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Thermal comfort and energy analysis in ceramic tile

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Thermal comfort;
Thermal inertia;
Touch comfort.

Abstract. This study investigated the thermal touch comfort of ceramic tiles. The surface temperature was calculated by calculating the heat transfer at the time of contact. It is explained how the thermal inertia phenomenon contributes to the calculation of the surface temperature, and ceramic tiles feel cold when touched. To examine tactile comfort, the structure of the human skin and the mechanism of sensing the temperature are shown. In addition, the surface temperatures during touch were calculated and compared for other coating materials at the same temperature as the ceramic tile. The applicability of the coating option and how close it is to the goal of increasing thermal comfort are discussed. Thus, by calculating how much the coated ceramic tile improves thermal comfort, an essential study has been put forward to evaluate the thermal comfort improvements made on many surfaces used as coating elements in buildings and touched by people. It was calculated that the thermal inertia could increase by 4% with a 0.25 mm thin coating, and the prototype for this experiment was built. The calculated touch temperature of the coated ceramic tile increased by 0.2°C compared to the uncoated tile.

1. Introduction

Thermal comfort has been a significant problem waiting to be solved in engineering and architecture since the end of the 19th century. With the development of heating technology, many studies were conducted to make people feel more comfortable. With the development of cooling technology in the 20th century, thermal comfort has become much more critical. Controlling the temperature of the air around the person provides a significant part of thermal comfort. However, this is not enough. Every surface the human skin touches, or presses can cause discomfort when it is too hot or cold. The temperature range in which a person feels comfortable, and the limit values that cause pain are given in Table 1 [1]. Accordingly, the human body feels pain when it touches a place at 10°C or lower temperature. A temperature of 45°C and above also causes people to feel pain.

The building techniques used in human living spaces also concern thermal comfort. A difference is created by creating surfaces with high tactile thermal comfort. The user can see this difference, especially on surfaces that are stepped on with bare feet.

Wall and floor coverings used in buildings are expected to have features such as durability, hygiene,

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Table 1. Critical body temperatures [1].

	Skin temperature (°C)	**Deep tissue temperature (°C)**	**Regulatory zone**
Feeling pain	45	42	Death
		40	Hyperthermia
			Sweating
			Vasodilation
	31 – 34	37	Comfort
			Vasoconstriction
			Heat generation
		35	Hypothermia
Feeling pain	10	25	Death

and cheapness. Considering these mentioned features, it can be said that ceramic tiles are superior to other options. Ceramic tiles (floor and wall tiles) are durable, hygienic, and affordable. Despite all these superior features, ceramic floor and wall tiles may not be the first choice of users. Some users do not prefer ceramic flooring because of the "coldness" feeling it gives. Today, ceramic tiles are produced in the color and texture of natural wood. These tiles make users feel more "warm" with their wooden look. However, when the user touches or presses the wood-like tile, he still feels cold.

To solve the problem, first of all, the temperature on the touch surface must be calculated. For the thermal comfort properties of ceramic tiles both studies on the thermal properties of ceramic tiles and general thermal comfort studies have been investigated.

There are many previous studies on the thermal properties of ceramic surfaces. In these studies, it is mentioned that changing the thermal properties of ceramic material by making some changes.

The thermal conditions in the environments where people live, or work have been studied by many scientists. Standard documents, some of which are still valid and published by standard organizations such as ISO and BSI, on thermal comfort also shed light on thermal conditions. Organizations such as NASA and ASHRAE, where many studies on thermal comfort have been made, also reveal data that can form the basis for this issue.

One of the oldest studies on tactile comfort examines the psychological effects of the thermal comfort of touch. In this study, it was stated that when touching a material with known thermal properties, it is possible to calculate the temperature at which the touch surface will be felt [2]. It has also been emphasized that the material's specific heat, thermal conductivity coefficient, and density are sufficient, and the one with higher values will feel colder.

The most extensive studies for the thermal examination of touch have been done within NASA. In these studies, the temperature on the touch surface was considered a safety factor [3]. Accordingly, studies have been carried out with six materials similar to the surfaces touched by humans in spacecraft. People were asked to press their hands against a plate, and the temperature of this plate was raised. People were asked to withdraw their hands at the temperature at which they felt "pain", and it was determined how many seconds they pulled their hands away. For example, while subjects can touch the aluminum plate at 63°C for 2 seconds, The masonite material, which consists of compressed wood fibers at 110°C, can be touched for 2 seconds. At the same time, theoretical calculations were added to the study, which was carried out with more than 2000 trials. The thermal inertia phenomenon is explained, and the differences between the thermal inertia of the touched materials are indicated. As a result of this study, material safety conditions used by NASA were created.

Chianta's study [3] by NASA was criticized by another study [4]. Accordingly, it was stated in the previous research that the threshold for feeling pain was misinterpreted. In addition, it has been determined that the −18°C cold pain sensation value in the previous study is not based on any scientific basis. A correlation is derived for hot and cold touch surface temperatures, including all touch materials. A linear equation is derived from this correlation, and the touch time changes the coefficients of the linear equation. According to the work of Ungar and Stroud [4], NASA's standard for touch surface temperature limits has been updated.

The NASA standards mentioned above and other studies on touch surface temperature refer to international standards. According to the current standard published by ISO, people's reactions to the temperature on the touch surface were evaluated [5]. In this document, thermal inertia is defined, and how it is calculated is shown. In addition, it was stated that the most crucial factor in contact with the surface is thermal inertia. The mentioned ISO standard was also created to set security criteria like the NASA standard. However, measurement and calculation methods are generally crucial for the thermal touch analysis of ceramic floor tiles.

