# Thermal Comfort Effect of Natural Radiation: Color Factor in Industrial Safety Helmets, Human Health

## *Doğal Radyasyonun Termal Konfora Etkisi: Endüstriyel Baretlerde Renk Faktörü, İnsan Sağlığı*

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## Abstract

This article presents the effects of helmet colors from protective clothing on the thermal protection factor under natural radiation. Thermal exposure distributions were measured using a thermal camera to determine the sun protection effectiveness of helmets under various exposure conditions. Increasing the thermal comfort of the hard hat, which is a work safety protective clothing, has become one of the biggest areas of interest of hard hat designers. Helmets protect human health by providing simple and useful protection against natural radiation rays. To identify the effect of the colors of the helmets, temperature distributions were detected using a thermal camera. White color is important for human health as it has the greatest effect on the thermal protection factor of helmets, which are protective clothing. In this study, recommendations for the engineering of hard hats, which are protective clothing with adequate thermal protection, are presented. Experimental results of white, blue and yellow colored helmets have been determined.

***Keywords:*** Human health, natural radiation, protective clothing, thermal comfort.

## Öz

Bu makale, koruyucu giysilerdeki kask renklerinin doğal radyasyon altında termal koruma faktörü üzerindeki etkilerini sunmaktadır. Haskların çeşitli maruz kalma koşulları altında güneşten korunma etkinliğini belirlemek için termal maruz kalma dağılımları bir termal kamera kullanılarak ölçülmüştür. İş güvenliği koruyucu giysisi olan baretin termal konforunun arttırılması, baret tasarımcılarının en büyük ilgi alanlarından biri haline gelmiştir. Kasklar doğal radyasyon ışınlarına karşı basit ve kullanışlı koruma sağlayarak insan sağlığını korur. Haskların renklerinin etkisini belirlemek için termal kamera kullanılarak sıcaklık dağılımları tespit edildi. Beyaz renk, koruyucu giysi olan haskların termal koruma faktörü üzerinde en büyük etkiye sahip olduğundan insan sağlığı açısından önemlidir. Bu çalışmada yeterli termal korumaya sahip koruyucu giysi olan baretlerin mühendisliğine yönelik öneriler sunulmaktadır. Beyaz, mavi ve sarı renkli haskların deneysel sonuçları tespit edilmiştir.

***Anahtar Kelimeler:*** İnsan sağlığı, doğal radyasyon, koruyucu giysi, termal konfor.

## 1. Introduction

Depending on the conditions of the age, the increasing expectation of employees to 'feel good as well as feel safe' has led to the progress of studies on personal protective equipment designs to ensure comfort in recent years towards smart applications that function passively or actively depending on the material properties. Comfort is a complex concept that includes many parameters related to the body-safety-environment system, and changes in any of the factors may cause discomfort (Kaplan & Memiş, 2023). Thermal comfort, one of the most effective components of comfort, occurs based on the thermal balance between the body and the environment, varies depending on the ambient temperature as well as relative humidity and air speed, and can be achieved to a certain extent by a perfectly functioning thermoregulation mechanism ( Yelkovan et al., 2023). In general, we can talk about a neutral feeling, that is, thermal comfort, when the heat energy produced in the body is equal to the heat energy removed (Aydın, & Günaydın, 2012). One of the basic conditions for a person to continue his life in a healthy way is to keep his body temperature at a normal temperature. Thermal comfort refers to the fact that the majority of employees in the working environment are at a certain level of comfort while continuing their physical and mental activities in terms of climatic conditions such as temperature, humidity and air flow speed (Günaydin et al., 2019). If thermal comfort conditions are insufficient in the working environment, distress is felt and human health deteriorates, resulting in a decrease in human working capacity and work efficiency. Especially in the summer months, work done outdoors such as construction, agriculture, and machine assembly, which often need to be completed in a limited time, causes deterioration in human health. Under the influence of high temperature, the heartbeat accelerates to keep the body's internal temperature low. Capillaries in the skin carry more blood, so both the cooling rate and body temperature gradually increase. The basic condition for the good functioning of the body, human health and life is provided by keeping the body temperature at normal levels (Kaplan & Memiş, 2023).

In business lines where the work area is narrow or where many activities are carried out at the same time and in the same place, such as the construction, mining, metal and forestry sectors, the risks of employees encountering head injuries are high. For this reason, head protective equipment must be used to prevent or minimize the effects of head injuries that may occur as a result of a possible work accident. Head injuries pose a serious risk to working life. It is necessary to select protectors that meet the requirements of the relevant standards and are suitable for the characteristics of the work performed, the working environment and the legislation (Günaydın et al., 2019). In addition to the mandatory features, these additional features should also be sought when choosing a helmet. Considering the need for protection and working conditions in the work performed, additional features such as use at low temperatures, electrical insulation, resistance to hot metal splashes should be sought in the helmet when necessary, and it should be ensured that there are markings on the helmet indicating that these optional tests have been carried out. Having ventilation holes on the helmet can increase comfort for some applications ( Shuaeib et al., 2002). However, it should not be used in places and applications where ventilation should not be open (Reischl, 1986).

Thermal discomfort is one of the biggest complaints of helmet users (Egglestone & Robinson, 1999; Meinander, 1992). Many workers are not willing to wear helmets at work because they are not comfortable (Abeysekera & Shahnavaz, 1988). Wearing a helmet reduces the air flow over the head, which can affect the temperature, which can lead to increased heat-related stress (Gilchrist & Mills, 1994; Kostopoulos et al., 2002). Helmet thermal properties are important factors, especially in hot climates, so helmet comfort and physiological safety aspects of helmets have become a field (Liu & Holmér, 1995; Masso-Moreu & Mills, 2003). The value in dry heat transfer (conduction, convection and radiation in helmets) properties in helmets has been examined.

