Fashion and function: challenges faced by textiles incorporated with phase change materials

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Published in:
[Host publication title missing]

2014

FASHION AND FUNCTION: CHALLENGES FACED BY TEXTILES INCORPORATED WITH PHASE CHANGE MATERIALS

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Abstract

Designers focus on fashion and appearance, whereas safety and protection engineers and physiologists emphasize functions in terms of developing functional and protective clothing. Phase change materials (PCMs) have been used in textiles and clothing to achieve cooling or warming function. The objective of this paper was to compare effectiveness of PCM cooling or warming determined by critical factors. Cooling or warming effectiveness and duration were directly dependent on physical activity level (body heat production), PCM mass and temperature gradient between the skin temperature and PCM phase change temperature. Given these factors, textiles and clothing incorporated with PCMs may be lightweight, well-designed, smart and fashionable, but are insufficiently functional when the amount of the PCM and latent heat are small relative to the body heat production and duration of activities. It is therefore challenging by incorporating PCMs into textiles and clothing to achieve desirable light weight, fashion, thermal comfort and effective alleviation of body heat strain unless the critical factors are taken into account.

Keywords: *fashion and function, design challenge, smart textiles, phase change material, thermal comfort and physiology*

1 Introduction

Phase change materials (PCMs) are responsive to temperature change by absorbing or releasing heat, and thus have potential of self-regulating human skin temperature and thermal sensation. They are therefore regarded as a type of smart and functional material. Depending on how the PCMs are used and incorporated into textiles and clothing, the thermal regulation capacity may be limited for a very short period of time from thermal physiology and thermal comfort point of view [1-5]. Considering the human-clothing-environment system as a whole, there are a number of factors that may affect the PCM cooling/warming effects.

The objective of this paper was to compare effectiveness of PCM cooling or warming function determined by the quantity of the PCM, the intensity of physical activity, and the temperature gradient between the skin temperature and PCM phase change temperature.

2 Body heat production and effectiveness of PCM cooling or warming

Human body heat production increases with physical activities and metabolic rate. The average metabolic rate during resting is 115 W, low activity 180 W, moderate activity 295 W, high activity 415 W and very high

activity 520 W [6]. Therefore, the dissipation of heat from the body to environments should increase to maintain body heat balance and thermal comfort. Accordingly, the cooling power of textiles or clothing incorporated with PCM should increase. If the quantity of the PCM is small, the duration of cooling or warming function will be limited (Figure 1). Assuming that the weight of clothing is 800g, PCM incorporated in clothing is 20 wt%, the latent heat of the PCM is 200 J/g, the PCM does not absorb or release heat from or to environment, the duration of the cooling or warming effect can only last for about 15.5, 9.9, 6.0, 4.3 and 3.4 min at the above mentioned five physical activity levels respectively if the PCM absorbs 30% of the body heat production [5]. If the PCM is to absorb 100% of the body heat production, the duration of the cooling effectiveness becomes even shorter. Thus, the function is substantially restricted. If the PCM mass is increased to 1 kg, the functioning duration will extend about six times (Figure 1). Admittedly, the increase of PCM mass and bulk will compromise the fashion. However, a good balance between fashion and function can be challenging [7].

