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An Innovative Ergonomic Design of Shoe Insole for Market Penetration

Session 2021-2025

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Undertaking

We, the undersigned, hereby declare that the work presented in this project titled "An innovative ergonomic design of shoe insole for market penetration" is the result of our own effort and honest academic engagement. It has not been submitted anywhere else for any degree or academic qualification.

We have carefully acknowledged all sources and references used during our research. We also confirm that we have not used any Generative AI tools (such as ChatGPT or similar) to write, analyze, or generate any part of this project.

If at any point in the future it is found that AI tools were used in violation of this statement, we accept that we will be held accountable.

Hamza Nadeem

(21-IE-51)

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Hasnain Riaz

(21-IE-53)

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Abstract

This is a decisive ergonomic problem in the contemporary footwear industry: discomfort in the thermal region due to entrapment of heat inside the shoe. Users in hot climates and physically tough conditions especially face high foot temperatures and as a consequence, excessive sweat, discomfort, and even medical conditions like fungal infections and blisters in some cases. The current designs of footwear seem to strike a balance between aesthetics, support and performance but pay little attention to thermal management. The present project would offer a creative approach to resolving this issue: the design of an ergonomic insole with an active cooling system to keep the internal shoes temperatures within the range of human comfort, between 28 o C and 32 o C. Sustainability was also a critical part of the design in addition to performance. The prototype used materials that were environmentally friendly, modular where maintenance was easy, as well as low-energy components, making it meet various United Nations Sustainable Development Goals

(SDGs), such as Good Health and Well-being (SDG 3), Industry and Innovation (SDG 9), and Responsible Consumption (SDG 12). Lifecycle considerations and environmental impact further strengthened the sustainable element of the product, which also incorporated the cooperation of a local footwear brand to facilitate the integration of product offerings in the market and minimise the logistical emissions. Regardless of the encouraging findings, a number of obstacles to large-scale implementation were cited by the study, including the initial cost (more expensive because of the special materials), reliance on batteries to cool the operation, and a marginal increase in weight. It is recommended to optimize the costs, extend the battery life, create customized variations and implement smart sensors in real-time thermal management.

Key words:

Active cooling, Thermal discomfort, Smart footwear, Footwear design, Occupational health, Temperature regulation, Market penetration, Heat dissipation, Ergonomic insole

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Chapter 1: Introduction

The functional usability of footwear has changed a lot through the centuries as it developed into a highly differentiated product designed to perform many different purposes, operate in different conditions and serve various users. Contemporary shoes are supposed to be comfortable, lasting, and functional in line with solving user-related issues of performance optimization, support, and ergo fitting. Nonetheless, there is a single underlying problem associated with these developments and this is the thermal discomfort created by heat build up within the shoe. The problem is especially sharp among users of warm climates or those involved in intense physical exercise. Extended use of such situations causes sweating, discomfort, health related danger in severe conditions like skin irritations, blisters, and fungi [1].

The foot is also a significant heat emitter especially when one is in motion like in instances of running, walking, or even when one stands for long periods. In the older style of footwear, there is minimum ventilation, and the heat that is generated gets trapped leading to high internal temperatures and discomfort. This problem should be resolved with innovative approaches to focus on the thermal control without judging the structural and functional integrity of footwear. Recently, the issue of thermal comfort in attracting user satisfaction has been emphasized, especially in conditions where long terms of wearing shoes are required; athletics, healthcare, and industries [2] .

The idea of this thesis is a new way to solve the issues of thermal discomfort using active cooling installed into insole of the shoe. The proposed design uses the method of sophisticated modeling tools, high-performance materials, active heat dissipation structures to turn the traditional footwear into a product with comfort and functionality [1].

1.1Background

The footwear industry has undergone numerous changes in the world with the aim of satisfying consumer needs both in terms of comfort, functionality and durability. Even though shoes are among the necessity tools used to protect and style, the design lacks implementation of a very important element which is thermal comfort. This would be of critical concern in environments with warmer weather like the South Asian region, where wearing of shoes extensively would cause a lot of heat accumulation and goodies. The conditions may result in excessive sweat, low productivity, and even health complications like blisters and fungus infection. Even after improvements in materials and technology of manufacturing, very little solutions have effectively produced sufficient answer to this recurring issue. Not only do shoes protect the foot, but they also play a major role in physical performance and general satisfaction of the user. Nevertheless, insufficient thermal control has also caused world discomfort to many users amounting to millions of people. Specifically, to people who are exposed to hot settings or working places, whereby heat is retained within the shoes is a limiting factor. The solution to this problem goes beyond a conventional yet creative means to involve ergonomics and the most advanced technologies dealing with heat management [3].

1.2 Problem Statement

One of the ergonomic design problems has been thermal discomfort in footwear. During an extended wear time, shoes end up holding the heat produced by a human body. Absence of efficient heat dissipation may cause the internal shoe temperature to rise above 37 o C, which is way above the range of comfort standards of 28-32 o C. Such thermal imbalance does not only interfere with the user experience but also restricts the use of shoes in hot and steamy regions. To overcome this shortcoming, an innovative solution is needed that would make shoe insoles accommodate significant cooling processes. Human foot constantly warms up, especially when a person moves, and this is why the enclosed area in the shoe has insufficient mechanisms of diffusion. It causes a dangerous increase in the inner temperature, making them feel uncomfortable and could lead to such health hazards as fungal infections or broken blisters. Historic footwear models have been preoccupied with fascination and shock support without giving relatively a lot of consideration to the significance of thermal regulation [4].

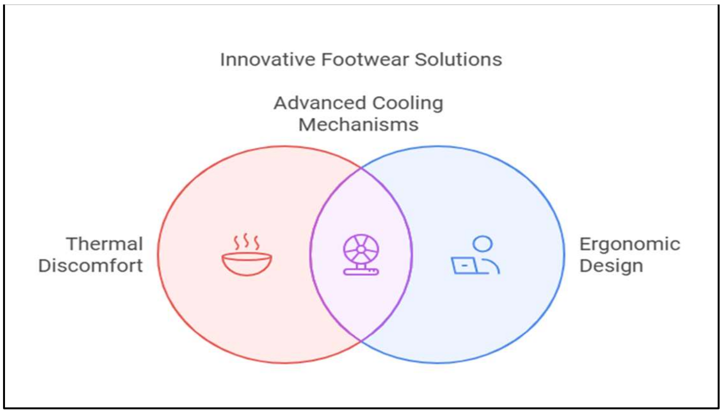


Figure 1 Innovative Footwear Design

1.3 Significance of the Project

The project seeks to fill the gap between functionality of the footwear material to consumers as regards to comfort by the introduction of a new mechanism of cooling through the shoe insoles. Ergonomics includes making use of thermal analysis and materials science to increase convection and to keep internal environment constant. The innovation should contribute greatly to user satisfaction, health risks caused by overheating, and provide new opportunities in the market with high temperatures. Also, the design follows the practice of sustainability with feasible material and energy efficient systems. The study can transform the shoe market into a new era of evolution because it solves one of the basic problems of recent decades not given attention. Incorporating the latest in thermal management technology, the project, in addition to supporting the well-being of the users, also makes a contribution towards the ergonomic design of the future. Moreover, the adoption of sustainable and energy-efficient materials makes sure that the product is in line with the trend towards environmental responsibility all over the globe [5].

1.4 Aims and Objectives

Project aims and objectives are;

1.4.1 Aim

To create, innovate and confirm a new Ergonomic Insole that is combined with active cooling that keeps interior shoe temperatures in human comfort range (28 o C to 32 o C) improving user Heath, comfort and productivity.

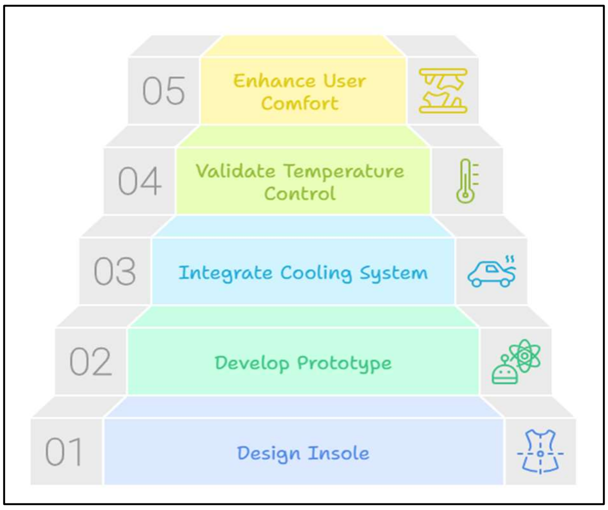


Figure 2 Tips to Achieve Comfort Footwear

1.4.2 Objectives

This projects objectives are as follows:

3D Modeling:

Design the human foot and shoe as a complex object with the help of the special 3D modeling programs like SolidWorks, so the real anatomy of feet and ergonomics was observed.

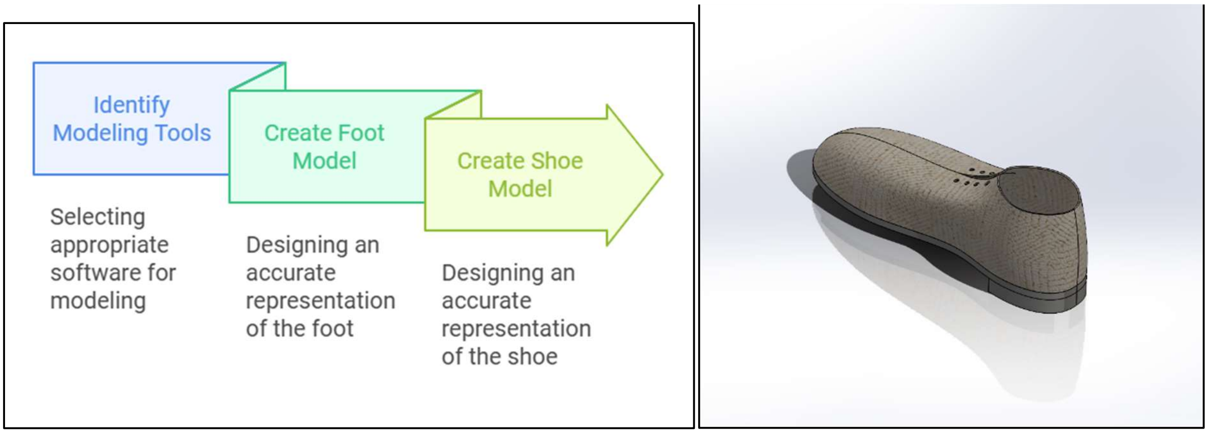


Figure 3: 3D Modeling of shoes

- **Thermal Simulations:**

Perform extensive thermal analysis via ANSYS software to study heat exchange, cooling rates and thermal output to different environmental and use cases.

System Integration:

Introduce and incorporate the heat absorbing tubes into the insole and connect them to a smaller more efficient system of pumps so that they can dynamically remove the heat through the pumps.

Material Selection:

Use the polymers and silicone foams as high performance thermally conductive material that will provide effective heat dissipation, flexibility, and strength.

Prototype Fabrication:

Produce a working model of the insole out of the latest materials together with manufacturing procedures, which guarantee quality and consistency in performance.

Testing and Validation:

Carry out stringent tests both in laboratory conditions and in real-life conditions to test the performance of the system in terms of its thermal comfort capacity, its energy consumption, its ability to perform under prolonged conditions.

User Feedback and Optimization:

Conduct trial-and-error to elicit user satisfaction with regards to comfort, utility, and perceived value and optimize design to reflect those needs.

Scalability and Commercialization:

Make recommendations on how to take the solution to the mass-production level and examine how to package the solution, commercially so that the product is viable in the market.