They were interested in the characteristics of occupational safety helmets and measured the heat flux required to protect (Abeysekera & Shahnavaz, 1990; Abeysekera et al., 1991). Hsu et al. used the average temperature under the helmet, the rate of dissipation by convection, and the temperature under the helmet shell to describe the thermal properties of the helmet. Hsu et al. attempted to evaluate the physiological and psychological responses of workers in a high temperature environment (Hsu et al.,2000). Coleman et al., Roszkowski, et al. Thermal discomforts associated with helmet use are addressed. Heat transfer properties of Reischl helmets were investigated (Coleman & Mortagy, 1973; Roszkowski, 1980). Breckemidge et al., Mecheels et al., with heat loss due to sweating in hot environments, thermal balance becomes increasingly dependent on evaporation (Breckenridge, 1977; Mecheels & Umbach 1976).

In this study, the thermal values of yellow, blue and white helmets with the same structure were compared. The best explanation of the relationship between colors has been proposed in the selection of paints by developing helmets for Ultra Violet transmission and thermal protection.

## 2. Materials and Methods

Existing methods are divided into two: indirect and direct. In indirect methods, physical parameters such as Infrared Radyasyon (IR) reflectivity, permeability and emissivity, resistance and radiant power of the treated helmet are measured, while in direct methods, skin surface and microclimate temperatures are measured (Kodaloğlu & Kodaloğlu 2024). In these devices, parameters such as reflectance and emissivity are measured (Halimi et al., 2009). Since the developed measurement methods measure only one of many parameters related to heat transfer, the results do not reflect real life in some cases: for example, the low IR transmittance of the helmet does not mean that it has high reflectivity (Dimitrovski et al., 2010). The helmet may also cause an extra temperature increase by transmitting heat to the body due to high IR absorption and emissivity (IR emissivity equals absorption) . Figure 1 shows the helmet colors used in the study.

**Figure 1.** Helmet colors used in the study

It is assumed that the sun's rays penetrating the surface of the helmet shell are equal. In order to assist helmet makers with optimum thermal comfort, measurements were made based on helmet colors. The method of modeling thermal comfort presented in this article clearly reveals the dependence between the parameters characterizing helmet color. Figure 2 shows the measurement made with a thermal camera.

**Figure 2.** Measurement made with thermal camera

For yellow, blue and white helmets, the helmets were exposed to sunlight between 12:00 and 13:00 on November 7, 2023, and how the outer shell and inner shell temperatures of the helmets changed according to their colors was determined with the FLIR E40 thermal camera. Table 1 FLIR thermal camera features are given.

**Table 1.** FLIR thermal camera features

| | |
|---|---|
| Thermal Resolution | 120x90 |
| Thermal Sensitivity | <0.10°C |
| Spatial Resolution | 6.3mrad |
| Heat | –20°C to 250°C |

## 3. Results and Discussion

Preserving to consider all types of paints, therefore we studied the colors yellow, blue, white selected for our research. Therefore, although the thermal change is affected by the chemical structure of the dye molecules, the hue is determined by the color parameters that characterize the helmet color in the visible spectrum range.

### 3.1. Thermal Camera Measurement Applied to White Colored Helmet

The white helmet was exposed to sunlight between 12:00 and 13:00 on November 7, 2023, and the outer shell and inner shell temperatures of the helmet were determined with the FLIR E40 thermal camera.

