Design and Development of a Two-Stage Thermo-Electric Cooling Systems(TEC's)

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INTRODUCTION

- **Project Background:**
- The world has seen a lot of Technical revolution in the field of science and technology in the past decade. The field of Refrigeration and Air conditioning has lead to the development of better cooling systems, adding to the comfort level of the customer.
- The Cooling systems have been performing well for the past years, but with the passage of time the customer demanded a better cooling systems in terms of maintenance, mobility, environmental effects. Also the economical factor must be feasible to the customer. This has lead to the birth of the Novel cooling systems which are economical and ecofriendly. We Intend to present a similar new cooling technology in form Thermoelectric cooling Systems.

- **Project Objective:**
- The objective of this project is to design a cooling system which is much better than the conventional cooling systems.We intend to design a cooling system which has:

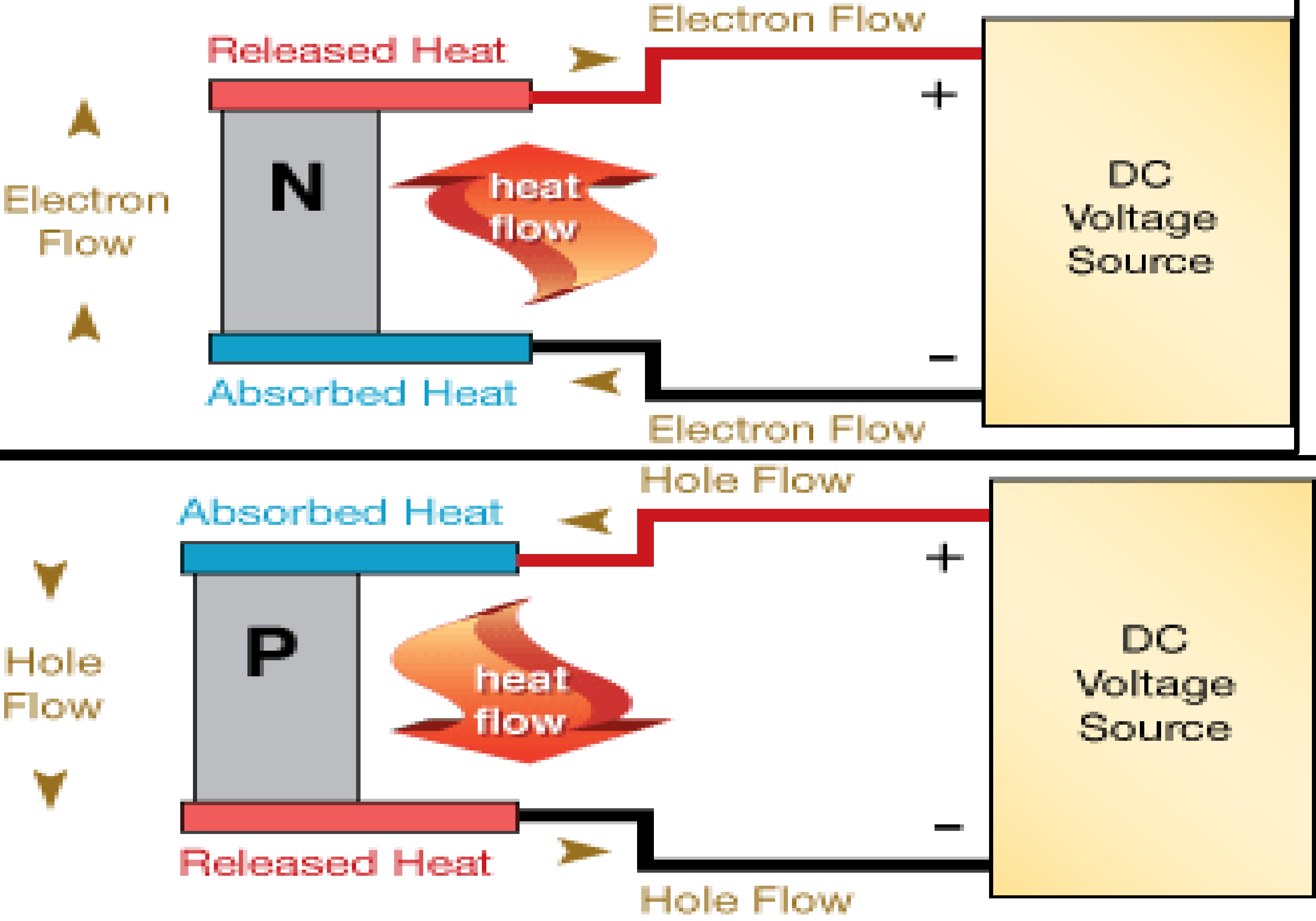
  1) More economical than the conventional systems in the long run.

  2) Low maintenance and running cost in comparision with the conventional power consuming components.

