

Key Tech Services Publication, India

<http://www.ktjme.com>

<https://doi.org/10.64188/3048956325024>

Vol.: 2, No. 3, 2025, Pages: 25-37

Experimental Investigation of COP improvement in conventional vapor Compression cycle air conditioner by application of thermoelectric cooler and Ground coupled Heat pipe system

Rahul S. Deshmukh¹

¹Depart. of Mechanical Engineering, Genba Sopanrao Moze College of Engineering, Balewadi, Pune
Savitribai Phule Pune University (SPPU) Pune

Abstract

The main objective of the paper is to study the performance of hybrid air conditioning system and analyze the variation of COP in different combinations of vapour compression system, earth heat exchanger and Peltier module. According to the fieldwork study, most of the work is carried out by using only VCC with thermoelectric system and VCC with earth heat exchanger. Keeping in mind this, individually these ideas do not stand good but by combination of two or more concept in a collaborative manner stands a possibility to develop an energy efficient method of air conditioning. Therefore, enhancing the performance of the existing system by adding earth heat exchanger and Peltier module was studied. The proposed study includes design of hybrid air conditioning system. From this proposed study, it is expected to decide feasibility hybrid air conditioning system. The outcomes of this study will help to design, modify, and manufacture a kit based on hybrid air conditioning system for improvement of performance, dehumidification enhancement, lower cost of refrigeration as the heat load is reduced by non-conventional earth heat exchanger can find applications in post-harvest handling of horticulture and floriculture produce. It can be applied to low-cost domestic cooling, commercial installations, and industrial installations.

1. Introduction

In the present age with depleting sources of energy there is always a target to get the best energy ratios so that there will be minimum electric power consumption in operation of the air conditioning units. Many methods and ideas from evaporative cooling, thermoelectric cooling

Received: 14.8.2025

Revised: 19.9.2025

Accepted: 05.10.2025

Published Online: 15.10.2025

Keywords: Thermoelectric cooler, Ground coupled heat pipe system, COP, Peltier effect,

*Corresponding author name and email: Rahul S. Deshmukh, rahul15.2009@gmail.com

How to cite this article: Rahul S. Deshmukh, Experimental Investigation of COP improvement in conventional vapor Compression cycle air conditioner by application of thermoelectric cooler and Ground coupled Heat pipe system, KT Journal of Mechanical Engineering, 2 (3) 2025, 25-37. <https://doi.org/10.64188/3048956325024>

etc have been tried to keep the electricity consumption to a minimum in air conditioning applications. Individually these ideas do not stand good but by combination of two or more concepts in a collaborative manner stands a possibility to develop an energy efficient method of air conditioning. Thus, there is a proposal to use the conventional vapor compression cycle in conjunction to thermoelectric cooling and earth heat exchanger technique to reduce the power consumption of the air conditioner and thereby increase the COP of system. A collaborative technique is used in development of a novel air conditioner where in the conventional vapor compression cycle air conditioning equipment is used in conjunction to two other techniques namely the thermoelectric cooler and ground cooling heat pipe system is A ground-coupled heat exchanger is an underground heat exchanger that can capture heat from and/or dissipate heat to the ground. They use the Earth's near constant subterranean temperature to warm or cool air or other fluids for residential, agricultural or industrial use. Earth tubes are often a viable and economical alternative or supplement to conventional central heating or air conditioning systems since there are no compressors, chemicals or burners and only blowers are required to move the air. These are used for either partial or full cooling and/or heating of facility ventilation air. Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other side against the temperature gradient (from cold to hot), with consumption of electrical energy

2. Literature Review

They studied experimentally that; a heating and cooling system is provided for use on a work machine. The system includes one or more temperature sensors configured to collect environmental temperature information and a compressor-based HVAC unit having a compressor and providing in cabin climate control based on circulation. The system also includes a thermoelectric HVAC unit to supplement the compressor-based HVAC unit [1]. They investigated the effect of heat-pipe air-handling coil on energy consumption in a central air-conditioning system with return air. By taking an office building as an example, the study shows that compared with conventional central air-conditioning system with return air, the heat-pipe air-conditioning system can save cooling and reheating energy. In the usual range of 22–26.8°C indoor design temperature and 50% relative humidity, the RES (rate of energy saving) in this office building investigated is 23.5–25.7% for cooling load and 38.1–40.9% for total energy consumption. The RES of the heat-pipe air-conditioning system increases with the increase of indoor design temperature and the decrease of indoor relative humidity. The influence of indoor relative humidity on RES is much greater than the influence of the indoor design temperature. The study indicates that a central air-conditioning system can significantly reduce its energy consumption and improve both the indoor thermal comfort and air quality when a heat-pipe air-handling coil is employed in the air-conditioning process [2]. The author experimentally investigated that, how the sensible heat ratio (SHR) of HPHX was influenced by each of three key parameters of the inlet air state, namely, dry-bulb temperature, and relative humidity and air velocity. Based on this study, it is recommended that tropical HVAC systems should be installed with heat pipe heat exchangers for dehumidification enhancement and