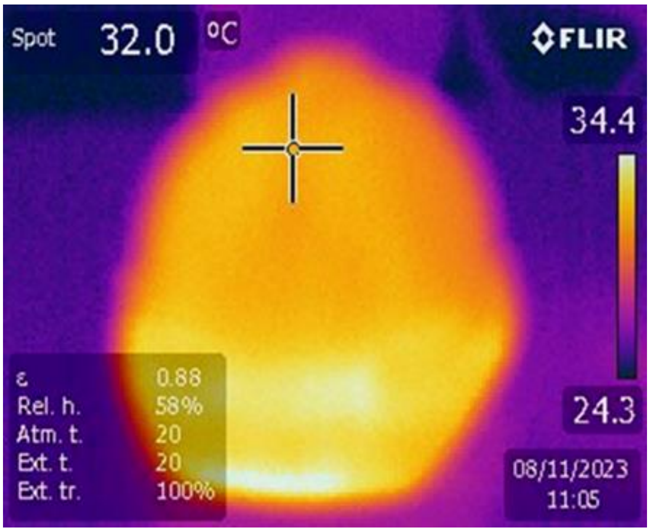


**Figure 3.** White helmet outer shell temperature measurement

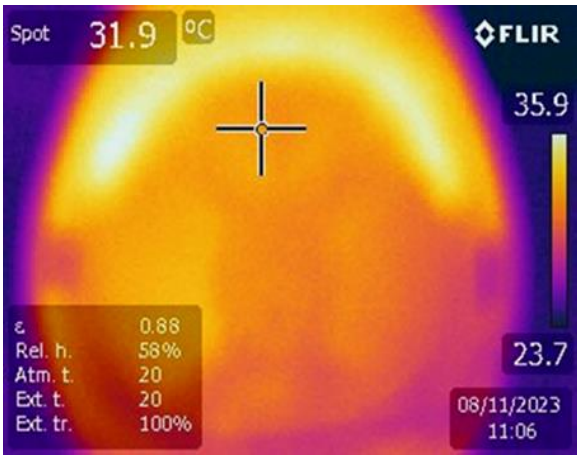


**Figure 4.** White helmet inner shell temperature measurement

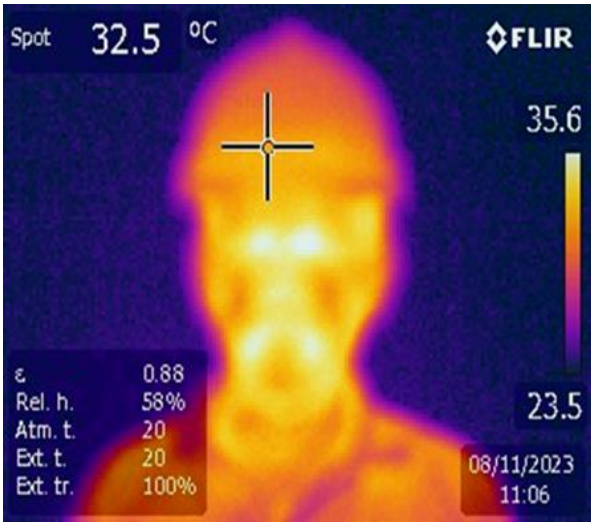


**Figure 5.** White helmet front shell temperature measurement

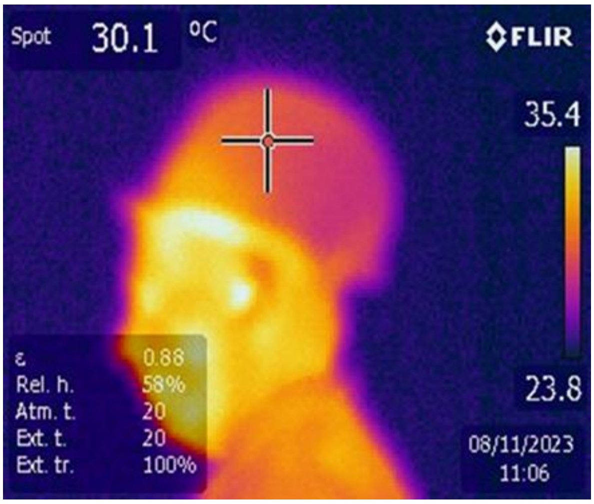


**Figure 6.** White helmet side shell temperature measurement

Measurement values for the white helmet are given in the graphs numbered Figure 3-4-5-6. White helmets provide very good protection against rays and reduce heat. Outer shell temperature: 32 ° C, inner shell temperature: 31.9 ° C, 31.9 ° C from the front on the worker, and 30.1 ° C from the side on the worker. These levels are important to consider for thermal comfort. By applying thermal insulation to the inner surface of the muscle, heat transfer between the hot environment and the worker is reduced. In this way, heat balance in the environment can be achieved. Figure 7 shows the helmet shell temperature change graph depending on time and humidity.

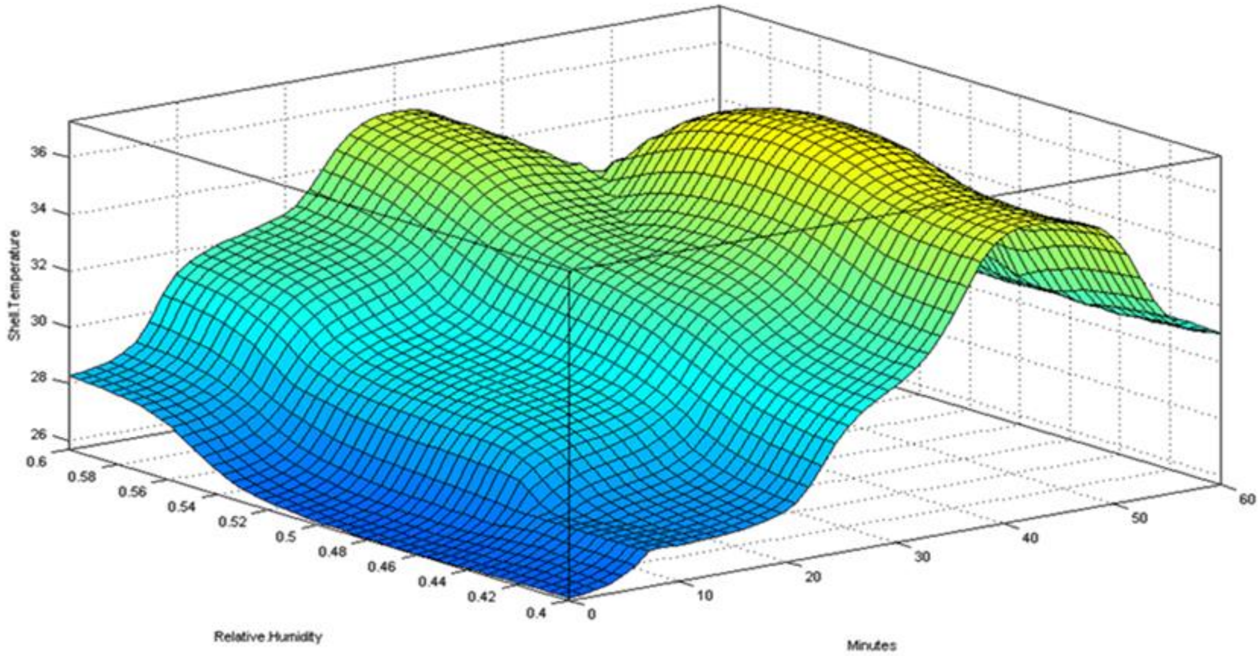


**Figure 7.** Helmet shell temperature change graph depending on Time (min) and humidity

When the connection graph between outer shell temperature, relative humidity and time is examined, it is seen that the relative humidity increases with time and the shell temperature value reaches 35.60 C. Figure 8 shows the helmet shell temperature change over time.

