Wearable Personal Cooling System

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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ABSTRACT

Heat Stroke is a major problem these days. A lot of people from hot temperature environments are suffering from the very decease and many of the lot have died due to the very decease. A device is needed to be developed to protect people for overcoming this disease. The device under study solves the very problem. Human race has been looking for comfort since early ages, and a surrounding temperature of one’s own desire is one of the ultimate kind of comfort that a person looks for. The device protects from heat strokes and provides the desirous temperature for the human body at all times and remotely everywhere.

This is a product based project. The device or the product is a wearable temperature moderating device. The ultimate design is a wrist based prototype which provides enough temperature moderation for a single human being. It is a cost and power efficient alternative of an air conditioner. The main principle of the product is Peltier effect and the principle equipment used in the device is thermoelectric materials based on Peltier effect.

A thermoelectric material consists of a junction of two metals, using the phenomenon of Peltier effect, when electric current is supplied on the junction of the metals, due to the power supplied, one metal becomes colder and the other becomes hotter. In principle, one side of the thermoelectric material becomes colder and the other becomes hotter.

The cold side is put in contact with the human body for the purpose of temperature moderation while the hot side temperature is moderated by heat exchangers and forced convection by fin type heat exchanger and fan respectively. The cold side is put on top of wrist artery, which cools the human skin on top of it while the cold human skin cools the artery and hence the blood flowing into the artery which flows into the whole body and provides a cooling sensation for the whole body hence fulfilling the device’s purpose.

The device thus made used a power of 65 W, which is minimal as compared to that used by the air conditioner. The cooling sensation provides a satisfying effect on the body on a hot day.

ACKNOWLEDGMENTS

We would like to express our special thanks and gratitude to our supervisor Dr. Emad as well as our advisors who are responsible for giving us the golden opportunity to do this innovative project on the topic of wearable personal cooling system which helped us expanding our knowledge in Mechanical Engineering as well as other Engineering fields.

Secondly, we would like to thank our department SMME for offering this project and providing us all the necessary equipment required and gave us the permission to use the labs for fabrication and other tests.

We have put a lot of efforts and research in this project. However, the kind support and help of many individuals and staff of SMME paved the way for the completion of the project. We would like to extend our sincere thanks to all the stakeholders involved.

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Gaziosmanpasa Universitesi Student Paper	%2
2	M. Behnia, D. Copeland, D. Soodphakdee. "A comparison of heat sink geometries for laminar forced convection: Numerical simulation of periodically developed flow", ITherm'98. Sixth Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (Cat. No.98CH36208), 1998 Publication	%1
3	Submitted to CSU, San Jose State University Student Paper	%1
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10	Submitted to Higher Education Commission Pakistan Student Paper	<%1
11	kuscholarworks.ku.edu Internet Source	<%1
12	repository.unimilitar.edu.co Internet Source	<%1
13	R.A. Taylor, G.L. Solbrekken. "Comprehensive system-level optimization of thermoelectric devices for electronic cooling applications", IEEE Transactions on Components and Packaging Technologies, 2008 Publication	<%1
14	Submitted to iGroup Student Paper	<%1
15	Submitted to Stourbridge College Student Paper	<%1
	Submitted to Dartford Grammer School	

16	Student Paper	<% 1
17	Submitted to Oxford Brookes University Student Paper	<% 1
18	en.m.wikipedia.org Internet Source	<% 1
19	Yongan Yang, David K. Taggart, Matthew A. Brown, Chengxiang Xiang et al. "Wafer-Scale Patterning of Lead Telluride Nanowires: Structure, Characterization, and Electrical Properties", ACS Nano, 2009 Publication	<% 1
20	Submitted to University of New York in Prague Student Paper	<% 1
21	www.slideshare.net Internet Source	<% 1
22	putnam.lib.udel.edu Internet Source	<% 1
23	www.faichneymedical.com Internet Source	<% 1
24	Submitted to University of Sheffield Student Paper	<% 1
25	Submitted to Shanghai World Foreign Language Middle School Student Paper	<% 1

26	Submitted to Institute of Technology Carlow Student Paper	<%1
27	repositorio.unesp.br Internet Source	<%1
28	www.answers.com Internet Source	<%1
29	Andrew Shinko. "Introduction to Mechanical Recycling and Chemical Depolymerization", Elsevier BV, 2018 Publication	<%1
30	Submitted to Cranfield University Student Paper	<%1
31	Submitted to University of Hertfordshire Student Paper	<%1
32	store.arduino.cc Internet Source	<%1
33	J. Couzin. "GENOME RESEARCH: NSF's Ark Draws Alligators, Algae, and Wasps", Science, 09/06/2002 Publication	<%1
34	www.dissertations.wsu.edu Internet Source	<%1
35	ceskysnooker.cz Internet Source	<%1

36	lbms03.cityu.edu.hk Internet Source	<%1
37	doras.dcu.ie Internet Source	<%1
38	www.investigo.biblioteca.uvigo.es Internet Source	<%1
39	www.waterlooregionalhomes.com Internet Source	<%1

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NOMENCLATURE

A	Area [m^2].
I	Electric current [A].
k	Thermal conductivity [W/mK].
L	Length [m].
N	Number of thermocouples.
Q	Heat flow [W].
R	Electrical resistance [Omega].
T	Temperature [K].
W	Input electric work [W].

CHAPTER 1: INTRODUCTION

The project is a wearable cooling wrist band, which is used for the purpose of cooling the target individual rather than the whole space. Whether you are feeling a little too warm or a little too cold, we are going to deliver an instant dose of localized thermal relief at the touch of a button which gives you a body-wide sensation of thermal comfort. The concept is cool or warm the body, why wasting the energy and cost to cool the room.

We are doing this project to provide people of Pakistan a low-cost cooling equipment that is efficient and have the ability to not just replace the applications of household air-conditioners but also where these air-conditioners do not apply for its cooling purposes. Besides we have to buy costly DC inverters to serve the purposes of both cooling and heating at the expense of large electrical energy. This device will be an alternative to these inverters. Besides as a consumer of this product, we will not be saving our expenses of costly inverters but also the energy which it is using.

Develop a wearable technology that can improve thermal comfort in livable environments while reducing the energy needs associated with space heating and cooling which is based on the Peltier effect by the use of thermoelectric materials. The concept behind the project is to provide efficient cooling and heating to the individuals at places where we cannot provide it by available technology, at a cost much lower than the conventional air conditioners and inverters. The project would also be a solution for people suffering from heat strokes. Not only the cost but also the energy will also be saved. The wearable equipment will be a watch and a jacket.

1.1) Problem statement:

- At high temperatures people suffer from heat stroke which can cause death
- Areas where people can’t afford AC
- Power consumption

1.2) Objectives:

Our objective is to prepare a wearable personal cooling device which has the following characteristics.

- Temperature difference: can cause max temperature difference and maintain the temperature of the whole body relative to the external temperature.
- Temperature control: temperature of the body can be controlled by the person himself up to the range of the device.
- Cost: has a minimum cost that is easily affordable by lower middle and lower class of Pakistan.
- Efficiency: has a maximum efficiency and can give maximum temperature difference.
- Environment friendly: device that is environment friendly and do not cause any kind of harm to the environment
- Low maintenance: Does not require any kind of maintenance and has along lifetime
- Size: has a minimum size and weight that can easily be wore and can be taken to any remote place

CHAPTER 2: LITERATURE REVIEW

2.1) Basic Concept:

2.1.1) Seebeck Effect:

The Seebeck impact is a wonder in which a temperature distinction between two different electrical conveyors or semiconductors delivers a voltage contrast between the two substances.

The Seebeck impact is a great case of an electromotive power (emf) and prompts quantifiable streams or voltages similarly as some other emf. Electromotive powers adjust Ohm's law by producing streams even without voltage contrasts (or the other way around); the nearby current thickness is given by

$$J = \sigma\,(-\nabla V + E_{emf}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where V is the nearby voltage [4] and σ is the neighborhood conductivity. When all is said in done, the Seebeck impact is portrayed locally by the production of an electromotive field

$$\mathrm{E_{emf}} = -\mathrm{S}\nabla\mathrm{T}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

here S is the Seebeck coefficient (otherwise called thermopower), a property of the neighborhood material, and T is the temperature inclination.

2.2.2) Peltier effect:

The Peltier impact is the proximity of warming or cooling at a jolted intersection of two unique conductors When a current is made to move through an intersection between two conductors, An and B, warmth might be engendered or evacuated at the intersection. The Peltier warm engendered at the intersection per unit time is

$$Q = (\tau_A - \tau_B)I) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where τ_A and τ_B are the Peltier coefficients of conductors A and B, and I is the electric current (from A to B). The total heat engendered is not resolute by the Peltier effect alone, as it may withal be influenced by Joule heating and thermal-gradient effects.

2.2) Climate of Pakistan:

Pakistan recorded one of the most elevated temperatures on the planet – 53.5 °C (128.3 °F) – on 26 May 2010, the most smoking temperature at any point recorded in Pakistan, yet in addition the most sizzling dependably estimated temperature at any point recorded on the landmass of Asia. Pakistan is situated on an extraordinary landmass north of the Tropic of Cancer (between scopes 25° and 36° N), it has a mainland kind of atmosphere described by outrageous varieties of temperature, both occasionally and day by day. [2]

2.3) Importance:

Air conditioner ownership in Pakistan is particularly low at 7.2%, WHICH MEANS 92.8% of Pakistan population does not have access to air conditioner
The excessive use of air conditioners or space heaters, a luxury in the developed world, is one of the main causes of global warming and unpredictable meteorological patterns. By excessive, we mean 87% of homes in the United States use energy for artificial climate control, in comparison to 2% that a populated country like India requires. This has influenced the rise of several inventions in the Information Age to save the planet and yet maintain comfortable lifestyles.

Energy use in U.S. and European homes is predicted to flatten, for the most part. But it will soar in developing and middle-income countries. The main culprit, according to new research from the University of California, Berkley, is air conditioning.

Using data from Mexico, researchers at UC Berkley's Haas School of Business built a model that took into account the relation between climate, income, and air conditioning.

When accounting for increases in incomes and expected higher temperatures, they found the number of homes with air conditionings would rise from 13 percent today to more than 70 percent at the end of the century. [3]

2.4) Thermoelectric material:

Thermoelectric materials demonstrate the thermoelectric impact in a solid or auxiliary frame.

The thermoelectric impact alludes to marvels by which either a temperature contrast makes an electric potential or an electric potential makes a temperature distinction. These wonders are referred to all the more concretely as the Seebeck impact (transmuting over temperature to current), Peltier impact (transmuting over current to temperature), and Thomson impact (conductor warming/cooling). While all materials have a nonzero thermoelectric impact, in many materials it is too diminutive to ever be valuable. Notwithstanding, minimal effort materials that have an adequately solid thermoelectric impact (and other required properties) could be utilized as a component of utilizations including power age and refrigeration. A generally utilized thermoelectric material in such applications is bismuth telluride. [4]

2.5) Materials selection criteria:

The helpfulness of a material in thermoelectric frameworks is controlled by the two variables gadget effectiveness and power factor. These are dictated by the material's electrical conductivity, warm conductivity, Seebeck coefficient and conduct under evolving temperatures.

2.5.1) Device efficiency:

The proficiency for power age of a thermoelectric gadget is given by η, characterized by

$$\eta = \frac{Energy\ Provided\ to\ the\ load}{Heat\ Enery\ absorbed\ at\ the\ hot\ junction} \ldots\ldots \quad (4)$$

The capacity of an offered material to proficiently create thermoelectric power is identified with its dimensionless figure of legitimacy given by [3]

$$ZT = \frac{\sigma S^2 T}{k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

which relies upon the Seebeck coefficient S, warm conductivity κ, electrical conductivity σ, and temperature T.

In a thermoelectric device, two materials are used. The maximum efficiency η_{max} is then given by

$$\eta_{max} = \frac{T_H - T_C}{T_H} \frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_C}{T_H}} \ldots\ldots\ldots\ldots \quad (6)$$

From the above equation, the hot junction temperature is T_H and and the cold junction temperature is T_C. ZT is the modified dimensionless figure which defines the merit of the thermoelectric material.