saving the energy. The experimental results demonstrated that for all cases examined, the overall SHR of the HVAC system was reduced from the maximum of 0.688 to the minimum of 0.188 by the HPHX as inlet DBT to the HPHX evaporator increased. These results implied that the moisture removal capability for the HVAC system with HPHX was increasing as inlet DBT for HPHX evaporator increased. On the basis of this study, it is recommended that tropical HVAC systems should be installed with heat pipe heat exchangers for dehumidification enhancement [3]. The researcher studied experimentally, a heat pipe heat exchanger to dehumidification enhancement in tropical HVAC systems a baseline performance characteristics study, the author had established the baseline performance characteristics of the eight-row wickless heat pipe heat exchanger (HPHX) for a vertical configuration under a range of conditions appropriate for a tropical climate. Now, the same basic experimental set-up was to be used in the present research with the HPHX tilted 30° C [4]. They studied experimentally that, the HVAC system including at least one thermoelectric device for providing supplement heating and cooling for air supplied to compartment. The first circuit was configured to remove the heat from an electric side of a hybrid vehicle. The second circuit can configure to remove heat from a fuel-fed of a hybrid side [5,6]. They numerically studied thermal performance of Earth to air heat exchanger connected villa type house located in Marrakech suburb. The heat exchanger consists of 3 parallel and similar PVC pipes of 77.7m length and 15cm inside diameter these pipes are buried under 3.5m depth. It is found that when ambient temperature during the hot period reaches to 40.9°C the Earth to air heat exchanger can maintain the outlet temperature below 23.4°C achieving total temperature reduction of 17.6°C. During the cold period of the year the EAHX maintains the air temperature in the range 10-17 °C, while the ambient air temperature oscillates between -1.8 °C and 25 °C in the same period [7]. They designed a ground heat exchanger that utilizes geothermal energy in heating to exchange the primary geothermal fluid with a secondary clean fluid. For designing the system energy and momentum equations are applied around the geothermal fluid circuit. FLUENT software program is used to calculate the ground heat exchanger parameters and the amount of energy saved. The study shows that the Geo-exchange systems represent a savings to homeowners of around 70% in the heating mode, and up to 50% in the cooling mode compared to conventional fossil fuel systems [8]. They analyzed air conditioning system with HPHX for Indian climatic conditions. They focused on the use of HPHX for energy savings in air conditioning system by considering a case study of process air conditioning facility located in Pune city, India. HPHX can be used for exchange of heat between fresh outdoor air and conditioned return air (heat recovery application) and enhancing the dehumidification capability of cooling coil as well as reheat savings (dehumidification enhancement with reheat application [9-10]. They studied that solar air conditioning might be a solution to reduce the changing electrical demands. In his research work the idea was to build an alternative for AC and to provide air conditioning effect. The research aims to design and build a miniature prototype of thermoelectric cooling system for a conventional air conditioned to provide air conditioning to reduce the consumption of electricity and to reduce the pollution [11-13]. They evaluated the working of Peltier module for producing effective heating and cooling placed inside an aluminium cabinet. The device is powered by PV cells which are a non-conventional energy resource. The formulated model

shows that the life span of thermoelectric heater cum refrigeration system is more than twice the life span of existing conventional refrigeration or heater system. The Solar powered thermoelectric heater cum refrigeration system will be a large aspect in terms of energy saving capacity and the fact that the system is eco-friendly [14]. They studied the design and developed a working thermoelectric refrigerator interior cooling volume of 5L that utilizes the Peltier effect to refrigerate and maintain a selected temperature from 5 °C to 25 °C. They designed this system to cool this volume to temperature within a period of 6 hrs and provide retention of at least next half an hour. With the help of design module, the achieved retention time was 52 min. The retention time can be increased by using additional heater on heat sink up to 57. [15]. They studied the theoretical determination of a thermoelectric module and heat sinks sizing and it was discovered that for a cooling time of 2 min and a beverage size of 474 mL (16 oz), 6 TEC modules and hence 12 heat sinks (one for each side of the TEC module) were needed. However, by increasing cooling time to 4 min and decreasing beverage size to 325 mL, 4 TEC modules and hence 8 heat sinks could be used [16-19]