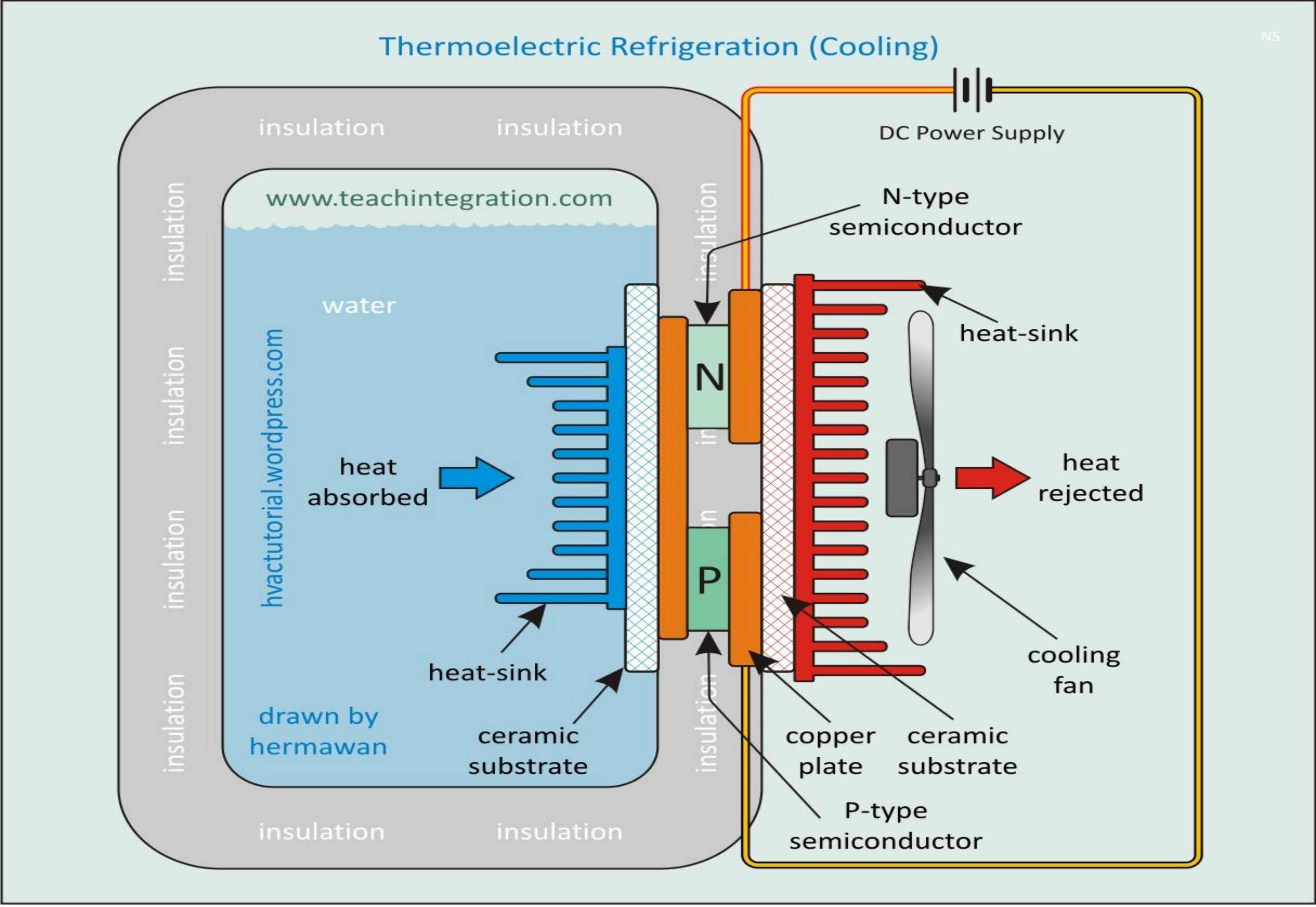
  3) No use of harmful refrigerants ,therby reducing the toxicity of the system
- **Project Scope:**
- Different from conventional cooling systems, thermoelectric cooling , based on the Peltier effect, does not require any compressor, expansion valves, condensers or solution pumps. Moreover, it does not require refrigerants or any moving parts, which is harmful to the environment and hence results in an increase in reliability. It simply uses electrons rather than cooling as a heat carrier. Nowadays, thermoelectric cooling devices have a distinct place in medical applications, electronic applications, scientific apparatus and other applications, where a high-precision temperature-control is required. We demonstrate a Novel, Refrigeration cum Heater utilizing 4 Thermoelectric (Te) modules mounted around a cabinet. The Performance of this model is Evaluated experimentally with an closed Aluminium cabinet.