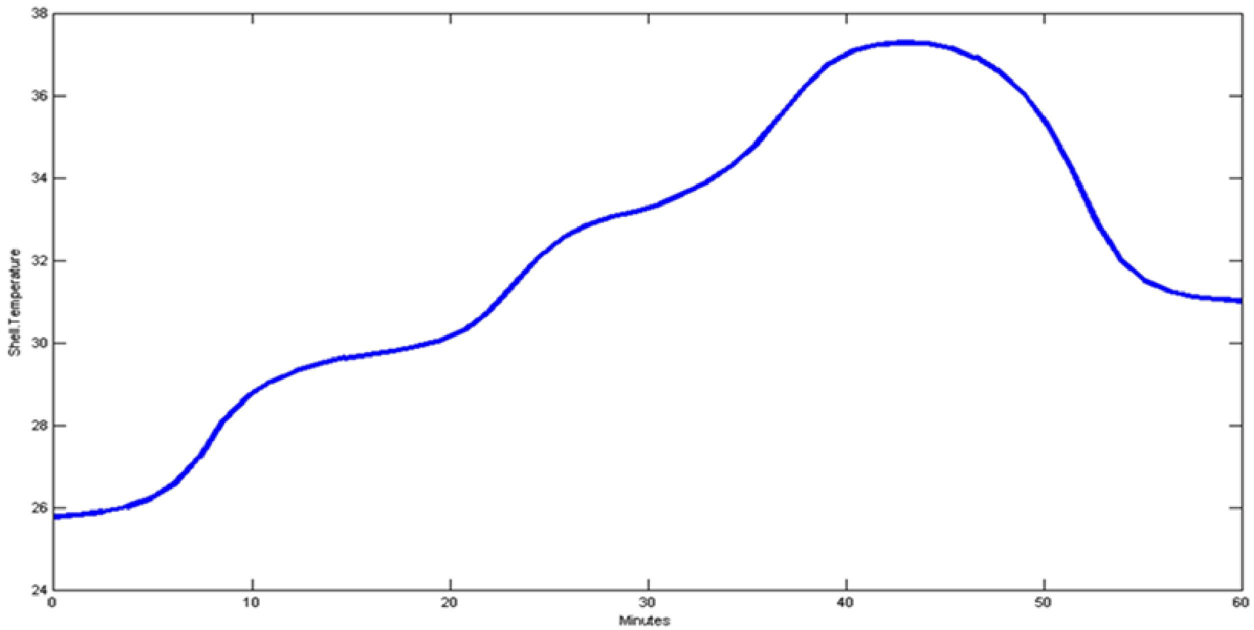


**Figure 8.** Helmet shell temperature change with time (min)

It is seen that the temperature rises to 20-300 C in 10-20 minutes, reaches 28-330 C in 20-30 minutes, reaches 33-350 C in 30-40 minutes, and decreases from the maximum level of 37.80 C in 40-50 minutes. These measured values show that the increase that occurs at certain time intervals begins to decrease after a while.

### 3.2. Thermal camera measurement applied to yellow helmet

The yellow helmet was exposed to sunlight between 12:00 and 13:00 on November 7, 2023, and the outer shell and inner shell temperatures of the helmet were determined with the FLIR E40 thermal camera.

