The Effects of Flooring Material on Thermal Comfort in a Comparative Study Marble and Parquet Flooring

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***Abstract* —** Flooring is an important part of the building, it plays a role for structure as well as aesthetics and it can be a major contributing factor towards thermal comfort of a building if it is designed properly. That is why this article is going to focus on a comparative study of two different flooring materials, one of them is stone and the other is timber. More specifically, we will focus on the marble and parquet flooring materials. The research objective of this article is to investigate how flooring materials affect thermal comfort and to identify the problems that lead to low thermal comfort of a space and to recommend which type of flooring material is better for the space. Our analytical results show that the parquet flooring is more appropriate for thermal comfort because it has lower U-value which is the measurement of the heat transfer rate. The low U-value proves the better insulation of the parquet floors compared to marble floors.

Keywords **—** Thermal comfort, floor material, temperature, comparison, recommendation

I. INTRODUCTION

Buildings, all over the world, consume large energy amounts as the majority of these amounts go towards either cooling or heating the buildings. The surface temperature, e.g., flooring, ceiling or walls, are the main elements that affect the temperature of the building and consequently the amount of consumed energy.

In this study, we focus only on one example of building surfaces which is the floor. We study the effect of different flooring materials, specifically, marble and parquet, on the thermal comfort of a room or a space. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55 defines thermal comfort as "that state of mind which expresses satisfaction with the thermal environment." [1].

Recently, the healthy buildings design has attracted the attention of both the construction companies and standardization organizations, worldwide, and the focus shifted towards designing and constructing buildings with high standards to ensure the well-being of the occupants in different environmental conditions. Towards that end, thermal comfort is one of the key points that could affect the occupants physiological, psychological and their behaviors and productivity [2].

There are many factors that contribute to building's thermal comfort including air temperature, surface materials, radiant temperature, air movement, humidity, human activity, clothes, etc. [3, 4]. In this study, we focus on one of these factors which is the flooring materials, more specifically, marble and parquet flooring. We particularly select these two materials because of their popularity, meaning that they are widely used in different building types, e.g., offices, homes, exhibitions, therefore, understanding their thermal contribution to a building would help us to efficiently utilize the consumed energy of that building. Marble is a very popular natural stone for floors. It has unique and elegant appearance with different colors. On the other hand, parquet is a form of wood flooring where different wood materials (e.g., oak, cherry, lime or pine) can be used for flooring and decorative effect. In this study, we aim to comparatively study how flooring material, e.g., marble and parquet, affects thermal comfort and to identify the problems that lead to low thermal comfort of a space. And the end of this study, we aim to recommend which type of flooring material is better for different spaces and environmental conditions.

II. LITERATURE REVIEW

Background- To clearly understand how each material store the heat energy, we need to study the thermal mass of the material. Thermal mass is the ability of a material to absorb and store the heat, in other words, how much heat energy a material can store [7]. On the other hand, thermal resistance is the material's ability to resist or reduce the effect of the heat flow. It is a function of thermal conductivity and the temperature. For example, a lot of heat energy is required to change the temperature of high density materials like concrete, bricks and tiles. Several studies in the literature has investigated the contribution of thermal mass to the human thermal comfort for specific buildings. Authors in [8] showed how thermal mass combined with optimal building operation can regulate the building's internal temperature to maintain comfortable internal conditions of some office buildings even in very high summer temperatures in Frankfurt, Germany.Fig.1 describes

clearly how thermal mass affects the human thermal comfort. In the mornings, sunlight enters the room and the heat is absorbed into the flooring to keep the room temperature comfortable. In the evenings, the floor releases the observed energy (during the day) and add warmth to the room and that is the cooling phase. The question is what happens if we are using an appropriate flooring material or flooring material with insufficient thermal mass*?* In that case, the heat coming from the sunlight will be reflected into the room, because the floor will not be able to store/absorb it, and that will cause low human thermal comfort as the room will be very warm. In addition, during the nights, and as the flooring material did not store any energy, the room temperature will be very cold and that again will cause low thermal comfort for the occupants.

Thermal comfort related studies- Studying the effect of flooring on human thermal comfort can be traced back to the very early work in 1964 with a series of studies conducted by researchers in Kansas State University (KSU) [5,6]. The experiments were conducted on both females and males and with different floor surface temperatures range from 15.6 °C to 37.8 °C. In addition, the subjects have been asked to do different activity levels starting from sedentary to light work. And in most of the studies, the room air temperature was kept fixed at 23.9 °C. With these set of experiments, the researchers identified the human thermal comfort point for different flooring temperature and with different activity levels. However, this study was using radiant floor and it did not take into account the actual flooring materials. Studying the flooring material is more complex because each material can hold/store the heat with different levels and the amount of stored energy/heat is not fixed over time, unlike the case of radiant floors which makes it more challenging.

