^0C	**14^0C**	14^0C	14^0C	14^0C	**14^0C**	14^0C	**14^0C**	14^0C	14^0C	14^0C
Tc [°C]	50^0C	50^0C	**50^0C**	**50^0C**	**40^0C**	**40^0C**	**39^0C**	**39^0C**	**35^0C**	**35^0C**	**48^0C**	**48^0C**
Qe [kW]	3.516	3.516	**3.516**	**3.516**	**3.516**	**3.516**	**3.516**	**3.516**	**3.516**	**3.516**	**3.516**	**3.516**
Qc [kW]	4.159	4.125	**4.079**	**4.046**	**3.893**	**3.876**	**3.876**	**3.861**	**3.808**	**3.799**	**4.034**	**4.010**
COP	5.47	5.77	**6.28**	**6.64**	**9.34**	**9.76**	**9.78**	**10.20**	**11.93**	**12.40**	**6.75**	**7.12**
W [kW]	**0.643**	**0.609**	**0.560**	**0.530**	**0.376**	**0.360**	**0.359**	**0.345**	**0.294**	**0.283**	**0.520**	**0.494**
REMARKS	As per present standard design across all over India for 1 TON Airconditioning capacity	As per present standard design across all over India for 1 TON Airconditioning capacity	As per Zone-wise AC selection Case 1, will be more suitable and the power saving per ton from the present standard unit is (0.643-0.560) = 0.083 kW unit. i.e. **12.91 % Unit saving on existing AC unit.**	As per Zone-wise AC selection Case 1, will be more suitable and the power saving per ton from the present standard unit is **(0.609-**0.530) = 0.079 kW unit. i.e. **12.97 % Unit saving on existing AC unit.**	As per Zone-wise AC selection Case 2, will be more suitable and the power saving per ton from the present standard unit is (0.643-0.376) = 0.267 kW unit. i.e. **41.52 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 2, will be more suitable and the power saving per ton from the present standard unit is **(0.609-**0.360) = 0.249 kW unit. i.e. **40.89 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 3, will be more suitable and the power saving per ton from the present standard unit is (0.643-0.359) = 0.284 kW unit. i.e. **44.17 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 3, will be more suitable and the power saving per ton from the present standard unit is **(0.609-**0.345) = 0.264 kW unit. i.e. **43.35 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 4, will be more suitable and the power saving per ton from the present standard unit is (0.643-0.294) = 0.349 kW unit. i.e. **54.28 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 4, will be more suitable and the power saving per ton from the present standard unit is **(0.609-**0.283) = 0.326 kW unit. i.e. **53.33 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 5, will be more suitable and the power saving per ton from the present standard unit is (0.643-0.520) = 0.123 kW unit. i.e. **19.13 % Unit save on existing AC unit.**	As per Zone-wise AC selection Case 5, will be more suitable and the power saving per ton from the present standard unit is **(0.609-**0.494) = 0.153 kW unit. i.e. **23.65 % Unit save on existing AC unit.**

Again COP & Compressor Power Consumption Comparison is Shown by graphical representation for refrigerants R290 & R600a in Figure 6.8 below.

Figure 6.8: Compressor Power consumption W [kW] & COP for Different Climate Zones with considering standard design corresponding to 1TON air-conditioning capacity for both R290 & R600a refrigerants



	Present standard design		Case 1 Hot and Dry Climate Zone (45C & RH 40%) MAX.		Case 2 Warm and Humid Climate Zone (35C & RH 90%) MAX		Case 3 Temperate Climate Zone (34C & RH 85%) MAX		Case 4 Cold (Sunny/ Cloudy) Climate Zone (30C & RH 80%) MAX		Case 5 Composite Climate Zone (43C & RH 95%) MAX	
	R290	R600a	R290	R600a	R290	R600a	R290	R600a	R290	R600a	R290	R600a
COP	5.43	5.77	6.24	6.64	9.32	9.76	9.76	10.2	11.92	12.4	6.72	7.12
W [kW]	0.647	0.609	0.563	0.53	0.377	0.36	0.36	0.345	0.295	0.283	0.523	0.494

