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"THERMAL ANALYSIS AND IMPROVEMENT OF EFFICIENCY OF HEATING JACKET USING ELECTRIC HEATING PAD MATERIAL"

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ABSTRACT

The research investigates multiple aspects related to thermal comfort, including the effects of cold environments on human health, the heat transfer properties of clothing, gender differences in thermal comfort, and the development of wearable electronic products. Additionally, the study focuses on design using 3-D modeling tools and simulation software to predict the effectiveness of heated clothing, the assessment of material and clothing attributes, and the development of new production techniques for wearable electronics. Furthermore, the evaluation of electrically and chemically heated clothing is also conducted. The findings indicate that alternative heating methods demonstrate higher efficiency than electrically heated jackets currently available in the market. These alternative methods exhibit exceptional heat transfer, energy efficiency, and advanced temperature control, which have the potential to improve comfort, performance, and reduce environmental impact. The research also highlights that efficiency is influenced by atmospheric temperature, with lower temperatures resulting in higher heat loss and reduced efficiency. It is recommended to use the electrically heated jacket at specific indicator settings depending on the atmospheric temperature, ensuring thermal comfort and efficiency. Moreover, the research emphasizes the significance of energy efficiency for heated jackets that rely on portable power supplies. The jackets are designed to be easily accessible in the market and effectively generate and retain heat while minimizing energy consumption. This ensures longer-lasting warmth and reduces the need for frequent recharging or power source replacements. The jackets achieve an energy efficiency range of 33.21% to 17.45%, making them flexible for use in any season. Overall, this research provides valuable insights into thermal comfort and presents practical solutions for improving energy efficiency in heated jackets.

Key Words: *Modeling, efficiency, thermal comfort, heat transfer, temperature.*

I. INTRODUCTION

India has a highly diverse climate due to its vast geography and topography. It is divided into six major climatic subtypes, ranging from arid deserts in the west to alpine plains and glaciers in the north, and wet tropical regions with rainforests in the southwest and island territories. The country experiences different microclimates, making it one of the

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most climatically diverse countries in the world. India follows four seasons: winter, summer, monsoon season, and a post-monsoon period. After the monsoons, temperatures gradually decrease across the country. December and January are the coldest months, with the lowest temperatures in the Indian Himalayas. Dras, the coldest place in India, experiences a Mediterranean continental climate with extremely cold winters. Heating jackets are essential in various industries, and the integration of electronic heating pads offers improved thermal performance and energy efficiency compared to traditional methods like steam or electric resistance heating elements.

In this study, we aim to conduct a comprehensive thermal analysis of heating jackets utilizing electronic heating pads and explore strategies for enhancing their overall efficiency. By examining the underlying principles, design considerations, and operational characteristics of electronic heating pads, we seek to uncover opportunities for optimizing their performance in heating jacket applications.

The first phase of this research will involve a detailed examination of the existing literature on electronic heating pads and their application in heating jackets. By surveying prior studies and advancements in the field, we will establish a foundation of knowledge and identify gaps in current understanding, laying the groundwork for our own investigation.

Next, we will design and implement a series of experiments to evaluate the thermal performance of electronic heating pads within a heating jacket setup. Parameters such as temperature distribution and energy consumption will be carefully measured and analysed. Comparative studies will be conducted to assess the performance of electronic heating pads against conventional heating methods, providing valuable insights into their advantages and limitations.

Furthermore, we will explore various techniques to enhance the efficiency of electronic heating pads in heating jacket applications. This may include optimizing the pad's thermal conductivity, insulation materials, or control algorithms to ensure uniform heating and minimize energy loss. Through systematic experimentation and data analysis, we aim to identify effective strategies for improving the overall performance and energy efficiency of heating jackets incorporating electronic heating pads.

II. RESEARCH METHODOLOGY

2.1 Tools and Materials used

The two main elements of heating jacket are a blazer and 2 sets of electric heating pad (13pcs). A coat with a cotton exterior and insulated lining interior. For the heating element, used the 2.1A output interface USB powered mode, so it cannot exceed the limited power. easy to connect it with most USB devices to use, like Power-bank, Laptop, USB socket, etc. so it cannot exceed the limited power.

Besides the coat and heater, we will also need both sewing items and electrical items. Such as:

Heavy Needle, Thread, Scissors, Laboratory Thermometer, Ruler / Tape measure, Paper Pins, Coat, Heating Pad.

2.2 Jacket (Blazer)

A blazer is a type of jacket resembling a suit jacket, but cut more casually. A blazer is generally distinguished from a sport coat as a more formal garment and tailored from solid color fabrics. A coat generally is a garment for the higher body as worn by either gender for heat or fashion. Coats generally have long sleeves and square measure open down the front and shutting by means of buttons, zippers, hook-and-loop fasteners, toggles, a belt, or a mix of a number of these. alternative attainable options embrace collars, shoulder straps and hoods.

Material used: A Grey Colored, Raymond Sapphire Material is used. (Material 65% Polyester, 35% Wool).