One of the studies on the thermal comfort properties of ceramic tiles stated that the thermal touch comfort on ceramic tile surfaces is related to the temperature on the touch surface [6]. It has also been shown that the temperature at the touch surface depends on the thermal inertia of the ceramic tile. With the improvements made in the ceramic tile material, gaps have been created in the material. Thanks to these gaps, a decrease in the thermal conductivity coefficient has been achieved. It has been stated that creating a void on the surface of the ceramic material also creates roughness on the ceramic surface, and this roughness contributes to the improvement of thermal touch comfort by reducing the thermal transfer. In the same study, it was also stated that the hollow structure created in the ceramic material reduces the mechanical strength of the ceramic tile. In a similar study, it was stated that the thermal properties of ceramics were changed and the thermal touch comfort properties were increased by using industrial waste materials in ceramics [7]. In this study, abrasive dust (silicon carbide, SiC) was used as industrial waste. It has been emphasized that silicon carbide forms cavities with the help of oxygen at high cooking temperatures. It was stated that the density of the ceramic decreased due to the voids, and the thermal touch comfort properties increased.

Measuring the thermal properties of ceramic floor tiles and natural materials such as granite and marble used as flooring materials is also important for this study. In one of the studies to determine the best flooring materials to be used in underfloor heating systems, the thermal properties of ceramic tile materials were measured [8]. The materials' thermal diffusivity and specific heat values were measured by the laser flash method. The thermal conductivity coefficient was calculated using the density value along with these values. In floor heating systems, it is aimed to have a high thermal conductivity coefficient to transfer the heat source under the floor covering to the top of the floor most efficiently. This study experimentally measured that the percentage of alumina (Al_2O_3) in the ceramic and the total void structure changed the thermal properties. In addition, comparisons were made with granite, facing brick, marble, and PVC flooring materials. It was stated that the total void structure increased as the firing temperature increased. Therefore the thermal conductivity was lower in porcelain tiles with higher firing temperatures.

Melo et al. studied the peeling problems in ceramic tiles. In the study, tensile and shear forces were simulated simultaneously. Within the scope of the study, 120 different samples were evaluated. According to the results, it was determined that the bond strength at the interface decreased with the increase of adhesive rupture [9].

Busch and França Holanda investigated coffee grounds' use and physical performance in producing floor tiles. The test results showed that coffee grounds strongly influenced the thickening behavior, technological properties, and sintered microstructure [10].

Novais et al. investigated the effects of phase change materials in ceramic tile production. According to the results obtained, it has been observed that the new type of ceramic tiles reduces indoor temperature change and increases thermal comfort [11].

Santamouris et al. investigated using cold materials to reduce heat islands in residential buildings. The materials were examined under four main headings, and their performances were evaluated [12].

Pezeshki et al. investigated the thermo-physical properties and performances of building materials used in the construction industry. Within the scope of the study, nine different building materials were examined, and their thermo-physical properties were explained in detail [13].

In their study, Shojaeefard and Tafazzoli Aghvami emphasized the difficulties of determining the contact resistance in laboratory conditions for the contact of two solid surfaces. They focused on numerical modeling to estimate the contact resistance [14].

In another study, Shojaeefard and Tafazzoli Aghvami worked on the mathematical modeling of contact resistance for different contact geometries. The Artificial Neural Networks method was used with Multi-Layer Perceptron for modeling purposes. The R^2 value for the modeling results was 0.996 [15].

Carlini et al. investigated using ceramic plates to provide comfort conditions in residences. Scenarios created according to different conditions were evaluated, and heat savings were determined by calculating thermal resistances [16].

Abrahem et al. investigated the effects of exterior insulation materials on thermal comfort in residences in Iraq. For external insulation, five different materials were evaluated [17].

Gomez et al. investigated the insulation of ceramic kilns for the drying and firing stages of ceramic material production. Within the scope of the study, four different insulation materials were evaluated [18].

In another study, Silva et al. theoretically evaluated ceramic materials' heat and mass transfers during the drying process during the production of ceramic materials. The materials' heat and mass transfer coefficients for different air temperatures were determined theoretically [19].

Xue and Zhao researched thermal comfort in residences based on energy savings. For the different ambient conditions modeled, the human body's heat transfer and thermal comfort conditions in the building are also emphasized [20].

Colmenares et al. investigated the thermal behavior of building materials. Within the scope of the study, the thermal properties of four different ceramic building materials were examined and compared [21].

Shariff et al. investigated the effects of different firing temperatures on the final product's thermal conductivity during the firing process in ceramic tile production. The sample product was fired at different temperatures: 1150 ° C, 1175°C, 1200°C, and 1225°C. It was stated that the ceramic sample fired at 1150° C had the lowest heat transfer coefficient among all samples [22].

Flores Cuautle et al. investigated the thermal conductivity of the ceramic product. While it has been reported that ceramic material consists of three different layers, the thermal conductivity of three different layers separately has been determined [23].

Pan et al. prepared a thermal insulation material by micro-foaming method and investigated the thermal properties of the formed material [24].

This research aims to increase the tactile thermal comfort of ceramic tiles. For this purpose, it has been investigated how the ceramic tile is covered with a polymer material and how it changes the comfort of touching the touch surface. First, the temperature on the contact surface will be calculated while touching the ceramic tile. In this calculation, the phenomenon of thermal inertia will be explained, and how the thermal inertia variable changes the temperature at the contact surface will be examined. Then, the temperature at the contact surface of a ceramic tile coated with polymer material will be calculated [25].

There has been a previous study on how the thermal properties of the polymer-coated tile change. Thanks to this research, the calculation method for the temperature on the touch surface of the materials used as flooring, especially ceramic floor tiles, will be revealed. Thus, an energy phenomenon that we encounter every day in our daily lives can be expressed with numerical values.

Coating ceramic tile with a polymer is innovative for the ceramics industry. The recommended coating method in this study is coating the ceramic tile with Dupont Surlyn® 1706, an ionomer. This material can reveal significant advantages for industrial applications. Industrial application is not covered in this study and should be considered independently of this study.

The thermal properties of the human body were also used in the calculations made during this research. It is assumed that there is no variation in these properties. Variables such as human gender and age were not included in the study.