3. Methodology

3.1 Thermoelectric Cooling

It uses the Peltier effect to create a heat flux between the junctions of two materials. It is a solid-state heat pump which transfers heat from one side of the device to the other against the temperature gradient (from cold to hot), with consumption of electrical energy depending on the direction of current. Such an instrument is called a Peltier device, Peltier heat pump, solid state refrigerator or thermoelectric cooler (TEC).

3.2 Peltier Cooler

A thermoelectric (TE) module, also called a thermoelectric cooler or Peltier cooler, is a semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power to a TE module, heat will be moved through the module from one side to the other. One module face, therefore, will be cooled while the opposite face is simultaneously heated. It is important to note that this phenomenon may be reversed whereby a change in the polarity (plus and minus) of the applied DC voltage will cause heat to be moved in the opposite direction. Consequently, a thermoelectric module may be used for both heating and cooling thereby making it highly suitable for precise temperature control applications. A thermoelectric module can also be used for power generation. In this mode, a temperature differential applied across the module will generate a current.

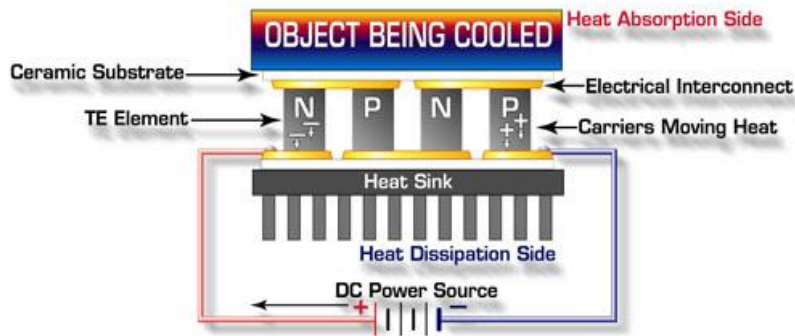


Fig.1: Typical thermoelectric module assembly

N-type material is doped so that it will have an excess of electrons (more electrons than needed to complete a perfect molecular lattice structure) and P-type material is doped so that it will have a deficiency of electrons (fewer electrons than are necessary to complete a perfect lattice structure). The extra electrons in the N material and the "holes" resulting from the deficiency of electrons in the P material are the carriers which move the heat energy through the thermoelectric material. Most thermoelectric cooling modules are fabricated with an equal number of N-type and P-type elements where one N and P element pair form a thermoelectric "couple." For example, the module illustrated above has two pairs of N and P elements and is termed a "two-couple module".

3.3 Heat Pipe

The main regions of the standard heat pipe are shown in Fig. In the longitudinal direction (see Fig. 1.9 a), the heat pipe is made up of an evaporator section and a condenser section. Should external geometrical requirements make this necessary; a further, adiabatic, section can be included to separate the evaporator and condenser. The cross-section of the heat pipe, Fig. 1.9 b, consists of the container wall, the wick structure, and the vapour space. The performance of a heat pipe is often expressed in terms of 'equivalent thermal conductivity'. A tubular heat pipe of the type illustrated in Fig. 1.9, using water as the working fluid and operated at 150 °C would have a thermal conductivity several hundred times that of copper. The power handling capability of a heat pipe can be very high – pipes using lithium as the working fluid at a temperature of 1500 °C will carry an axial flux of 10–20 kW/cm². By suitable choice of working fluid and container materials, it is possible to construct heat pipes for use at temperatures ranging from 4K to more than 2300 K. For many applications, the cylindrical geometry heat pipe is suitable but other geometries can be adopted to meet special requirements. The high thermal conductance of the heat pipe has already been mentioned; this is not the sole characteristic of the heat pipe.