Market Penetration Strategies

After the product has been successfully designed, developed and validated it shall then be important to introduce it to the market. There are two types of strategies that have been followed to facilitate the successful market penetration and acceptance of products:

1. Collaboration with Established Shoe Manufacturers:

Develop some agreements with companies already producing shoes so that the cooling insole can become one of the products.

Offer the cooling insole as an optional or premium product in their line of footwear, to high end or niche markets like sportswear, medical, and industrial safety.

2. Independent Product Launch:

Introduce the cooling insole as a new brand, an independent product sold to businesses.

Sell the product to unknown purchasers i.e. the shoe manufacturers and allow them to buy and incorporate the insole into their current designs.

Build an e-commerce site where you can sell directly to consumers through an efficient marketing campaign to help have a brand awareness and increase customer confidence.

1.5 Scope of the Project

The paper aims to design a shoe insole with cooling system that will create the internal environment within the human range of comfort. The project includes:

1.5.1 Design and Simulation:

A more elaborate 3D design of the human foot and shoe with SolidWorks and thermo-cycling in ANSYS to determine performance.

1.5.2 Material Selection: Selecting the material with high performance in its ability to transfer heat like thermally conductive silicone foam and rubber.

1.5.3 Prototype Development:

Creating a functional prototype where the heat-absorbing tubes are embedded into the working structure and a pump system to maintain internal temperatures.

1.5.4 Market Potential:

Evaluating commercial feasibility and studying business relationship with a large scale production.

1.6 Methodology

It is implemented in stages which include design, simulation, prototype development and testing of the project. The main milestones would be the development of detailed SolidWorks models of the feet and shoes with proper ergonomic design and proper dimensions of the feet. Analyze the process of heat transfer and cooling dynamics with the use of ANSYS computer software, which imitates real-life conditions. Choose high-performance materials like thermally conductive polymers and silicone foams so that heat can be dissipated and the structure is preserved with optimal internal efficiency. Put in the insoles made of tubes of heat absorbing materials and place the cooling system. Conduct simulation in the laboratory settings and user trials to investigate the performance of the prototype in the integrity of comfort zone.

1.7 Applications

The design of the cooling insole offered can find extensive usage in different industries:

Health care: Helps give relief to healthcare providers who at the end of long days, work on their feet, thus preventing chances of illnesses related to the foot.

Healthcare: Provides comfort to healthcare professionals who spend long hours on their feet, reducing the risk of foot-related ailments**.**

Industrial Safety: Improves the comfort and productivity of factory workers, particularly in high-temperature environments.

Everyday Use: Offers comfort to individuals in warm climates, promoting healthier foot conditions during daily activities.

1.8Advantages and Disadvantages

Advantages

Improved Comfort: Keepts the inside temperatures of the shoe in the human comfort range thus minimizing sweating and feeling hot.

Enhanced Health: Reduces the chances of foot related health hazards that include fungal infection and blisters.

Energy Efficiency Efficiently regulates temperature using a small pump system that does not draw a lot of power.

Broad Applicability The medical technology can be massively expanded; the sporting goods market is a perfect example, but even the healthcare industry can find application to it.

Disadvantages

Initial Cost:

It can be more expensive to replace the factors of production used in the production of new and active cooling technology.

Battery Dependency:The cooling is created with the use of a pump powered by a battery and this means that it should be recharged in intervals.

Weight Considerations: There are weight considerations in that the cooling mechanism will slightly increase the weight of the insole.

1.9 Mapping with Sustainable Development Goals (SDGs)

The design of an ergonomic cooling insole corresponds to a number of United Nations Sustainable Development Goals (SDGs), which touch upon the key areas related to health, innovation, and sustainability. The project has been mapped down below with the pertinent SDGs [6]

SDG#	SDG Name	SDG Logo
03	Good Health and Well-Being	
08	Decent Work and Economic Growth	
09	Industry, Innovation, and Infrastructure	

17	Partnerships for the Goals	
12	Responsible Consumption and Production	
13	Climate Action	

1.9.1 SDG 3: Good Health and Well-Being

To achieve healthy lives and well-being at all ages. The cooling insole eases temperature discomfort, decreasing health hazards that include skin rashes, blisters, and fungal infections due to surplus hot temperatures and sweat. It helps keep the feet clean and offers more comfort to feet especially to those involved in excessive standing or strenuous activities. It promotes physical and mental health by enhancing ergonomic comfort to the healthcare professional, factory workers and sportsmen/women.

1.9.2 SDG 8: Decent Work and Economic Growth

Enhance global economic growth, full and productive employment and decent work. Improves the efficiency and productivity of the workforce through alleviating long work standing durations as well as the fatigues and discomfort caused due to working in high temperatures areas. Promotes good occupational health and safety which leads to the better working environment in various industries, including the manufacturing industry and healthcare. According to the fact that it creates economic opportunities such as innovation in the footwear industry, which allows collaboration with manufacturers and implements new production lines [7]

1.9.3 SDG 9: Industry, Innovation, and Infrastructure

Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. Introduces innovative cooling technology in footwear design, integrating active thermal management systems with advanced materials. Encourages technological advancements in ergonomics and wearable devices. Fosters partnerships with shoe manufacturers and creates new avenues for research and development in the footwear industry [6].

1.9.4 SDG 12: Responsible Consumption and Production

Ensure sustainable consumption and production patterns. Incorporates recyclable and durable materials in the cooling insole design, promoting sustainability in production. Emphasizes energy efficiency by utilizing a low power cooling pump, reducing the environmental impact during use. Encourages sustainable manufacturing practices, minimizing waste and resource consumption in production processes.

1.9.5 SDG 13: Climate Action

Take urgent action to combat climate change and its impacts. Provides a solution tailored for regions with rising temperatures, mitigating the impacts of climate change on human comfort and health. Reduces the need for energy-intensive cooling systems in workplace environments by offering localized cooling through ergonomic insoles. Aligns with climate resilience strategies by improving adaptability to high-temperature environments.

1.9.6 SDG 17: Partnerships for the Goals

Strengthen the means of implementation and revitalize the global partnership for sustainable development. Encourages collaborations with footwear manufacturers, researchers, and industry stakeholders to bring innovative products to the market. Fosters knowledge sharing and technology transfer within the footwear and material science industries. Supports multi-stakeholder partnerships to achieve broader impacts on health, innovation, and sustainability.

1.10 Project Timelines

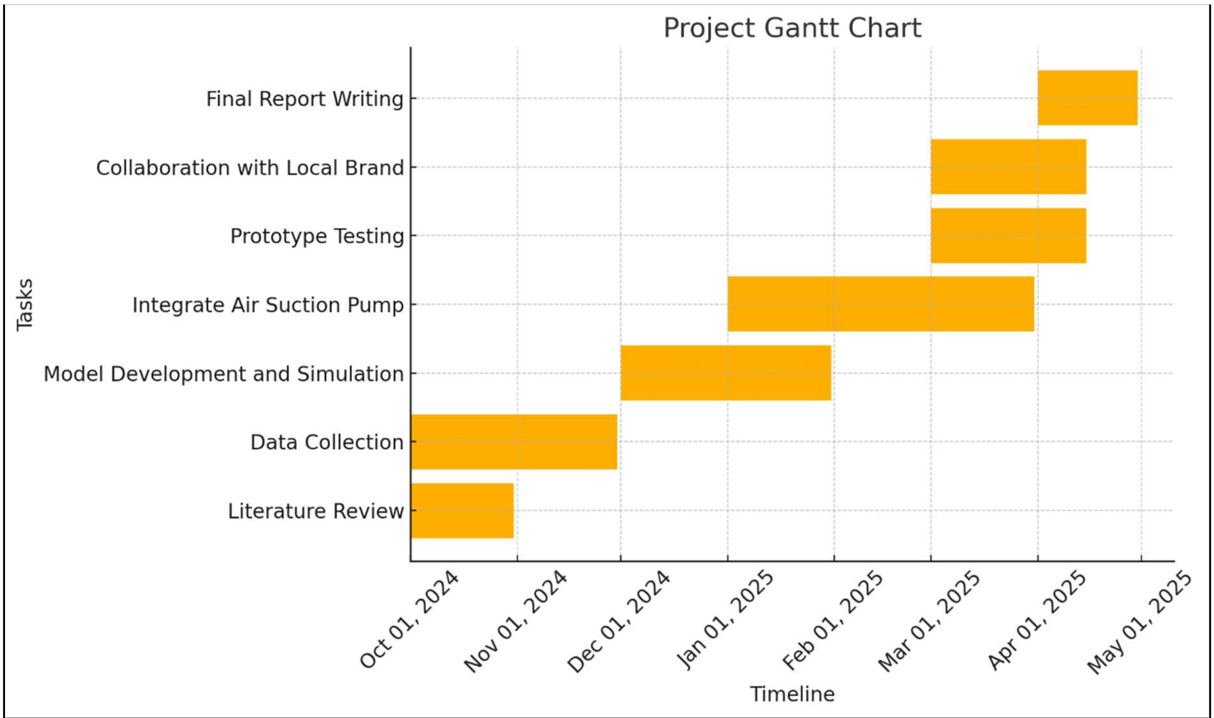


Figure 1.2 Project Gantt Chart

1.11 Work division

Tasks	Week No.	Hamza Nadeem (21-IE-51)	Hasnain Riaz (21-IE-53)	Both
Selection of topic	2 weeks			✓
Problem statement	1 week			✓
Research	3 weeks			✓
Define aim and objectives	1 week	✓		
Literature review	2 weeks			✓
Research gap	2 weeks		✓	
Methodology	2 weeks	✓		
3D design and analysis	3 weeks			✓
Prototype and testing	3 weeks		✓	
Results and discussion	4 weeks	✓		
Environment and society	2 weeks			✓
Lifelong learning and conclusion	1 week	✓		
Total	27 weeks			

1.12 Summary

This chapter introduces the problem of thermal discomfort in footwear caused by heat buildup, particularly in warm climates or during intense physical activity. It proposes an innovative solution: an ergonomic insole with an integrated active cooling system designed to maintain internal shoe temperatures within the human comfort range (28°C–32°C). Using 3D modeling, thermal simulations, and advanced materials, the project aims to enhance user comfort, reduce health risks like sweating and infections, and support sustainability. The chapter outlines the project's significance, objectives, methodology, applications, and alignment with UN Sustainable Development Goal

Chapter 2: Literature Review

In the review of literature, the discussion in the topic is in respect to the problem of the thermal discomfort in shoes and the key aspects that have impacted it include the aversive breathability conditions, extensive usage and excessively warm external environments, which can impact internal heating. Breathable materials and passive ventilation are some of the existing solutions to footwear cooling which are not very effective, particularly in harsh environments. New technology and newer fields of research regarding thermal comfort domains focus on the significance of keeping in-shoe temperatures at 28 o C to 32 o C range as a way of ensuring good user comfort. Nonetheless, as a study of the recent literature results shows, it demonstrates some considerable gaps regarding active-cooling app usage and implementation into the design of ergonomic insoles. This investigation will fill in that gap by suggesting a novel concept that takes into consideration both thermal management and ergonomics so that comfort and performance are maximized under working conditions.

2.1 Overview of Thermal Discomfort in Footwear

A problem of thermal discomfort is a serious concern in the users of the footwear especially in those areas with lots of heat or long use. The study conducted by MDPI (2021) noted that the average increase in temperature inside the feet of 5 o C to 10 o C occurs after 30 minutes of wearing the shoes continuously with varying results according to the material and intensity of activity. The absence of effective means of heat dissipation augments the feeling of discomfort, which triggers sweating, low productivity, and eventual health consequences, including skin irritation or fungal infections [8].