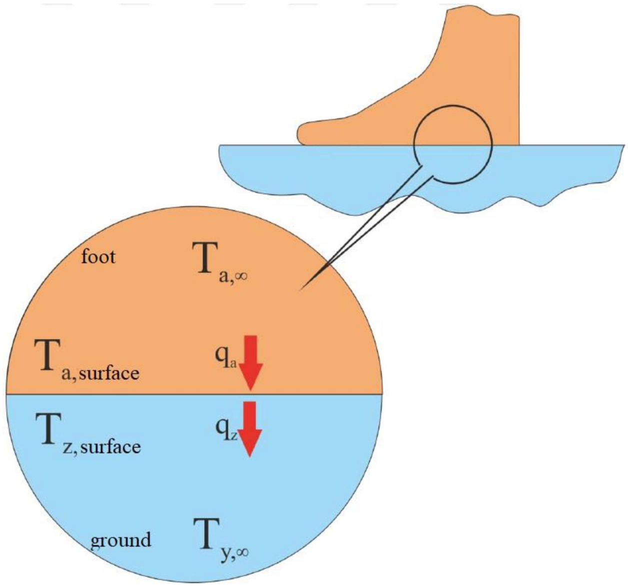

Figure 1. Heat exchange between foot and floor.

2. Energy analysis

2.1. Calculation of the temperature on the touch surface

The thermal resistance and heat transfer of the human body with the ground surface are shown in Figure 1. Indeed, two objects in contact with each other and an isolated environment will reach the same temperature in an infinite time. However, when there is no time to get the same temperature, there is a limited thermal exchange between the two objects in shorter contact.

In short-term touches, different temperatures are felt depending on the type of surface touched. When marble and wood are touched at equal temperatures, it is thought that the marble is colder.

If the touched surface and the human body are considered two separate objects, the internal temperature of both objects will not change in a short-term touch. Since the mass of the ground is relatively large, no temperature change can be observed in the entire ground by human touch. It is a fact that a person constantly maintains his inner temperature due to his metabolism. In other words, the internal temperatures of the objects can be accepted as constant.

The resolution is about ceramic floor tiles. Therefore, it can be assumed that the surface on which people step barefoot is a house and that the floor of a house heated under normal conditions is 20°C. Likewise, it is a well-known fact that the internal temperature of a healthy human body is approximately 36°C.

Considering that the problem is to step on the floor with feet, a solution can be made by equating the heat transferred from the human body to the floor and the heat received by the floor. The temperature on the touch surface will also be equal for the foot and the floor. The analysis can be performed using these two assumptions and the assumption that the internal temperatures of the bodies are constant:

- The energy lost by the foot equals the energy gained by the ground.

$$q_a = q_z. \tag{1}$$

- The surface temperatures of the foot and the floor are equal in the tactile plane.

$$T_{a,surface} = T_{z,surface} = T_{surface}. \tag{2}$$

- The internal temperatures of the foot and the surface do not change during contact.

$$T_{a,\infty} = constant \text{ and } T_{z,\infty} = constant. \tag{3}$$

2.2. Thermal inertia

Thermal inertia is a thermophysical property. The thermal conductivity (k) is equal to the square root of the product of the density (ρ) and the specific heat (c).

$$I = \sqrt{k.c.\rho}. \tag{4}$$

Although this property is defined as inertia, contrary to what is generally known, it is easy to change the temperature of materials with high thermal inertia, and it is difficult to change the temperature of materials with low thermal inertia.

It has been seen that different names are given to the same phenomenon in various sources. In some sources, this phenomenon is called thermal inertia [3,4,8]. In addition, some sources used thermal effusivity for the same phenomenon [7].

The temperature exchange between bodies in short-term contact with each other is also more easily explained by the phenomenon of thermal inertia. The temperatures of two bodies, whose thermal inertia and initial temperatures are known, can be calculated in one step at the moment of contact.

Using the 1st law of thermodynamics and the heat transfer formulas by conduction, the contact surface temperature of two objects in short-term contact can be calculated.

2.3. Fourier's law

The Fourier law is called the cornerstone of heat conduction [26]. The schematic representation of Fourier's law is shown in Figure 2. According to the Fourier law, the relationship between the magnitude of the heat flux and the temperature difference is revealed. Fourier's law is expressed as:

$$\ddot{q}_x = -k.\frac{dT}{dx}. \tag{5}$$

Fourier's Law is not derived from the first law of thermo dynamics but is based on experimental results. It defines the thermal conductivity coefficient.

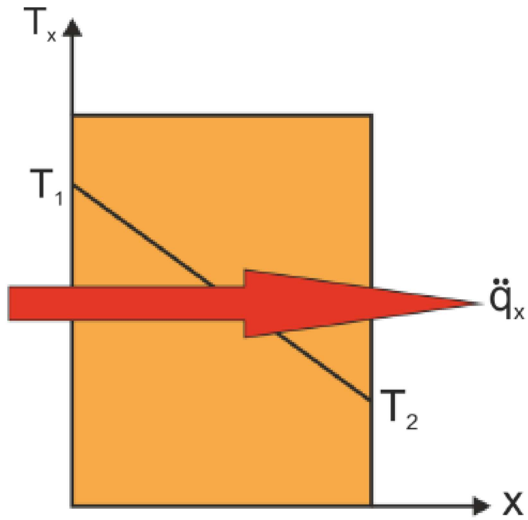

Figure 2. Fourier's law.

2.4. Analysis

First law of thermodynamics:

$$\dot{q}_a = \dot{q}_z. \tag{6}$$

The fourier law for boundary conditions can be expressed as:

$$q = \frac{k.\left(T_\infty - T_{surface}\right)}{\sqrt{\pi.\alpha.t}}. \tag{7}$$

Using Eqs. (6) and (7) above, the following equation is obtained:

$$-\frac{k_a\left(T_{a,surface} - T_{a,\infty}\right)}{\sqrt{\pi.\alpha_a.t}} = \frac{\mathrm{k_z}\left(T_{z,\infty} - T_{z,surface}\right)}{\sqrt{\pi.\alpha_z.t}}. \tag{8}$$

According to the temperature differences, the following equation is obtained:

$$\frac{T_{a,\infty} - T_{a,surface}}{T_{z,surface} - T_{z,\infty}} = \sqrt{\frac{k_z.\rho_z.c_z}{k_a.\rho_a.c_a}}. \tag{9}$$

Eq. (9) can be simplified and replaced by thermal inertia for $\sqrt{k.c}$. Also, according to the assumptions mentioned in the previous section, the surface temperatures during contact are equal. Accordingly, the following equation is found:

$$\frac{T_{a,\infty} - T_{surface}}{T_{surface} - T_{z,\infty}} = \frac{I_z}{I_a}. \tag{10}$$

The surface temperature can be derived from this equation:

$$T_{surface} = \frac{I_a \times T_{a,\infty} + I_z \times T_{z,\infty}}{I_a + I_z}. \tag{11}$$

As can be seen, the temperature at the touch surface can be easily calculated from the objects' internal temperature and thermal inertia.

