Study of performance and safety parameters of Wearable E-Textile for Heating Application

Phase 1 report

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1. INTRODUCTION

Today, heating is still the most successful application of e-textiles, accounting for over 80% of the market value in 2023. From motorcycle riders to outdoor workers to people enjoying snow sports, heated clothing provides much-needed warmth in cold winter conditions. Heated blankets have also been popular for several decades, and interest has been spurred on in recent years by drastic rises in energy costs. The success of heating as an application of e-textiles owes its thanks to the technology's ability to provide local heating to the person in a comfortable form factor. Compared to alternatives, such as heating the entire room (costly), to hand warmers (only heats a small area), to simply wearing more clothing (bulky), heated textiles leverage the strengths of both textiles and electronics.

While power supply remains a key problem in this application, with users having to either carry a rechargeable battery or be tethered to a power source, the increasing availability of portable USB power banks is helping to drive heated apparel to consumers.

The constant temperature of a human body for maintaining body functions is 37°C, anything below resulted by prolonged exposure to cold temperatures can cause hypothermia and can be fatal for the survival of human body. The aim of the textile-based heating systems is to provide necessary warmth to the user/environment in a cooler environment.

Applications of heating electronic textile products: Heating E-textiles have a wide range of applications in a variety of industries due to their superior comfort in cold environments when compared to their traditional counterparts. Below are a few examples of Heating E-textile products.

- **Industrial Applications**: Heating electronic textiles are commonly used in industrial applications in apparel form factors or as heating garments such as jackets, vests, gloves, and socks. These products provide warmth and comfort to users during cold weather, allowing them to work outdoors for extended periods without discomfort.
- **Medical Applications**: Heating electronic textiles are also used in medical applications to help manage symptoms of conditions such as arthritis and Raynaud's disease. The textiles are incorporated into garments that can be worn to provide localized heating to specific areas of the body, helping to improve blood circulation and reduce pain.
- **Automotive Applications**: Heating electronic textiles are increasingly being used in the automotive industry. They are integrated into car seats and steering wheels to provide warmth and comfort to drivers and passengers during cold weather.
- **Outdoor Recreation Applications**: Heating electronic textiles are also used in outdoor recreation activities such as skiing and snowboarding. Apparel such as heated jackets,

gloves, and socks provide warmth and comfort to users during cold weather conditions, allowing them to enjoy their activities for longer periods.

- **Military Applications**: Heating electronic textiles are also used in military applications. Soldiers in cold weather environments can benefit from heated clothing, which can help them maintain body temperature and prevent hypothermia.

2. HEATED E-TEXTILES

2.1. WHAT IS WEARABLE HEATED E-TEXTILES?

Wearable heated e-textiles are garments or accessories embedded with electronic heating elements that provide warmth to the wearer. They are incorporated with conductive threads or fabrics which generate heat when connected to a power source such as battery. There are also Smart fabrics with embedded heating elements.

Here are some examples:

1. Heated Jackets: The heated jacket features built-in heating elements like carbon fiber heating elements strategically placed that provide warmth across the targeted areas like chest, back, sleeves and collar. It offers adjustable heat settings and could be powered by a rechargeable battery.

2. Heated Gloves: These gloves include integrated heating elements in the fingers and back of the hand, powered by a rechargeable battery. They're often used for outdoor activities like skiing or motorcycling.

3. Heated Insoles: While primarily for footwear, these heated insoles can be considered part of a heated e-textile ensemble. They are remote-controlled and provide adjustable warmth to the feet.

4. Heated Socks: These socks have built-in heating elements made of polymer based conductive yarns knitted to the bottom of the foot through the heel and the toes, are powered by rechargeable batteries, and may be controlled via a smartphone app. They're particularly popular among outdoor enthusiasts in cold climates.

5. Heated slippers/footwear: The heated slippers have a heating system generally made of woven structure composed of conductive fibres throughout the insole and placed between the foam and foot bed lining. In all systems, rechargeable lithium-ion batteries are used as power supply to generate heat with a controller adjusting warmth level.


6. Heated Vests: The vest offers adjustable heat settings with heating zones in the chest, back, and neck. It's often used as a layering piece, providing balanced warmth.


7. Heated Scarves: A simple yet effective heated scarf with a built-in heating element powered by a rechargeable battery, offering warmth around the neck area. This scarf could be with technology, providing adjustable warmth via an app or remote control.

8. Heated Beanies: The beanie features integrated heating panels on the ears and forehead, keeping the head warm in cold conditions.

9. Heated Pants: These pants include heating elements in the thighs and lower back, providing core warmth underneath regular clothing.

10. Heated Therapy Wraps: Wearable wraps designed for therapeutic purposes, incorporating heating elements to alleviate muscle pain or discomfort.





These wearable heated e-textiles are commonly used for outdoor activities, sports, or everyday wear in cold climates, offering the convenience of portable warmth without the need for bulky layers.

Understanding the principle of heating in wearable heated e-textiles is essential for formulating standards because it directly influences the attention to critical aspects such as safety, performance, durability and user comfort.

2.2. PRINCIPLE OF ELECTRICAL RESISTANCE HEATING IN TEXTILES

The main principle of electrical resistance heating relies on conversion of electrical energy into heat due to the resistance of a conductive material. We know, an electric current passing through any conductive material will generate heat as the electrons collide with the atoms of the material transferring energy in the form of heat. This heating effect is known as Joule heating, and the amount of heating is proportional to the current flowing through the material and its resistance as described by the Joule's law $P=I^2R$, where P is the amount of heat generated, I is the current flowing, and R is the resistance of the material. So, electric current passing through the resistor generates an amount of heat depending on the current flow & the resistance. The resistance values can change depending on the conductive element type particularly from a few ohms to many kilo ohms. Temperature could be varied by varying the current, and controlled using feedback from the temperature sensor by the control electronics.

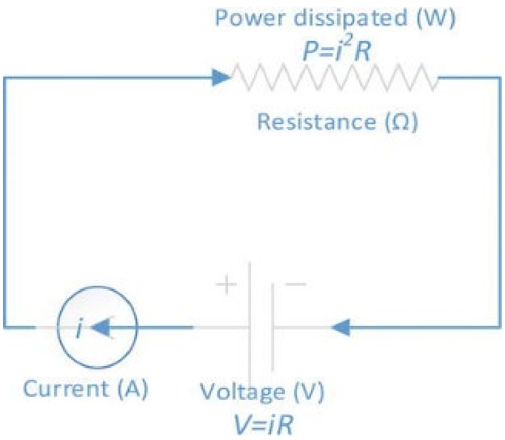


Figure: Joule resistive heating

Conductive elements can be placed in the form of parallel and series in order to form electrical networks inside/over the fabric structure. The way of formation and insertion of conductive tracks are critical in a textile-based heating system. The conductive tracks embedded should be thin enough to be bend and to allow flexibility, and at the same time strong enough for not to be broken and provide an efficient heating. Composition of the fiber also affects the washability and heating behaviour of the system.

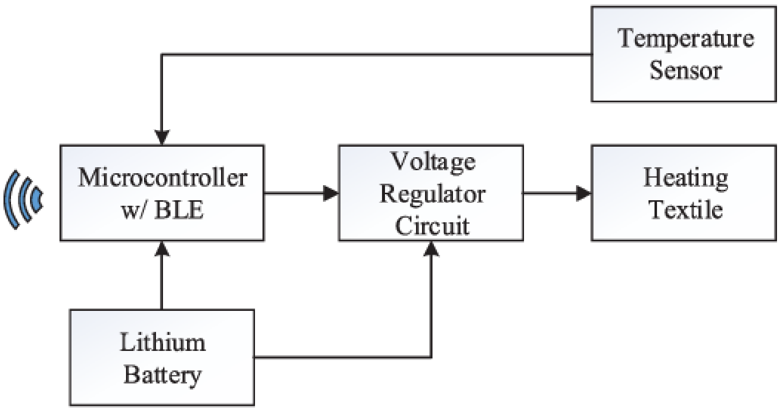


Figure: E-textile heating system framework. (Caya, 2021)

A typical system framework of the heating e-textile wear is as shown in the figure. This system also shows Bluetooth Low Energy (BLE) module for wireless connectivity. The temperature sensors e.g., LM35 sensors are connected to the analog port of the microcontroller which is then digitized by the microcontroller to sense the actual temperature value. This value is compared against the set temperature. This difference between the set temperature and the actual temperature is considered as the error value, and is used to correct the amount of current flowing to the heating textile. Typically, MOSFETs like BC557 are used to switch the current. The control is generally by Pulse Width Modulation (PWM) which is efficient and easy to implement. Individual areas of the wear can be temperature regulated by having multiple sensors in strategic locations, and current to each of the area is switched by a PWM switched MOSFETs. Also controlled by a Proportional-Integral-Derivative (PID) controller programmed unto the microcontroller. The PID control offers a feedback control for a quick and more precise temperature to meet the target temperature.

2.3. KEY COMPONENTS OF WEARABLE HEATED E-TEXTILES

- Heating Elements: Made from conductive fabrics and materials like carbon fibers, metallic threads, polymer based, or printed circuits that produce heat when electricity flows through them.
- Power Source: Often powered by a rechargeable battery, with provision for power control to adjust the level of heat required.
- Flexible and Durable: The textile remains flexible and comfortable for wearing, despite the integration of electronic components.
- Sensors and Temperature Control: Most wearable heated e-textiles offer adjustable temperature settings to ensure required comfort and avoid overheating.
- Safety Considerations: To ensure user safety, these products often include thermal cutoffs, overheat protection, and insulation layers to prevent burns and damage to the users.

2.4. PRIMARY CHALLENGES IN THE DESIGN:

Developing and implementing e-textile heating technology faces several significant challenges, each requiring innovative solutions to ensure functionality, safety, comfort, and market acceptance. Here are some of the primary challenges:

- **Temperature Fluctuations and Stability**: Maintaining consistent temperatures in e-textile heating elements can be tricky. Temperature fluctuations can lead to electronic instability, affecting device resistors. Moreover, excessive heat can cause discomfort and skin burns, especially when the device's temperature exceeds the skin's comfort zone (typically around 30–34 °C) (Yu, 2024)
- **Comfort and Wearability**: E-textiles need to strike a balance between functionality and comfort. Bulky or rigid heating elements can make garments less wearable. Designing lightweight, flexible, and unobtrusive heating components is essential for user comfort.
- **Integration with Clothing and Fashion**: E-textile heating systems must seamlessly integrate into clothing without compromising aesthetics or practicality. The challenge lies in creating functional garments that people actually want to wear.
- **Energy Efficiency**: Efficient energy utilization is crucial. E-textile heaters should provide sufficient warmth while minimizing power consumption. Balancing performance with battery life or energy harvesting mechanisms is an ongoing challenge.
- **Materials and Durability**: Choosing suitable materials for e-textile heating elements is critical. These materials must withstand repeated bending, washing, and wear. Durability and longevity are essential for practical use.

- **Whole-System Integration**: Integrating e-textile heating components with control electronics, power sources, and sensors requires careful system design. Ensuring seamless communication and compatibility is challenging.
- **Safety and Skin Interaction**: E-textile heaters should not cause skin irritation, allergies, or burns. Ensuring safe contact with the skin is vital, especially for prolonged use.
- **Scalability and Mass Production**: While prototypes exist, scaling up production of e-textile heating garments remains a challenge. Achieving cost-effective, large-scale manufacturing without compromising quality is essential.
- **Sustainability and Lifecycle**: As e-textiles move toward commercialization, sustainability becomes crucial. Managing the lifecycle of e-textiles—especially considering hazardous materials—poses a significant challenge (Zheng, 2021).
- **Regulatory Compliance**: Meeting safety standards and regulations for wearable electronic devices is essential. E-textile heating systems must adhere to guidelines to ensure user safety.

Despite these challenges, researchers and engineers continue to innovate, addressing each obstacle to make e-textile heating more practical, comfortable, and efficient.

2.5. DESIGN INNOVATIONS

Integration of Heating Elements

- **Flexible and Durable Connections:** Ensuring that heating elements maintain conductivity and durability despite the constant flexing and stretching inherent in textiles.
- **Uniform Heat Distribution:** Designing heating elements to provide even heat distribution without creating hotspots, which can lead to discomfort or burns.

Power Supply and Management

- **Battery Life:** Balancing the need for lightweight, compact batteries with sufficient power capacity to provide extended heating durations.
- **Power Efficiency:** Developing power-efficient heating elements and control systems to maximize battery life while delivering consistent heat.

Control and Safety

- **Temperature Regulation:** Implementing reliable temperature sensors and control systems to maintain safe and comfortable temperatures, preventing overheating.
- **User-Friendly Controls:** Designing intuitive interfaces for users to adjust heating levels easily, whether through manual controls or smartphone apps.

Material Selection and Durability

- **Durable Conductive Materials:** Choosing conductive materials that are not only efficient and flexible but also durable enough to withstand repeated washing, wear, and environmental exposure.
- **Fabric Compatibility:** Ensuring that heating elements and conductive pathways are compatible with a variety of fabrics used in garments, maintaining comfort and aesthetics.

Manufacturing and Scalability

- **Consistent Quality:** Developing manufacturing processes that ensure consistent quality and performance of the heating elements and the overall garment.
- **Scalable Production:** Scaling up production while maintaining quality, managing costs, and ensuring that the integration of electronic components does not compromise the textile's properties.

Safety and Compliance

- **Electrical Safety:** Ensuring that the heating elements and electrical components meet safety standards to prevent electrical hazards such as shorts or fires.
- **Washability:** Designing e-textiles to be washable without degrading the performance or safety of the heating elements and electronics.

Comfort and Wearability

- **Weight and Bulk:** Minimizing the weight and bulk added by heating elements and batteries to ensure that the garments remain comfortable and wearable for extended periods.
- **Skin Comfort:** Ensuring that the materials used do not cause irritation and that the heating elements do not create uncomfortable pressure points or uneven surfaces.

Cost and Market Acceptance

- **Affordability:** Balancing advanced features and performance with cost to make the products affordable and attractive to a wide range of consumers.
- **Consumer Education:** Educating consumers about the benefits, usage, and care of e-textile heating products to drive market acceptance and adoption.

Environmental Impact

- **Sustainable Materials:** Using environmentally friendly materials and production processes to minimize the environmental footprint.
- **End-of-Life Recycling:** Designing products with end-of-life considerations, ensuring that components can be recycled or disposed of safely.

Technical Innovation

- **Advancing Technology:** Continuously innovating to improve the efficiency, durability, and functionality of heating elements and control systems.
- **Interdisciplinary Collaboration:** Collaborating across fields such as materials science, electrical engineering, and textile design to overcome technical challenges and develop superior products.

2.6. HOW DO THEY ADDRESS SAFETY CONCERNS?

Addressing safety concerns in e-textile heating products is crucial to ensure user well-being and reliable functionality. Some strategies and considerations are as follows:

- **Material Selection**: Choosing safe and non-irritating materials for e-textiles is fundamental. The materials used in heating elements should not cause skin allergies, irritation, or discomfort. Manufacturers often opt for hypoallergenic fabrics and conductive yarns that are skin-friendly.
- **Electrical Safety**: E-textile heating systems involve electrical components. Ensuring proper insulation and shielding is essential to prevent accidental shocks or short circuits. Manufacturers follow safety standards related to electrical insulation and grounding.
- **Temperature Control and Limits**: E-textile heaters must maintain safe operating temperatures. Overheating can lead to burns or discomfort. Implementing temperature sensors and control algorithms helps regulate the heat output and prevent excessive temperatures.
- **Washing and Durability**: E-textiles need to withstand washing and wear. Manufacturers provide guidelines for cleaning e-textile garments without damaging embedded electronics. Avoiding harsh chemicals and high heat during drying is essential.
- **Connectivity and Insulation**: Ensuring proper connectivity between conductive threads or yarns is crucial. Loose connections can lead to hotspots or malfunction. Insulating components against sweat, moisture, and external environmental factors is essential for safety and durability.
- **Power Sources**: Managing power sources effectively is critical. Batteries or power banks should be securely integrated into the garment to prevent accidental exposure or damage. Overcharging protection mechanisms are also important.
- **Flexibility and Comfort**: E-textile heating systems should remain flexible and comfortable. Rigidity or stiffness can cause discomfort during movement. Manufacturers design flexible circuits and integrate them seamlessly into fabric structures.
- **User Guidelines and Education**: Providing clear instructions to users is vital. Manufacturers include information on safe usage, washing procedures, and any

precautions. Educating users about potential risks and safe practices enhances overall safety.

- **Testing and Certification**: Rigorous testing ensures compliance with safety standards. Manufacturers conduct electrical safety tests, thermal stability tests, and durability assessments. Certifications from relevant authorities validate safety claims.
- **Health Monitoring and Feedback**: Some e-textile systems incorporate health monitoring features. These can detect anomalies (e.g., overheating) and provide real-time feedback to users. Alerts or automatic shut-off mechanisms enhance safety.
- **Regulatory Compliance**: Adhering to regional safety regulations and standards is essential. Manufacturers must consider guidelines related to electronic textiles, wearable devices, and consumer safety.

Remember that safety is a collaborative effort involving manufacturers, researchers, and end-users. As e-textile technology evolves, continuous improvement in safety practices remains a priority.

3. STANDARDS AND LITERATURE

Wearable heating e-textiles represent an exciting intersection of fashion, technology, and materials science, with applications ranging from personal comfort to medical therapy. Wearable heating e-textiles are an emerging field that blends textile materials with electronic components to provide heating functionality. The development and use of these textiles are governed by various international and national standards, as well as other relevant literature. This review will provide an understanding of the regulatory frameworks, performance criteria, safety standards, and recent advancements in the field. Here's a detailed review of the existing standards and literature:

3.1 KEY AREAS OF FOCUS IN THE STANDARDS AND LITERATURE

- **Thermal Performance:** Standards and literature focus on the ability of wearable heating e-textiles to provide consistent and controllable heat. This includes testing for uniform heat distribution, adjustable temperature settings, and the ability to maintain heat over time.
- **Safety and Durability:** Safety is a critical concern, particularly with respect to electrical safety, overheating, and the potential for skin burns. Durability testing covers the textiles' ability to withstand repeated washing, stretching, and environmental exposure without degrading performance.
- **Material Selection:** The choice of conductive materials (e.g., carbon-based materials, metallic fiber) is a significant focus, as it affects the flexibility, weight, and comfort of the final product. Standards guide the selection of materials that balance these factors with thermal efficiency.
- **Power Supply and Management:** Efficient power management is essential for wearable heating e-textiles. This includes the integration of batteries or energy

harvesting systems, as well as ensuring that the power supply does not compromise the wearability of the textile.

- **User Comfort and Ergonomics:** The literature emphasizes the importance of designing heating e-textiles that are comfortable to wear for extended periods. This includes considerations of weight, breathability, and the avoidance of hotspots that could cause discomfort.

3.2 E-TEXTILE STANDARDS

The major reason for the absence of standards for e-textile is that it is a relatively new field in the world of electronics and because of the many criteria and sub-criteria that need to be considered in an e-textile system (from the type of fabric to the type of conductive yarn to be used) based on individual applications. While trial-and error methods can be feasible for DIYs and small-scale projects, standardization is needed if e-textile manufacturing processes are to be commercialized. Standardization is a vital component in the widespread commercialization of e-textiles. The standards must be in place to ensure the safety of the technology, as well as quality control. It has also been said by several sources that a lack of standards for assembly of electronic components can reduce the performance of e-textile systems (Inc, n.d.).

3.2.1. INTERNATIONAL STANDARDS

IPC Standards: The Interconnecting and Packaging and Components (IPC) is releasing new set of standards to help bring the next generation of e-textile technology to modern products. As more companies begin to integrate e-textiles into their products, new standards will become increasingly necessary.

- **IPC-8921** - Requirements for Woven and Knitted Electronic Textiles Integrated with Conductive Fiber, Conductive Yarns, and/or Wires, released in May of 2019, outlines 20 terms and definitions for e-textiles. This standard also establishes classifications for e-textiles that are made with e-fiber, e-yarns, and e-wires. Additionally, this standard highlights the key characteristics and test methods for e-textiles. (Inc, n.d.).
- **IPC-9204** - Guideline on Flexibility and Stretchability Testing for Printed Electronics: Provides a standard guideline for the qualification by s flexibility and stretchability tests that may be used to evaluate printed electronics for flexible, stretchable and wearable application, including those used in e-textiles. (IPC org, n.d.)
- **IPC-8952**, "Design Standard for Printed Electronics on Coated or Treated Textiles and E-Textiles" was published, along with **IPC-8971**, "Requirements for Electrical Testing of Printed Electronics on Textiles." (Cobb, 2024). IPC-8952 standard outlines specific requirements for the design of printed electronic applications and their forms of component mounting and interconnecting structures on coated or treated textile substrates which may have a coating or treatment localized or across the full substrate.

- **IPC-8971**, “Requirements for Electrical Testing of Printed Electronic E-Textiles” establishes requirements for electrical testing printed electronic e-textiles, including selecting the test analyzer, test parameters, test data, and fixturing required to perform electrical testing. This standard also provides e-textile manufacturers with guidance for electrical test setup, test techniques and test equipment. This standard is set to be officially completed by this summer (Inc, n.d.).

The IPC standards are the first baseline compilation of definitions and terminologies from the textiles and electronics industries in one document. The IPC-8971 and IPC-8952 standards, which are variations of the IPC- 8922, are some of the released standards. They establish the test requirements for printed e-textiles on a coated textile substrate and their components. These standards have established the layout design and electrical & mechanical tests essential for printed e-textiles. For example, in the IPC-8952 standard, it was specified that the minimum width and thickness of conductors on printed e-textiles are based on the current capacity and maximum permissible temperature. There is still a need to understand how these recommendations apply to other fabrication methods and to translate guidelines into specific, measurable values and relationships in order to develop design rules to support design automation. The IPC organization has started developing some new standards for “Qualification and Performance Specification for Printed Electronics or Coated or Treated Textiles and E-Textiles,” which will be a counterpart to IPC-8952, IPC-8953, “Design Standard for Embroidered E-Textiles,” which draws on the work of IPC-8952, IPC-8981, “Quality and Reliability of E-Textiles Wearables,” will establish 15 testing requirements for mechanical and exposure characteristics, including washability, IPC-8961, “Guidelines on E-Textiles Wearables,” planned for 2025, will reference IPC-8981 as a guideline for designers and manufacturers of wearables, IPC-8921A, a revision of the earlier standard, with requirements for the performance of woven, knitted and braided e-textiles and IPC/JPCA-8911, “Requirements for Conductive Yarns for E-Textile Applications,” which will include at least six new test methods, is expected to see its final draft some time in 2024. IPC is accredited by the American National Standards Institute as a standards-developing organization and is known globally for its standards. (Cobb, 2024)

ISO/IEC Standards: The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

- **ISO 63203-2** This document contains provisions for conductive yarns and defines measurement methods of properties of conductive yarns used in electronic textile (e-textile) in wearable electronics. A conductive yarn can be incorporated into the fabric which, in turn, can be used to manufacture a wearable electronics product. The conductive yarn can transmit electric signals and/or supply electric power. Therefore, measurement methods are defined for the characteristics of conductive yarns. The IEC 63203-2 series relates mainly to measurement methods for electronic textile (e-textile) in wearable electronics.

The IEC 63203-2 series consists of the following parts:

IEC 63203-201: E-textile materials

- IEC 63203-201-1: E-textile materials – Conductive yarn
- IEC 63203-201-2: E-textile materials – Conductive fabrics and insulation materials

IEC 63203-202: Passive electric parts for e-textiles

- IEC 63203-202-1: Passive e-textile parts – Connectors for e-textile applications

IEC 63203-203: E-textile functional elements

IEC 63203-204: E-textile systems (Evaluation method for garment-type wearable systems)

- IEC 63203-204-1: E-textile systems – Test method for assessing washing durability of leisurewear and sportswear e-textile systems

IEC 63203-201-1: Electronic textile – Measurement methods for basic properties of conductive yarns: This part of IEC 63203-201 specifies provisions and test methods for measurement of properties of conductive yarns.

  - Resistance of conductive yarn: The electrical resistance of conductive yarn is determined using the four-wire method. The electrical resistance of conductive yarn is defined as the electrical resistance per unit length of the conductive yarn Ω / m.
  - Fusing current: The fusing current is a fundamental measurement value for obtaining the maximum permissible current for the conductive yarn. The electrical current at the time when the conductive yarn melts or ignites is registered as the fusing current.
  - Perspiration resistance: The resistance change ratio between initial resistance, and the resistance after treating with artificial perspiration alkaline solution is recorded.
  - Detergent resistance: The resistance change ratio between initial resistance and the final resistance after immersion in aqueous detergent solution is recorded.

IEC 63203-201-3: This standard provides a test method for determining the electrical resistance of conductive fabrics used in e-textiles. It specifically considers the temperature and humidity conditions between the fabric and the wearer's skin. Ensuring proper electrical behaviour is essential for safety and functionality.

- **ISO 3178:1981** - *Textiles – Woven fabrics – Determination of resistance to water penetration – Hydrostatic pressure test*. This standard, although not specifically for e-textiles, is relevant as it deals with the durability of textile materials against water penetration, which is crucial for wearable electronics.

- **ISO/IEC 27001:2013** - *Information technology – Security techniques – Information security management systems – Requirements*. This standard is relevant for the cybersecurity aspects of e-textiles that might involve data transmission, particularly in smart clothing.

- **ISO 18190:2016** - *Textiles – Test methods for determining the abrasion resistance of fabrics containing conductive fibers and/or filaments*. This is directly related to e-textiles as it assesses the durability of conductive materials within fabrics, which is essential for maintaining the heating functionality.

- **ISO 21195:2019** - *Textiles – Specification for gloves for protection against mechanical risks*. While primarily for mechanical protection, this standard also covers testing for materials that might be used in protective heating garments.

- **ISO 8124 Series:** While primarily focused on toy safety, parts of these standards address the safety of materials in contact with the skin, which could be relevant to wearable textiles.

- ISO **11092:2014** is a standard that specifies the testing method for determining the thermal and water-vapor resistance of textiles. It is used to evaluate the comfort properties of materials, particularly in terms of how they handle heat and moisture transfer. The physical properties of textile materials which contribute to physiological comfort involve a complex combination of heat and mass transfer. Each may occur separately or simultaneously. They are time dependent, and may be considered in steady-state or transient conditions. ISO 11092:2014 is particularly relevant for wearable heated e-textiles because it assesses the **thermal and water-vapor resistance** of the fabric, which are crucial factors in ensuring the comfort, safety, and functionality of heated garments. Thermal resistance (R_{ct}) in square meter kelvin per watt, is the net result of the combination of radiant, conductive and convective heat transfer, and its value depends on the contribution of each to the total heat transfer. Although it is an intrinsic property of the textile material, its measured value may change through the conditions of test due to the interaction of parameters such as radiant heat transfer with the surroundings. Higher thermal resistance means better insulation, which is important for cold-weather clothing or environments requiring heat retention. The Water-Vapor Resistance (R_{et}) in square meters pascal per watt, measures how well a fabric allows moisture (such as sweat) to evaporate and pass through the material. Lower water-vapor resistance indicates better breathability, which is crucial for keeping the wearer comfortable in warm or high-activity conditions. The water-vapour permeability index (i_{mt}) is the ratio of thermal and water-vapour resistances. This is dimensionless and has values between 0 and 1. A value of 0 implies that the material is water-vapour impermeable, and a material with a value of 1 has both thermal resistance and waver-vapour resistance of an air layer of the same thickness. The water-vapour permeability (W_d) expressed in grams per square meter hour pascal, is the characteristic of a material

Test Method:

The test uses a sweating guarded hotplate (“skin model”) to simulate heat and moisture transfer through a fabric. The plate is heated to a set temperature, and the amount of heat and moisture that passes through the fabric is measured under controlled environmental conditions. Measurements involving one or both processes may be carried out either separately or simultaneously using a variety of environmental conditions, involving combinations of temperature, relative humidity, air speed, and in the liquid or gaseous phase. In this International Standard only steady-state conditions are selected. Both dry and wet measurements are taken to assess the fabric’s performance in different scenarios (such as when dry or during sweating).

For the wearable heated e-textile, this standard can be referenced to assess the thermal and water vapor resistance of the fabric which are crucial factors in ensuring comfort, safety and functionality. The importance of this standard for such applications are:

Thermal Regulation and Insulation

Wearable heated e-textiles are designed to provide warmth by actively generating heat. ISO 11092:2014 helps evaluate the thermal resistance (Rct) of the fabric, ensuring that the material can:

- Effectively retain the heat generated by the heating elements, improving the efficiency of the heating system.
- Provide sufficient insulation to keep the user warm while preventing excessive heat loss to the environment.

Testing for thermal resistance allows manufacturers to balance the right amount of insulation, ensuring that the garment maintains warmth while remaining lightweight and comfortable.

- Moisture Management: As heated e-textiles are often worn in cold or variable environments, moisture management is critical to comfort. ISO 11092:2014 measures water-vapor resistance (Ret), which is essential for:
- Breathability: Heated garments need to allow sweat and moisture to escape from the body to prevent overheating or discomfort. Lower Ret values indicate better breathability, allowing sweat to evaporate through the fabric while maintaining thermal performance.
- Moisture Evaporation: High-performance e-textiles must be able to handle sweat during physical activity without compromising the effectiveness of the heating element or causing discomfort.
- Comfort Optimization: ISO 11092:2014 ensures that the fabric offers an optimal combination of thermal insulation and breathability, which is critical for comfort in wearable heated e-textiles. The standard helps verify that the fabric will keep users

warm without causing excessive sweating or overheating, making it suitable for various environments, such as outdoor sports, workwear, or medical applications.

- Preventing Overheating: Heated e-textiles can run the risk of trapping too much heat, which can lead to discomfort or even safety concerns. Testing with ISO 11092:2014 ensures that the fabric's breathability and thermal resistance are balanced so that the wearer remains warm without overheating.
- Safety and Efficiency: In heated garments, it's essential to avoid moisture buildup, as excessive dampness can affect the electrical components and efficiency of the heating elements. ISO 11092:2014 helps ensure that the material allows adequate moisture management, contributing to both electrical safety and long-term durability of the heating elements.

Hence, by applying ISO 11092:2014, manufacturers of wearable heated e-textiles can ensure their products offer an ideal combination of warmth, breathability, and moisture control, which enhances user comfort, safety, and product performance.

