# Design and Fabrication of a Peltier Operated Portable Air Cooling System

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**Abstract –** *Air Conditioning is the science of controlling primarily three parameters of human comfort, temperature, relative humidity and air quality. Air conditioners, dehumidifiers and evaporative coolers serve the purpose however air conditioners are termed expensive and coolers prove ineffective in humid conditions. The study conducted in the work aims at developing a Peltier operated air cooler coupled with a dehumidifier to achieve dual objective of dehumidification and sensible cooling. The work aims to performance testing of Peltier for indoor cooling. The desired design is intended to provide a good alternative to Air Conditioners which consume sufficiently high power with very large initial investment.*

***Key Words***: Peltier, Dehumidification, sensible cooling, relative humidity, human comfort, air conditioning.

## 1. INTRODUCTION

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation. Maintaining this standard of thermal comfort for occupants of buildings or other enclosures is one of the important goals of HVAC (heating, ventilation, and air conditioning) design engineers. Two of the most important parameters that are taken into account while evaluating thermal comfort are rh (Relative Humidity) and ambient temperature. These two parameters are dependent on 'n' number of factors which vary from person to person depending on their metabolism. The best range of rh for human comfort is known to occur from 45-55%. We here consider effects only due to high humidity because of Mumbai being a coastal region and rh values here generally being well above 75 %. The project idea was developed based on the following research work published earlier.

A. S. Alosaimy [1] studied and also did some research work to understand the working of a desiccant based dehumidifier where solar energy was being used to regenerate the calcium chloride desiccant. Use of solar energy for regenerating desiccant was not very cost effective and also the lack of availability of desiccant based dehumidifiers and their high running costs made compressor based dehumidifiers a better alternative.

A.F. Rudd [2] investigated the important parameters that needed to be assessed for achieving thermal comfort. Surrounding temperature and RH were the two most pre-dominant factors that needed to be considered as per the research paper by him based on residential dehumidification. The optimum range of RH for human comfort lies between 50-55% and temperature of 24$^0$C were the derived conclusions from this research paper.

Matthew Carl [3], Upendra Kulshreshtha [4] and his research group analyzed various heat exchangers and studied automobile Heat Exchangers to a great depth. For the selection of appropriate heat exchanger, these references based on automotive Heat Exchangers were used to get a brief idea about working of car Heat Exchangers and also to understand the basic difference between evaporating coils and Heat Exchangers and which one would be more suitable for the required application. An idea about the coolant flow through the heat exchanger and air flow over fins for convective cooling was understood.

Lewis G Harriman III [5], second edition of Dehumidification Handbook, was used to understand the key concepts regarding psychometric chart and also for load calculations based on design conditions. The key fundamentals of psychometrics such as difference between dry bulb temperature and wet bulb temperature, relative humidity based on percentage of saturation, humidity ratio based on grains of water vapour, dew point temperature and enthalpy in Btu's per pound of air were studied. Various types of dehumidifiers and their respective applications in HVAC field are of prime importance. Moisture load calculations due to humans, leakages inside the room, furniture and other things inside the room were studied in detail so as to consider the appropriate dehumidifier for our use.

Umesh V. Sangale [7], Prof. Priyanka Jhavar [7] and Dr.G.R.Seloskar.S [7] made use of thermoelectric modules in a unique way by using solar cell powered Peltier junctions for refrigeration purpose. These authors have used 4 Peltier modules for obtaining a refrigeration of one liter capacity. They have used fans to cool the hot junction of Peltier module and we wish to do the same if required.

Thus the idea was developed to build Peltier cooled water heat exchanger to condition air.

## 2. AIM AND OBJECTIVE

Objective: To provide an alternative for Air Conditioners as they are deemed too expensive for vast majority of people in India.

Aim: Design and fabrication of a Peltier Operated Portable Air Cooling Unit.