2.5.2) Power factor:

Power factor is used to decide the effectiveness of a material in a thermoelectric. The power factor depends upon the See beck coefficient and the electrical conductivity of the material under a temperature range

$$Power\ Factor = \sigma S^2 \text{ [5] } \ldots\ldots\ldots\ldots \quad (7)$$

2.6) Lead telluride:

Lead telluride, PbTe, is a halfway thermoelectric power generator. Its most extreme working temperature is 900 K. PbTe has a high dissolving point, great compound security, low vapor weight and great substance quality notwithstanding high figure of legitimacy Z

Table 2.1: Properties of Lead Telluride

Thermal Properties	
Heat of Formation	393 kJ/mol
Thermal Conductivity	2.30 W/mK
Mechanical Properties	
Density	8.16 g/cm^3
Melting Point	907°C
Mohs Hardness	3

Fig.2.1 demonstrates the variety of the figure of legitimacy Z of the most well-known thermoelectric materials versus temperature. Table 3 demonstrates the most extreme working temperature, scope of working temperatures, figure of legitimacy, and the greatest effectiveness of some thermoelectric materials. [6]

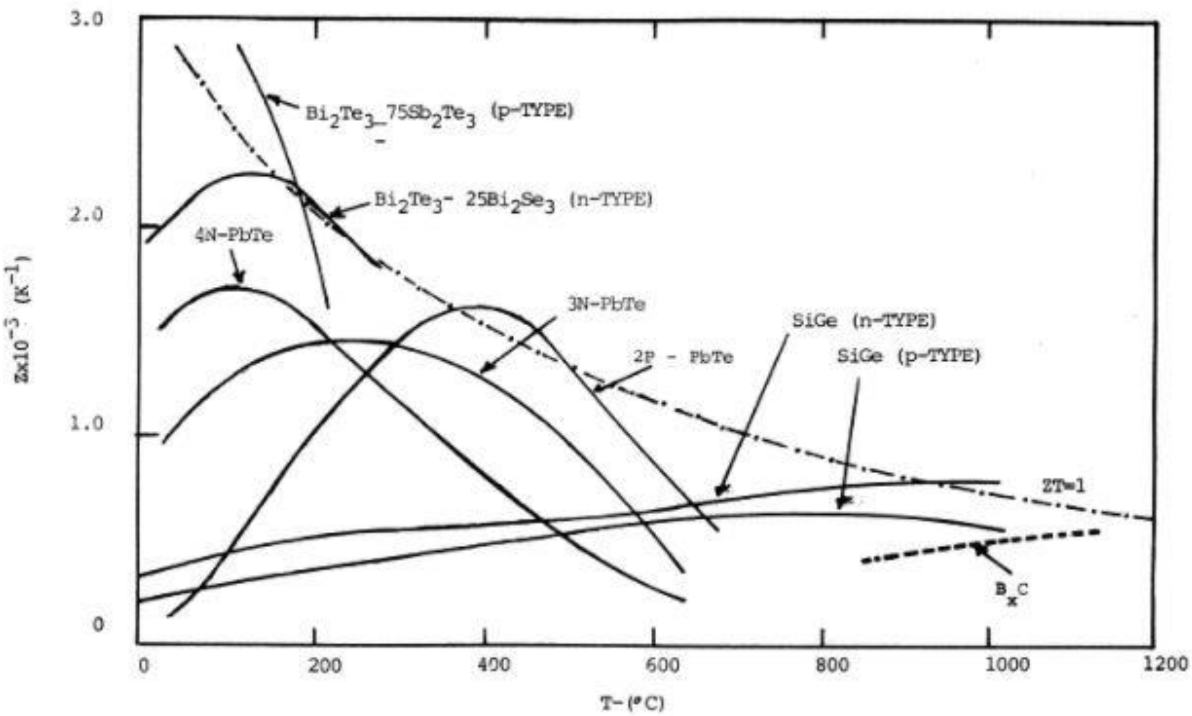

Fig 2.1: Variety of the figure of legitimacy Z

Table 2.2: Properties of Thermoelectric Materials

Material	Max. temp. (K)	ΔT (T_C=450 K)	Average Z (K^{-1})	Max. efficiency $\eta_0 = 14 Z \Delta T$
Bismuth telluride (Bi_2Te_3)	550	100	0.0018	0.04
Lead telluride (PbTe)	900	450	0.0010	0.11
Silicon–germanium (Si–Ge)	1400	850	0.0070	0.15
Boron-based material	1300	950	0.00070	0.015

2.7) Body Temperature:

Typical body temperature differs by individual, age, movement, and time of day. The normal ordinary body temperature is for the most part acknowledged as 98.6°F (37°C). A few investigations have demonstrated that the range of the "typical" body temperature can vary from 97°F(36.1°C) to 99°F (37.2°C). [7]

2.8) Skin:

The skin is the biggest organ in the human body. Notwithstanding its numerous physiological capacities (e.g. thermo-direction, vitamin D amalgamation, neurotransduction), the skin goes about as a complex biophysical interface shielding the inner body structures from the outside condition.

Skin is made out of three essential layers: the epidermis, the dermis and the hypodermis.

The epidermis contains no veins and is sustained by dispersion from the dermis. Epidermis is partitioned into the accompanying 5 sublayers or strata

The dermis is the layer of skin underneath the epidermis that comprises of connective tissue and pads the body from anxiety.

The subcutaneous tissue (additionally hypodermis and subcutis) isn't a piece of the skin and lies beneath the dermis. [8]

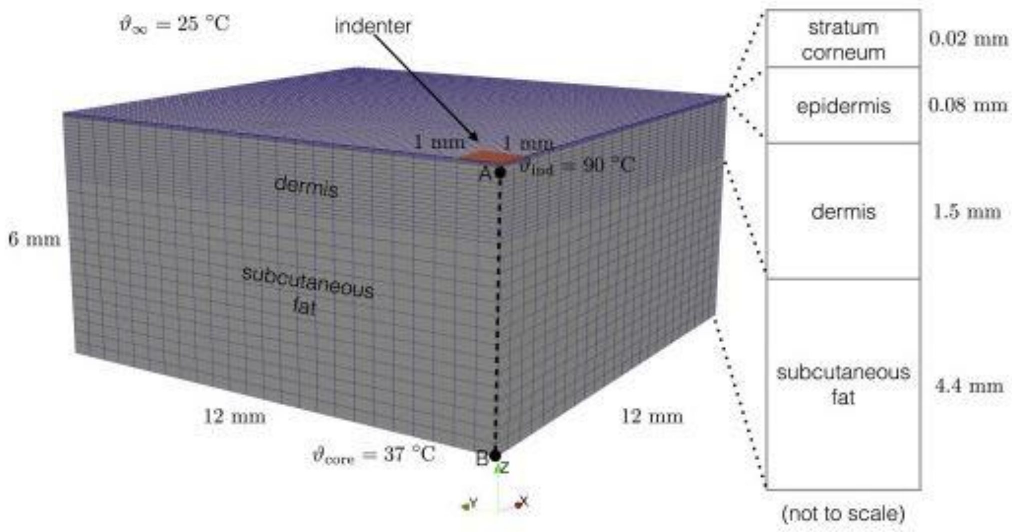

Fig 2.2 Analysis of Human Skin

Table 2.3: Properties of skin

Skin:						
			Stratum corneum	Epidermis	Dermis	Subcutaneous fat
Young's modulus	E	[N/mm^2]	1998	102	10.2	0.0102
Poisson's ratio	ν	[–]	0.48	0.48	0.48	0.48
Density	ρ	[kg/mm^3]	1500×10^{-9}	1190×10^{-9}	1116×10^{-9}	971×10^{-9}
Conductivity	k_0	[N/sK]	0.235	0.235	0.445	0.185
Heat capacity	c	[Nmm/kgK]	3600×10^3	3600×10^3	3300×10^3	2700×10^3
Blood perfusion	w^b	[kg/sm^3]	0	0	0.00125	0.00125
Metabolic supply	q_{met}	[N/mm^{2}s]	368.1×10^{-6}	368.1×10^{-6}	368.1×10^{-6}	368.1×10^{-6}
Blood:						
Density		ρ	[kg/mm^3]		1060×10^{-9}	
Heat capacity		c	[Nmm/KgK]		3770×10^3	

2.9) Effect of temperature on the skin:

When the human body is encountered with a constant cold temperature for a distinctive amount of time, it adjusts to that temperature and no longer perceives it as cold. The human skin quickly adjusts to the encountered constant temperature however the skin can sense the rapid and minute changes in temperature. When a warmer or colder temperature is introduced, it gives a quick sensation or comfort of that temperature. When the change in temperature is rapidly introduced again and again, the body can be essentially tricked into feeling cold or hot. EMBR Labs group found out that if anybody is encountered with a temperature of 0.1 C per second, than the entire body feels a bit colder or hotter. The feeling is similar to putting your feet in cold water.

Warm sensations in the body to be quick, exact, and powerful there can be three mechanical advancements:

Conduction - coordinate contact with the skin gives quick, exact, and vitality proficient conductive warming and cooling;

Waveforms - dynamic temperature profiles composed around how our skin feels and adjusts to temperature.

Personalization - customized warm sensations to address singular fluctuation, changes in the earth, and warm needs. [9]

2.10) Other Design:

1) Wristify:

One such product, dubbed Wristify, has been created by student researchers at MIT. Wristify is a manually operated thermostatic wristband that helps regulate the wearers' body temperature according to their preferences. It does this by emitting natural diffusing waves. For example, a reporter out in a snowstorm can push a button on the bracelet to feel instant warmth on the skin radiating from the blood-rich wrist to other parts. Similarly, the device can be made to cool the body when it is hot or the air is humid, like in crowded places or during outdoor activities.

The device's principle component is thermoelectric material, which is responsible for transporting heat from one junction to another junction with the passage of electric current. The thermoelectric material is generally copper-alloy based sink, a heat exchanger for delivering heat. The warm junction absorbs heat from high temperature junction leaving a cooling effect. For safety purposes, this warm junction is isolated from the skin with an insulator. It is joined by an automated control framework with proprietary control algorithms responsible for the intensity and duration of the warm beats. The current prototype can cool or warm a body at about 0.4 C per second. It cycles between 5 seconds on i-e cooling effect and 10 seconds off i-e no cooling effect until a set temperature is recognized. The overall body temperature can be controlled by the in-build thermometers. The measure the outer and body temperature accordingly.

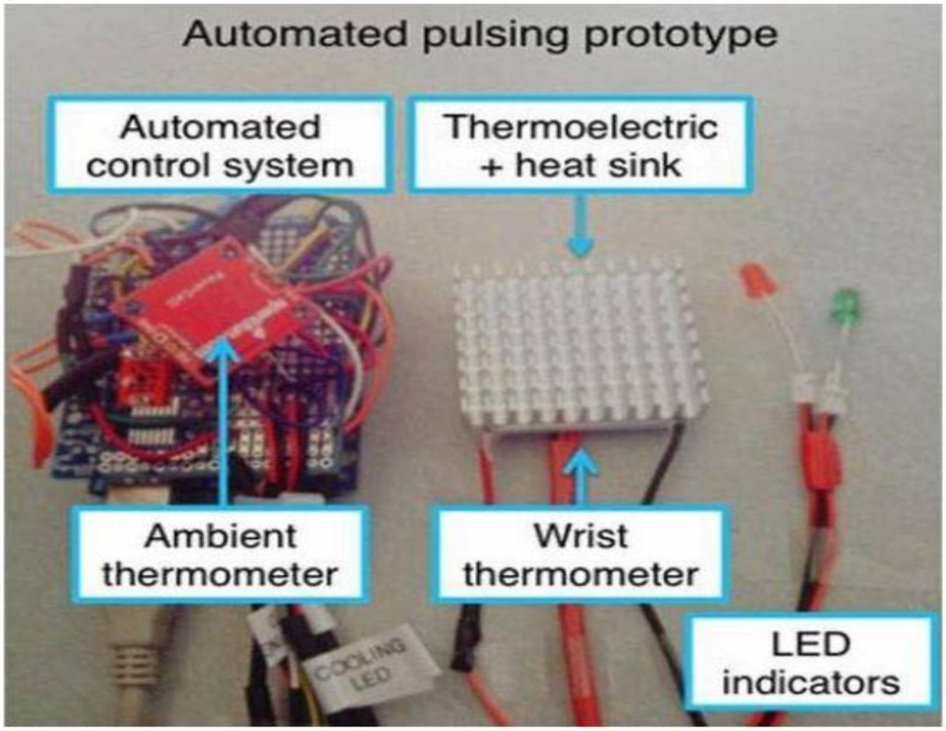

Fig 2.3: Wristify Automated Pulsing Design

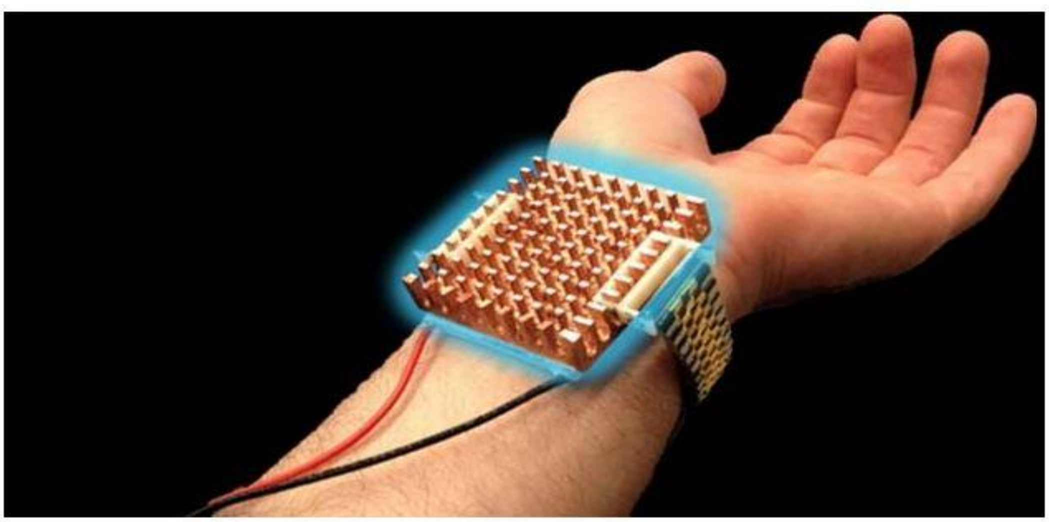

Fig.2.4: Wristify Design

2) Cap having evaporative cooling interior apparatus

A cap utilizing evaporative cooling interior apparatus includes a cap having a generally dome-shaped head covering portion defining an interior cavity. A plurality of elongated tapered porous liquid evaporating pads is removably secured within the cap interior in a spaced apart arrangement. A plurality of air passage channels is formed between the evaporative pads to promote air circulation about the pads within the cap interior. The pads are formed of a porous material having the capacity to absorb and retain a substantial quantity of liquid such as water. The pads preferably contact the user's head and provide a cooling effect thereon as the liquid within the porous pads evaporates. [10]