Fig 1 Raymond sapphire coat used

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SJIF Impact Factor : 6.008

2.3 Heating Pad

Heating pads supply topical heat therapy to completely different parts of the body. Heating pads are available numerous sizes and kinds, together with electrical, infrared, chemical, and liquid or gel pads.

2.3.1 Infrared

Infrared heating pads also use electricity. However, infrared products convert electricity to infrared, that produces heat. Like electrical heating pads, infrared could use battery packs or plug into a wall outlet. These products typically have options like differing heat levels and automatic shut-off timers.

Fig.2 Infrared heating pad

2.3.2 Chemical Pads

Chemical pads trust a chemical action to form temporary heat. Some chemical heating pads heat up mechanically once someone exposes the product to air. different products could involve compressing the pad to unharness heat. These pads square measure usually accessible in packs and cling on to a person's skin or wear. Chemical heating pads square measure usually single-use, and folks can get to throw them away once they need cooled down.

Fig .3 (a) Chemical heating pad

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SJIF Impact Factor : 6.008

Fig .4(b) Chemical heating pad

2.3.3 Gels or liquid pads

Gel or liquid pads usually need heating in a microwave before they unharness heat. people will wear these pads within clothing or directly on the skin, counting on the manufacturer's directions. These products square measure usually reusable. folks can get to heat up the pads in a microwave before using them to prevent.

Fig .5 Gel heating pad.

2.3.4 Electronic

In my experiment, I used electronic heating pads integrated into jackets for heating purposes during winter. These heating pads were designed to provide warmth and comfort in cold temperatures. The heating pads were strategically placed within the jacket to distribute heat evenly. They were powered by a rechargeable battery pack, allowing for convenient and portable use. The temperature of the heating pads could be adjusted using a control mechanism. The experiment aimed to assess the effectiveness of the heating pads in keeping the participants warm during winter activities. The results showed that the electronic heating pads in the jackets provided effective and customizable heat, enhancing comfort and preventing cold-related discomfort.

Fig.6 (a) EHP (1-in-1)

Fig 6 (b) EHP (5-in-1)

ISSN : 2455-9679
SJIF Impact Factor : 6.008

The DIY electric heating pad is a simple and convenient solution for creating heated clothing. It can be easily placed in jackets, vests, and other garments for winter use. The pad is made of soft and durable material with integrated carbon fiber heating elements, ensuring a long service life. It can be stitched directly into the fabric, making it highly convenient. With fast heating and high efficiency, it is safe, non-radiative, and non-toxic. The lightweight and flexible design is water-resistant, anti-folding, and washable. It operates on USB battery power, making it compatible with various devices like power banks, laptops, and USB sockets.

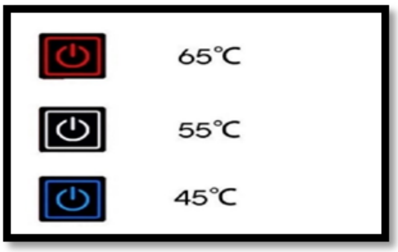

Fig .7 Electric Heating Pad Temperature settings.

2.4 Electronic Heating Pad Temperature Setting

An electric heating pad typically offers three temperature settings to provide customizable warmth and comfort. These settings allow users to adjust the level of heat according to their preference and needs. The lowest temperature setting provides a gentle and mild heat, suitable for individuals who only require a slight increase in warmth or have sensitive skin. The medium temperature setting offers a moderate level of heat, which is often the most commonly used setting for everyday comfort. It provides a balanced amount of warmth, suitable for relieving muscle aches, promoting relaxation, or soothing mild discomfort. The highest temperature setting delivers a more intense heat, ideal for individuals who need more warmth or wish to alleviate more severe pain or tension. This setting is commonly used for therapeutic purposes, such as targeting specific areas of the body that require deeper heat penetration. The availability of these three temperature settings on an electric heating pad ensures that users can find their desired level of comfort and effectively manage their personal thermal needs.

2.4.1 Red Light Indicator

High temperature setting up to 65°C, and has a red-light indicator as shown in the figure.

Fig.8 Picture of Electronic Heating Pad Temperature settings at red.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

2.4.2 White Light Indicator

High temperature setting up to 55°C, and has a White light indicator as shown in the figure.

Fig 9 Picture of Electric Heating Pad Temperature setting at white.

2.4.3 Blue Light Indicator

High temperature setting up to 5°C, and has a blue light indicator as shown in the figure.

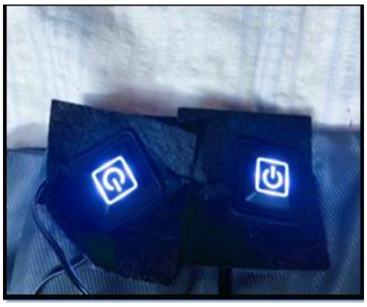

Fig 10 Picture of Electric Heating Pad Temperature setting at blue.