- **ISO 13934-1** is a standard that specifies a method for determining the maximum force and elongation of textile fabrics using a strip method, also known as the "tensile strength test." The test measures the fabric's breaking strength and elongation (stretch before breaking) under a controlled tensile load. A fabric sample is clamped in a **constant-rate-of-extension (CRE) testing machine**, and a force is applied until the fabric breaks. The force required to break the fabric and the elongation at the breaking point are recorded. The standard specifies the size of the sample, the speed of the testing machine, and other factors that ensure consistent results across different laboratories and conditions. ISO 13934-1 is commonly used alongside other fabric testing standards to ensure quality and performance in textiles. ISO 13934-1 is relevant for wearable heated e-textiles because it helps assess the **strength and durability** of the textile materials used in these products. E-textiles, which incorporate electronic components into fabric, need to maintain structural integrity under stress and wear over time.
  - Durability and Wear Resistance: Wearable heated e-textiles are subject to frequent movement, stretching, and stress, especially in clothing or other wearables. Testing the fabric's tensile strength ensures it can withstand the physical demands of regular use without tearing or breaking, even when integrated with electronic components.
  - Ensuring Longevity of Electronics: In heated e-textiles, delicate electrical circuits and heating elements are often embedded into or sewn onto the fabric. If the fabric tears or weakens, the electronic components could also be damaged, leading to product failure. ISO 13934-1 testing ensures that the base fabric is strong enough to support the embedded electronics over time.
  - Safety: Strength testing is crucial to ensure that the fabric doesn't degrade or fail when exposed to stress, which is particularly important when dealing with heated textiles. A fabric failure could expose wiring or heating elements, posing safety risks such as burns or electrical malfunctions.

- Compliance with Industry Standards: Manufacturers of e-textiles need to meet both electronic and textile industry standards. ISO 13934-1 helps ensure the fabric component meets the necessary strength and performance benchmarks, contributing to overall product reliability and market acceptance.

- **ISO 10993 Series**: Standards for the biological evaluation of medical devices – Evaluation and testing within a risk management process. These standards are particularly important for wearable e-textiles with medical applications, ensuring biocompatibility.

  The **ISO 10993** document outlines a structured biological evaluation plan within a risk management process for medical devices. The standard addresses the determination of the biological response to medical devices, mostly in a general way, rather than in a specific device-type situation. It emphasizes the importance of considering biological hazards, material biocompatibility, and design aspects during evaluation. It outlines specific endpoints to be addressed in a biological risk assessment, such as degradation, toxicity, hemocompatibility, material characterization, and specific aspects of biological evaluation etc. The range of biological hazards is wide and complex. The biological response to a constituent material alone cannot be considered in isolation from the overall medical device design. Thus the choice of the best material with respect to its biocompatibility might result in a less functional medical device, biocompatibility being only one of a number of characteristics to be considered in making that choice. Where a material is intended to interact with tissue in order to perform its function, the biological evaluation needs to address this. However, It is not intended that this standard to provide a rigid set of test methods, including pass/fail criteria.

- **ISO 21156:2020:** This standard addresses the general requirements for active implantable medical devices, which includes considerations for the interaction between the device and the human body, relevant for heating elements in e-textiles.

- **ISO 3376:2020:** Though this standard is about leather, it covers tensile strength and elongation tests, which are indirectly relevant when considering the mechanical properties of wearable e-textiles.

- **ISO 10993:** Biological evaluation of medical devices, which can be relevant for therapeutic e-textiles in contact with skin.

- **ISO 16533:** Although not exclusively for heating textiles, ISO 16533 addresses the measurement of exothermic and endothermic properties of textiles under humidity change. **Exothermic property** is the property of material whereby it releases heat to the surroundings while **endothermic property** of material whereby it absorbs heat from the surroundings. The **hygroscopic and exothermic property** of material generates heat by absorbing moisture and releases the generated heat to its surroundings where relative humidity changes from low to high over time. The **hygroemissive and endothermic property** of material loses heat and cools down by releasing moisture through evaporation to its surroundings where relative humidity changes from high to low over time. A test specimen is placed in a low humidity atmosphere and then exposed to a high humidity atmosphere, and then the other way round. The temperature of the test specimen is measured over time with a temperature sensor. The exothermic and endothermic properties of the test specimen are determined from the difference in temperature measured with the temperature sensor, between a test with and another without the test specimen mounted on the sensor probe. While this standard covers a broader range of textile properties, understanding how textiles respond to humidity changes is relevant for wearable heating products.

- **ISO 18782:** This standard focuses on the determination of dynamic hygroscopic heat generation in textiles. Hygroscopic heat generation refers to the heat released or absorbed by textiles due to moisture changes. While not specific to heating, understanding this property can impact overall comfort and safety.

- **ISO 6330:2012** -- Domestic washing and drying procedures for textile testing: Specifies washing and drying procedures to evaluate how textiles including those integrated with heating elements, including fabrics and garments, react to domestic laundering processes, including washing and drying, under controlled conditions. It helps assess how fabrics and garments withstand repeated washing and drying, which is crucial for determining their durability and performance over time. Evaluation criteria are checks for colour fastness, shrinkage, and changes in texture or finish after laundering, assesses any deterioration in the fabric's functional properties, such as strength, elasticity, or dimensional stability. For wearable e-textiles, the component Integrity may be evaluated. Hence proper testing helps ensure that the electronic elements (like heating wires or sensors) remain intact and functional despite the mechanical action and temperatures encountered during laundering. The care Labels ensures the users that care instructions are accurate and reflect the garment's ability to handle typical home laundering processes.

- **ISO 9237:1995** Textiles -- Determination of the permeability of fabrics to air: Measures the breathability of fabrics. The rate of flow of air passing perpendicular through a given area of fabric is measured at a given pressure difference of 100 pascal across the test area for apparel fabrics over a given time period. This standard is important to assess:
  - Breathability and Comfort: Wearable heated e-textiles need to balance thermal insulation with breathability. Air permeability testing ensures that the fabric allows adequate air flow, which is crucial for:
  - Comfort: Fabrics that are too impermeable can trap excessive heat and moisture, leading to discomfort for the wearer.

- Moisture Management: Breathable fabrics help in the efficient evaporation of sweat, reducing moisture buildup inside the garment.
- Performance of Heating Elements: The effectiveness of heating elements in e-textiles can be influenced by the fabric's air permeability. Adequate airflow ensures that:
- Heat Distribution: The generated heat is evenly distributed and not trapped in one area, which enhances the overall warmth provided by the garment.
- Electronics Safety: Proper airflow prevents overheating of the heating elements and associated electronics, reducing the risk of component failure or safety issues.
- Temperature Regulation: For wearable heated e-textiles, managing temperature is crucial to avoid overheating or excessive cooling. Ensuring appropriate air permeability helps in maintaining a comfortable microclimate close to the skin, adjusting to both external environmental conditions and internal body heat.
- Long-Term Wearability: In high-activity scenarios, such as sports or outdoor activities, garments are subject to dynamic conditions that affect both comfort and performance.

- **ISO 14001** sets out criteria for an effective environmental management system (EMS). It provides a framework that organizations can follow to reduce their environmental impact, ensure legal compliance, and improve their environmental performance. The standard follows a Plan-Do-Check-Act (PDCA) cycle, which emphasizes continuous improvement and is applicable to any organization, regardless of size, industry, or location. The Key aspects of this standard specification include Environmental Policy, Planning, Implementation & Operation, Monitoring & Measurement, and continual improvement.

- **ISO 12947-1:1998** specifies the Martindale method for determining the abrasion resistance of textile fabrics. This part of the standard outlines the general principles and requirements for testing fabric durability by subjecting samples to rubbing motions under controlled conditions. The standard is designed to test how well fabrics resist abrasion, or surface wear, caused by friction. It is essential for fabrics used in products that experience frequent rubbing, such as clothing, upholstery, and industrial textiles.
  Martindale Method: The test involves placing fabric samples in a machine that simulates repeated rubbing motions. A circular sample of the fabric is rubbed against a standard abrasive surface under controlled pressure. The number of rubs (cycles) until noticeable wear or failure (e.g., yarn breakage or fabric hole) is recorded.
  ISO 12947-1:1998 is relevant for **wearable heated e-textiles** because it assesses the **abrasion resistance** of the fabric, which is critical for ensuring durability and long-term performance in garments that combine textile and electronic components.
  The importance of this standard in wearable heated e-textiles are:
  - Durability of E-Textiles in Daily Use: Wearable heated e-textiles are often subjected to regular wear, stretching, and friction during use, whether in clothing or accessories.

Abrasion resistance testing ensures that the fabric can withstand the physical stresses caused by:

- Daily movement and friction in high-contact areas like elbows, knees, or the back.
- Repeated washing and handling, which may lead to fabric wear over time.
- Protecting Electronic Components: In heated e-textiles, electronic circuits and heating elements are embedded or integrated into the fabric. If the fabric wears down due to abrasion, it could expose or damage the electronics, leading to:

- Malfunctioning heating elements or circuits.
- Safety concerns such as short circuits, electrical failure, or overheating. Testing for abrasion resistance helps to ensure that the fabric can protect these sensitive electronic components and maintain their functionality over time.
- Extended Product Lifespan: Wearable heated e-textiles, especially in outdoor, sports, or medical applications, are expected to be durable and maintain performance over extended periods. ISO 12947-1:1998 helps manufacturers ensure that the outer layers of the textile can withstand the frictional forces of daily use without degrading, which extends the overall lifespan of the product.
- Comfort and Aesthetics: As abrasion can lead to pilling, surface wear, or the breakdown of fabric integrity, testing ensures that the e-textile remains:
  - Comfortable to wear without causing irritation from worn or rough fabric.
  - Aesthetically pleasing, as worn-out fabrics can detract from the garment's appearance, affecting user satisfaction.
- Reliability in Extreme Conditions: Wearable heated e-textiles are often used in demanding environments, such as outdoor sports, industrial applications, or military use, where they may encounter harsher wear conditions. Abrasion resistance ensures that the fabric will hold up in these extreme scenarios, maintaining both functionality and comfort for the user.

By applying ISO 12947-1:1998, manufacturers of heated e-textiles can guarantee that their products meet the necessary standards for abrasion resistance, ensuring that they remain durable, reliable, and safe throughout their lifecycle.

- **IEC 62366-1:2015** - *Medical devices – Application of usability engineering to medical devices*. This standard could be indirectly applied to wearable heating e-textiles, particularly those designed for medical applications, such as for therapeutic heating.

- **IEC 60601-1: IEC 60601-1** sets the baseline for the safety and essential performance of medical electrical equipment. It applies to devices that have one or more parts that come into direct or indirect contact with the patient, are used to transfer energy to/from the patient, or detect signals from the patient. If the e-textile is intended for medical use, adherence to this standard may be critical. This governs the safety and performance requirements for medical electrical equipment. It is widely used for ensuring that medical devices are safe for both patients and operators. The standard is essential for regulatory approvals in many countries and is often used in conjunction with other related standards for specific device types.

IEC 60601-1-1 is part of the IEC 60601 series of standards, which governs the safety and performance of medical electrical equipment. Specifically, IEC 60601-1-1 focuses on the general requirements for the safety of medical electrical systems. Here's a summary of its key points:

Scope: The standard applies to medical electrical systems, which consist of interconnected equipment that could include both medical and non-medical devices.

- Risk Management: It requires manufacturers to perform a risk analysis and implement appropriate safety measures to prevent hazards such as electrical shocks, fires, or malfunctions. Manufacturers must implement a formal risk management process, typically following ISO 14971, to identify and mitigate potential hazards throughout the product lifecycle.
- Isolation and Protection: The standard outlines requirements for electrical isolation between medical equipment and other devices to avoid electrical interference, particularly in life-support systems.
- Power Supply and Earthing: It provides guidelines on power supply configurations and grounding to ensure reliable and safe operation of interconnected equipment.
- Electromagnetic Compatibility (EMC): The standard addresses the need for systems to be protected from electromagnetic interference, which can disrupt medical equipment.
- Protection Against Radiation: The standard includes provisions for protection against unintended radiation, both ionizing and non-ionizing.
- Mechanical and Environmental Safety: Devices must be designed to minimize risks from physical hazards such as moving parts, sharp edges, or instability. Protection against mechanical failures is also considered. Systems must be designed to withstand environmental factors, such as vibrations, temperature changes, and mechanical stress.

This standard is particularly important for ensuring that when multiple medical devices are used together, they function safely and reliably as an integrated system.

- **IEC 60601-1-2** is an international standard focused on the electromagnetic compatibility (EMC) of medical electrical equipment and systems. This standard ensures that such devices operate safely without causing or being susceptible to electromagnetic disturbances. Here is a summary of its key points:

  Scope: IEC 60601-1-2 applies to medical electrical equipment and systems used in medical environments, addressing both EMC emissions (how much electromagnetic noise the equipment generates) and immunity (how resistant the equipment is to external electromagnetic interference).

  Main Objectives:

- Safety: Ensures that medical devices do not create unacceptable risks due to EMC-related issues.
- Performance: The equipment should function as intended even when subjected to electromagnetic disturbances.
- Regulatory Requirements: Provides specific EMC testing and compliance criteria for manufacturers to meet safety regulations globally.
- Key Components:
- Emission Limits: Medical devices must limit the amount of electromagnetic interference (EMI) they emit to ensure they do not affect nearby equipment.
- Immunity Requirements: Devices must be resilient to external EMI, including radio frequencies and electrostatic discharges, to maintain proper functioning.
- Test Procedures: It outlines detailed test methods for assessing both emission and immunity, specifying levels based on the intended use environment (e.g., hospitals, home care settings).
- Risk Management: Manufacturers must assess risks related to EMC during the device's design and include this in their risk management processes.
- Labelling & Documentation: Requires specific information about the equipment's EMC performance in labelling and instructions to help users manage EMC-related risks.

This standard is often used in conjunction with other standards from the IEC 60601 series to ensure the overall safety and performance of medical electrical equipment.

- **IEC 62304:** Software life cycle processes standard for medical device software, relevant for e-textiles with embedded electronics.

- **IEC 62133:** Safety requirements for portable sealed secondary cells and batteries, commonly used in e-textiles.

- **IEC 60721-3-7:1995**: Classification of environmental conditions -- Part 3-7: Classification of groups of environmental parameters and their severities -- Portable and non-stationary use: Specifies environmental conditions for portable and non-stationary use, relevant for wearable e-textiles to ensure they can withstand various environmental conditions.

- **IEC 60068-2** series deals with environmental testing methods for electronic and electrical products, including e-textiles. It contains many parts (sub-standards), each detailing specific tests. It ensures these products can withstand various environmental stresses during their lifecycle. Some relevant sub-standards are:
  - **ISO 60068-2-1: Test A: Cold:** Tests how the material and electronic components behave under cold conditions. It ensures the heated elements and textile materials function in low-temperature environments without mechanical or electrical failure. Temperature chambers are constructed and verified in accordance with specifications IEC 60068-3-5 and IEC 60068-3-7. The chamber shall be large enough compared with

the size and amount of heat-dissipation of the test sample. The specimen is introduced into the test chamber. The temperature in the chamber is then decreased gradually so as to cause no detrimental effects on the test specimen due to the temperature change. The rate of change of temperature within the chamber shall not exceed 1 K per minute, averaged over a period of not more than 5 min.

- **ISO 60068-2-2: Test B: Dry Heat:** This standard deals with dry heat tests applicable both to heat-dissipating and non-heat dissipating specimens. A specimen is considered heat-dissipating only if the hottest point on its surface, measured in free air conditions, is more than 5 K above the ambient temperature of the surrounding atmosphere after temperature stability has been reached. Tests the product's endurance under high temperatures. It ensures the heating mechanisms and materials can tolerate exposure to heat without degradation or malfunction. The temperature chamber(s) shall be constructed and verified in accordance with specifications IEC 60068-3-5 and IEC 60068-3-7. The specimen is introduced into the test chamber. The temperature in the chamber is then increased gradually so as to cause no detrimental effects on the test specimen due to the temperature change. The rate of change of temperature within the chamber shall not exceed 1 K per minute, averaged over a period of not more than 5 min.
- **ISO 60068-2-6: Vibration:** Assesses the product's ability to withstand vibration. It ensures that heating elements, sensors, and connections within the e-textile are resistant to physical movement and vibrations common in daily use.
- **ISO 60068-2-14: Temperature Change:** Evaluates how temperature fluctuations impact performance. It ensures the e-textile can endure rapid transitions between hot and cold environments without damage or operational issues.
- **ISO 60068-2-27: Shock:** Tests the product's resistance to mechanical shocks. Verifies that the heating elements and connections are durable against sudden physical impacts.
- **ISO 60068-2-30: Damp Heat (Cyclic):** Tests against Simulates humid, tropical environments. Tests the fabric's and electronics' resistance to moisture, ensuring the product functions without corrosion or short-circuiting.
- **ISO 60068-2-38: Composite Temperature/Humidity Cycles:** Tests with combined temperature cycling with humidity exposure. This ensures that the wearable heated e-textile can withstand combined temperature and humidity stress, simulating real-world conditions.
- **ISO 60068-2-78: Steady-State Damp Heat:** Tests the effects of prolonged exposure to high humidity at constant temperatures. Ensures that the product resists long-term moisture exposure, crucial for wearables subjected to sweat or outdoor conditions.

For wearable heated e-textiles, these tests are important to guarantee they remain functional, safe, and reliable under various everyday conditions such as temperature fluctuations, sweat exposure, and movement stresses. The tests simulate real-world environmental stresses that these textiles might encounter, ensuring their performance and longevity.

- **IEC 61140:2016:** Protection against electric shock -- Common aspects for installation and equipment: Provides guidelines for protection against electric shock, critical for ensuring the safety of users of wearable e-textiles.

- **IEC 80601-2-56:2017:** Medical electrical equipment -- Part 2-56: Particular requirements for basic safety and essential performance of clinical thermometers for body temperature measurement: Ensures the safety and performance of devices measuring body temperature, relevant for e-textiles with integrated temperature sensors.

- **IEC 62430 : Environmental assessment of electrical and electronic products: A life cycle approach** is an international standard that set requirements and give guidance on how an organization can integrate environmentally conscious design (ECD) into their design and development. The standard offers a framework for evaluating the environmental impacts of electrical and electronic products throughout their entire life cycle, from production to disposal. It aims to help manufacturers and organizations understand and manage the environmental effects of their products, including resource use, emissions, and waste generation.
  The standard promotes a life cycle assessment (LCA) approach, which considers all stages of a product's life:
    - Raw Material Extraction: Impact of sourcing materials.
    - Manufacturing: Environmental effects of production processes.
    - Use: Energy consumption and emissions during product use.
    - End-of-Life: Waste management, recycling, and disposal impacts.

ASTM International (American Society for Testing and Materials):

- **ASTM D737-18** - *Standard Test Method for Air Permeability of Textile Fabrics*. This is important for wearable heating e-textiles, as it assesses the breathability of the fabric, which is crucial for user comfort.
- **ASTM F1868-17** - *Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate*. This directly relates to measuring the thermal properties of heating textiles, evaluating how well they can retain and distribute heat.
- **ASTM F2732-16** - *Standard Practice for Determining the Temperature Ratings for Cold Weather Protective Clothing*. While not specific to e-textiles, this standard provides a method for evaluating the thermal performance of textiles, which can be adapted for assessing wearable heating e-textiles. This standard can be applied to wearable heating e-textiles, ensuring they meet specific thermal performance criteria.

- **ASTM D7005:** Standard Test Method for Strength Properties of Tension Devices used in the installation of tensile membranes, which can be adapted for testing the tensile properties of e-textiles.
- **ASTM D1776:** Standard Practice for Conditioning and Testing Textiles, providing guidelines on environmental conditions during testing, essential for consistency in results when testing e-textiles.
- **ASTM F2407:** Standards specifically for heated fabrics, which would cover the safety and performance of heating elements within textiles.
- **ANSI/AAMI ES60601-1:2005/(R)2012 - Medical Electrical Equipment, Part 1:** This is the U.S. adoption of IEC 60601-1, focusing on the safety of medical electrical equipment. It is relevant for e-textiles used in therapeutic heating applications.

BSI (British Standards Institution):

- **BS EN 1149-5:2018** - *Protective clothing – Electrostatic properties – Part 5: Material performance and design requirements*. This standard is relevant for e-textiles that must manage electrostatic discharge, which could affect the performance and safety of heating elements.

CSA (Canadian Standards Association):

- **CSA Z96-15** - *High-Visibility Safety Apparel*. This standard is important for e-textiles designed to provide visibility in addition to heating, commonly used in outdoor or industrial applications.

Safety and Performance Standards for Heating Elements

- **IEEE 1625:** Standard for Rechargeable Batteries for Portable Computing, important for e-textiles that integrate heating elements powered by rechargeable batteries.
- **UL 962:** This standard addresses the safety of household and commercial furnishing, which might include certain e-textile applications.
- **EN 50299:** This European standard focuses on the safety requirements for electrical devices, particularly those with heating elements, which can apply to e-textiles.

UL (Underwriters Laboratories):

- UL 817: Covers cord sets and power-supply cords, relevant for ensuring safe electrical connections in e-textiles.
- UL 1642: Addresses lithium batteries, ensuring that any integrated batteries meet safety standards.
- UL 2056: Safety of power banks, which can be used as power sources for e-textiles.

3.2.2. OTHER STANDARDS

- ASTM WK61480- Durability of textile electrodes after laundering (in development)
- ASTM WK61479- Durability of textile electrodes exposed to perspiration (in development)
- ASTM WK61478- New terminology for smart textiles (in development)
- AATCC RA111(a)- Electrical resistance of electronically integrated textiles (in development)
- AATCC RA111(b)- Electrical resistance changes after home laundering (in development)
- CEN EN 16812:2016- Linear electrical resistance of conductive tracks
- IEC 63203–204-1- Washable durability for leisure and sportswear e-textile system (in development)
- IEC 63203–201-3- Electrical resistance of conductive textiles under simulated microclimate (in development)
- IEC 63203–250-1- Snap button connectors (in development)
- IEC 63203–201-1- Basic properties of conductive yarns (in development)
- IEC 63203–201-2- Basic properties of conductive fabric and insulation materials (in development)

Thermal (Total of 4 test standards, 1 published and 3 in development)

- CEN EN 16806–1:2016- PCM - Heat storage and release capacity
- CEN EN 16806–2 PCM- Heat transfer using a dynamic method (in development)
- CEN EN 16806–3 PCM- Determination of the heat transfer between the user and the product (in development)
- IEC 63203–406-1- Measuring skin contact temperature (in development)

Mechanical (Total of 2 test standards in development)

- IEC 63203–401-1 - Stretchable resistive strain sensor (in development)
- IEC 63203–402-1 – Finger movements in glove-type motion sensors (in development)

Physical environment (Total of 1 test standard in development)

- IEC 63203–402-2 - Fitness wearables – step counting (in development)

Optical (Total of 1 test standard in development)

- IEC 63203–301-1 - Electrochromic films for wearable equipment (in development)

Others (Total of 4 test standards, 2 published and 2 in development)

- ASTM D8248–19- Standard terminology for smart textiles
- CEN 16298 - Definitions, categorization, applications and standardization needs

- IEC 63203–101-1 – Terminology (in development)

3.3. OTHER RELEVANT LITERATURE

Research Articles: Numerous research articles have been published on the development, characterization, and application of heating e-textiles. Key areas of focus include:

- The integration of conductive materials like carbon nanotubes, graphene, or metallic fibers to achieve efficient heating.
- Durability and washability of heating textiles, which are critical for their practical use.
- Power management and safety concerns, including the risk of overheating and electrical short-circuiting.

Technical Reports: Reports from industry groups and academic institutions often address the challenges and innovations in wearable e-textiles. These documents provide insights into current trends, such as the miniaturization of electronic components and the use of flexible batteries.

Patents: Several patents exist in the field, covering various aspects of e-textile technology, including heating elements, fabric integration methods, and safety features. Reviewing these patents can provide a comprehensive view of the state-of-the-art technologies and potential future developments.

Research Literature and Technical Reports

a. Performance and Durability

- Recent studies focus on the durability of heating elements in e-textiles, including their washability, flexibility, and long-term wear. Key metrics include resistance to mechanical stress, electrical reliability, and heat uniformity.
- Innovations in conductive yarns and inks are frequently discussed, with emphasis on balancing electrical conductivity and textile properties.

b. Biocompatibility and Skin Interaction

- Research is ongoing to address the biocompatibility of materials used in heating e-textiles. This includes assessing the risk of skin irritation, thermal burns, and allergic reactions.
- Studies also cover the thermal management of e-textiles to avoid excessive heating that could lead to discomfort or injury.

c. Integration and Usability

- Advances in integrating flexible circuits and battery systems into textiles are explored, with a focus on maintaining comfort, flexibility, and user safety.

- Wearable e-textiles are increasingly incorporating smart sensors to monitor temperature and adjust heating dynamically, enhancing both safety and efficiency.

Other Relevant Literature and Guidelines

1. "Smart Textiles and Their Applications" (Woodhead Publishing Series in Textiles, 2016):

This book offers a comprehensive overview of smart textiles, including chapters on heating textiles. It discusses material choices, integration methods, and performance testing.

2. "Wearable Technology and Wearable Devices: Everything You Need to Know" by B. Preetham and S. R. Rao (2018):

This paper provides an introduction to wearable technologies, including heating textiles, and discusses the current trends and challenges in the field, such as power supply, thermal management, and user comfort.

3. "Electrically Heated Clothing: Design and Evaluation" by X. Tao et al. (Textile Research Journal, 2014):

This study evaluates the design and performance of electrically heated clothing, providing insights into the thermal comfort, safety, and energy efficiency of wearable heating e-textiles.

4. "Integration of Heating Elements in Wearable Textiles" (IEEE Transactions on Industrial Electronics, 2020):

This paper explores the technical challenges and solutions related to embedding heating elements into textiles, including the choice of conductive materials, power supply considerations, and durability testing.

A Wearable Heating System with Controllable e-Textile-Based Thermal Panel: In a study published in an open-access chapter by Senem Kurşun Bahadir and Umut Kivanc Sahin, researchers explored the development of a heated vest using e-textile technology (Sahin, Oct. 03, 2018). Here are the key points from their work:

- Objective: The goal was to create a wearable heating system that could maintain realistic thermal body balance while ensuring uniform heating for irregular geometries.
- E-Textile Panels: The researchers produced several e-textile-based thermal panels using hot air welding technology. These panels incorporated different conductive yarns.
- Heating Behaviour: The e-textile panels were tested for their heating behaviour at varying direct current (DC) power levels.

- Optimum Design: Based on experimental results, the team selected an optimum e-textile-based thermal panel design that balanced flexibility and uniform heating.
- Control Algorithm: An electronic control module was designed, integrating a control algorithm, electrical circuit, and electrical connection network.
- Wearable Heating Vest: Finally, the electronic module was integrated with the attachable e-textile-based thermal panel to create a practical wearable heating vest.

3.4. CHALLENGES AND GAPS IN STANDARDS

- **Interdisciplinary Nature:** Wearable heating e-textiles involve a convergence of textiles, electronics, and ergonomics, making it difficult for a single standard to cover all aspects. The existing standards often focus on either the textile or the electronic component, but not on the integration of the two.
- **Standardization Gaps:** While there are numerous standards for related technologies, there is still a lack of comprehensive standards specifically for wearable heating e-textiles, especially in terms of long-term wearability and real-world conditions.
- **Safety Concerns:** While there are standards for electrical safety, specific guidelines for the safe operation of heating elements within wearable textiles are still evolving. Issues like thermal regulation, skin safety, and fire hazards are critical areas that need further standardization.
- **Environmental Impact:** The sustainability of e-textiles, particularly the environmental impact of electronic waste and the recyclability of these products, is a growing concern. Current standards do not adequately address these issues.
- **Emerging Trends:** The integration of IoT with wearable e-textiles is growing, leading to smart heating systems that adjust based on user activity and environmental conditions. This trend calls for new standards that address the complexities of interconnected systems. As wearable heating e-textiles increasingly integrate with IoT systems for real-time monitoring and control, there is a need for standards that address data security, interoperability, and system reliability.

Conclusion

The landscape of standards and literature for wearable heating e-textiles is complex, involving multiple international and national standards bodies. The field of wearable heating e-textiles is supported by a range of standards, primarily focusing on the textile or electronic aspects. However, there is a need for more comprehensive and integrated standards that address the unique challenges of e-textiles, particularly in terms of safety, durability, and environmental impact. While there are existing standards that partially cover the safety, performance, and durability of these textiles, there is still a need for more specific guidelines tailored to the unique challenges posed by wearable e-textiles. As this field evolves, both standards organizations and researchers must continue to collaborate to ensure that these technologies are both safe and effective for consumers. As the industry grows, it is likely that new standards will emerge, tailored specifically to the needs of wearable heating e-textiles. New standards for e-textiles mean two things: improved technology and more advanced products.

3.5. TESTS AND EVALUATION:

The tests that are necessary can be listed as below:

1. Testing of power sources - could be a AC adaptor, or Battery - safety and compliance testing - environment testing at various humidity and ambient temperatures.
2. Comfort and Mobility testing and evaluation - sweat absorption
3. Temperature test - overheating, and underheating, propose tolerance bands for different levels of heat setting - degradation tests
4. Flexibility testing - whether all the components are integrated tightly, and if any compromise on functionality
5. Washability and hygienic evaluation and studies - multiple people can use same product? Contamination issues? Abrasion resistance
6. Safety considerations - automatic shutoffs, failure mechanisms, risk to the user when encountering fault while usage etc
7. Proper user manual document on usage instructions and care and maintenance of these products
8. Power management - energy conservation that decides the battery life and its wear and tear,
9. Risks of water damage, Battery ignition and fire hazards
10. Other durability
11. Different biometric sensors integrated - including heart rate, respiration rate, and body temperature- evaluation, risk factors, false positive, false negative analysis
12. Response time tests - switch ON to the achievement of set conditions.
13. uniformity of the actuation - Thermometry and thermography
14. e-waste and recycling possibilities

3.5.1. IN-DEPTH EVALUATION OF WEARABLE HEATING E-TEXTILE PRODUCTS

Wearable heating e-textiles integrate electronic components into fabrics to provide controlled heating, offering comfort and therapeutic benefits. Evaluating these products involves analyzing several key aspects: technology, materials, power sources, control mechanisms, safety, performance, user experience, and market potential.

1. Technology and Design

Heating Elements:

- **Materials:** Common materials include conductive yarns, carbon fibers, or metal alloys. These materials are chosen for their flexibility, conductivity, and durability.
- **Design:** Heating elements are strategically woven or printed into the fabric to ensure even heat distribution. The design should avoid hotspots and ensure consistent performance.