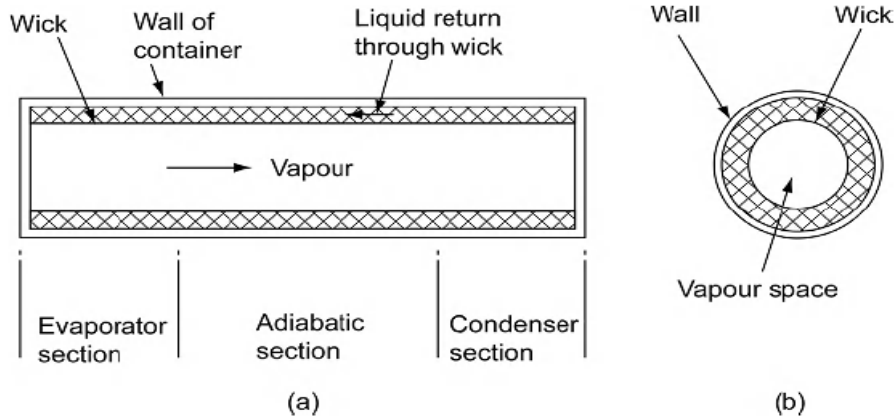


Fig. 2: The main regions of heat pipe

The heat pipe is characterized by (i) Very high effective thermal conductance (ii) The ability to act as a thermal flux transformer and (iii) An isothermal surface of low thermal impedance. The condenser surface of a heat pipe will tend to operate at uniform temperature. If a local heat load is applied, more vapour will condense at this point, tending to maintain the temperature at the original level.

4. Experimentation

It consists of two heat pipes of 275mm length and 12mm diameter. One end of heat pipe is buried under the soil chamber in water is percolated to have an effect like that under the ground at a depth of 2 to 3m. The other end of heat pipe with is in air flow stream created by a single-phase fixed speed motorized blower of 6 watt having maximum speed of 2350 rpm and maximum flow rate of 0.08 m³/s. The refrigeration unit is charge with refrigerant R-134a. The heat pipe is provided with radial fins made up of aluminium. It also consists of Peltier cooler SP-262-1.0-2.5 (Series) of 144 watts. Spiral fins over a cylinder are provided to increase the heat transfer area. The capacity of air conditioner is of 0.75 TR.

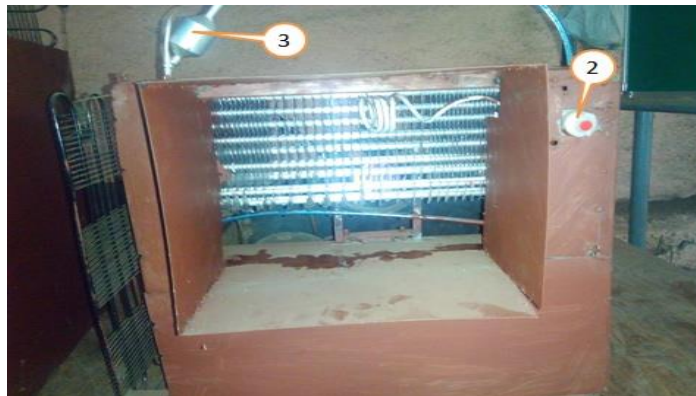


Fig.3: Test rig of hybrid AC using VCC with peltier module and earth heat Exchanger

The above figure 5.1 shows test rig of hybrid AC using VCC with Peltier module and earth heat Exchanger with following components. 1-Compressor, 2-Thermostat, 3-Accumlator, 4-

Evaporator coils, 5-Heat pipe, 6-Radial fins, 7-Peltier cooler with a cylinder and spiral fins, 8-Air blower, 9-Soil chamber, 10-body.

4.1 Measuring Instruments

a) Anemometer (Fan Type)

An anemometer is a device used for measuring wind speed, and is used to describe any air speed measurement instrument used in meteorology or aerodynamics. Fig. 4 is the picture of anemometer. Anemometer is used to measure the velocity of air. Details of instrument are, Range: 0.4 to 100 m/s, Resolution: 0.01 m/s, Accuracy: 3% \pm 0.2 m/s



Fig. 4. Velocity measurement using anemometer

b) Digital Thermometer:

Digital Thermometer is used to measure temperature of air at the inlet and outlet of test section. Technical Parameters: Temperature range: -50°C to $+70^{\circ}\text{C}$, Uses Temperature: -10°C to $+50^{\circ}\text{C}$, Accuracy: $\pm 10^{\circ}\text{C}$, Power Button Battery (DC 1.5V), Distinguish rate: 0.1°C , Switch between $^{\circ}\text{C}$ and $^{\circ}\text{F}$,

c) **Digital Voltmeter and Ammeter:** Digital volt meter and digital ammeter are used to measure voltage and current supply to the compressor of a window air conditioning system respectively as shown in fig.5.