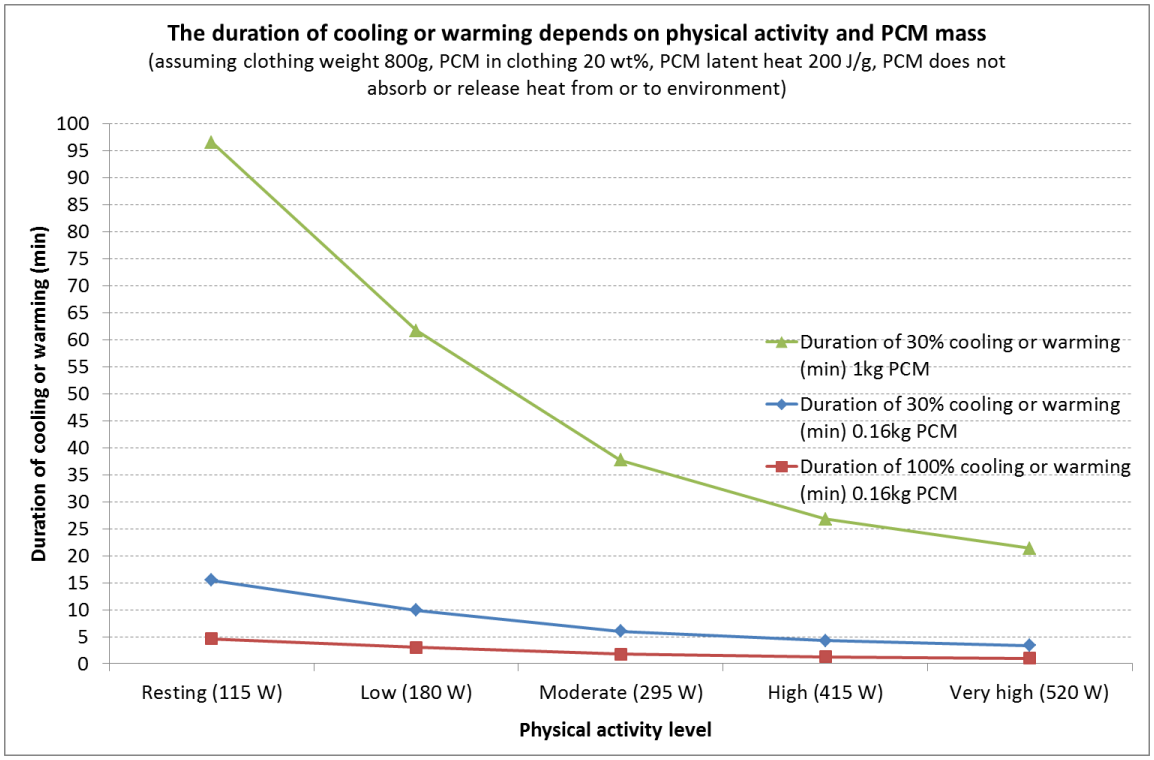

Figure 1. The duration of cooling or warming depends on physical activity and PCM mass.

3 Temperature gradient between the skin temperature and the phase change temperature

In addition to the PCM mass, latent heat and physical activity level, the temperature gradient between the skin temperature and the PCM melting/solidifying temperature plays an important role in determining the cooling rate. The relationship between the PCM cooling rate and the temperature gradient was investigated and demonstrated that the cooling rate increased exponentially with the temperature gradient (Figure 2) [3]. The required temperature gradient (RTG) is suggested being equal or greater than 6 °C in order to achieve tangible cooling effect in hot environments. This could be another challenge to obtain both cooling and warming effects during temperature transient conditions, in which a 12 °C or greater

temperature span is desirable, i.e. 6 °C above and 6 °C below the phase change temperature. Take an example of a PCM melting/solidifying temperature 28 °C, the skin temperature should be at 34 °C or above in order to reach a reasonable cooling rate, which is not difficult when the PCM is worn close the skin. However, in most circumstances, it is not possible to use the same clothing incorporated with PCM during temperature transition and falling to 22 °C, at which it is already too cold for the body.

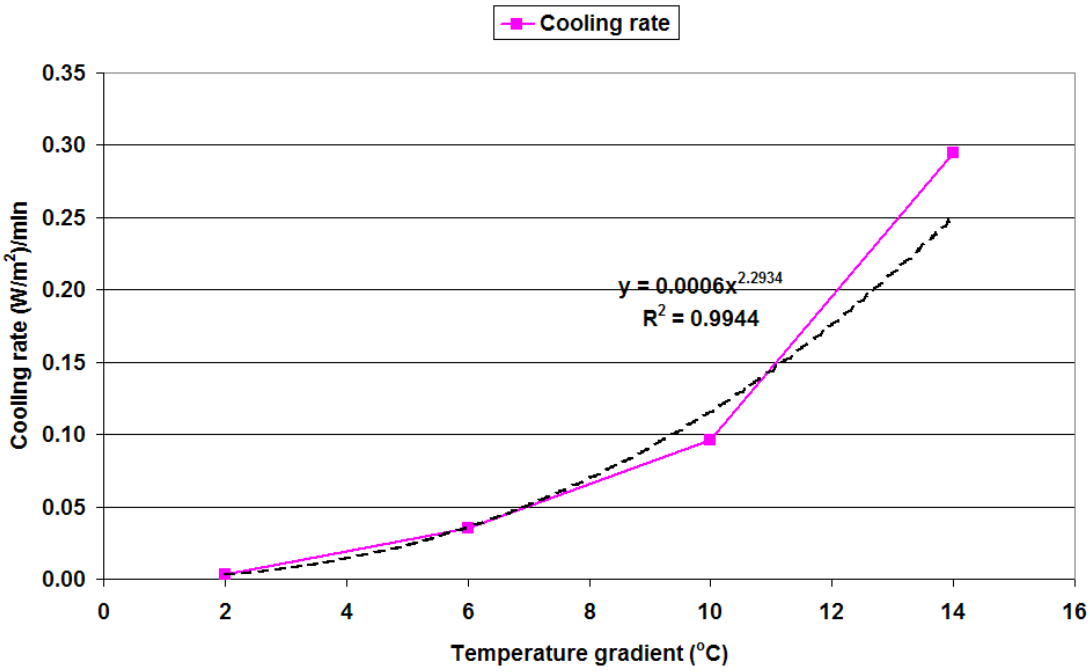

Figure 2. Absolute cooling rate $Y = |a|$, where "a" is the cooling rate (slope in the regression $Y=aX+b$), increases exponentially with temperature gradient [3].

4 Conclusions

From the perspective of the human physiology-clothing-environment system and thermal physiology, it is challenging for textile and clothing designers to achieve effective cooling or warming function and reasonable duration using textiles incorporated with phase change materials. The body heat production at different physical activity levels, PCM mass and melting/solidifying temperature and temperature gradient are among the critical factors that must be taken into account. Fashion and function should be well balanced so that textiles and clothing incorporated with PCMs not only look cool, but also bring about effective cooling function.

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