6.4 Conclusion:

In this present work, the authors give a direction toward the micro design of the air conditioning system based on different Indian climatic conditions by resizing all necessary components like the compressor, evaporator, and condenser for optimum power consumption as well as economical aspect. The opportunities of energy saving potential compact to a fixed standard design are estimated using software named CoolPack version 1.50.and the result is cross verified by EES Software Professional V9.478 version 11.319 which reflects the same result. Here natural refrigerant R290 is considered for its environmental behaviour. Especially compressor work and COP of the system is estimated considering comfort climate conditions as the temperature of 25^0C and RH 50%. The results indicate huge saving opportunities in energy consumption by the compressor if the evaporator and condenser temperatures are varied according to the different climatic zones. i.e., 12.99 % in a Hot and Dry Climate Zone; 41.73%

in a Warm and Humid Climate Zone; 44.36% in a Temperate Climate Zone; 54.41% in a Cold (Sunny/ Cloudy) Climate Zone; 19.17% in Composite Climate Zone.

Also, using R600a refrigerant instead of refrigerant R290 has also huge energy-saving possibilities i.e., 12.97 % in a Hot and Dry Climate Zone; 40.89% in a Warm and Humid Climate Zone; 43.35% in a Temperate Climate Zone; 59.77% in a Cold (Sunny/ Cloudy) Climate Zone; 23.65% in Composite Climate Zone. From the present analysis, the authors suggested resizing compressor capacity based on the different climatic zone to achieve the best performance of the system with optimized energy consumption.
One of the major important points that due to application of R600a (with 5^0C superheat) we can able to save in compressor power consumption comparing with R290 on standard consideration (without superheating) is 6.24% extra whereas in case of superheating for both the cases, R600a shows better performance by reducing 5.28% compressor power consumption comparing with R290.

This work emphasizes resizing air conditioning system components, especially the compressor system to have optimum power consumption. This paper is also directed towards solar thermal (Superheating) and photovoltaic power utilization to run Air conditioners for a sustainable future.

References:

[1] Prasanta Kumar Bal, Andimuthu Ramachandran, Kandasamy Palanivelu, Perumal Thirumurugan, Rajadurai Geetha1, and BhaskiBhaskaran, “Climate Change Projections over India by a Downscaling Approach Using PRECIS”, Asia-Pac. J. Atmos. Sci., 52(4), 353-369, 2016 pISSN 1976-7633 / eISSN 1976-7951, DOI:10.1007/s13143-016-0004-1

[2] Yanjie Li, Victor Nian, HailongLi, Changchun Liu, Yabo Wang, “A life cycle analysis techno-economic assessment framework for evaluating future technology pathways – The residential air-conditioning example”, Applied Energy 291 (2021) 116750, Science Direct.

[3] Gustavo de, Novaes Pires Leitea, Franciele Weschenfelder, Alex Mauricio Araujo, Alvaro Antonio Villa Ochoaa, Newton da Franca Prestrelo Netoa, Andrea Krajc, “An economic analysis of the integration between air-conditioning and solar photovoltaic systems” Energy Conversion and Management 185 (2019) 836–849, Science Direct.

[4] I. Dauta, M. Adzriea, M. Irwantoa, P. Ibrahima, M. Fitraa, Energy Procedia 36 (2013) 444 – 453

[5] F.J. Aguilar, S. Aledo, P.V. Quiles, Applied Thermal Engineering 123 (2017) 486–497

[6] Saurav Dubey, Sunil Chamoli1 and Ravi Kumar, “Indian Scenario of Solar Energy and its Applications Cooling Systems: A Review” International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 6, Number 4 (2013), pp. 571-578

[7] Zixu Yang, Youlin Zhang, Hansong Xiao, Rong Zhuang, Xiangfei Liang, Mengdi Cui, Xin Li, Jiaan Zhao, Qi Yuan, Ruiqi Yang, Baolong Wang, Wenxing Shi, “Comprehensive test of ultra-efficient air conditioner with smart evaporative cooling ventilation and photovoltaic”, Energy Conversion and Management 254 (2022) 115267, Science Direct.