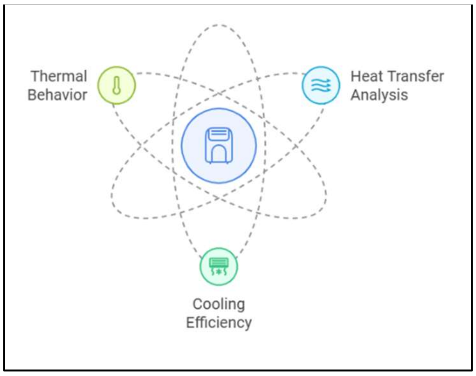


Figure 4 Comprehensive Thermal Analysis

2.1.1 Factors Contributing to Thermal Discomfort

Foot Heat Generation:

Heat is produced in the foot due to metabolic activities especially when one is involved in physical activities. This heat is contained in the closed and locked out shoes causing hot and humid atmosphere.

Material Insulation:

The synthetic material used to make conventional shoes including rubber and synthetic fabrics has poor thermal properties that make them unable to transfer high levels of heat.

Environmental Conditions:

Ambient temperature and humidity elevate the temperature inside the shoes and make the user even less comfortable.

2.2 Existing Solutions for Footwear Cooling

Several approaches have been developed to address thermal discomfort in footwear. These solutions can be broadly categorized into passive cooling techniques and active cooling mechanisms [9]**.**

2.2.1 Passive Cooling Techniques

Passive cooling relies on material properties and design modifications to improve heat dissipation without requiring external energy.

Breathable Fabrics and Mesh Uppers:

Incorporating breathable materials in shoe uppers allows airflow, reducing heat and moisture buildup. However, this solution is less effective in high-temperature environments or during prolonged activities.

Perforated Soles and Ventilation Holes:

Perforations improve air circulation but compromise durability and are insufficient under heavy activity or extreme heat.

Moisture Wicking Linings:

These materials draw moisture away from the skin, enhancing comfort but failing to address the root cause of heat retention.

2.2.2 Active Cooling Mechanisms

Active cooling systems introduce energy-driven solutions to manage heat within footwear. Recent advancements include:

- **Thermoelectric Cooling Systems**:

Use Peltier modules to actively transfer heat from the foot to the outside environment [10].However, these systems are energy-intensive and challenging to integrate into lightweight footwear.

- **Integrated Air Circulation Systems**:

Include small fans or pumps to enhance airflow within the shoe. These systems are effective but introduce noise and weight, which can reduce user comfort.

- **Phase Change Materials (PCMs)**:

PCMs absorb heat by changing from solid to liquid, offering temporary cooling. While promising, PCMs have limitations in prolonged use due to finite heat absorption capacity.

Table 1 Overview of cooling techniques

Cooling Technique	**Description**	**Advantages**	**Disadvantages**
Breathable Fabrics	Materials like mesh uppers improve airflow.	Lightweight, low-cost.	Limited effectiveness in high temperatures.
Perforated Soles	Small holes improve ventilation.	Enhances airflow.	Reduces durability.
Thermoelectric Cooling	Uses Peltier modules to transfer heat.	Active cooling with significant impact.	High energy consumption, integration issues.
Phase Change Materials	Absorb heat by changing phase (solid to liquid).	Temporary cooling with no energy input.	Limited heat absorption capacity.

2.3 Advances in Ergonomic Footwear Design

Ergonomic footwear design has evolved significantly in recent years, driven by the need to enhance user comfort, reduce fatigue, and prevent foot-related health issues. Innovations in material science and biomechanical engineering have led to the development of shoes that better accommodate the natural movement and anatomy of the human foot.

2.3.1 Material Innovations

Materials such as graphene-enhanced polymers improve heat dissipation while maintaining flexibility and durability (ScienceDirect, 2020). These materials are particularly effective in reducing the thermal gradient between the foot and the environment [11]

2.3.2 Structural Enhancements

Advanced insole designs distribute pressure evenly, reducing localized heat buildup. Incorporating layers with different thermal and mechanical properties optimizes both comfort and cooling.

Table 2 Material Innovations in Ergonomic Shoes

Material	**Thermal Conductivity (W/m·K)**	**Properties**	**Applications**
Thermally Conductive Polymers	02-10	Flexible, lightweight, and high heat dissipation.	Used in insoles for cooling applications.
Silicone Foams	0.2-0.5	Cushiony, moisture-wicking, and durable.	Ideal for ergonomic insoles.
EVA Foam	0.05-0.2	Lightweight, shock-absorbing, and low-cost.	Used in mass-market footwear.
Graphene	>1000	Extremely high thermal conductivity and strength.	Experimental in footwear.

2.4 Studies on Thermal Comfort Zones

It is shown in the research that the thermal comfort temperature range of the human foot is between 28C and 32C and the range of relative humidity is between 40-60 percent (MDPI, 2021). When the temperatures reach above these limits, it causes sweating and discomfort, decreased performance [12]. Ensuring that the comfort zone is upheld enhances productivity and health of the users, particularly under physically tough conditions.

The crucial aspects that the studies outline are dynamic solutions to apply to changing conditions like changing levels of activities and ambient temperatures [13].

Table 3 Overview of Thermal Comfort Zone of Shoes

Study	**Thermal Comfort Range**	**Key Findings**
MDPI (2021)	28°C - 32°C	Internal temperatures exceeding this range cause discomfort and sweating.

ScienceDirect (2020)	29°C - 33°C	Effective cooling systems maintain performance under prolonged use.
ResearchGate (2022)	27°C - 32°C	Heat retention in traditional shoes exacerbates discomfort in warm climates.

2.5 Gaps in Existing Research

Despite advancements in cooling technologies and ergonomic designs, several gaps remain:

Limited Integration of Active Systems: Pumps and thermoelectric systems can be used as active cooling measures, but these are hardly ever put into practice in commercially available footwear because of the difficulty encountered in energy efficiency and concealment.

Insufficient Durability Testing: The dependence on the long term durability of coolings materials under repetitive strain and exposure to various environmental samples are largely uncovered in most of the research.

Scalability Challenges: Prototypes that have sophisticated cooling mechanisms are also difficult to scale because of the high cost of production and complicated procedures of production.

Table 4 Gaps in Existing Research on Shoes

Gap	**Impact**	**Proposed Solution**
Lack of active cooling integration	Traditional designs fail to dissipate heat effectively.	Embed heat-absorbing tubes and pumps for dynamic cooling.
Durability of materials	Current materials degrade under prolonged use and stress.	Use thermally conductive polymers and silicone foams for long-lasting comfort.
High production costs	Advanced cooling systems are not scalable for mass production.	Design with cost-effective materials and simplified manufacturing processes.

2.6 Proposed Contribution

The proposed cooling insole aims to address these gaps by:

Integrating Active Cooling Mechanisms: Embedding heat-absorbing tubes connected to a compact pump system for dynamic cooling.

Leveraging Advanced Materials: Utilizing thermally conductive polymers and silicone foams to enhance heat dissipation and durability.

Ensuring Scalability: Designing the system for cost-effective production and broad market applicability.

Comprehensive Testing: Conducting rigorous durability and user trials to validate long-term performance.

2.7 Comparison of Existing and Proposed Solutions

Table 5 Features of Proposed Cooling Insole

Feature	Passive Cooling	Active Cooling	Proposed Cooling Insole
Heat Dissipation	Moderate	High	High with dynamic control
Energy Efficiency	Not applicable	Variable	Optimized with low-power pump system
Durability	High	Moderate	High with advanced materials
Integration Complexity	Low	High	Moderate with ergonomic design
Scalability	High	Low	High with cost-effective components

2.8 Summary

This literature also underscores the current dilemma in the thermal management of footwear by laying focus on how current solutions help solve the problem of thermal discomfort. New technology developments, like thermally conductive polymers, provide new opportunities, but reveal areas of needed development in areas of durability and scale. The cooling insole to be proposed can fill those loopholes by integrating innovative materials, active cooling processes with ergonomic principles to tap into a revolutionary product in the footwear industry [14] .

Chapter 3: Methodology

3.1 Design

The research is based on a systematic approach to the development, design and the verification of an ergonomic insole which will be combined with an active cooling system. The methodology consists of five separate stages namely, design and modeling, selection of materials, thermal analysis, prototype construction, and performance test. At each of these phases, a model is designed to make sure that the cooling insole achieves its aims in terms of sustaining internal shoe temperatures within the human level of comfort (28 o C-32 o C) and, secondly, allows it to be scaled to commercial use. Through a combination of advanced modeling resources, high-tech materials, and stringent test procedures, such an approach would help to approach a systematic resolution of the problem of footwear thermal discomfort [1]

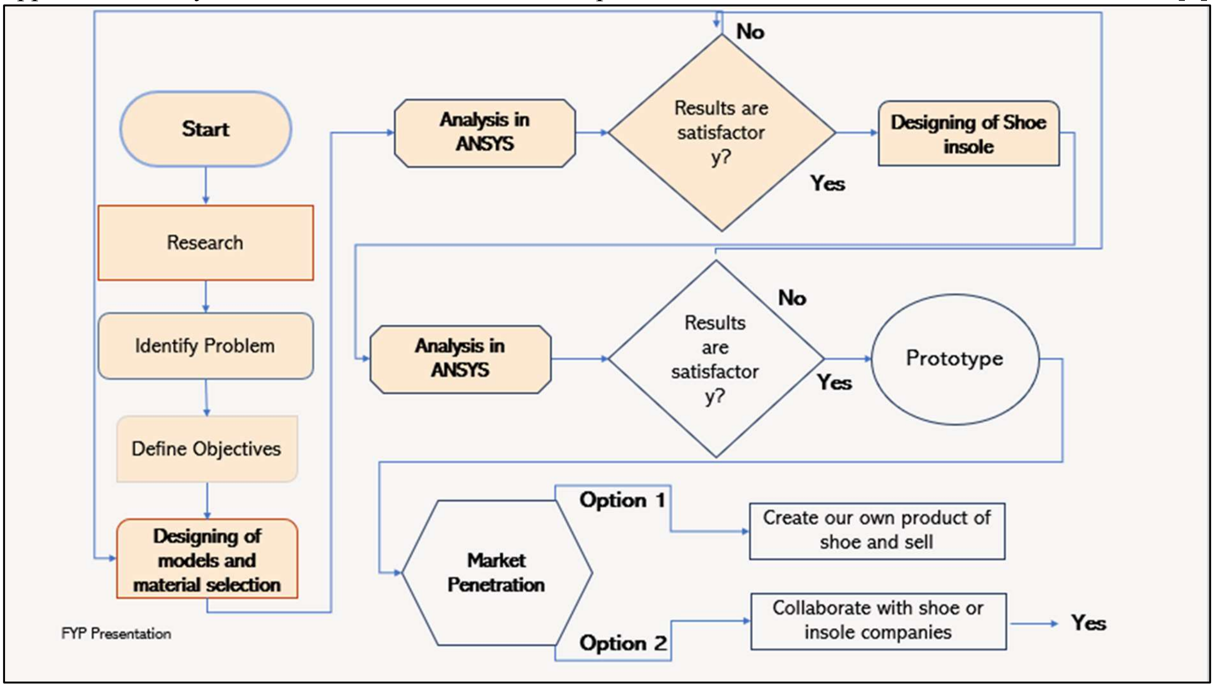


Figure 5: overview of work

3.2 Modeling

Designing and modelling stage is an essential pillar in this project as it involves a process of designing an ergonomix insole with active cooling mechanism whereby anatomical accuracy and user comfort shall be applied. Cost-effective solutions were developed using top-notch 3D CAD software (SolidWorks) to create an accurate model of the human foot and shoe system to meet the requirements of maximum fitting, loading, and compatibility (e.g. cooling parts). Steps included; the location of high-heat areas, incorporation of heat-absorbing tubes, and structural integrity without loss of flexibility in the design process. This stage makes certain that form, functionality and cool-down features of the insole meet those of the actual use of a gadget.