Principle of Operation

- Thermoelectric coolers operate by the Peltier effect (which also goes by the more general name thermoelectric effect). The device has two sides, and when DC current flows through the device, it brings heat from one side to the other, so that one side gets cooler while the other gets hotter.
- The "hot" side is attached to a heat sink so that it remains at ambient temperature, while the cool side goes below room temperature.
- A thermoelectric cooling system typically employs a matrix of semiconductor pellets sandwiched in between two large electrodes.
- When a DC voltage source is connected between the electrodes, the negatively-charged side becomes cooler while the positively-charged side becomes warmer.
- Thermoelectric cooling is used in electronic systems and computers to cool sensitive components such as power amplifiers and microprocessors.

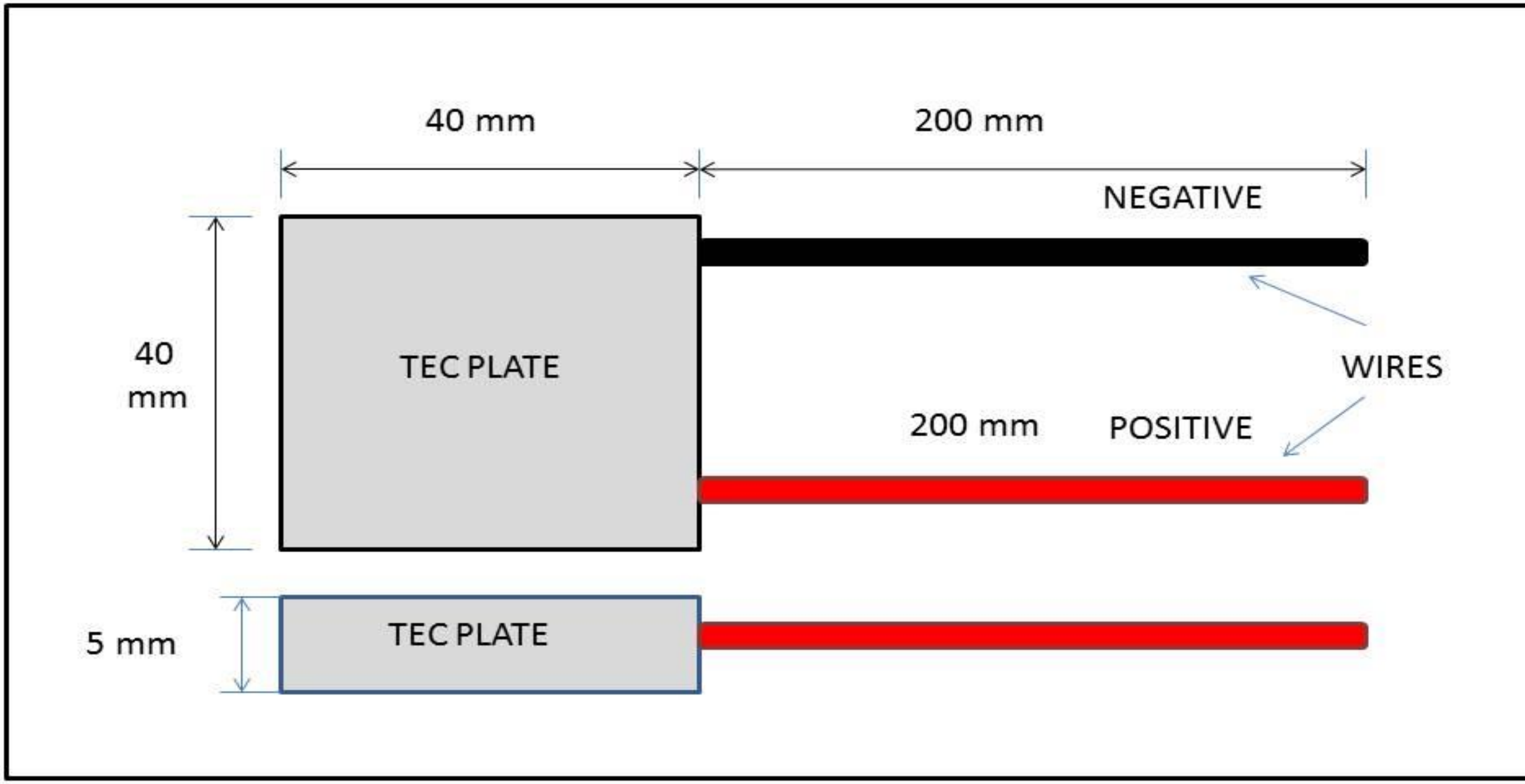


Electron Flow
Released Heat
Electron Flow
N
heat flow
+
DC Voltage Source
−
Absorbed Heat
Electron Flow
Hole Flow
Absorbed Heat
Hole Flow
P
heat flow
+
DC Voltage Source
−
Released Heat
Hole Flow


