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Experimental Analysis of Air Conditioner by Combination of Different Techniques

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Abstract

In the world scenario the biggest problem is always attach with energy. We are facing a large scarcity of energy and for that it will always beneficial to minimize the energy consumption. So for that this paper contain an experimental method by which we can see how much energy we can save by applying three different energy source for establishing an air conditioning system. While in three energy source one is conventional energy source and another two is non conventional energy source. The conventional energy source is applied to simple vapor compression cycle and non conventional energy source is applied to extract energy from peltier effect and earth heat exchanger. This paper also contains a big role of heat pipe which is used to transport energy from on point to other. This project also contains the compression of energy consumption with three different conditions which are:

1. *When only vapor compression cycle is use withpeltiermoduel.*
2. *When vapor compression cycle is used with earth heat exchanger.*
3. *When vapor compression cycle is used with earth heat exchanger as well as peltiermoduel*

Keyword—*VCC, Peltier module, Earth heat exchanger, Thermal analysis of Radial & Rectangular fins.*

1. Introduction

The effect of air-conditioning demand makes the energy consumption has been increasing quickly. The investigation report shows that of the total energy consumption in buildings in Metro city, the energy amount used by air-conditioning system is 46.1% in restaurant building, 40.5% in commercial building, 49.7% in office building, and 30.3% in hospital building. The ever increasing energy requirement puts a great burden on the further economical development as India is poor in energy resources. How to reduce the energy consumption by using new energy saving technologies and equipment is an important task now days. In order to reduce the energy consumption in air-conditioning building, apparatus dew-point air supply is usually used in air-Conditioning systems. But as the moist air leaving the cooling coil is usually too high in relative humidity (about 95% Rh) and too low in temperature to be used in occupied spaces directly, people usually feel uncomfortable. Besides, if the relative humidity in occupied spaces and low-velocity ducts and plenums exceeds 70%, fungal contamination such as mold, mildew, etc., can occur and threatens public health. Therefore, from the requirement of keeping good indoor thermal comfort and air quality, and of reducing the risk of catching disease, it is a strong recommendation to keep the supply air humidity below 70%. This means that relative humidity control in the air supply is important aspect. But if conventional cooling coils are used to improve the indoor thermal comfort and air quality, external energy will be used to reheat the air stream from the apparatus dew-point to the required air supply state. To solve this problem, a Peltier Module and Earth heat Exchanger air-handling coil can be employed [1].

2. Objective

The main objective of this investigation is to study the performance of the Hybrid Air Conditioning System. The proposed work includes the determination of heat load, to maintain 13 to 15ºC temperature in the cabinet of volume close to 5 liters.

1) Test &Trial on combined air conditioner determine temperature gradient, cooling ability (tonnage) and COP of system, under given conditions
   - Vapor Compression Air Conditioning unit and derive performance characteristic
   - Vapor Compression Air Conditioning unit with Earth heat exchanger unit and derive performance characteristic
   - Vapor Compression Air Conditioning with Peltier module unit and derive performance characteristic.
   - Vapor Compression Air Conditioning with Earth heat exchanger and Peltier module unit and derive performance characteristic.
2) Performance analysis of combined air conditioner with temperature under given conditions
   - Vapor Compression Air Conditioning unit and derive performance characteristic

- Vapor Compression Air Conditioning unit with Earth heat exchanger unit and derive performance characteristic
- Vapor Compression Air Conditioning with Peltier module unit and derive performance characteristic.
- Vapor Compression Air Conditioning with Earth heat exchanger and Peltier module unit and derive performance characteristic.

3. Literature review

In view of proposed dissertation work concerned, following few of the researchers have done their experimental study and investigated results which have been review as follows

Ankit kumar& Rajneesh Kumar Gedam [1]The demand of air –conditioning system makes the consumption of energy very largely. According to world energy report it shows that from the total available energy the total energy consumption in different buildings in metro city only by air-conditioning system is around 46.1% while by restaurant it is found to be 40.5%. Other than this commercial building and hospital building used 49.7% and 30.3% respectively of their useful energy on air conditioning system. So in this project the main concept is to investigate the performance of hybrid air conditioning system.Also to determine the heat load to maintain 22 to 250C temperature in the closed volume. Another point is comparison between different available system and also the performance and testing of different system with different combination.