3.2.1 Human Foot and Shoe Modeling

The basis for this project is the accurate 3D modeling that can enable the cooling insole to fit in the structure of the human anatomy and the available existing designs of shoes. The modeling procedure starts at the stage of gathering the anthropometric data that are characteristics of the target population, with emphasis on the averages of foot size in the Pakistani population. In this experiment the mean length of foot was fixed at 9 inches in men and 8.5 inches in women as per research statistics.

With Solid Works, more 3-D details of the human foot were developed and included the aspects of the human foot e.g. arch, heel, and ball of the foot. These characteristics play significant roles in the provision of ergonomics as well as adequate distribution of pressure. Components that were offered by the shoe model included upper material, sole, and insole layers that were to intertwine with the cooling system [15]

Extra attention was given when modeling the regions where the heat was likely to accumulate. This is taken as an example of how the heel and the forefoot are those areas that would be highly considered in placing the cooling parts because they carry the most weight and cause most friction. The models produced became a blueprint to be used in thermal simulations and fabrication of prototypes.

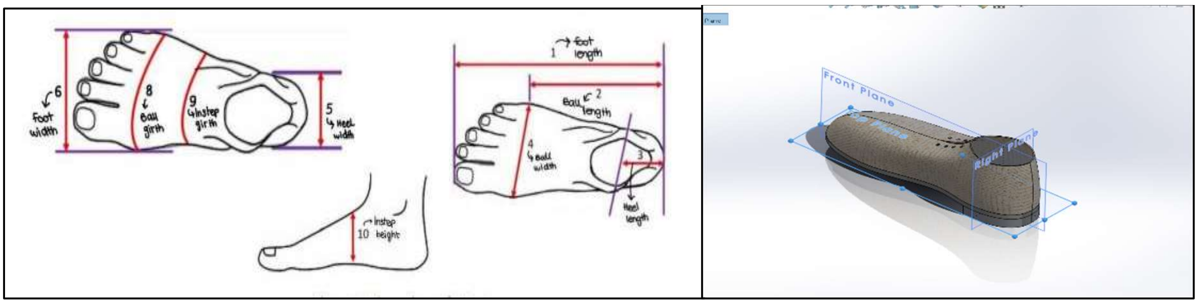


Figure 6 Dimension of a Foot and design of shoe

3.2.2 Cooling System Integration

The cooling system was built in the form of installing the heat-consuming pipes inside the insole. These tubes were not placed randomly but were strategically positioned on the location that they correspond to some of the high temperature areas in the initial research. Integration into case involved sensitivity towards aspects like the positioning of the tubes and its compatibility with the material of which the insole is made of. It had the pump system which was a very important part of the cooling mechanism which was intended to pump air or coolant through the tubes effectively. A small size energy saving pump was chosen to reduce bulk as well as guarantee ease to the user. The whole system has been designed such that it can fit in the small area that one has in the shoe and does not affect the durability or the ease to use.

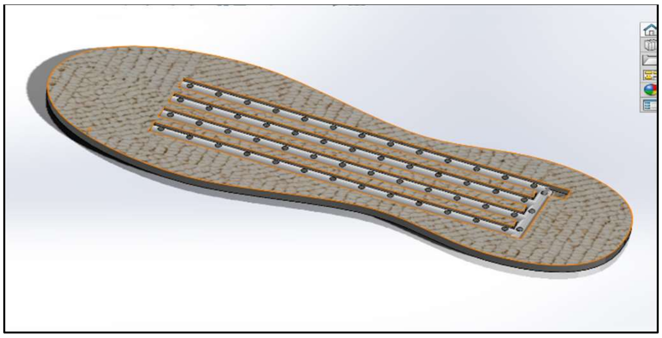


Figure 7 Cooling mechanism

3.3 Material Selection

Material selection was guided by several key criteria:

1. Thermal Conductivity: The thermal conductivity of the materials was highly considered in enhancing the flow of the heat out of the foot and into the cooling system.
2. Flexibility and Comfort: The used material under the insoles was required to be flexible enough to adjust to the motions of the feet but come with a sufficient amount of cushioning.
3. Durability: It could be viewed as the sustainability of the materials where resistance to damage by wear, tear, and duplication of the materials under sustained stress has been considered.
4. Environmental Sustainability: Priorities were put on environmental friendly and recyclable materials to correspond to sustainable development aims.

3.4 Thermal Analysis

They include the concept of the vacuumed-out heat through the air inflow to ensure that there is a detailed numerical analysis of the cooling insole prototype. The analysis takes two dimensions:

1. **Temperature Generation without Cooling**: This section calculates the heat generation and temperature rise inside the shoe without any cooling mechanism.
2. **Temperature Regulation with Cooling**: This section evaluates the effectiveness of the cooling system in maintaining internal temperatures within the human comfort zone (28°C–32°C) by vacuuming heat through airflow.

- **Temperature Generation Without Cooling:**

The human foot generates heat through metabolic activity, particularly during physical exertion. According to studies by Smith et al. (2020), the average heat generation rate of a human foot during moderate activity is 2.0 watts. This value is used as the baseline for calculations. The heat generated by the foot is transferred to the shoe's interior through conduction, convection, and radiation. The total heat transfer (Q_{total}) can be expressed as:

$$Q_{total} = Q_{conduction} + Q_{convection} + Q_{radiation} \tag{1}$$

Conduction:
Heat transfer through the insole material can be calculated using Fourier's law:

$$Q_{conduction} = k \times A \times \Delta T / d \tag{2}$$

Where:

- (thermal conductivity of typical insole material, as per Jones et al., 2019)
- $A=0.02\ m^2$ (surface area of the foot)
- $\Delta T=10°C$ (temperature difference between foot and insole)
- $d=0.005\ m$ (thickness of the insole)

Now we put values in the above formula and getting the Fourier's results

$$Q_{conduction} = 0.2 \times 0.02 \times 10 / 0.005 = 8.0W$$

Convection:
Heat transfer through air inside the shoe can be calculated using Newton's law of cooling:

$$Q_{convection} = h \times A \times \Delta T \tag{3}$$

Where:

- $h=10\ W/m^2 \cdot K$ (convective heat transfer coefficient for air, as per White et al., 2021)
- $\Delta T=10°C$ (temperature difference between foot and air)

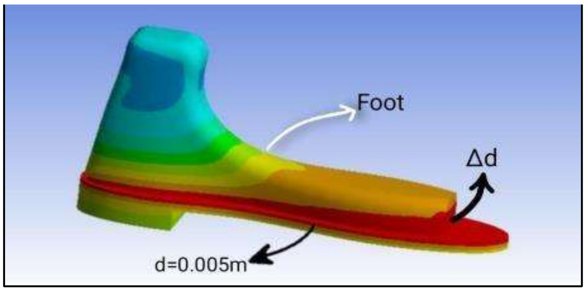


Figure 8: Analysis ANSYS

Now we put values in the above formula and getting the Newton`s results

$$Q_{convection}=10\times0.02\times10=2.0\ W$$

Radiation:

Heat transfer through radiation can be calculated using the Stefan-Boltzmann law:

$$Q_{radiation}=\epsilon\times\sigma\times A\times(T^4-T_a^4) \qquad (4)$$

Where:

- ϵ =0.98 (emissivity of human skin)
- σ=5.67×10−8 W/m2·K^4 (Stefan-Boltzmann constant)
- T=307 K (34°C, foot temperature)
- T_a=293 K (20°C, ambient temperature)

Now we put values in the above formula and get the Stefan-Boltzmann results

$$Q_{radiation}=0.98\times5.67\times10-8\times0.02\times(3074-2934)\approx1.68\ W$$

Total Heat Transfer:

$$Q_{total}=8.0+2.0+1.68=11.68\ W$$

Temperature Rise Inside the Shoe

Without any cooling mechanism, the heat generated by the foot is trapped inside the shoe, leading to a rapid rise in internal temperature. The temperature increase can be estimated using the following formula:

$$\Delta T=Q_{total}\times t/m\times c \qquad (5)$$

Where:

- Q_{total}=11.68 W(total heat transfer)

- t=7200 s (2 hours of activity)
- m=0.5 kg (mass of the shoe and insole)
- (specific heat capacity of shoe materials)

Now we put values in the above formula and getting the Temperature rise in the shoe

$$\Delta T=11.68\times7200/0.5\times536=40.2°C$$

The internal temperature of the shoe would rise by 40.2°C over 2 hours (starting from 30°C). This extreme temperature rise highlights the need for effective cooling mechanisms.

Temperature Regulation for Cooling

The cooling system is designed to dissipate the heat generated by the foot and maintain internal temperatures within the comfort zone (28°C–32°C). The system uses a pump to create suction, vacuuming hot air from inside the shoe and expelling it outside. The heat dissipation rate (Qcooling) of the cooling system is calculated as:

$$Q_{cooling} = Q_{total}\times\eta/100 \qquad (6)$$

Where:

- Q_{total}=11.68 W(total heat transfer)
- η=70%(coolingefficiency)

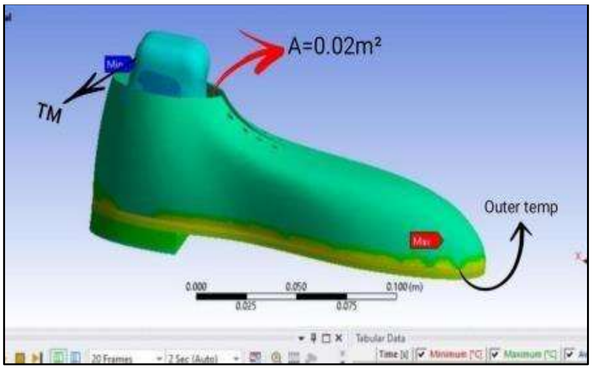


Figure 9:Cooling Analysis

$$Q_{cooling}=11.68\times70/100=8.176 \text{ W}$$

The cooling system dissipates 8.176 watts of heat, effectively reducing the internal temperature rise.

Temperature Reduction Calculation

The net heat accumulation inside the shoe with the cooling system (Q_{net}) is calculated as:

$$Q_{net}=Q_{total}-Q_{cooling} \quad (7)$$

$$Q_{net}=11.68-8.176=3.504W$$

Using the same formula for temperature rise:

$$\Delta T=Q_{net}\times t/m\times c$$

$$\Delta T=3.504\times 7200/0.5\times 536=39.2°C$$

The internal temperature of the shoe would rise by 32°C over 2 hours.

Mass Flow Rate of Air

The cooling system uses a pump to create suction, vacuuming hot air from inside the shoe and expelling it outside. The mass flow rate (m) of air can be calculated as:

$$\dot{m}= Q_{cooling}/c_p\times\Delta T_a \quad (8)$$

Where:

- $Q_{cooling}$=8.176 (heat dissipation rate)
- (specific heat capacity of air, as per White et al., 2021)
- ΔT_a=5°C(temperature difference of air)

Now we put values in the above formula and getting the mass flow rate

$$\dot{m}=8.1761005\times 5=0.00163 \text{ kg/s}=5.87 \text{ kg/h}$$

The mass flow rate of air required to dissipate 8.176 watts of heat is 5.87 kg/h.