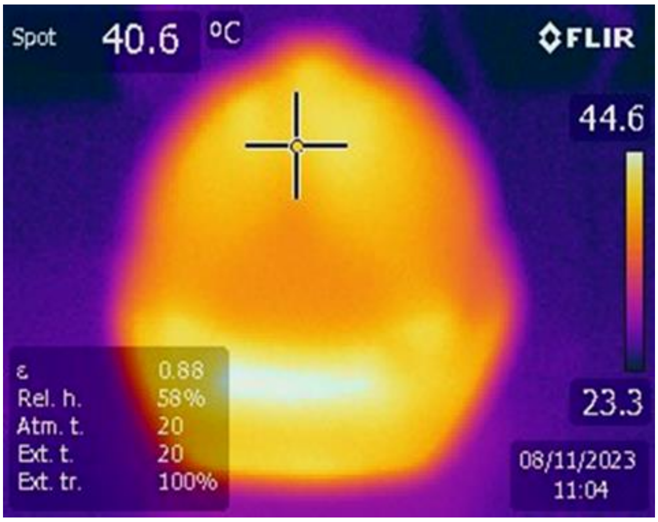


**Figure 9.** Yellow helmet outer shell temperature measurement

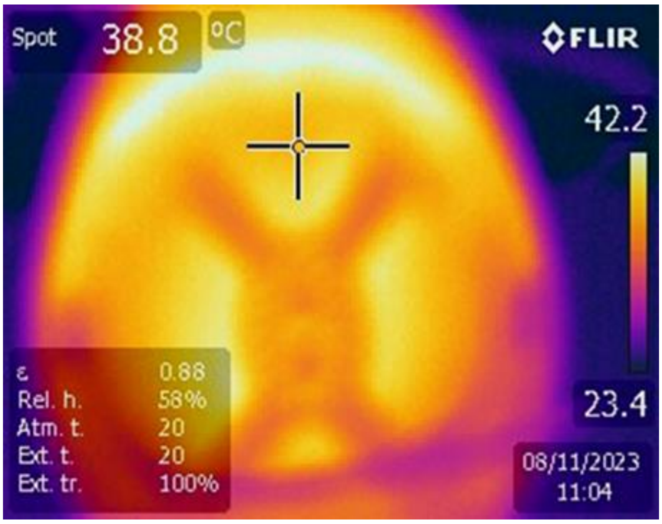


**Figure 10.** Yellow helmet inner shell temperature measurement

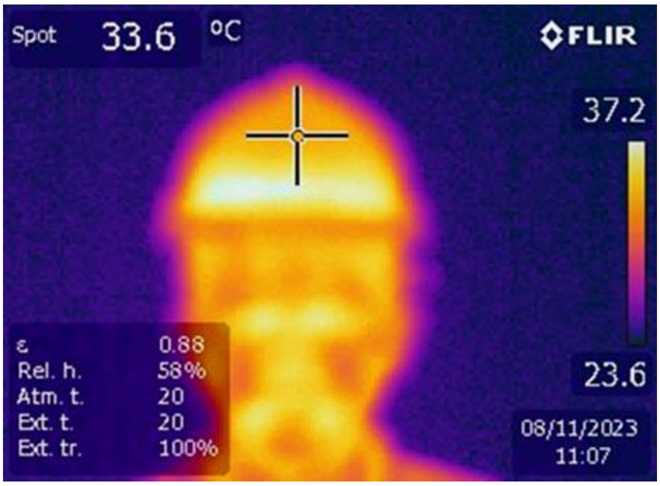


**Figure 11.** Yellow helmet front shell temperature measurement

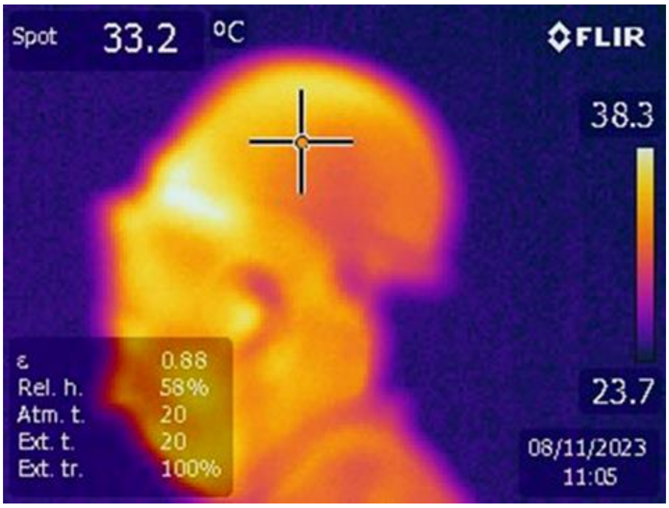


**Figure 12.** Yellow helmet side shell temperature measurement

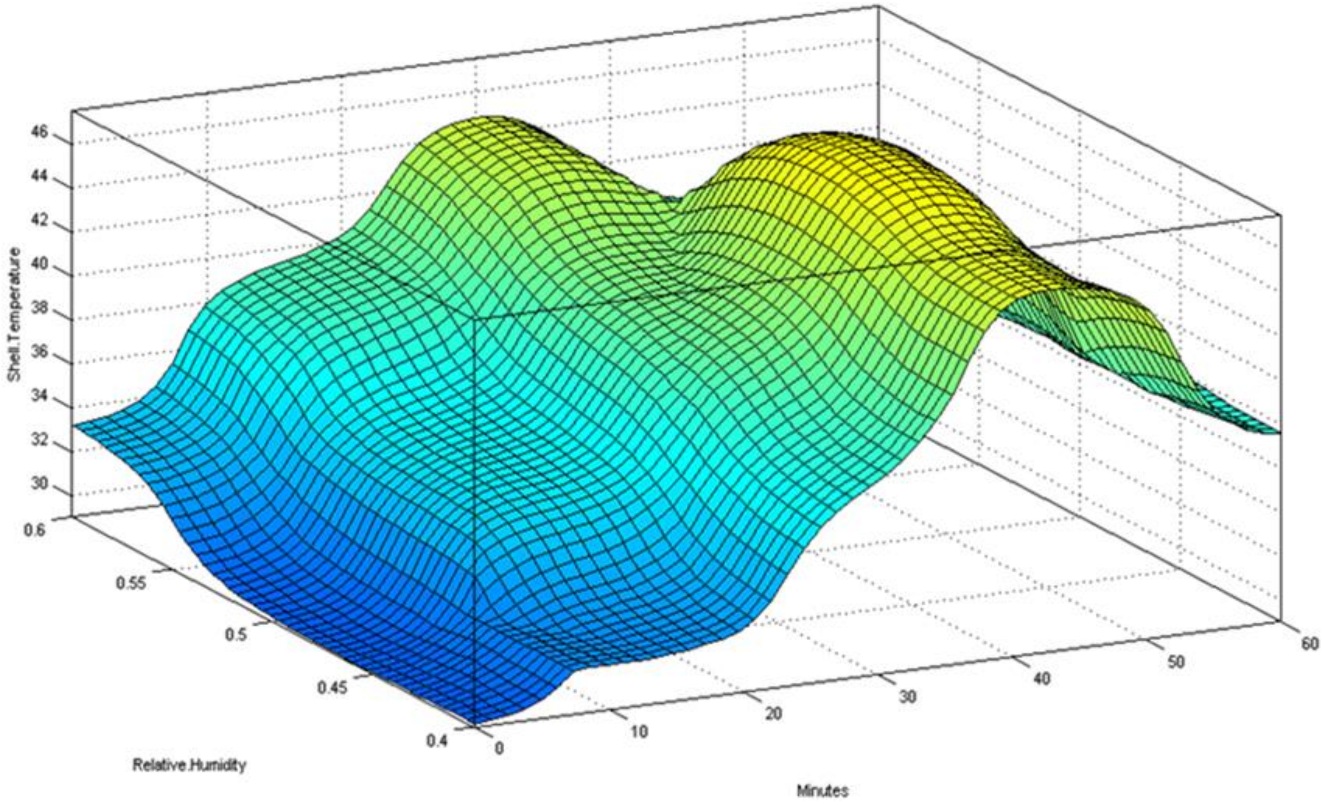


**Figure 13.** Helmet shell temperature change graph depending on time and humidity

When the connection graph between outer shell temperature, relative humidity and time is examined, it is seen that the relative humidity increases with time and the shell temperature value reaches 46.6 ° C. Figure 14 shows the helmet shell temperature change over time.