[8] Jay Prakash Bijarniya, Jahar Sarkar, Pralay Maiti, “Performance improvement of the CO_2 air conditioner by integrating photonic radiative cooler as sub-cooler or/and roof envelope, Energy Conversion and Management 251 (2022) 115019.

[9] Aziz Haffafa, Fatiha Lakdjaa, Djaffar Ould Abdeslam, and Rachid Meziane, “Solar energy for air conditioning of an office building in a case study: Techno-economic feasibility assessment”, ELSEVIER, Renewable Energy Focus _ Volume 39 _ December 2021.

[10] Nihar Shah, Won Young Park, Chao Ding, “Trends in best-in-class energy-efficient technologies for room air conditioners”, Energy Reports 7 (2021) 3162–3170, Science Direct.

[11] B. Saleh, and Ayman A. Aly, “Flow Control Methods in Refrigeration Systems: A Review”, INTERNATIONAL JOURNAL OF CONTROL, AUTOMATION AND SYSTEMS VOL.4 NO.1 January 2015. ISSN 2165-8277 (Print) ISSN 2165-8285 (Online)

[12] Karthik Panchabikesan, Kumaresan Vellaisamy, Velraj Ramalingam, “Passive cooling potential in buildings under various climatic conditions in India”. Renewable and Sustainable Energy Reviews 78 (2017) 1236–1252, Science Direct.

[13] Cool Pack Software version 1.50, https://www.ipu.dk/

[14] Naskar, R., Ghosh, A., Mandal, R., “ADVANCEMENT OF SOLAR REFRIGERATION TECHNOLOGY AND ITS IMPACT IN SOCIETY” at Journal of SCIENCE AND CULTURE, VOL. 85, NOS. 9–10, SEPTEMBER-OCTOBER, 2019.

CHAPTER 7

Chapter 7

Summary, Discussion & Concluding Remarks

7.1 Summary & Discussion:

The thesis is started with the major objective to create a model for solar air conditioning that runs all year long using green energy. Actually, air conditioning and the effect of load on air conditioning systems on energy consumption, and pattern of load changes are studied in detail, and try to develop renewable energy-based air conditioning systems operated with natural refrigeration. The whole work is presented in the form of a thesis consists of the following sections.

The thesis is started with the major objective to create a model for solar air conditioning that runs throughout years long using green energy. The authors try to annualize a 20-year energy consumption pattern for solar air conditioning system in domestic sector and its impact on energy sector and environmental aspects. This thesis assessed and compared the effectiveness of various natural and synthetic refrigerants to provide the better performance in terms of energy saving and sustainable environment. Accordingly, the main objectives of the work are fixed and presented in Chapter-1.

Rigorous literature review was conducted in Chapter-2. The knowledge gap identified as normal AC is now available with high power usage. Inverter ACs can help to reduce power consumption. There are natural solar powered (DC) air conditioners with low power requirements; however, they are not yet on the market. The focuses on developing a natural solar powered (DC) air conditioner utilizing solar thermal technology to use the least amount of compressor power.

In Chapter-3 the authors made several assumptions for the study including data analysis on gathering demand information based on per capita income growth, weather information, and calculated hourly, monthly, and yearly solar radiation; calculating the cooling load to ascertain the type and quantity of cooling required. The components of the AC system can be developed and scaled using specific design conditions. The designed system should be optimized to use the least amount of energy possible. Performance assessment and economic analysis was done. The system's economic viability has been assessed. In order to be competitive in terms of price and thermal efficiency for household applications, the lifetime costs for solar cooling systems are evaluated. The results are examined, and potential solutions are identified.