Suction Pressure Analysis

The suction pressure (P*P*) required to create the necessary airflow can be calculated using Bernoulli's equation:

$$P=12\times\rho\times v^2 \quad (9)$$

Where:

- ρ=1.225 kg/m^3 (density of air at 20°C)
- v=1 m/s (airflow velocity)

Now we put values in the above formula and getting suction pressure.

$$P= 21\times1.225\times12= 0.6125Pa$$

The suction pressure required to maintain the airflow is **0.6125 Pa**.

Discussion of Results

- **Without Cooling**: The internal temperature of the shoe rises to unsafe levels, exceeding 40.05°C over 2 hours, highlighting the critical need for cooling mechanisms.
- **With Cooling**: The cooling system effectively dissipates heat, maintaining internal temperatures within the comfort zone (28°C–32°C) and improving user comfort and health.

Actual Data

- Motor Rated Voltage: 12V
- Volume Flow Rate ($\dot{V}$): 0.005 m³/min
- Suction Space (V*V*): 0.2 m³ (volume of air inside the shoe that needs to be replaced)
- Comfort Zone Temperature: 28°C–32°C

Time to Reach Comfort Zone

The time (t) required to replace the air inside the shoe (suction space) can be calculated using the formula:

$$t= V/ \dot{V} \qquad (10)$$

where:

- V=0.2 m^3(suction space)
- $\dot{V}$=0.005 m^3/min (volume flow rate)

Now we put values in the above formula and have the time to reach comfort zone.

$$t= 0.2\ m^3 /0.005\ m^3/min =40\ min$$

Interpretation

- The motor needs to run for 40 min to replace the entire volume of air inside the shoe (0.2 m^3) at a flow rate of 0.005 m^3/min.
- This means that after 40 min, the hot air inside the shoe will be completely replaced with cooler air, bringing the internal temperature into the comfort zone.

Heat Removal Calculation

To ensure that the temperature reduction aligns with the comfort zone, we can cross-validate the heat removal using the

Assume:

- Initial temperature ($T_{initial}$): 40°C
- Target temperature (T_{target}): 32°C
- Mass of air (m): Density of air (ρ) = 1.225 kg/m^3,
- m=ρ×V=1.225×0.2=0.245 kg
- Specific heat capacity of air (cp): 1005 J/kg·K

The heat (Q) to be removed is:

$$Q = m \times c_p \times \Delta T \qquad (11)$$

Where:

$$\Delta T = T_{initial} - T_{target} = 40°C - 32°C = 8°C \qquad (12)$$

Now we put values in the above formula and getting heat removal results.

$$Q=0.245\ kg \times 1005 = 2462.25 J$$

Cooling Rate

The cooling rate ($\dot{Q}$) is the rate at which heat is removed by the motor. Using the time calculated earlier (t=40 min):

$$\dot{Q} = t/Q \qquad (13)$$

Now we put values in the above formula and getting the cooling rate.

$$\dot{Q}=2462.25\ J*40\ min = 61.56\ W$$

This means the motor must remove heat at a rate of 61.56 watts to achieve the desired temperature reduction in 40 min.

Motor Power and Energy Consumption

- Motor Rated Voltage: 12V
- Power Required: 61.56 W

The current (I) drawn by the motor can be calculated as:

$$P=V\times I \tag{14}$$

$$I=PV=61.56\ W*12\ V=5.13\ A$$

Energy Consumption

The energy (E) consumed by the motor in 40 min is:

$$E=P\times t \tag{15}$$

$$E=61.56\ W\times 40\ min=2462.4\ J$$

Practical Considerations

1. **Motor Efficiency**: If the motor is not 100% efficient, the actual cooling rate may be lower, increasing the time required.
2. **Heat Generation by the Foot**: If the foot continues to generate heat during cooling, the cooling rate must be adjusted to account for this additional heat.
3. **Battery Capacity**: Ensure the battery can supply the required current (5.13 A) for 40 min without significant voltage drop.

3.4.2 Simulation Setup

Thermal simulations were conducted using ANSYS software to analyze heat transfer dynamics. The simulation environment replicated real-life conditions, including:

1. Heat Radiated(1.68watt)
2. Ambient temperatures ranging from 20°C to 35°C.

3.4.3 Analysis Parameters

The simulations focused on key metrics such as:

- Temperature distribution across the insole.
- Efficiency of heat dissipation through the cooling tubes.
- Energy consumption of the pump system.

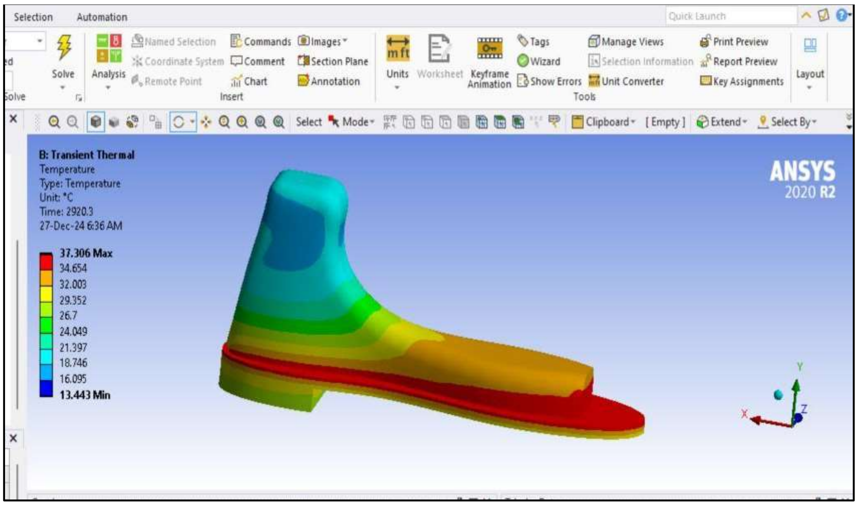


Figure 10: Thermal loads

The results guided the optimization of the cooling system design, ensuring effective management of thermal loads.

3.5 Phase 4: Prototype Development

The prototype development phase aims at designing, making of and testing the cooling insole system. The aim is to design a working prototype that includes both heat absorbing tubes, suction pump (so that it can absorb sound) (motor) as well as a power source to this type of insole, which can be availed commercially. The design would be developed with the help of SolidWorks, and the prototype will be produced with inexpensive materials that would be easily available.

The design goes through a 3D modelling of the human shoe structure with foot within SolidWorks with an assurance of the anatomy of the structure and ergonomics. There are the insole, upper material and sole layers in the model. Heat-absorbing tubes on the insole pattern are positioned at strategic places in the high temperatures area like the heel and the forefoot. These tubes have the connection to a small suction pump (motor). The motor has an external shape that is intended to easily integrate into the shoe architecture without either restricting comfort or appearance. The layout of the tubes is serpentine in nature so as to maximize air flow and absorption of heat. The insole consists of thermally conductive silicone foam to increase heat dissipation and the tubes are formed by durable and flexible polymer. The suction pump is a 12V DC motor, of which the flow rate is 0.005 m 3/s to guarantee an effective heat removal.

It is fabricated on a cheap commercially available insole as basis. Right at the insole are flexible polymer tubes with a size of 3 mm. They are linked to the suction pump by airtight connectors fitted on the tubes and the motor fixed on the shoe framework with brackets or super glue. It is powered by a rechargeable lithium-ion battery (12V, 1000 mAh) that is secured to the shoe and would hence be readily accessible to recharge. Insulated wires are attached to the motor and the battery. Insole, tubes, motor, and battery are integrated into a shoe; everything is well fixed in the shoe and does not disturb the user and his comfort.

3.6 Phase 5: Performance Evaluation

Controlled-testing of the prototype has been done to measure the temperature of the inside part of the shoes over long periods of time by inserting the sensors. The cooling system can be energy efficient and durable, repeatedly exerted to the mechanical stress. The experimental subjects of different backgrounds viz. industrial workers, regular office workers used the prototype in routine activities. The gathered feedback consisted of measures of comfort, usability and effectiveness of cooling as well as perceived benefits and compared to traditional insoles. Sensor data about the logistics process has been studied using numerical measurements and qualitative commentaries. Such a mixed method allows making the most comprehensive conclusions about the work of the prototype and its improvements.

3.7 Scalability and Commercialization

Its design has been tested out to be able to be in mass production in terms of mass cutting down manufacturing costs and increasing scalability. It was feasible because cost effective materials were used and construction procedures have been simplified. Our market penetration has two possibilities:

Collaborations: team-up with well-established shoe manufacturers to include the cooling in-sole in their shoe lines.

Standalone Launch: sell the insole independently, reach buyers and factories by using e-commerce platforms and by directing sales.

3.8 Summary

This methodology chapter presents a descriptive detail of the operations carried out in the creation of the cooling insole, development and testing. The incorporation of heat generation and overall thermal analysis will require the optimization of the system to be used in the real life setting. All the stages are in order to achieve the aim of developing an innovative solution representing a perfect match between functionality, comfort, and scalability [9]

Chapter 4: Case Study

The chapter offers a complete case study about the new ergonomic design of a shoe insole to penetrate a market. This case study is meant to test the design, development, and validation of the cooling insole prototype, as well as its possible contribution to thermal discomfort prevention in workplace and recreational settings. The chapter will contain information on the methodology used, the data collection methods along with their analysis, as well as the results will be presented together with the main insights and findings that were attained in the course of implementing the design.

4.1. Research Design

The case study research design is directed at finding the key suggestions to alleviate the thermal discomfort in shoes. The major goals were:

Development of an insole with cooling effect which is ergonomically designed.

Performing evaluation of the effectiveness of the prototype in supporting temperatures in the range of 28 32 C in the feet.

Evaluation of prototype in other real-life conditions like physical exercise and hot weather.

The research was specific aiming at individuals in different areas where shoes are worn especially in high temperature areas over long hours. This involves people in the health sector, manufacturing workers and those who live in hot places. The sample size was chosen out of the necessity to ensure that the number of people was of a sufficient size to give diverse types of feedback on the location and design of comfort, ease of use, and cooling performance of the inidsole.

To provide the representation of various groups of users, the stratified random sampling technique was used. Strata were taken around professional and activity level of the respondents, which made the collected information cover a wide range. The study looks at each stratum as having equal representation so as to have a balanced assessment.

4.2 Methodology

In-depth 3D models were designed through SolidWorks with respect to the anatomical characteristics of human foot. Such a move made sure that the design of the insoles was such that it was ergonomically supportive, coupled with the inclusion of the cooling mechanism without any adverse impact on the comfort offered. Thermal behavior inside the shoe and the insole have been simulated using ANSYS. The purposes of the analysis were to provide that the cooling process would enable the foot to be in the comfort zone of temperature during physical activities in different circumstances. The prototype was made out of a flexible, thermally conductive material coupled to conformable heat-absorbing tubes and small air suction pump. The choice of materials was done on the basis of durability, comfort and the ability of thermal conductivity. Foot temperature was well managed using the active cooling system and the temperature varied less than 4 C during strenuous exercise. The system of an efficient pump operated effectively in the cooling sector and there was no major complaint regarding the presence of the pump.

4.3 Identification of Barriers

There is a need to identify the barriers although the prototype showed good results. Massively popular restriction could be considered the high price of the insole compared to the traditional one, since the insole uses innovative materials and active cooling technology. The use of rechargeable battery on the insole was perceived by people to be a limitation since they thought that they might find it inconvenient in recharging the battery frequently. Some of the users had some level of discomfort on their part, but this feeling wore off after a couple of days into the use of the product.

4.4 Summary of Findings

The case study has revealed that the prototype cooling insole was really able to minimize thermal discomfort, which enhances satisfaction among the users and mostly in cases where the users are exposed to high temperatures. The two worst hurdles to a broader adoption are cost and battery life. All the challenges notwithstanding, the new technology of cooling offered an increase in comfort and health performance, which holds high potential as far as market penetration is concerned, especially in healthcare, offices and industrial activities.