Integration Techniques:

- **Embroidery:** Conductive threads are stitched into the fabric.
- **Printing:** Conductive inks are printed onto the textile surface.
- **Lamination:** Thin heating elements are laminated between fabric layers.

Power Sources:

- **Battery-Powered:** Rechargeable lithium-ion or lithium-polymer batteries are commonly used. Evaluation should consider battery life, charging time, and portability.
- **USB-Powered:** These can be powered by external USB power banks, providing flexibility in power sources.

Control Mechanisms:

- **Manual Controls:** Simple switches or buttons to adjust heat levels.
- **Smart Controls:** Integration with smartphone apps for precise control and customization, allowing users to set temperatures, timers, and track usage.

2. Materials and Comfort

Fabric Choices:

- **Breathability:** Fabrics like cotton, polyester, and blends that ensure breathability and comfort.
- **Flexibility:** Stretchable materials to maintain ease of movement.
- **Durability:** Fabrics that can withstand repeated bending, washing, and wearing.

Comfort:

- **Fit:** The design should ensure a snug fit without being too tight, ensuring the heating elements stay close to the body.

Weight: Lightweight components to avoid adding bulk to the garment.

3. Safety and Reliability

Temperature Regulation:

- **Sensors:** Integration of temperature sensors to monitor and maintain safe heating levels.
- **Overheat Protection:** Safety mechanisms to prevent overheating and potential burns.
- **Even Heat Distribution:** Design ensuring uniform heat spread to avoid localized overheating.

Durability and Washability:

- **Waterproofing:** Protection of electronic components from moisture and sweat.
- **Washability:** Ability to withstand multiple wash cycles without degrading performance.

Certifications and Compliance:

- **Safety Standards:** Compliance with safety standards such as UL, CE, or FCC.
- **Testing:** Rigorous testing for electrical safety, fabric durability, and overall performance.

4. Performance and Efficiency

Heating Efficiency:

- **Heat-Up Time:** Quick heat-up times for immediate comfort.
- **Heat Retention:** Ability to retain and distribute heat effectively over time.
- **Battery Life:** Long-lasting battery life to provide sufficient heating duration.

Energy Consumption:

- **Power Efficiency:** Optimization of power consumption to extend battery life.
- **Adjustable Settings:** Multiple heat settings to customize power usage and comfort.

5. User Experience and Aesthetics

Ease of Use:

- **User Interface:** Intuitive controls, whether manual or app-based.
- **Maintenance:** Clear instructions for care and maintenance, including washing and battery handling.

Aesthetics:

- **Design:** Stylish and fashionable designs to appeal to a wide range of users.
- **Versatility:** Ability to blend seamlessly with everyday clothing or be used in various environments, from casual wear to outdoor activities.

Feedback and Reviews:

- **User Feedback:** Collecting and analysing user reviews to identify common praises and complaints.
- **Field Testing:** Conducting real-world tests to gather data on performance and user satisfaction.

6. Market Potential and Trends

Market Demand:

- **Target Demographics:** Identifying key user groups, such as athletes, outdoor workers, medical patients, or everyday consumers seeking comfort.
- **Applications:** Exploring various use cases, from outdoor activities and sports to therapeutic uses and everyday comfort.

Competitive Landscape:

- **Competitor Analysis:** Evaluating similar products in the market to identify strengths, weaknesses, opportunities, and threats.
- **Innovation:** Keeping abreast of technological advancements and emerging trends in e-textiles.

Pricing Strategy:

- **Cost vs. Value:** Balancing production costs with the perceived value to set competitive pricing.
- **Affordability:** Offering different models or versions to cater to various price points and customer segments.

The evaluation of wearable heating e-textile products encompasses a comprehensive analysis of the technology, materials, power sources, control mechanisms, safety, performance, user experience, and market potential. A successful product not only integrates advanced technology and materials to provide effective heating but also ensures user comfort, safety, and satisfaction. By continuously innovating and adapting to market needs, manufacturers can create high-quality, reliable, and desirable wearable heating e-textile products.

4. INDUSTRIAL VISITS

We have collected a list of possible Indian manufacturers of the heated e-textile garments. We have initiated communication these manufacturers listed below. We have visited one of the companies based in Pune. There is no positive response from the other manufacturers. We plan to follow up to arrange for the industrial visits for the collection of relevant data as per the requirement of the project. We intend to purchase the items after confirming if the items are manufactured by the respective companies and just not imported and rebranded.

- MEDTECH LIFE PVT. LTD., B6, Byculla Service Industries, D. K. Marg, Byculla (E), Mumbai - 400027
- Jungle earth - Junglearth, Punjab Hotel Junction, Vishakapatnam - 530018
- SandPuppy, Pune, Maharashtra
- Expressions Arts and Crafts Private Limited. Village Dhulkot, Main Road, Near Gurudwara Sahib, Ambala City, Haryana - 134003
- Ascent Meditech Limited, Block/Sry.No-1545 Dungari 66KVA Road, Dungari, Valsad Gujarat - 396375
- Odessey products, Krishna Enterprises, SICOP Industrial Estate, Bari Brahmana Jammu, Jammu & Kashmir -181133
- Elove Technologies, B-2/28, DSIDC Jhilmil Flatted Factory Complex, Dilshad Garden, Delhi

4.1 INDUSTRIAL VISIT – SANDPUPPY PUNE

An industrial visit to the SandPuppy, Pune, a leading manufacturer of heated e-textile wear, founded in 2016, provided a valuable opportunity to understand the intricate processes involved in designing and producing wearable heated textiles. The company specializes in the integration of efficient heating technologies into fabrics. Their target application is of pains, aches and surgery interventions prevalent globally in population groups of forty. According to them, four of five adult experiences serious back pain at some point in their lives. Women are a particularly vulnerable group, being most affected by knee pain & shoulder pain. Their vision is to help people manage everyday pain and fatigue.

FIR Heating Pad:

Heating pad - It is a pad that uses heat to relieve the pain in several body parts. It is a heating medium covered in a thick, insulated fabric that helps to contain and emit heat. A heating pad is versatile and can be used on any body part, be it the knee, back, calves, arms, or shoulder. These heating pads generally use heat therapy for pain relief to calm the discomfort in the different body parts. A heating pad typically releases pain by increasing the blood flow to the affected body part.

SandPuppy specializes in using a different heating element, according to them is the FIR (Far Infrared) heating pad. Far Infrared technology basically works by converting electricity into far infrared light, which in turn produces heat. And Far Infrared heating pads use the same technology to induce heat for pain management. The feature that differentiates it from other types of heating pads is that its heat penetrates deep into the tissues and relaxes the muscles. (Tiwari, n.d.) A regular heating pad's heat does not penetrate deep into the tissue, and the user can feel the heat only till the pad is in contact with the skin. It just warms the skin and doesn't have a long-lasting heating effect. Whereas infrared's heat reaches deep into the tissue, relieves muscle tension, and provides longer-lasting pain relief.

Many regular heating pads use electricity to produce heat by metal coils, while some also use cotton as an insulator. However, infrared heat pads do not emit EMF in the heating process. It converts heat into infrared rays. Infrared rays are not harmful to the human body in any way as we are exposed to them daily from the sun.

FIR heating pads use carbon wires to heat. Carbon wires are suitable for heating and provide durability to the heating pads. According to a National Library of Medicine (Gale GD, 2006 Autumn) report, FIR heating pads are suitable for reducing chronic back pain as the penetrative heat might help cure it better. The research was on a group of people who were aged 60. Hence, we can say it is also safe for older adults.

According to SandPuppy, the main features to look for a heating pad are

1. Soft, sweat & stain resistant fabric
2. Inbuilt safety thermostat
3. Lightweight and easy to carry
4. Has different temperature levels (high, medium, low)
5. Can be taken off-grid, can be battery or power bank operated
6. I prefer FIR therapy, which has the longest-lasting relief and heals better

The major components include:

- **Fabrics:** For outer, inner layers
- **Conductive Threads**: Woven into the fabric to create the heating elements.
- **Battery or Power Source**: A lightweight, portable power source.
- **Thermostat**: To regulate and maintain a consistent temperature.
- **Control Units**: Embedded microcontrollers that allow users to adjust temperature settings via buttons.

Raw materials:

Of the raw materials, the liner fabric, the control module and the power adapter are sourced locally while the heating element of various specifications is been imported.

Manufacturing Process

The visit provided a detailed view of the manufacturing process, which can be divided into the following stages:

Design and Prototyping: The initial product development stage involves the design team collaboration with their inhouse and external specialists to develop e-textiles with integrated conductive fibers as heating systems. Prototypes been built and tested for performance, and safety to meet the customer's requirements.

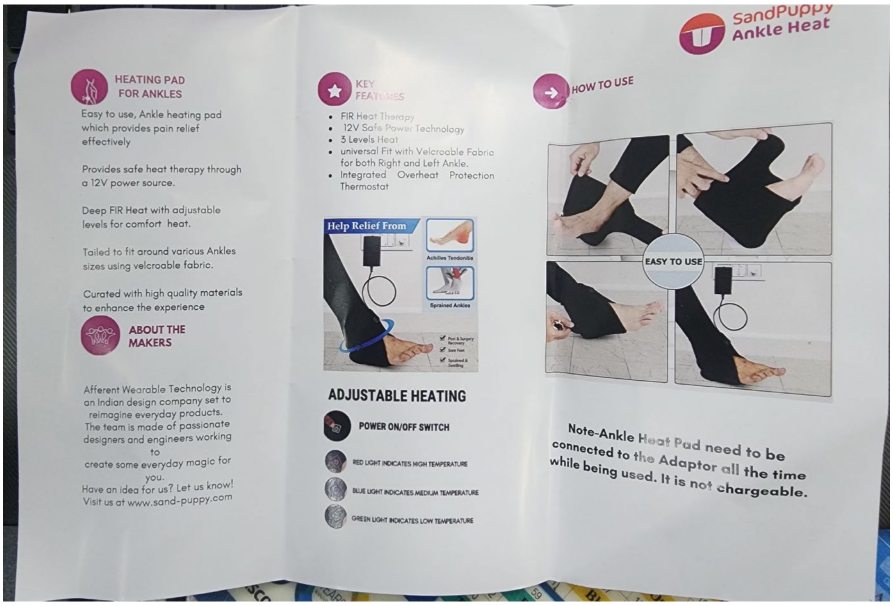
Cutting: Cotton based fabrics are chosen and cut according to the design of the wear. The cotton fabric forms the inner layer and the middle heating pad layers. A foam layer forms the outside of the wear.

Fabrication of Heating Layers: Conductive carbon FIR Fibers are laid and sandwiched between two cotton-based fabric layers. These fiber pads form the heating zones within the garment. A thermostat safety switch is also sandwiched on to this layer.

Assembly of Components: Power adaptor socket, thermostat, heating pad terminals and control units are integrated into the garment. Special attention is given to the placement of heating elements to ensure even distribution of heat. The above materials were sandwiched or integrated and stitched and given an overall shape and finished.

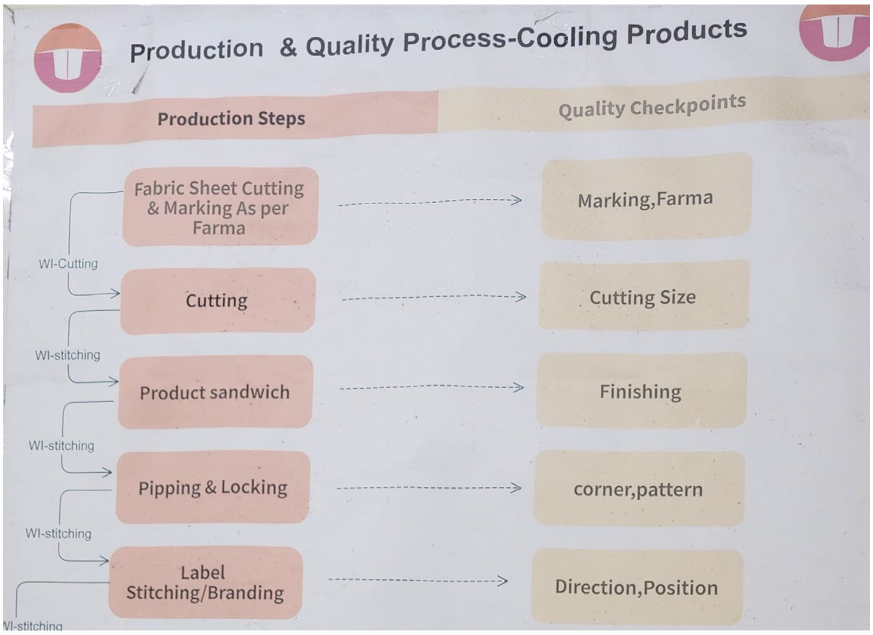
Testing and Quality Control: The company employs rigorous testing protocols to ensure safety and performance. Fabrics are tested for durability, heat distribution, and wearability. The heating filaments/fibers/finished pads, and the control units are also tested to verify their functionality and efficiency in regulating temperature.

Final Inspection and Packing: Each garment undergoes a final inspection before packaging. The inspection includes testing temperature control, and fabric quality. The product is also labelled for safety usage instructions, and an instruction leaflet is also enclosed in the eco-friendly cardboard box.


SandPuppy
Ankle Heat
HEATING PAD FOR ANKLES
Easy to use, Ankle heating pad which provides pain relief effectively
Provides safe heat therapy through a 12V power source.
Deep FIR Heat with adjustable levels for comfort heat.
Tailed to fit around various Ankles sizes using velcroable fabric.
Curated with high quality materials to enhance the experience
ABOUT THE MAKERS
Afferent Wearable Technology is an Indian design company set to reimagine everyday products. The team is made of passionate designers and engineers working to create some everyday magic for you.
Have an idea for us? Let us know! Visit us at www.sand-puppy.com
KEY FEATURES
FIR Heat Therapy
12V Safe Power Technology
3 Levels Heat
universal Fit with Velcroable Fabric for both Right and Left Ankle.
Integrated Overheat Protection Thermostat
Help Relief From
Achilles Tendonitis
Sprained Ankles
ADJUSTABLE HEATING
POWER ON/OFF SWITCH
RED LIGHT INDICATES HIGH TEMPERATURE
BLUE LIGHT INDICATES MEDIUM TEMPERATURE
GREEN LIGHT INDICATES LOW TEMPERATURE
HOW TO USE
EASY TO USE
Note-Ankle Heat Pad need to be connected to the Adaptor all the time while being used. It is not chargeable.


IDEAL FOR
Safer heat therapy for chronic cervical pain, spasms and fatigue.
Penetrative deep muscle FIR therapy
Improved blood circulation and relaxing sore neck muscles and stiffness
Age-related chronic pains affecting elderly
CARE DETAILS
Do not wash
Do not iron
Do not wring
SAFETY INSTRUCTIONS
Do not use it while sleeping.
Do not assess the heating with bare hands as it is deep muscle therapy which is better felt when used directly on the affected area.
Do not use the belt with ointment
Do consult your medical expert before usage as SandPuppy is not designed as a medical or curative device.
Do not use SandPuppy directly on the skin or sensitive areas.
WARRANTY
Warranty period of 12 months will start from date of purchase.
contact us for extended warranty
www.sand-puppy.com
or dial
+917767813666
EXPERT ADVICE
MEET OUR CONSULTING PHYSIOTHERAPIST.
For FREE Physio Consultation
CALL US ON
+91 7767813666
WhatsApp Code - to join pain management community
YouTube Code - Subscribe for pain specific exercises
FIR THERAPY
Deep tissue penetration
Improves blood circulation
Muscle & Tissue healing
Chronic pain relief
SandPuppy is now safer, faster, and better, ready to provide instant heating and lasting relief.
SAFER | FASTER | BETTER
we've got your back!
SandPuppy
Ankle Heat
WE CARE ABOUT YOU
SandPuppy Online Physio Services was started with sole purpose of making daily pain manageable.
Our In-house physiotherapist, Dr. Mahima Handa (PT) would be glad to help assess your pain and provide the right support you would need on your journey to a pain-free lifestyle.
SandPuppy online physio
Register on our website for more offers
WELCOME TO THE SANDPUPPY FAMILY
We have designed our products with the best technology that gives long-lasting pain relief and comfort for you and your family.
We believe that holistic healing lasts longer and our in-house Physiotherapist will be glad to guide and help you and your loved ones manage pain better.
Wishing you pain free days ahead.


Manufactured / Marketed by / Customer Service Contact :
Afferent Wearable Tech Pvt. Ltd.
K R Plaza, Office No 201,
Survey No 12/1 Baner-Balewadi
Road, Near Laxmi Temple,
Balewadi, Pune 411045
Email : care@sand-puppy.com
Tel : +91 7767813666
Website : www.sand-puppy.com



Sustainability: The company emphasized their efforts in sourcing eco-friendly fabrics and creating long-lasting, energy-efficient products.

Safety instructions while using a heating pad:

- Do not apply directly on bare skin
- Do not fold the heat pad
- Do not sleep with it on
- Before using it consult your doctor if you have any underlying medical condition.

The visit to SandPuppy was highly educational, providing insights into the cutting-edge technology behind heat able e-textile wear. The company is at the forefront of innovation, working on overcoming the challenges of durability, safety, and user comfort. The experience broadened our understanding of smart textiles and highlighted the growing demand for such wearables in various industries.

4.2 QUESTIONNAIRE

1. Raw materials used
    a. Cloth
    b. Cotton
    c. Liner
    d. Polyester
    e. Foam
    f. Silicone coated carbon fiber for heating
2. Sources of raw materials – countries
    a. Electrical components – Noida, Gurugram
    b. Fabric related items - Gujarat

3. Manufacturing methodology and process control

   Described in detail before the questionnaire section

4. Varieties manufactured
   a. Knee cap
   b. Ankle cap
   c. Elbow cap
   d. Wrist-wrap
   e. Neck-wrap
   f. Weighted heating pad for neck and shoulder pain
   g. Heating pad for back pain
5. Test facilities available
   a. Thermal camera: To test heat distribution
   b. Electrical testing facility: To check the current and temperature stability
   c. Manual testing for twisting: To check the flexibility of the electrical wires
6. Test methods used
   a. Heat distribution: A thermal camera is employed to record the heat distribution of the heating pad after 1 minute, 5 minutes, 10 minutes and 20 minutes to monitor the heat distribution and the stability of temperature.
   b. Electrical testing: The samples are kept under power supply for 30-45 minutes to check the performance of the heating element.
      i. Test for resistance: Measurement of the resistance of the wire before and after the heating cycle
      ii. Current testing: Measurement of current during the heating cycle at different heating levels.
      iii. Overheat protection: A thermocouple is used in series with the heating element and stitched within the fabric to cut-off the power supply when the temperature reaches 85℃. The power supply resumes when the thermocouple temperature comes down to 65℃. The working of the thermocouple is tested for several cycles.
   c. Mechanical testing: The flexibility of the heating element, fabric and stitching materials are tested by manually twisting and folding for 1000 cycles the heating pad/cap several times and then by putting them under voltage/current stress for hours.
7. Test equipment available for complete testing
   a. Thermal camera
   b. Power source
   c. Multimeter
8. Frequency of testing of each parameter:
   a. Mechanical and electrical stress: 5/6 samples out of a batch of 100 are chosen randomly to perform the tests.

b. DC resistance and current: All samples

9. Sampling data for testing

Same as mentioned in the previous point

10. Marking and labelling requirements

There is no labelling on the product but the product package comes with the following manual.

11. Packaging:

Depending on the product the packaging is either recyclable card board box or the fabric-based bags as shown below.

12. Post-production quality check facilities

Same as the test methods described in item 6.

13. Data on sales - domestic and export consumption

The seller sales their products in domestic market only. The monthly estimate of the product wise sales figures and cumulative turnover is given below in the table.

Product name	Unit price (Rs.)	Units sold per month	Monthly turnover (Rs.)
Knee cap	1470	200	294000
Ankle cap	1400	125	175000
Shoulder cap	1550	125	193750
Wrist wrap	1400	100	140000
Neck-wrap	1450	100	145000
Neck+Shoulder wrap	1860	200	372000
Back heating pad	1520	150	228000
Total		1000	1547750

14. Collection of datasheet/tech specs of each variety of product

	DC current based	AC current based
Product	Small area covering products, such as, knee cap, ankle cap, wrist band	Large area covering products, such as, neck wrap, neck and shoulder wrap, pad for back pain relief
Heating wire material	Silicone coated carbon fiber	Silicone coated carbon fiber
Heating wire resistance	33 Ω/m	133 Ω/m
Response time	15 mins	15 mins
Power requirement	24 W	45-50 W
Heating wire layout	Series and parallel combination	Series combination
Resistance requirement	2 Ω	1 kΩ
Voltage requirement	12V DC	230V AC

Maximum temperature	85℃	85℃
Overheat protection	Tc cut-off temp. - 85℃ Tc turn-on temp. - 65℃	Tc cut-off temp. - 85℃ Tc turn-on temp. - 65℃

15. Steps taken to ensure energy conservation/efficiency

    Silicone coated carbon fiber heating wires are 30% more efficient over the normally used nichrome or tungsten wires.

16. Sustainable processes followed in the production process

    All the materials used are biodegradable and recyclable

17. Waste disposal management

    There is no major waste product other than extra fabrics after cutting. Those are sent factories for recycling.

Acknowledgments: We would like to thank the directors of SandPuppy for their kind hospitality and the detailed tour of their facilities.

5. TEST METHODOLOGIES

Testing wearable heated e-textiles for performance and safety involves a combination of standard protocols for textiles, electronics, and wearables. These tests assess various aspects like heating efficiency, durability, safety, comfort, and electrical integrity.

5.1. KEY PARAMETERS

The key parameters that could be tested for are the following.

Thermal Efficiency:

- **Heating Speed:** Measure the time it takes for the e-textile to reach the desired temperature.
- **Temperature Uniformity**: Check how evenly the heat is distributed across the textile surface using thermal cameras.
- **Target Temperature Maintenance**: Assess how well the textile maintains a set temperature over time.
- **Energy Input vs. Heat Output**: Calculate how much electrical power (in watts) is required to generate a specific amount of heat (in joules). This can help in understanding the power-to-heat conversion efficiency.

Power Consumption

- **Battery Life**: For e-textile wearables with inbuilt battery - Monitor the battery life under different heating levels. A higher efficiency product will last longer for the same battery capacity.
- **Voltage & Current Usage**: Evaluate the voltage and current required for the heating element to operate efficiently

Insulation Performance

- **Heat Retention**: Check how long the heat is retained in the textile after turning off the power.
- **Thermal Resistance:** Measure the insulation quality of the material itself in trapping the heat.

Wearability & Comfort

- **Surface Temperature**: Ensure the surface temperature of the fabric is within a safe and comfortable range for continuous skin contact.
- **Weight & Flexibility**: Assess how the integration of heating elements affects the fabric’s flexibility, weight, and overall comfort during wear.
- **Breathability**: A more breathable fabric may help in preventing overheating and sweat buildup.

Durability

- **Wear and Tear:** Monitor how the heating elements and electrical components perform under physical stress like bending, stretching, or washing.

- **Lifespan of Heating Element**: The heating element's durability over time is critical for efficiency, as wear and tear can reduce heat output.

5.2. KEY TEST METHODOLOGIES

1. Performance Testing

a. Temperature Control and Distribution:

- **Objective**: Evaluate how uniformly and efficiently the heating elements distribute heat across the textile. Measure the accuracy and stability of the heating element to reach and maintain specific target temperatures.
- **Test Method**: Use thermal imaging cameras or sensors to measure surface temperature across different zones while the textile operates at various settings. Measure the time taken to reach target temperatures.

b. Heating Duration and Battery Life:

- **Objective**: Test the duration the textile can sustain a consistent temperature. Measure the time it takes to reach the desired operational temperature (heat-up) and the time to cool down to ambient levels.
- **Test Method:** Time-based thermal profiling with data loggers to track temperature changes over time.

c. Maximum Operating Temperature:

- Ensure the maximum temperature is within safe limits for skin contact.
- **Method**: Use temperature sensors to monitor surface temperature under different operating conditions (e.g., max power, extreme ambient conditions).

d. Thermal Retention and Efficiency:

- Evaluate how well the material retains heat when powered off.
- **Method:** Perform tests in varied environmental conditions (temperature and humidity).

e. Environmental Testing (Temperature and Humidity):

- **Objective**: Ensure the textile performs under various environmental conditions (cold, heat, humidity).
- **Test Method**: Place the e-textile in a controlled environmental chamber, varying temperature and humidity levels, and evaluate its heating response and any degradation in performance.

2. Electrical Performance Testing

Power Consumption:

- Measure power consumption across different operating conditions.
- Method: Use wattmeter to record power usage.

Durability under Repeated Use:

- Evaluate electrical performance after multiple cycles of heating and cooling.
- Method: Conduct endurance tests, with controlled powering cycles, to monitor degradation over time.

Short Circuit and Overload Protection:

- Test for built-in safety mechanisms, such as automatic shutoff in case of electrical faults.
- Method: Deliberately introduce faults like short circuits and overloads to confirm protective features.

3. Safety Testing

a. Electrical Safety (Overheating, Short Circuit, and Insulation Integrity):

- **Objective**: Ensure electrical components are safe to use in wearable textiles, preventing overheating or short circuits. Ensure that textiles won't overheat to the point of causing burns. Check for electrical insulation and protection against shocks.
- **Test Method:** Apply electrical loads at varying intensities and simulate fault conditions (e.g., short-circuit scenarios) to monitor for system failures.
- Test under high-demand scenarios, ensuring that any auto-shutoff mechanisms or temperature regulators work effectively.
- Insulation Test: Check for leakage currents or loss of insulation using a high-voltage test (dielectric testing) to prevent electric shocks.

b. Thermal Protection and Skin Contact Safety:

- **Objective**: Evaluate the textile's safety for skin contact at elevated temperatures.
- **Test Method:** Monitor surface temperature at maximum power and simulate skin contact to ensure it does not exceed safe temperature thresholds (typically $< 42°C$ for long-term contact). Also, monitor for thermal runaway scenarios.

c. Moisture and Sweat Resistance:

- Ensure that the device can function safely in humid conditions and with exposure to sweat.

- **Method:** Perform tests under high humidity or artificial sweat environments to simulate real-world usage.

d. Flame Resistance:

- Test the material for fire resistance in case of malfunctions.
- **Method:** Subject samples to flame or high-heat environments to assess their flammability.

e. Durability and Washability Testing:

- **Objective**: Assess the durability of heating elements and their integration with the textile during normal use, including repeated washes.
- **Test Method**: Wash the e-textile under standardized conditions for a set number of cycles, then evaluate its performance and safety.

f. Flexibility and Bending Stress:

- Evaluate the performance of heating elements when the textile is bent, stretched, or folded.
- **Method:** Perform repeated bending and folding tests to ensure no loss of function.

e. Impact Resistance:

- Assess whether impact or pressure can damage the heating elements or compromise their safety.
- **Method:** Perform drop or compression tests to simulate accidental impacts.

4. Comfort and Ergonomic Testing

a. Comfort and Flexibility Testing:

- **Objective**: Ensure that the e-textile remains comfortable and flexible when worn.
- **Test Method**: Conduct bending and stretching tests to measure the flexibility and elasticity of the material. Also, perform user-based comfort assessments.

b. Moisture Management and Breathability:

- **Objective**: Test moisture-wicking properties and breathability while the textile is heated.
- **Test Method**: Use a sweating thermal manikin or water-vapor transmission tests to measure how the textile handles perspiration and maintains breathability.

5. User Interface and Usability Testing

a. Control Mechanism Testing:

- **Objective**: Assess the functionality and ease of use of the controls (manual or via smartphone).
- **Test Method**: Conduct usability testing where participants operate the controls under various conditions (wearing gloves, in low light, etc.) to ensure easy and reliable operation.

b. Battery and Connectivity Testing:

- **Objective**: Evaluate wireless communication (if present) and the durability of the battery.
- **Test Method:** Test wireless connections and app reliability in varying conditions. Perform cycle tests on the battery to ensure longevity.

6. Environmental Testing

a. Extreme Temperature Resistance:

- Test the textile's performance in extreme cold and hot environments.
- **Method:** Conduct tests in environmental chambers that simulate various climate conditions.

b. Waterproofing/Water Resistance:

- Ensure the material and heating elements are safe to use in wet environments or when exposed to rain.
- **Method:** Conduct water ingress tests such as IPX testing for water resistance.

7. Compliance Testing

For commercial products, compliance with regulatory standards is essential for safety and market access:

- FCC/CE Certification (for wireless communication)
- RoHS (Restriction of Hazardous Substances) Compliance
- Battery Compliance Testing for transport safety (UN 38.3).

This comprehensive testing approach ensures both the performance and safety of wearable heated e-textiles for consumer and industrial use.

a. EMC/EMI Testing (Electromagnetic Compatibility and Interference)

Electromagnetic Emission:

- Test for compliance with regulations on electromagnetic emissions, ensuring the device does not interfere with other electronics.

- Method: Perform tests in an EMC chamber to measure emissions and susceptibility to interference.

5.3. TEST METHODS

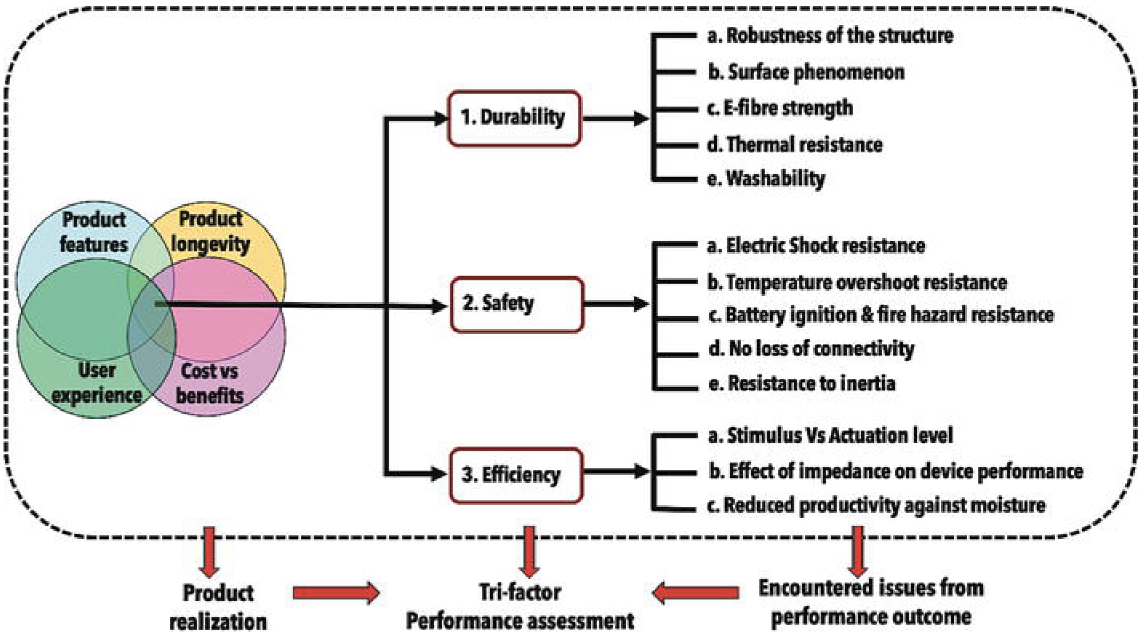


Figure: Assessing the performance of e-textiles (Iftekhar Shuvo I, Mar 2021)

The e-textiles could be tested for performance on three factors broadly – Durability, Safety and Efficiency.