In Chapter-4 a preliminary experimental setup employing R-290 as a natural refrigerant is set up on the roof of the School of Energy Studies building at Jadavpur University. Different solar

AC with DC compressor setup components indicates indoor and outdoor units to observe solar thermal impact. The experimental result reveals significant changes of refrigerant pressure by introducing solar thermal energy at the compressor inlet to reduce compression energy consumption.

Software called CoolPack1.50 is used to conduct the current analysis and is discussed in Chapter-5. For developing, dimensioning, analysing, and optimizing refrigeration and air conditioning systems, a group of simulation software programs is available in whichCoolPack1.50 is chosen for the same. A 1 Ton capacity solar air conditioner is taken into account while analysing the system initially. It uses various synthetic as well as natural refrigerants as its working medium and runs on a vapour compression cycle powered by DC solar photovoltaic energy. The natural refrigerants R290 and R600a were chosen because they have no potential to deplete the ozone layer and very little GWP in comparison to other refrigerants currently in use. The various qualitative parameters of natural refrigerants show that R290 has a high Latent heat of vaporization at a lower boiling point temperature. While R718 and R123 cannot be chosen due to their high boiling point temperatures at atmospheric pressure, as well as R114 & R502 having high molar masses, R600a also has more or less comparable attributes to those of R290. As a result, it is determined that R290 and R600a are the best candidates for use as natural refrigerants in air conditioning and refrigeration systems. Reheating is also offered in order to maintain a realistic working cycle for R600a. The same analysis also carried out with other different cooling capacity (2 Ton, 3 Ton and 5 Ton) with R290 and R600a (with super heating and without superheating) which justified the result with similar pattern.

For the purpose of designing vapour compression cycle air conditioning systems with a capacity of 1 Ton and natural refrigerants (R 290 and R600a with 5 ^{0}C reheating), the authors took into account various climate zones in India which is discussed in Chapter-6. They then compared the compressor capacity and its full load power consumption based on various condenser temperatures in the various climate zones with respect to the readily available standard system for all locations. The evaporator temperature is held constant at 10°C, while the condenser temperature and humidity are changed according to the zone's maximum temperature and humidity in order to comprehend the techniques better. Since the compressor is the system's main power-consuming component, solely its power consumption is calculated here. The Cool Pack (Version 1.50) and EES Software are utilized for analysis. Summary, discussion and concluding remarks of the whole work is given in Chapter-7

The avenue of future work is discussed in the following Chapter-8.

7.2 Concluding Remarks:

It is more economically advantageous to use green technology if demand and supply for the green good are closely connected. There is a strong correlation between solar-dependent heat gain and sunlight. Using green technology, which maximises the economic efficiency of the most expensive system components. Through the creation and use of this application, solar cooling and heating significantly expands the mechanical element of a work, increasing revenue and the GDP of the Indian government. In this present work the authors identified the rectification of solar thermal heating. For this purpose, natural refrigeration is used. 1 Ton air conditioning systems is studied in respect of energy saving in Chapter-1. Energy consumption pattern changes, hence, new technology, solar, photovoltaic can be used.

Rigorous literature review was conducted and summarised the findings in Chapter-2. The authors found that at the end of the day, an air conditioner is recommended for residential comfort at home. It is true that you get what you pay for, despite the allure of selecting a less priced evaporative cooling system. It is unlikely that any homeowners will ever express satisfaction with this development. A dehumidifier and a humidifier operating in the same space would cancel each other out; therefore, it is also impossible to really mix the best of both worlds. Evaporative coolers shouldn't be totally off the table, though. When you have a tiny workshop, they can function rather well. Workshops frequently feature big apertures similar to a garage door, which serve as an efficient source of airflow for meeting basic cooling demands. These novel methods systems may make sense if the space does not need to be totally sealed off, such as in a detached office when ductless air conditioning is used.

After rigorous study on the literature review based on the power consumption pattern changings for domestic air conditioning system, work has been done.