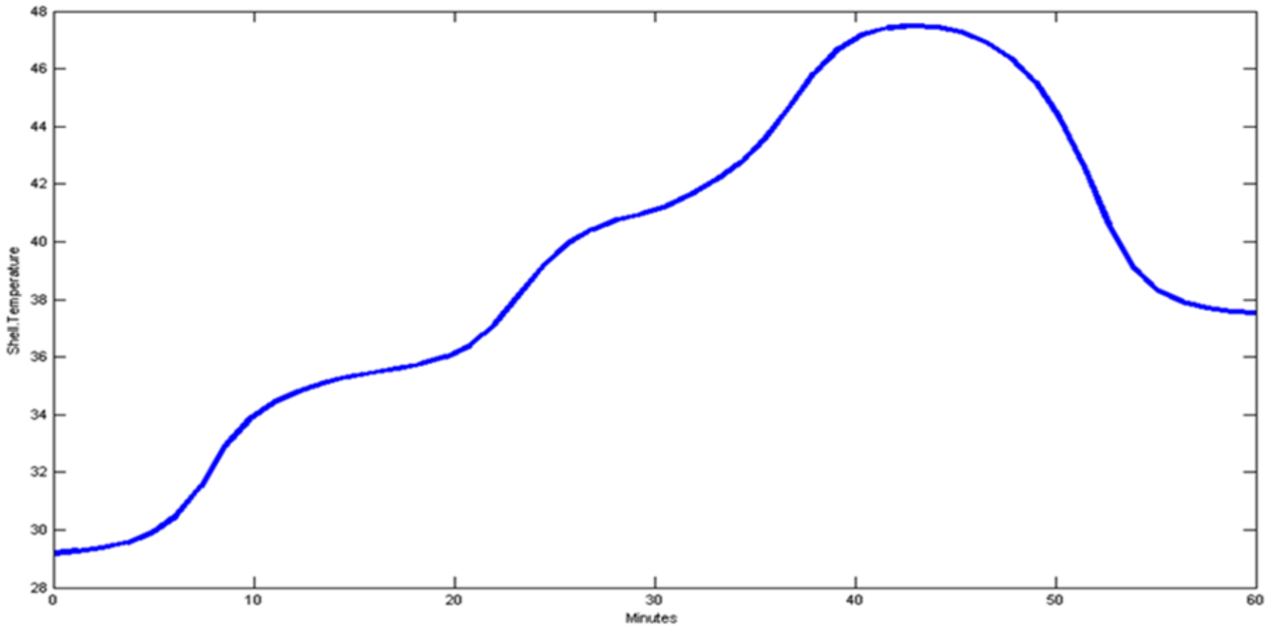


**Figure 14.** Helmet shell temperature change with time

It is seen that the temperature rises to 32-360 C in 10-20 minutes, reaches 36-430C in 20-30 minutes, rises to 43-450 C in 30-40 minutes, and decreases from the maximum level of 47.9 0 C in 40-50 minutes. These measured values show that the increase that occurs at certain time intervals begins to decrease after a while.

### 3.3. Thermal camera measurement applied to blue colored helmet

The blue helmet was exposed to sunlight between 12:00 and 13:00 on November 7, 2023, and the outer shell and inner shell temperatures of the helmet were determined with the FLIR E40 thermal camera.