Test thermal resistance of the system and electrical parameters at different test conditions – Resistance to heat is a critical factor for electro-thermal e-textiles. The heating components and the material in contact have to be able to sustain the heat generated with in operation without losing their conductivity, strength and other performance, and without getting on fire or melting. The setup will also have data logger to do prolonged tests related to durability, repeatability, reliability and safety explained later.

The main element of the test stand was an electrically heated 200 mm x 200 mm plate with temperature control placed in a climate test chamber. Tests were carried out according to the method described in the standard ISO 11092:2014. The station was equipped with an additional system for measuring the voltage and current in the heating insert. The system included a laboratory power supply and two multimeters set to measure direct voltage (voltmeter) or direct current (ammeter).

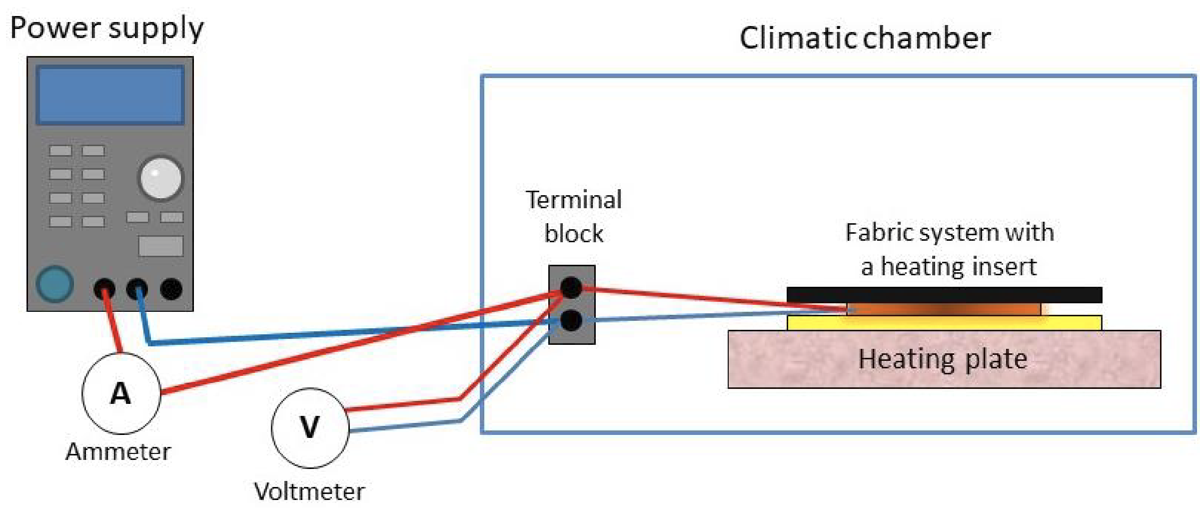


Figure: Measurement of thermal resistance (Sylwia Krzemińska, 2023)

Before determining the thermal resistance of the material system, it was necessary to determine the thermal resistance of the “bare plate” of the skin model. For this purpose, the temperature of the plate was set to 35 deg C, the air temperature to 20 degC, and the air flow rate to 1 m/s. After reaching equilibrium conditions, the thermal resistance of the “bare plate” R_{ct0} was calculated in m^2K/W using the following formula:

$$R_{ct0} = \frac{A.(T_m - T_a)}{(H - \Delta H_c)}$$

where A is the surface area of the measuring plate (m^2); T_m is the temperature of the measuring plate (C); T_a is the air temperature in the climatic chamber (C); H is the heating power supplied to the measuring plate (W); and ΔH_c is the correction factor of the heating power (W).

Then, the material system with a heating insert was placed on the measuring plate and an analogous measurement was made. The thermal resistance of sample R_{ct} was calculated in m^2K/W using the formula:

$$R_{ct} = \frac{A.(T_m - T_a)}{(H - \Delta H_c)} - R_{ct0}$$

where R_{ct0} is the thermal resistance of the plate alone (m^2K/W). It was assumed that the heating inserts will be assessed on the basis of the power and electrical resistance of the inserts and current intensity measurements, as well as the thermal resistance of the material systems with a heating insert (in the on and off state). The electrical power of the heating insert was determined using Joule’s law, and the electrical resistance of the insert was determined using Ohm’s law.

Durability after repeated bending and twisting: The test consists of subjecting the heating inserts to 9000 cycles of bending and twisting followed by examination of change in the thermal resistance of the system of fabrics containing the heating inserts. After the bending and twisting process, the tested inserts were also visually evaluated for possible damage.

Durability - Effect of biomechanical stresses during wear – An apparel product is subjected to large biomechanical stresses during wear. Movements like when bending elbows (for sleeves), bending knees (for trouser legs) or bending over exerted significant stresses on the product. If the smart/e-textile product is not robust enough to withstand such biomechanical stresses, they will be easily damaged and experience a loss in functionality and safety.

Durability against sweat (artificial) - Salt from body sweat during workouts or from seawater for example in marine applications may also corrode metallic elements of the e-textiles. Testing the of heating inserts to artificial sweat involved assessing the performance of the inserts after direct contact with a sweat solution and determining changes in the thermal resistance of the system of fabrics containing the heating insert. A certain amount of the prepared sweat solution was measured and pipetted onto the surface of the heating insert, which was placed in a glass pan. The application was started from one side of the insert, gradually moving to the other side. After the application was completed, measurements of the voltage and current flowing through the insert were conducted (after 5 min and after 24 h). The results were read at a voltage set to 4 V. The heating insert was assessed in terms of electrical properties by determining power and electrical resistance. In addition, the heating insert was subjected to a thermal resistance test to check the effects of sweat exposure on heat-insulating properties.

Durability against household washing conditions - A change in resistance is the parameter most often used to assess washability which will also affect the thermal response and performance. It is a critical concern for e-textile users as the washing and drying processes subject the product to damaging conditions and could eventually destroy the connectivity between the electronic components or the electronic components themselves (Tao X, 2017). Chemical stress (detergent, surfactants), thermal stress (washing/drying temperature), solvent (water), and mechanical stress (e.g., friction, abrasion, flex, hydro-dynamic pressure, and garment twist) are the dominant forces that could damage electronic components during washing cycles. The main purpose of a washing process is the ensuing cleanliness of the laundry. This aspect is not addressed by any of the reviewed sources except Rotzler et al. (Sigrid Rotzler, 2021). Because of the presence of electronic components, or at least electrically conductive materials in e-textiles, possible health or safety issues could arise for the user (or the environment) in the case of a damaged or malfunctioning product caused by the washing process. Potential dangers include electric shock, overheating, and ignition. Toxic or otherwise problematic substances can contaminate the washing water—metallized textiles are prone to losing their metal coating over time during washing.

Safety - Safety is the biggest concern for e-textile users because of the fear of electric shocks. **Electric shocks and shorts:** Embedded heater electronics in e-textiles may suffer from short-circuits or mechanical failures, e.g. due to body sweat or ambient moisture like in marine environments (Mariello M, 2019). Such malfunctioning can cause serious health hazards or fire accidents. The electrical insulation of conductive components can be achieved by surrounding the conductive components with an electrically insulating layer, for instance through core spinning, using a tubular intarsia knitting, or by encapsulation in a water-resistant polymer for instance (Castano LM, 2014).

Exposure to high temperatures: Burns due to exposure to high temperatures is a serious safety concern for users of heating textiles. Skin temperature is around 34-35 °C although it differs slightly between different regions of the human body while the core temperature of the human body is maintained at around 37 °C (T. Starner, 19-20 October 1998). The burning pain threshold is at 43 °C, extended exposure of the skin to 45 °C can lead to 2nd and 3rd degree burns. Temperature overshooting or the malfunctioning of heating textiles could cause severe burn injuries, in particular for people with impaired sensations.

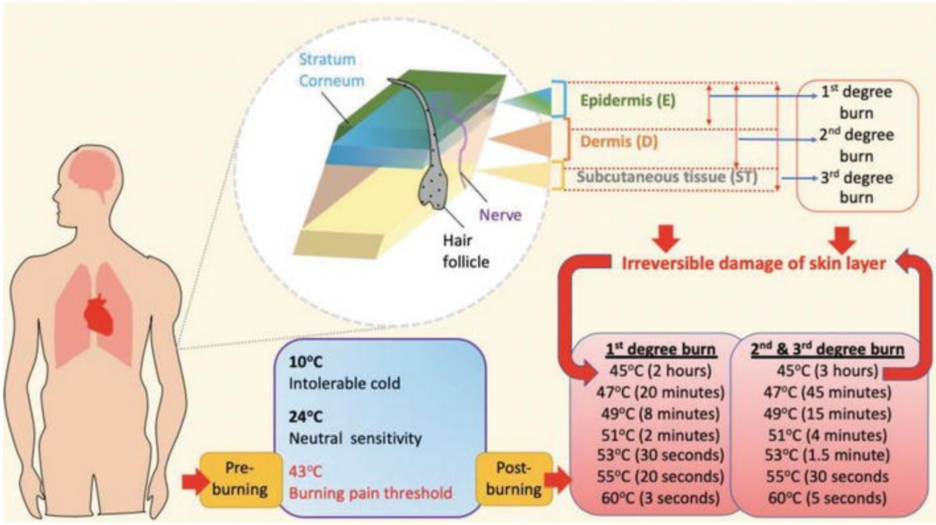


Figure: Resistance of the human skin layers to low and elevated temperatures (Iftekhar Shuvo I, Mar 2021)

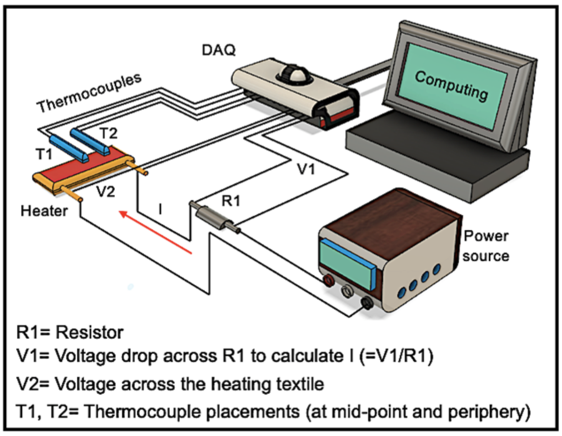
In addition, the accumulation of heat over time could also make the users of different electronic wearables feel uncomfortable (Mbise E, 2015). Such issue is particularly critical in the case of heating textiles where it could lead to burns for the user or instance of fires. Due to the accumulation of heat in the textile over the successive heating cycles for instance, the temperature may keep on increasing even if the power input remains constant. Thermal inertia may also lead to issues of overheating as the temperature experienced may exceed the set value, which can be associated with a phenomenon of overshooting.

Battery ignition and fire hazards: On-body batteries or supercapacitors are needed to store the energy to provide some power supply autonomy to the wearable clothing system. These integrated batteries could suffer from battery ignition.

Unstable connectivity: Any inconsistency or flaw in the interconnecting conductive tracks may render the emergency smart textiles dysfunctional, with potential dramatic consequences. Moreover, if the textile antennas or wireless communication system suffer any disruption in the communication protocol, it will make the user vulnerable to life-threatening situations.

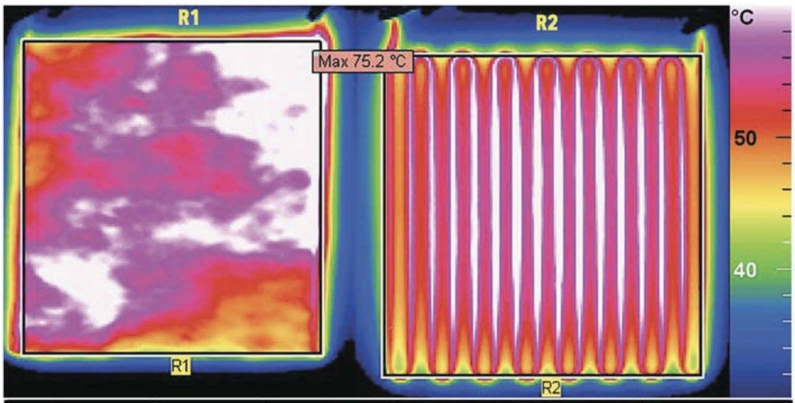
Efficiency - Efficiency covers aspects such as the actuating performance against applied stimulus level or the quality of the bio signal detection in physiological applications. These aspects are also critical for the satisfaction of the smart/e-textile user.

Response time – Response time can be defined as the delay between the input, i.e., the activation by the stimulus, and the output of the smart/e-textiles. In the case of joule heating textiles, the response time can be determined from the time–temperature curves. R_{90} refers to the time required to reach 90% of the steady state temperature (Yunna Hao, 2018). Another parameter used is the heat time constant (τ) which characterizes the system's inertia. It is defined as the time required to reach 63.2% of the maximum value. The measurement would employ data logging module similar to the setup used in reference (Sylwia Krzemińska, 2023)



Power efficiency - power efficiency is critical to maximize the wearability of the device. For joule heating textiles, researchers generally express the maximum temperature reached as a function of the applied power density to characterize the heating performance of the heating system (Huang Y, 2020). Work on thermoregulatory devices for cooling and heating applications, stretchable knit heating cotton gloves, and stretchable smart textile heaters based on copper nanowires have relied on heat flux density measurements to quantify the resistive heating performance. However, power efficiency is still a weakness for products currently on the market (Dolez, 2020).

Uniformity of actuation – The uniformity of actuation is a critical parameter when considering heating textiles. The hotspots are to be tested. This would employ a thermal camera when the sample is set to various test conditions. A test result of the temperature measurement of two different heating fabrics: (i) a nonwoven heater (R1) and (ii) a fabric with heating wires (R2) is shown below. Different patterns of spatial heat distribution are observed with both types of heating textile structures.



Specimen	Mean	Min	Max	Std. Dev	Eps
R1	56.3ºC	40.2ºC	75.2ºC	4.68ºC	1.00
R2	54.8ºC	36.8ºC	68.3ºC	4.84ºC	1.00

Figure: Comparison between the infrared temperature measurement of heating textiles using a conductive nonwoven structure (R1) and a conductive wire (R2)

Repeatability/stability of the actuation level - to evaluate the thermal stability of electro thermal textiles during repeated heating–cooling cycles of different amplitudes. The test would involve a series of stepwise or periodic or cyclic applied voltages, with the resulting temperature changes being recorded (Xiao Z, 2019). Some researchers also used specific actuation patterns. For example, Sun et al. characterized his segregated carbon Nanotube/thermoplastic polyurethane (s-CNT/TPU) heater with three different types of heating–cooling cyclic patterns (Sun W-J, 2019): (a) ten on/off periodic cycles at 6 V, (b) three cycles of 1.5–3-4.5-6 V step increase followed by an off period, and (c) five on/off periodic cycles at increasing then decreasing voltages (3–4.5-6-4.5-3 V). In general, two types of approaches have been observed among researchers investigating the efficiency of wearable heaters: (a) cyclic heating–cooling tests at a fixed voltage, and (b) repetitions of the continuous profile of variable voltages.

Negative impact of moisture - Moisture reduces the performance of all types of batteries, including textile batteries or batteries integrated into smart textiles. Moisture may also cause chemical and physical interferences in the control module of e-textiles, reducing its efficiency before a total failure occurs. It may also experience decreased efficiency due to slow corrosion process when exposed to sweat. Besides the possibility of electric shocks or complete signal loss from corrosion, in case of marine e-textiles, it could also experience decreased efficiency when exposed to the salt of seawater. As soon as the saltwater propagates the localized corrosion process of textile electrodes or conductive interconnects, it could affect the overall signal quality, lowering the transduction efficiency.

5.4. EXAMPLE CASE STUDY: REAL-TIME MONITORING OF THE HEATING VEST PERFORMANCE

The heated vest tested is made by the authors of the document referred, (Sahin, Oct. 03, 2018) from two PU-coated thermoplastic fabrics, namely Polyester and Polyamide fabrics. Three different welding tapes were selected for protection and waterproofness of the circuits made of conductive yarns, namely ST-604 with two PU layers, ST-306 with two PU and one Nylon layers, and ST-318 with two PU and one Polyester layers. The welding tapes used are strong, resilient, and easy to work with. Since they do not contain plasticizers or volatile organic compounds, they are suitable for use in the production of e-textile transmission lines via a hot air welding technique. Three 3.7 V batteries are connected in series, and used as power supplies. The control circuit also brings protection against short circuits and electrical overload. The 12 V applied Polyester – ST306–550°C – 6 ft./min has 5 Ω resistance. So It has 17 h of battery life and can heat the garment up to 57–58°.

a) b)

Figure: Wearable heating vest: a.Inside view, b. Outside view

For observation and monitoring of the heating performance of the heated vest in real-time, the vest was worn by a volunteer, and thermal camera images from the front and back of the torso were taken after wearing for 30 s, and from the back torso when the heating vest is on for 10 min and immediately after putting off at an ambient temperature of 21°C. As the ambient temperature was 21°C, the heating vest was set for a heating level of 5. As presented in Figures, the front temperature on the surface of the vest reached 23.5°C, and back temperature on the surface of the vest reached 25.5°C just 30 s after wearing the heating vest, respectively. It is apparent that the heating vest quickly starts heating up, and the heat is evenly distributed even after 30 s. As presented in the later Figures, the back temperature on the surface of the vest reached 30.2°C, 10 min after wearing, and the surface temperature on the top clothing immediately after putting off was observed as high as 38.4°C, respectively.

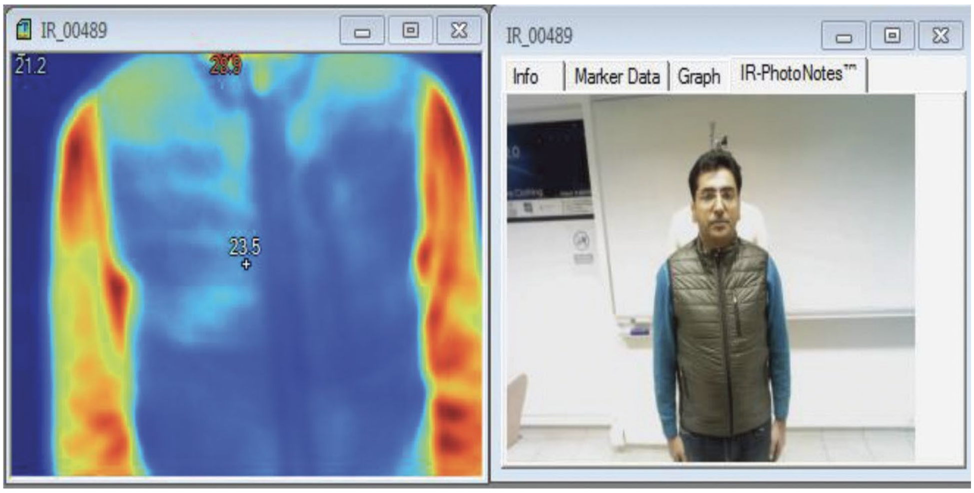


Figure: Thermal and actual images on first 30 s after wearing the heating vest (Front surface temperature on the vest:

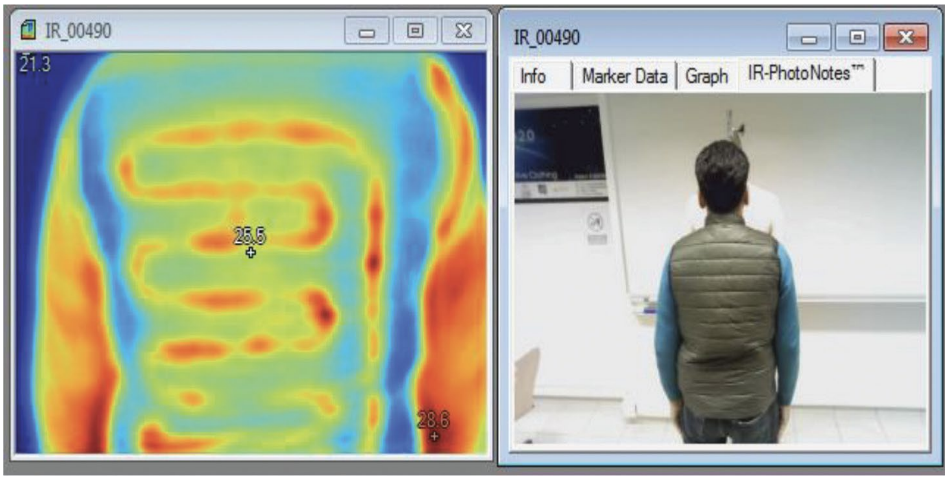


Figure: Thermal and actual images on first 30 s after wearing the heating vest (Back surface temperature on the vest:

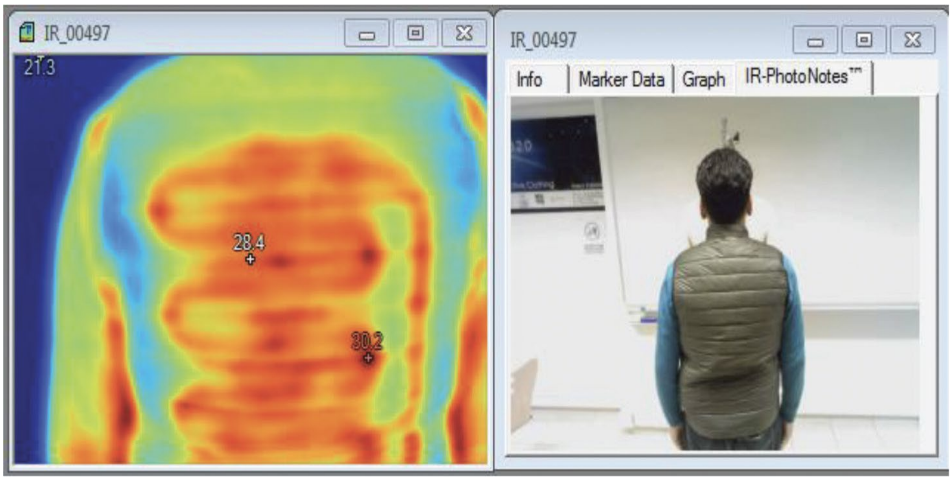


Figure: 10 min after wearing the heating vest (Back surface temperature on the vest: 30.2°C, ambient temperature: 21°C).

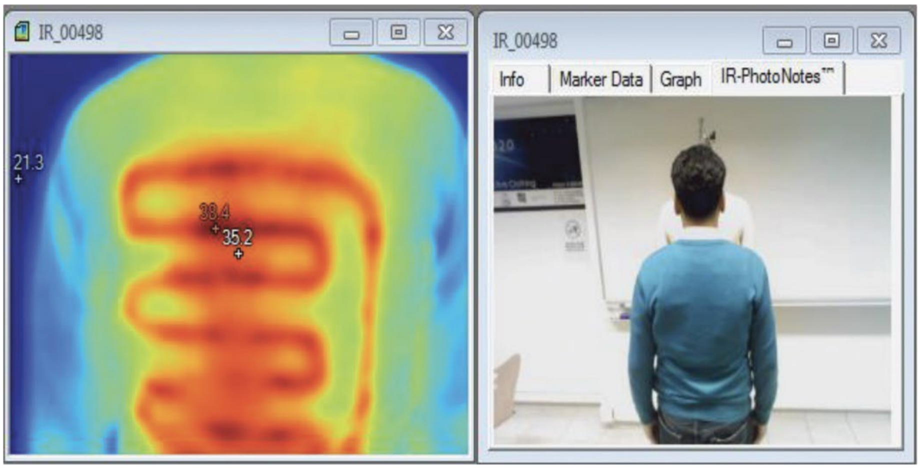


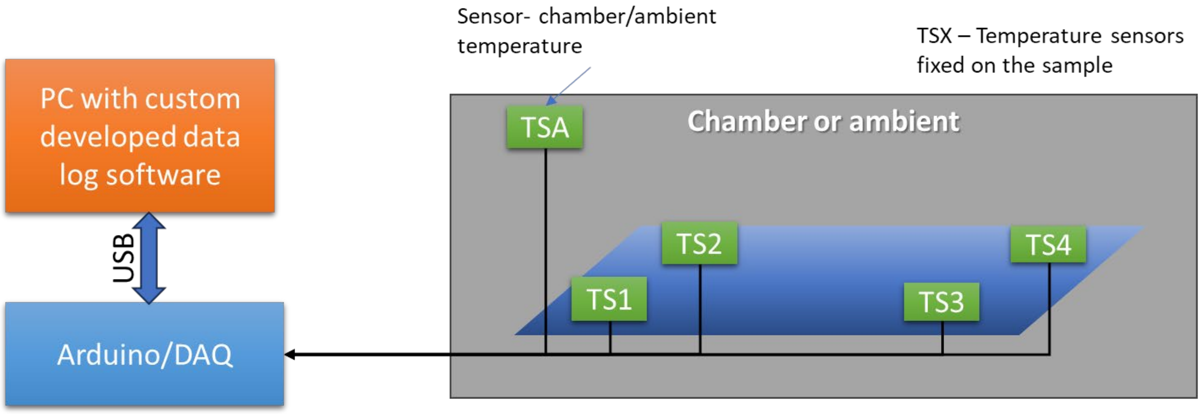
Figure: 10 min after wearing the heating vest (Back surface temperature on the top clothing of wearer: 38.4°C, ambient

6. PRODUCT TESTING

6.1 TESTING TOOLS

Development of a Temperature data log system:

- Required to log temperature on different spots on the sample.
- Need to fix temperature sensors on the targeted points.
- Temperature sensors chosen are digital.
- Need an acquisition controller to read the temperature values from all the sensors.
- Data acquisition controller (DAQ) made from Arduino with its custom written onboard program.
- Data need to be logged / recorded. Data logging custom program written on a PC.
- Communicates to the data acquisition card via USB.



Customization of a thermal camera for non-contact temperature mapping/measurement:

- Needed a way of getting uncompressed image/data from the thermal camera
- Re-written the FPGA code and the firmware of the USB controller to output raw video output.
- Need to record/log the thermal map of the target surface.
- Developed a video record and data log from the marked area and points of interests from the sample surface.

6.2 GENERAL TEST PROCEDURE

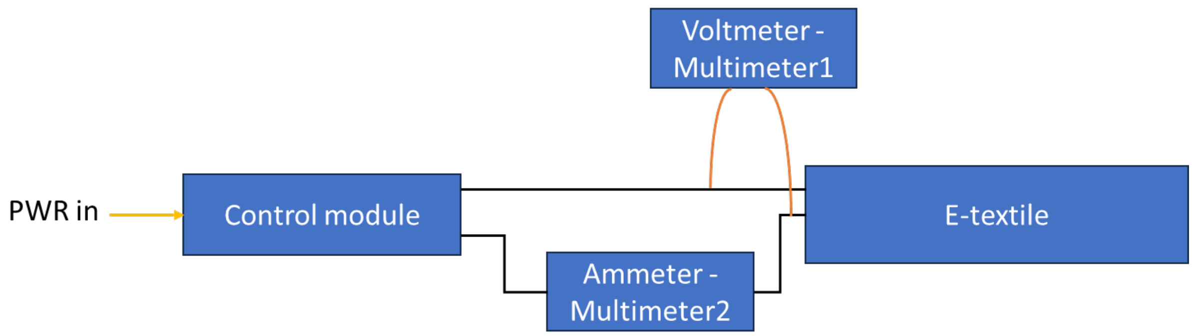
Initial Assessment

- Visual Inspection: Check for any visible defects, such as poor stitching or faulty connections that may impact efficiency.
- Electrical Continuity Test: Ensure the electrical circuit within the e-textile is working properly.

- After physical evaluation and basic functional testing, physical architecture is studied.

Prepare the Test Setup

- Sample Preparation: Ensure that the wearable heated e-textile is properly set up according to its design (e.g., placement of heating elements, power source, control unit). Alternately, the control module can be identified and can then separated from the heating pads keeping intact the feedback mechanism if any.
- Test Environment: Control environmental conditions such as temperature, humidity, and airflow to simulate typical usage conditions.
- Sensors, Instruments and connections: *(as explained in "TEST TOOLS")*
    - Temperature sensors fixed in strategic locations and connected to the DAQ module.
    - Power measurement tools to monitor voltage, current, and power consumption.
    - Infrared cameras (thermal cameras) to capture heat distribution and assess uniformity. The camera is placed, directed and focussed on the complete sample surface.
    - Connections: Connection to multimeter, control module and the heating pads is made to measure voltage and current
- The heat setting options of the control module is listed.



EXPERIMENT

- Data logs recording is initiated before powering up the control module.
- After confirming stability of the readings, the control module is powered ON and allowed to data acquired and recorded for some time to establish the initial condition.
- After stability is confirmed, the setting is set to lowest heat in the control module.
- Post stability, other heat settings are also recorded similar procedure.
- Then switch OFF the heater and continue data log during cooldown
- Repeated heat-cool cycle and data record
- Data is presented and analysed.

TARGET TESTING PARAMETERS:

Thermal Efficiency Testing

- Heat-Up Time:
  - Power the e-textile and record the time it takes to reach a specified temperature. Shorter heat-up times indicate better efficiency.
- Temperature Distribution:
  - Use the thermal camera to monitor the uniformity of heat distribution across the fabric. Efficiency and comfort is better when heat is evenly distributed.
- Maximum Temperature:
  - Measure the maximum temperature the textile can achieve and compare it with the intended design parameters and the suggested safe temperature range.
- Cooling Time:
  - Once powered off, record the time it takes for the fabric to return to ambient temperature. This can indicate heat retention properties. The Fabrics with better insulation will retain heat longer, improving overall efficiency.