Thermal comfort measurement methodology- Studying thermal comfort is crucial, not only to control the indoor environment to satisfy the occupants but also for other different reasons highlighted by Raw et al. [11]. These reasons are achieving better air quality, controlling energy consumption, greener environment by reducing the emission of CO_2, enabling efficient work environment and providing suggestions and recommendations for the standards. However, measuring the thermal comfort is a challenging task. Generally speaking, there are two main approaches to determine the thermal comfort and has been discussed in [12]. First is the steady-state studies which conducted in environmentally-controlled test chambers where the different environmental conditions (e.g., air temperature, humidity, radiant temperature) is controlled and the subject is asked to report their state and comfort conditions. Second is the field studies. The key difference between these two is that the field study is real world study where the study is conducted on subjects in their normal workplaces and there is no attempt to control the environment. In addition, other variables such as clothing and metabolic rate [12] are also taken into account. The key objective of this type of studies is that understand what combinations of environmental variables contribute the most to the subjective response of the subjects. As an instance of this field studies category, there have been great focus on studying the thermal comfort in two buildings categories named by de Dear et at. [13], (i) naturally ventilated buildings and (ii) centrally conditioned buildings. The focus was to understand the differences between these types of buildings in terms of thermal comfort [14],[15].Despite all these efforts to study the factors that contribute to the thermal comfort, none of the previous works have focused on the type of different flooring materials. In this study, we focus on two commonly used flooring materials, parquet and marble flooring. Using TISOFT software, we design a realistic flooring material that include all the details of both parquet and marble flooring and compare, mathematically, between the two flooring alternatives. To the best of our knowledge, this paper is the first to compare the effect on these two materials on the thermal comfort of a building.

III. METHODOLOGY

A comparative study between marble and parquet flooring will be conducted in this work to understand the contribution of each material to the human thermal comfort in a room. To achieve that objective, we applied two methodologies. First, we intensively studied the similarities, advantages/disadvantages and characteristics of each flooring materials and highlight the results in Table.1. We focus on several comparison items in this study, including, how practical and efficient (i.e., cost, maintenance) each flooring material is and what are the health concerns of using each flooring material. The second methodology is a mathematical comparison between the two flooring materials in terms of their (i) Thermal mass, (ii) Thermal conductivity (K-Value), (iii) R-Value and (iv) U-Value. We will achieve that mathematical comparison using a TISOFT software [9]. K-Value is the measurement of how easy the heat passes through the material. It is a very important measurement to assess the potential for heat transfer between the inside and outside of a building. R-Value is the measure of thermal resistance of a material, in other words, the resistance to heat transfer across the material.

U-Value is the inverse of R-Value. R-Value is calculated as:

$$R - Value = \frac{Thicknessofthematerial}{K - Value}$$

When R-Value of a material is high (and accordingly, the U-Value is low), that means high insulated material.

Starting with the qualitative comparison, we will highlight the advantages and disadvantages of each flooring materials. Marble flooring has a superior decorative appearance and used heavily in royal palaces. It is known for its adaptability in all art forms (i.e., sculptures). Marble is easy to maintain and re-polish when needed and that returns it to shine again. However, marble flooring is very expensive and it is considered to be cool materials where its temperature is usually very low and cannot be considered a good option during the winter (We will discuss that in more detail mathematically in the following).

Comparison	Marble flooring	Parquet flooring
Maintenance	• Last longer than parquet flooring. • It is not recommended in busy areas because that will require frequent maintenance. • Easy to maintain.	• Last for 5 - 6 years. • Require special care and cleanliness without using water.
Cost	Very expensive, used in royal palaces.	relatively cheaper
Installation	Require strong building structure	Easy to install and more suitable for housing
Temperature	Cold stone and it is not suitable in cold climates	provide warmth and does not get cold
Healthy indoor environment	better healthy environment	can create an unhealthy environment due to dust

Table.1: Comparison between Marble and Parquet flooring

Another disadvantage of marble flooring is its weight, the marble is a heavy stone, and therefore, it requires a strong structure for the underlying area before placing the marble flooring.On the other hand, parquet flooring provides warmth better than marble floors and it does not get cold when the temperature is low (we will explain the reasons in the next paragraph). Parquet can also re-polished after shorter period, i.e., 5 or 6 years, compared to the marble floors. Another advantage is the cost where the parquet flooring is very cheap compared to the marble floors which make it more reasonable for housing and flats. However, parquet flooring is very susceptible to wet conditions and it is always recommended to avoid cleaning the parquet floors with water. Also, it is not recommended to move the furniture on the floor to avoid having undesirable scratches. One of the main disadvantages of the parquet floors is that it cannot resist the fire and in case of fire, it might make the situation even worse. Also, it can create unhealthy interior environment due to its ability to collect dust, if it is not cleaned properly. Table.1 summarizes the qualitative comparison between the two flooring materials.