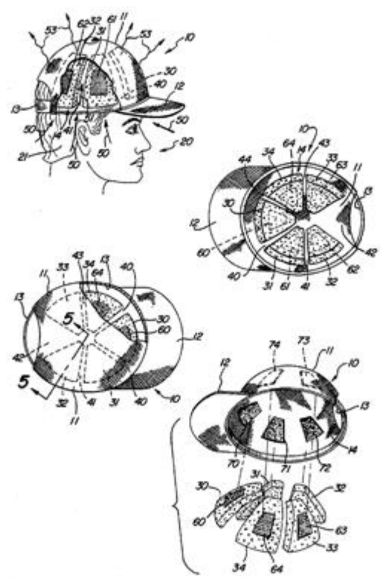

Fig 2.5: Cap Designs

3) Personal Evaporative personal cooler

An independent evaporative individual cooling gadget has an explained C-molded lodging that fits conformally around a client's neck or temple. The lodging holds and desires no less than one warmth disseminating plate comparably against the client's neck or temple. A wipe material inside the lodging contacts upper or potentially bring down parts of the metal plates however is separated from the plate to frame a plenum. Being used, the wipe material is soaked with water presented through openings in the lodging. A DC fueled fan inside the gadget draws air into the lodging and circles the air inside the plenum and out through leave openings in the wipe material and lodging. Dampness from the wipe material wets the plenum-confronting surface of the metal plates, which surface ideally has been treated with a wicking material. Fan-coursed air advances vanishing and warmth is pulled back by the plates from the client's neck or brow, along these lines cooling the client. [11]

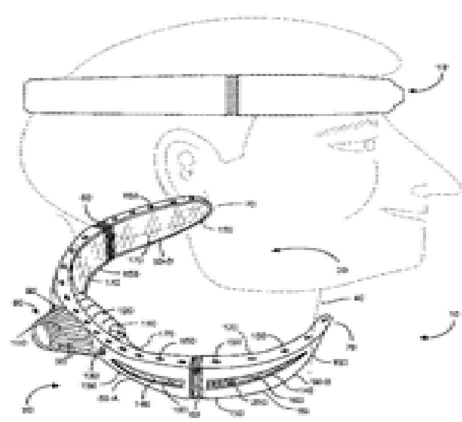

Fig 2.6: Neck Cooler Designs

4) Thermoelectric crash helmet cooling system

A device and technique for cooling the inside of an avionics crash protective cap without consolidation of any mechanically moving segments or liquids. The said framework can cool or warm the leader of the client using thermoelectric cooling components, strong state fans or electro-streamlined pumps, warm exchangers, and an altered ventilation framework. None of the segments in the present development contain mechanically moving parts, liquids, or synthetics. The favored epitome was intended for air ship crash caps, yet this innovation can be consolidated into any current crash protective cap which can suit joining thermoelectric pumping modules and give a consistent power supply to the said segments. This present innovation can be consolidated into any current crash head protector through customization of cap embeds. It can likewise be fused into the plan of new crash head protectors which would encourage the amplification of the proficiency of the said cooling framework. [12]

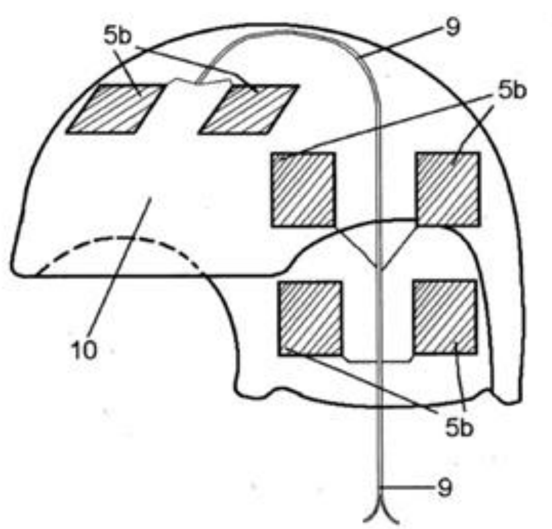

Fig 2.7: Helmet Designs

5) Personal heat control

An individual warmth control has a lodging pleasing a Peltier-impact unit, at least one batteries and a planning switch for specific energisation of the unit. The lodging is releasably joined to a piece of a man's body, e.g. the wrist, by a tie with a cooling surface cooled by the unit in contact with the body part to improve warm exchange between the individual's body and the encompassing air for solace and refreshment purposes when the unit is invigorated. [13]

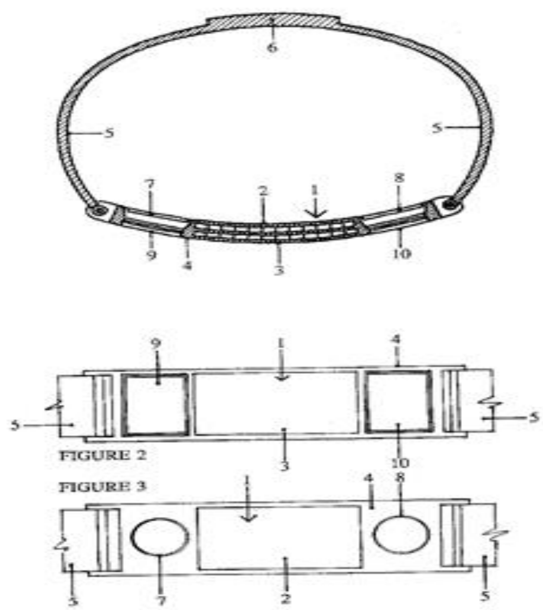

Fig 2.8: Heat Controller Designs

CHAPTER 3: METHODOLOGY

3.1) Coefficient of Performance (COP):

DV= 12V

Max Voltage = 15V

Max Power = 120W

Max Current = 10A

Ambient Temperature = 23 ± 1 ℃ (1 KHz AC)

Internal Resistance = 1.5 – 1.8 Ohm

Max $\Delta T = 75$℃

$$P = 85 \frac{N}{cm^2}$$

$$T_c = -15\ ℃$$

$$T_h = 60\ ℃$$

Power of thermoelectric Cooler:

$$P = \alpha\, I\, (T_h - T_c) + I^2 R \qquad (8)$$

$$P = 120\ W$$

$$R = 1.65\ Ohms$$

$$\Delta T = 75\ ℃$$

$$\alpha = 1.5 \times 10^{-3} K^{-1}$$

This results in $I = 8.5\ A$

Now

$$Q_h = \alpha I (T_h) + 0.5 I^2 R - k(T_h - T_c) \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where $k = 2.3\ W/m$°C

This results in $Q_h = -108.646$ W

Now we will find Q_c using the following equation:

$$Q_c = \alpha I (T_c) - 0.5 I^2 R - k(T_h - T_c) \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

This results in $Q_c = -228.81$ W

Now we will find COP of Q_c and Q_h

$$COP_h = 0.905$$

$$COP_C = 1.91$$

3.2) Heat Sink Analysis:

- There are numerous plans for heatsinks, yet they normally involve a base and various distensions joined to this base. The base is the element that interfaces with the contrivance to be cooled. Warmth is directed through the base into the bulges. The projections can take a few structures, including:
- Plate Fin
    - Staggered Plate
    - Parallel Plate
- Pin-Fin
    - Inline Circular
    - Inline Square
    - Staggered Square
    - Staggered Circular

- Elliptical Fin / Staggered Elliptic

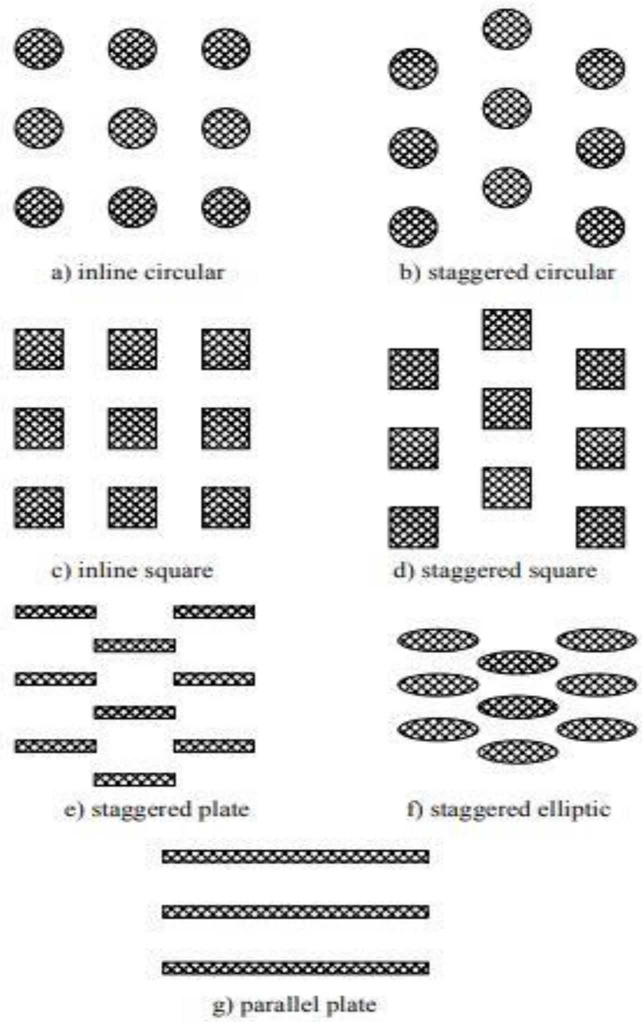

Fig 3.1: Types of Heat Sinks

3.2.1) Heat Sink Performance:

The performance of heatsinks are a consequence of many parameters, including:

- Geometry
- Surface treatment
- Material
- Air velocity
- Device Interface

3.2.2) Comparison:

The heat sink performance according to different geometries will be analyzed on the basis of thermal resistance from the base to the ambient air.

The comparison of the different geometries of Fins is done on FLUENT, a CFD Finite Volume Analysis, in which case.

In order to make a comparison for the purport of optimizing heat transfer rate, some parameters are fine-tuned for all geometries. These are:

- The cross-sectional area per base area of fin
- The wetted perimeter per base area
- The area for air flow passage per base area.

The fixed parameters are as follows

Fin Cross-Sectional Area:

$$\lambda_{section} = \frac{\pi w^2/4}{P_S P_L} = \frac{\pi (1)^2/4}{2\times 2} = 0.19635 \ (\approx 19.6\%) \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \ (11)$$

Air Flow Passage Area and Wetted Parameter:

$$\lambda_{flow} = 1 - \lambda_{section} = 1 - \frac{\pi w^2/4}{P_S P_L} = 0.80365 \quad \text{………………..} \ (12)$$

Hydraulic Diameter:

From the above two equations, the hydraulic diameter to be used in CFD calculations is as follows.

$$D_h = \frac{4 \times \lambda_{flow}}{\Pi} = \frac{4 \times 0.80365}{0.78540} = 4.0929\, mm \quad \text{………………..} \ (13)$$

3.2.3) CFD Modeling and Validation:

- The overseeing conditions are of two-dimensional coherence, Navier-Stokes and the vitality condition in their incompressible laminar frame.
- Since the regular completely created stream condition can't be connected on account of stream in stick balance exhibit. The occasionally completely created stream condition proposed by Patankar et al.16, actualized in FLUENT, was utilized.
- All however initial couple of lines of blades are occasionally completely created stream, so a little unit cell estimating one traverse savvy pitch (PS) and two the long way pitches (PL), were utilized to demonstrate the whole heatsink.

- The blades have negligible decrease and divider thickness and free stream impacts are limited to little areas toward the finish of the balances, allowing a two-dimensional model to be utilized.
- An aluminum heat sink put in air has a strong/liquid warm conductivity proportion of 7000, and temperature angles in the blades are irrelevant every which way aside from ordinary to the heatsink base. With both of these contemplations, an isothermal model adjusted by a logical balance effectiveness is defended and utilized here.
- In the computational area, in heading of the stream, an intermittent limit condition is embraced. symmetry condition is utilized for the transverse way. For the warm limit condition on the strong surfaces, an isothermal condition is forced.
- All liquid (i.e. air) properties are considered to be consistent.

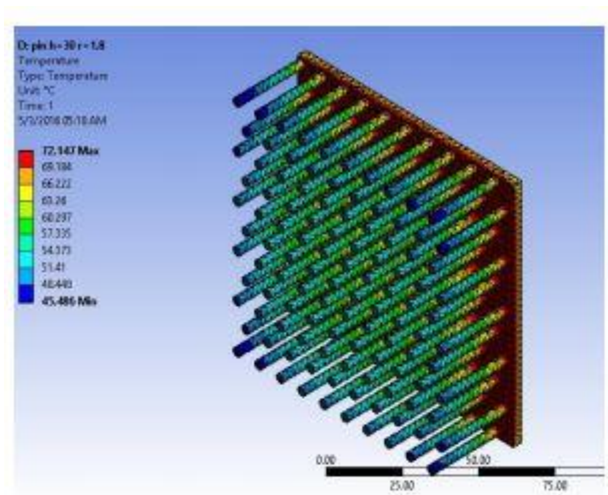

Fig 3.2: Heat Sink Designs

3.2.4) Results:

For every geometry, comes about were acquired at different air speeds in the scope of 0.5 to 5 m/s.