2.5. Comparison of thermal inertia

To better explain the thermal inertia phenomenon, the thermal inertia of some materials used in daily life will be found, and the contact temperature on the touch surface will be calculated.

To make these calculations, the thermal inertia of the human body must first be calculated. Various studies have been conducted on the human body's thermal conductivity, density, and specific heat. These studies will be explained in another section.

The thermal inertia information of the materials of the surfaces that people frequently touch in daily life is shown in Table 2. As seen in the table, the thermal inertia values of metals are very high. Again, marble, concrete, and ceramic materials have high thermal inertia. In addition, the thermal inertia values of wood and polymer-based materials are much lower than metals.

2.6. Thermal properties of the human body

Humans exchange heat with their whole bodies. With metabolism, body temperature is kept at an ideal level for life.

2.6.1. Skin physiology

Human skin has layers as shown in Figures 3 and 4. The skin is the body's largest organ, making up about 15% of the total adult body weight. It fulfills many vital functions, such as preventing excessive water loss from the body and its role in thermoregulation, including protection against external physical, chemical, and biological aggressors [29]. The skin has three layers: epidermis, dermis, and subcutaneous tissue [29]. The outermost level epidermis contains a specific cluster of cells known as keratinocytes, which synthesize keratin, a long, thread-like protein with a protective role. The middle layer, the dermis, mainly comprises a fibrillar structural protein known as collagen. The dermis is located on the subcutaneous tissue or panniculum containing small fat cells known as lipocytes. The thickness of these layers varies considerably depending on the region in the body's anatomy. For example, the eyelid has the thinnest epidermis layer, less than 0.1 mm thick. However, the thickness of the epidermis on the palms and soles is about 1.5 mm. The dermis is 30-40 times wider than the overlying epidermis [27].

2.6.2. Thermoregulation

Apart from protecting from external factors, one of the skin's main functions is thermoregulation. The temperature of the core of the body depends on the balance between heat production and heat loss, and heat loss is entirely mediated by the skin, with a minor contribution from the respiratory system. Two mechanisms contribute to this process: Control of blood flow in the skin and sweating. These mechanisms

Table 2. Heating values of commonly used building materials.

Material	k	ρ	c	I
	W/(m.K)	kg/m^3	J/(kg.K)	$\sqrt{\frac{kg}{s}}$/K.s^2
Ceramic (tile)	1.60	2700	423.6	1352
Concrete	2.10	2400	1050	2300
Glass	1.00	2470	750	1361
Wood (oak)	0.17	704	1260	388
Wood (pine)	0.15	614	1380	356
Marble	2.51	2700	880	2442
Granite	2.85	2700	790	2465
Gypsum board	0.17	2300	1090	653
Aluminum	205	2700	897	22282
Steel (1% carbon)	43	7820	490	12836
PVC	0.19	1390	1005	515
Plastic (ABS)	0.175	1100	1423	523
Plastic (cast PA)	0.29	1140	1700	749.7
Leather	0.14	860	1500	424
Rubber	0.13	1100	2615	611
Brass	109	8480	375	18617
Zamak 5	108.9	6700	418.7	17478

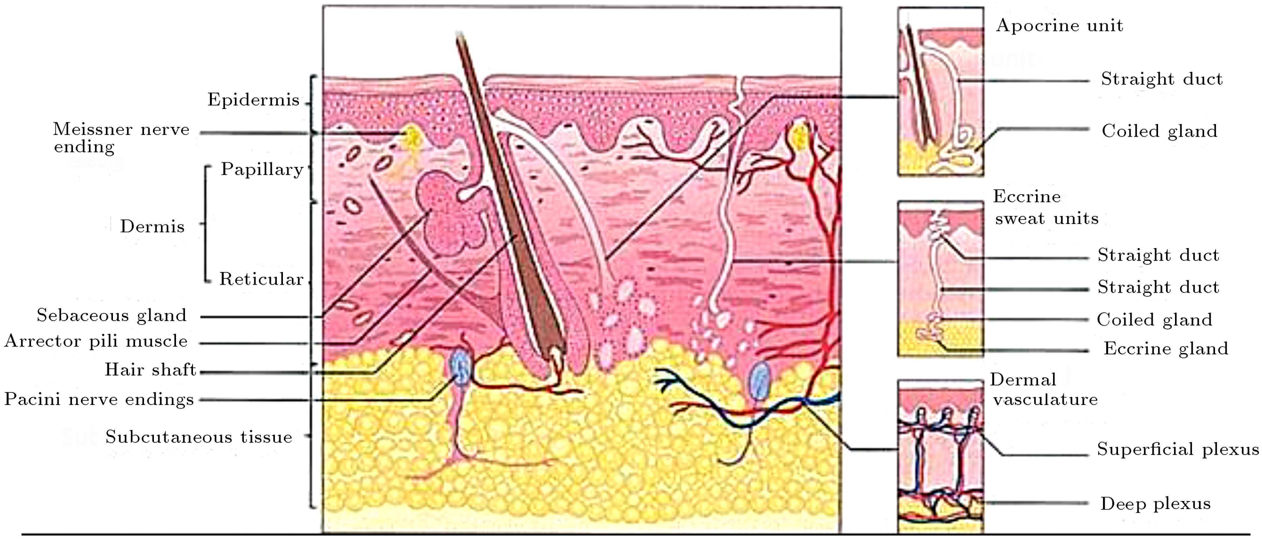

Figure 3. Human skin layer [27].