Kumar Rawat et al [2] Studied experimentally that, Thermoelectric Refrigeration system and they have been designed and developed an experimental thermoelectric refrigeration system having a refrigeration space of 1 liter is cooling by four numbers of thermoelectric cooling module (Q_{max}=19W) and a heat sink fan assembly (R_{th}=0.50 ºC/W) for each thermoelectric module used to increase heat dissipation rate. A temperature reduction of 11º C without any heat load and 9º C with 100 ml of water in refrigeration space with respect to 23º C ambient temperature has been experimentally found in first 30 minutes at optimized operating conditions. The calculated COP of thermoelectric refrigeration cabinet was 0.1. Also compatibility of thermoelectric cooling systems with solar energy made them more useful and appropriate for environment protection.

M.J. Goldsworthy [3] Residential buildings should be places in which their occupants feel comfortable and content. In an energy conscious world the challenge of offering improved indoor comfort is contrast with the desire to minimize grid energy consumption (both from an efficient distribution perspective and to minimize fossil fuel consumption) as well as the associated cost. Selecting the most cost effective building designs or modifications that met these dual goals regardless of occupant behavior is a non-trivial task. One way of approaching this problem that guarantees no grid connected energy usage is to use an off-grid PV battery driven air-conditioner. Here we use a detailed simulation model to investigate the suitability of a small off-grid PV-battery system to power an air-conditioner to provide occupant comfort for a range of different building thermal designs across Australian climates. Results show that even in tropical climates, there are certain building thermal designs that lead to indoor temperatures <25°C at all times with a modest size PV-battery system.

4. Vapor-Compression Cycle

The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Figure 1 provides a schematic diagram of the components of a typical vapor-compression refrigeration system.

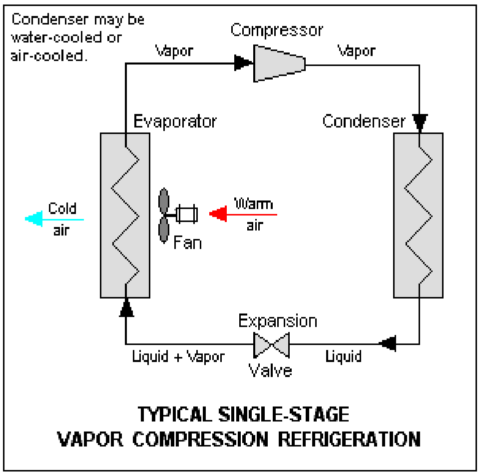


Fig. 1 Vapor-compression refrigeration

That results in a mixture of liquid and vapor at a lower temperature and pressure. The cold liquid-vapor mixture then travels through the evaporator coil or tubes and is completely vaporized by cooling the warm air (from the space being refrigerated) being blown by a fan across the evaporator coil or tubes. The resulting refrigerant vapor returns to the compressor inlet to complete the thermodynamic cycle.

The above discussion is based on the ideal vapor-compression refrigeration cycle, and does not take into account real-world effects like frictional pressure drop in the system, slight thermodynamic irreversibility during the compression of the refrigerant vapor, or non-ideal gas behavior.

TABLE 1 Specification of VCC System

Capacity (Ton	0.25
Star Rating	1
Cooling (watt)	549 WATT
Compressor	Rotary
EER (BTU / Hr./W)	0.49
Noise Level (db)	45
Cooling Function	
Temp. Control	Thermistor
Connivance function	
Operation Control	Electronic
Energy saver	Yes
Durability Features	
Evaporator Fin Type	Blue
Condenser Fin Type	Gold
Electricity Rating	
Power Supply (Volt/Phase/Hz.)	230 / Single / 50
Power Input (Watts)	200
Running Current (Amps)	4.6
Dimensions	
Width x Height x Depth (mm)	470x495x440
Weight	
Unit (kg)	17 kg

5.Peltier module

The Peltier effect was discovered in 1834 by a French watchmaker and part time physicist Jean Charles Athanase Peltier. Peltier found that the use of a current at an interface between two dissimilar materials results in the absorption of heat and release of heat at the subatomic level, this is a result of the different energy levels of materials, particularly n and p type materials. As electrons move from p type material to n type material, electrons jump to a higher energy state absorbing energy, in this case heat, from the surrounding area. The reverse is also true. As electrons move from n type material to p type material, electrons fall to a lower energy state releasing energy to the surrounding area [4].

TABLE 2 Specification of Peltier Module

Parameters of Category	Series-Parallel Modules
Imax	ser 1.9 par 3.7 amp(s)
Qmax	36.6 watt(s)
Vmax	ser 31.8 par 15.9 volt(s)
DT max	72 Th=300K
A	40 mm
B	40 mm
C	40 mm
D	40 mm
H	4.8 mm

6.Heat pipes

Heat pipes are two-phase heat transfer devices with high effective thermal conductivity. Due to the high heat transport capacity, heat exchanger with heat pipes has become much smaller than traditional heat exchangers in handling high heat fluxes. With the working fluid in a heat pipe, heat can be absorbed on the evaporator region and transported to the condenser region where the vapor condenses releasing the heat to the cooling media

When heat is added to the evaporator section, the working fluid boils and converts into vapour absorbing latent heat. After reaching the condenser section, due to partial pressure build up, the vapour transforms back into liquid thus releasing latent heat. From the condenser section, heat is taken away by means of water cooling / air cooling with fins etc. The liquid condensate returns to the original position through the capillary return mechanism, completing the cycle. Due to very high latent heat of vaporization a large quantity of heat can be transferred.