Power Efficiency

- Power Consumption:
  - Monitor the electrical power consumed by the e-textile using a multimeter. Calculate the total energy used during the heating cycle.
- Thermal Conductivity:
  - Test the fabric's ability to conduct heat from the heating element to the wearer. Lower thermal resistance between the element and skin will increase heating efficiency.
- Energy Efficiency:
  - Compare the amount of heat generated to the electrical energy consumed. A higher ratio of heat generated per unit of energy consumed indicates higher efficiency.
  - Efficiency can be calculated as:

$$\text{Efficiency (\%)} = [\text{Thermal Output (W)} / \text{Electrical Input (W)}] \times 100$$

Thermal Comfort Testing

- User Comfort (Subjective Testing):
  - Human subjects can wear the garment, and their perception of warmth, discomfort, and overall experience can be noted. Assess thermal comfort after prolonged usage at operating temperatures. Comfort levels can provide

insight into practical efficiency. The textile should not cause discomfort, irritation, or excessive heating at any point of contact.
  - Wear Trials: Real-life trials where the e-textile is worn by volunteers under various conditions to gather feedback on usability, comfort, and any adverse reactions.
- Temperature Thresholds:
  - Measure the temperature at the skin interface to ensure it stays within a safe range (usually between 32°C to 38°C for comfort).

Durability and Long-term Efficiency

- Washing and Cleaning Durability:
  - Assess how the e-textile components withstand washing and cleaning procedures. Test how the textile performs after several wash cycles in a standard washing machine, with measurements taken after each cycle to assess the functionality and appearance. This washing durability can affect long-term efficiency.
- Flexibility Test:
  - Test how the textile performs after repeated bending and flexing cycles especially around seams or areas where heating elements are integrated to simulate body movements (e.g., bending at joints).
- Abrasion Resistance Test:
  - A Martindale abrasion tester can be used to evaluate wear resistance by rubbing the fabric against a standard abrasive surface repeatedly.
- Thermal Durability (Thermal Cycling) and Repeated Usage:
  - To Test the ability of the heating elements and textile to withstand repeated heating and cooling cycles.
  - Heat the e-textile to its operating temperature, hold it at that temperature, and then cool it down. This cycle should be repeated for hundreds or thousands of cycles to simulate prolonged use.
  - Measure electrical resistance and heating efficiency after each cycle
  - Also, run the heating system for prolonged periods and measure any reduction in performance over time.
- Environmental Durability (Water, Humidity and Temperature Exposure):
  - Humidity Test: Place the e-textile in a humidity chamber to simulate high-moisture environments and assess performance after exposure.
  - Water Resistance Test (IP Rating): Evaluates the product's ability to withstand moisture or sweat, ensuring that electrical components remain functional and safe.
  - Temperature Extremes: Test at both low and high temperatures to simulate environmental conditions.

- Electrical Durability:
  - Assess the electrical reliability - Measure the electrical resistance of the heating elements before and after each of the above durability test (washing, flexibility, environment, and thermal cycling).
  - May conduct short-circuit and open-circuit tests to ensure there is no electrical failure.
  - Insulation Resistance Testing may also be performed to ensure safety.
  - The electrical properties should remain within a specified tolerance range after repeated stress tests.
- The textile should maintain its structural integrity. Heating elements and connections should still function correctly, and the textile should not show signs of degradation like discoloration, shrinking, or damage to conductive pathways after a set number of cycles.
- The heating performance (temperature consistency) and electrical integrity (resistance stability) should not degrade beyond acceptable limits after the thermal cycling test.
- Longevity: Performance Retention Evaluation
  - Repeatedly measure the heat output and distribution after various durability tests.
  - Check if the temperature settings (if variable) are consistent and still within designed operating conditions.

Safety Testing

- Overheating Protection Test:
  - Check if the textile has overheating protection mechanisms, such as automatic cut-offs or temperature regulation.
- Uniform Heat Distribution:
  - Test whether the heat is evenly distributed to avoid localized overheating.
- Skin Contact Temperature Limits:
  - Ensure that the temperature at the skin-contacting surface does not exceed safety limits for prolonged wear.
- Electrical Safety Test:
  - Current Leakage Test: Ensures no excessive current flows through the fabric that might pose a shock hazard.
  - Insulation Resistance Test: Checks if the electrical insulation of the heating elements is adequate to prevent short circuits.
  - Overcurrent and Overvoltage Protection: Verifies that the system safely shuts down or reduces heating if the voltage or current exceeds design limits.

    Fire and Flammability Testing
- Battery Safety (if battery-powered)

- Short Circuit Test: Ensures that the battery doesn't overheat or catch fire in case of a short circuit.
- Overcharging and Over-discharging Protection: Verify that the battery has appropriate circuits to prevent dangerous charging and discharging scenarios.
- Thermal Runaway Test: Ensures that the battery does not reach dangerous temperatures during operation.
- Impact and Compression Test: Simulates accidental impact or compression to check whether the battery is safely housed and will not explode.

- Flammability Test:
  - Test whether the fabric and any integrated components do not catch fire easily.
- Heat Resistance of Materials:
  - Test the thermal stability of materials at elevated temperatures to ensure they do not degrade or combust when exposed to heat.
- The e-textile should not exceed safe temperature limits and should prevent electrical hazards like short circuits or electric shocks.
- EMF (Electromagnetic Field) and EMI (Electromagnetic Interference) Testing
  - Electromagnetic Emission Test: Ensures that the heating elements and associated electronics do not emit harmful electromagnetic radiation.
  - Electromagnetic Interference Test: Checks for interference with nearby electronic devices (e.g., medical implants, mobile phones).

Data Analysis

- Graphical Analysis:
  - Plot temperature vs. time curves, and power consumption vs. time to visualize how efficiently the system heats up and maintains heat.
- Efficiency Comparison:
  - Compare the performance with industry standards or similar products to evaluate the textile's relative efficiency.

Data interpretation:

- Observing for overshooting, thermal runouts and temperature hotspots
- Calculate average minimum and maximum temperature, Uniformity
- Response time between powering on and achieving the set temperature – time-temperature curves. Calculating the Power efficiency – Maximum temperature reached as a function of applied power density on each setting
- Observing for variation in the achieved temperature over a period
- Evaluate the thermal stability and repeatability

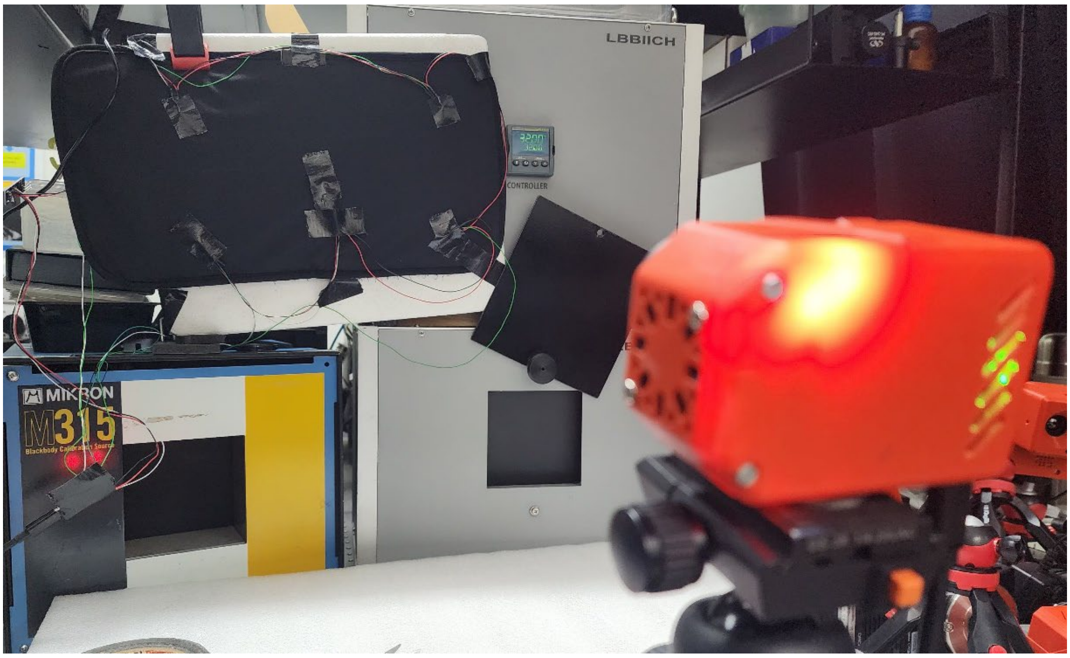
6.3 TEST HARDWARE AND SOFTWARE

PROBE TEMPERATURE DATA ACQUISITION HARDWARE:

Six temperature sensors/probes are connected to the input output pins of the microcontroller. The first sensor can be used as a reference measuring room/ambient temperature. Firmware is developed to acquire temperature from all the sensors and relay the temperature data from all the sensors to the connected computer through USB interface.

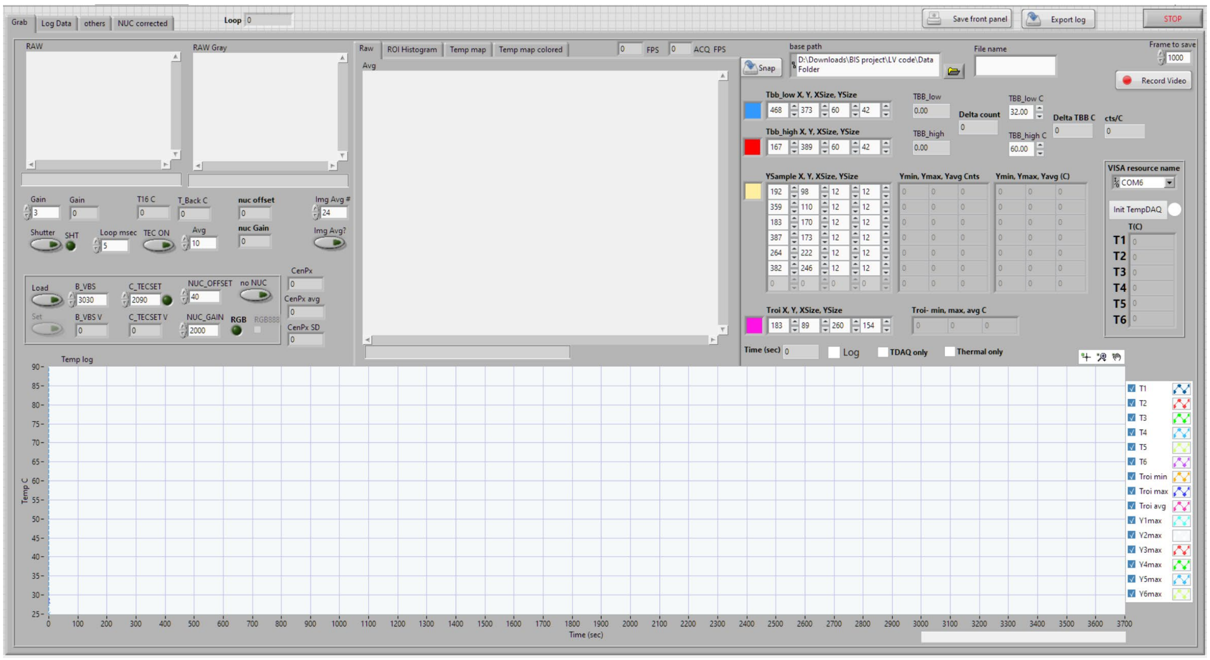
THERMAL CAMERA HARDWARE:

A custom infrared/thermal camera made of high-resolution data acquisition system acquires the pixel photocurrent and forms an image data array and relays to the connected computer via USB. The implemented image processing also involves computing the temperature of each pixel data. Active reference is kept in the field of view of the camera in order to ensure the computed temperature values.

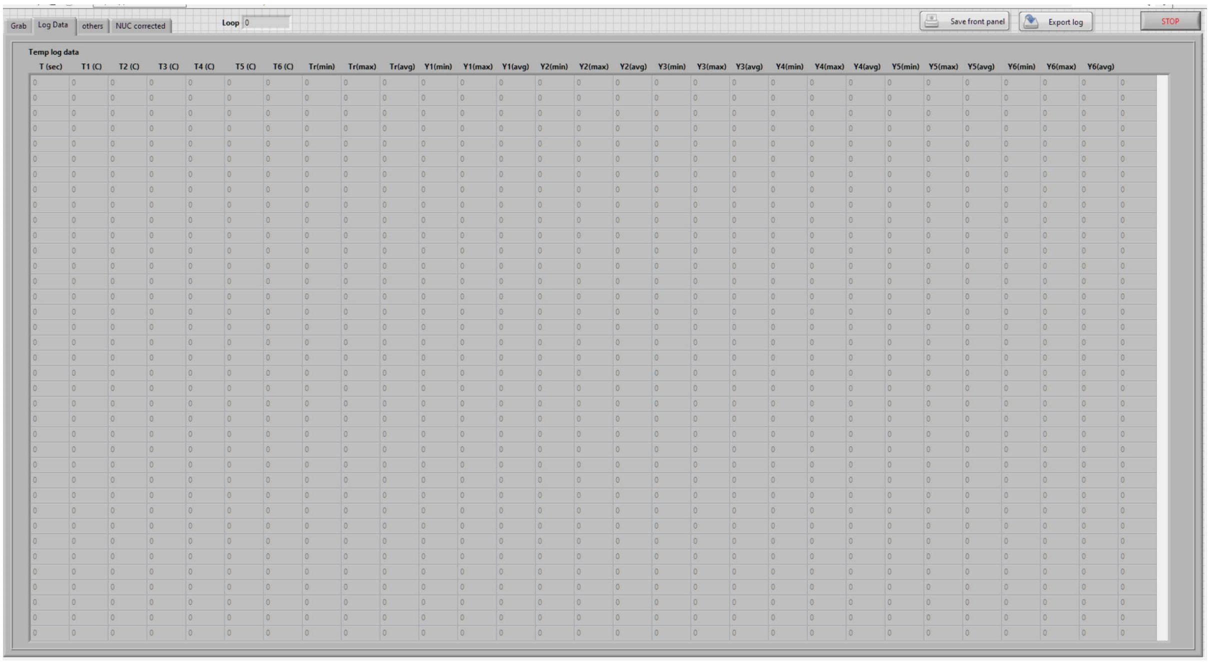


DATA ACQUISITION SOFTWARE:

The data from both the measuring hardware – the temperature probes and the thermal camera is acquired by the custom developed software. Provisions are given to channelize individual data sets. The region of interest can be chosen according to the sample dimensions. Provision is given to data log against time and also to export the data to a file. The front panel of the software is as shown below.



T1 to T6 represent the data from the six temperature probes. Sample region of interests can be chosen in the Ysample parameter list. The corresponding temperature statistics is 733computed and collected in the Ymin, Ymax, Yavg fields. The second tab shows the log numbers as shown below.



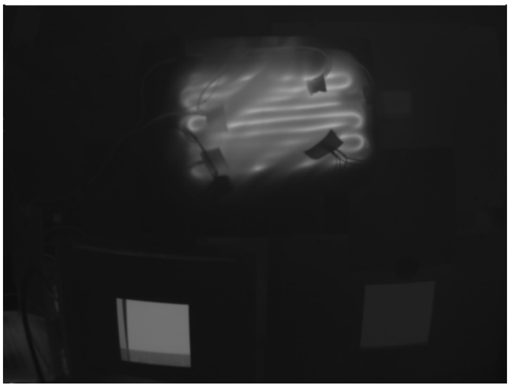
6.4. MEASUREMENTS

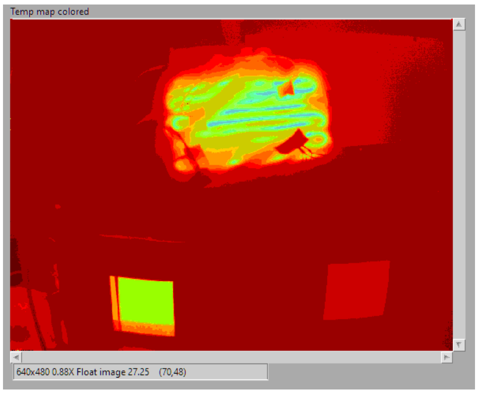
We present the initial results of testing few samples purchased from online shops. For samples in 5.4.1 and 5.4.2, we attempt to measure both temperature from sensors and the temperature mapping by the thermal cameras at the same time. In samples of 5.4.3 and

5.4.4, these measurements are done separately to avoid the effects of tape used to fix the sensors as seen in the first two results.

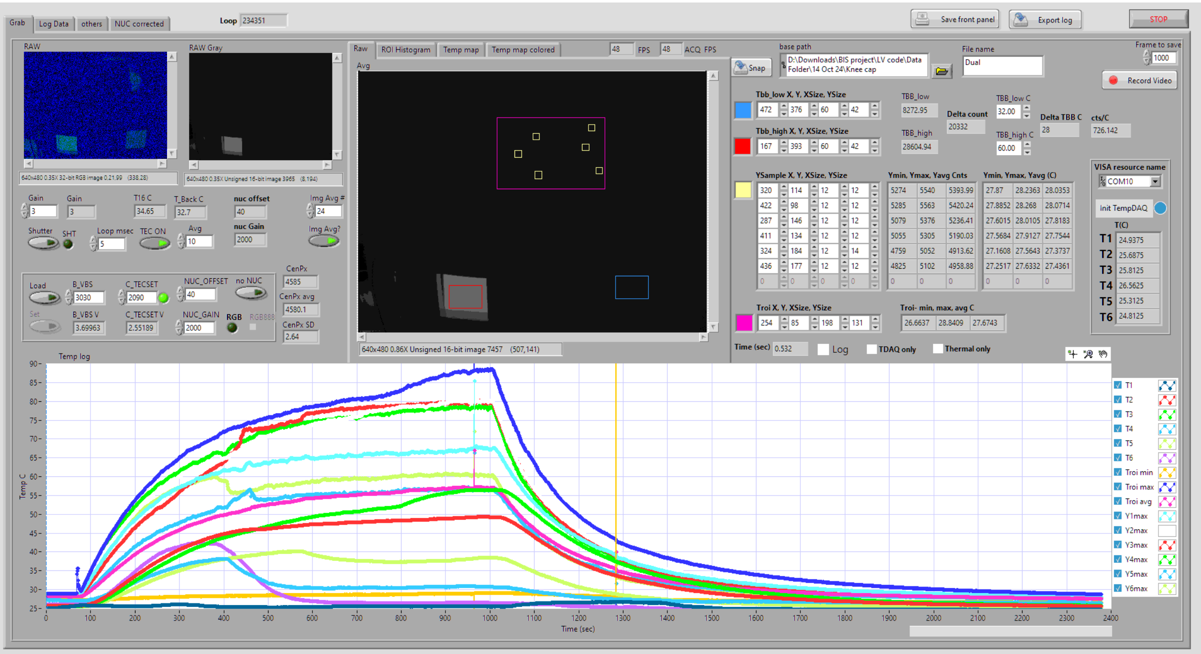
5.4.1. KNEE CAP, SANDPUPPY

The measurement setup is as presented in the previous sections. The thermal image or the temperature map of the sample when in operation is shown below.





The front panel of the software with data acquired is shown below.



Grab | Log Data | others | NUC corrected

Loop 234351

Save front panel | Export log | STOP

Temp log data

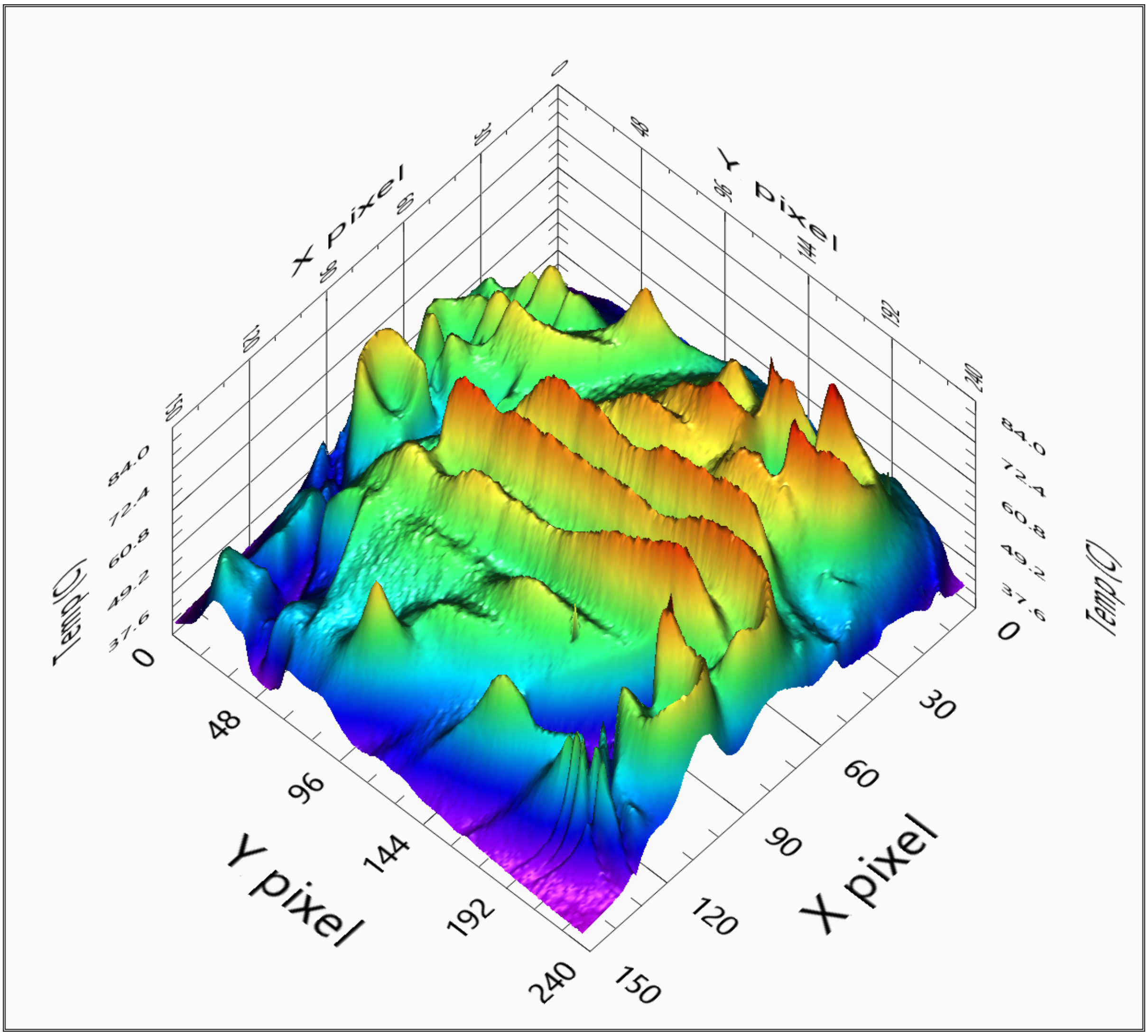
T (sec)	T1 (C)	T2 (C)	T3 (C)	T4 (C)	T5 (C)	T6 (C)	Tr(min)	Tr(max)	Tr(avg)	Y1(min)	Y1(max)	Y1(avg)	Y2(min)	Y2(max)
0.531	25.125	25.8125	25.75	27.3125	25.6875	26.25	27.3276	29.0423	28.2219	28.4986	28.8602	28.6875	28.3603	28.6739
1.016	25.125	25.875	25.75	27.3125	25.6875	26.25	27.3439	29.0512	28.2226	28.4949	28.8511	28.6867	28.3496	28.6881
1.548	25.125	25.875	25.75	27.3125	25.6875	26.25	27.3186	29.037	28.2172	28.4683	28.8643	28.6825	28.334	28.6971
2.033	25.1875	25.8125	25.75	27.3125	25.625	26.1875	27.3252	29.0641	28.2155	28.4995	28.8558	28.6822	28.3502	28.6777
2.565	25.1875	25.875	25.8125	27.3125	25.625	26.1875	27.3391	29.0575	28.2144	28.497	28.8615	28.682	28.3408	28.6752
3.047	25.1875	25.875	25.8125	27.3125	25.625	26.25	27.332	29.0483	28.2162	28.4949	28.8552	28.6777	28.3388	28.699
3.578	25.1875	25.875	25.75	27.3125	25.6875	26.25	27.326	29.0553	28.2173	28.5017	28.8676	28.6837	28.3455	28.6785
4.061	25.1875	25.875	25.75	27.3125	25.6875	26.25	27.3227	29.0404	28.2207	28.5057	28.8759	28.6869	28.3467	28.6894
4.596	25.125	25.8125	25.75	27.3125	25.625	26.25	27.2941	29.0446	28.2127	28.4922	28.8691	28.6835	28.3469	28.6786
5.08	25.1875	25.8125	25.75	27.25	25.625	26.1875	27.3019	29.0589	28.2105	28.4979	28.8778	28.6789	28.3374	28.6625
5.613	25.1875	25.8125	25.75	27.25	25.625	26.1875	27.313	29.0533	28.2098	28.4865	28.8584	28.6779	28.352	28.6539
6.096	25.125	25.8125	25.75	27.3125	25.625	26.25	27.3073	29.0449	28.2077	28.4863	28.8761	28.6746	28.3408	28.6702
6.628	25.125	25.875	25.75	27.3125	25.625	26.25	27.3055	29.0498	28.2051	28.4967	28.8618	28.6743	28.332	28.6724
7.111	25.125	25.875	25.75	27.25	25.6875	26.25	27.3035	29.0337	28.2109	28.4945	28.8759	28.6804	28.3367	28.677
7.642	25.1875	25.8125	25.8125	27.3125	25.625	26.25	27.2887	29.0387	28.2109	28.4805	28.8508	28.6787	28.3338	28.6807
8.123	25.1875	25.8125	25.8125	27.3125	25.625	26.25	27.3093	29.032	28.2079	28.4879	28.8676	28.6745	28.3427	28.6716
8.655	25.1875	25.8125	25.75	27.3125	25.625	26.25	27.2806	29.0599	28.2063	28.4636	28.8584	28.6674	28.3471	28.6733
9.138	25.1875	25.8125	25.75	27.3125	25.625	26.25	27.3192	29.0403	28.214	28.4936	28.8595	28.6794	28.325	28.684
9.672	25.1875	25.8125	25.75	27.3125	25.625	26.25	27.3123	29.0583	28.211	28.4758	28.8569	28.6741	28.3402	28.6869
10.155	25.1875	25.875	25.8125	27.3125	25.625	26.25	27.3147	29.05	28.2083	28.4715	28.8581	28.6724	28.3564	28.684
10.639	25.1875	25.875	25.8125	27.3125	25.625	26.25	27.3077	29.064	28.2086	28.4612	28.8818	28.6774	28.3325	28.6818
11.173	25.1875	25.8125	25.75	27.3125	25.625	26.25	27.3175	29.0564	28.2133	28.4959	28.8604	28.6906	28.3411	28.7124
11.656	25.1875	25.8125	25.75	27.3125	25.625	26.25	27.2985	29.0424	28.206	28.4666	28.8518	28.6784	28.3144	28.6914
12.188	25.1875	25.8125	25.75	27.3125	25.625	26.25	27.2985	29.0573	28.2033	28.4733	28.8791	28.6741	28.3116	28.6995
12.67	25.1875	25.875	25.75	27.3125	25.625	26.25	27.2942	29.0426	28.2002	28.4721	28.8629	28.669	28.3103	28.6874
13.205	25.1875	25.875	25.8125	27.25	25.625	26.25	27.2837	29.0681	28.2135	28.4898	28.8708	28.6847	28.3459	28.6926
13.688	25.1875	25.875	25.8125	27.25	25.625	26.25	27.2981	29.0602	28.2165	28.4957	28.8793	28.6878	28.3285	28.6793
14.223	25.1875	25.8125	25.75	27.25	25.625	26.25	27.3094	29.0686	28.2129	28.4904	28.8631	28.6789	28.337	28.6973
14.705	25.1875	25.8125	25.75	27.25	25.625	26.25	27.2936	29.0667	28.2116	28.4994	28.8475	28.6772	28.3295	28.6871
15.187	25.1875	25.8125	25.75	27.3125	25.625	26.25	27.2839	29.0682	28.209	28.5104	28.8394	28.679	28.3337	28.6694
15.721	25.1875	25.875	25.75	27.3125	25.625	26.25	27.3049	29.0643	28.2098	28.5053	28.8561	28.6828	28.3258	28.6903
16.253	25.1875	25.875	25.75	27.3125	25.625	26.25	27.2937	29.0486	28.2059	28.4797	28.8416	28.6707	28.3275	28.6785
16.735	25.1875	25.875	25.75	27.3125	25.6875	26.25	27.324	29.0786	28.2157	28.4919	28.8579	28.6811	28.3466	28.6797
17.268	25.1875	25.8125	25.75	27.3125	25.6875	26.25	27.327	29.0531	28.2143	28.5024	28.8572	28.6845	28.3366	28.7093
17.749	25.1875	25.8125	25.75	27.3125	25.6875	26.1875	27.3111	29.0608	28.2117	28.5059	28.8484	28.6813	28.3236	28.6909
18.282	25.1875	25.8125	25.75	27.25	25.6875	26.1875	27.2963	29.0625	28.2057	28.4747	28.857	28.6817	28.3212	28.683
18.766	25.1875	25.8125	25.75	27.25	25.6875	26.1875	27.3051	29.0569	28.2045	28.4826	28.8431	28.6752	28.314	28.6786