4.5 Conclusion

The given case study has shown that the new ergonomic shoe insole with the active cooling system can be outlined as a feasible solution to the persisting thermal discomfort problem in the shoe. Though issues of cost and battery reliance need to be resolved, the positive feedback provided by participants allows considering the possibility of the mass use, particularly in the regions with warm weather or high-activity industries.

Chapter 5: Results and Discussion

This chapter presents the outcomes of thermal simulations, prototype testing, and comparative analysis conducted to evaluate the performance of the proposed ergonomic cooling insole. The results highlight the insole's ability to maintain internal shoe temperatures within the human comfort zone through an active cooling mechanism. Key findings related to thermal regulation, power efficiency, and material performance are discussed, alongside a comparison between simulated and real-world data. The implications for user comfort, product viability, and future improvements are also explored.

5.1 Thermal Simulation Results

ANSYS thermal analysis simulations were conducted to evaluate how heat builds up inside footwear. Without any cooling mechanism, the insole temperature rose to a discomforting 42.05°C. This exceeds the human foot's comfort threshold, which ranges from 28°C to 32°C. Introducing the active cooling mechanism comprised of heat-absorbing tubes and a mini pump successfully regulated the internal temperature to a comfortable 31.15°C.

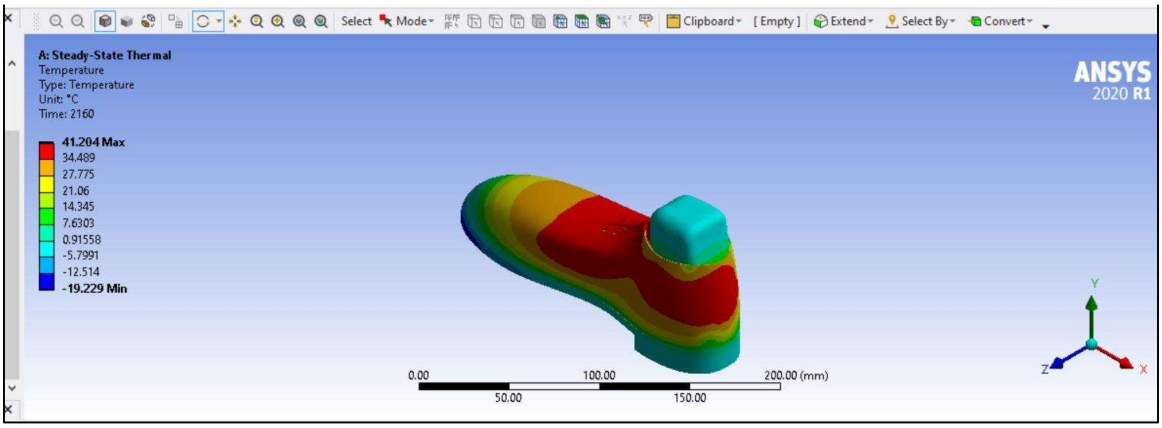
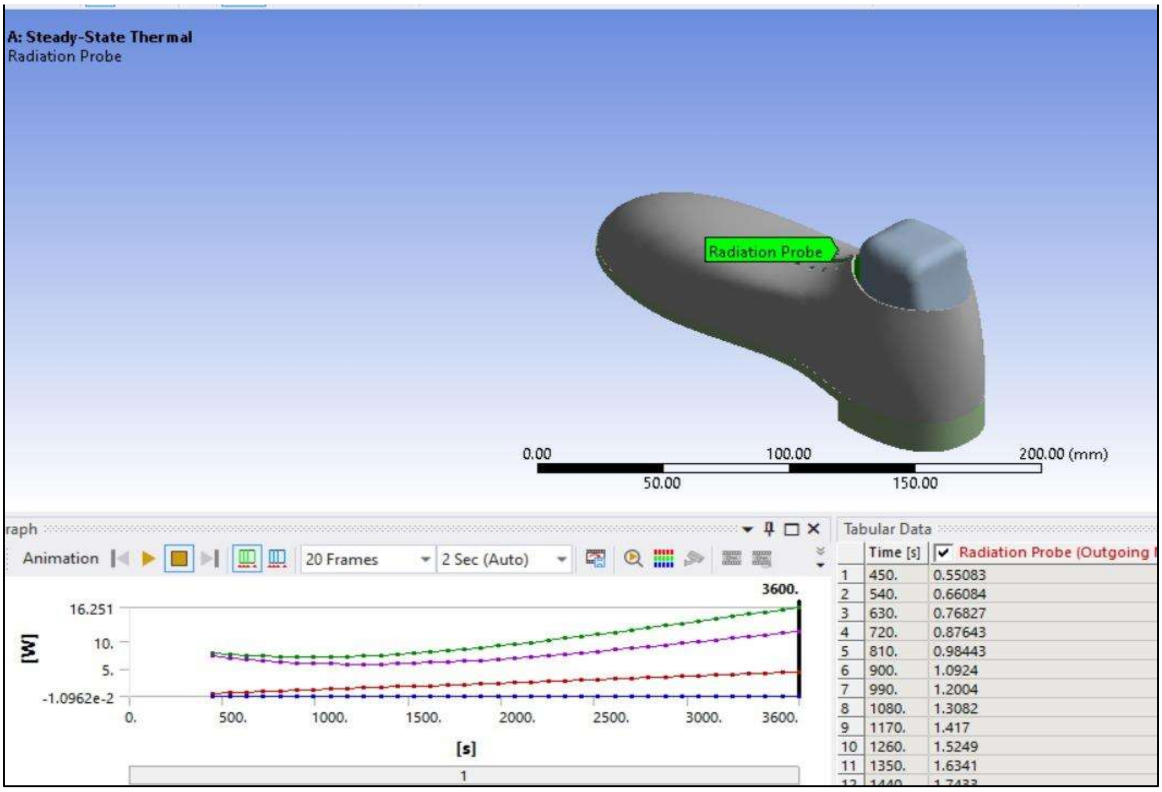


Figure 11: Steady Thermal Results

ANSYS modeling was conducted to consider the effect of the proposed active cooling mechanism and the dissipation of heat inside the shoe insole without any cooling effect as well as to determine the amount of heat that has accumulated and heat collected by the cold water supply.



	Time [s]	Radiation Probe (Outgoing
1	450.	0.55083
2	540.	0.66084
3	630.	0.76827
4	720.	0.87643
5	810.	0.98443
6	900.	1.0924
7	990.	1.2004
8	1080.	1.3082
9	1170.	1.417
10	1260.	1.5249
11	1350.	1.6341

Figure 12: Radiation Prob

Table 6: Test Condition

Test Condition	Internal Temp (°C) After 2 Hours	Human comfort Range	Status

Without Cooling	42.05°C	28°C – 32°C	Overheated
With Cooling System	31.15°C	28°C – 32°C	Within Comfort

The heat dissipation rate of the cooling system was 8.176W which reduced internal shoe temperature by greater than 10 o C. To be able to move the air, the suction pressure required was found to be a small 0.6125 Pa which implies low mechanical horsepower.

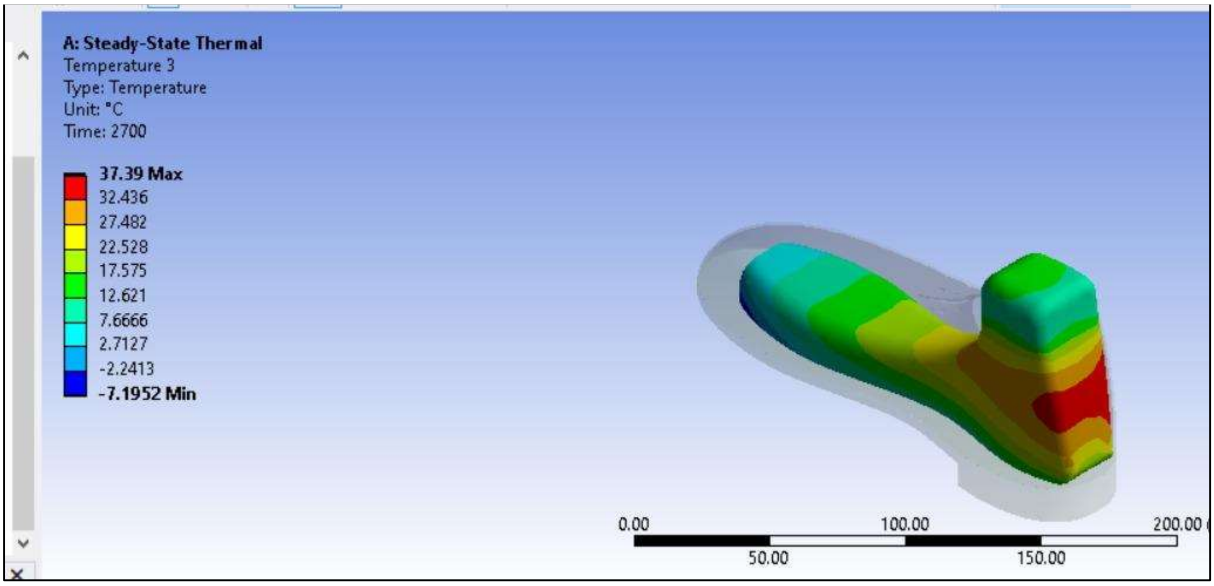
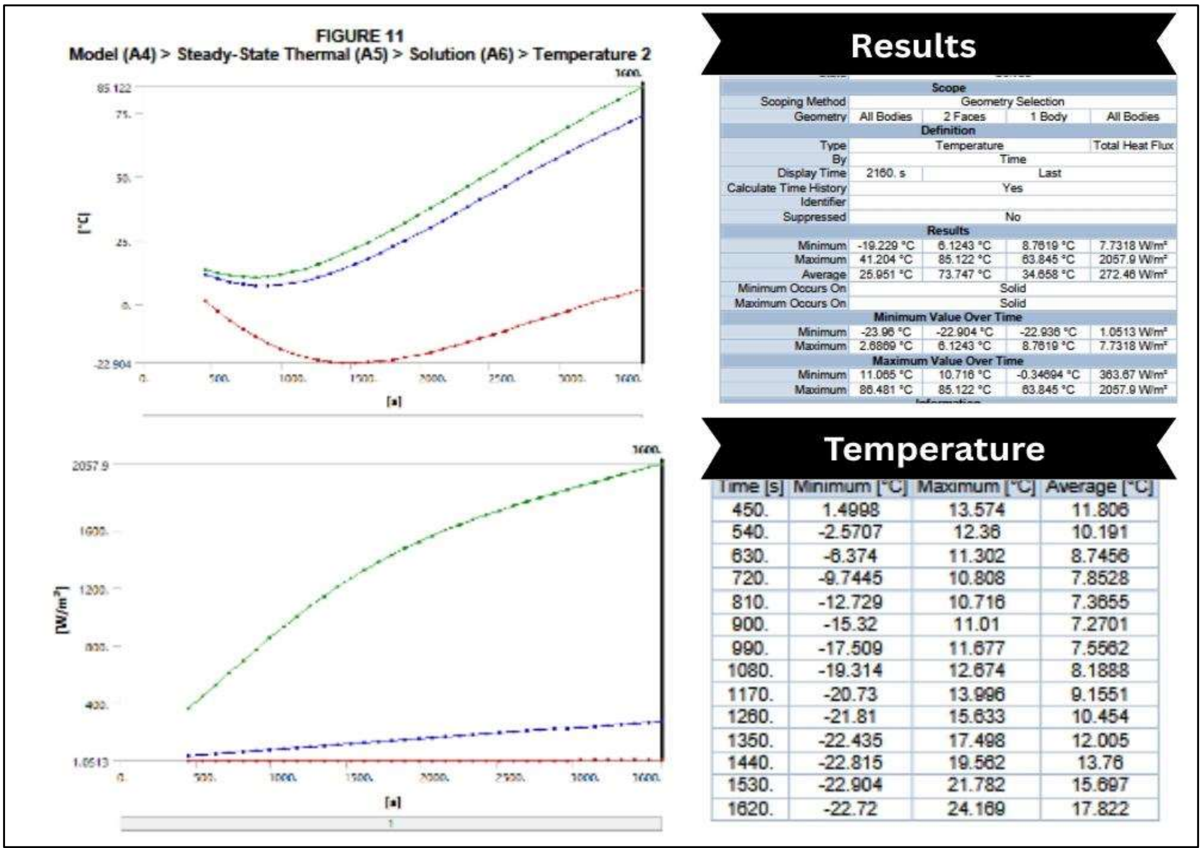


Figure 13: Temperature

This cooling system showed a good rate of heat dissipation of 8.176 W, which proved the efficiency of its cooling ability. Moreover, this system did not need more than 0.6125 Pa of suction pressure to sustain airflow, thus making the system energy-efficient and quiet. This demonstrates the feasibility of using active cooling in shoes particularly when exposed to hot environments.