Thermoelectric Refrigeration (Cooling)
NS
insulation
insulation
DC Power Supply
www.teachintegration.com
N-type semiconductor
water
heat-sink
hvactutorial.wordpress.com
N
heat absorbed
heat rejected
P
heat-sink
cooling fan
drawn by hermawan
ceramic substrate
copper plate
ceramic substrate
P-type semiconductor
insulation
insulation

Thermo-Electric Module

- Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to carrier current passing through the circuit and the number of couple.
- The semiconductor materials are N and P type, and are so named because either they have more electrons than necessary to complete a perfect molecular lattice structure (N-type) or not enough electrons to complete a lattice structure (P-type).
- The extra electrons in the N-type material and the holes left in the P-type material are called "carriers" and they are the agents that move the heat energy from the cold to the hot junction. Good thermoelectric semiconductor materials such as bismuth telluride greatly impede conventional heat conduction from hot to cold areas, yet provide an easy flow for the carriers. In addition, these materials have carriers with a capacity for transferring more heat.
- The most commonly used semiconductor for electronics cooling applications is Bi_2Te_3 because of its relatively high figure of merit. However, the performance of this material is still relatively low and alternate materials are being investigated with possibly better performance.


40 mm
200 mm
NEGATIVE
40
mm
TEC PLATE
WIRES
200 mm
POSITIVE
5 mm
TEC PLATE

The Selection of Thermoelectric materials is done based on **Figure Of Merit(FOM)**. It has units of the reciprocal of temperature and is a function of the materials of the system only

For the Figure of Merit to be large, the couple must have:

- A large Thermoelectric Power
- Small Thermal Conductance
- Small Electrical resistance

The FOM for different materials is given by:

Positive Thermo-element		Negative thermo-element	
Material	**FOM**	**Material**	**FOM**
Pb-Te	1.2×10^{-3}	Pb-Te	1.5×10^{-3}
Pb-Se	1.2×10^{-3}	Bi_2-Te_3	2.2×10^{-3}
Sb_2-Te_3	1.2×10^{-3}	Bi_2(Se-Te)$_3$	3.0×10^{-3}
Bi_2-$Te_{3Vapour}$	1.8×10^{-3}		
$(BiSb)_2$-Te_3	3.3×10^{-3}		

METHODOLOGY

- The Work plan of our project is depicted as shown in the figure.

MONTH / WORK	JUlY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARAY	MARCH
INTRODUCTION									
LITERARTURE SURVEY									
DESIGN OF COMPONENTS									
PROTOTYPE BUILDING AND TESTING									
REPORT MAKING									