2.5 SPECIFICATION OF ELECTRONIC HEATING PADS USED

This study focuses on comparing two black electric heating pads: the 5-in-1 Heating Pad and the 8-in-1 Heating Pad. The heating pads are made of non-woven fabrics and carbon fiber materials, providing a combination of comfort and durability. With a maximum voltage of 5V and current of 2A, they ensure safe and efficient heating. The pads are compact, measuring 160 * 35 * 35mm (6.30 * 1.38 * 1.38in) and weighing 111g (3.91 ounces), making them portable and convenient for various applications. The packing list includes one unit each of the 5-in-1 and 8-in-1 Heating Pads, resulting in a total of 13 single units utilized in this analysis. By examining these features, this study aims to provide valuable insights into the characteristics and potential uses of these black electric heating pads.

Power (in watts) = Voltage (in volts) × Current (in amperes) eq- (4)

the voltage is given as 5 volts, and the current is 2 amperes. Therefore, the power consumption of each electric heating cloth pad would be:

ISSN : 2455-9679
SJIF Impact Factor : 6.008

Power (in watts) = 5 volts × 2 amperes = 10 watts

Since there were 13 electric heating cloth pads, the total power consumption is

Total Power Consumption (in watts) = Power (in watts) × Number of Pads eq- (5)

Total Power Consumption = 10 watts × 13 pads = 130 watts

Therefore, the total power consumption of the 13 electric heating cloth pads is **130 watts.**

2.6 Power Supply (Power Bank)

The power bank used is a high-capacity device with a capacity of 20000 mAh, designed to provide efficient energy support to a network of 13 electric heating pads and serves as a reliable and portable source of energy, equipped with multiple output ports enables simultaneous charging of all 13 heating pads ensuring that the 13 electric heating pads can function optimally in various settings. Its capacity allows for extended usage and reduces the need for frequent recharging, providing convenience and uninterrupted operation.

The power bank's capacity of 20000 mAh offers an ample power reserve, allowing the heating pads to operate for extended periods without the need for an external power source. This ensures sustained heat supply and convenience for users, whether in a clinical environment, home use, or outdoor activities.

Additionally, the power bank's compact and portable design makes it easy to carry and transport, further enhancing its usability and convenience. Its compatibility with various devices, including the 13 electric heating pads, makes it a versatile power solution.

In summary, the 20000 mAh power bank serves as an efficient and reliable energy source, powering a network of 13 electric heating pads. With its ample capacity, multiple output ports, and portable design, it enables prolonged and simultaneous operation of the heating pads, providing convenience and energy efficiency in a variety of settings.

The power rating of the power bank is

Power rating (Wh) = Capacity (mAh) × Voltage (volts) / 1000 eq- (6)

Capacity = 20,000mAh and Voltage = 5V

Power rating = 20,000mAh × 5V / 1000 = 100Wh

For determining the operating time,

Operating Time (in h) = Power rating (Wh) / Total Power Consumption (watts) eq- (7)

Operating Time = 100Wh / 130W ≈ 0.77 hours (46 min) of continuous supply

Power rating (W) = Power rating (Wh) / Operating Time

Power rating = 100 (wh) / 0.77 (h) = 129.8701 W

III. RESULT

The study focused on evaluating the performance and efficiency of a jacket equipped with 13 electronic heating pads, powered by a 20000 mAh power bank. Observations were conducted on both men and women to assess the thermal comfort provided by the jacket. Additionally, a 3-D model of the electronic heating pad was designed and analyzed using simulation software. Various calculations, including thermal efficiency and energy consumption, were performed using the provided formulas. The results revealed that the jacket with the electronic heating pads effectively provided warmth and comfort to both men and women. The 3-D model analysis indicated efficient heat distribution and

ISSN : 2455-9679
SJIF Impact Factor : 6.008

improved insulation properties. The calculated thermal efficiency and energy consumption values provided insights into the jacket's performance and energy utilization. These findings contribute to the understanding of the jacket's effectiveness and energy efficiency, providing valuable information for further optimization and design improvements.Initial Conditions and the Physical Constants.The calculations all over this work focused on the 3-D model of electric heating pad that has been designed, maximum temperature produced by the fabric and the behavior of human body's resistance. I assumed the initial conditions Then, these assigned initial conditions values are substituted in steady state thermal and transient thermal analysis using Ansys further which are solved numerically by c^{++} .