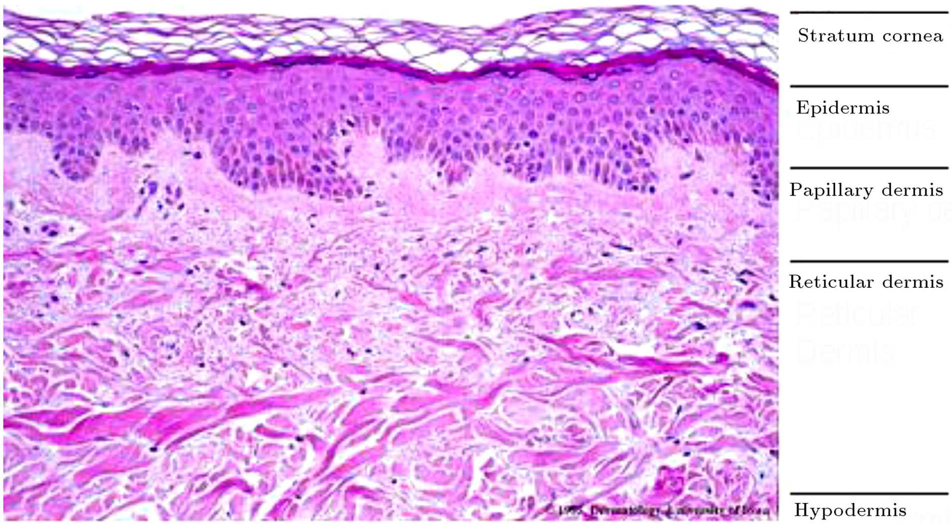

Figure 4. Human skin layer [28].

are interconnected to some extent: Blood flow changes alone can affect heat loss. However, blood flow control can achieve the supply of water necessary for sweating [30].

What kind of control mechanism exists for thermoregulation is still controversial. While some authors argue that the skin performs an open-circuit temperature control by measuring the external temperature; Some authors say that the skin is an organ of the body and that the body stabilizes the temperature with a closed-loop control of multiple temperature data. Many authors have defined the open circuit here as "feed-forward". Closed-loop control is defined as "feedback." An article explains the difference between the two controls with an example of room temperature control. The heating system of your house can operate according to the thermostat in the room, when the room temperature falls below the value set in the thermostat, the heating system is activated. This method is called a closed loop or feedback. Your home's heating system may only operate according to the outside temperature. The heating system comes on when the outside temperature drops and heats the house. This method is called open circuit or feed-forward [31].

During thermoregulation, the hairy surfaces of the skin contribute more to heat removal. Under normal conditions, perspiration is provided on hairy surfaces. Hairless surfaces such as palms and soles play a greater role in the sensation of warmth.

2.6.3. Sensation of temperature by the skin

The skin senses temperature with nerve cells between the layers. The thermoreceptor detects temperature

Table 3. Thermal properties of human tissue [32,33].

k_i (W/m.K)	ρ_i (kg/m^3)	c_i (J/kg.K)
0.209	980	3390

changes. Thermoreceptors are free nerve endings found in the skin, liver, skeletal muscles, and hypothalamus. Cold receptors are known to be 3.5 times more than other thermo receptors. Thermoreceptors respond very quickly.

2.6.4. Thermal properties of human tissue

To be used in this study, human tissue's thermal conductivity coefficient and specific heat information are needed. These values are given in Table 3 [32,33]. In addition, the specific gravity of human tissue will also be used in the calculations. It cannot be said that human tissue has homogeneously uniform thermal properties. As there are great thermal properties differences between human skin and internal tissues; It is known that even the skin has different properties according to its position on the body. For example, while the thermal conductivity coefficient is high in the parts where the epidermis layer is very thin, the thermal conductivity coefficient has a relatively small numerical value in the parts of the human body where the thickest epidermis layer is found, such as the soles of the feet. Since the thermal measurements made with human tissue are limited, the thermal conductivity coefficient value was taken as human skin for this study. In addition, the results of the measurements of the specific heat and specific gravity of the whole human body were taken into account. Accordingly, the following values were taken as reference.

The thermal inertia of human tissue can be calculated as follows:

$$I_i = \sqrt{k_i.c_{i\cdot i}}, \tag{12}$$

$$I_i = 833\frac{1}{\text{K.s}^2}\left(\sqrt{\frac{\text{kg}}{\text{s}}}\right). \tag{13}$$

2.7. Thermal comfort

Thermal comfort is a subjective evaluation that expresses satisfaction with the thermal environment. As stated in the table, an internal tissue temperature of 37°C is the state in which a person feels thermally comfortable. Comfort disappears at temperatures lower and higher than this temperature.

2.7.1. Critical temperatures for the human body

Heating techniques developed in the 18th century, and cooling techniques at the beginning of the 20th century. Thanks to these advances, thermal comfort has gained more importance. Also, it was thought that thermal comfort was only related to temperature in the past. At the beginning of the 19th century, Heberden revealed that humidity also significantly affected thermal comfort [1]. Houghton and Yaglou defined the comfort zone in the ASHVE laboratories in the early 1920s [34]. In addition, many engineering studies were carried out in the field of thermal comfort together with military technologies in the 2nd World War.

Critical body temperatures are indicated in the table. Separate evaluations were made for skin temperature and internal temperature. The deep tissue temperature represents the human body's internal temperature, and when it is 37°C, an ideal comfort condition is achieved. When the internal tissue temperature is 37°C, the skin temperature is between 31–34°C. The difference is due to the activities of human metabolism.