## 3. DESIGN LAYOUT, COMPONENT SELECTION AND CALCULATIONS

Air conditioning involves dehumidification and cooling of air. The process starts with dehumidification. Air at ambient conditions enters the dehumidifier where the humidity is extracted and collected in a tank. The air after passing through the dehumidifier is heated up which requires cooling. The heated air then is passed through cross flow heat exchanger. Water is stored in a sump equipped with a thermoelectric module to maintain the coolant temperature. Water is circulated through the heat exchanger where it absorbs heat from the air and flows back into the tank. Thus after rejecting heat to the water air is cooled and passed into the room. The process flow is shown in figure 1.

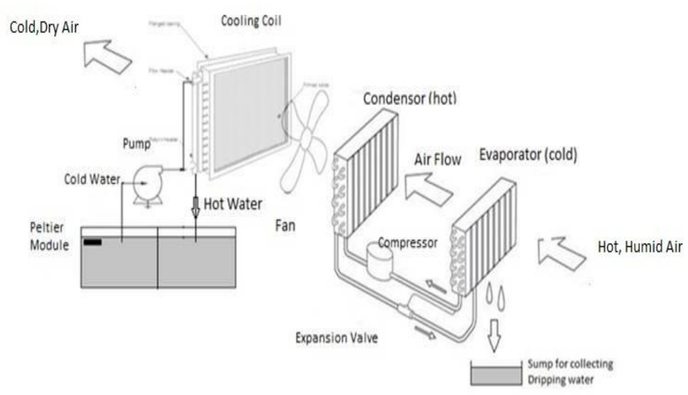


**Fig -1**: Layout of Air Cooling Unit

### 3.1 Components of Air Conditioning Unit

1. Dehumidifier - A dehumidifier is a device that removes moisture from an enclosed space and brings down the relative humidity.
2. Cooling Coils - Cooling coils are used to absorb heat of the dehumidified air.
3. Pumps - Pumps are used to pump the coolant in through the radiator.
4. Peltier Module – Peltier Module is a 12 V DC device used to cool the coolant from its cold side.
5. Heat Sink – Heat sink is used to dissipate the heat from the hot side.
6. SMPS (Switched-mode Power Supply) – It is used to power the Peltier Module and the fans used for heat dissipation on the heat sink.

### 3.2 Design Procedure

The air after dehumidification will enter a water cooled condenser (heat exchanger) where it will cool down to comfort conditions i.e. $24^0$C. The water in this process will take the heat from air and its temperature will rise which needs to be cooled using a Peltier device. The temperature rise of coolant water is calculated as follows:

1. Heat Load Calculations:

Calculation of temperature rise of coolant in single pass

Volume flow rate of air = 95 x 28.32 x 10-3 m3/min
= 2.6904 m3 /min

Mass flow rate of air,
$m_{air}$ = 2.6904 x Density of air
= 2.6904 x 1.128
= 3.03 Kg/min

Specific heat capacity of air,
Cair = 1.005 KJ/Kg

Inlet air temperature = 40 $^0$C
Outlet air temperature = 25 $^0$C

Heat loss by air, Qair = mair x Cair x ΔTair
= 3.03 x 1.005 x 15
= 45.67 KJ/min

Volume flow rate of coolant
= 750 L/hr.
= 12.5 L/min
= 12.5 x 10-3 m3/min

Mass flow rate of coolant,
Mc = 12.5 x 10-3 x Density of coolant
= 12.5 x 10-3 x 1000
= 12.5 Kg/min

Specific heat capacity of air,
Cc = 4.18 KJ/Kg

Heat lost by air = Heat gain by Coolant
mair x Cair x ΔTair = mc x Cc x ΔTC

$$\Delta TC = \frac{3.03\ X\ 1.005\ X\ 15}{12.5\ X\ 4.18}$$

$\Delta TC$ = 0.874 $^0$C

2. Cooling Surface Requirement & Design of Heat Exchanger :

The temperature after the dehumidifier is 1 $^0$C above ambient according to manufacturer's data. The ambient temperature in Mumbai during summer is 35$^0$C according to weather data which will be nearly 40$^0$C after passing through the dehumidifier. The area of heat exchanger required to cool air from 40$^0$C to 25$^0$C is calculated as follows:

For the heat transfer a fin surface of available condenser is as in figure 2.