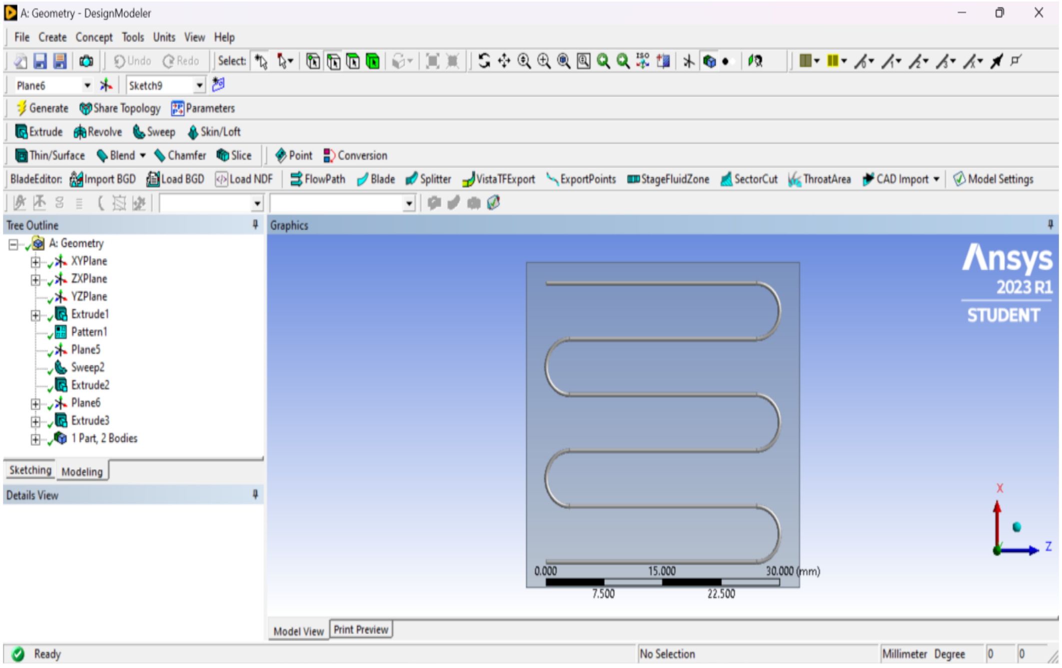

Fig.11 : 3-D model of an electric heating pad.

In Figure 9, the resulting temperature profile from both the steady state and transient state with initial temperature at 65°C, 55°C, and 45°C respectively obtained from the thermal analysis is presented. This figure showcases the variation in temperature across a specific system or material under investigation.

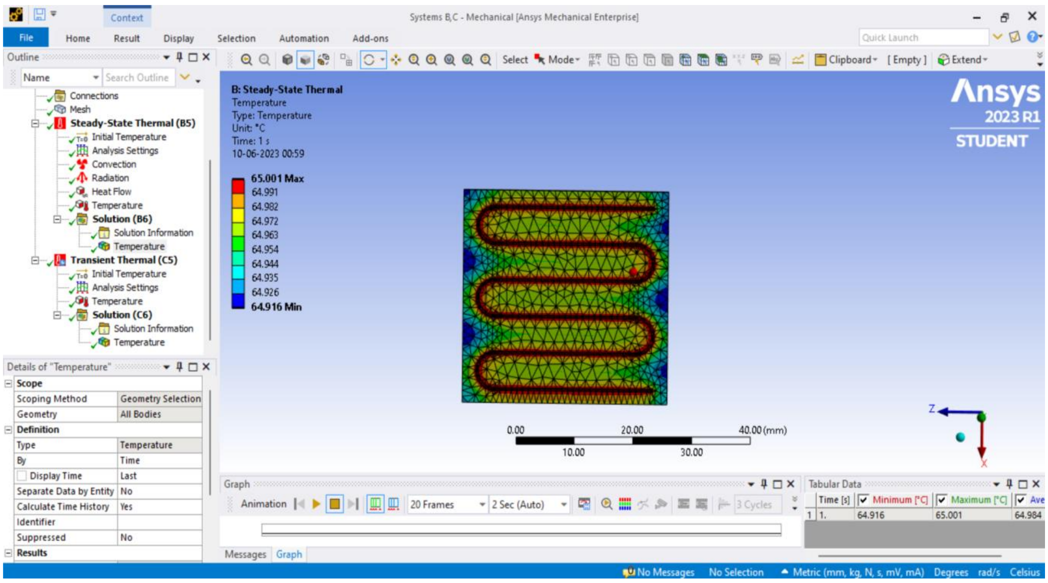

Fig 12 (a): Steady-State Thermal Temp. profile at 65°C.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