Fig.5. Digital Voltmeter and Ammeter

4.2 Test and trial on COP improvement

Test and Trial on hybrid air conditioner determine temperature gradient and COP of system, under given modes. (1) Mode-I: Vapor Compression Air Conditioning unit and derive performance characteristics. (2) Mode-II: Vapor Compression Air Conditioning unit with peltier module unit and derive performance characteristics. (3) Mode-III: Vapor Compression Air Conditioning unit with heat pipe unit and derive performance characteristics. (4) Mode-IV: Vapor Compression Air Conditioning unit with Peltier module, heat pipe and derive performance characteristics. The initial (ambient) air, final Air (air over evaporator coil) temperature is measured by Digital Thermometer after the time interval of three minutes. The discharge of blower is regulated so that mass of air per second is kept constant to a value of 10.4 kg/s.

4.2.1 Experiment No-1:

Mode I: Test and trial on conventional VC-model without condenser enhancement without Peltier module. Take temperature readings after every 3 min

Table 1: Observations of Mode I

SN	time (min)	mass of air (kg/s)	Initial temp T1(°c)	final temp T2(°c)	Δt (°c)	compressor power (w)
1	3	10.4	31	30	1	98
2	6	10.4	30	26	4	96
3	9	10.4	31	23	8	95
4	12	10.4	31	19	12	94
5	15	10.4	31	16	15	94

Table 2: Results of Mode I

SN	Δt (°c)	Net input power(kw)	$M cp \delta t$ (kw)	COP
01	1	17.64	10.4675	0.593396
02	4	34.56	41.87	1.211516
03	8	51.3	83.74	1.632359
04	12	67.68	125.61	1.85594
05	15	84.6	157.0125	1.85594

4.3 Sample Calculation

- 1) The coefficient of performance: The coefficient of performance of Air-Conditioning system is given by,
- $$COP = \frac{Q_r(\text{KW Refrigeration effect})}{Q_i(\text{KW input power})}$$

Where,

$$Q_r = m \times cp \times \Delta T$$

$$Q_i = \frac{\text{compressor power} \times \text{time} \times 60}{1000}$$

- I) The Coefficient of Performance at 15 min. for VCC module is given by,

$$COP = \frac{10.4 \times 1.004 \times 15}{94 \times 15 \times 0.06} = 1.85$$

- II) The Coefficient of Performance at 15 min. for VCC with Peltier module is given by,

$$COP = \frac{10.4 \times 1.004 \times 18}{88 \times 15 \times 0.06} = 2.37$$

The coefficient of Performance at 15 min. for VCC with Earth Heat Exchanger is given by,

$$COP = \frac{10.4 \times 1.004 \times 16}{89 \times 16 \times 0.06} = 2.32$$

- I) The coefficient of Performance at 15 min. for VCC with Earth Heat Exchanger and peltier module is given by,

$$COP = \frac{10.4 \times 1.004 \times 20}{81 \times 15 \times 0.06} = 2.86$$

5. RESULT AND DISSCUSSION

The first mode of operation in which air conditioner is operated only is considered as the base case. The performances of other modes are compared with the base case, which is purely a active cooling system without enhancement. (Since in first case it is not coupled with heat pipe or Peltier cooler)

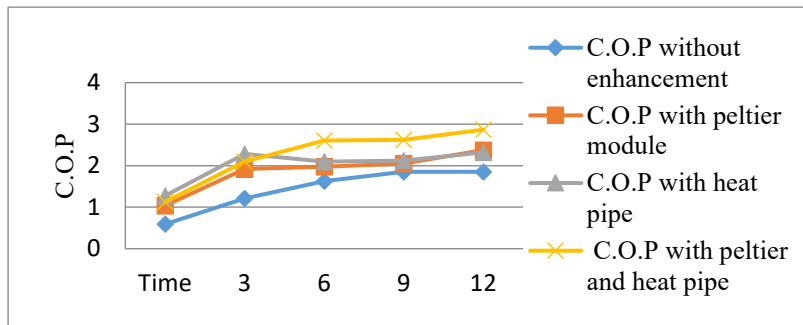


Fig.6: C.O.P Vs Time (min)