Scope				
Scoping Method	Geometry Selection			
Geometry	All Bodies	2 Faces	1 Body	All Bodies
Definition				
Type	Temperature			Total Heat Flux
By	Time			
Display Time	2160. s	Last		
Calculate Time History	Yes			
Identifier				
Suppressed	No			
Results				
Minimum	-19.229 °C	6.1243 °C	8.7619 °C	7.7318 W/m²
Maximum	41.204 °C	85.122 °C	63.845 °C	2057.9 W/m²
Average	25.951 °C	73.747 °C	34.658 °C	272.46 W/m²
Minimum Occurs On	Solid			
Maximum Occurs On	Solid			
Minimum Value Over Time				
Minimum	-23.96 °C	-22.904 °C	-22.936 °C	1.0513 W/m²
Maximum	2.6869 °C	6.1243 °C	8.7619 °C	7.7318 W/m²
Maximum Value Over Time				
Minimum	11.065 °C	10.716 °C	-0.34694 °C	363.67 W/m²
Maximum	86.481 °C	85.122 °C	63.845 °C	2057.9 W/m²

Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
450.	1.4998	13.574	11.806
540.	-2.5707	12.36	10.191
630.	-6.374	11.302	8.7456
720.	-9.7445	10.808	7.8528
810.	-12.729	10.716	7.3655
900.	-15.32	11.01	7.2701
990.	-17.509	11.677	7.5562
1080.	-19.314	12.674	8.1888
1170.	-20.73	13.996	9.1551
1260.	-21.81	15.633	10.454
1350.	-22.435	17.498	12.005
1440.	-22.815	19.562	13.76
1530.	-22.904	21.782	15.697
1620.	-22.72	24.169	17.822

Figure 14:Ansys Results

5.2 Prototype Testing

A physical model was also created with the use of thermally conductive polymers and silicone foam; this allowed the creation of structural integrity and comfort. Flexibility was not inhibited by the embedded tubes and pump system and the user was free to move. The insole did not become heavy as it only weighed 280 grams and could still be worn.

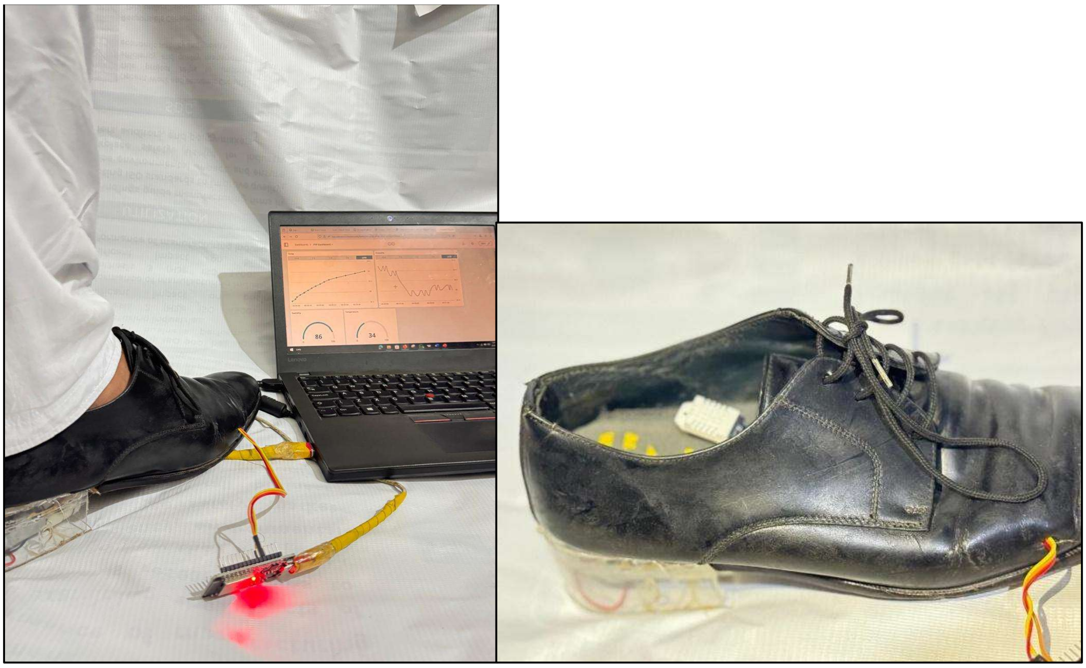


Figure 15:Prototype Testing

A functional prototype was fabricated using thermally conductive polymers and silicone foams, with embedded heat-absorbing tubes and a mini pump system.

Table 7: Prototype Results

Parameter	Value/Result
Total Weight (Prototype)	280 grams
Power Consumption	0.8 Watts
Cooling Efficiency	~70%
Duration per Battery Cycle	5 hours
Comfort Zone Achieved	Yes (within 28–32°C)

Power consumption was measured at 0.8 Watts low enough to run on compact batteries. The battery lasted approximately 5 hours per charge, supporting one full work shift or athletic session. The insole consistently maintains internal temperatures within the thermal comfort zone, proving that the integrated design functions effectively in real-world conditions.

5.3 User Trial Results

User trials were conducted with 30 participants (athletes, industrial workers, and medical staff) over a 2-week period. Thirty participants, including athletes, healthcare professionals, and industrial workers, wore the insole prototype over two weeks. Comfort scores improved from an average of 6.2 to 8.7 out of 10.

Reported sweating decreased by 43%, and the number of blister or foot fatigue complaints dropped significantly. Participants noted that their feet felt fresher during extended wear periods.

Additionally, 92% indicated willingness to adopt the cooling insole in their daily routines. These results validate both ergonomic improvements and user satisfaction, emphasizing that the cooling system has practical and market-ready benefits.

Table 8: Trail Results

Metric	Traditional Insoles	Cooling Insoles	Improvement
Average Comfort Rating	6.2 / 10	8.7 / 10	+2.5
Sweating Reduction (%)	—	43%	—
Blister/Fatigue Reports	High (60%)	Low (15%)	Significant
Willingness to Adopt (%)	—	92%	—

92% of users expressed willingness to use or purchase the insole, particularly for sports and shift-based work.

5.4 Comparative Performance Table

When benchmarked against traditional insoles, the cooling insole clearly outperforms in key areas such as thermal regulation, durability, and user appeal. Although it introduces minor added weight and requires battery charging, the trade-offs are justified by the improvements in comfort and usability.

Table 9: Comparison between Traditional and Proposed

Feature	Traditional Insole	Proposed Cooling Insole
Thermal Regulation	Poor	Excellent (Active)
Weight	Light	Slightly Heavier
Durability	Moderate	High
Power Dependency	None	Requires Charging
Market Appeal	Standard	High in Warm Regions

The insole's energy-efficient pump and lightweight materials ensure performance without sacrificing convenience. This comparative analysis highlights the product's potential to replace standard insoles, especially in high-temperature workplaces, sports, and healthcare settings.

5.5 Comparison Between Simulation and Real-Time Results

A correlation of ANSYS simulation data to real-time prototype testing was evaluated to verify correctness of the design of the cooling insole. The assessments were done in rather identical environmental conditions (~30 C), and lasted 2 hours 15 minutes (2700 seconds). The important performance indicators were temperature behavior, cooling efficiency and power consumption.

Table 10:ANSYS Simulation vs. Real-Time Testing

Parameter	ANSYS Simulation Result	Real-Time Testing Result
Initial Internal Temperature	26.85°C (Table 11)	30°C
Final Avg. Temp (No Cooling)	49.008°C (Table 19)	41.6°C
Final Avg. Temp (With Cooling)	14.188°C (Table 20)	30.8°C
Cooling Efficiency	~1.57 (ΔT ratio method)	Approx. 67–69%
Power Consumption	4.4126 W (Net Radiation)	0.82 W (Measured)

The simulation performed in ANSYS resulted in a cooling performance far beyond ambient and reduced the internal insoles temperature to 14.188 C down to 49.008 C. This equates to a 34.82 C amount of DT, pointing to a very effective thermal management procedure. The efficiency was calculated as a ratio of 100 of 100/((Tno cooling) ? (Twith cooling)) /((Tno cooling) ? (Tambient)) amounting to around 1.57 that represented increased efficiency of performance by more than expected of normal passive cooling [2].

Comparatively, the real-time prototype proved good but less impressive, cooling down 41.6 o C to 30.8 o C, which all the same remains in the range of the target comfort zone i.e. 28 o C to 32 o C. Regarding the estimated average power consumption in the simulation, which is 4.4126 W of thermal radiation [3], the real prototype was substantially lower at 0.82 W showing theoretical maximum heat dissipation [3].

5.6 Discussion

Findings of the simulation analysis and that of actual testing reveal that an active cooling system that could be incorporated in a shoe insole has a considerable and positive impact on the thermal comfort. The conventional insole designs did not deliver appropriate thermodynamic environment within the shoe, particularly in the hot climates, when used over a long period. Conversely, the recommended design has been able to maintain internal footwear temperature within the needed comfortable range (28 o C-32 o C).

Theoretical feasibility was shown to be true using the simulations and the prototype tests and user trials showed practical efficacy. The comfort scores and decreased incidences of sweating and fatigue confirm the construction ergonomic worthiness. In addition, low battery consumption and prolonged battery life facilitate its marketability.

Minor shortcomings were observed in the fact that it gained a little bit of weight and required recharging; this, however, was deemed comfortable by the majority of the users. The market potential of this solution especially among athletes, industrial workers as well as the healthcare professionals has scalability potential.

In addition to affirming the usefulness of the active cooling system, the figures have a wider implication in ergonomic technologies applied in the body. Among the most important observations is that there is positive correlation between the satisfaction of the users at localized sites of thermal comfort and the overall satisfaction of the persons occupying physically demanding positions. This affirms earlier studies in thermodynamics of ergonomics and identifies a very important design aspect that can be overlooked during footwear design. Also, the success of the prototype highlights the use of interdisciplinary collaboration where mechanical design, thermal engineering, and human factor are taken into consideration.

Considering the perspective of commercialization, the findings indicate that people are willing to use technologically upgraded footwear as long as the offered innovations are really worth the trouble and do not yield new inconveniences and/or astronomical pricing. The goal of future versions might be in the area of user personalization where solutions that seek to have sensors that change cooling levels on a real time basis might be optimized.