When the temperature rises, vasodilation occurs first. Vasodilation means the dilation of the vessels. In this case, the blood flow rate increases, but blood pressure (blood pressure) decreases. The blood flow to the skin increases 2–3 times; thus, heat transfer inside the body to the outside environment rises. It is observed that the skin becomes a little pinker. If the temperature rises further, sweating begins and grows. Thanks to sweating, water evaporation takes place on the skin, and the body loses excess heat. The total amount of water in the body affects the amount of sweating. In addition, external factors may prevent perspiration from turning into evaporation; for example, when the external relative humidity is very high, the evaporation rate decreases. In this case, sweating may not be enough. When sweating is not enough, the body goes into hyperthermia. In the case of hyperthermia, some of the central nervous system functions disappear, and body functions are impaired. It is a condition known as "heat stroke" among people. When the deep tissue temperature reaches 42°C, the body cannot provide many vital processes, and death occurs.

When the temperature drops from 37°C, the comfort temperature and vasoconstriction occur first. This is the narrowing of the blood vessels. Blood flow decreases but blood pressure (blood pressure) increases. Since the blood flow is reduced, the internal body temperature is preserved. If the temperature drops, a body response called heat production (thermogenesis) occurs. Many physical and chemical body reactions are seen, especially the secretion of adrenaline and noradrenaline for heat production. Shivering is one of these reactions. When the body temperature drops further, a condition called hypothermia occurs. Body reactions and control are partially lost. While a temperature of 37°C is specified as a comfort temperature, hypothermia begins at an internal tissue temperature of 35°C. In other words, the internal tissue temperature is susceptible to temperature drop. Further cooling from hypothermia leads to the abolition of vital cycles. Death occurs at 25°C internal tissue temperature.

2.8. Increasing thermal comfort on ceramic surfaces

Various studies have been conducted to increase thermal comfort during touch on ceramic surfaces. As explained in the introduction section, thermal inertia must be reduced to improve thermal comfort on the touch surface. In other words, if the density, thermal conductivity, or specific heat is reduced, the thermal inertia decreases, and the loss of comfort during touch decreases.

Thermal inertia can be reduced by creating a hollow structure in ceramic tiles. This study was mentioned in the Introduction.

Another method of increasing thermal comfort on ceramic surfaces is to cover ceramic tiles with a material that has lower thermal inertia than ceramic. In this case, the thermal inertia on the touch surface will result from the ceramic and the coating material. When the coated ceramic is considered whole, it will have lower thermal inertia than ceramic. This value was calculated as follows.

2.8.1. Coated ceramic tile

It was stated in the introduction that voids were created in the ceramic body in previous studies to increase the thermal comfort of ceramic floor tiles. It is also known that the thermal properties of ceramic floor tiles are improved by adding other materials to the ceramic body.

This study investigated the thermal properties of ceramic tile coated with ionomer resin. The coating material used is a special ionomer resin known by the Surlyn̂ trademark from Dupont. In this study, 0.25 mm thick Surlyn® 1706 was used. The 0.25 mm coating was chosen because it is commercially available. In addition, it is aimed to make a coating as thin as possible so that the texture and pattern of the tile are not distorted. The method of making the coating and the discussions about it are the subject of another study and will not be mentioned here.

This study will explain in detail how this coating changes the thermal properties and how much the temperature on the touch surface is improved.

The Dupont Surlyn® material used for the coating is known for its transparency and hardness. For this reason, it is widely used in the packaging industry. There are also examples in the literature proving this situation [l-o]. It is known that there is a wide variety of perfume bottles made from Surlyn® material. Also another example includes a golf ball covered with Surlyn® material. As can be seen, it is transparent enough to be used in perfume bottles; It has a solid and hard structure that can withstand all the impacts of the golf ball. The self-healing property of Surlyn̂ material was also mentioned in another study. Considering these features, it can be said that it is a very suitable material for ceramic tile coating. Other features of SurlynTM 1706 can be viewed on the manufacturer's website [35].

Table 4. Material properties of the coating side.

k_p (W/m.K)	ρ_p (kg/m^3)	c_p (J/kg.K)
0.33	940	2700

As a result of covering the ceramic tiles with Surlyn® material, all the patterns on the ceramic tile can be seen as they are. When the user looks from the outside, it looks like an ordinary ceramic floor tile. Again, thanks to the strength properties of the material, it will be able to meet all the forces on the ceramic tile. The high temperature and pressure applied during the coating process ensure that the coating material fills the gaps on the upper surface of the tile and adheres completely. Since it is located on top of the tile, it is only exposed to the force from above after the coating. These forces cannot damage the coating either.

It is a fact that wood-patterned ceramic tile, which is frequently used today, will have more positive psychological effects on the user and improve thermal properties.

For this study, 0.25 mm Surlyn® 1706 material was coated on the wood-patterned ceramic floor tile, and the sample was prepared.

The ceramic side of the coated ceramic tile has the characteristics of traditional ceramic material. The material properties of the coating side are shown in Table 4.

When calculating the thermal properties of the coated tile, 9 mm thick ceramic floor tiles and 0.25 mm thick polymer coating were calculated.

2.8.2. Coefficient of thermal conductivity of coated tile

The thermal conductivity equation for double-layer material can be used to calculate the thermal conductivity coefficient:

$$k_{sp} = 1.449\frac{\mathrm{W}}{\mathrm{K.m}}. \tag{14}$$

2.8.3. The specific heat of the coated tile

As it is known, the specific heat scaler is a value. As stated in the definition of specific heat, it is the amount of energy that increases the temperature of a unit mass of matter by 1°C. While calculating the specific heat of the coated tile, which is the subject of this study, the mass ratios of the tile and coating material used in the coated tile with a unit area are found. Then, the amount of heat that raises the temperature of a unit mass of the coated tile by 1°C is calculated.

Accordingly, the specific heat of the coated ceramic tile is found as follows.