Since the power breadth of water was settled as noted beforehand, this secured a settled scope of Reynolds number for every geometry

In playing out the work refinement, once the Nusselt number transmuted by under 0.5% the framework was thought to be adequately fine. This established a greatest number of 50,000 components for the most delicate case.

For every geometry, seven recreations were done by fluctuating the wind current rate. The bends verbalize with the lines of best fit through the seven focuses acquired in the recreations. All the examination done on the geometries are as per the following.

Nusselt number versus Reynolds number diagram was gotten for every geometry, which is as per the following.

Nusselt number v/s Reynolds Number:

Nusselt number versus Reynolds number graph was obtained for each geometry, which is as follows.

- It can be clearly seen from the graph that all staggered geometries have a better Nusselt number for convection purposes than theirs respective in-line counter parts.
- Secondly circular pin heat sink has a better Nusselt number than parallel plate at different air flow rates.

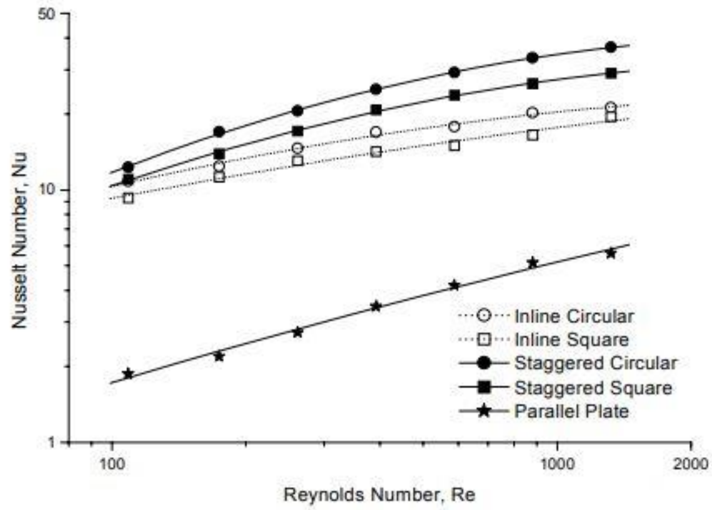

Fig 3.3: Graph between Nusselt number and Reynolds number

Friction Coefficient vs Reynolds number:

The graph for friction coefficient vs Reynolds number is as follows:

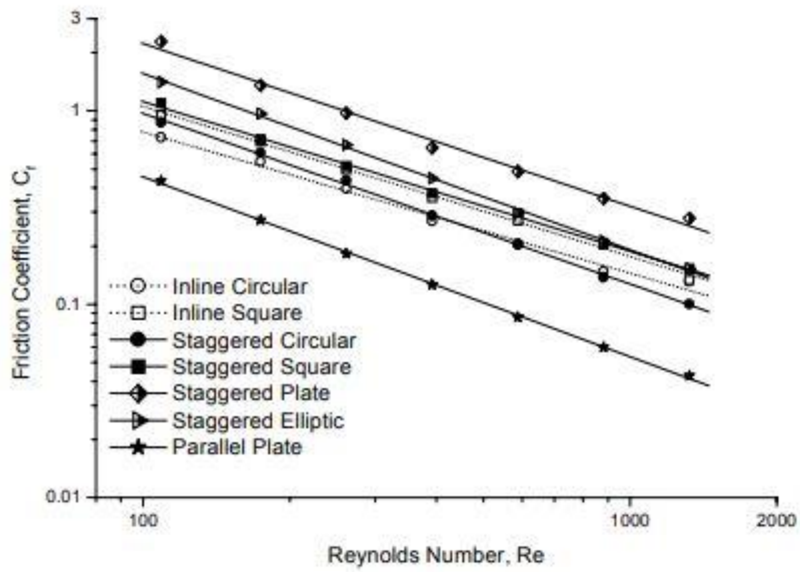

Fig 3.4: Graph between Friction coefficient and Reynolds number

It is evident from the graph that as the Reynolds number or the air flow rate for a geometry increases, the friction coefficient decreases and the effect is almost linear for all geometries.

Pumping Power (W) vs Heat Conductance:

The graph for heat dissipated per unit time and heat conductance of a specific geometry is as follows:

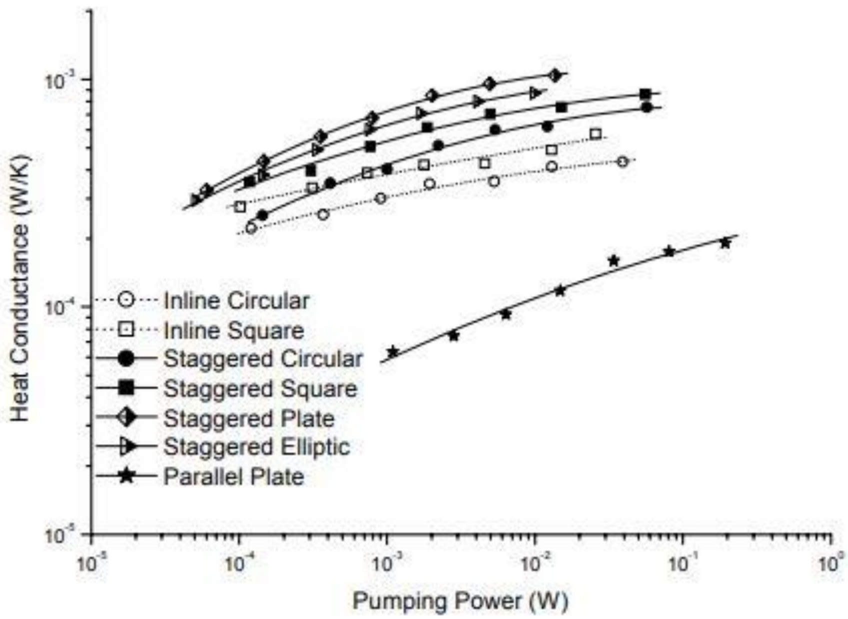

Fig: 3.5 Graph between Pumping power and Heat conductance

It can be seen from the graph that the Heat conductance of staggered fins is best at all values of the Pumping. Also, elliptical fins work best at lower values of Pumping Power and Pressure Drop, while at higher values of Pumping Power round pin fins are the most efficient.

The case for Wearable Cooling Device:

As the pumping power of our device is rather high, that is almost equal to 65W, staggered round pin fins were the best heat sink for our project but due to its unavailability in the market of Pakistan, we went for the next best and economical choice, Parallel plate heat sink, which works better than round pin fins and provide greater heat conductance at very higher pumping powers as can be seen from the behavior of the graph. That is, as the pumping power is increased, the heat conductance of the parallel plate heat sink is increased more than any other heat sink.

The graph for parallel plate heat sink is rather linear i-e, as the pumping power is increased, the heat conductance is almost equally increased,

While for all other geometries of the heat sink, the graph is becoming a straight line, i-e for every increase in the pumping power of the device, the increase in the heat conductance is reduced.

3.3) Material Data

We used following materials in the analysis

- Lead Telluride (Thermoelectric Material)
- Ceramic Porcelain (Walls of Thermoelectric Cooler)
- Aluminum Alloy 6063-O (Heat Sink and plate between skin and cooler)
- Polyethylene cross-linked (Frame of exhaust fan)
- PE high Density (Exhaust Fan)
- Cold Human Skin

3.4) Geometry of Solid-Works Model:

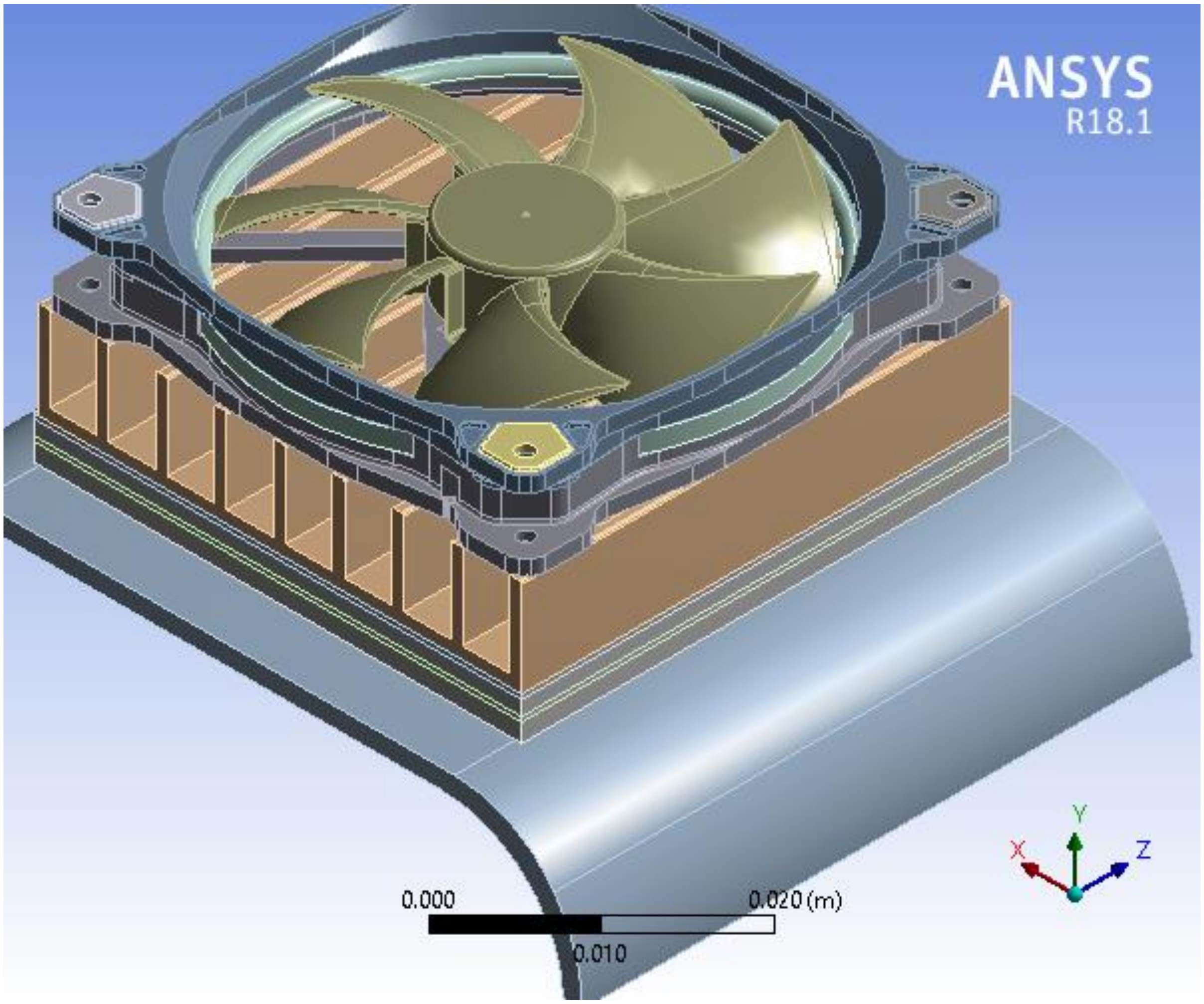

Fig 3.6: Design of Personal Cooler

Model (A 4) > Geometry > Thermoelectric Material-1 > Thermoelectric Material

Model (A 4)

Geometry

TABLE 3.1: Parts Graphic Properties

Model (A 4) > Geometry > Parts

Object Name	*Thermoelectric Material-1*	*Ceramic Plate-1*	*Ceramic Plate-2*	*Aluminium Heat sink-1*	*TT Riing14 Frame (1)-1*	*TT Riing14 Frame (1)-1[2]*	*TT Riing14 Frame (1)-1[3]*	*TT Riing14 Frame (1)-1[4]*	*TT Riing14 Frame (1)-1[5]*	*TT Riing14 Frame (1)-1[6]*	*TT Riing14 Frame (1)-1[7]*
State	Meshed										
Graphics Properties											
Visible	Yes										
Transparency	1										
Definition											
Suppressed	No										
Stiffness Behavior	Flexible										
Coordinate System	Default Coordinate System										

Reference Temperature	By Environment									
Behavior	None									
Material										
Assignment	Lead Telluride	Ceramic Porcelain	6063-O	Polyethylene Cross-Linked						
Nonlinear Effects	Yes									
Thermal Strain Effects	Yes									
Nodes	7956		47353	1936	667	527	656	875	37408	667
Elements	1089		8448	208	98	74	96	130	20272	98
Mesh Metric	None									