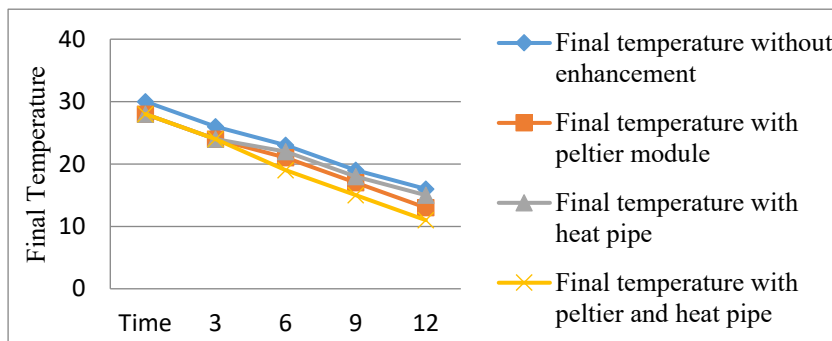


Fig.7: Final temperature Vs Time (min)

From fig 6 temperature reduction is maximum with mode-IV. When compared with the base case i.e. Mode-I, values of maximum temperature percentage reductions are 18.75, 6.25 and 31.25 for Mode-II, III, and IV respectively. The maximum energy saving is also one of the important parameters that should also be considered. The maximum energy saving is observed to be 14.89% with mode-III since heat pipe is a passive cooling enhancement. The values with mode-IV and II are 13.83% and 6.38% when compared with the base case respectively.

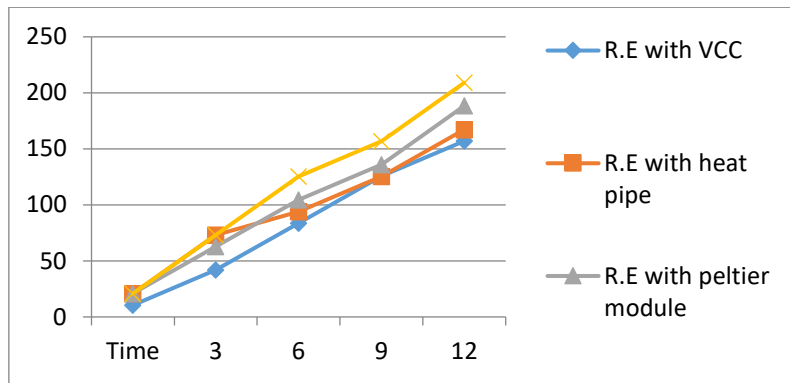


Fig.8: Refrigerating Effect Vs Time (min)

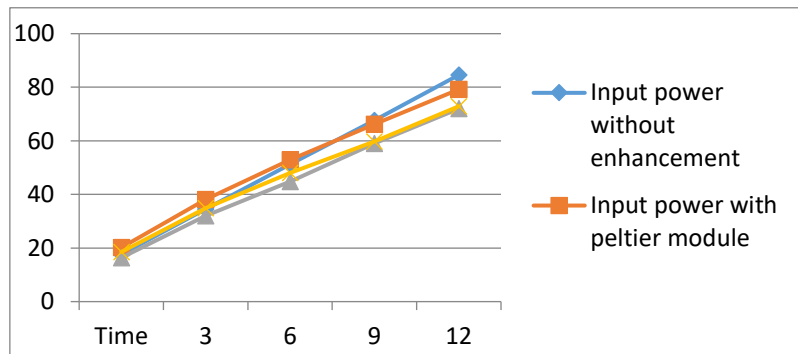


Fig. 9: Input Power Vs Time (min)

COP of mode-IV (VCC+PM+HP) is maximum and thus most effective of the three combinations hence it is recommended that all three combinations of the hybrid system be used for best results. Fig 5 represents Comparison of the COP of different mode with time. Comparison of the COP of mode-II (VCC+PM) & III (VCC+HP) represents that mode-II (VCC +PM) show better COP as compared to the mode-III (VCC+HP) 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. Comparison of the COP of mode-II (VCC+PM) & III (VCC+HP) shows that mode-III (VCC+HP) shows better COP as compared to the mode-II (VCC+PM) over short duty cycle i.e., from 0 to 12min, hence will be recommended if the temperature cycling is to done over a range below 12minutes time. The maximum COP of module-I, II, III, IV are 1.8531, 2.3745, 2.3227, 2.8675 respectively