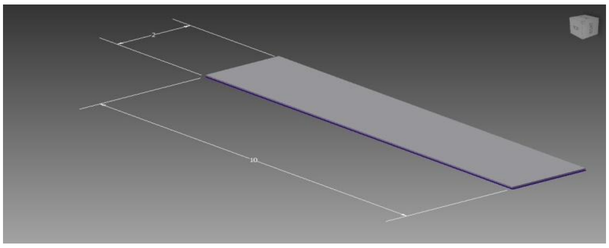

**Fig -2**: Fin surface

Height: 10" (25.4 cm)

Width: 2" (5.08 cm)

The heat transfer co-efficient for laminar flow over a plate is given by:

$$\frac{hL}{k} = 0.664\ X\ \sqrt[2]{\frac{\rho\ V\ L}{\mu}}\ X\ \sqrt[3]{\frac{\mu\ Cp}{k}}$$

For air at 40$^0$ C and for fin surface assuming properties of air are:

L=0.05 m
$\rho$ = 1.127 kg/m3
$\mu$ = 19.12 x 10-6 Ns/m
k = 0.0271 W/mk
v = 16.97 x 10-6 m2/s
Pr = 0.699 = $\frac{\mu\ Cp}{k}$

Substituting in equation,

$$\frac{h\ X\ 0.05}{0.0271} = 0.664\ X\ \sqrt[2]{\frac{1.127\ *\ 1.38\ X\ 0.05}{19.12\ X\ 10^6}}\ X\ 0.699$$

h = 19.68 W/m2K

Substituting this value in the equation,

Outlet temperature of coolant = Inlet temperature + $\Delta TC$

= 20 + 0.874
= 21$^0$C

Calculating LMTD:

$$\text{LMTD} = \frac{X2-X1}{\ln(\frac{X2}{X1})}$$

$$= \frac{(40-21)-(25-20)}{\ln(\frac{40-21}{25-20})}$$

= 10.48 $^0$C

Substituting values in the equations,

Q = h x A x LMTD

$\frac{45.67}{60}$ = 19.68 x A x 10.48

A = 4.05 m$^2$

All the design calculations as shown below in table 1.

**Table - 1:** Design Dimensions

| Sr No. | Summary of design calculations | | |
|---|---|---|---|
| | Components | Dimensions | Quantity |
| 1 | Dehumidifier | L = 14 "<br>W = 7.5 " | 1 |
| 2 | Cooling Coils | L = 11"<br>W = 2" | 1 |
| 3 | Peltier Module | L = 4.2 cm<br>W = 4.2 cm | 1 |
| 4 | Heat Sink | L = 8 cm<br>W = 8 cm | 2 |
| 5 | SMPS | O/P=12,5A | 1 |
| 6 | Water Cooling Block | L = 4.2 cm<br>W = 4.2 cm | 1 |

3. Heat sink and Peltier cooling assembly :

The hot water outlet of condenser is fed into the water cooling block and Peltier assembly as in figure 4 for cooling the water for its recirculation. The heat taken from the water by the Peltier and that generated by the hot junction of the Peltier needs to be rejected. A heat sink and fan assembly is used to take up the rejected heat. Proper heat rejection is important or else the cold junction of Peltier would not reach the required low temperature.
The methods employed to increase the heat rejection are as follows:

1. Increase the size of heat sink.
Increasing the size of heat sink increases the heat rejection area thus allowing the Peltier cold junction to achieve lower temperatures.

2. Forced convection over the heat sink
Removal of heat from the heat sink is equally important which is achieved by heat rejection. A different approach was used in the design to increase the flow rate of air over the heat sink. A diffuser shaped section as in figure 3 was designed and a fan assembly was mounted on the larger opening side and heat sink assembly was placed near the smaller opening.