In Chpater-3 advancement of solar refrigeration technology and its impact in society is studied. The authors propose a high performance and eco-friendly refrigeration system to meet the growing demand as well as maintain of steady grown-up market economy. Working on a highly effective, reasonably priced thermoelectric refrigeration system is another effort to address the issue of overall entropy of the system and its surroundings is maximised in equilibrium through temp minimization. Additionally, efforts are being made to reduce the size of the solar PVs used, making the system more portable. Thus, one of the enticing aspects of refrigeration technology is the necessity for cooling. With the aforementioned scope, we draw the conclusion that even in middle-class and lower-income homes, air conditioners are increasingly seen as a necessary item.

Some studies on energy conservation and thermal comfort using natural refrigerants in solar thermal and solar photovoltaic powered air-conditioning and refrigeration systems are studied in Chapter-4. There are a few solar hybrid air conditioners that are grid independent on the market. These are a great combo since they let you use heating and cooling systems without sacrificing your carbon footprint. Even so, this system's DC-only variant could work throughout the day. Cloud cover will also have an impact on its effectiveness. In such situation, batteries are needed for it to work, even during the day. This device can't deliver acceptable service at night without a large investment in battery storage capacity. Unquestionably, people may attribute convenient living since it offers a lot of comfort, especially on warm days, and choosing it will undoubtedly result in lower energy costs. Like other items that are exposed to the sun, solar panels will ultimately degrade. Other external variables, in addition to weather, can cause this electricity-generating equipment to be destroyed. In order for solar panels to operate well, adequate care may periodically offer and monitor them.

This study has been focused to focus on the exact investigation of various refrigerants using a 1 Ton capacity vapour compression air conditioning system. Because of their environmental friendliness, natural refrigerants should be used in place of all synthetic ones. In Chapter-5 the authors studied and analysed the feasibility of two different natural refrigerants based solar powered air-conditioning systems of 1 Ton capacity. The entire comparative analysis was performed using the CoolPack software platform, and it was discovered that the natural refrigerants R290 and R600a exhibit promising results in terms of heat removal from the evaporator, condenser, compressor work and COP, while maintaining fixed evaporator and condenser temperatures of 10°C and 50°C, respectively. To keep the working cycle within a practical operating range, it is necessary to superheat the refrigerant R600a by 50C at the compressor's suction.

For a 1 Ton vapour compression cycle air conditioning system based on R290, it was discovered that the compressor work consumption was 640 W. This means that the motor power input for a single-phase induction motor would be around 1000 W. DC motors, on the other hand, will reduce energy usage by around 30% and are readily driven by solar photovoltaic systems. So, by bringing solar thermal (needed for R600a) and solar photovoltaic power (DC) application for natural refrigerants R290 and R600a, the current study illustrates the possibility of dependable operation with optimised power usage and will contribute to a sustainable environment. The same analysis also carried out with other different cooling capacity (2 Ton, 3 Ton and 5 Ton) with R290 and R600a (with super heating and without superheating) which justified the result with similar pattern.

In Chapter-6the energy optimization of natural refrigerant-based air conditioning system for a sustainable environment on the basis of the major five climatic zones in India has been done. We identify 5 climatic zones in India on the basis of humidity and temperature.

The authors of the current work provide guidance for the micro design of the air conditioning system based on various climatic conditions in India by downsizing all essential parts like the compressor, evaporator, and condenser for the best possible power consumption and financial aspect. The potential for energy savings is calculated using the CoolPack version 1.50 software, and the results are cross-checked with those from the EES Software Professional V9.478 version 11.319, which also show the same results. Here, the environmental behaviour of the natural refrigerant R290 is taken into account. The system's COP and compressor work, in particular, are approximated using comfortable climatic conditions like a temperature of 25°C and a 50% relative humidity. The results show that changing the evaporator and condenser temperatures in accordance with the various climatic zones may significantly reduce the energy consumed by the compressor. Specifically, 12.99% of the area is in a hot and dry climate zone, 41.73% is warm and humid, 44.36% is temperate, 54.41% is cold (sunny/cloudy), and 19.17% is in a composite climate zone. In order to have the best possible power usage, this effort emphasises downsizing air conditioning system components, particularly the compressor system.