6. CONCLUSIONS

1. The maximum COP with mode-IV will rise to 2.8675 which is better as compared to the base case which is 1.8531.

2. The Maximum percentage temperature reduction with mode-IV is 31.25% compared to the base case with total energy saving slightly (negligibly) less than mode-III
3. The maximum energy saving is observed to be 14.89% with mode-III since heat pipe is a passive cooling enhancement

REFERENCES

1. US20060150657A1, US, Jan.10, 2005, Thermoelectric enhanced HVAC system and method
2. J.W. Wan et al, The effect of heat-pipe air-handling coil on energy consumption in central air-conditioning system, *Journal of Energy and Buildings*, 2007, 39, 1035–1040
3. Yat H. Yau, Application of a heat pipe heat exchanger to dehumidification enhancement in a HVAC system for tropical climates—a baseline performance characteristics study, *International Journal of Thermal Sciences*, 2007, 46, 164–171
4. Yat H. Yau, Experimental thermal performance study of an inclined heat pipe heat exchanger operating in high humid tropical HVAC systems, *International Journal of Refrigeration*, 2007, 30, 1143–1152
5. A.M. Alklaibi, Evaluating the possible configurations of incorporating the loop heat pipe into the air-conditioning systems, *International Journal of Refrigeration*, 2008, 31, 807-815
6. US7779639B2, HVAC System for hybrid vehicles using thermoelectric devices, 2010
7. Hassan Bouhess, Dynamic simulation of an earth-to-air heat exchanger connected to a villa type house in Marrakech, 13th Int. Conference of the Int. Building Performance Simulation Association, 2013
8. Mohammed Awwad Ali Al-Dabbas, Achievement of geothermal energy using ground heat exchanger, *Journal of Mechanical Science and Technology*, 2011, 25 (8), 2014-2023
9. Mostafa A. Abd El-Baky and Mousa M. Mohamed, Heat pipe heat exchanger for heat recovery in air conditioning, *Applied Thermal Engineering*, 2007, 27, 795–801
10. M. Ahmadzadehtalatapeh and Y. H. Yau, The application of heat pipe heat exchangers to improve the air quality and reduce the energy consumption of the air conditioning system in a hospital ward—A full year model simulation, *Energy and Buildings*, 2011, 43, 2344–2355
11. Ashok Kumar Yadav, Solar air-conditioning: design for a compressor-less system using Peltier effect, *International Journal of Advance Research, and Innovation*, 2014, 2(2), 429-432
12. Surith Nivas M., Photovoltaic driven dual purpose thermoelectric refrigerator for rural India, *International Journal of Advancements in Research and Technology*, 2013, 2(6), 111-117
13. Mayank Awasthi, K. V. Mali, Design and development of thermoelectric refrigerator, *Int. J. Mech. Eng and Rob*, 2012, 1(3), 389–399
14. A. A. Adeyanju and W. Compton, Theoretical determination of thermoelectric module and heat sink sizing,” *International journal of electrical and Power Engineering*, 2010, 4(2), pp.66-72
15. V. W. Bhatkar, Anirban Sur, An experimental analysis of liquid air jet pump, *Frontiers in Heat and Mass Transfer*, Vol. 17 (12) pp.1-5, 2021. <https://doi: 10.5098/hmt.17.12>
16. V. W Bhatkar, A. Sur, R. Kumar, Study of refrigeration system with minichannel condenser using R1234ze, R134a, R152a, R600a, R290 and mixture of R290/R600a (50/50), *Proceedings of the Institution of Mechanical Engineers*, Vol. 239 (2) 616-626, 2025.

<https://doi:10.1177/09544089231193923>

17. Bhatkar, Vijay W., Shastri, Dhires S., Kaithari, Dinesh K., Bhambare, Parimal S., Allampallewar, Girish L., Meherkar, Amar A., Heat transfer analysis of stratified chilled water storage tank for district cooling systems, International Journal of Heat and Technology, Vol. 43 (1) pp. 39-46. [https://doi: 10.18280/ijht.430105](https://doi:10.18280/ijht.430105)
18. Vishvas S Choure, Mahesh R Jagdale, Vijay W. Bhatkar, Heat transfer enhancement using perforated pin fins, International journal for technological research in engineering, Vol. 3, No. 2, pp. 2347-4718, 2015.
19. M. J. Indhe, Vijay W. Bhatkar, Optimization of longitudinal fin profile for double pipe heat exchanger, International Research Journal of Engineering and Technology, Vol. 2 (4) 517-529, 2015.