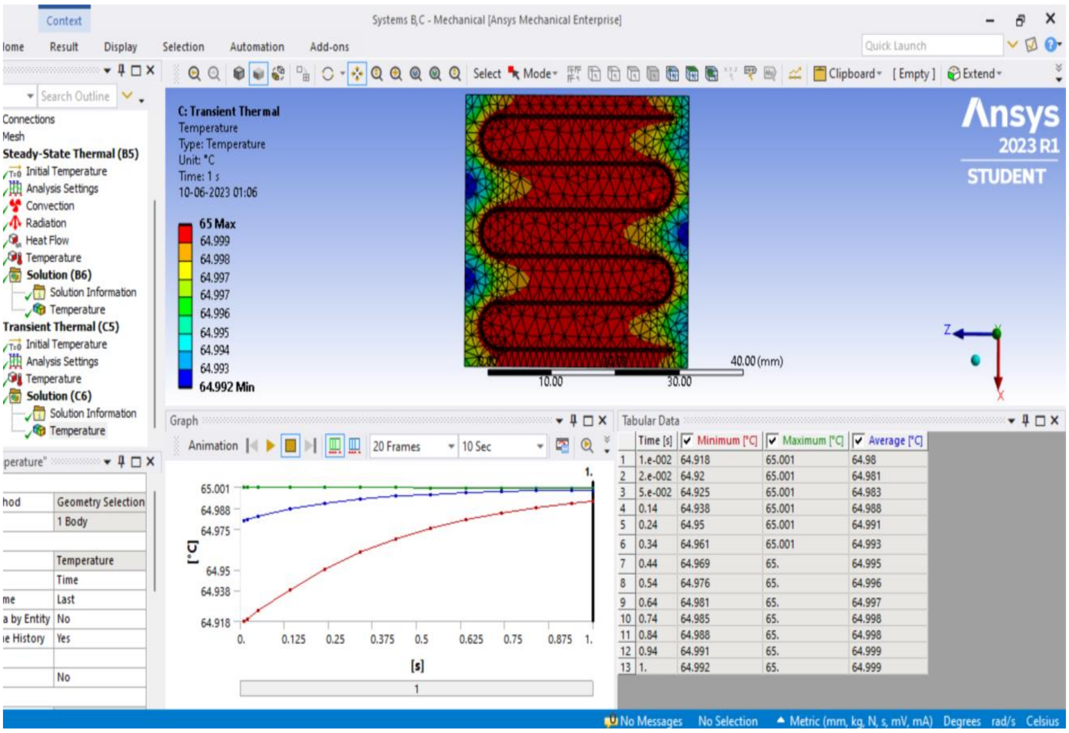

Fig12 (b): Transient Thermal Temp. profile at 65°C.

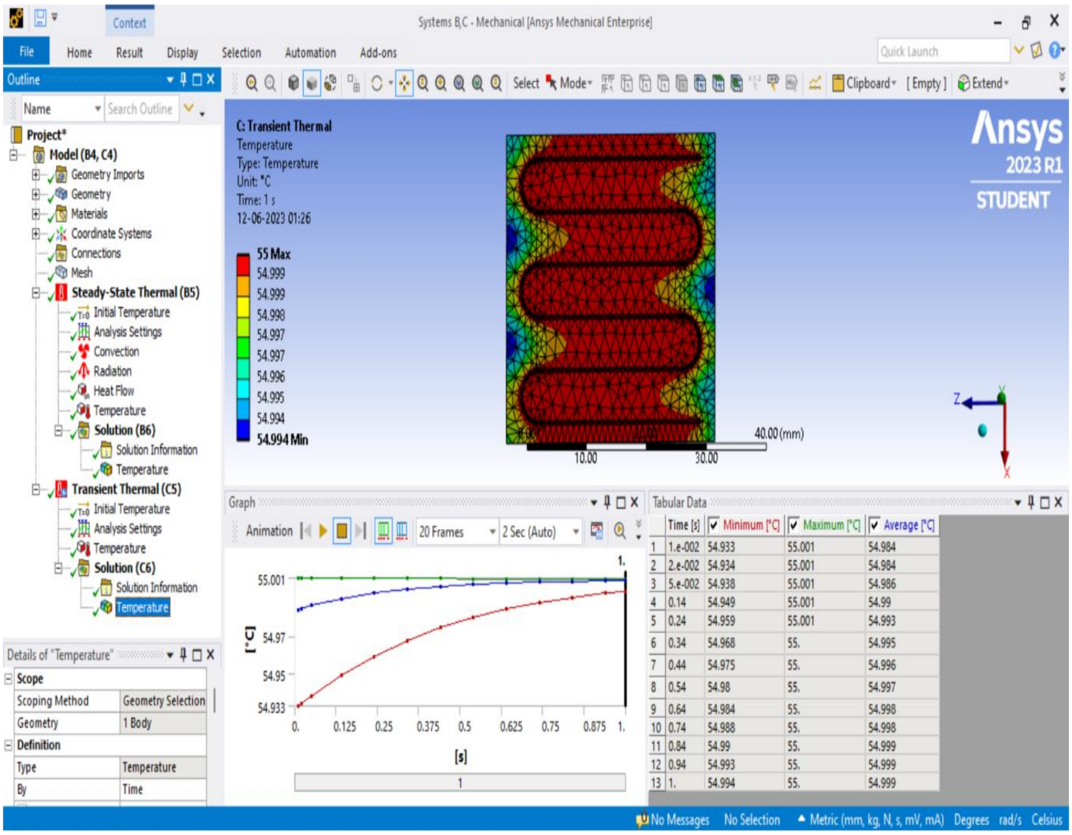

Fig13 (a): Transient Thermal Temp. profile at 55°C.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