A heat pipe is a simple device that can transfer heat from one point to another without having to use an external power supply. It is a sealed tube that has been partially filled with a working fluid. In HVAC applications, this fluid is refrigerant. The sealed refrigerant - which will boil under low-grade heat - absorbs heat from the warm return air such as in an air-conditioning system and vaporizes inside the tube. The vapor then travels to the other end of the heat pipe (the high end), which is placed in the stream of cold air that is produced by the air conditioner. The heat that was absorbed from the warm air at the low end is now transferred from the refrigerant's vapor through the pipe's wall into the cool supply air. This loss of heat causes the vapor inside the tube to condense back into a fluid. The condensed refrigerant the travels by gravity to the low end of the heat pipe where it begins the cycle all over again[5].

Selection of Fan/ Blower for Hot Side

- Model: fan -172-230 V
- Bearing type: single row deep groove ball bearing
- Rating voltage: 220 / 240 Vac
- Frequency: 50/60 hz.
- Power (amp): 0.35 a
- Speed (rpm) = 2700
- Air flow (cfm) = 150
- Power: 35 Watt
- Make: Fanon

Heat Pipe Geometry- Size Selection

Heat pipes are available in standard diameters from 3 to 12mm and in lengths from 50mm to 250 mm, shape be as shown in figure below:

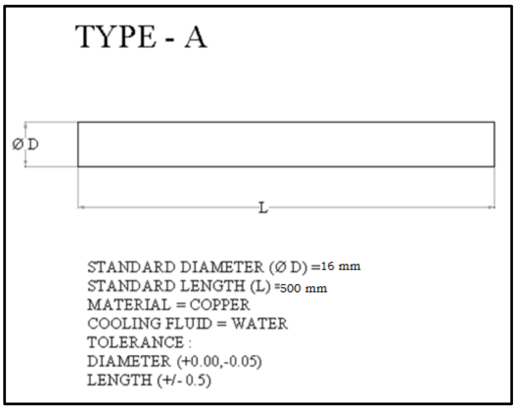


Fig. 2 Configuration of heat pipe

Heat Transfer Capability For Above Heat PipeMaximum Watts at Different Temperature

TABLE 3 Maximum Watts at Different Temperature

DIAMETER	20^0C	40^0C	80^0C	120^0C
16 mm	147	179	196	216

Thermal Analysis of Spiral Radial Fins for Heat Pipe Module Experimentation and Experimental calculation, we check the Performance analysis of fins or validation through the following way

a) Spiral radial fin profile and geometry drawing using 2D AUTOCAD-2000.

b) Solid modeling of the Spiral radial fin models using Unigraphix.

c) Thermal analysis for temperature distribution using ANSYS.

On Test models of Fins which is Spiral radial fin.

7.Test model Analysis

I. Test Model-I Analysis

Following is the Test Model-I 3D model of Spiral radial Fins in NX Unigraphix is given below.

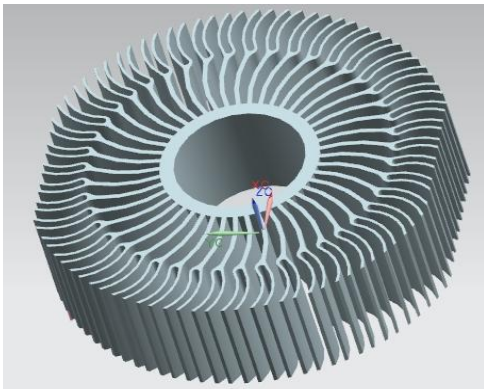


Fig. 3 Test Model-I of Spiral radial Fins in NX Unigraphix

*A. Geometry of Spiral radial Fins:*Material: Aluminum

TABLE 4 Displayed Mass Property Values

Volume	45749.346346060 mm³
Area	106970.325514622 mm²
Mass	0.121693261 kg
Weight	1.193404297 N
Radius of Gyration	31.397539329 mm
Centroid	-0.000855740 mm, -0.001402973 mm, 13.000000000 mm

TABLE 5 Detailed Mass Properties

Analysis calculated using accuracy	0.990000000
Information Units	kg - mm
Density	0.000002660
Volume	45749.346346060
Area	106970.325514622
Mass	0.121693261