T (sec)	Y2(avg)	Y3(min)	Y3(max)	Y3(avg)	Y4(min)	Y4(max)	Y4(avg)	Y5(min)	Y5(max)	Y5(avg)	Y6(min)	Y6(max)	Y6(avg)	
0.531	28.5273	28.1617	28.5054	28.344	28.1767	28.5109	28.332	27.896	28.2206	28.0615	27.8563	28.1904	28.0286	0
1.016	28.5273	28.1578	28.488	28.3429	28.1797	28.4839	28.3306	27.9002	28.24	28.0696	27.8632	28.2017	28.0281	0
1.548	28.523	28.1792	28.4861	28.339	28.1696	28.4834	28.3222	27.8941	28.2312	28.0671	27.838	28.1997	28.0178	0
2.033	28.5196	28.1556	28.4982	28.3401	28.1652	28.4899	28.3179	27.9007	28.2131	28.0538	27.8336	28.2008	28.0167	0
2.565	28.5228	28.1531	28.4902	28.338	28.175	28.4792	28.3224	27.89	28.2257	28.0511	27.842	28.1997	28.0203	0
3.047	28.5258	28.1758	28.4963	28.3367	28.1771	28.4867	28.322	27.8895	28.2196	28.0562	27.8525	28.2114	28.0316	0
3.578	28.5278	28.1537	28.5168	28.3446	28.1742	28.5031	28.3238	27.8988	28.2181	28.0556	27.8371	28.2386	28.033	0
4.061	28.5296	28.1726	28.5181	28.3457	28.1589	28.4948	28.3227	27.9039	28.2206	28.0609	27.8395	28.2179	28.0316	0
4.596	28.5215	28.1673	28.5072	28.3415	28.1508	28.4908	28.3186	27.8835	28.2057	28.0517	27.8438	28.1947	28.0227	0
5.08	28.52	28.1413	28.4869	28.3301	28.1564	28.4869	28.3147	27.8684	28.2167	28.0516	27.8492	28.1893	28.0233	0
5.613	28.5222	28.1571	28.5029	28.3342	28.1557	28.481	28.3166	27.8551	28.2024	28.0401	27.84	28.2051	28.0281	0
6.096	28.5183	28.1514	28.4931	28.323	28.1596	28.4822	28.3183	27.8838	28.2077	28.0382	27.8206	28.2173	28.0225	0
6.628	28.5196	28.1454	28.4775	28.3247	28.1523	28.4899	28.316	27.8737	28.2181	28.0331	27.8421	28.2044	28.0191	0
7.111	28.5217	28.146	28.4959	28.3293	28.1666	28.5041	28.3313	27.8661	28.2187	28.0413	27.8386	28.1995	28.0253	0
7.642	28.5252	28.1445	28.4819	28.3247	28.1541	28.4928	28.3202	27.8771	28.2172	28.0444	27.8277	28.2158	28.0233	0
8.123	28.5177	28.1289	28.477	28.3223	28.1645	28.503	28.3236	27.8657	28.2056	28.0344	27.8397	28.1946	28.0175	0
8.655	28.5199	28.1415	28.4855	28.3268	28.1538	28.502	28.3159	27.8591	28.2031	28.0336	27.844	28.2031	28.018	0
9.138	28.5235	28.1482	28.4867	28.3299	28.1523	28.4936	28.3279	27.8728	28.1976	28.0364	27.8303	28.203	28.0233	0
9.672	28.5271	28.1483	28.4896	28.3259	28.1497	28.495	28.3241	27.8701	28.2141	28.0364	27.8523	28.2209	28.0279	0
10.155	28.523	28.1494	28.4743	28.325	28.122	28.4853	28.3103	27.8712	28.2166	28.0386	27.8534	28.2303	28.0307	0
10.639	28.5223	28.1448	28.4845	28.3291	28.1407	28.4873	28.3159	27.8817	28.2009	28.0335	27.842	28.2311	28.0233	0
11.173	28.5292	28.1643	28.4918	28.3315	28.1575	28.5041	28.3241	27.8752	28.2027	28.0367	27.8382	28.2123	28.0229	0
11.656	28.5168	28.143	28.483	28.3296	28.1485	28.4967	28.315	27.8565	28.2006	28.0372	27.8332	28.191	28.0177	0
12.188	28.5117	28.1539	28.4733	28.3211	28.1525	28.4774	28.3136	27.8633	28.2128	28.0347	27.8235	28.2046	28.0195	0
12.67	28.507	28.132	28.4831	28.3161	28.143	28.5023	28.3103	27.8495	28.1869	28.0262	27.8331	28.202	28.0157	0
13.205	28.523	28.1704	28.4651	28.3357	28.1526	28.5021	28.3209	27.8854	28.2253	28.0439	27.8429	28.2211	28.0261	0
13.688	28.5197	28.1737	28.4765	28.3354	28.1545	28.4929	28.3221	27.8846	28.2244	28.0529	27.8352	28.2093	28.0228	0
14.223	28.5241	28.1767	28.4918	28.3356	28.1479	28.474	28.3086	27.8835	28.2233	28.0514	27.8246	28.2109	28.0124	0
14.705	28.5213	28.1431	28.483	28.3279	28.1336	28.4583	28.3066	27.865	28.2117	28.0454	27.8335	28.2171	28.0212	0
15.187	28.5104	28.1514	28.4817	28.3228	28.1363	28.4721	28.307	27.8869	28.2144	28.0489	27.8334	28.2062	28.0101	0
15.721	28.5164	28.1517	28.4546	28.3132	28.1353	28.4587	28.3088	27.8887	28.2066	28.0472	27.8215	28.2024	28.014	0
16.253	28.5094	28.1438	28.4591	28.3103	28.1246	28.4934	28.3088	27.8833	28.2123	28.0427	27.8229	28.2151	28.0126	0
16.735	28.5239	28.1547	28.4713	28.319	28.1423	28.485	28.3213	27.8874	28.2218	28.0549	27.849	28.2287	28.0222	0
17.268	28.5259	28.1517	28.4723	28.3245	28.1476	28.4983	28.3175	27.8983	28.2202	28.06	27.8476	28.2216	28.0276	0
17.749	28.5194	28.1592	28.4675	28.3186	28.1414	28.4867	28.3122	27.8879	28.2168	28.0475	27.84	28.2154	28.0252	0
18.282	28.5089	28.1431	28.4569	28.3163	28.1308	28.4925	28.3095	27.865	28.2048	28.0443	27.8143	28.2281	28.0171	0
18.766	28.5069	28.1372	28.4483	28.3147	28.129	28.4895	28.3078	27.8726	28.2112	28.036	27.8178	28.1893	28.0098	0

The following is the time events during the data log taken against time.

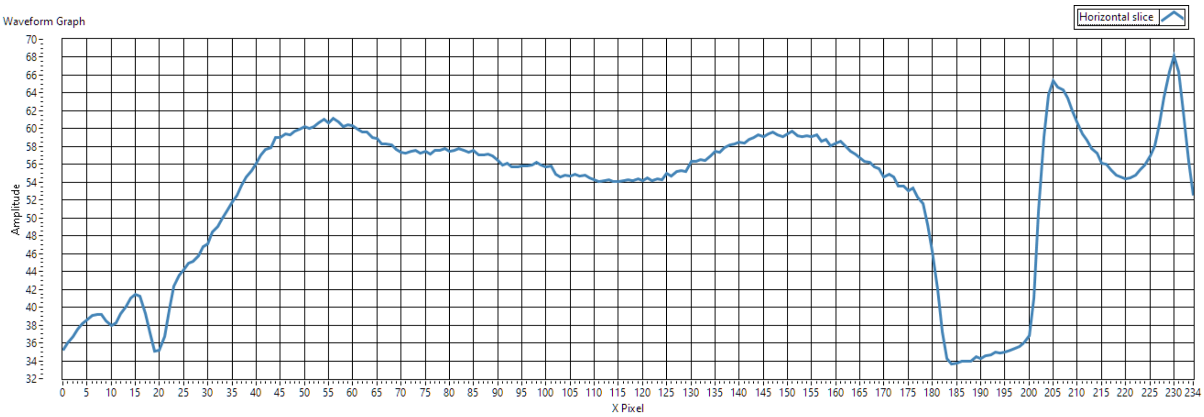
- Unit switched on at 72 seconds
- Switched OFF at 1000 seconds

Thermal map over the sample can be represented in the 3D plot below.



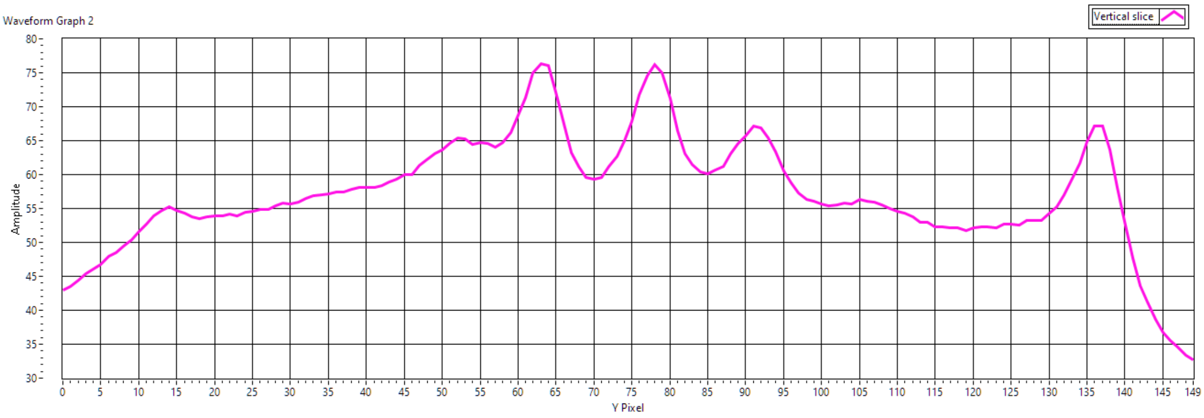
The temperature profile of the horizontal and vertical cross section along the middle of the sample area is shown below.

Horizontal temperature profile:



- Minimum temperature = 33.64 deg C
- Maximum temperature = 68.12 deg C
- Average temperature = 52.90 deg C

Vertical temperature profile:



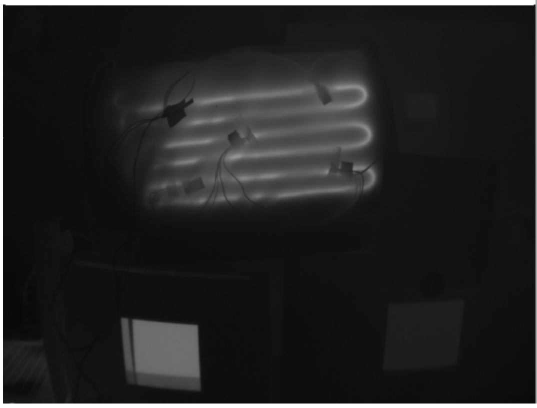
- Minimum temperature = 32.714 deg C
- Maximum temperature = 76.35 deg C
- Average temperature = 57.34 deg C

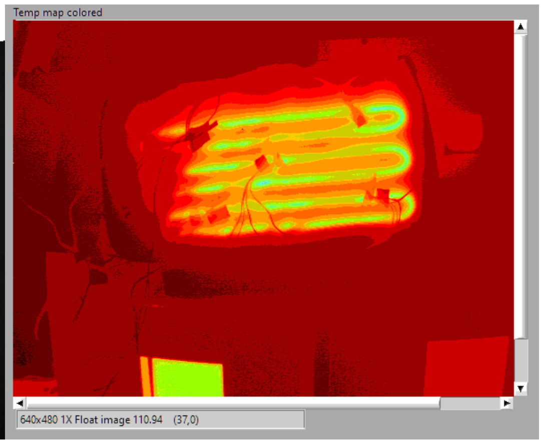
Summary of the experimental results:

Product	Knee cap
Manufacturer	Sand Puppy, Pune
Power Supply	DC 12-volt adopter or DC 12 V battery
Heating wire material	Silicone coated carbon fiber
Response time	15 mins
Power consumption	23 W
Measured current	1.937 A
Measured resistance	6.2 Ω
Heating wire layout	Series and parallel combination
Horizontal temp. profile	• Minimum temperature = 33.64 deg C • Maximum temperature = 68.12 deg C • Average temperature = 52.90 deg C
Vertical temp. profile	• Minimum temperature = 32.714 deg C • Maximum temperature = 76.35 deg C • Average temperature = 57.34 deg C

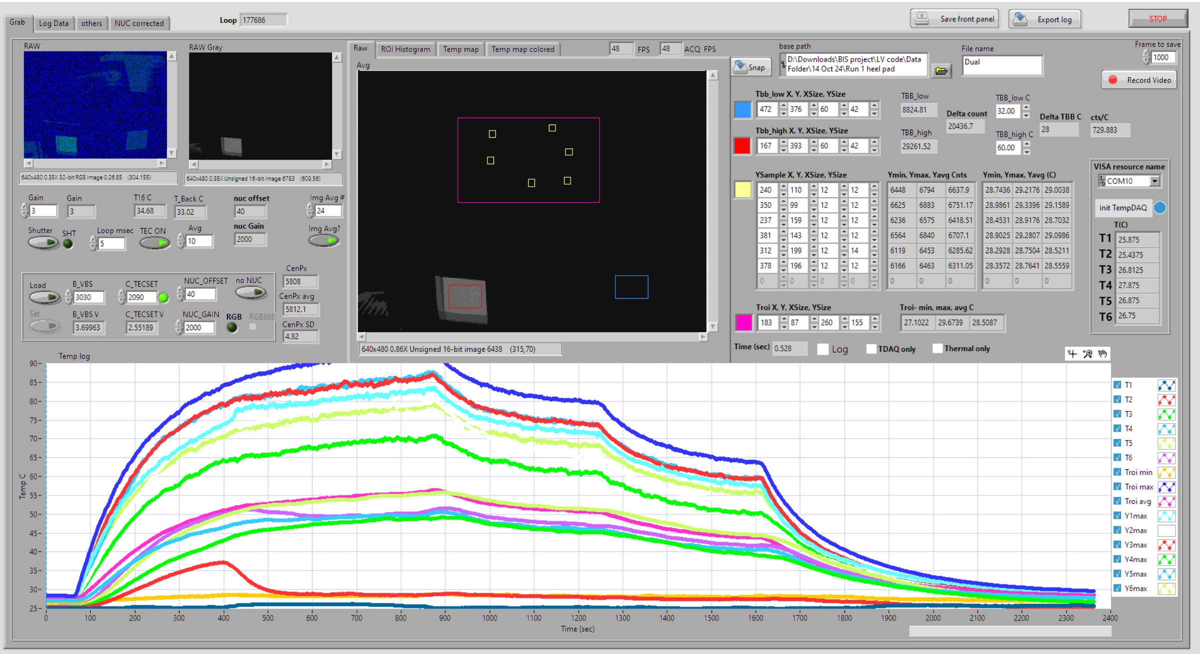
6.4.2. ANKLE PAD, SANDPUPPY

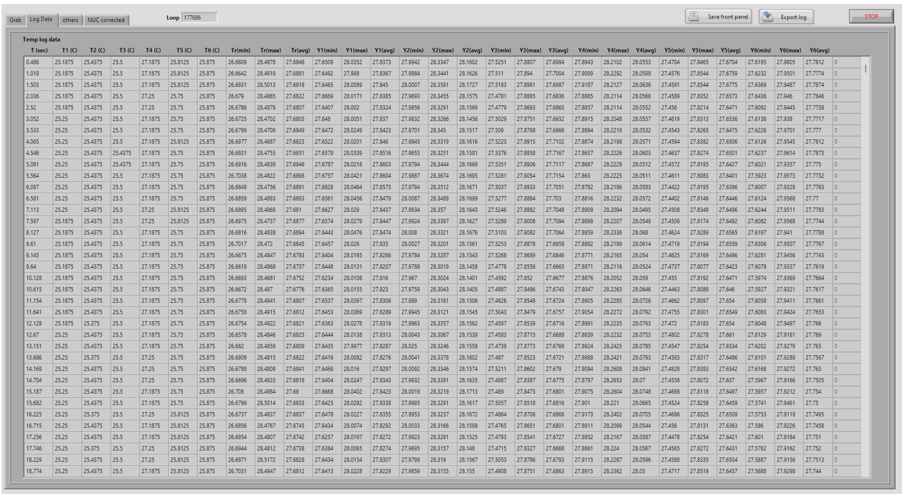
The thermal image or the temperature map of the sample when in operation is shown below.





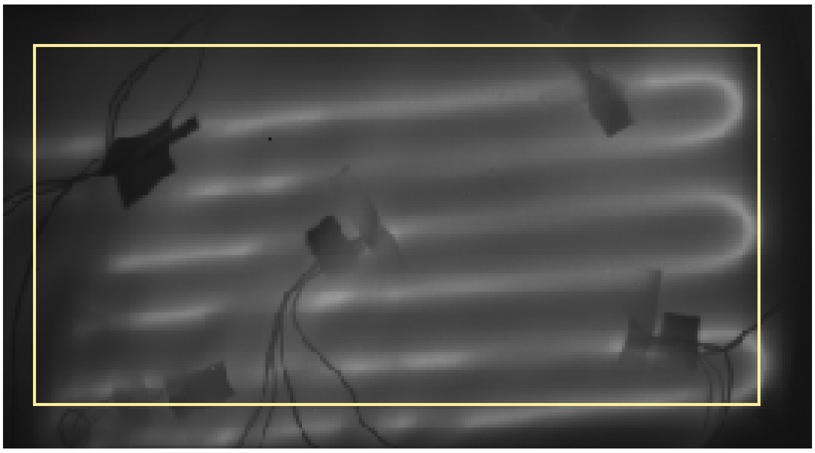
The front panel of the software with data acquired is shown below.

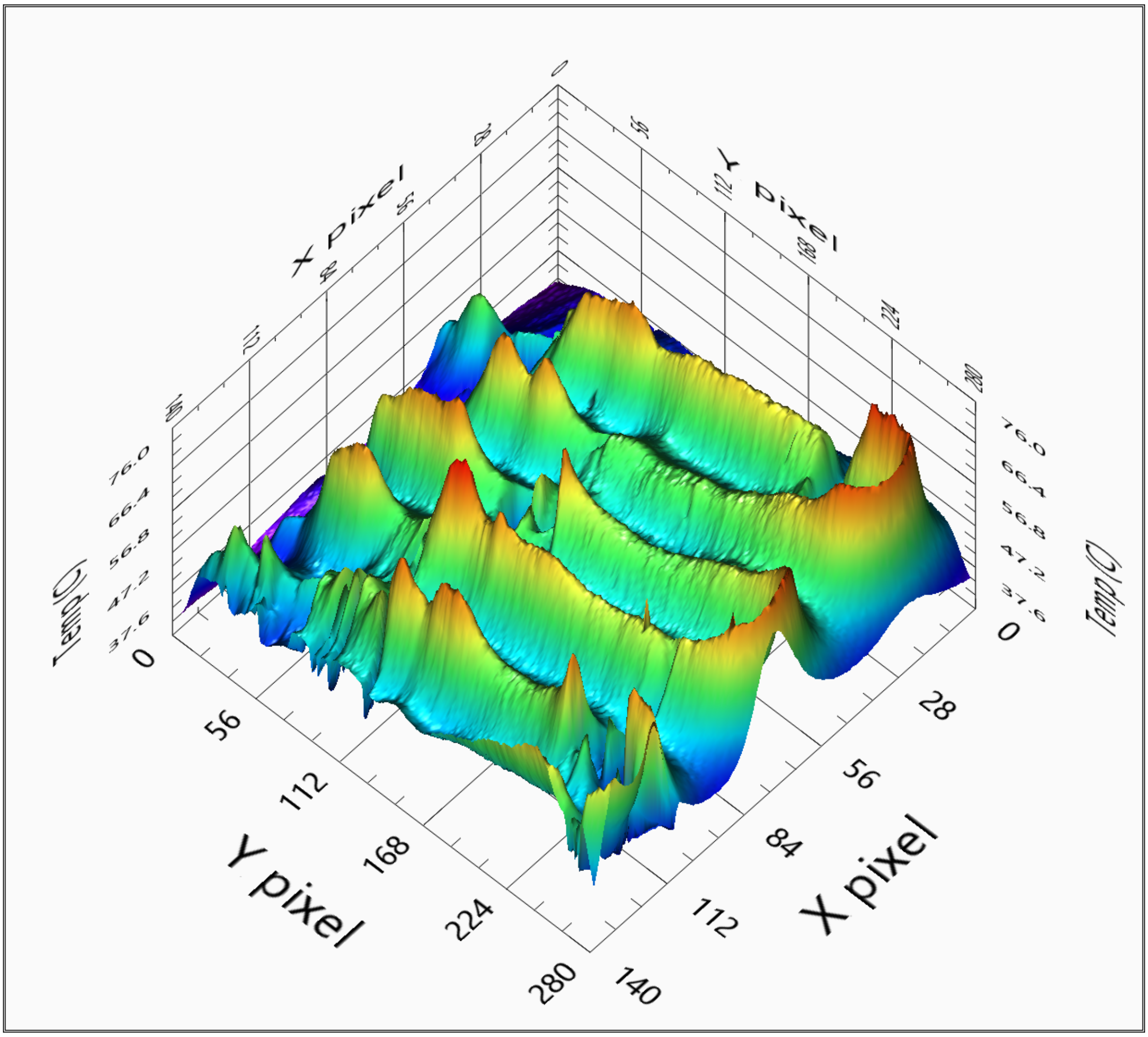




The following is the time events during the data log taken against time.

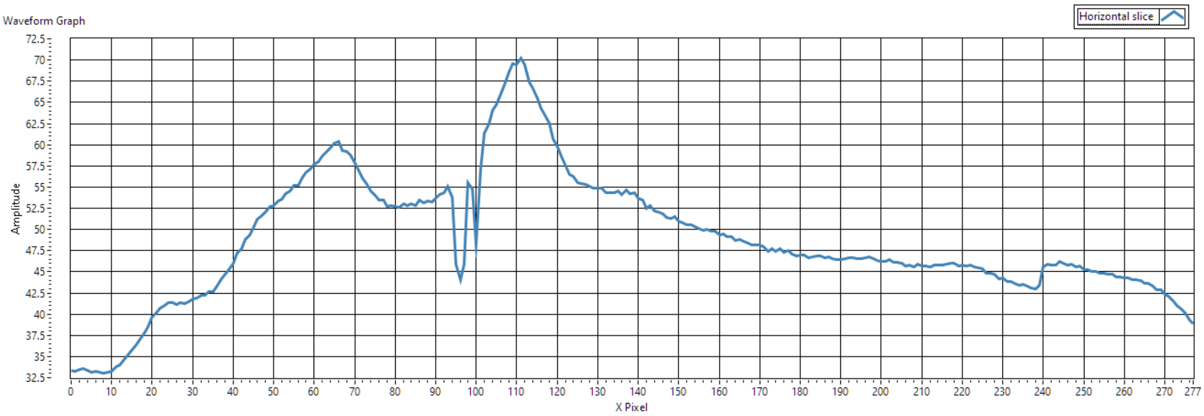
- Unit switched on to Level 1 at 60 seconds
- Switched to Level 2 at 869 seconds
- Switched to level 3 at 1240 seconds
- Switched OFF at 1608 seconds





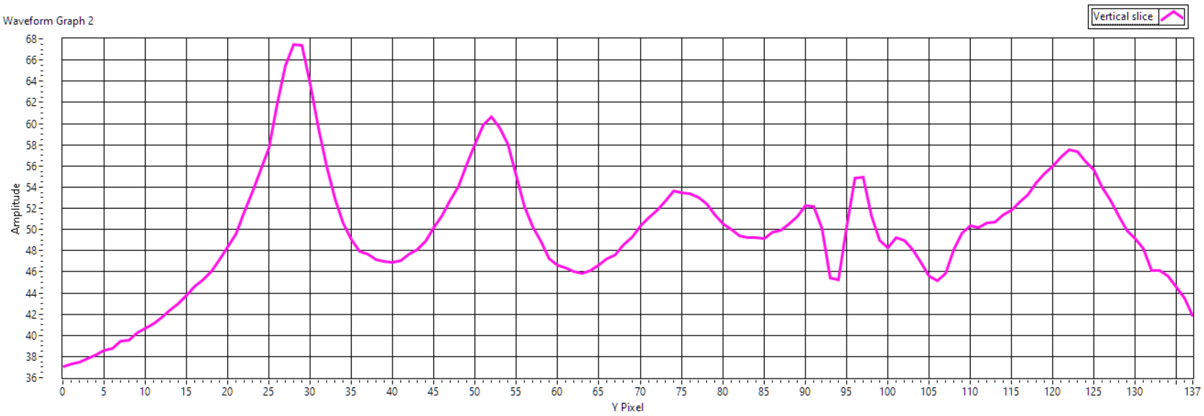
The temperature profile of the horizontal and vertical cross section along the middle of the sample area is shown below.

Horizontal temperature profile:



- Minimum temperature = 33.06 deg C
- Maximum temperature = 70.18 deg C
- Average temperature = 48.77 deg C

Vertical temperature profile:



- Minimum temperature = 37.01 deg C
- Maximum temperature = 67.49 deg C
- Average temperature = 49.87 deg C

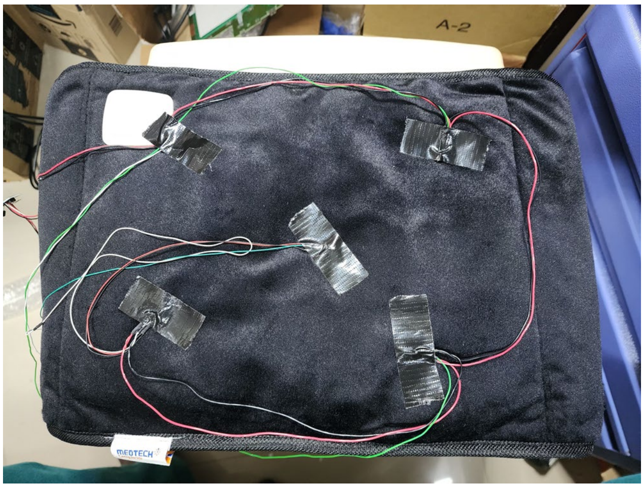
Summary of the experimental results:

zroduct	Ankle cap
Manufacturer	Sand Puppy, Pune
Power Supply	DC 12-volt adopter or DC 12 V battery
Heating wire material	Silicone coated carbon fiber
Response time	12 mins
Power consumption	19 W
Measured current	1.596 A

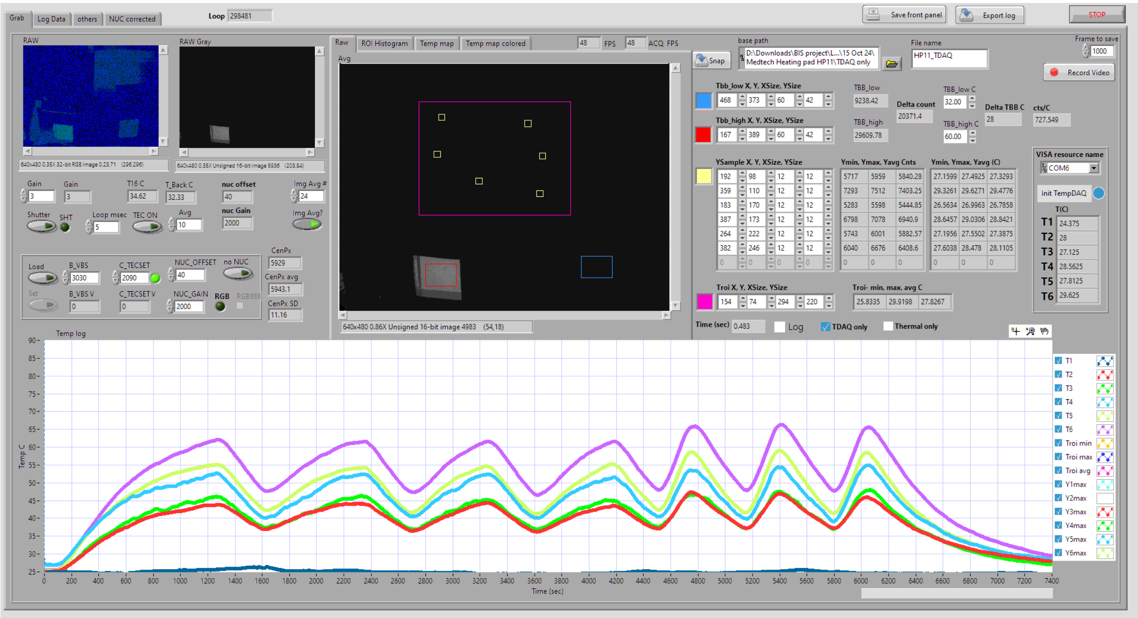
Measured resistance	7.5 Ω
Heating wire layout	Series and parallel combination
Horizontal temp. profile	• Minimum temperature = 33.06 deg C • Maximum temperature = 70.18 deg C • Average temperature = 48.77 deg C
Vertical temp. profile	• Minimum temperature = 37.01 deg C • Maximum temperature = 67.49 deg C • Average temperature = 49.87 deg C

6.4.3. HP11 HEATING PAD, MEDTECH

TEMPERATURE PROBE TEST:



The front panel of the software with data acquired is shown below.



Temp log data

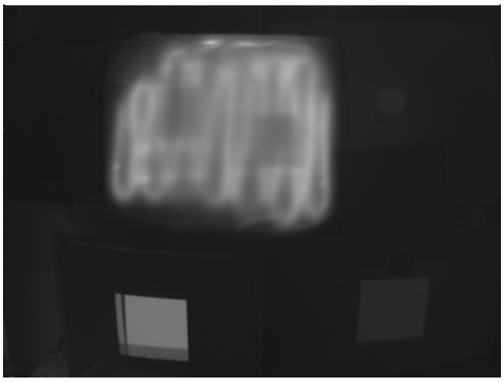
T (sec)	T1 (C)	T2 (C)	T3 (C)	T4 (C)	T5 (C)	T6 (C)	Tr(min)	Tr(max)	Tr(avg)	Y1(min)	Y1(max)	Y1(avg)	Y2(min)	Y2(max)	Y2(avg)	Y3(min)	Y3(max)	Y3(avg)	Y4(min)	Y4(max)	Y4(avg)	Y5(min)	Y5(max)	Y5(avg)	Y6(min)	Y6(max)	Y6(avg)
0.483	24.875	25.25	24.9375	27.125	25.5	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.019	24.875	25.25	24.9375	27.125	25.5	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.501	24.8125	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.033	24.8125	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.516	24.8125	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.048	24.875	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.53	24.875	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.061	24.875	25.25	24.9375	27.125	25.4375	25.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.541	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.074	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.555	24.8125	25.25	25	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.087	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.57	24.8125	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.102	24.8125	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.586	24.8125	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.118	24.875	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.599	24.8125	25.25	25	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.131	24.8125	25.25	25	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.613	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.145	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.63	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.165	24.8125	25.25	24.9375	27.0625	25.375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.645	24.8125	25.25	24.9375	27.0625	25.375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.177	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.659	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.192	24.8125	25.25	24.9375	27.0625	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.673	24.875	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.204	24.875	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.686	24.875	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.219	24.8125	25.25	25	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15.702	24.8125	25.25	25	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.188	24.875	25.25	25	27.125	25.375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.722	24.875	25.25	24.9375	27.125	25.375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.206	24.875	25.25	24.9375	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.74	24.875	25.25	25	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.222	24.875	25.25	25	27.125	25.4375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.755	24.875	25.25	24.9375	27.0625	25.375	25.6875	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

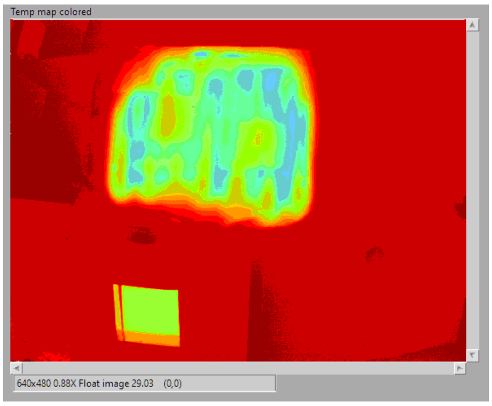
The following is the time events during the data log taken against time.