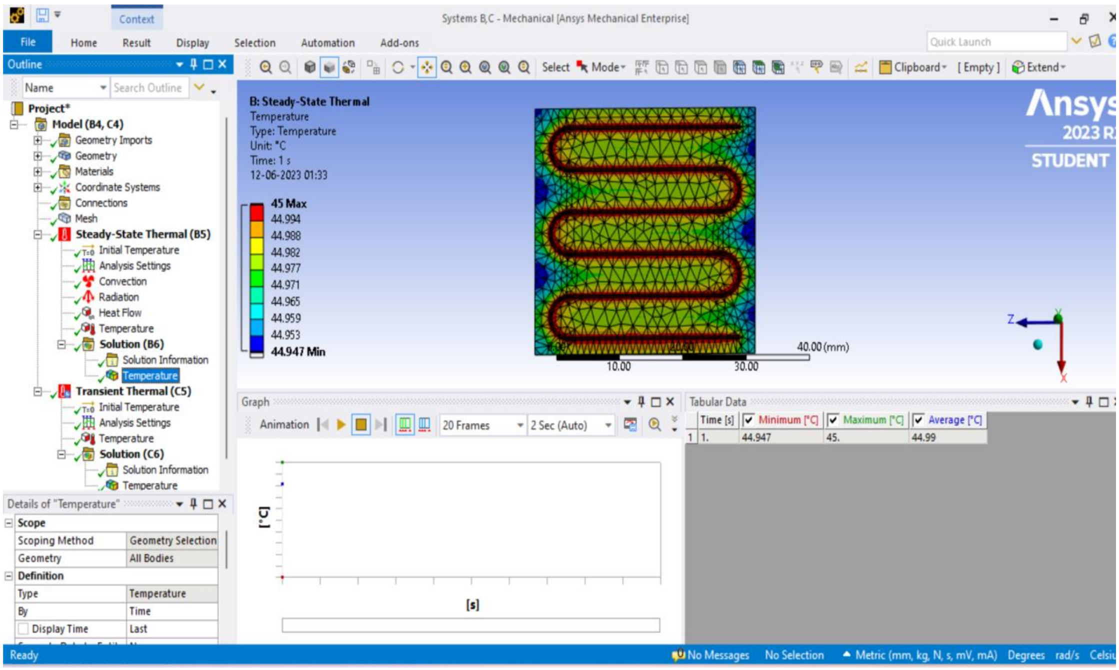

Fig 14 (a): Steady-State Thermal Temp. profile at 45°C.

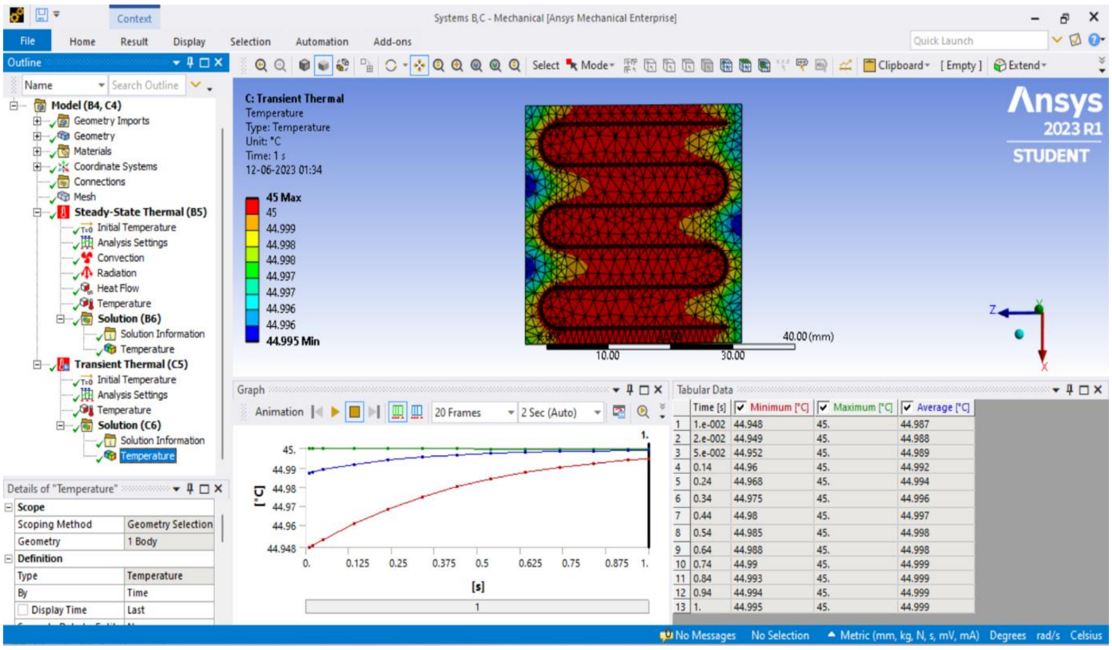

Fig.14 (b) Transient Thermal Temp. profile at 45°C.

Results of thermal analysis by measuring heat adjustment of fabrics and human body and assemblies are shown in Table by analyzing it day by day.

This is to be observed that the w (weight of jacket) is 0.38 kg and the specific heat capacity of the material (c_m) is 1.34 kJ/kg-°C.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

EFFICIENCY = (HEAT GENERATED/ ELECTRICAL ENERGY CONSUMED)*100

$\eta = (Q_g / Q_c) \times 100$

Q_g **(kJ) =** $w \times c_m \times \Delta t$

Q_c **= Power rating (W) x Time of usage (hours)**

$Q_c = 129.8701 \times 0.5$

$Q_c = 64.93506$ (kJ)

These observations have been taken on 19th December 2021 from 08:00 (IST) to 20:30 (IST) inside a room. Where atmospheric pressure is 1.023 bar, the air velocity (V_a) is 1.1m/s, I_{cl} of heating coat for men is 0.49 is from the table 2.