Using R600a refrigerant instead of refrigerant R290 has also huge energy-saving possibilities i.e., 12.97 % in a Hot and Dry Climate Zone; 40.89% in a Warm and Humid Climate Zone; 43.35% in a Temperate Climate Zone; 59.77% in a Cold (Sunny/ Cloudy) Climate Zone; 23.65% in Composite Climate Zone. From the present analysis, the authors suggested resizing compressor capacity based on the different climatic zone to achieve the best performance of the system with optimized energy consumption.

One of the major important points that due to application of R600a(with 5^0C superheat) we can able to save in compressor power consumption comparing with R290 on standard consideration(without superheating) is 6.24% extra whereas in case of superheating for both the cases, R600a shows better performance by reducing 5.28% compressor power consumption comparing with R290.

The output from the analysis considering different climatic zones author found possible decrease in compression capacity 27-40% indicated lower consumption of energy compared to the standard design. In case of R600a with 5 ^{0}C author obtained better results compared to R290. Further, using DC compressor can help to reduce energy consumption by 30%. This thesis also discusses on the use of solar thermal (superheating for R600a) and photovoltaic energy to power air conditioners in the future. Therefore, in this work the authors propose to save energy consumption by pre-size designing of domestic air conditioning system on the basis of different climatic zones of India.

CHAPTER 8

Chapter 8

Avenue of the Future Work

8.1 Future Scope:

In this present work the pattern of energy consumption in domestic air conditioning systems is studied rigorously and tries to find out the alternatives in energy savings and environmental sustainability. For that the authors try to climate-based design of air conditioning system with different natural refrigerants.

The whole work is carried out experimentally as well as theoretically analysis but the experimental part of the work cannot be elaborated with different types of refrigerants at different locations. But the theoretical analysis is carried out considering natural refrigerants R 290 and R600a considering different climatic zones. Further experimentation is needed to validate the results obtained theoretically for different climatic zones. So that can be the avenue of the future work.

Further analysis of heat balancing for different components of standard air conditioning systems can be carried out while using solar energy to drive (DC) the systems with other different natural refrigerants (R 290 and R600a).

If the temperature of air can be maintained at low temperature at inlet of the condenser (outdoor) unit, the overall energy consumption can be reduced further that can be done by placing the condenser unit at cool place with proper shading and an arrangement can be made for cooling the air flow by using some evaporative cooling.

For this purpose, optimum designing of the evaporative cooling systems can be done considering different types of materials (i.e., clay pot) that may be another avenue of the future work.

Another analysis on power savings opportunities for using solar based air conditioning systems can be analysed for the whole country and the load forecasting analysis by using different optimization techniques like artificial neural network (ANN), deep learning, etc. for air conditioning systems can be done. Based on that a proper load management can be ensured.

So, the present work has a large importance as it shows directions on future research on air conditioning systems towards sustainable goals.

PLGIARISM CHECK RESULTS:

Plagiarism_check_R. Naskar_PhD_Thesis _Sept_2023.pdf

ORIGINALITY REPORT

05 %

SIMILARITY INDEX

Mr. Rakesh Naskar

PhD_Thesis_Rakesh _Naskar

ORIGINALITY REPORT

5%
SIMILARITY INDEX

PRIMARY SOURCES

1	www.scienceandculture-isna.org Internet	587 words — 1%
2	Yan, Gang, Chengfeng Cui, and Jianlin Yu. "Energy and exergy analysis of zeotropic mixture R290/R600a vapor-compression refrigeration cycle with separation condensation", International Journal of Refrigeration, 2015. Crossref	119 words — < 1%
3	Christian J.L. Hermes. "Refrigerant charge reduction in vapor compression refrigeration cycles via liquid-to-suction heat exchange", International Journal of Refrigeration, 2015 Crossref	103 words — < 1%
4	eprints.umm.ac.id Internet	101 words — < 1%
5	www.jaduniv.edu.in Internet	98 words — < 1%
6	www.researchgate.net Internet	89 words — < 1%
7	C.S. Choudhari, S.N. Sapali. "Performance Investigation of Natural Refrigerant R290 as a	79 words — < 1%