- Unit switched on to Level 1 at 60 seconds
- Switched to Level 2 at 2478 seconds
- Switched to level 3 at 4450 seconds
- Switched OFF at 6097 seconds

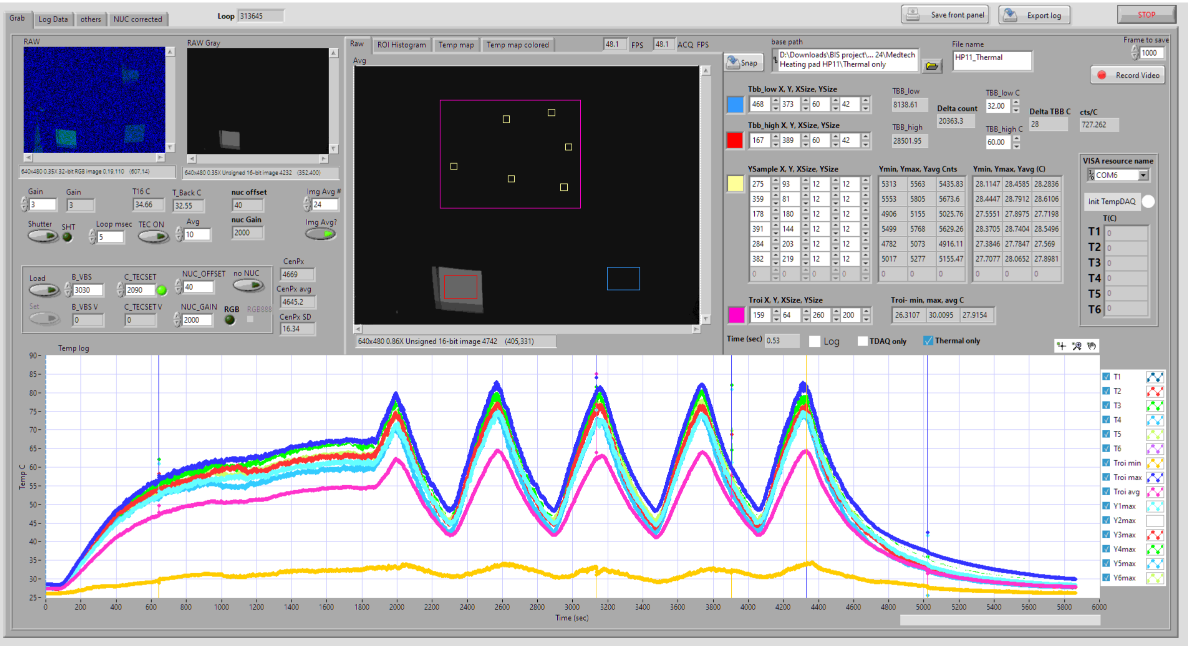
THERMAL IMAGING TEST:

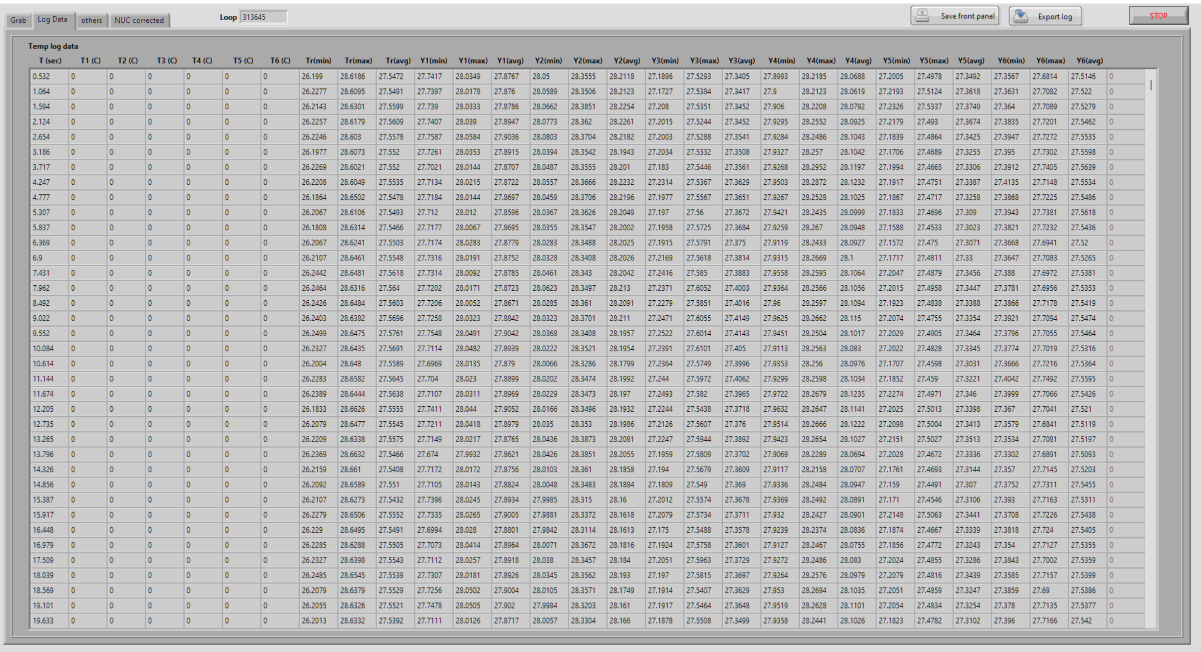
The thermal image or the temperature map of the sample when in operation is shown below.





The front panel of the software with data acquired is shown below.



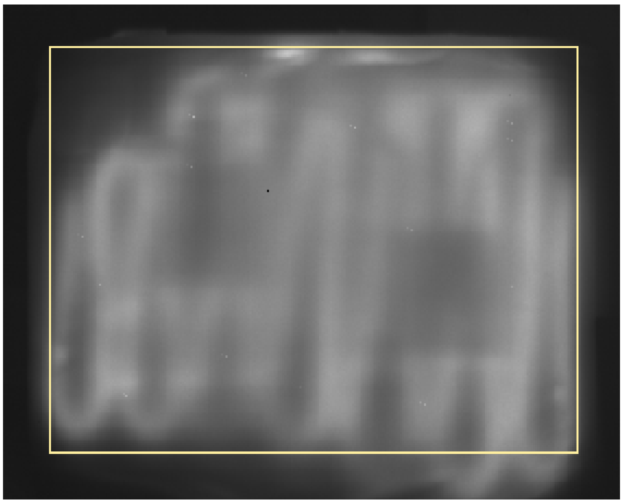


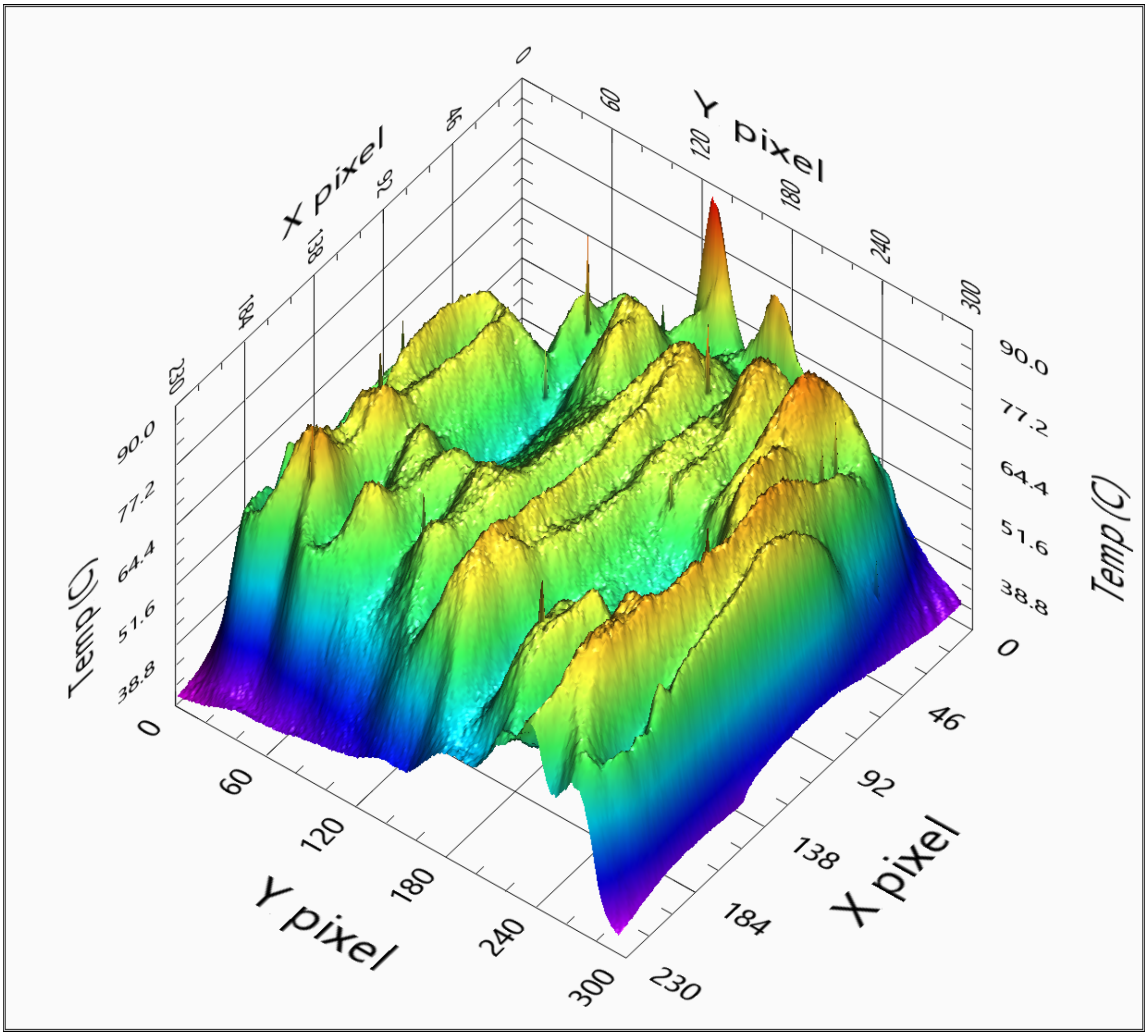
Temp log data

T (sec)	T1 (C)	T2 (C)	T3 (C)	T4 (C)	T5 (C)	T6 (C)	Tr(min)	Tr(max)	Tr(avg)	Y1(min)	Y1(max)	Y1(avg)	Y2(min)	Y2(max)	Y2(avg)	Y3(min)	Y3(max)	Y3(avg)	Y4(min)	Y4(max)	Y4(avg)	Y5(min)	Y5(max)	Y5(avg)	Y6(min)	Y6(max)	Y6(avg)	
0.532	0	0	0	0	0	0	26.199	28.6186	27.5472	27.7417	28.0349	27.8767	28.05	28.3555	28.2118	27.1896	27.5293	27.3405	27.8993	28.2185	28.0688	27.2005	27.4978	27.3492	27.3567	27.6814	27.5146	0
1.064	0	0	0	0	0	0	26.2277	28.6095	27.5491	27.7397	28.0178	27.876	28.0589	28.3506	28.2123	27.1727	27.5384	27.3417	27.9	28.2123	28.0619	27.2193	27.5124	27.3618	27.3631	27.7082	27.522	0
1.594	0	0	0	0	0	0	26.2143	28.6301	27.5599	27.739	28.0333	27.8786	28.0662	28.3851	28.2254	27.208	27.5351	27.3452	27.906	28.2208	28.0792	27.2326	27.5337	27.3749	27.364	27.7089	27.5279	0
2.124	0	0	0	0	0	0	26.2257	28.6179	27.5609	27.7407	28.039	27.8947	28.0773	28.362	28.2261	27.2015	27.5244	27.3452	27.9295	28.2552	28.0925	27.2179	27.493	27.3674	27.3835	27.7201	27.5462	0
2.654	0	0	0	0	0	0	26.2246	28.603	27.5578	27.7587	28.0584	27.9036	28.0803	28.3704	28.2182	27.2003	27.5288	27.3541	27.9284	28.2486	28.1043	27.1839	27.4864	27.3425	27.3947	27.7272	27.5535	0
3.186	0	0	0	0	0	0	26.1977	28.6073	27.552	27.7261	28.0353	27.8915	28.0394	28.3542	28.1943	27.2034	27.5332	27.3508	27.9327	28.257	28.1042	27.1706	27.4689	27.3255	27.395	27.7302	27.5598	0
3.717	0	0	0	0	0	0	26.2269	28.6021	27.552	27.7021	28.0144	27.8707	28.0487	28.3555	28.201	27.183	27.5446	27.3561	27.9268	28.2952	28.1197	27.1994	27.4665	27.3306	27.3912	27.7405	27.5639	0
4.247	0	0	0	0	0	0	26.2208	28.6049	27.5535	27.7134	28.0215	27.8722	28.0557	28.3666	28.2232	27.2314	27.5367	27.3629	27.9503	28.2872	28.1232	27.1917	27.4751	27.3387	27.4135	27.7148	27.5534	0
4.777	0	0	0	0	0	0	26.1864	28.6502	27.5478	27.7184	28.0144	27.8697	28.0459	28.3706	28.2196	27.1977	27.5567	27.3651	27.9267	28.2528	28.1025	27.1867	27.4717	27.3258	27.3868	27.7225	27.5486	0
5.307	0	0	0	0	0	0	26.2067	28.6106	27.5493	27.712	28.012	27.8596	28.0367	28.3626	28.2049	27.197	27.56	27.3672	27.9421	28.2435	28.0999	27.1833	27.4696	27.309	27.3943	27.7381	27.5618	0
5.837	0	0	0	0	0	0	26.1808	28.6314	27.5466	27.7177	28.0067	27.8695	28.0355	28.3547	28.2002	27.1958	27.5725	27.3684	27.9259	28.267	28.0948	27.1588	27.4533	27.3023	27.3821	27.7232	27.5436	0
6.369	0	0	0	0	0	0	26.2067	28.6241	27.5503	27.7174	28.0283	27.8779	28.0283	28.3488	28.2025	27.1915	27.5791	27.375	27.9119	28.2433	28.0927	27.1572	27.475	27.3071	27.3668	27.6941	27.52	0
6.9	0	0	0	0	0	0	26.2107	28.6461	27.5548	27.7316	28.0191	27.8752	28.0328	28.3408	28.2026	27.2169	27.5618	27.3814	27.9315	28.2669	28.1	27.1717	27.4811	27.33	27.3647	27.7083	27.5265	0
7.431	0	0	0	0	0	0	26.2442	28.6481	27.5618	27.7314	28.0092	27.8785	28.0461	28.343	28.2042	27.2416	27.585	27.3883	27.9558	28.2595	28.1064	27.2047	27.4879	27.3456	27.388	27.6972	27.5381	0
7.962	0	0	0	0	0	0	26.2464	28.6316	27.564	27.7202	28.0171	27.8723	28.0623	28.3497	28.213	27.2371	27.6052	27.4003	27.9364	28.2566	28.1056	27.2015	27.4958	27.3447	27.3781	27.6956	27.5353	0
8.492	0	0	0	0	0	0	26.2426	28.6484	27.5603	27.7206	28.0052	27.8671	28.0285	28.361	28.2091	27.2279	27.5851	27.4016	27.96	28.2597	28.1094	27.1923	27.4838	27.3388	27.3866	27.7178	27.5419	0
9.022	0	0	0	0	0	0	26.2403	28.6382	27.5696	27.7258	28.0323	27.8842	28.0323	28.3701	28.211	27.2471	27.6055	27.4149	27.9625	28.2662	28.115	27.2074	27.4755	27.3354	27.3921	27.7094	27.5474	0
9.552	0	0	0	0	0	0	26.2499	28.6475	27.5761	27.7548	28.0491	27.9042	28.0368	28.3408	28.1957	27.2522	27.6014	27.4143	27.9451	28.2504	28.1017	27.2029	27.4905	27.3464	27.3796	27.7055	27.5464	0
10.084	0	0	0	0	0	0	26.2327	28.6435	27.5691	27.7114	28.0482	27.8939	28.0222	28.3521	28.1954	27.2391	27.6101	27.405	27.9113	28.2563	28.083	27.2022	27.4828	27.3345	27.3774	27.7019	27.5316	0
10.614	0	0	0	0	0	0	26.2004	28.648	27.5589	27.6969	28.0135	27.879	28.0066	28.3286	28.1799	27.2364	27.5749	27.3996	27.9353	28.256	28.0976	27.1707	27.4598	27.3031	27.3666	27.7216	27.5364	0
11.144	0	0	0	0	0	0	26.2283	28.6582	27.5645	27.704	28.023	27.8899	28.0202	28.3474	28.1992	27.244	27.5972	27.4062	27.9299	28.2598	28.1034	27.1852	27.459	27.3221	27.4042	27.7492	27.5595	0
11.674	0	0	0	0	0	0	26.2389	28.6444	27.5638	27.7107	28.0311	27.8969	28.0229	28.3473	28.197	27.2493	27.582	27.3965	27.9722	28.2679	28.1235	27.2274	27.4971	27.346	27.3999	27.7066	27.5426	0
12.205	0	0	0	0	0	0	26.1833	28.6626	27.5555	27.7411	28.044	27.9052	28.0166	28.3496	28.1932	27.2244	27.5438	27.3718	27.9632	28.2647	28.1141	27.2025	27.5013	27.3398	27.367	27.7041	27.521	0
12.735	0	0	0	0	0	0	26.2079	28.6477	27.5545	27.7211	28.0418	27.8979	28.035	28.353	28.1986	27.2126	27.5607	27.376	27.9514	28.2666	28.1222	27.2098	27.5004	27.3413	27.3579	27.6841	27.5119	0
13.265	0	0	0	0	0	0	26.2209	28.6338	27.5575	27.7149	28.0217	27.8765	28.0436	28.3873	28.2081	27.2247	27.5944	27.3892	27.9423	28.2654	28.1027	27.2151	27.5027	27.3513	27.3534	27.7081	27.5197	0
13.796	0	0	0	0	0	0	26.2369	28.6632	27.5466	27.674	27.9932	27.8621	28.0426	28.3851	28.2055	27.1959	27.5809	27.3702	27.9069	28.2289	28.0694	27.2028	27.4672	27.3336	27.3302	27.6891	27.5093	0
14.326	0	0	0	0	0	0	26.2159	28.661	27.5408	27.7172	28.0172	27.8756	28.0103	28.361	28.1858	27.194	27.5679	27.3609	27.9117	28.2158	28.0707	27.1761	27.4693	27.3144	27.357	27.7145	27.5203	0
14.856	0	0	0	0	0	0	26.2092	28.6589	27.551	27.7105	28.0143	27.8824	28.0048	28.3483	28.1884	27.1809	27.549	27.369	27.9336	28.2484	28.0947	27.159	27.4491	27.307	27.3752	27.7311	27.5455	0
15.387	0	0	0	0	0	0	26.2107	28.6273	27.5432	27.7396	28.0245	27.8934	27.9985	28.315	28.16	27.2012	27.5574	27.3678	27.9369	28.2492	28.0891	27.171	27.4546	27.3106	27.393	27.7163	27.5311	0
15.917	0	0	0	0	0	0	26.2279	28.6506	27.5552	27.7335	28.0265	27.9005	27.9881	28.3372	28.1618	27.2079	27.5734	27.3711	27.932	28.2427	28.0901	27.2148	27.5063	27.3441	27.3708	27.7226	27.5438	0
16.448	0	0	0	0	0	0	26.229	28.6495	27.5491	27.6994	28.028	27.8801	27.9842	28.3114	28.1613	27.175	27.5488	27.3578	27.9239	28.2374	28.0836	27.1874	27.4667	27.3339	27.3818	27.724	27.5405	0
16.979	0	0	0	0	0	0	26.2285	28.6288	27.5505	27.7073	28.0414	27.8964	28.0071	28.3672	28.1816	27.1924	27.5758	27.3601	27.9127	28.2467	28.0755	27.1856	27.4772	27.3243	27.354	27.7127	27.5355	0
17.509	0	0	0	0	0	0	26.2327	28.6398	27.5543	27.7112	28.0257	27.8918	28.038	28.3457	28.184	27.2051	27.5963	27.3729	27.9272	28.2486	28.083	27.2024	27.4855	27.3286	27.3843	27.7002	27.5359	0
18.039	0	0	0	0	0	0	26.2485	28.6545	27.5539	27.7307	28.0181	27.8926	28.0345	28.3562	28.193	27.197	27.5815	27.3697	27.9264	28.2576	28.0979	27.2079	27.4816	27.3439	27.3585	27.7157	27.5399	0
18.569	0	0	0	0	0	0	26.2079	28.6379	27.5529	27.7256	28.0502	27.9004	28.0105	28.3571	28.1749	27.1914	27.5407	27.3629	27.953	28.2694	28.1035	27.2051	27.4859	27.3247	27.3859	27.69	27.5386	0
19.101	0	0	0	0	0	0	26.2055	28.6326	27.5521	27.7478	28.0505	27.902	27.9984	28.3203	28.161	27.1917	27.5464	27.3648	27.9519	28.2628	28.1101	27.2054	27.4834	27.3254	27.378	27.7135	27.5377	0
19.633	0	0	0	0	0	0	26.2013	28.6332	27.5392	27.7111	28.0126	27.8717	28.0057	28.3304	28.166	27.1878	27.5508	27.3499	27.9358	28.2441	28.1026	27.1823	27.4782	27.3102	27.396	27.7166	27.542	0

The following is the time events during the data log taken against time.

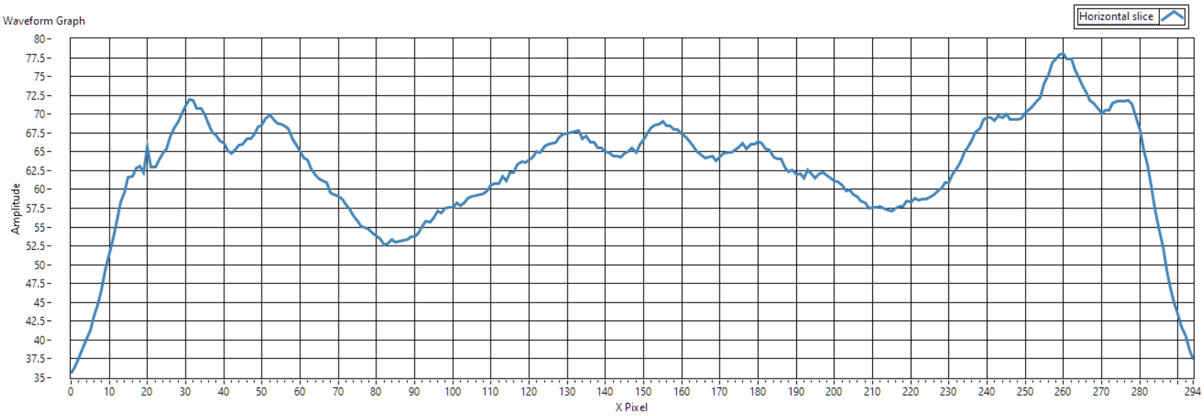
- Unit switched on to Level 1 at 60 seconds
- Switched to Level 2 at 1200 seconds
- Switched to level 3 at 1850 seconds
- Switched OFF at 4308 seconds





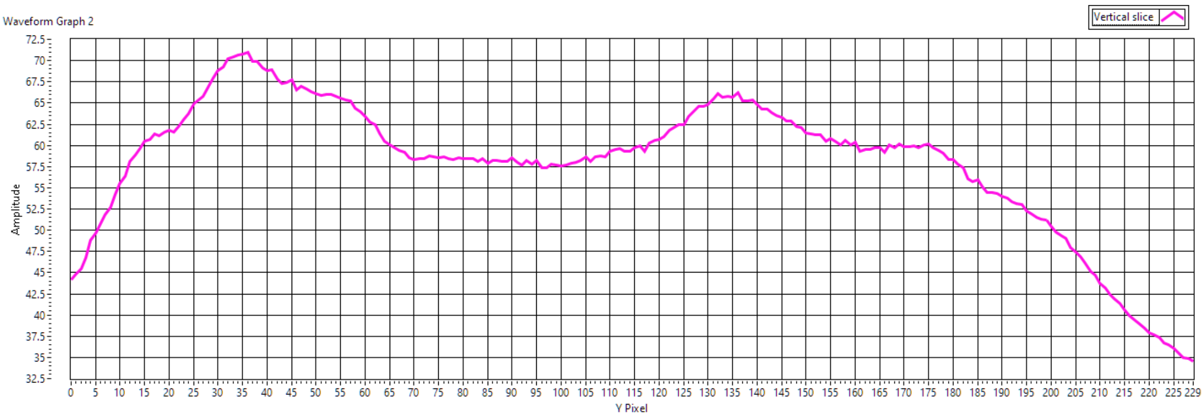
The temperature profile of the horizontal and vertical cross section along the middle of the sample area is shown below.

Horizontal temperature profile:



- Minimum temperature = 35.55 deg C
- Maximum temperature = 78.06 deg C
- Average temperature = 62.66 deg C

Vertical temperature profile:



- Minimum temperature = 34.58 deg C
- Maximum temperature = 70.98 deg C
- Average temperature = 58.01 deg C

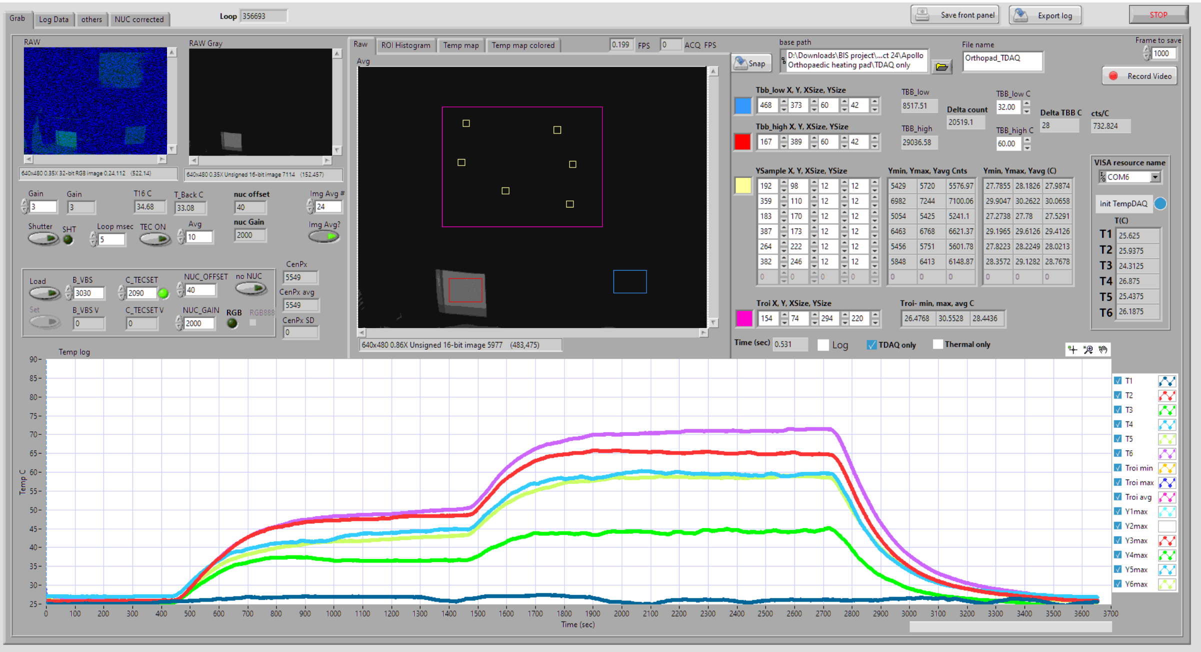
Summary of the experimental results:

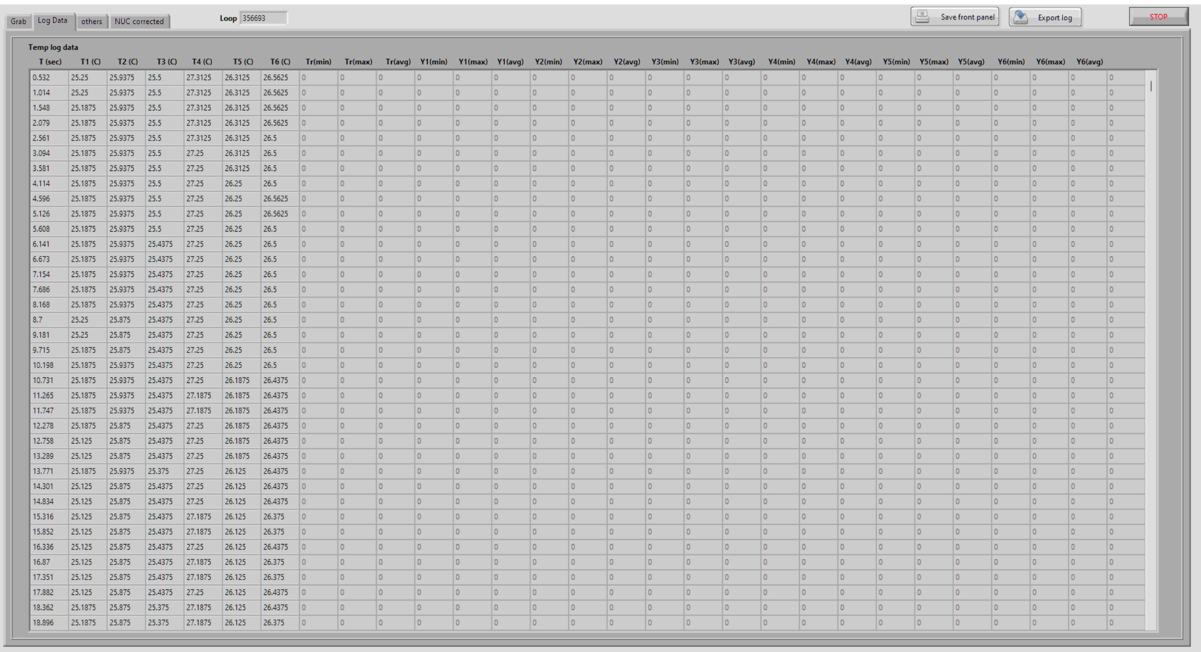
Product	Wearable heating pad
Manufacturer	MEDTECH LIFE PVT. LTD., Mumbai
Power Supply	AC 230V line supply
Response time	17 mins
Power consumption	38 W
Heating wire layout	Series and parallel combination
Horizontal temp. profile	• Minimum temperature = 35.55 deg C • Maximum temperature = 78.06 deg C • Average temperature = 62.66 deg C
Vertical temp. profile	• Minimum temperature = 34.58 deg C

	• Maximum temperature = 70.98 deg C • Average temperature = 58.01 deg C
Heating modes	• Low: 64 deg. C max. • Medium: 68 deg. C max. • High: 82 deg. C max.
Overheat protection	• Tc cut-off temp.: 80-83°C • Tc turn-on temp.: 48-50°C

6.4.4. HEATING PAD, APOLLO

TEMPERATURE PROBE TEST:

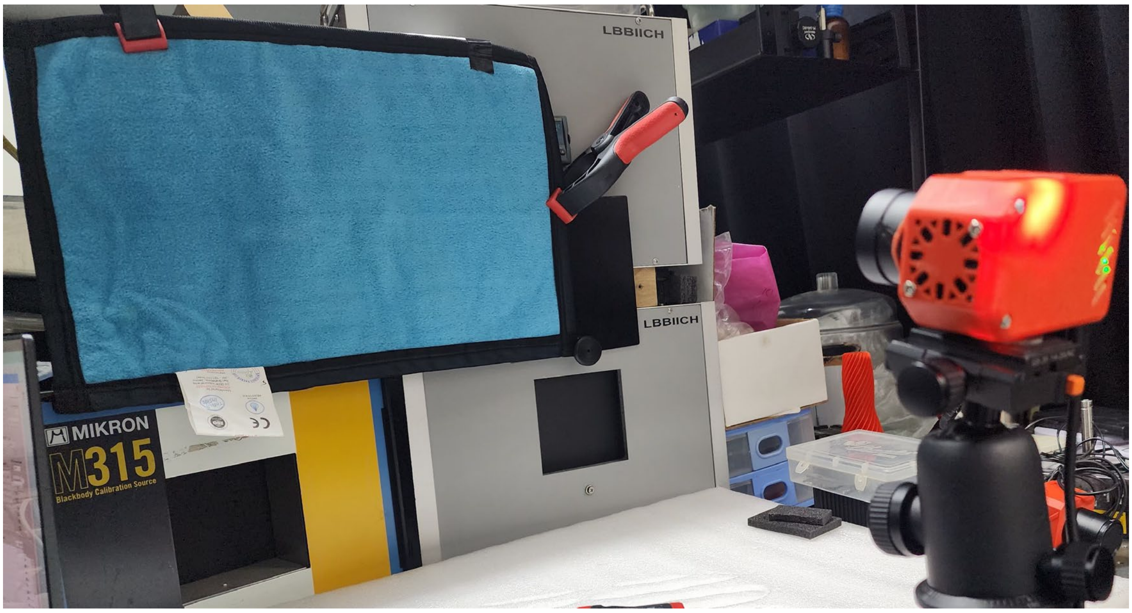




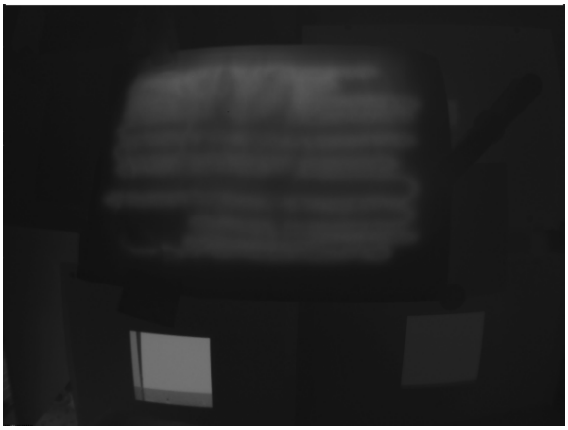
The following is the time events during the data log taken against time.