B. Thermal Analysis of Test Model-I:

Thermal analysis of Spiral radial fin structures using ANSYS of Test Model Spiral radial Fins is given in that Geometry,IGES file of the model imported to ANSYS work bench 14.5 meshing is carried out using free meshed by tetrahedron elements the number of elements and nodes is given below for each fin structure. Meshing done with Nodes are 9368 and Elements are 4528 then, we applied boundary condition to Spiral radial fin of all four test models like Convection at 35W/m²°C and Temperature at 21°C which is given in following diagrams, finally thermal analysis for finding different parameters like Total Heat Flux, Directional heat flux in x-direction and Temperature gradient as shown in figure.

1. Geometry:

Geometry of Test Model-I of Spiral radial fins is done in ANSYS of work bench 14.5

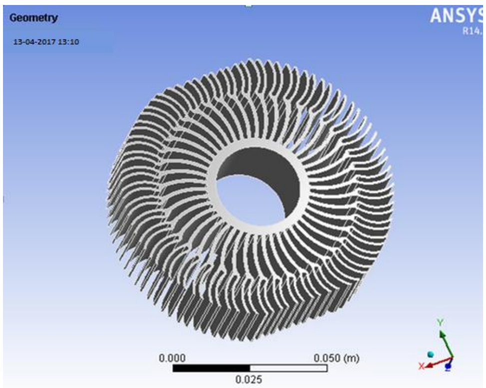


Fig. 4 Geometry of Test Model-I in ANSYS

2. Meshing

Meshing of Test Model of Spiral radial Fins is done with Nodes are 9368 and Elements are 4528.

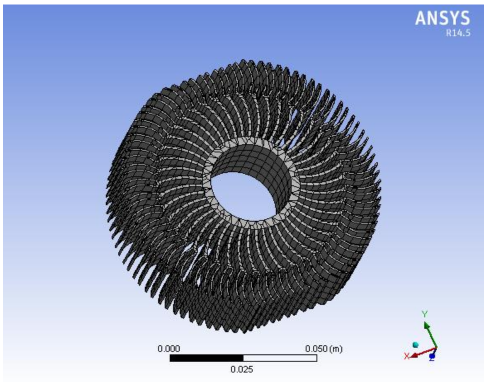


Fig. 5 Meshing of Test Model-I

3. Applying Boundary Conditions

Now,we applied the boundary conditions to the given Spiral radial fin structure convection at 35W/m²°C and Temperature at 21°C.

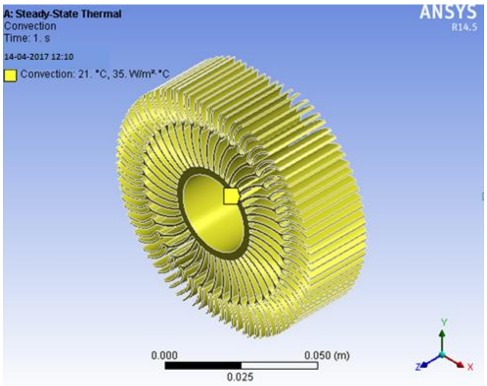


Fig. 6 Boundary Condition at 21°C

4 .Temperature at 32°C
Boundary condition temperature at 32°C of Test Model of Spiral radial Fins

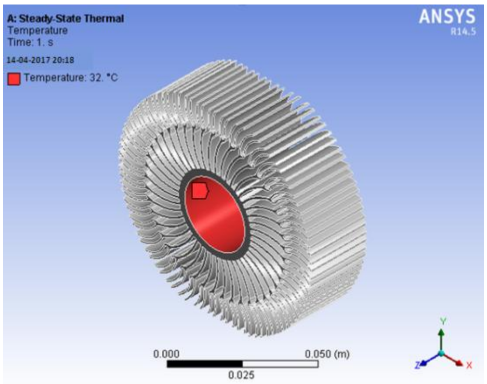


Fig. 7 Boundary Condition at 32°C

5. Analysis Results

Now, after applying the boundary condition we find the analysis results with following points like maximum Total Heat Flux at 20334 W/m², maximum Directional heat Flux in x-direction at 20192 W/m² and Maximum Temperature Gradient at 32℃.