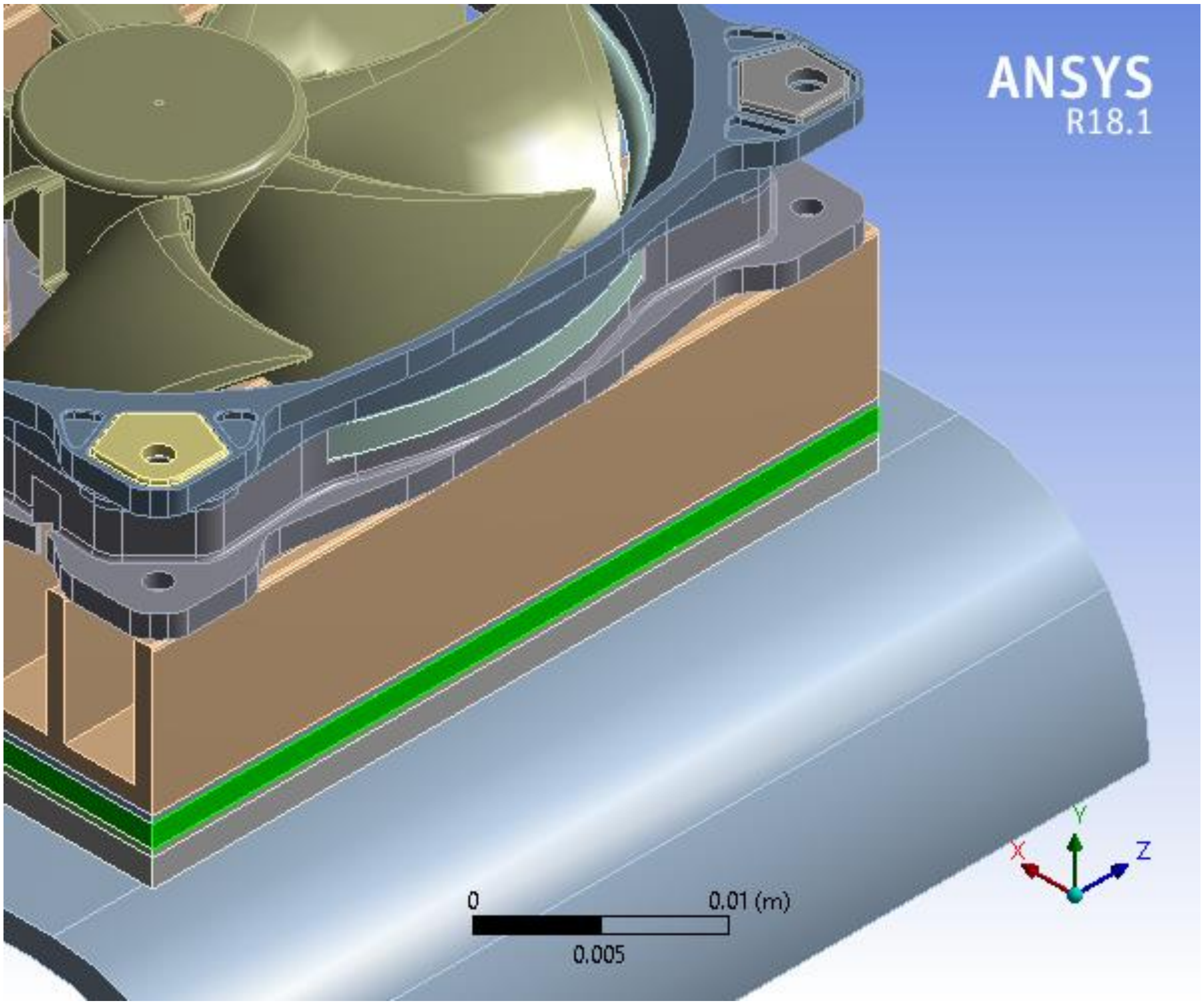

Fig 3.7: Analysis of Peltier Plate

Model (A 4) > Geometry > Thermoelectric Material-1 > Thermoelectric Material

TABLE 3.2: Properties and Statistics

Model (A 4) > Geometry > Parts

Object Name	*TT Riing14 Frame(1)-1[8]*	*TT Riing14 Frame(1)-1[9]*	*TT Riing14 Frame(1)-1[10]*	*TT Riing14 Frame(1)-1[11]*	*TT Riing14 Hub-Blades(1)-1*	*Aluminium Sheet-2*	*Cold Wrist-2*
State	Meshed						
Graphics Properties							
Visible	Yes						
Transparency	1						
Definition							
Suppressed	No						
Stiffness Behavior	Flexible						
Coordinate System	Default Coordinate System						
Reference Temperature	By Environment						
Behavior	None						
Material							
Assignment	Polyethylene Cross-Linked				PE High Density	6063-O	Cold Skin
Nonlinear Effects	Yes						

Thermal Strain Effects	Yes						
Bounding Box							
Length X	4.8609e-003 m	4.4326e-003 m	4.8609e-003 m	4.e-002 m	3.813e-002 m	4.e-002 m	5.9994e-002 m
Length Y	6.0086e-004 m			4.1769e-003 m	5.2035e-003 m	1.5e-003 m	1.1419e-002 m
Length Z	4.8609e-003 m	4.4326e-003 m	4.8609e-003 m	4.e-002 m	3.7465e-002 m	4.e-002 m	5.e-002 m
Properties							
Volume	1.0076e-008 m³	7.7136e-009 m³	1.0076e-008 m³	8.8699e-007 m³	4.7182e-007 m³	2.4e-006 m³	5.962e-006 m³
Mass	9.5719e-006 kg	7.3279e-006 kg	9.5719e-006 kg	8.4264e-004 kg	4.4918e-004 kg	6.48e-003 kg	6.7043e-003 kg
Centroid X	2.863e-002 m	-6.0213e-003 m	2.863e-002 m	1.0997e-002 m	1.1286e-002 m	1.1626e-002 m	1.1629e-002 m
Centroid Y	2.9243e-002 m			3.0666e-002 m	3.3236e-002 m	1.8361e-002 m	1.4968e-002 m
Centroid Z	1.5622e-002 m	5.0273e-002 m	5.031e-002 m	3.3153e-002 m	3.2965e-002 m	3.2966e-002 m	
Moment of Inertia Ip1	1.4506e-011 kg·m²	1.0944e-011 kg·m²	1.4502e-011 kg·m²	1.7059e-007 kg·m²	2.8581e-008 kg·m²	8.6521e-007 kg·m²	1.4515e-006 kg·m²

Moment of Inertia Ip2	3.0204e-011 kg·m²	1.9832e-011 kg·m²	3.02e-011 kg·m²	3.4834e-007 kg·m²	5.5074e-008 kg·m²	1.728e-006 kg·m²	3.9495e-006 kg·m²
Moment of Inertia Ip3	1.6267e-011 kg·m²	9.3225e-012 kg·m²	1.6266e-011 kg·m²	1.7984e-007 kg·m²	2.858e-008 kg·m²	8.6521e-007 kg·m²	2.6145e-006 kg·m²
Statistics							
Nodes	568	774	733	64613	26552	12512	27873
Elements	80	116	110	35108	12966	2178	4920
Mesh Metric	None						