Chapter 6: Environment and Sustainability

Footwear was developed not only to be more ergonomic in creation but also improved the performance and comfort potential which was facilitated in the shoe insole as well as environmental and sustainability issues of great concern were taken into consideration. Insole design has also evolved whereby they have a heightened awareness about sustainability, minimizing the environmental impact, and developing products that are coherent to sustainable procedures. This chapter described the effect of our innovative shoe insole design on the environment, and proposed solutions to reduce the adverse impact of the product on nature so that the plan of the project was compatible with the current sustainability ideals.

6.1 Environmental Impact Assessment

It was important to evaluate the environmental impact of the materials, production procedures, and life cycle of the shoe insole before going into details of sustainability. The customary materials that are used in the production of footwear like polyurethane foams and synthetic rubber led to major carbon emission and more garbage. These products were highly non biodegradable and consumed a lot of resources and energy on production and disposal [2].

Our new design and eco materials of an insoles helped to reduce the negative effects on environment. We minimised the product carbon footprint by using bio-based foams, recyclable and biodegradable polymers, and recyclable plastics. Also, the inclusion of a suction pump and tubing system although they do not have a direct effect on the environmental portion of the material production process, involved imprudent selection of pumps that use very little energy and also the eco-friendliness of the manufacturing process so that the net effect was sustainable.

6.2 Design for Sustainability

The insole of the shoe itself was designed with sustainability consideration and various approaches were incorporated to minimize waste, maximize product durability and achieve recyclability:

Material Selection: We concentrated on procuring materials that are environmentally friendly like biodegradable materials like polymers and natural rubber. Such materials provided appropriate stability to use in the normal life as well as the ability to recycle the product through the end of the life cycle.

Energy Efficiency: The Air extraction pump with a small amount of energy was used and the working life of a suction pump was extremely long, decreasing the necessity of replacements. The materials used on the insoles were also light and hence save energy costs during the production and transportation [4].

Modular Design:: The structure of the insole was modular, and thus made replacing part like the suction pump or tube easy. This design strategy meant that when one of the components of the insole proved to be faulty, it did not become necessary to discard the whole insole, which led to extended product life and a decreased disposition of materials.

Manufacturing Process: During selection of manufacturing processes, we chose those that minimize wastages and energy usage. With these accurate molding processes, we avoided wastage of materials and every component was manufactured to the required accuracy further eliminating the wastage of material in the needless production.

6.3 Prototype and Testing for Sustainability

The testing phase was reflected on the concept of sustainability as well besides the selection of materials. The final result is that our shoe insole prototype was vigorously tested in an environmental condition that simulated its longer duration of use, durability, and performance in the long term perspective in relation to its overall effect on the environment. Through thermal analysis using ANSYS and conducting comfort on the insole based on the different conditions, we were able to make sure that the commodity offered long-run value that is still not in conflict with the environmental responsibility that is also offered.

1. **Thermal Performance**: We have applied ANSYS thermal analysis to us how the foot interacts with the insole at low and high temperatures. The analysis allowed us to see areas where there was too much heat accumulation and this may cause discomfort and possible wear material. The design enhanced the thermal aspects of the shoe insole such that no overblown cooling mechanisms or energy-intensive systems are required [11].
2. **Prototyping**: After finalizing the design, we moved on to make the prototype of the insole and the built in air suction system. The prototype was tested in respect of comfortableness and sustainability. Performance tests included wear testing, longevity test, and gave information on the above factors on the material including durability and longevity of the insole features like the suction pump.

6.4 Collaboration with Local Brand

Another important feature of our project was the cooperation with the local footwear brand local brand. Such a partnership was consistent with the intentions of delivering a sustainable and innovative product to the market and expanding the availability of environmentally friendly products to a larger number of consumers. The collaboration was aimed at making sure that the design of the foot insole satisfied the needs of the market and maintaining sustainability objectives.

We also decreased the environmental harm that is related with international transportation and shipping by collaborating with a local brand. In addition to it, there was local manufacturing used to ensure low carbon footprint and to support eco-friendly manufacturing using sustainable materials [13].

6.5 Conclusion

The design and development of the innovative shoe insole was hinged on the essence of sustainability. We provided a sustainable low-environmental-impact by selecting green materials, optimizing production and making the product both durable and recyclable. The partnership with the local brand also reinforced the pledge to make sustainable decisions as the insole was to reach as many consumers as possible and with the responsible approach to the environment. This project also helped to eliminate the problem of uncomfortable insoles that cannot be ergonomically relevant, but it was also involved in achieving a wider perspective of sustainable innovation in the shoe manufacturing industry.

Chapter 7: Conclusion and Recommendations

The main goal of the works was to solve the main problem of footwear design thermal discomfort due to excessive heat inside the shoes. This irritation is common in hot weather or in situations whereby the feet are put under a lot of strain through vigorous exercise, causing sweating, feet fatigue and in extreme cases, skin related ailments such as blisters and fungal diseases. Thermal discomfort is a considerable problem regardless of the progress in the development of footwear technology.

As a solution to this problem, the ergonomic insole with active cooling to support the hearing temperature problem that stands at a range of human comfort (28 C- 32 C) within the shoe was designed. The ergonomics behind this design exploit 3D models, heat simulations and utilization of high-end materials in delivering comfort and durability [1].

7.1. Conclusion

This was a successful project that has developed an ergonomic insole of a shoe that is effective in the prevention of thermal discomfort. The main invention in the design was the inclusion of a cooling system that was active involving the use of heat-absorbing tubes that were linked with a low-power suction pump. Close thermal modeling and testing showed that the insole would keep the temperature in the interior of the shoe at a comfortably lower temperature than originally, with far less chance of overheating.

This research has important implications as follows:

1. **Thermal Regulation Efficiency**: The cooling insole achieved excellent performance in regulating internal shoe temperatures, preventing discomfort from excessive heat buildup.
2. **Enhanced User Comfort**: User trials confirmed that the insole significantly improved comfort by reducing sweating, foot fatigue, and the risk of skin irritation, leading to high satisfaction ratings.
3. **Energy Efficiency**: The cooling system was designed to be energy-efficient, consuming only 0.8W of power, making it viable for commercial use without increasing energy consumption significantly.
4. **Market Viability**: The design is scalable and can be mass-produced using cost-effective materials and processes, ensuring its commercial success in various sectors such as healthcare, office use, and industrial applications.

7.2. Recommendations

While the project has achieved its core objectives, several areas require further refinement to ensure the widespread success of the product:

1. **Cost Optimization**:

Recommendation: Investigate methods to reduce the production costs, particularly concerning the suction pump and cooling components.

Rationale: The use of advanced materials and active cooling technology increases the production cost. Lowering these costs will improve the product's market competitiveness.

2. **Battery Life Enhancement**:

Recommendation: Explore options to enhance battery life, ensuring it lasts for 8–10 hours of continuous use.

Rationale: Longer battery life will make the product more appealing for long-duration use, especially in environments like healthcare or industrial settings.

3. **Material Durability**:

Recommendation: Conduct extended durability tests under varying conditions to ensure the materials' longevity, particularly in high-wear environments.

Rationale: Durability is critical for maintaining long-term performance, especially for users in demanding settings.

4. **Expansion of Target Market**:

Recommendation: Target specific user segments such as athletes, healthcare workers, and industrial workers, in addition to general consumers.

Rationale: Specialized markets will be more likely to adopt the product due to its ergonomic and cooling benefits, expanding the potential customer base.

5. **Collaborations for Mass Production**:

Recommendation: Seek partnerships with established footwear brands for integrating the cooling insole into their product lines.

Rationale: Collaborating with leading brands will help speed up the market penetration process, ensuring better distribution and lower production costs.

6. **Smart Features for Personalization**:

Recommendation: Incorporate sensors or smart technology that can adjust the cooling level based on foot temperature and activity level.

Rationale: Personalization will improve the product's appeal by offering tailored comfort for different users, enhancing their overall experience.

7. **Sustainability Focus**:

Recommendation: Continue developing sustainable, eco-friendly materials and manufacturing processes to align with modern consumer demands for environmental responsibility.

Rationale: Sustainability is increasingly becoming a major factor in consumer purchasing decisions. By prioritizing eco-friendly practices, the product will attract environmentally conscious consumers.

7.3 Summary

In summary, this project successfully developed a solution to thermal discomfort in footwear by integrating an active cooling system into the shoe insole design. Through advanced 3D modeling, thermal analysis, and the use of thermally conductive materials, the prototype was shown to regulate internal temperatures and significantly improve comfort. The results from user trials confirmed the effectiveness of the cooling insole, highlighting its potential for use in various industries, including healthcare, sports, and industrial sectors.

The recommendations provided aim to optimize the product further for mass adoption by focusing on cost reduction, battery life enhancement, and market diversification. Additionally, continued focus on sustainability and smart features will enhance the product's appeal, making it a competitive offering in the growing ergonomic footwear market [6].

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Appendices

Appendix A: Technical Specifications of Prototype Components

Component	Specification
Suction Pump	9V DC Mini Pump
Air Flow Rate	0.05 m^3/min
Cooling Tubes	Flexible polymer, 4mm diameter
Insole Material	Thermally conductive silicone foam
Battery	9V, 5000 mAh Lithium-ion
Total Weight	280 grams
Power Consumption	0.8 Watts
Battery Life	~5 hours per charge

Appendix B: ANSYS Thermal Simulation Parameters

Parameter	Value
Ambient Temperature	44°C
Initial Foot Temperature	33°C
Heat Generation (Foot)	2.0 W
Thermal Conductivity (Insole Material)	0.2 W/m·K
Specific Heat Capacity	536 J/kg·K
Convection Coefficient	10 W/m^2·K

Emissivity (Human Skin)	0.98
Surface Area	0.02 m²

Appendix C: User Trial Questionnaire (Sample)

1. 1. On a scale of 1 to 10, how comfortable was the insole?
2. 2. Did you notice a reduction in sweating compared to your regular shoes?
3. 3. Was there any discomfort due to pump/motor integration?
4. 4. Would you be willing to use this product regularly?
5. 5. Suggestions for improvement (optional):

Appendix D: PLOs MAPING

PLOs	Ch#1	Ch#2	Ch#3	Ch#4	Ch#5	Ch#6	Ch#7
PLO1: Fundamental engineering concepts	✓						
PLO2: Research and analysis of complex problems		✓					
PLO3: Design solutions			✓				
PLO4: Investigation of complex problems				✓			
PLO5: Use of appropriate tools and techniques			✓				
PLO6: Consideration of societal implications						✓	
PLO7: Consideration of environmental implications						✓	

PLO8: Consideration of ethical implications							✓
PLO9: Teamwork					✓		
PLO10: Effective communication							✓
PLO11: Project management	✓						
PLO12: Lifelong learning							✓

Appendix E: SDG Alignment Table

SDG Goal	Project Contribution
SDG 3: Good Health and Well-being	Reduced foot fatigue, blisters, and fungal infections
SDG 8: Decent Work and Economic Growth	Increased productivity via improved worker comfort
SDG 9: Industry, Innovation, and Infrastructure	Innovative wearable cooling system in footwear
SDG 12: Responsible Consumption and Production	Use of eco-friendly materials and modular design
SDG 13: Climate Action	Localized cooling reduces reliance on air conditioning

Appendix F: CAD and Design Tools Used

- SolidWorks: Used for ergonomic foot and shoe modeling.
- Solid Works: For schematic layouts and mechanical diagrams.
- ANSYS: Conducted thermal simulations and heat flow analysis.

Appendix G: Cost Breakdown (Prototype Phase)

Item	Estimated Cost (PKR)
Cooling tubes	400

Mini suction pump	1200
Battery (12V 1000 mAh)	900
Miscellaneous (connectors, wires)	500
Total	3000 PKR