6. Total Heat Flux

Figure shows Maximum Total Heat Flux at 20334 W/m²

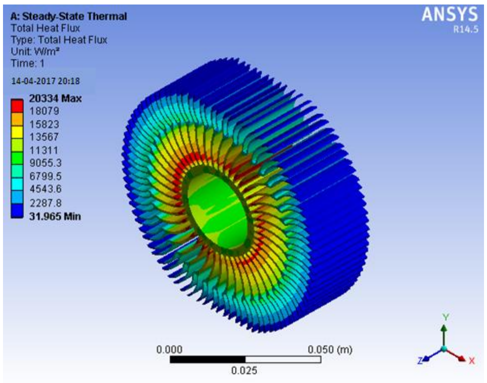


Fig. 8 Total Heat Flux of Test Model-I

7. Directional Heat Flux in x-Direction

Figure shows maximum Directional heat Flux in x-direction at 20192 W/m²

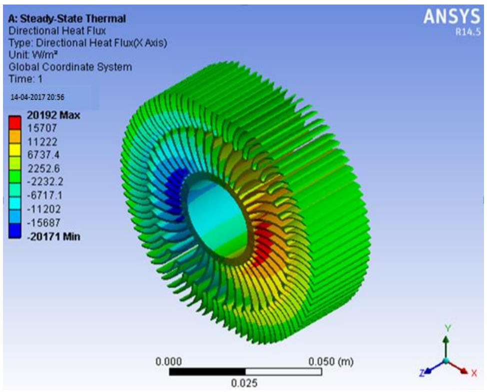


Fig. 9 Directional heat Flux in x-direction of Test Model-I

8. Temperature Gradient

Figure shows maximum temperature Gradient at 32℃.

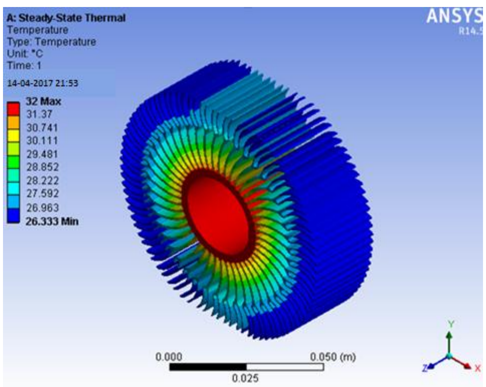


Fig. 10 Temperaturegradientof Test Model-I

II.Test Model-II Analysis

Geometry of RectangularFins

1. Measurement Mass Properties

TABLE 6 Displayed Mass Property Values

Volume	59124.000000000 mm³
Area	89656.000000000 mm²
Mass	0.165192456 kg
Weight	1.619986060 N
Radius of Gyration	33.279045697 mm
Centroid	-31.857519789 mm, 39.000000000 mm, -17.967018470 mm

TABLE 7 Detailed Mass Properties

Analysis calculated using accuracy	0.990000000
Information Units	kg - mm
Density	0.000002794
Volume	59124.000000000
Area	89656.000000000
Mass	0.165192456

2. Thermal Analysis of Test Model-II:

Thermal analysis of Rectangular fin structures using ANSYS of Test Model Rectangular Fins is given in that Geometry, IGES file of the model imported to ANSYS work bench 14.5 meshing is carried out using free meshed by tetrahedron elements the number of elements and nodes is given below for each fin structure. Meshing done with Nodes are 23650 and Elements are 3402 then, we applied boundary condition to Rectangular fin of all four test models like Convection at 46W/m²°C and Temperature at 28°C which is given in following diagrams, finally thermal analysis for finding different parameters like Total Heat Flux, Directional heat flux in x-direction and Temperature gradient as shown in figure.

3. Geometry

Geometry of Test Model-I of Rectangular fins is done in ANSYS of work bench 14.5

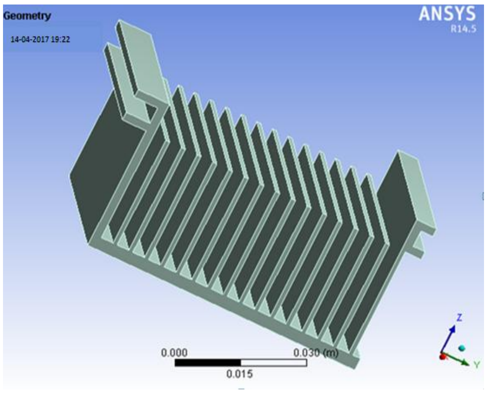


Fig. 11 Geometry of Test Model-II

4. Meshing:

Meshing of Test Model of RectangularFins is done with Nodes are 23650 and Elements are 3402.