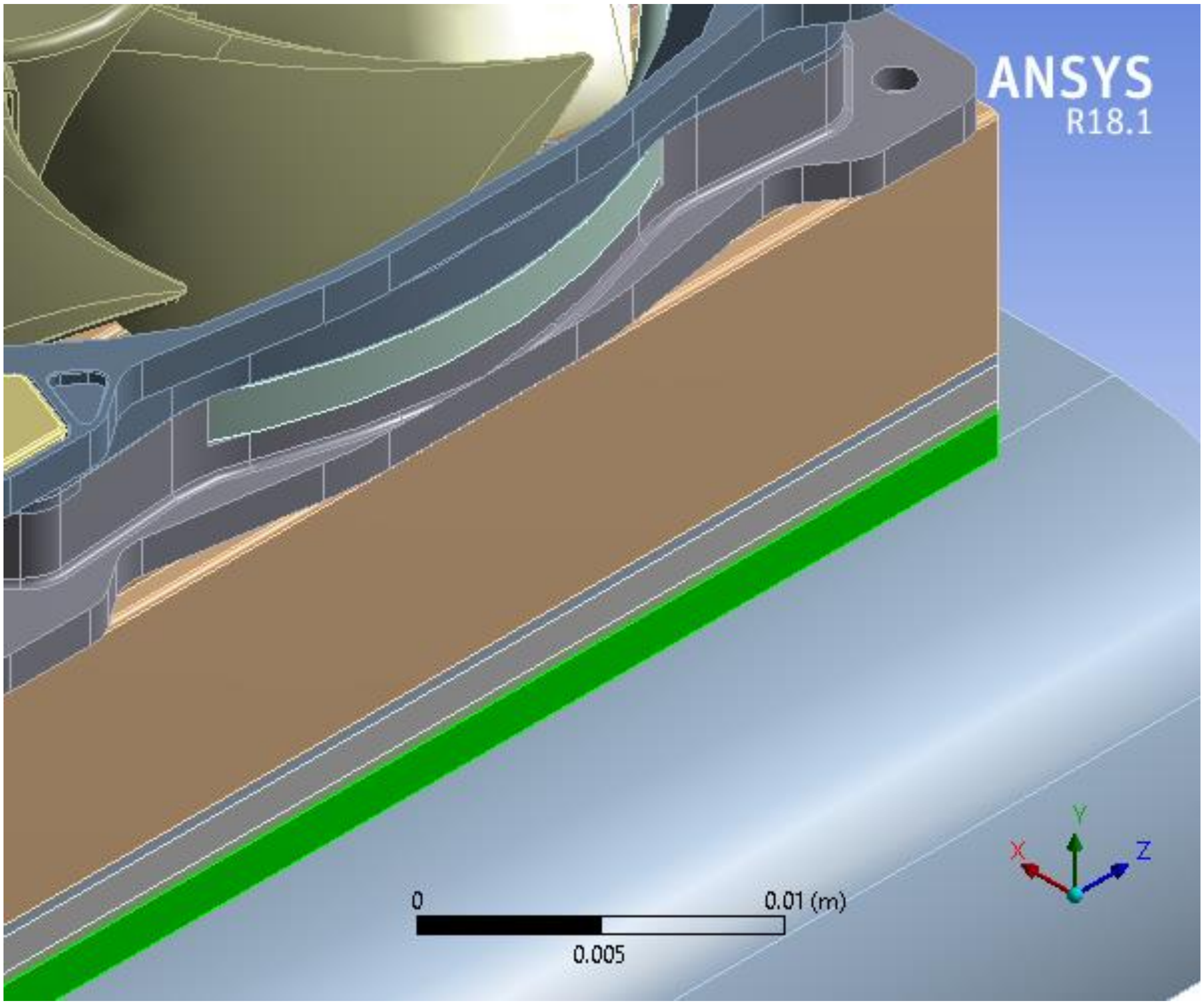

Fig 3.8: Analysis of Heat Sink

Model (A 4) > Geometry > Aluminium Sheet-2 > Aluminium Sheet

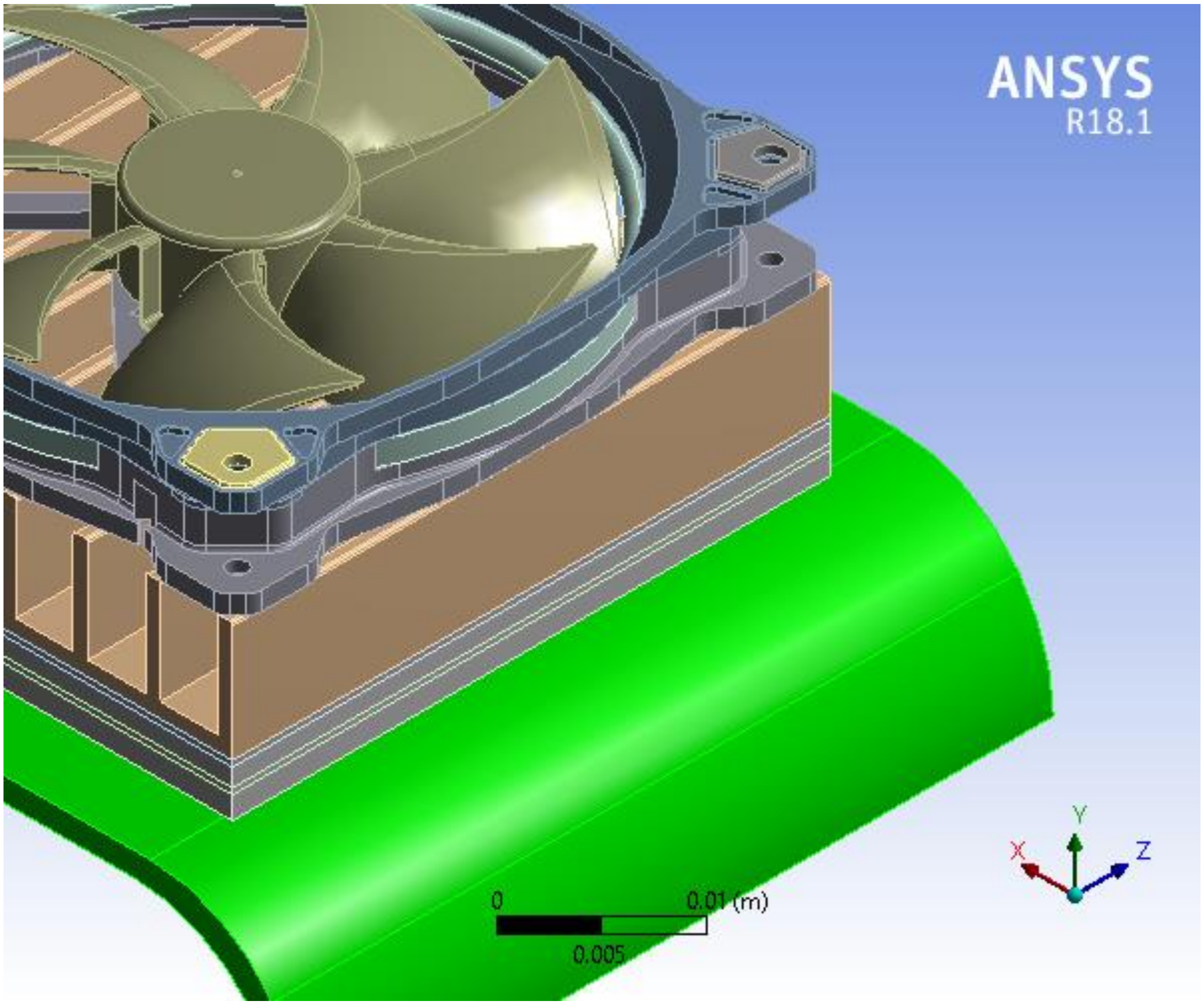

Fig 3.9: Analysis of Aluminum plate

Model (A 4) > Geometry > Cold Wrist-2 > Human Wrist

TABLE 3.3: Contact Regions and Scope of Material

Model (A 4) > Connections > Contacts > Contact Regions

Object Name	*Frictionless - TT Riing14 Frame(1)-1 To TT Riing14 Hub-Blades(1)-1*	*Contact Region 13*	*Contact Region 14*	*Contact Region 15*	*Contact Region 16*	*Contact Region 17*	*Contact Region 18*	*Contact Region 19*	*Contact Region 20*	*Contact Region 21*	*Frictionless - TT Riing14 Frame(1)-1[11] To TT Riing14 Hub-Blades(1)-1*
State	Fully Defined										
Scope											
Scoping Method	Geometry Selection										
Contact	1 Face	13 Faces			1 Face	5 Faces	13 Faces		1 Face	13 Faces	2 Faces
Target	7 Faces	25 Faces			1 Face	4 Faces	25 Faces		1 Face	25 Faces	17 Faces
Contact Bodies	TT Riing14 Frame(1)-1	TT Riing14 Frame(1)-1[2]	TT Riing14 Frame(1)-1[3]	TT Riing14 Frame(1)-1[4]	TT Riing14 Frame(1)-1[5]	TT Riing14 Frame(1)-1[6]	TT Riing14 Frame(1)-1[7]	TT Riing14 Frame(1)-1[8]	TT Riing14 Frame(1)-1[9]	TT Riing14 Frame(1)-1[10]	TT Riing14 Frame(1)-1[11]
Target Bodies	TT Riing14 Hub-Blades(1)-1	TT Riing14 Frame(1)-1[6]				TT Riing14 Frame(1)-1[11]					TT Riing14 Hub-Blades(1)-1
Definition											
Type	Frictionless	Bonded									Frictionless
Scope Mode	Automatic										

3.4.1) FEM Analysis

Static Structural Analysis

TABLE 3.4: Static Structural Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	22. °C
Generate Input Only	No
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	Yes
Solver Units	Active System
Solver Unit System	mks

TABLE 3.5: Static Structural Analysis Rotations

Object Name	*Rotational Velocity*
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Define By	Vector
Magnitude	100. rad/s (ramped)
Axis	Defined
Suppressed	No

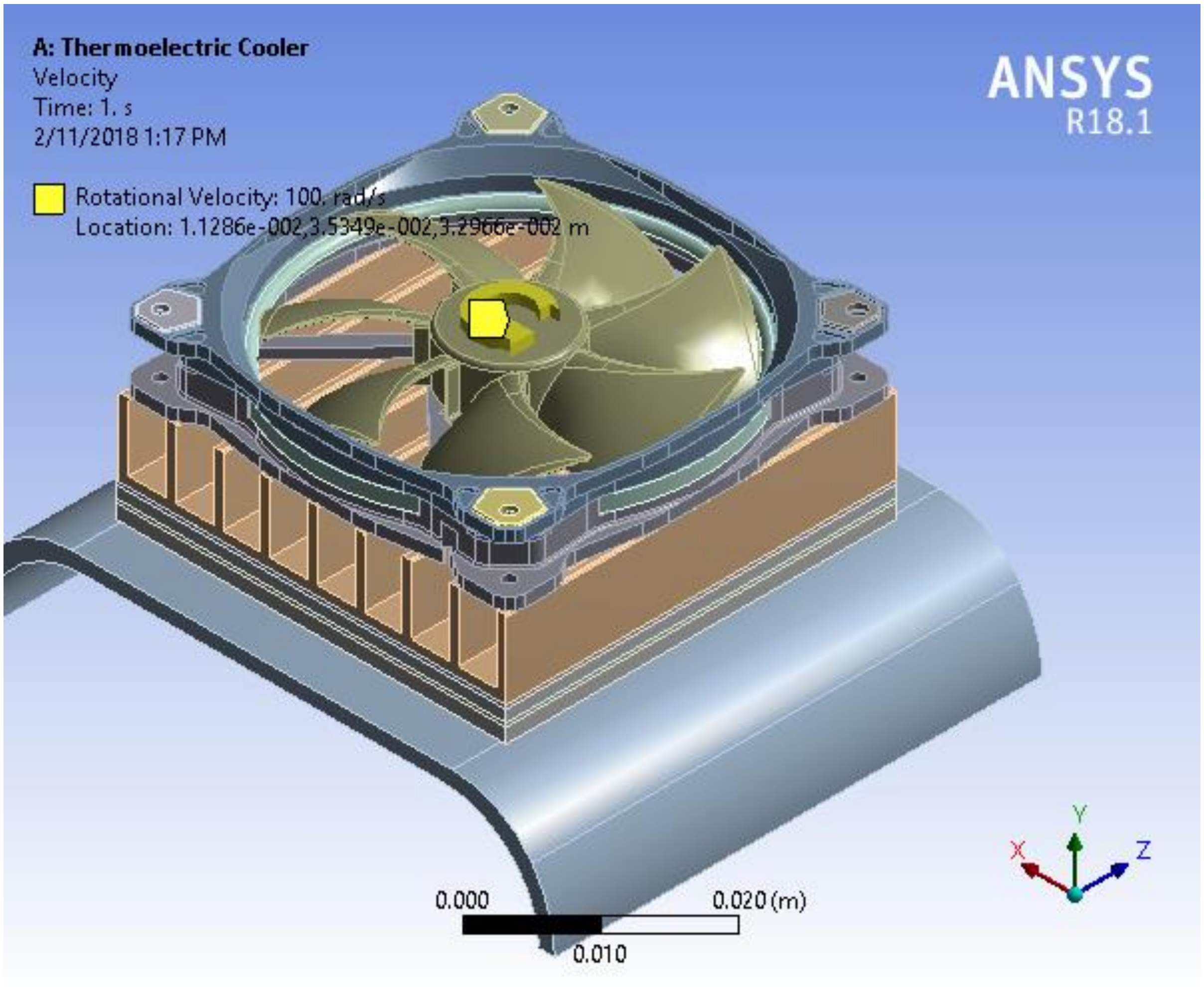

Fig 3.10: Static Structural Analysis of Design

Model (A 4) > Static Structural (A 5) > Rotational Velocity

TABLE 3.6: Static Structural Analysis Load

Object Name	Support	*Frictionless Support*	*Temperature*	*Temperature 2*
State	Fully Defined			
Geometry	12 Faces	1 Face	1 Body	
Definition				
Type	Fixed Support	Frictionless Support	Thermal Condition	
Suppressed	No			
Magnitude			60. °C (ramped)	-15. °C (ramped)