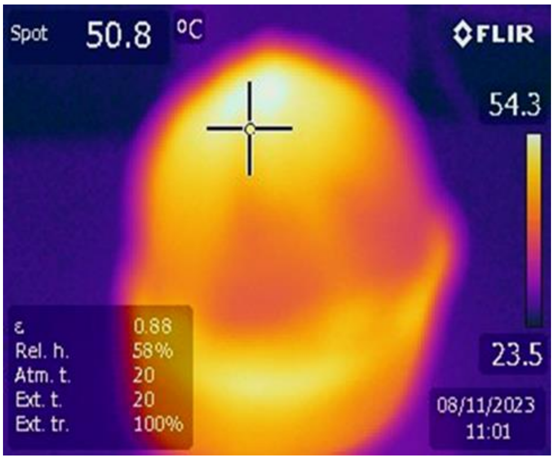


**Figure 15**. Blue helmet outer shell temperature measurement

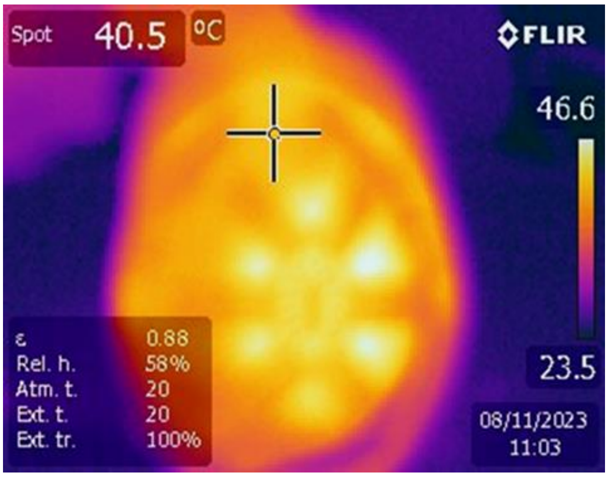


**Figure 16.** Blue helmet inner shell temperature measurement

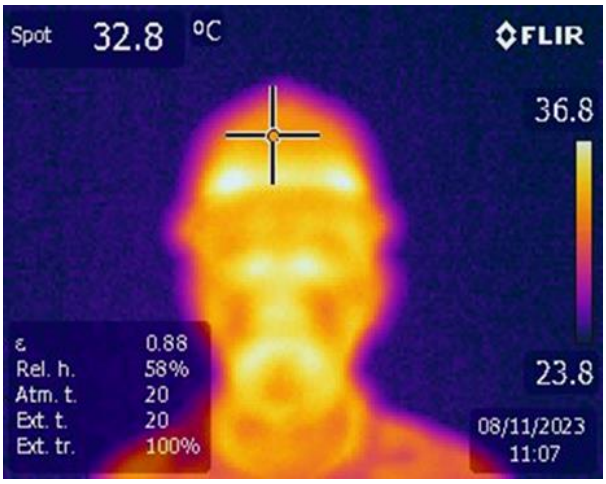

**Figure 17.** Blue helmet front shell temperature measurement

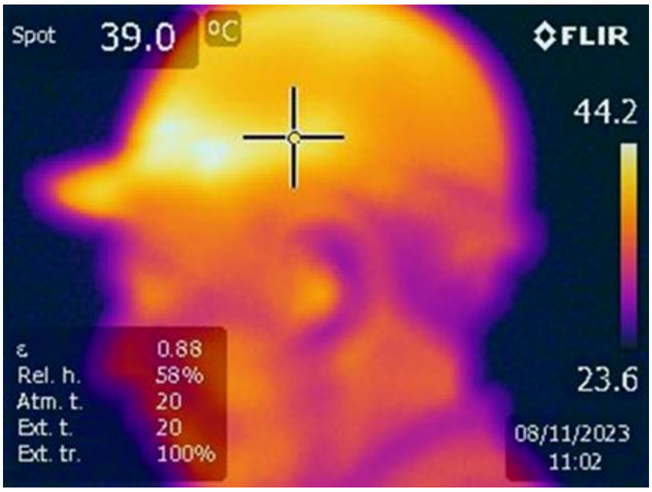


**Figure 18.** Blue helmet side shell temperature measurement

Measurement values for the blue helmet are given in the graphs numbered Figure 15-16-17-18. Blue colored helmets collect a lot of heat and give an unpleasant feeling when wearing. Outer shell temperature: 50.8 ° C, inner shell temperature: 40.5 °C, 32.8 ° C from the front on the worker, and 39.0 °C from the side on the worker. These levels are important to consider for thermal comfort. By applying thermal insulation to the inner surface of the muscle, heat transfer between the hot environment and the worker is reduced. In this way, heat balance in the environment can be achieved. Figure 19 shows the helmet shell temperature change graph depending on time and humidity.

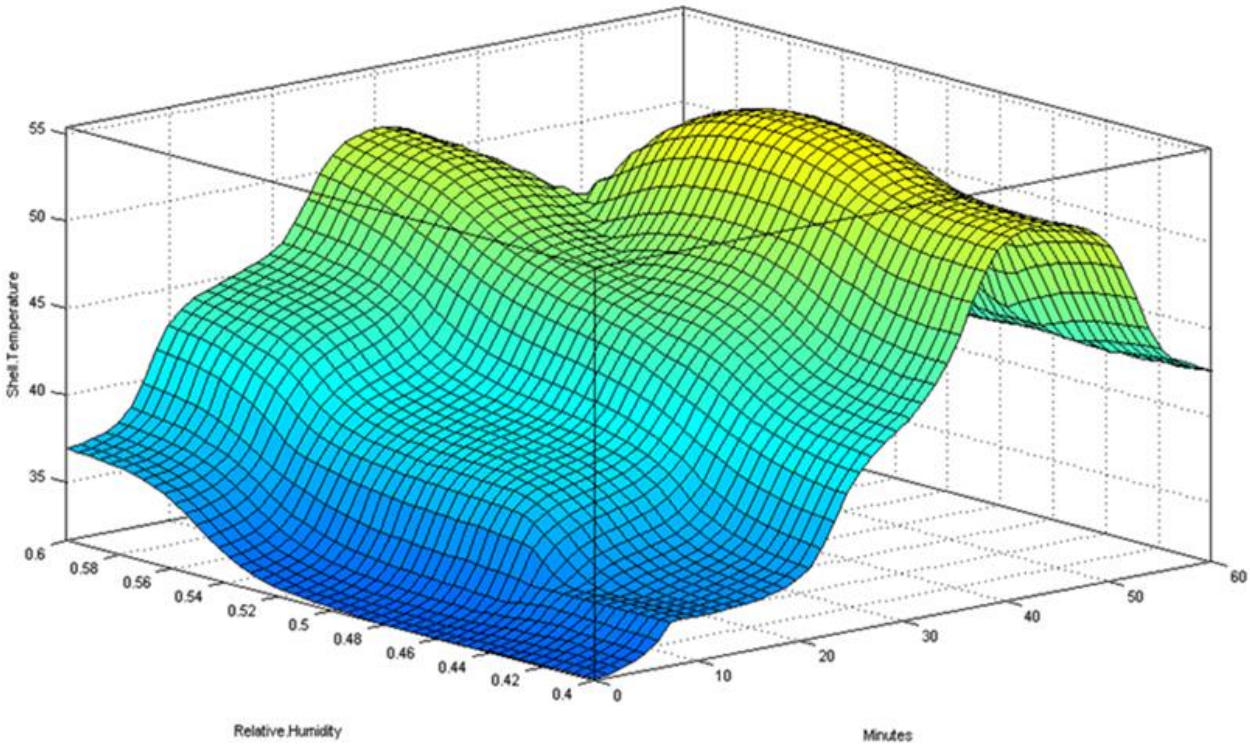


**Figure 19.** Helmet shell temperature change graph depending on time and humidity

When the connection graph between outer shell temperature, relative humidity and time is examined, it is seen that the relative humidity increases with time and the shell temperature value reaches 54.30 C Figure 20 shows the helmet shell temperature change over time.