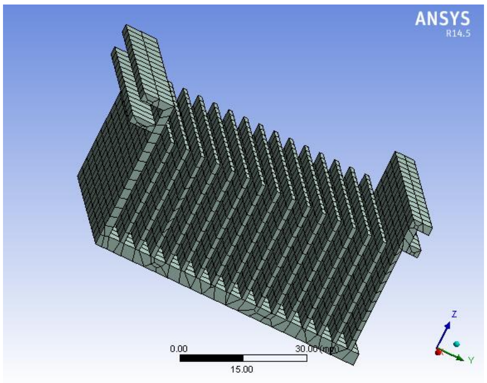


Fig. 12 Meshing of Test Model-II

5. Applying Boundary Conditions

Now,we applied the boundary conditions to the given Rectangular fin structure convection at 46W/m²°C and Temperature at 28°C.

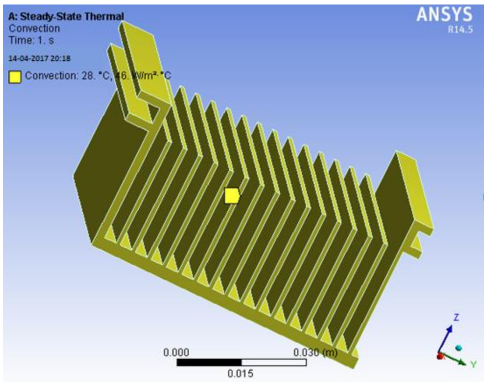


Fig. 13 Boundary Condition Temperature at 28°C

6. Temperature at 80°C

Boundary condition temperature at 80°C of Test Model of Rectangular Fins

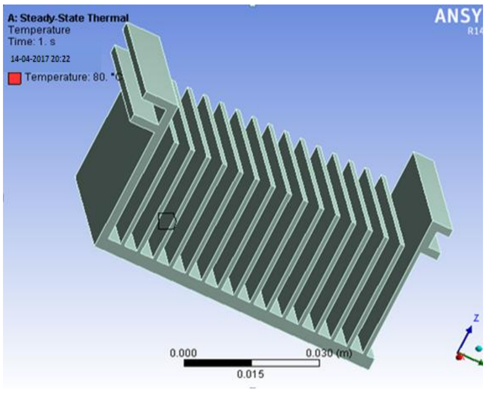


Fig. 14 Boundary Condition Temperature at 80°C

7. Analysis Results

Now, after applying the boundary condition we find the analysis results with following points like maximum Total Heat Flux at 102610 W/m^2, maximum Directional heat Flux in x-direction at 3235.6 W/m^2 and Maximum Temperature Gradient at 80℃.

8. Total Heat Flux

Figure shows Maximum Total Heat Flux at 102610 W/m^2

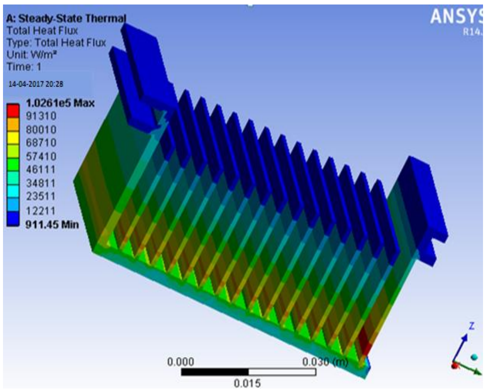


Fig. 15 Total Heat Flux of Test Model-II

9. Directional Heat Flux in x-Direction

Figure shows maximum Directional heat Flux in x-direction at 3235.6 W/m^2

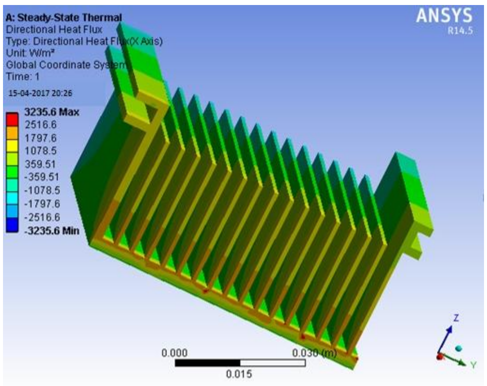


Fig. 16 Directional heat Flux in x-direction of Test Model-II

10. Temperature Gradient

Figure shows maximum temperature Gradient at 80℃.