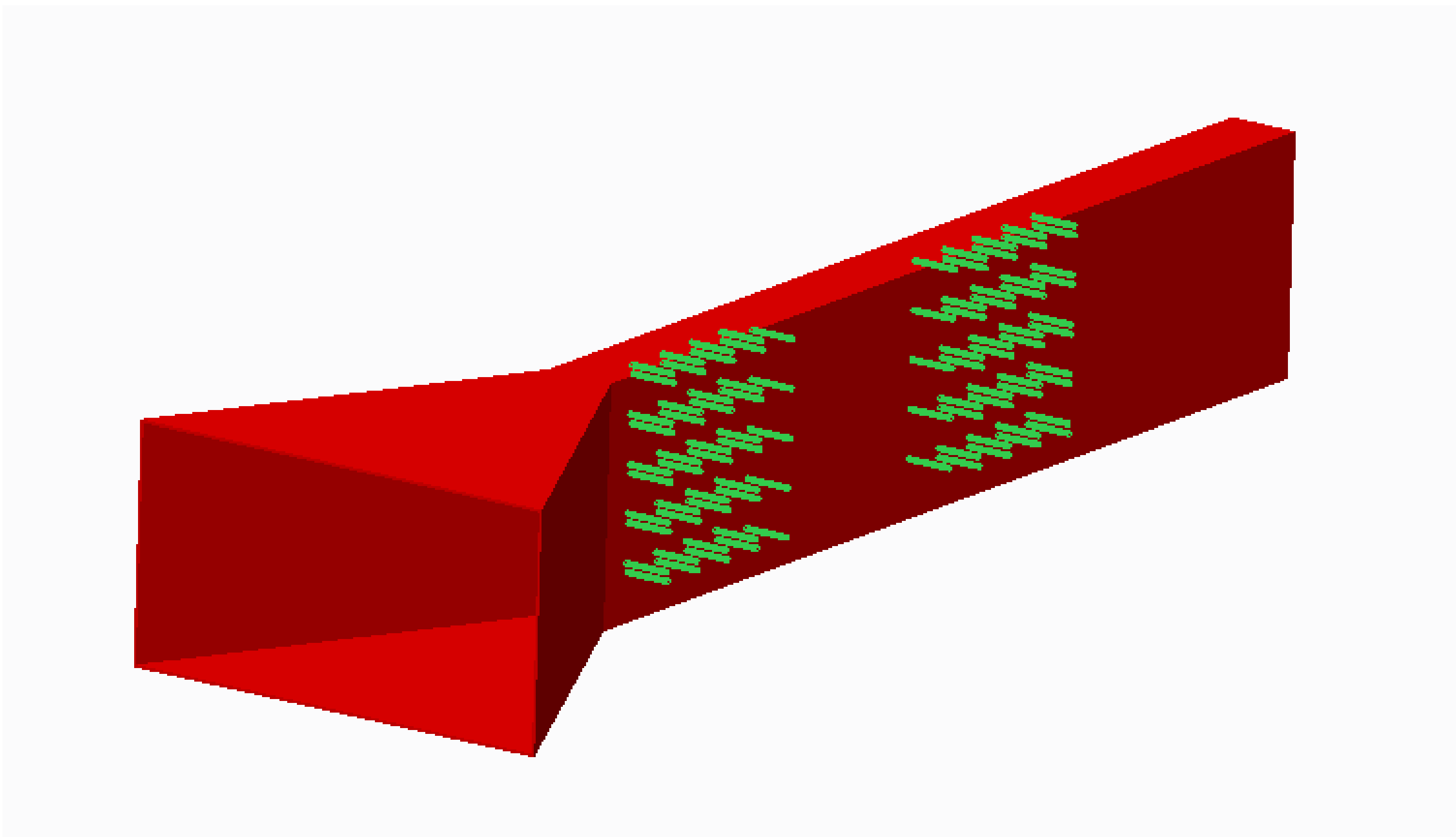
DESIGN OF COMPONENTS

- **Thermoelectric Module:**
- It is available in the market with standard size of 40×40×5mm . It has rated voltage of 12V and 1A supply.
- We intend to use 4 thermoelectric plates of the above specifications.
- **Conducting Duct:**
- The conducting plate has the following dimensions:23×1.5×5cm .The thermoelectric plate will be fixed at a distance of 2cm from each other.
- **Heat sinks and exhaust fan for thermoelectric plates**
- The heat sinks are made from aluminium and the exhaust fans are conventional computer cooling fans with a rated 12 V supply. The Diameter of exhaust fan for thermoelectric fan is 9.5cm.
- **Cooling pad:**
- The cooling pad is a normal Jute based cooling with Cotton Plugs sandwiched between them is used in evaporative coolers.

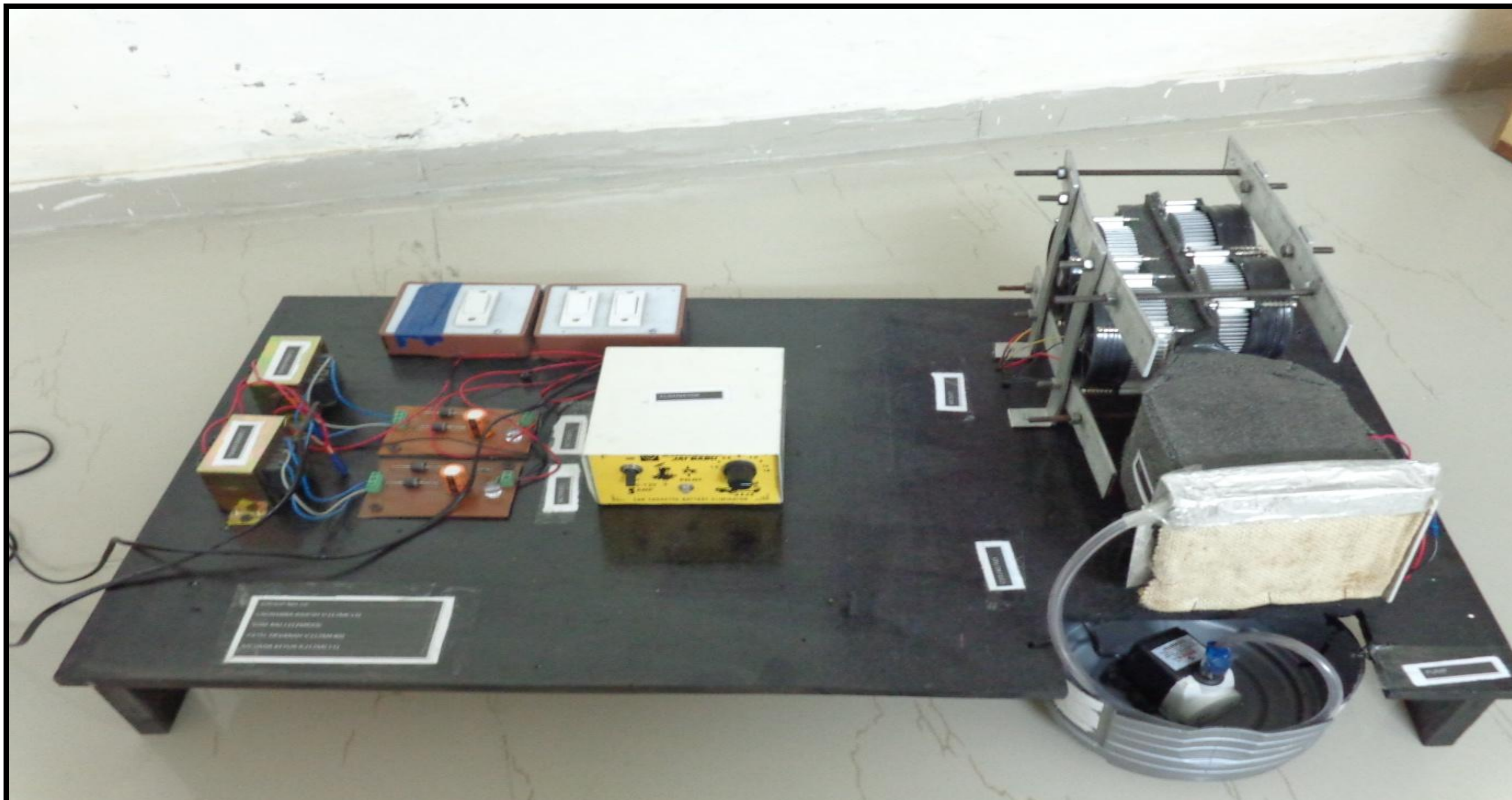
- **Insulation:**
- The area besides the thermoelectric plates would also be sealed using a suitable insulator. The material used for Insulation is Nitrile Foam commonly used as a insulator on copper pipes in AC.
- **Holding Fixtures:**
- The Duct and Thermoelectric Plate are holded together with bolts and nuts which provide proper contacting force.
- **Design of Duct:**
- The duct is designed to facilitate the passage of air through and produce the cooling effect.