The coated tile consists of 9 mm ceramic tile and 0.25 mm polymer. Calculation of the mass of 1 m^2 of coated tile:

$$m_{sp} = m_s + m_p, \tag{15}$$

$$m_{sp} = 9.10^{-3}\ [\text{m}].\ 1\ [\text{m}^2].\ 2700\ [\text{kg/m}^3] + 0.25.10^{-3}[\text{m}].1\ [\text{m}^2].940\ [\text{kg/m}^3], \tag{16}$$

$$m_{sp} = 24.535\ \text{kg}. \tag{17}$$

Calculation of the heat that increases the temperature of 1 m^2 of coated tile by 1°C:

Heat absorbed by ceramic tile:

$$Q_s = m_s.c_s.\Delta T, \tag{18}$$

$$Q_s = 24.3\ [\text{kg}].423.6\ [\text{J/kg.K}].1\ [\text{K}], \tag{19}$$

$$Q_s = 10293\ \text{J}. \tag{20}$$

Heat absorbed by polymer coating:

$$Q_p = m_p.c_p.\Delta T, \tag{21}$$

$$Q_p = 0.235\ [\text{kg}].2700\ [\text{J/kg.K}].1\ [\text{K}], \tag{22}$$

$$Q_p = 634.5\ \text{J}. \tag{23}$$

Total heat absorbed by 1 m^2 of coated tile:

$$Q_{sp} = Q_s + Q_p, \tag{24}$$

$$Q_{sp} = 10928\ \text{J}. \tag{25}$$

Calculation of the specific heat of the coated tile:

$$Q_{sp} = m_{sp}.c_{sp}.\Delta T, \tag{26}$$

$$c_{sp} = \frac{Q_{sp}}{m_{sp}.\Delta T}. \tag{27}$$

Using Eqs. (26) and (27), the specific heat of the coated tile is calculated:

$$C_{sp} = 445.4\ \text{J/kg.K}. \tag{28}$$

2.8.4. Calculation of the specific gravity of the coated tile

The weight of the coated tile per 1 m^2 area was calculated. Since this mass was calculated for 9 mm ceramic tile and 0.25 mm polymer coating, this weight was found as 24.535 for the sample piece with 1 m^2 and 9.25 mm thickness. Accordingly, the specific gravity can be calculated as:

$$\rho_{sp} = 2652\ \frac{\text{kg}}{\text{m}^3}. \tag{29}$$

2.8.5. Calculation of the thermal inertia of the coated tile

The thermal inertia of the coated tile is calculated as:

$$I_{sp} = 3210 \frac{1}{K.s^2}\left(\sqrt{\frac{\text{kg}}{\text{s}}}\right). \tag{30}$$

2.8.6. Touch thermal comfort of coated ceramic floor tiles

Considering the thermal values of the coated ceramic floor tile and human tissue specified in the previous sections, the temperature on the touch surface will be calculated if a person steps on the coated tile with his foot. Human internal tissue temperature at the time of calculation is 37°C; the ceramic floor tile temperature will be considered as 20°C.

According to the calculation made using the equations, the temperature felt by someone stepping on the coated ceramic floor tile with bare feet is as follows:

$$T_{surface,sp} = \frac{I_i \times T_{a,\infty} + I_{sp} \times T_{sp}}{I_i + I_{sp}}, \tag{31}$$

$$T_{surface,sp} = 26.61°\text{C}. \tag{32}$$

2.8.7. Comparison and discussion

To determine the performance of the coating to increase the tactile thermal comfort of the ceramic tile, a comparison will be made with the uncoated tile and other materials in the table. The temperature assumptions in the coated ceramic tile will remain the same; accordingly, the temperature of the interior texture will be 37°C, and the ceramic floor tile's temperature will be considered 20°C. Touch temperature was calculated for other frequently used materials using the same method. Accordingly, the temperature on the touch surfaces of other materials is shown in Figure 5.

As can be seen in the table and graphic, low temperatures are felt on the contact surface when the surfaces made of materials with high thermal inertia are touched. The highest tactile comfort is calculated in wood and leather materials. Accordingly, it can be seen that high-strength materials used in buildings and serving as carriers have lower tactile comfort. However,

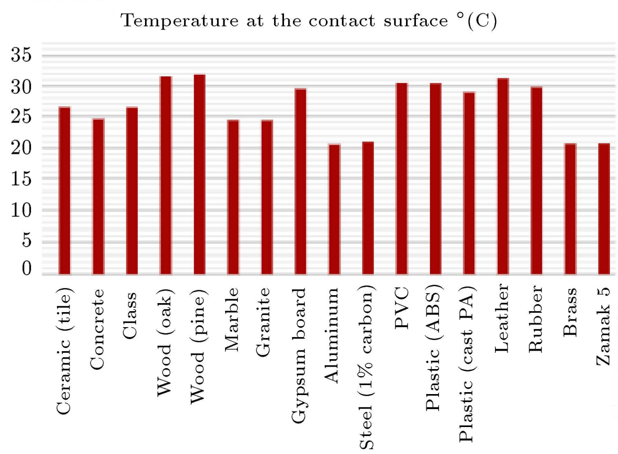

Figure 5. The temperature at the contact surface.

tactile comfort can be improved on the surfaces by coating the carrier elements. The polymer coating option, which is the subject of this study, should be considered.

When the temperature at the touch surface of the coated ceramic tile is compared with the uncoated ceramic tile, it is seen that the difference is very small.

In previous studies on thermal touch comfort, the importance of thermal inertia has been emphasized, just as in this thesis.

In previous studies, what was done to increase the thermal comfort of ceramic tile was explained in the Introduction section. It was tried to reduce the thermal conductivity coefficient and density by creating voids in the ceramic structure. The aforementioned Effting et al. In his study, it was stated that a 30% decrease was achieved in the thermal inertia of the ceramic. In the coating studied in this thesis, the thermal inertia of the coated ceramic tile could only decrease by 4%. Efftin et al. [6] did not question the manufacturability of the mentioned tile in their study. In addition, the negative effect of the voids created within the ceramic tile on the structural strength should also be considered.

3. Conclusion

Ceramic tiles are a critical coating material for building elements today. Wet floors in buildings in most of the world are covered with ceramic floor tiles. Despite its many superior features, ceramic feel cold when touched. In this study, this problem has been examined.

Thermal analysis was conducted to determine how cold the ceramic floor tiles felt. It has been suggested that thermal inertia can be used to calculate the temperature felt during short-term touch. Accordingly, the ratio between the thermal inertia of two touching objects determines the temperature on the touch surface.