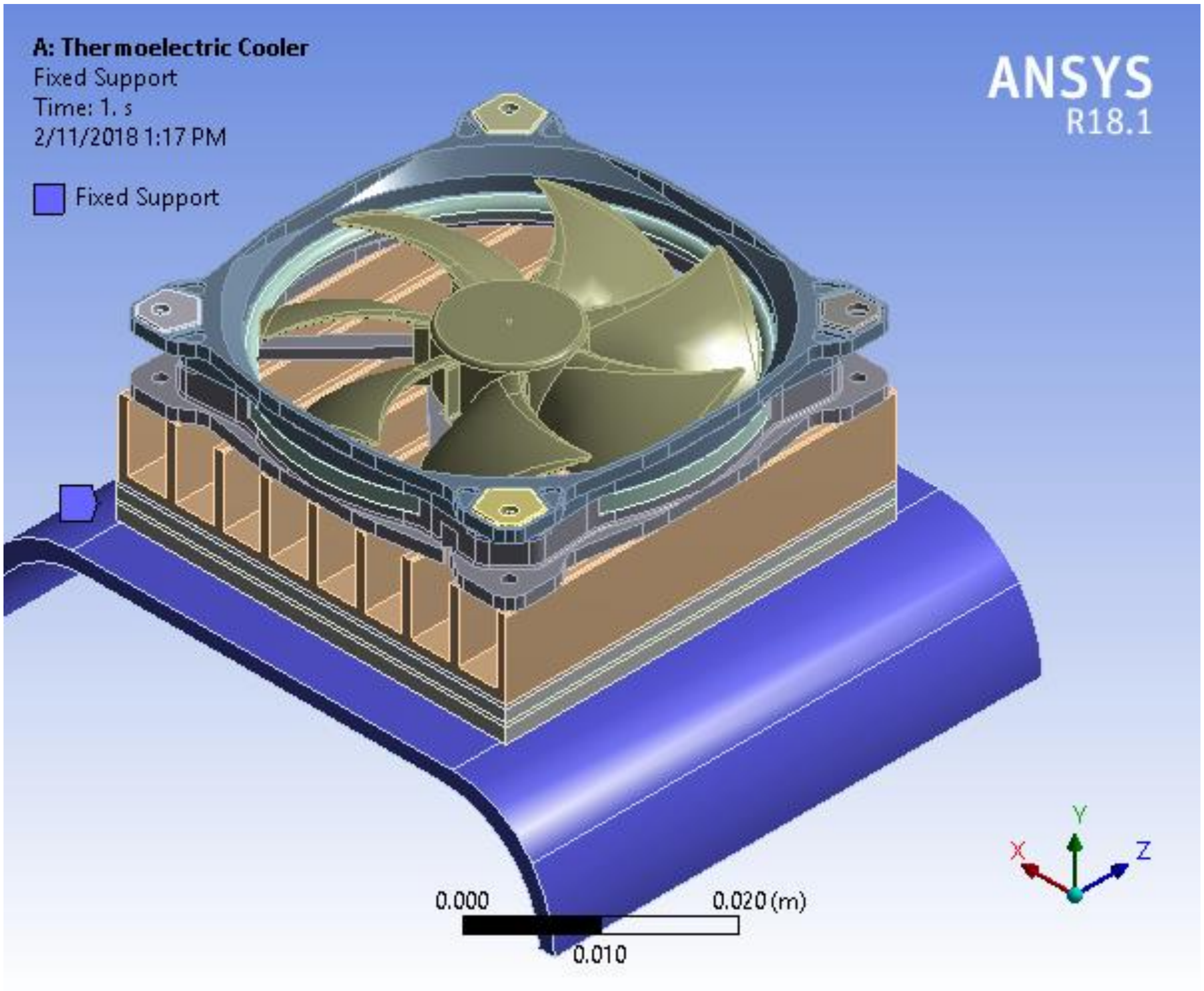

Fig 3.11: Static Structural Analysis of Aluminum Plate

Model (A 4) > Static Structural (A 5) > Fixed Support > Fixed Support

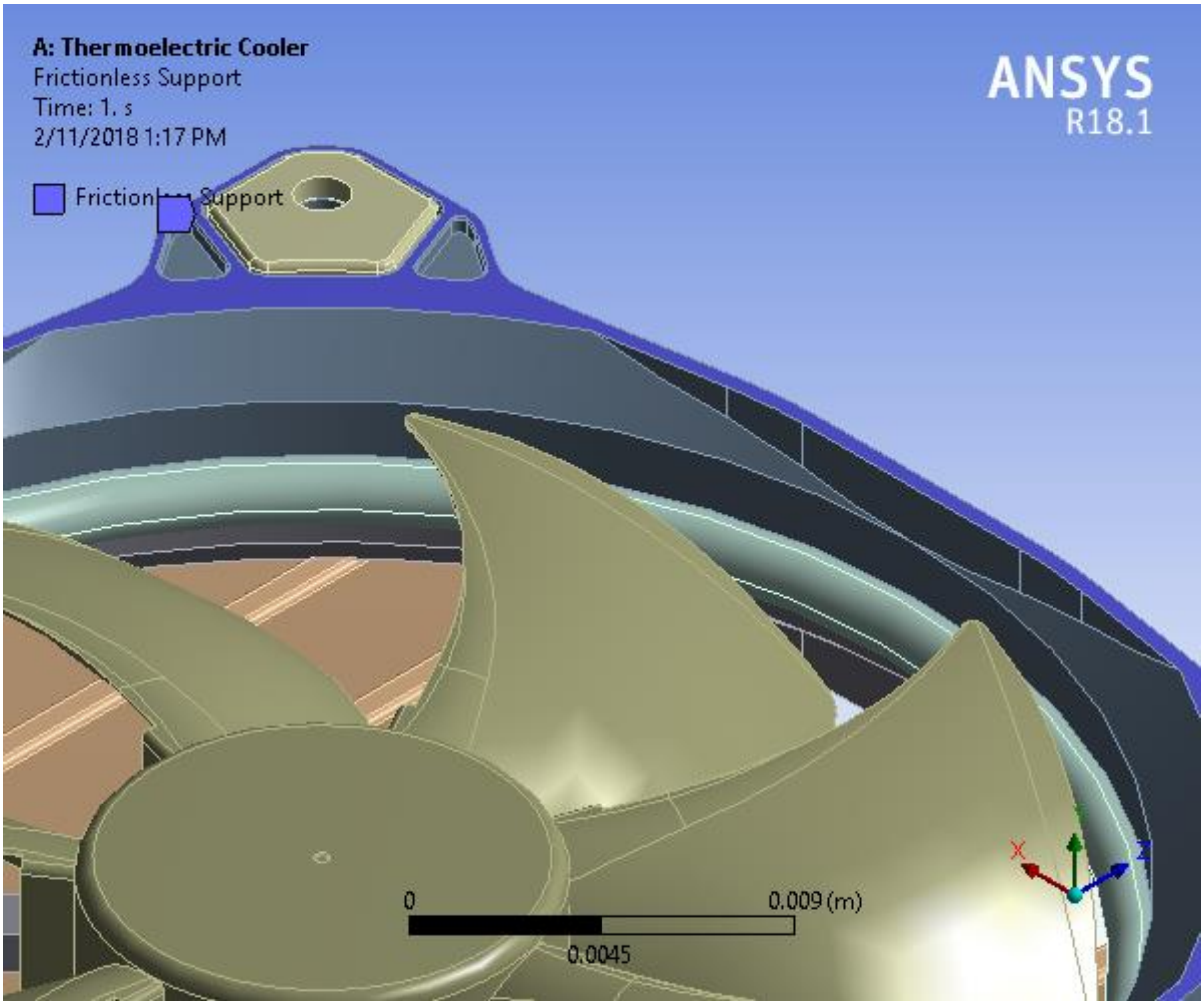

Fig 3.12: Static Structural Analysis of Fan

Model (A 4) > Static Structural (A 5) > Frictionless Support > Frictionless Support

3.5) DIGITIZATION:

We have used the Arduino based circuit that energizes the unit through a dry battery, and a program has been feed into the Arduino that helps to set the desired temperature range of the surface of the thermo-electric material cooling the skin. When the set upper temperature range of the surface gets higher than the circuit energizes the device and on achieving the lower temperature set, the circuit deenergizes the device by turning it off. There is also a timing switch which choose the time duration for the on/Off operation of the device during the cooling operation.

The components used in digitizing the device includes

- Arduino
- An electrical circuit containing resistor, capacitor, input and output ports
- LED with buttons to display and set the temperature range and the timer
- A thermal sensor attached to the surface of the cooling side of the thermoelectric material to sense it's temperature

The working of the circuit is such that the direct current provided by the dry battery passes through the capacitor and reaches to the Arduino and energizes it. The Arduino then On or Off the device on the basis of the temperature feedback by the thermal sensor. If the temperature sensed is in the desire range of what we have setted then it does not turn off the device. As soon as the temperature gets higher and finally cross the setted upper temperature range the Arduino turns off the device and it starts cooling. Now, on cooling, when the setted lower temperature limit is reached, the Arduino turns off the device again. Thus, it not only enables to set our own desired temperature range but also provides an efficient way of controlling our power consumption.

The electric circuit along with the sensor is shown below

Fig 3.13: Available Prototype

3.5.1) Arduino

The Arduino used in the project is the UNO Arduino because it is the most commonly used and documented board of the Arduino family. It is basically a microcontroller board with 14 digital I/O ports, 6 analog inputs, 16 MHz quartz crystal, USB connection, power jack, ICSP header and a reset button. The program was made in the Arduino software which have been outsourced and was fed into the Arduino by simply using a power cable and connecting it to the computer. After the program was incorporated in the Arduino, it was powered by a 5V dry battery, which energizes it through a capacitor.

3.5.2) Electrical Circuit

The electrical circuit consists of capacitor, resistor and an input port and two output ports. The capacitor is installed after the input port and the current goes through it to the Arduino to energize it. The capacitor actually filters the current so that it may not damage the Arduino board. After that the current passes through a resistor and to the output ports to power the device and the fan. One output port is connected to the device and the second output port is connected to the fan. The resistor provides a better control of current through it so to avoid damaging the deice and the fan. The Arduino board also has an LED installed to it

3.5.3) LED

The LED is connected to the Arduino board and displays the information extracted from the Arduino board and the thermal sensor attached to the cooling surface of the device. It displays the current temperature of the surface by extracting the information from the thermal sensor. With the help of several buttons connected to the Arduino board, placed below the LED, it helps us to set the desired temperature range and the timer. The timer actually turns on the device during its operation for the desired time, and then keeps the device off for the same time to avoid any cooling sensation jerk experiences to the user. For example, if we set the timer to seconds, it will keep the device on for 5 seconds and then keep it off for 5 seconds afterward during the operation of the device.

3.5.4) Thermal Sensor

The thermal sensor is placed on the cooling side of the surface of the device to record the current temperature readings and display it on the LED. The sensor also provides feedback to the Arduino on the basis of which it makes decision of whether to keep the device On or Off. If the sensor shows a current value that is higher than the setted temperature limit on the LED, the device will get turned On by the Arduino and when the sensor starts showing the lower temperature limit as the current temperature of the cooled side, the Arduino will turn Off the device until it reaches the upper temperature limit.

3.5.5) Advantages

The advantage of digitization of the project is that it has helped in setting the desired temperature range of the device and preventing it from cooling the person more than the desired cooling temperature. It not only helps us to achieve the desired cooling temperature but also has contribute a lot in the power consumption efficiency. It turns off the device when the lower temperature limit is achieved and keeps it off until the upper temperature limit is reached, thus not only keeping the temperature between our desired range but also providing a very effective way to reduce the power consumption. Moreover, it has enabled the project to provide an instant dose of thermal comfort at the touch of a button whenever you need it and for how much time. The timer built in the digitization also helps to prevent sudden jerks from high cooling rates by controlling the time limit of the device On/Off operation during it's working. The future goal is to incorporate the electric circuit and the LED onto the device and making it compact, simple and easy to use, while at the same time, giving it a shape of just a wrist watch.

3.5.6) Disadvantages

The disadvantages of digitization of the project is that it has used a complex electrical circuit in which certain problems can arise due to voltage fluctuations and could burn up the component, and if even one component gets damaged, there is a risk of damaging the other components and also a complete shutdown of the whole project. Sensitivity has become a problem. Another problem with digitization is the space that it is going to take on the device. As one of our goals is to make the device simple and compact, digitization has incurred a barrier in compacting it. This problem was solved by making the electrical circuit simple and using Arduino based programming and it can be now fitted into another small box placed right close to the device box.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1) REAL TIME TEMPERATURE RESULTS:

We measured the temperature response of the thermoelectric material with respect to time by an IR Thermometer on these bases.

- By powering the device directly with the power supply
- By powering the device through an electrical circuit with one second timer
- By powering the device through the digitization circuit

- **By powering the device directly with the power supply**

Table 4.1: Temperature measured w.r.t Time

Time (sec)	Temperature
0	33.5
20	30.9
40	29.2
60	26.9
80	25
100	22.1
120	23.5
140	22
160	20.9
180	18.3
200	20
220	18.5

240	17.1
260	16.6
280	15.9
300	16.9

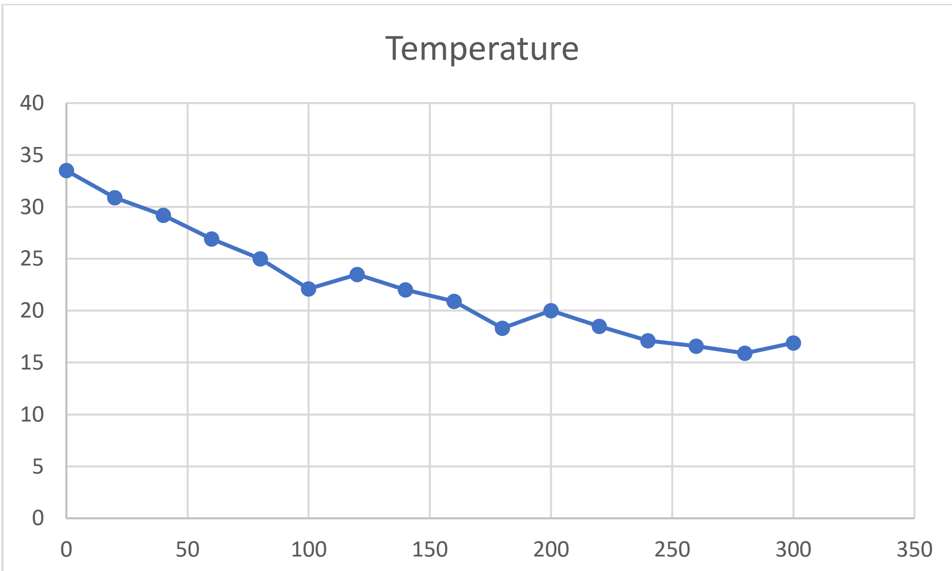

Fig 4.1 Temperature measured w.r.t Time

The minimum temperature shown by the IR thermometer during the 5-minute period was 15.8 and an average of 16.1 was shown on it.

- **By powering the device through an electrical circuit with one second timer**

Table 4.2: Temperature measured w.r.t Time

Time (sec)	Temperature

0	35.4
20	32.3
40	30.3
60	30.8
80	30.4
100	28.4
120	27.7
140	27.4
160	28
180	28.2
200	28.4
220	27.8
240	27.7
260	26.9
280	26.5
300	26.2

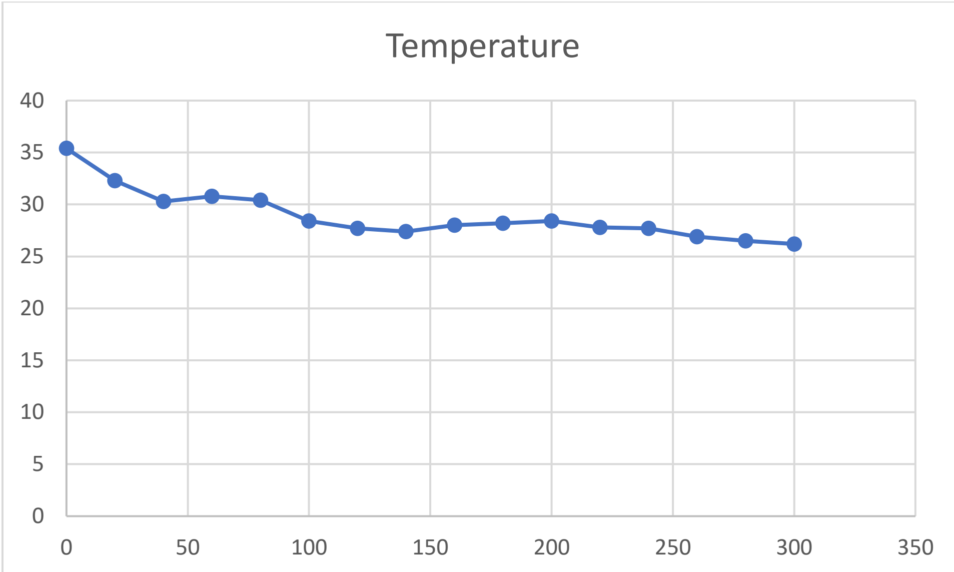

Fig 4.2 Temperature measured w.r.t Time

The minimum temperature shown by the IR thermometer during the 5-minute period was 26.2 and an average of 27.8 was shown on it.