There were 5 number of trails for 0.5 hours each has been performed in a single day at different intervals of time from 08:00 (IST) to 20:30 (IST) inside a room.

$h_c = 12.1\ V_a^{0.5}$

$F_{cl} = 1.05 + 0.1 I_{cl}$

$\eta_R = 35.78943$

$\eta_W = 28.10458$

$\eta_B = 20.5452$

IV. CONCLUSION

This dissertation work provides a comprehensive understanding of thermal comfort and the significance of clothing in achieving and enhancing comfort in different environmental conditions. The objectives of these investigations show a wide range of aspects, including the effects of cold environments on human health, heat transfer properties of clothing, gender differences in thermal comfort, development of wearable electronic products, design using 3-D modelling tools and simulation software predicts the effectiveness of heated clothing, assessment of material and clothing attributes, development of new production techniques for wearable electronics, and evaluation of electrically and chemically heated clothing.

In conclusion, the observed estimated efficiencies of alternative heating methods surpass the electrically heated jackets in the market, showcasing exceptional heat transfer, energy efficiency, and advanced temperature control. These findings emphasize the potential for improved comfort, performance, and environmental impact reduction through alternative heating solutions. It observed that efficiency gets affected by atmospheric temperature, the lower the temperature higher the heat loss which results in low efficiency. It is suggested to use the electrically heated jacket at a red indicator setting (65°C) to attain thermal comfort where the atmospheric temperature is less than 10°C, a white indicator setting at an atmospheric temperature below 15°C and rest would be used while experiencing medium to low thermal discomfort as well as used for medical treatment also.

From the above, it can also be concluded that energy efficiency is crucial for heated jackets that require a portable power supply. It has a removable power bank, which has a limited amount of energy. Therefore, in order to keep the cold out and provide sufficient warmth, the heated jackets need to be energy efficient. It is designed to be easily accessible in the market and effectively generates and retains heat while minimizing energy consumption. By ensuring energy efficiency between 33.21% to 17.45% which makes it flexible to use in any season, the jackets can provide longer-lasting warmth and reduce the need for frequent recharging or power source replacements.

ISSN : 2455-9679
SJIF Impact Factor : 6.008

1. Weight reduction: The results can contribute to reducing the weight of jackets. By improving energy efficiency and optimizing design, researchers can identify ways to minimize the bulk and weight of heated jackets, making them more comfortable and convenient for wearers.
2. Simple working jackets with maximum runtime: The research can assist in designing jackets with a simple working mechanism that maximizes the runtime. By understanding the factors that influence energy consumption and heat retention, one can develop jackets that efficiently utilize the available power, providing longer-lasting warmth without complex or excessive components.
3. Cost-effective jackets: The findings can contribute to the development of jackets at lower prices. By optimizing energy usage and design, manufacturers can potentially reduce production costs, making heated jackets more affordable and accessible to a wider range of consumers.
4. Improved reliability: This research helps in reducing the chances of faults in heated jackets. By gaining a comprehensive understanding of thermal comfort and clothing insulation, potential design flaws or areas of improvement were identified. This can lead to the development of more reliable jackets with enhanced performance and durability, minimizing the risk of malfunctions or failures.

Overall, the research outcomes have the potential to revolutionize the design and manufacturing of heated jackets by making them lighter, simpler, cost-effective, and more reliable, thereby improving user experience and satisfaction.

V. FUTURE SCOPE

The results obtained from this research highlight the potential for future advancements in thermal management and energy optimization. By understanding the fundamental principles, leveraging advanced experimental techniques, and applying thermal analysis in practical scenarios, researchers and engineers can further enhance the performance, efficiency, and sustainability of various systems and processes. This thesis project serves as a stepping stone for future investigations and advancements in the field of thermal analysis, paving the way for innovative solutions in temperature management and energy optimization.

1. Developing more energy-efficient heated jackets: The emphasis on energy efficiency for heated jackets with portable power supplies suggests a need for further research and development in this area. Future studies could focus on designing jackets that maximize heat generation and retention while minimizing energy consumption, thereby extending the duration of warmth provided by the jackets.
2. Developing new yarn and cloth production techniques for wearable electronics, with a focus on creating semiconducting yarns and fabrics.
3. Exploring advanced heating technologies: To improve energy efficiency and overall performance, future research could investigate and develop innovative heating technologies for jackets. This may include exploring new materials, such as conductive fabrics or advanced heating elements, that enhance heat distribution and reduce energy loss.