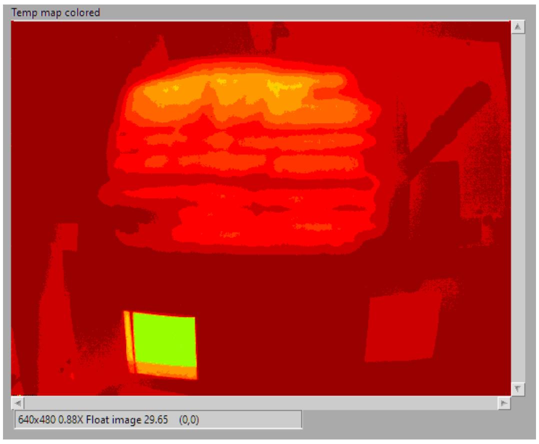
- Unit switched on to Level 1 at 434 seconds
- Switched to Level 2 at 1165 seconds
- Switched to level 3 at 1450 seconds
- Switched OFF at 2712 seconds

THERMAL IMAGING TEST:

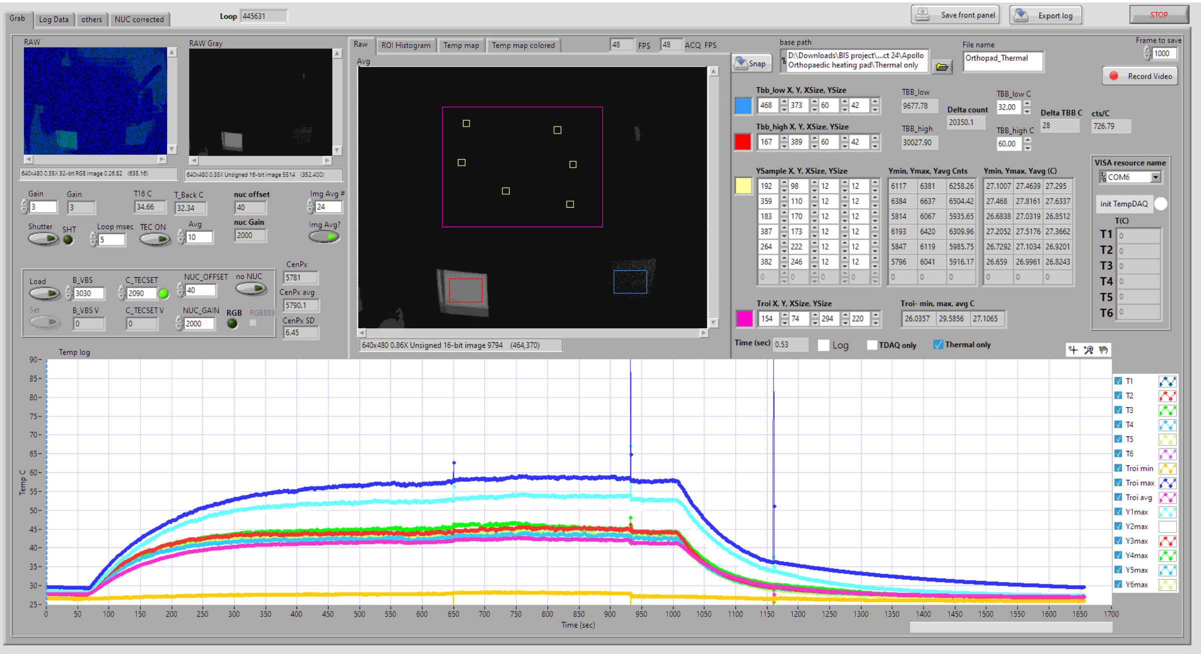


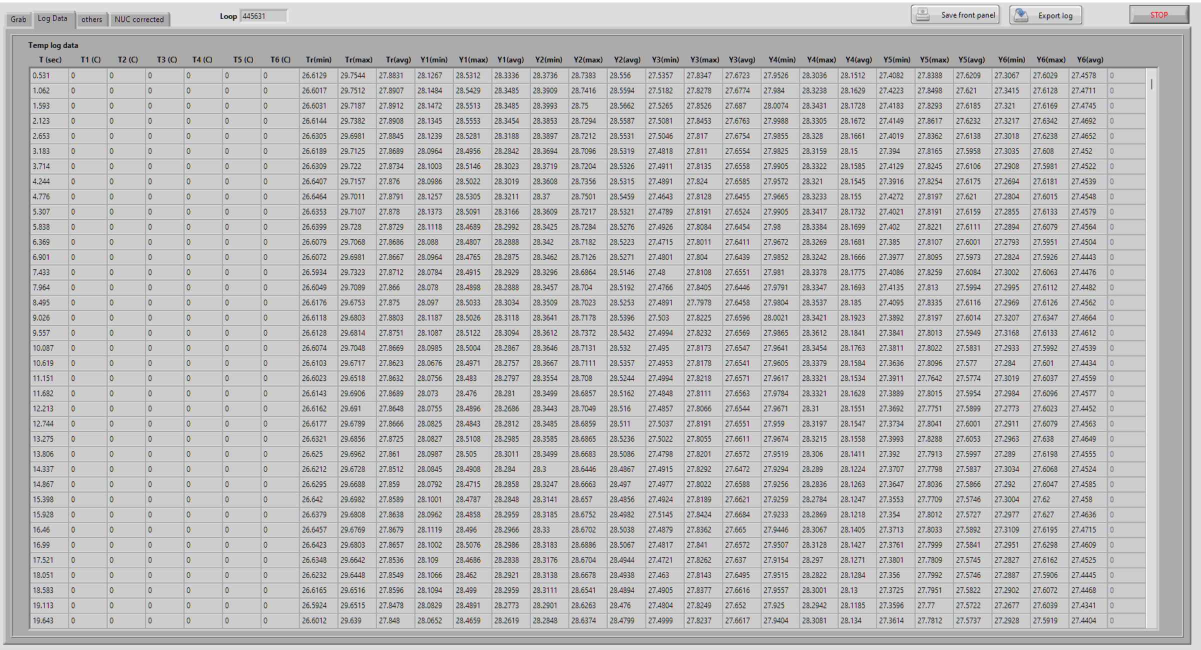
The thermal image or the temperature map of the sample when in operation is shown below.





The front panel of the software with data acquired is shown below.



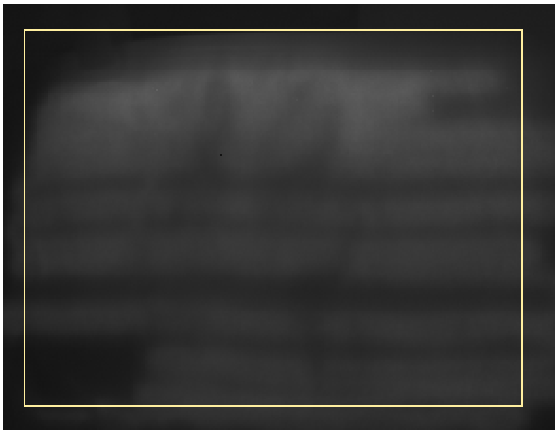


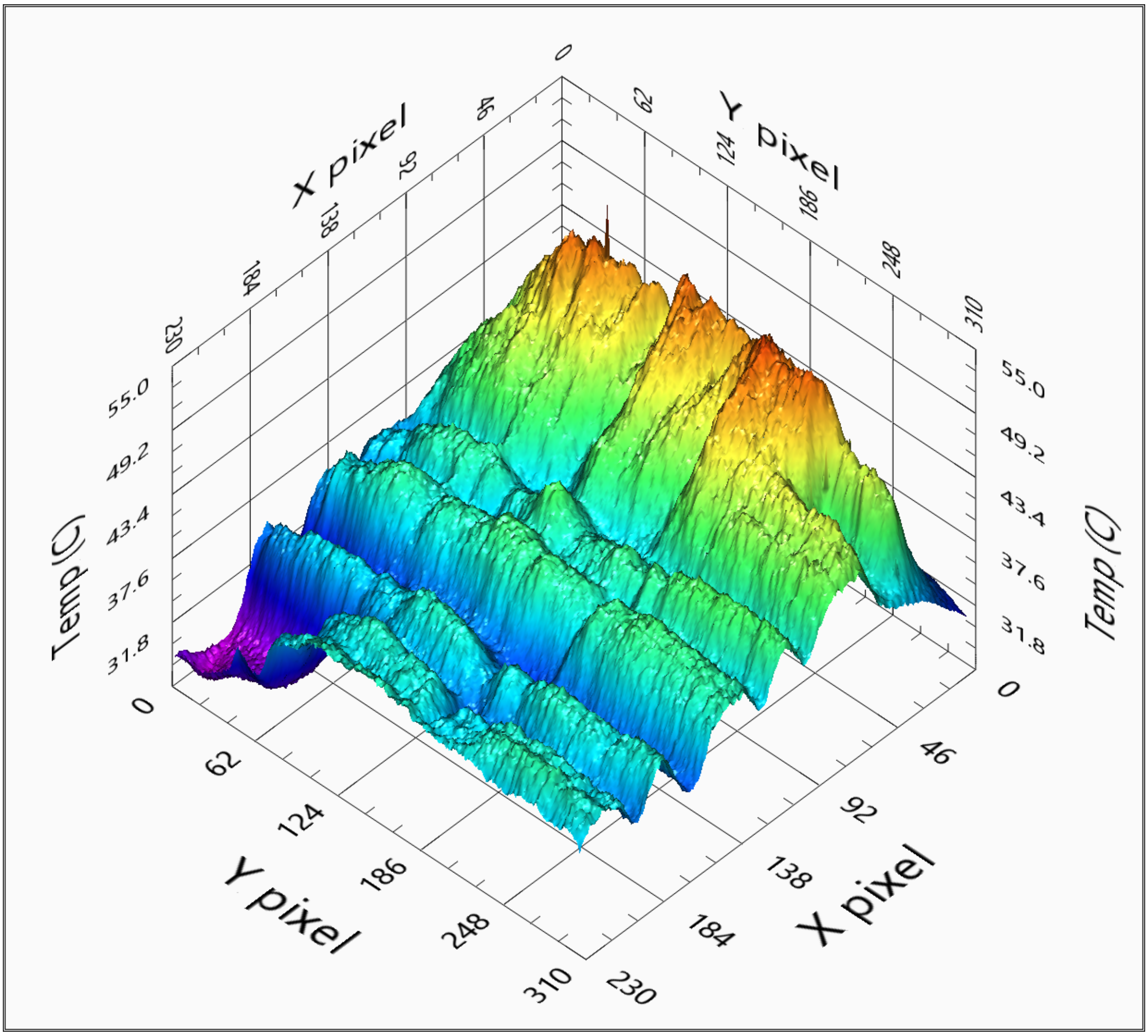
Temp log data

T (sec)	T1 (C)	T2 (C)	T3 (C)	T4 (C)	T5 (C)	T6 (C)	Tr(min)	Tr(max)	Tr(avg)	Y1(min)	Y1(max)	Y1(avg)	Y2(min)	Y2(max)	Y2(avg)	Y3(min)	Y3(max)	Y3(avg)	Y4(min)	Y4(max)	Y4(avg)	Y5(min)	Y5(max)	Y5(avg)	Y6(min)	Y6(max)	Y6(avg)	
0.531	0	0	0	0	0	0	26.6129	29.7544	27.8831	28.1267	28.5312	28.3336	28.3736	28.7383	28.556	27.5357	27.8347	27.6723	27.9526	28.3036	28.1512	27.4082	27.8388	27.6209	27.3067	27.6029	27.4578	0
1.062	0	0	0	0	0	0	26.6017	29.7512	27.8907	28.1484	28.5429	28.3485	28.3909	28.7416	28.5594	27.5182	27.8278	27.6774	27.984	28.3238	28.1629	27.4223	27.8498	27.621	27.3415	27.6128	27.4711	0
1.593	0	0	0	0	0	0	26.6031	29.7187	27.8912	28.1472	28.5513	28.3485	28.3993	28.75	28.5662	27.5265	27.8526	27.687	28.0074	28.3431	28.1728	27.4183	27.8293	27.6185	27.321	27.6169	27.4745	0
2.123	0	0	0	0	0	0	26.6144	29.7382	27.8908	28.1345	28.5553	28.3454	28.3853	28.7294	28.5587	27.5081	27.8453	27.6763	27.9988	28.3305	28.1672	27.4149	27.8617	27.6232	27.3217	27.6342	27.4692	0
2.653	0	0	0	0	0	0	26.6305	29.6981	27.8845	28.1239	28.5281	28.3188	28.3897	28.7212	28.5531	27.5046	27.817	27.6754	27.9855	28.328	28.1661	27.4019	27.8362	27.6138	27.3018	27.6238	27.4652	0
3.183	0	0	0	0	0	0	26.6189	29.7125	27.8689	28.0964	28.4956	28.2842	28.3694	28.7096	28.5319	27.4818	27.811	27.6554	27.9825	28.3159	28.15	27.394	27.8165	27.5958	27.3035	27.608	27.452	0
3.714	0	0	0	0	0	0	26.6309	29.722	27.8734	28.1003	28.5146	28.3023	28.3719	28.7204	28.5326	27.4911	27.8135	27.6558	27.9905	28.3322	28.1585	27.4129	27.8245	27.6106	27.2908	27.5981	27.4522	0
4.244	0	0	0	0	0	0	26.6407	29.7157	27.876	28.0986	28.5022	28.3019	28.3608	28.7356	28.5315	27.4891	27.824	27.6585	27.9572	28.321	28.1545	27.3916	27.8254	27.6175	27.2694	27.6181	27.4539	0
4.776	0	0	0	0	0	0	26.6464	29.7011	27.8791	28.1257	28.5305	28.3211	28.37	28.7501	28.5459	27.4643	27.8128	27.6455	27.9665	28.3233	28.155	27.4272	27.8197	27.621	27.2804	27.6015	27.4548	0
5.307	0	0	0	0	0	0	26.6353	29.7107	27.878	28.1373	28.5091	28.3166	28.3609	28.7217	28.5321	27.4789	27.8191	27.6524	27.9905	28.3417	28.1732	27.4021	27.8191	27.6159	27.2855	27.6133	27.4579	0
5.838	0	0	0	0	0	0	26.6399	29.728	27.8729	28.1118	28.4689	28.2992	28.3425	28.7284	28.5276	27.4926	27.8084	27.6454	27.98	28.3384	28.1699	27.402	27.8221	27.6111	27.2894	27.6079	27.4564	0
6.369	0	0	0	0	0	0	26.6079	29.7068	27.8686	28.088	28.4807	28.2888	28.342	28.7182	28.5223	27.4715	27.8011	27.6411	27.9672	28.3269	28.1681	27.385	27.8107	27.6001	27.2793	27.5951	27.4504	0
6.901	0	0	0	0	0	0	26.6072	29.6981	27.8667	28.0964	28.4765	28.2875	28.3462	28.7126	28.5271	27.4801	27.804	27.6439	27.9852	28.3242	28.1666	27.3977	27.8095	27.5973	27.2824	27.5926	27.4443	0
7.433	0	0	0	0	0	0	26.5934	29.7323	27.8712	28.0784	28.4915	28.2929	28.3296	28.6864	28.5146	27.48	27.8108	27.6551	27.981	28.3378	28.1775	27.4086	27.8259	27.6084	27.3002	27.6063	27.4476	0
7.964	0	0	0	0	0	0	26.6049	29.7089	27.866	28.078	28.4898	28.2888	28.3457	28.704	28.5192	27.4766	27.8405	27.6446	27.9791	28.3347	28.1693	27.4135	27.813	27.5994	27.2995	27.6112	27.4482	0
8.495	0	0	0	0	0	0	26.6176	29.6753	27.875	28.097	28.5033	28.3034	28.3509	28.7023	28.5253	27.4891	27.7978	27.6458	27.9804	28.3537	28.185	27.4095	27.8335	27.6116	27.2969	27.6126	27.4562	0
9.026	0	0	0	0	0	0	26.6118	29.6803	27.8803	28.1187	28.5026	28.3118	28.3641	28.7178	28.5396	27.503	27.8225	27.6596	28.0021	28.3421	28.1923	27.3892	27.8197	27.6014	27.3207	27.6347	27.4664	0
9.557	0	0	0	0	0	0	26.6128	29.6814	27.8751	28.1087	28.5122	28.3094	28.3612	28.7372	28.5432	27.4994	27.8232	27.6569	27.9865	28.3612	28.1841	27.3841	27.8013	27.5949	27.3168	27.6133	27.4612	0
10.087	0	0	0	0	0	0	26.6074	29.7048	27.8669	28.0985	28.5004	28.2867	28.3646	28.7131	28.532	27.495	27.8173	27.6547	27.9641	28.3454	28.1763	27.3811	27.8022	27.5831	27.2933	27.5992	27.4539	0
10.619	0	0	0	0	0	0	26.6103	29.6717	27.8623	28.0676	28.4971	28.2757	28.3667	28.7111	28.5357	27.4953	27.8178	27.6541	27.9605	28.3379	28.1584	27.3636	27.8096	27.577	27.284	27.601	27.4434	0
11.151	0	0	0	0	0	0	26.6023	29.6518	27.8632	28.0756	28.483	28.2797	28.3554	28.708	28.5244	27.4994	27.8218	27.6571	27.9617	28.3321	28.1534	27.3911	27.7642	27.5774	27.3019	27.6037	27.4559	0
11.682	0	0	0	0	0	0	26.6143	29.6906	27.8689	28.073	28.476	28.281	28.3499	28.6857	28.5162	27.4848	27.8111	27.6563	27.9784	28.3321	28.1628	27.3889	27.8015	27.5954	27.2984	27.6096	27.4577	0
12.213	0	0	0	0	0	0	26.6162	29.691	27.8648	28.0755	28.4896	28.2686	28.3443	28.7049	28.516	27.4857	27.8066	27.6544	27.9671	28.31	28.1551	27.3692	27.7751	27.5899	27.2773	27.6023	27.4452	0
12.744	0	0	0	0	0	0	26.6177	29.6789	27.8666	28.0825	28.4843	28.2812	28.3485	28.6859	28.511	27.5037	27.8191	27.6551	27.959	28.3197	28.1547	27.3734	27.8041	27.6001	27.2911	27.6079	27.4563	0
13.275	0	0	0	0	0	0	26.6321	29.6856	27.8725	28.0827	28.5108	28.2985	28.3585	28.6865	28.5236	27.5022	27.8055	27.6611	27.9674	28.3215	28.1558	27.3993	27.8288	27.6053	27.2963	27.638	27.4649	0
13.806	0	0	0	0	0	0	26.625	29.6962	27.861	28.0987	28.505	28.3011	28.3499	28.6683	28.5086	27.4798	27.8201	27.6572	27.9519	28.306	28.1411	27.392	27.7913	27.5997	27.289	27.6198	27.4555	0
14.337	0	0	0	0	0	0	26.6212	29.6728	27.8512	28.0845	28.4908	28.284	28.3	28.6446	28.4867	27.4915	27.8292	27.6472	27.9294	28.289	28.1224	27.3707	27.7798	27.5837	27.3034	27.6068	27.4524	0
14.867	0	0	0	0	0	0	26.6295	29.6688	27.859	28.0792	28.4715	28.2858	28.3247	28.6663	28.497	27.4977	27.8022	27.6588	27.9256	28.2836	28.1263	27.3647	27.8036	27.5866	27.292	27.6047	27.4585	0
15.398	0	0	0	0	0	0	26.642	29.6982	27.8589	28.1001	28.4787	28.2848	28.3141	28.657	28.4856	27.4924	27.8189	27.6621	27.9259	28.2784	28.1247	27.3553	27.7709	27.5746	27.3004	27.62	27.458	0
15.928	0	0	0	0	0	0	26.6379	29.6808	27.8638	28.0962	28.4858	28.2959	28.3185	28.6752	28.4982	27.5145	27.8424	27.6684	27.9233	28.2869	28.1218	27.354	27.8012	27.5727	27.2977	27.627	27.4636	0
16.46	0	0	0	0	0	0	26.6457	29.6769	27.8679	28.1119	28.496	28.2966	28.33	28.6702	28.5038	27.4879	27.8362	27.665	27.9446	28.3067	28.1405	27.3713	27.8033	27.5892	27.3109	27.6195	27.4715	0
16.99	0	0	0	0	0	0	26.6423	29.6803	27.8657	28.1002	28.5076	28.2986	28.3183	28.6886	28.5067	27.4817	27.841	27.6572	27.9507	28.3128	28.1427	27.3761	27.7999	27.5841	27.2951	27.6298	27.4609	0
17.521	0	0	0	0	0	0	26.6348	29.6642	27.8536	28.109	28.4686	28.2838	28.3176	28.6704	28.4944	27.4721	27.8262	27.637	27.9154	28.2822	28.1271	27.3801	27.7809	27.5745	27.2827	27.6162	27.4525	0
18.051	0	0	0	0	0	0	26.6232	29.6448	27.8549	28.1066	28.462	28.2921	28.3138	28.6678	28.4938	27.463	27.8143	27.6495	27.9515	28.2822	28.1284	27.356	27.7992	27.5746	27.2887	27.5906	27.4445	0
18.583	0	0	0	0	0	0	26.6165	29.6516	27.8596	28.1094	28.499	28.2959	28.3111	28.6541	28.4894	27.4905	27.8377	27.6616	27.9557	28.3001	28.13	27.3725	27.7951	27.5822	27.2902	27.6072	27.4468	0
19.113	0	0	0	0	0	0	26.5924	29.6515	27.8478	28.0829	28.4891	28.2773	28.2901	28.6263	28.476	27.4804	27.8249	27.652	27.925	28.2942	28.1185	27.3596	27.77	27.5722	27.2677	27.6039	27.4341	0
19.643	0	0	0	0	0	0	26.6012	29.639	27.848	28.0652	28.4659	28.2619	28.2848	28.6374	28.4799	27.4999	27.8237	27.6617	27.9404	28.3081	28.134	27.3614	27.7812	27.5737	27.2928	27.5919	27.4404	0

The following is the time events during the data log taken against time.

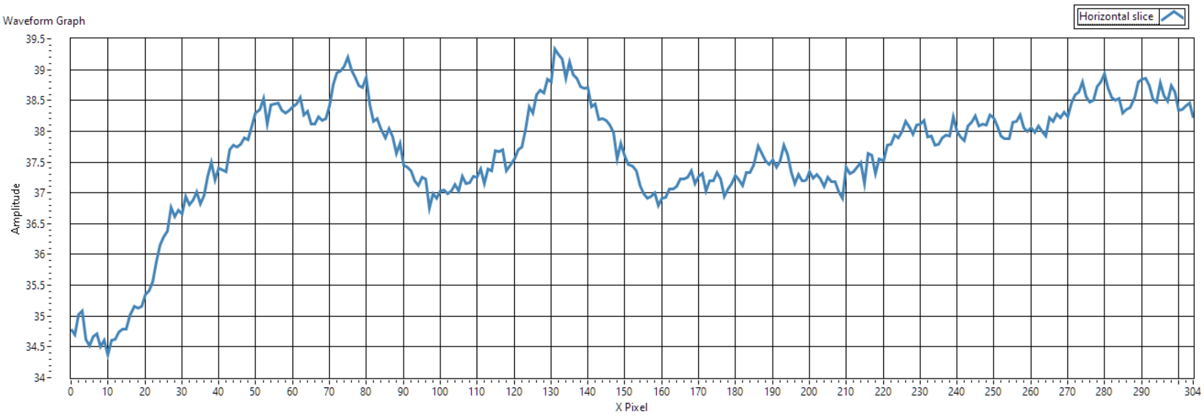
- Unit switched on to Level 1 at 60 seconds
- Switched to Level 2 at 600 seconds
- Switched to level 3 at 800 seconds
- Switched OFF at 1000 seconds





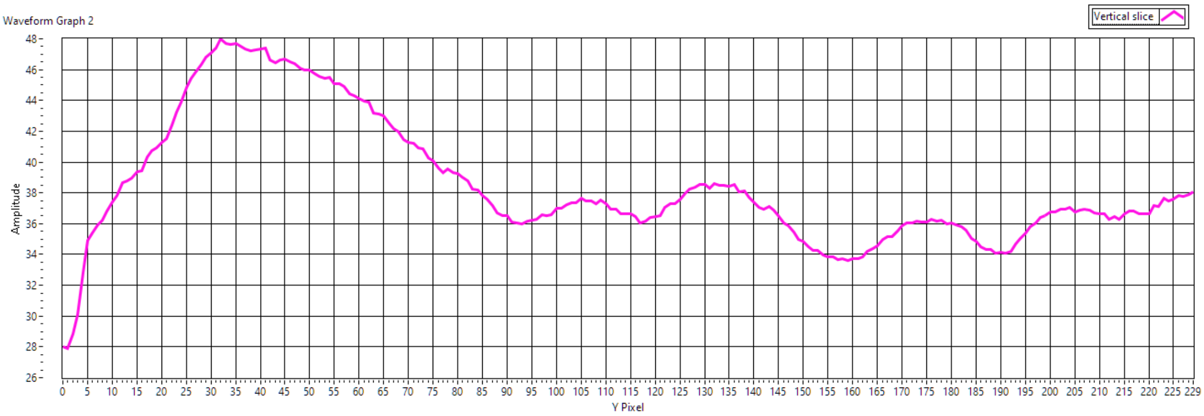
The temperature profile of the horizontal and vertical cross section along the middle of the sample area is shown below.

Horizontal temperature profile:



- Minimum temperature = 34.37 deg C
- Maximum temperature = 39.35 deg C
- Average temperature = 37.71 deg C

Vertical temperature profile:



- Minimum temperature = 27.9 deg C
- Maximum temperature = 47.99 deg C
- Average temperature = 38.48 deg C

Summary of the experimental results:

Product	Wearable heating pad
Manufacturer	Apollo, Jammu
Power Supply	AC 230V line supply
Response time	7 mins
Power consumption	32 W
Heating wire layout	Series and parallel combination
Horizontal temp. profile	• Minimum temperature = 34.37 deg C

	• Maximum temperature = 39.35 deg C • Average temperature = 37.71 deg C
Vertical temp. profile	• Minimum temperature = 27.9 deg C • Maximum temperature = 47.99 deg C • Average temperature = 38.48 deg C
Heating modes	• Low: 55 deg. C max. • Medium: 57.5 deg. C max. • High: 59 deg. C max.

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