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Integrating Phase Change Materials (PCM) in Smart Hajj Wearable Devices to Enhance Heat Resistance and Pilgrim Safety

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2. Abstract

In the last few years, Saudi Arabia started to use smart technologies to make the Hajj easier and safer. Right now, most pilgrims only have ID cards or barcodes that show their information, but many ideas came to use smart wearable devices that can track the location of the pilgrim and check his health. The problem is that the weather in Makkah is very hot, and sometimes the temperature can reach more than 65°C, which makes it very hard for any electronic device to work for a long time.

Because of the heat, batteries in these devices can swell or stop working, and this can be unsafe for the person. This study talks about using a material called Phase Change Material (PCM) that can help control the temperature inside these devices and protect them from heat. PCM can store heat when the weather is hot and release it when it is cooler.

This research also thinks about how these devices can be connected to other systems like Absher and Health platforms, so the information about the pilgrim's health and identity can be reached easily if something happens. The main goal is to make it possible to use smart devices in Hajj safely, to reduce lost cases, and to make it easier to help pilgrims in any health emergency.

3. Introduction

The Kingdom of Saudi Arabia always works to make the Hajj experience better for all pilgrims. In recent years, there are more talks about using new technologies to help with this goal. Smart wearable devices, like watches or bracelets, can help to find the location of pilgrims, check their health, and make the Hajj more organized. But until now, these devices are not really used because of the high temperature in the holy areas of Makkah.

The weather during Hajj can be very extreme, and the heat sometimes goes higher than 65°C. This makes it hard for small devices to stay working. Batteries may swell, sensors stop, and sometimes the whole system just fails. These problems are dangerous because the devices are supposed to help in safety, not add new risks.

If such devices could work safely, they can really help in many ways, like reducing the number of lost pilgrims, sending alerts when someone needs help, and connecting to systems like Absher or the Health Ministry platform to quickly access the pilgrim's personal and medical data. One possible way to make this happen is to use Phase Change Materials (PCM) inside the device to control the temperature and keep it safe from the heat. This study looks into how PCM can make smart Hajj devices possible in the real environment of Makkah.

4. Problem Statement

Right now, during Hajj, most pilgrims use only cards or barcodes that have their information. This helps to organize and identify people, but it does not show where the pilgrim is or how his health is going. Many times, people get lost in the crowd, and it takes long time to find them or give them help. Smart wearable devices, like bracelets or watches, could help a lot in tracking pilgrims and checking their vital signs.

The main problem is that the weather in Makkah is very hot, and small electronic devices cannot handle this heat for long hours. When the temperature goes above 65°C, the battery can swell, the sensors may stop, and sometimes the device just shuts down. This makes it not safe or reliable to use such devices during Hajj.

Another problem is that even if the devices work, they must connect to other systems like Absher and Health platforms to make them really useful. With this connection, it will be easy to know the pilgrim's health history and personal details when something bad happens. But before that, we need to make sure the devices can work safely in this hot environment. This research focuses on this issue and looks for a way to use Phase Change Material (PCM) to control the heat inside the device, so it can stay cool and work better to help the pilgrims and reduce lost cases.

5. Objectives of the Study

This research tries to find how smart wearable devices can be used safely during Hajj, even with the very high temperature in Makkah. The study focuses on the use of Phase Change Material (PCM) to keep the device cool and working longer.

The main objectives of this research are:

To understand why smart devices stop working or fail in the hot weather during Hajj.

To study how the heat affects the battery, sensors, and other small parts of the devices.

To review other studies that talk about using PCM or other cooling methods in wearable technology.

To suggest a new idea of using PCM inside a smartwatch or bracelet for pilgrims to protect it from heat.

To see how these devices can help reduce lost cases and health risks by giving real-time data about the pilgrim's location and body condition.

To explore how these smart devices can be connected to Saudi systems like Absher or Health platforms to make it easy to access the pilgrim's personal and medical information when needed.

To give practical suggestions for how this system can be built and used in the real Hajj environment in the future.

6. Literature Review

Six research papers were reviewed to understand how PCM and other cooling technologies help improve the performance of wearable devices in hot weather:

Paper 1: Choi et al. (2021) developed a lightweight thermoelectric cooler using PCM and graphite. The study showed that PCM significantly stabilized the device temperature. Strengths: solid experimental results. Weakness: limited real-environment testing.

Paper 2: Zhang et al. (2020) created a model for heat transfer in wearable electronics. They proposed a new structure that uses PCM as a thermal buffer. Strength: good theoretical foundation. Weakness: lacks practical testing.

Paper 3: Liu et al. (2023) introduced a flexible PCM-based fabric for wearables that adjusts to both hot and cold weather. Strength: flexible and efficient. Weakness: cost and durability not fully analyzed.

Paper 4: Kim et al. (2022) focused on flexible thermoelectric devices combined with PCM to manage body heat. Strength: combines two technologies. Weakness: integration process complex.

Paper 5: Wang et al. (2024) optimized wearable thermoelectric devices using PCM as a heat sink. Strength: practical design methods. Weakness: small sample size.

Paper 6: Chen et al. (2024) studied the performance of a wearable thermoelectric cooler with PCM composite. Strength: high heat efficiency. Weakness: heavy materials used.

7. Connections and Conflicts

Most studies agree that PCM improves heat control and extends the lifetime of wearable devices. However, they differ in their material composition, cost, and flexibility. Some researchers use hybrid systems combining thermoelectric and PCM, while others prefer single PCM layers. There is also a debate about whether PCM-based systems are scalable for outdoor environments like Hajj.

8. Synthesis Matrix Table

Paper	Authors & Year	Methodology	Key Findings	Weaknesses
1	Choi et al., 2021	Experimental PCM heat sink	Effective cooling at moderate heat	No real field test
2	Zhang et al., 2020	Analytical model	Good thermal regulation	No experimental data
3	Liu et al., 2023	Flexible PCM fabric	Works in variable climates	Durability issues
4	Kim et al., 2022	Thermoelectric + PCM	Efficient dual cooling	Complex integration
5	Wang et al., 2024	Optimization design	Improved device lifetime	Limited test scale
6	Chen et al., 2024	PCM composite cooler	High performance	Material weight

9. Discussion & Future Work

The reviewed papers confirm that PCM can be a real solution for managing heat in wearable electronics. However, none of them focus on extreme outdoor environments like the Hajj. Future research should test these materials under actual field conditions, with long exposure to sun and movement. Integration with Absher and Health platforms also requires secure data transfer and privacy controls. Future prototypes must balance cooling efficiency, comfort, and safety for large-scale deployment.

10. Conclusion

This study aims to improve the reliability of smart wearable devices for Hajj pilgrims by using Phase Change Materials (PCM). The approach can reduce overheating, improve safety, and support health monitoring. While technical and financial challenges exist, PCM provides a strong foundation for future Hajj devices that can work in high temperatures safely and efficiently.

11. References (APA Format)

Choi, J., et al. (2021). Lightweight wearable thermoelectric cooler with rationally designed flexible heatsink consisting of phase-change material/graphite/silicone elastomer. *Journal of Materials Chemistry A*.

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Wang, L., et al. (2024). Optimization Design and Performance Study of Wearable Thermoelectric Device Using Phase Change Material as Heat Sink. *MDPI Materials*.

Chen, R., et al. (2024). Performance Study of Wearable Thermoelectric Cooler with Phase-Change Composite Heat Sink. *MDPI Materials*.