Substitute to R22 in Refrigeration Systems", Energy Procedia, 2017
Crossref

8	Dutra, Thiago, and Cesar J. Deschamps. "A simulation approach for hermetic reciprocating compressors including electrical motor modeling", International Journal of Refrigeration, 2015. Crossref	62 words — < 1%
9	www.unep.fr Internet	53 words — < 1%
10	mts.intechopen.com Internet	51 words — < 1%
11	Armando C. Oliveira. "A novel solar façade concept for energy polygeneration in buildings", International Journal of Low-Carbon Technologies, 2015 Crossref	49 words — < 1%
12	dramarnathgiri.blogspot.com Internet	46 words — < 1%
13	repository.fuoye.edu.ng Internet	43 words — < 1%
14	dokumen.pub Internet	36 words — < 1%
15	www.ijetsr.com Internet	34 words — < 1%
16	Mustafa Ozsipahi, Haluk Anil Kose, Husnu Kerpicci, Hasan Gunes. "Experimental Study of R290/R600a Mixtures in Vapor Compression Refrigeration System", International Journal of Refrigeration, 2021 Crossref	32 words — < 1%

17	Houpei Li, Jun Li, Sihui Li, Jinqing Peng, Jie Ji, Jinyue Yan. "Matching characteristics and AC performance of the photovoltaic-driven air conditioning system", Energy, 2023 Crossref	30 words — < 1%
18	mospi.gov.in Internet	28 words — < 1%
19	www.mdpi.com Internet	26 words — < 1%
20	I. Daut, M. Adzrie, M. Irwanto, P. Ibrahim, M. Fitra. "Solar Powered Air Conditioning System", Energy Procedia, 2013 Crossref	22 words — < 1%
21	Shubham Soni, Punit Mishra, Govind Maheshwari, Devendra S. Verma. "Theoretical estimation of efficiency defect in cascade refrigeration system using low global warming potential refrigerant pair", Materials Today: Proceedings, 2022 Crossref	21 words — < 1%
22	docplayer.net Internet	21 words — < 1%
23	www.intechopen.com Internet	21 words — < 1%
24	www.laccei.org Internet	20 words — < 1%
25	www.slideshare.net Internet	20 words — < 1%

26	Ioan Sarbu, Calin Sebarchievici. "Review of solar refrigeration and cooling systems", Energy and Buildings, 2013 Crossref	18 words — < 1%
27	eprint.iitd.ac.in Internet	18 words — < 1%
28	dl.dropboxusercontent.com Internet	16 words — < 1%
29	Elias M. Salilih, Yilma T. Birhane. "Modelling and performance analysis of directly coupled vapor compression solar refrigeration system", Solar Energy, 2019 Crossref	15 words — < 1%
30	www.oreilly.com Internet	15 words — < 1%
31	www.sciencepub.net Internet	15 words — < 1%
32	Chitrarekha Kabre. "Sustainable Building Design", Springer Science and Business Media LLC, 2018 Crossref	14 words — < 1%
33	Guangping Liu, Zhenneng Lu, Yuan Yao, Yulie Gong. "Multi-variable extremum seeking control for high temperature heat pump system incorporating double refrigerant injection", International Journal of Refrigeration, 2023 Crossref	14 words — < 1%
34	Lew, Calvin L.. "New applications of infrared photography in cinema.", Proquest, 2014. ProQuest	14 words — < 1%

35 Qi Chen, Le Zhou, Gang Yan, Jianlin Yu. "Theoretical investigation on the performance of a modified refrigeration cycle with R170/R290 for freezers application", International Journal of Refrigeration, 2019
Crossref
13 words — < 1%