Materials with a low thermal conductivity coefficient are generally chosen when choosing materials for thermal comfort. This study shows that the thermal conductivity coefficient is not the only variable for this comfort. The thermal conductivity coefficient, density, and specific heat that make up the thermal inertia change the thermal inertia at the same rate.

The response of the human body to temperature has been studied. How people feel the heat and the physiological structure of the human skin are explained. The limits of thermal touch comfort for humans are defined.

The option of covering the ceramic floor tile with a polymer material was examined to solve the problem. This study covered 9 mm thick ceramic tile with 0.25 mm thick Surlyn® 1706 material. As a result of this coating, the thermal inertia of the ceramic tile was reduced by approximately 4%. The covering material is transparent, so it did not affect the visual design of the ceramic floor tile. In addition, it can be said that it is one of the most suitable materials for coating ceramic tile, as it is very hard when it becomes a coating, and the notches on it are self-healing.

Special equipment is required to coat ceramic floor tiles with a polymer such as Surlyn® 1706. This equipment should operate at a sufficiently high capacity according to mass production conditions. The polymer must be brought to a certain temperature and laid on the ceramic tile, and at the same time, pressure must be applied for a certain period. The prototype made in this study is at a laboratory scale. Results were obtained with a hot press machine at 180°C for approximately 36 seconds with a pressure of 2200 Pa. Precise control of temperature and pressure during this ironing will affect the quality of the final product.

According to the process, the process of placing the ceramic sample in the hot press machine is shown in Figure A.1 in Appendix A. After the process, the image of the papped and uncoated sample is shown in Figure A.2 in Appendix A.

In this case, it can be said that added value is achieved by performing a secondary treatment on an ordinary tile. However, the high investment costs of the special equipment required for coating the ceramic with the aforementioned ionomer resin is the biggest obstacle to the commercialization of this product.

With the detailed market research to be done, it should be calculated how much the ceramic floor tile with increased thermal touch comfort can increase the profitability, and a feasibility study should be done according to this value.

Today, many products create a sales volume directly proportional to the quality perceived by the user. A reverse process can occur with the tactile comfort calculation outlined in this study. In some products, a colder tactile sensation may leave a higher quality perception in the consumer. For example, today, many parts in the automotive and white goods sector are produced from polymer materials instead of metal. In some cases, these parts are coated with chromium so that the consumer perceives them as metal. A higher quality perception occurs when the user feels the surface to be touched as cold.

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Declaration of competig intrests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Nomenclature

α	Thermal diffusivity
α_a	Thermal diffusivity of foot
α_z	Thermal diffusivity of floor
c	Specific heat
c_i	Specific heat of human tissue
c_p	Specific heat of polymer coating
c_s	Specific heat of ceramic tile
c_{sp}	Specific heat of polymer coated tile
cz	Specific heat of floor
c_a	Specific heat of foot
I	Thermal inertia
I_{sp}	Thermal inertia of polymer coated tile
I_z	Thermal inertia of floor
I_a	Thermal inertia of foot
I_i	Thermal inertia of human tissue
k	Thermal conductance
k_p	Thermal conductance of polymer coating
k_{sp}	Thermal conductance of coated tile
k_i	Thermal conductance of human tissue
m_p	Mass of polymer coating
m_s	Mass of ceramic tile
m_{sp}	Mass of coated tile
q	Heat energy
q_a	Transmitted heat energy from foot to floor
q_z	Heat energy that the floor receives from the foot
q''_x	Heat flux
Q_p	Heat absorbed by polymer coating
Q_s	Heat absorbed by ceramic tile
Q_{sp}	Heat absorbed by coated tile
ρ	Density
ρ_p	Density of polymer
ρ_{sp}	Density of coated tile
ρ_i	Density of human tissue
ρ_z	Density of floor
ρ_a	Density of foot
t	Time
$T_{a,\infty}$	Human body internal tissue temperature
$T_{a,surface}$	Foot surface temperature
$T_{z,\infty}$	Deep ground temperature
$T_{z,surface}$	Ground surface temperature
$T_{surface}$	Surface temperature
$T_{surface,sp}$	Surface temperature of coated tile
T	Temperature
ΔT	Temperature difference
NASA	National Aeronautics and Space Administration
ISO	International Organization for Standardization
BSI	British Standards Institution
ASHRAE	American Society of Heating, Refrigerating and A-C Engineers
ASHVE	American Society of Heating and Ventilating Engineers

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Appendix A

An electrically operated laminating machine is shown by Figure A.1. The upper and lower surfaces are heated by electrical resistance and the surface temperature can be maintained up to 300°C. Its electrical power is 2000 W. The dimensions that can be processed on the machine are the size of an A4 sheet of paper. The machine applies pressure to the part by manually

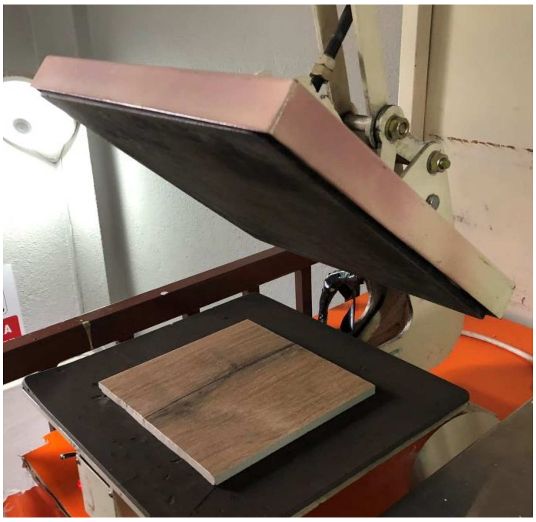

Figure A.1. Sample preparation with a hot press.

Figure A.2. Image of coated and uncoated sample.

pressing down the top cover. This work is suitable for manual prototyping in jobs like this. It was used to conduct various experiments within the scope of this research. The machine-produced prototype mentioned in Figure A.2. and the uncoated ceramic tile appear together. The ceramic tile used is 9 mm thick floor tile. It turns out that it is difficult to distinguish them from each other.

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