REFERENCES

1. Hu, J., He, Y., Hao, X., Li, N., Su, Y., & Qu, H. (2022). Optimal temperature ranges considering gender differences in thermal comfort, work performance, and sick building syndrome: A winter field study in university classrooms. Energy and Buildings, 254, 111554. https://doi.org/10.1016/J.ENBUILD.2021.111554 1
2. Indraganti, M., & Humphreys, M. A. (2021). A comparative study of gender differences in thermal comfort and environmental satisfaction in air-conditioned offices in Qatar, India, and Japan. Building and Environment, 206(August), 108297. https://doi.org/10.1016/j.buildenv.2021.108297 2
3. Molliet, Débora & Mady, Carlos. (2021). Exergy analysis of the human body to assess thermal comfort conditions: Comparison of the thermal responses of males and females. Case Studies in Thermal Engineering. 25. 100972. 10.1016/j.csite.2021.100972. 3
4. Špelić, I., Rogale, D. and Bogdanić, A. (2020) The Study on Effects of Walking on the Thermal Properties of Clothing and Subjective Comfort. Autex Research Journal, Vol. 20 (Issue 3), pp. 228-243. https://doi.org/10.2478/aut-2019-0016 4

5. Lei, Z. (2019). Review of application of thermal manikin in evaluation on thermal and moisture comfort of clothing. Journal of Engineered Fibers and Fabrics, 14. https://doi.org/10.1177/1558925019841548 5
6. Jianhua, H. (2019). Assessment of Clothing Effects in Thermal Comfort Standards : A Review Assessment of Clothing Effects in Thermal Comfort Standards : A Review. January 2007. https://doi.org/10.1520/JTE100707 6
7. Wilkins, Emma L; Havenith, George. "External heating garments used post-warm-up improve upper body power and elite sprint swimming performance". Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology. 231 (2): 91–101. doi:10.1177/1754337116650322. ISSN 1754-3371,2016. 7
8. Olesen, B. W. (2015). Are Women Feeling Colder Than Men in Air-Conditioning Buildings, REHVA Journal, October, 12–13. 8
9. Song, W., Wang, F., Zhang, C., & Lai, D. (2015). On the improvement of thermal comfort of university students by using electrically and chemically heated clothing in a cold classroom environment. Building and Environment, 94, 704–713. https://doi.org/10.1016/j.buildenv.2015.10.017 9
10. Kumar L, A. (2015). Study on Different Techniques of Fabricating Conductive Fabrics for Developing Wearable Electronics Garments. Journal of Textile Science & Engineering, 05(05). https://doi.org/10.4172/2165-8064.1000212 1
11. Kamalha, E., Zeng, Y., Mwasiagi, J. I., & Kyatuheire, S. (2013). The Comfort Dimension; a Review of Perception in Clothing. Journal of Sensory Studies, 28(6), 423–444. https://doi.org/10.1111/joss.12070 11
12. Faulkner, S. H., Ferguson, R. A., Hodder, S. G., & Havenith, G. (2013). External muscle heating during warm-up does not provide added performance benefit above external heating in the recovery period alone. European Journal of Applied Physiology, 113(11), 2713–2721. https://doi.org/10.1007/s00421-013-2708-6 12
13. Faulkner, Steve H.; Ferguson, Richard A.; Gerrett, Nicola; Hupperets, Maarten; Hodder, Simon G.; Havenith, George. "Reducing Muscle Temperature Drop after Warm-up Improves Sprint Cycling Performance". Medicine & Science in Sports & Exercise. 45 (2): 359–365. doi:10.1249/mss.0b013e31826fba7f. ISSN 0195-9131. PMID 22935735, 2013. 13
14. Wang, F., Gao, C., Kuklane, K., & Holmér, I. (2010). A review of technology of personal heating garments. International Journal of Occupational Safety and Ergonomics, 16(3), 387–404. https://doi.org/10.1080/10803548.2010.11076854 14
15. Wang F, Gao C, Holmer I. Effects of air velocity and clothing combination on heating efficiency of an electrically heated vest (EHV): a pilot study. J Occup Environ Hyg. 2010;7(9):501–5 (DOI:10.1080/15459624.2010.486696).
16. Voelker, C., Hoffmann, S., Kornadt, O., Arens, E., Zhang, H., & Huizenga, C.-L. (2009). UC Berkeley Indoor Environmental Quality (IEQ) Title Heat and moisture transfer through clothing Permalink https://escholarship.org/uc/item/8qk6h840 Publication Date Heat and Moisture Transfer Through Clothing. https://escholarship.org/uc/item/8qk6h840 15
17. Dorman LE, Havenith G. The effects of protective clothing on energy consumption during different activities. Eur J Appl Physiol. 2009 Feb;105(3):463-70. doi: 10.1007/s00421-008-0924-2. Epub 2008 Nov 15. PMID: 19011890.
18. Gao C, Kuklane K, Holmer I. The heating effect of phase change material (PCM) vests on a thermal manikin in a subzero environment. In: Proceedings of the 7th International Thermal Manikin and Modelling Meeting (7I3M) 2008. September 7, 2009.
19. Mondal S. Phase change materials for smart textiles—an overview. Appl Therm Eng. 2008;28(11–12):1536–50.
20. Chambers PA. Personal cooling or warming system using loop fluid flow. U.S. Patent No. 7 373 969 B2; 2008. Retrieved September 7, 2009, from: http://www.patentstorm.us/patents/7373969/fulltext.html
21. Li J, Li L, Cao X, Liu X. A study on design of carbon fiber heating garments. Jiangsu Tex. 2007;28(9):48–51. In Chinese.
22. Karjalainen, S. (2007), Gender differences in thermal comfort and use of thermostats in everyday thermal environments. *Building and Environment*, *42* (4), 1594–1603.