- **By powering the device through the digitization circuit**

Temperature range set (24-26)

Table 4.3: Temperature measured w.r.t Time

Time (sec)	Temp (24-26)
0	31.5
20	28.9
40	29.2
60	27.8
80	26.6
100	27.7

120	24.5
132	24
140	24.2
160	24.7
180	25.1
200	25.8
206	26
220	25.7
240	24.9
260	24.3
268	24
280	24.3
300	25.1

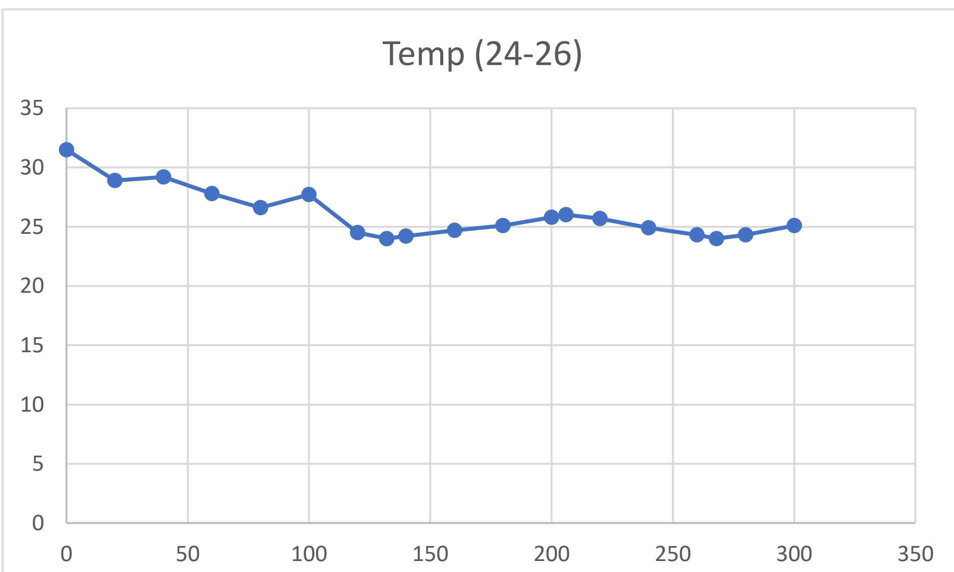

Fig 4.3 Temperature measured w.r.t Time

Temperature range set (20-22)

Table 4.4: temperature measured w.r.t Time

Time (sec)	Temp (20-22)
0	35
20	32.3
40	30.7
60	31.8
80	27.1
100	25.8
120	23.9
140	24.9
160	22.6
180	20.8
200	20.2
203	20
220	20.4
240	20.8
260	21.3
280	21.6
300	21.9

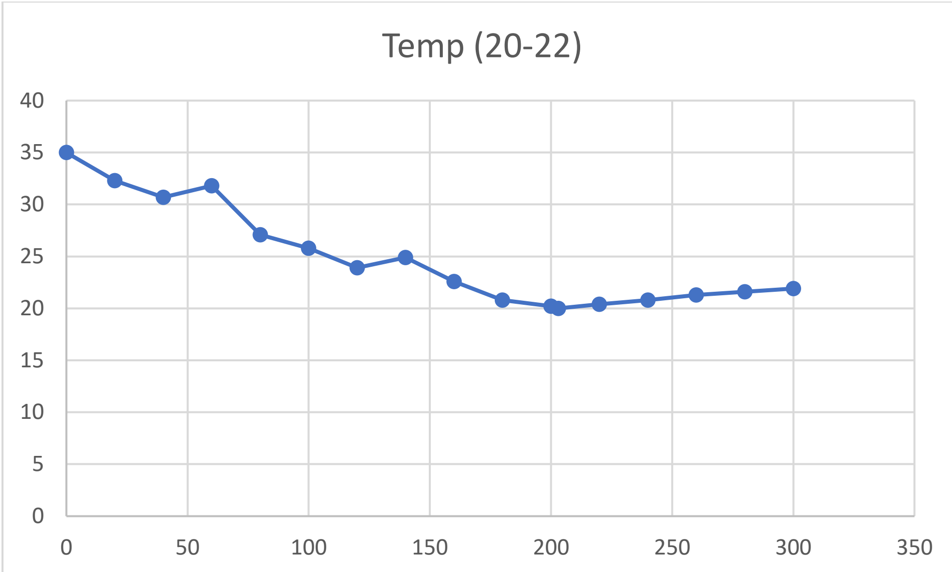

Fig 4.4 Temperature measured w.r.t Time

Temperature range set (18-20)

Table 4.5: temperature measured w.r.t Time

Time (sec)	Temp (18-20)
0	31.2
20	30.9
40	29.2
60	27.1
80	26.7
100	23.1
120	23.8
140	22
160	20.8

180	19.4
200	20.1
220	18.8
240	18.1
242	18
260	18.7
280	19.5
300	19.8

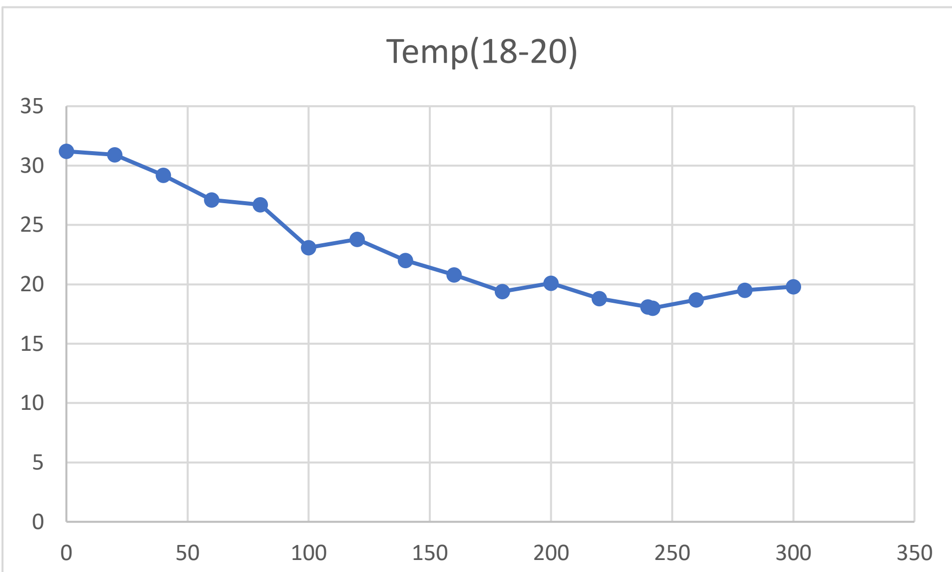

Fig 4.5 Temperature measured w.r.t Time

CHAPTER 5: CONCLUSION

In light of the progress report, the following can be concluded

5.1) Coefficient of Performance:

COP of the thermoelectric cooler that we're using is more than enough to produce a good cooling effect, although its efficiency is lower than the run of the mill Air Conditioners but the net power usage will be lesser, as the thermoelectric cooler is used to cool a single body rather than a whole room which is the case for Air Conditioners.

5.2) Structural FEM Analysis:

The FEM analysis of the prototype of thermoelectric cooler show that our model is structurally feasible and stable and can be used for further testing.

5.3) Thermal FEM Analysis (Static)

The thermal analysis which was carried out at a general 22 C ambient temperature show that a temperature of -7.6 C was produced under the skin in the blood line, after the convection and conduction. This cooling effect is more than enough for a single human body, it will definitely have to be controlled to control the temperature on the skin to prevent any disease resulting from a change in temperature more than 0.5 C.

5.4) Thermal FEM Analysis (Transient)

The results obtained from this analysis were the same as static thermal analysis after a little time, which shows that it takes a very low starting time which concludes that a lot of power is not lost while starting the device i-e it almost act as an electronic device as the change in temperatures from the initial condition to the steady condition are very rapid

5.5) Forced Convection Analysis

The convection without the fan was found to be more than enough for the cooling effect, but the analysis for cooling with the fan i-e forced convection analysis is being carried out, the results of which are expected to be favorable.

5.6) Final Design

The Heat Sink and Exhaust Fan heat exchanger is more than enough to carry out the main function of the prototype, but due to its size and weight, it cannot be used as the final

5.7) Product

The design as can be seen is uncomfortable to wear for a longer time right now, but research is being conducted to make it smarter, agile and prettier.

CHAPTER 6: RECOMMENDATION

6.1) Available Prototype:

We already have a working prototype of our model with a laptop processor heat sink and fan as heat exchanger and external battery.

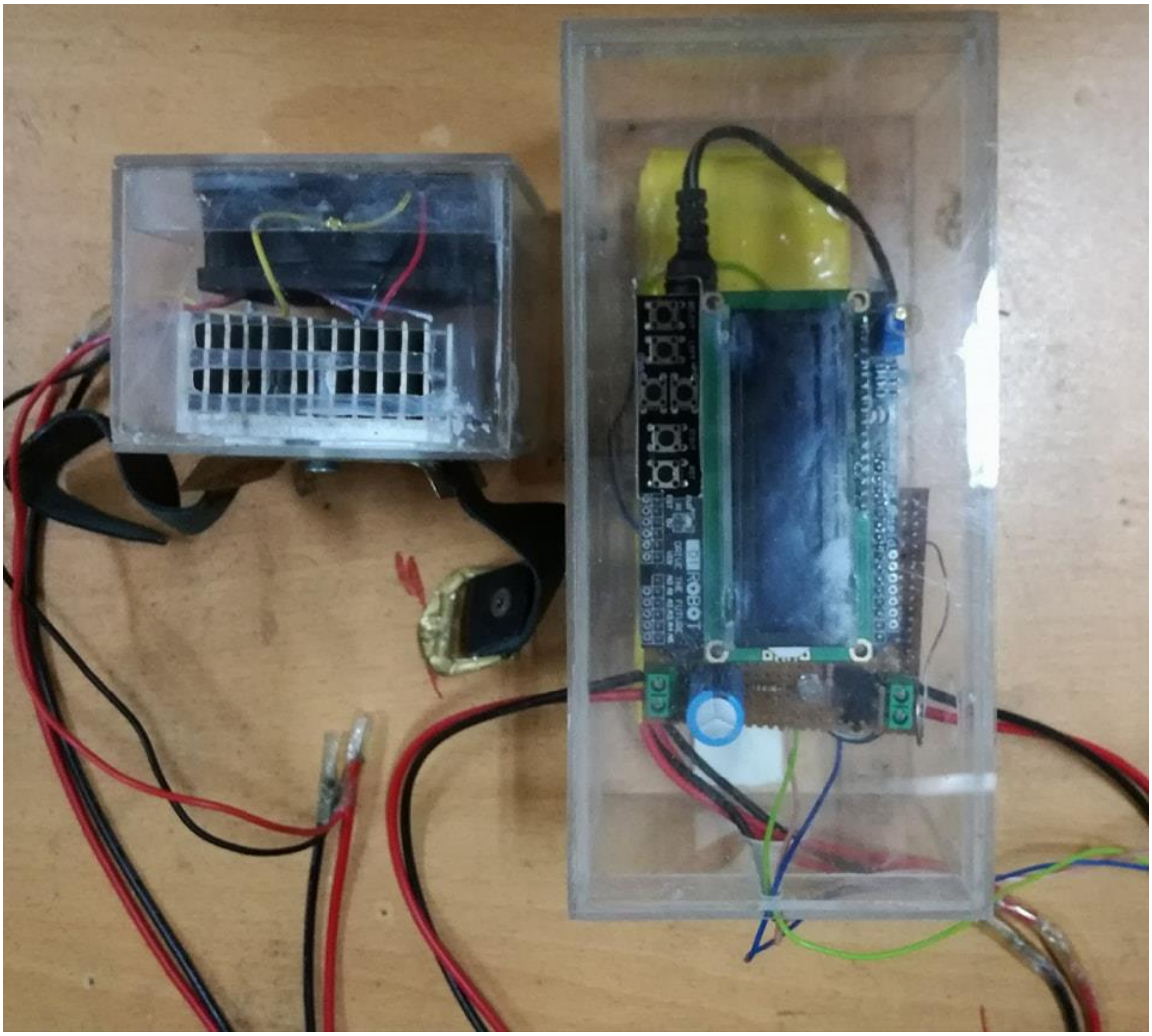

Fig 6.1: Available prototype

6.2) Future Work:

Work is being done on the forced convection analysis of the cooling system by a fan bolted on the top of the heat sink which can be seen in the model geometry.

The working prototype that we have right now is larger in size and is uncomfortable to be worn for longer time, also the battery used for the purpose right now is larger and separate from the prototype.

In future prospects, the size, weight and design need to be changed to give it a smarter, good looking and wrist band type look. The heat exchanger right now is a heat sink with a fan for forced convection which needs to be changed to micro heat exchanger to lessen the weight and size. Battery needs to be inserted in the prototype, so that its size needs to be shortened for which purpose we are thinking of using Lithium-Ion.

Furthermore, to design a jacket with both wrist band and neck cooling technology are under thinking process, also we are thinking of making a wearable cooling system powered by Solar Energy.

REFERENCES

[1] https://en.wikipedia.org/wiki/Thermoelectric_effect0029 [accessed on 06/10/2017]

[2] https://en.wikipedia.org/wiki/Climate_of_Pakistan [accessed on 15/10/2017]

[3] https://en.wikipedia.org/wiki/Thermoelectric_materials [accessed on 02/02/2018]

[4] https://en.wikipedia.org/wiki/Thermoelectric_materials [accessed on 02/02/2018]

[5] Dughaish, Z. H. "Lead telluride as a thermoelectric material for thermoelectric power generation." Physica B: Condensed Matter 322.1-2 (2002): 205-223.

[6] https://en.wikipedia.org/wiki/Human_body_temperature [accessed on 27/10/2017]

[7] McBride, A., et al. "Thermoelastic modelling of the skin at finite deformations." Journal of thermal biology 62 (2016): 201-209.

[8] https://spinoff.com/wristify [accessed on 27/12/2017]

[9] https://spinoff.com/wristify [accessed on 15/12/2017]

[10] Benevento Jr, Vincenzo P., and Barbara M. Benevento. "Cap having evaporative cooling interior apparatus." U.S. Patent No. 5,365,607. 22 Nov. 1994.

[11] Strauss, Ted N. "Evaporative personal cooler." U.S. Patent No. 5,802,865. 8 Sep. 1998.

[12] Chaplin, David V. "Thermoelectric crash helmet cooling system with no mechanically moving components or fluids." U.S. Patent Application No. 12/459,991

[13] Arnold, Anthony P. "Personal heat control." U.S. Patent No. 5,970,718. 26 Oct. 1999.