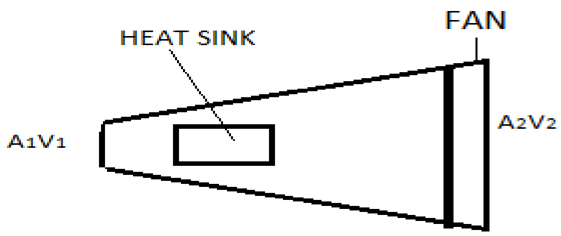


**Fig -3**: Forced convection over heat sink

By continuity equation:

$$A1V1 = A2V2$$

$$\text{Since } A1 < A2$$

$$V1 > V2$$

Thus higher velocity air and thus higher convection rate was thus achieved by change in design. The temperature achieved on water cooling block was 5 $^0$c.

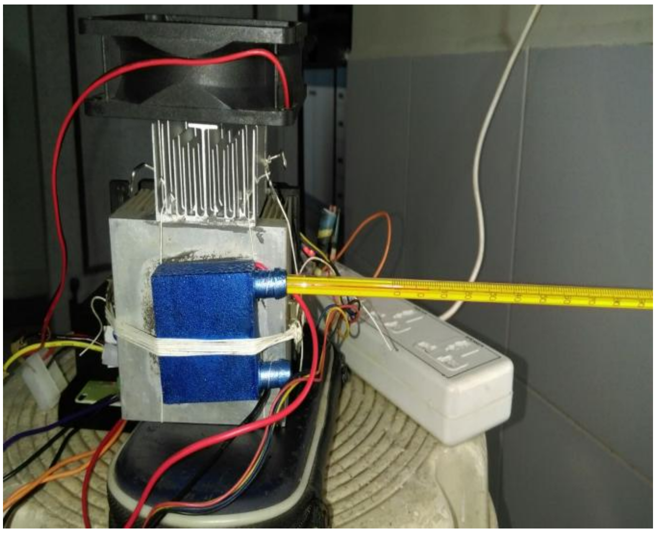

**Fig - 4**: Heat sink and Peltier block assembly

## 4. FABRICATION AND FINAL SETUP

A mobile steel frame supported on castor wheels is fabricated to hold all components in place. The wheel supported frame fulfills the objective of portability. Specification of final setup as shown in fig. 5 is as follows.

**DIMENSIONS:** 38cm X 38cm X 50cm

**WEIGHT** : 20 kg

The entire unit is mounted on a wheel frame for ease of portability.

**Fig -5**: Final fabricated air cooling unit.

## 5. TESTING AND RESULTS

The Air Cooling Unit was tested and the following results were obtained. Table 2 shows the Temperatures of air and water before and during testing. The temperature of air at ambient condition, after the dehumidifier and after the heat exchanger was noted down. Tests were conducted using normal tap water and water from refrigerator. The results obtained were as in Table 2 and Table 3:

**Table - 2:** Effect by using tap water

| Sr.No. | Description | Temperature ($^0$C) |
|---|---|---|
| 1 | Ambient Air Temperature | 25 |
| 2 | Temperature at the outlet of dehumidifier | 32 |
| 3 | Temperature of water in tank before operations | 24 |
| 4 | Temperature of air coming (in the room) out of Heat Exchanger | 26 |

**Table - 3:** Effect by using cold water at 13$^0$C

| Sr.No. | Description | Temperature ($^0$C) |
|---|---|---|
| 1 | Ambient Air Temperature | 36 |
| 2 | Temperature at the outlet of dehumidifier | 40 |
| 3 | Temperature of water in tank before operations | 13 |
| 4 | Temperature of air coming (in the room) out of Heat Exchanger | 25 |

## 3. CONCLUSIONS

1. The air cooling unit gives a cooling of up to 26°C and better results are achieved with use of cold water.
2. The Peltier module proves sufficient in air conditioning for indoor applications as desired in the above study.

## ACKNOWLEDGEMENT

We would like to express our regards to Prof. Nilesh Varkute for guiding us thorough the entire BE final year project. We would also like to thank Dr.T Mathewlal (Head of Department, Fr. C.R.I.T., Vashi, and (Navi-Mumbai)) for giving his valuable time to guide through the project.

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