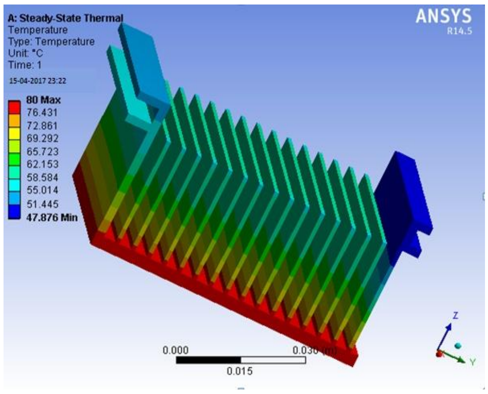


Fig. 17 Temperaturegradientof Test Model-II

8. Result Calculation

Fig. 18 AcualExprimental Set-up

A. Test & Trial-I on Conventional Vc-Model With Earth Heat Exchanger

1. Procedure

1) Start compressor
2) Peltier module off
3) Earth heat exchanger
4) Take temperature readings after every 3min

TABLE 8 Observation Table for trial-I

No	Time	Mass of air	T1	T2	ΔT	Compressor Power	Net comp. power
1	3	10.4	30	28	2	91	91
2	6	10.4	31	24	7	89	89
3	9	10.4	31	22	9	83	83
4	12	10.4	30	19	11	82	82

5	15	10.4	31	16	15	80	80

2.Calculation

1) KWH= (time/60) X (compression power)/1000
2) COP= (KWH)/((mcpΔt)*3600)
3) Tonnage=COP/3.516

3. Result table

TABLE 9 Result Table for trial-I

No	ΔT	Net Comp. Power	mcpΔt	COP	Tonnage
1	2	91	20.8832	1.27492	0.32858
2	7	89	73.0912	2.28124	0.58795
3	9	83	93.9744	2.09670	0.54038
4	11	82	114.857	1.94542	0.50139
5	15	80	156.624	2.17533	0.56065

B.Test& Trial-II on conventional VC-model withPeltier module

1. Procedure

1) Start compressor
2) Peltier module on
3) No earth heat exchanger
4) Take temperature readings after every 3min

TABLE 10 Observation Table for trial-II

No	Time	Mass of air	T1	T2	ΔT	Comp. Power	P.M. Power	Net comp. power
1	3	10.4	30	28	2	91	21	112
2	6	10.4	31	24	7	88	18	106
3	9	10.4	31	21	10	83	15	98
4	12	10.4	30	17	13	80	12	92
5	15	10.4	31	13	18	77	11	88

2.Calculation

1) KWH= (time/60) X (compression power)/1000
2) COP= (KWH)/((mcpΔt)*3600)
3) Tonnage=COP/3.516

3.Result table

TABLE 11 Result Table for trial-II

No	ΔT	Net Comp. Power	mcpΔt	COP	Tonnage
1	2	112	20.8832	1.035873	0.2669776
2	7	106	73.0912	1.915388	0.4936567
3	10	98	104.416	1.973091	0.5085287
4	13	92	135.7408	2.049227	0.5281513
5	18	88	187.9488	2.373091	0.6116214

C. Test & Trial-III on Conventional VC-Model with Peltier Module and Earth Heat Exchanger

1.Procedure

1) Start compressor
2) Peltier module on
3) Earth Heat Exchanger
4) Take temperature readings after every 3min

TABLE 12 Observation Table for trial-III

No	Time	Mass of Air	T1	T2	ΔT	Comp. Power	P.M. Power	Net Comp. Power
1	3	10.4	30	28	2	88	15	103
2	6	10.4	31	24	7	82	15	97
3	9	10.4	31	19	12	76	13	89
4	12	10.4	30	15	15	71	12	83
5	15	10.4	31	11	20	70	11	81

2. Calculation

1) KWH= (time/60) X (compression power)/1000
2) COP= (KWH)/((mcpΔt)*3600)
3) Tonnnage=COP/3.516

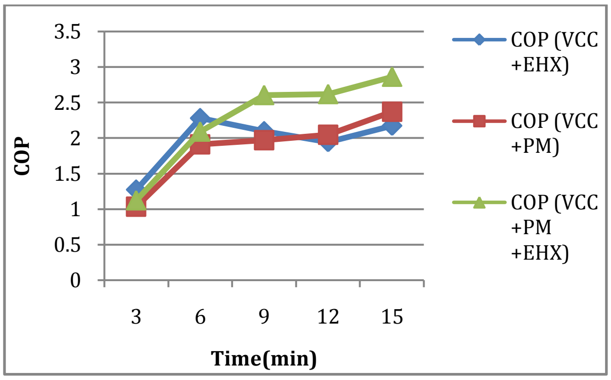
3. Result table

TABLE 13 Result Table for trial-III

No	ΔT	Net Compressor Power	mcpΔt	COP	Tonnage
1	2	103	20.883	1.12638	0.29030
2	7	97	73.091	2.09310	0.539S4
3	12	89	125.29	2.60714	0.67194
4	15	83	156.62	2.62088	0.67548
5	20	81	208.83	2.86463	0.73830

9. Graphical Result

A) Graph Result-I:



Graph No.1 Comparison of COP

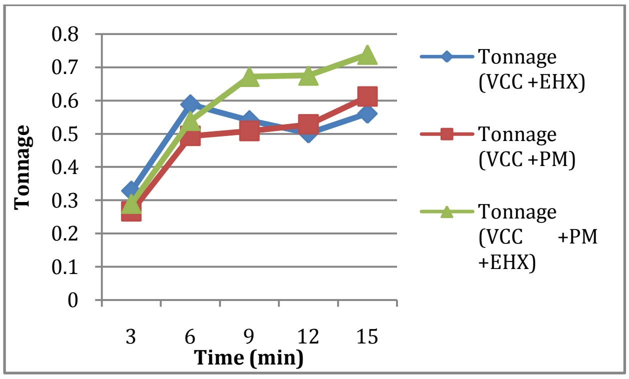
Result:

1. COP of (VCC+PM+HEX) is maximum and thus most effective of the three

combinations hence it is recommended that all three modifications of the hybrid system be used for best results.

2. Comparison of the COP of (VCC+ PM) & (VCC +EHX) shows that (VCC +PM) shows better COP as compared to the (VCC +EHX)over delayed duty cycle ie, from 12 to 15min , hence will be recommended if the temperature cycling is to done over a range above 12minutes time.
3. Comparison of the COP of (VCC+ PM) & (VCC +EHX) shows that (VCC +EHX) shows better COP as compared to the (VCC +PM)over short duty cycle ie, from 0 to 12min , hence will be recommended if the temperature cycling is to done over a range below 12minutes time.

B) Graph Result-II:



Graph No.2 Comparison of Tonnag

Result:

1. Tonnage of(VCC+PM+HEX) is maximum and thus most effective of the three combinations hence it is recommended that all three modifications of the hybrid system be used for best results.
2. Comparison of the Tonnage of (VCC+ PM) & (VCC +EHX) shows that (VCC +PM) shows better Tonnage as compared to the (VCC +EHX)over delayed duty cycle i.e., from 12 to 15min , hence will be recommended if the temperature cycling is to done over a range above 12minutes time.
3. Comparison of the Tonnage of (VCC+ PM) & (VCC +EHX) shows that (VCC +EHX) shows better Tonnage as compared to the (VCC +PM)over short duty cycle ie, from 0 to 12min , hence will be recommended if the temperature cycling is to done over a range below 12minutes time.

Conclusions

1. COP of the hybrid system increases with application of the Peltier module and Earth heat exchanger arrangement to up to 10 %
2. Tonnage of the hybrid system increases with application of the Peltier module and Earth heat exchanger arrangement to up to 11 %

References

[1].Ankit kumar& Rajneesh Kumar Gedam,(2016), "Hybrid Air Conditioning For Better Energy Economic Consumption" IJATES , Vol No 4.

[2]. Manoj Kumar Rawat, Prasanta Kumar Sen, Himadri Chattopadhyay, SubhasisNeogi,(2013), "Developmental and Experimental Study of Solar Powered Thermoelectric Refrigeration System" ,IJERAISSN: 2248-9622 ,Vol. 3, pp.2543-2547.

[3]. M.J. Goldsworthy,(2016) ,"Building Thermal Design For Solar Photovoltaic Air-Conditioning In Australian Climates" ,PII:S0378-7788(16)31600-0 ,Reference: ENB 7161.

[4]. Chetan Jangonda ,Ketan Patil , AvinashKinikar , RavirajBhokare , M.D.Gavali,(2016), "Review of Various Application of Thermoelectric Module" IJIRSET ,Vol. 5, Issue 3, March.

[5] Ehsan Firouzfar, and Maryam Attaran (2008), "A Review of Heat Pipe Heat Exchangers Activity in Asia" , International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical.vol:2 no;2.

[6]. Muhammad Tauseef Nasir Kyung Chun Kim ,(2016), "Working Fluids Selection and Parametric Optimization of an Organic Rankine Cycle Coupled Vapor Compression Cycle (ORC-VCC) for Air Conditioning Using Low Grade Heat",PII: S0378-7788(16)30678-8,Reference: ENB 6899.

[7].Jean Peltier Part C ,(2014), "Electronics Cooling Methods in Industry". MPE 635: Electronics Cooling.

[8]. Xin Zheng, Hong-Qi Li, Ming Yu, Gang Li, Qi-Ming Shang ,(2016), "Benefit analysis of air conditioning systems using multiple energy sources in public buildings",PII: S1359-4311(16)30565-8Reference: ATE 8125.

[9]. Haitao Wang, Shunbao Zhou, Zhongshi Wei, Ren Wang (2016), "A study of secondary heat recovery efficiency of a heat pi peheatexchanger air conditioning system" ,Energy and Buildings 133 (2016) 206–216 .