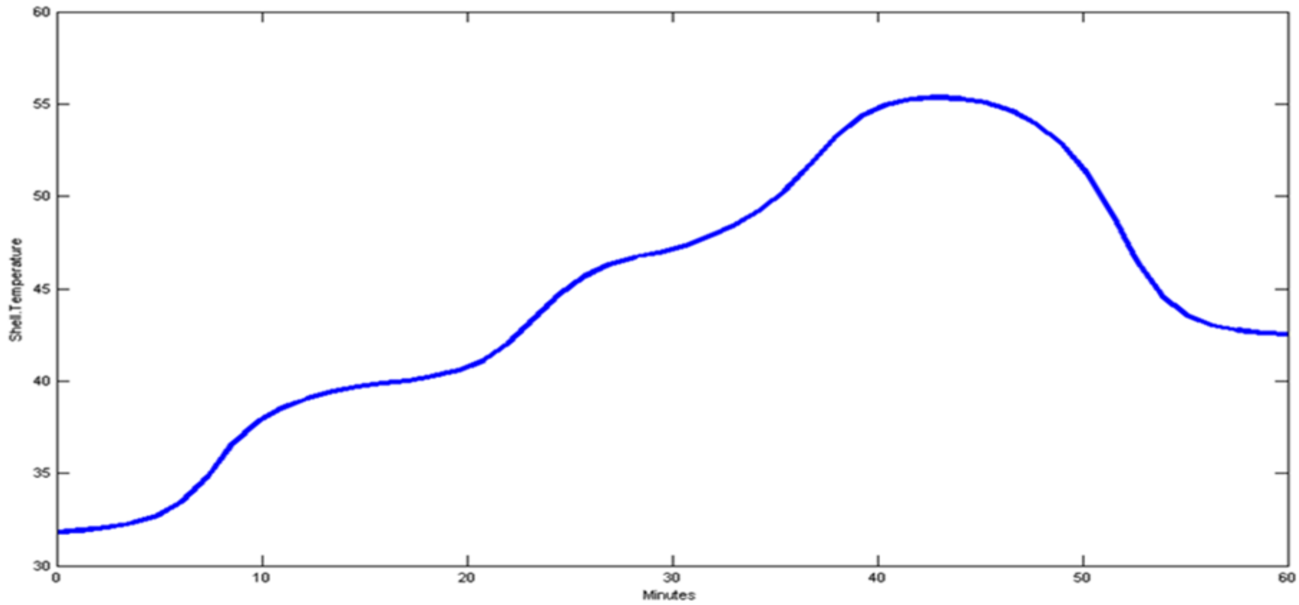


**Figure 20.** Helmet shell temperature change with time

It is seen that the temperature rises to 36-41 C in 10-20 minutes, reaches 41-470 C in 20-30 minutes, reaches 47-520 C in 30-40 minutes, and decreases from the maximum level of 54.90 C in 40-50 minutes. These measured values show that the increase that occurs at certain time intervals begins to decrease after a while.

## 4. Conclusion

It is clear that color has a big impact on heat preservation. Helmets with the same structure but different colors have very different heat protection. White colored helmets offer excellent heat protection; Dark colored helmets (yellow and blue) have low heat protection and are not suitable for providing us with thermal comfort. Dark colored helmets collect a lot of heat and give an unpleasant feeling when wearing them. It is necessary to improve insulation against solar heat, change the surface of the helmet shell and increase thermal protection. It is very important for the helmet manufacturer to meet the demands and develop a helmet that provides good thermal comfort as well as good protection against heat accumulation.

As a result of the study conducted to see the effect of color on thermal conductivity; It has been observed that the protective properties and permeability of helmets against rays decrease with the paint. The protection of dark colored straps is worse than light colored ones. If you want to be protected from harmful rays, helmets painted in light colors should be preferred.

Not only must the equipment be suitable for possible hazards, but helmets must also be well designed and comfortable in order to be used effectively. This requires research to be conducted not only on advanced materials, but also to evaluate how helmets perform in practice, including the physiology of protective equipment, and to include real application tests.

Reflecting the NIR rays coming from the sun as much as possible is one of the solutions for cooling applications and is used for products in contact with the sun outdoors. While the reflectivity of the structure is increased with micro/nano particles with high reflection index, the structure is also prevented from absorbing heat.

In this study, it is necessary to design helmets that use natural radiation energies to provide personal thermal comfort, that is, to cool the body, or where cooling can be carried out passively or actively with the same structure, in line with increasing comfort expectations.

Other issues that should be taken into consideration in the design of buildings are raw material costs during production and use, environmental damage, quantities used, complexity of processes and energy costs. In addition, in the management phase of the radiation component of heat transfer in the body-clothing-environment system, other heat transfer mechanisms such as conduction, convection and evaporation, and the combined heat and mass transfer mechanisms that occur with the transfer of sweat in vapor and liquid form, are considered as a whole. is important in determining their performance. In today's world where comfort expectations are changing rapidly, studies should be directed towards designing structures that heat/cool with radiation energy management in a way that can autonomously adapt to body and environmental conditions. As a result, it is aimed that the study will contribute to guiding scientists and sector representatives working on this subject and creating new ideas.

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