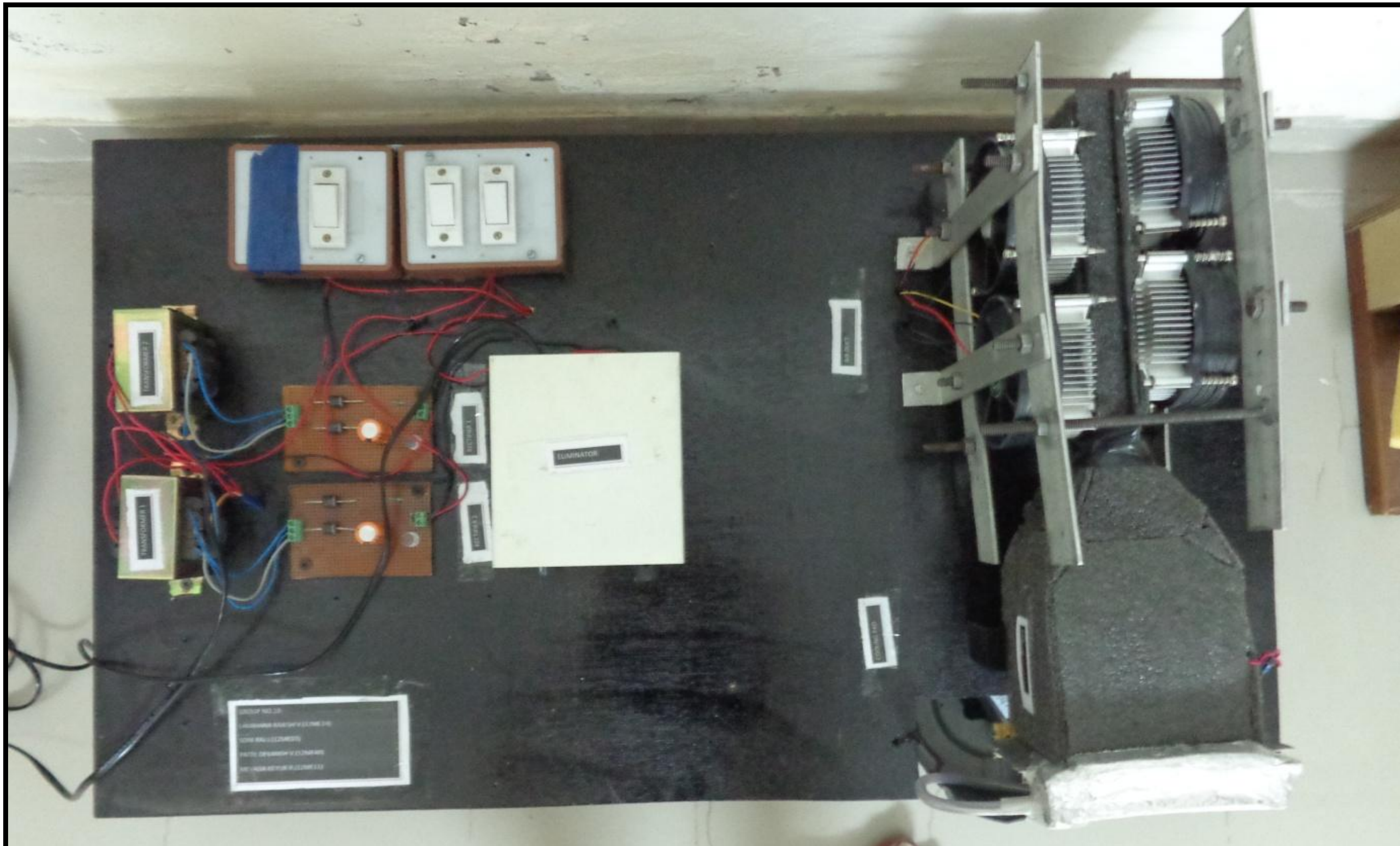
Specification	Details
Length of the duct	230mm
Width of Duct	15mm
Height of Duct	50mm
No. of Fins	80
Diameter of Fins	1mm
Length of fins	10mm
Structure of fins	Cylindrical
Material of plate	Copper
Material of fins	Copper
Thickness of duct wall	0.6mm
Spacing between each fin	10mm
No. Of Fins per Thermoelectric plate	20