36 link.springer.com
Internet
13 words — < 1%

37 mspace.lib.umanitoba.ca
Internet
13 words — < 1%

38 www.discoveryjournals.org
Internet
13 words — < 1%

39 www.grossarchive.com
Internet
13 words — < 1%

40 "Progress in Exergy, Energy, and the Environment", Springer Nature, 2014
Crossref
12 words — < 1%

41 Ali M. Baniyounes, M.G. Rasul, M.M.K. Khan. "Assessment of solar assisted air conditioning in Central Queensland's subtropical climate, Australia", Renewable Energy, 2013
Crossref
12 words — < 1%

42 Yuhe Gao, Jie Ji, Kedong Han, Feng Zhang. "Comparative analysis on performance of PV direct-driven refrigeration system under two control methods", International Journal of Refrigeration, 2021
Crossref
12 words — < 1%

43 repository.pauwes-cop.net
Internet
12 words — < 1%

44 worldwidescience.org
Internet
12 words — < 1%

45 www.hrv.co.nz
Internet
12 words — < 1%

46 repository.ju.edu.et
Internet
11 words — < 1%

47 www.metoffice.gov.uk
Internet
11 words — < 1%

48 Abdullah, Hussein Togun. "Experimental and Numerical Study of Heat Transfer to Nanofluid Flow in Sudden Enlargement of Annular Concentric Pipe", University of Malaya (Malaysia), 2023
ProQuest
10 words — < 1%

49 Aboah Boateng, Emmanuel. "Unsupervised Machine Learning Methods for Detecting Process Control Anomalies in Industrial Control Systems", Tennessee Technological University, 2023
ProQuest
10 words — < 1%

50 El-Shaarawi, M.A.I.. "Variation of the performance of intermittent solar refrigerators with initial temperature", Solar and Wind Technology, 1988
Crossref
10 words — < 1%

51 Gianluigi Lo Basso, Ali Mojtahed, Lorenzo Mario Pastore, Livio De Santoli. "High-efficiency solution for an open-loop desiccant assisted solar cooling system by integrating trans-critical CO2 heat pumps: a comprehensive techno-economic assessment", Energy Conversion and Management: X, 2023
Crossref
10 words — < 1%

52 Kaushik, S.C.. "Modeling and simulation studies on single/double-effect absorption cycle using water-multicomponent salt (MCS) mixture", Solar Energy, 1988
Crossref
10 words — < 1%

53 Mohammed Mumtaz A. Khan, R. Saidur, Fahad A. Al-Sulaiman. "A review for phase change materials (PCMs) in solar absorption refrigeration systems", Renewable and Sustainable Energy Reviews, 2017
Crossref
10 words — < 1%

54 W JONES. "Heat Gains from Solar and Other Sources", Air Conditioning Engineering, 2001
Crossref
10 words — < 1%

55 Zhenjun Ma, Haoshan Ren, Wenye Lin. "A review of heating, ventilation and air conditioning technologies and innovations used in solar-powered net zero energy Solar Decathlon houses", Journal of Cleaner Production, 2019
Crossref
10 words — < 1%

56 coek.info
Internet
10 words — < 1%

57 discovery.ucl.ac.uk
Internet
10 words — < 1%

58 eprints.qut.edu.au
Internet
10 words — < 1%

59 i-scholar.in
Internet
10 words — < 1%

60 isroset.org
Internet
10 words — < 1%

61	pt.scribd.com Internet	10 words — < 1%
62	uir.unisa.ac.za Internet	10 words — < 1%
63	vdocuments.mx Internet	10 words — < 1%
64	www.frontiersin.org Internet	10 words — < 1%
65	www.ibecc.in Internet	10 words — < 1%
66	www.ncei.noaa.gov Internet	10 words — < 1%
67	www.tdx.cat Internet	10 words — < 1%

EXCLUDE QUOTES	OFF	EXCLUDE SOURCES	OFF
EXCLUDE BIBLIOGRAPHY	ON	EXCLUDE MATCHES	< 10 WORDS