CREO Model



EXPERIMENTAL SETUP





APPLICATIONS,ADVANTAGES AND LIMITATIONS

- Avionics
- Calorimeters
- CCD (Charged Couple Devices)
- Cold Chambers
- Compact Heat Exchangers
- Electronics Package Cooling
- Immersion Coolers
- Integrated Circuit Cooling
- Infrared Detectors
- Infrared Seeking Missiles
- Laser Collimators
- Laser Diode Coolers
- Long Lasting Cooling Devices
- Low Noise Amplifiers
- Microprocessor Cooling

← APPLICATIONS

ADVANTAGES:

- No moving parts so maintenance is required less frequently
- No chlorofluorocarbons
- Temperature control to within fractions of a degree can be maintained
- Flexible shape (form factor); in particular, they can have a very small size
- Can be used in environments that are smaller or more severe than conventional refrigeration
- Has a long life, with mean time between failures (MTBF) exceeding 100,000 hours
- Is controllable via changing the input voltage/current

LIMTATIONS:

- Only a limited amount of heat flux is able to be dissipated
- Relegated to applications with low heat flux.
- Not as efficient, in terms of coefficient of performance, as vapor-compression systems.

<u>THEORETICAL ANALYSIS</u>

- **<u>Heat Transfer Coefficient for Cylindrical fins</u>**

L=0.254 m

D=1mm

$Nu=(hD)/k=C(Re_L)^n (Pr)^{0.33}$

$t_{mb=}26.5°C=299.5K$

$\mu = 18.482\times10^{-6}$ Kg/m s

$\rho=1.17833$ Kg/m^3

Pr=0.71235

- **Re= (ρ*v*L)/ μ**

$=(1.17833*12.56*0.254)/18.482\times10^{-6}$

=203395

$Nu=0.027(Re_L)^{0.805}(Pr)^{0.33}$

For Re=203395.49,c=0.027,n=0.805

Nu=(h*L)/k=452.35

=452.35

h=46.519 W/m^2 °C

- **6.4 Mass Flow rate:**

Velocity of air through the duct= **0.8 m/s**

Area of duct: **0.05*0.015=0.00075m^2**

Hence Volume flow rate or discharge through the duct

=Q=A*v= (0.00075*0.8)=**0.0006m^3/s=2.16m^3/hr**

- This is the volume flow rate of the air coming out of the duct. This volume flow rate is multiplied with the density of air to get mass flow rate through the duct.

- **6.5 Area of Duct:**
- Cross Sectional Dimensions of the duct: **50mm×15mm**

  Hence c/s area of duct=**750mm^2**

MATHEMATICAL MODELING

- **Calculation of Dry Bulb Temperature and Wet Bulb Temperature for:**
- **(a) Without Humidifier:**
- At Inlet:

Dry Bulb Temperature	**33^{o}C**
Wet Bulb Temperature	22^{o}C

- At outlet:

Time (min)	Dry Bulb(^{o}C)	Wet Bulb(^{o}C)
0 minutes	33	22
1 minutes	30	22
2 minutes	28.5	21.5
3 minutes	28	21.5
4 minutes	27.7	21
5 minutes	27.5	20.5
6 minutes	27	20
7 minutes	27	19
8 minutes	27	19
9 minutes	27	19
10 minutes	27	19

- **(a) With Humidifier:**
- Inlet Conditions :

Dry Bulb Temperature	**35°C**
Wet Bulb Temperature	21.5°C

- Outlet Conditions:

Time (min)	Dry Bulb(°C)	Wet Bulb(°C)
0 minutes	35	21.5
1 minutes	32	21.5
2 minutes	31	20
3 minutes	30	19.5
4 minutes	28	19.2
5 minutes	27	19
6 minutes	26.5	19
7 minutes	25.5	19
8 minutes	25	19
9 minutes	25	19
10 minutes	25	19

Calculations without humidifier

- **(a) Without Humidifier:**
- Inlet: **DBT:33^{O}C**
  Outlet:**DBT:27^{O}C**
- **WBT:22^{O}C**
  WBT:19^{O}C
- From Psychrometric Chart
- **h_1=64.7 kJ/kg**
  h_2=53.5 kJ/kg
-
- **$\Delta h = h_1 - h_2$**
  =11.2 kJ/kg
- **υ= 0.865 m^3/kg, hence ρ_a=(1/ υ)**
  =1.1560 kg/ m^3
- **m_a= $\rho_a \times Q$ =1.1560×0.0006**
  =6.936 ×10^{-4} kg/s
- **$\Delta q = m_a\ \Delta h$= 6.936 ×10^{-4}×11.2×1000**
  =8.46192 J/s
  =8.46192 W

- **υ= 0.865 m^3/kg, hence ρ_a=(1/ υ)**
  =1.1560 kg/ m^3

- **m_a= ρ_a×Q =1.1560×0.0006**
  =6.936 ×10^{-4} kg/s

- **Δq=m_a Δh= 6.936 ×10^{-4}×11.2×1000**
  =8.46192 J/s
  =8.46192 W

- **W=(Watt rating of plates+ Watt rating of fans)**
  =((12×1)*4 +1.8)

Finally COP is given by

- **COP=(Heat Transfer/energy input)**
  =(Δq/49.8)
  =(8.46192 /49.8)
  =0.1699

Calculations with Humidifier

- Inlet: **DBT:35^{O}C**
  Outlet:**DBT:25^{O}C**
  WBT:21.5^{O}C
  WBT:19^{O}C

- From Psychrometric Chart

- **h_1=64.7 kJ/kg**
  h_2=51kJ/kg

- **Δh = h_1-h_2**
  =13.7 kJ/kg

- **υ= 0.865 m^3/kg, hence ρ_a=(1/ υ)**
  =1.1560 kg/ m^3

- **υ= 0.865 m^3/kg, hence ρ_a=(1/ υ)**
  =1.1560 kg/ m^3

- **m_a= ρ_a×Q =1.1560×0.0006**
  =6.936 ×10^{-4} kg/s

- **Δq=m_a Δh= 6.936 ×10^{-4}×13.7×1000**
  =9.50232 J/s
  =9.50232 W
-
- **W=(Watt rating of plates+Watt rating of fans)**
  =((12×1)*4 +1.8)
- **Finally COP is given by**

- **COP=(Heat Transfer/energy input)**
  =(Δq/49.8)
  =(9.50232/49.8)
  =0.2001

CONCLUSION

- Although there are varieties of applications that use thermoelectric devices, all of them are based on the same principle. When designing a thermoelectric application, it is important that all of the relevant electrical and thermal parameters be incorporated into the design process. Once these factors are considered, a suitable thermoelectric device can be selected based on the guidelines presented in this article.
- The System developed by us is an extension and combination of thermoelectric cooling with the direct evaporative cooling. Thermoelectric system if used alone do not offer more COP than 0.12-0.15.So the core idea was to combine the thermoelectric system with the conventional direct evaporative cooling stage so as to improve the COP.
- As described in our work the system was integrated with a humidifier using a jute pad with cotton plugs. The humidifier helped to pre-cool the air before entering to the main duct. The readings were taken both times, i.e. keeping the humidifier off and keeping the humidifier on.

- The calculations were carried out on the basis of Psychrometric properties and the COP was evaluated. Also as it is evident from the reading a temperature drop of 10 degree centigrade was observed when the humidifier was kept on. The COP of the system improved from 0.1699 to 0.2001.
- If we can somehow try to minimize the limitations of the thermoelectric systems, we can develop sustainable and reliable cooling systems for future.
- **FUTURE SCOPE:**
- The polarity of the plates can be reversed to make it a heating systems for cooler regions. This device can work as cooler too if used with reverse polarity.
- The arrangement of fins inside the duct can also enhance the heat transfer rate through the duct. Changing the pattern of arrangement of fins in the duct can have an effect on the heat transfer rate.
- The change in the shape of fins can also ffectthe overall heat transfer rate of the duct.
- Reduction in the gap of the duct i.e: less than 15mm can effectively reduce the bypass factor thereby increasing the contact air with the cooling coil.
- Usage of Larger plate can generate cooling effect for a larger space too.

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THANK YOU