IV RESEARCH AND FINDINGS

Marble and wood flooring are nice flooring choices with their own advantages and drawbacks and that one to buy or get depends on several factors. Including type of space, ability to take care of floor properly and homeowners preferences ought to be taken under consideration whereas selecting between marble and wood.In alternative words, users tend to forget however their alternative of flooring can have an effect on their thermal comfort as a result of each floor has its properties and every property will have an impression on the area temperature that affects health and skills. Thermal comfort is influenced by many factors that primarily contain air temperature, air humidness, air speed, mean effulgent temperature, human clothing, and activity levels. Many specialists during this domain trust that indoor air quality could also be the foremost vital and comparatively unnoticed environmental issue of our time. Indoor pollutants result in poor indoor air quality.The indoor environmental quality impacts not solely health and luxury, however additionally the occupants, productivity, because it powerfully affects operating and learning ability, with results on production and social prices.Parquet flooring is good for many rooms within the house, however not counseled for installation in areas with potentially high wet level such as bogs, powder rooms, or laundry rooms. Best choice for a front room or bedroom. In addition, prefinished wooden floors installation isn't a complicated task and plenty of homeowners are able to

know how to install it. In terms of the cost, it is much cheaper than marble flooring and its lifespan varies from 25 to 50 years. On the other hand, marble is a very popular natural stone for floors. It has unique and elegant appearance with different colors. On the other hand, parquet is a form of wood flooring where different wood materials (e.g., oak, cherry, lime or pine) can be used for flooring and decorative effect. In this study, we will examine which floor material is better for thermal comfort by looking at four factors: (i) Thermal conductivity (K-Value), (ii) R-Value and (iii) U-Value. K-Value is the measurement of how easy the heat passes through the material. It is a very important measurement to assess the potential for heat transfer between the inside and outside of a building. R-Value is the measure of thermal resistance of a material, in other words, the resistance to heat transfer across the material. U-Value is the inverse of R-Value. R-Value is calculated as mentioned above. When R-Value of a material is high (and accordingly, the U-Value is low), that means high insulated material. To accurately measure the U-Value and R-Value, we used Ti-SOFT software [9] where we designed a proper floors using both parquet and marble materials. As illustrated in Fig.2, we constructed a marble floor that consists of several different layers including, marble slabs, cement mortar, plasterboard, cotton, water insulation, concrete, gravel and compact soil. As shown in the figure, the thermal resistance (R-Value) of that constructed floor is 0.4263 $m^2 \frac{K}{W}$which equals to the summation of the R-values of all the layers that construct the flooring material.

[1] The total K-Value (thermal conductivity) is 11.86 $\frac{W}{(m.K)}$. The K-Value is calculated by dividing the thickness of each layer to its R-Value we calculated in the previous step. For example, as shown in Fig.2, the marble slabs thickness is 0.02m and its R-Value = 0.0057 $m^2 K/w$, then the K-Value = $\frac{0.02}{0.0057} = 3.51\, w/m.K$. We calculate the R-Value for each layer using that equation and sum all the values to get the total K-value for the flooring material which is 11.86 $w/m.K$for the marble floor.

[2] The U-Value is the inverse of the R-value which calculated by the following equation, $\frac{1}{R-Value} = \frac{1}{0.4263} = 2.346 \frac{W}{m^2} K$.

On the other hand, the parquet floor consists of different materials and it includes, wooden parquet, acrylics, chipboard, insulation, cotton, plasterboard, concrete, gravel and compact soil. The thermal resistance (R-Value) of that constructed floor is 3.5444 $m^2 \frac{K}{W}$which equals to the summation of the R-values of all the layers that construct the flooring material:

[1] The total K-Value (thermal conductivity) is 7.097 $\frac{W}{(m.K)}$. The K-Value is calculated again using the same methodology as described for marble flooring by dividing the thickness of each layer to its R-Value we calculated in the previous step. For example, as shown in Fig.3, the thickness of wooden parquet pieces is 0.025m and its R-Value = 0.1190 $m^2 K/w$, then the K-Value = $\frac{0.025}{0.1190} = 0.210\, w/m.K$. We calculate the R-Value for each layer using that equation and sum all the values to get the total K-value for the flooring material which is 7.097 $w/m.K$for the parquet floor.

[2] Moreover, the U-Value is the inverse of the R-value which is calculated by the following equation, $\frac{1}{R-Value} = \frac{1}{3.5444} = 0.282 \frac{W}{m^2} K$.

From these results, we can conclude the parquet flooring is better for thermal comfort because it has lower K-Value compared to the marble flooring which means better insulation from the conditions outside and it also has higher R-Value which even be improved by increasing the thickness of the floor..

VII. CONCLUSION

This paper uses a hybrid technique to measure the effect of flooring materials on the thermal comfort. It used a mathematical model to estimate the key parameters that affect the thermal comfort combined with a survey approach to highlight the advantages and disadvantages of both marble and parquet flooring materials from the consumer perspective. In this study, we highlighted that the use of parquet flooring material is more appropriate for thermal comfort because it has lower U-value which is the measurement of the heat transfer rate. In addition, and from the previous results, we can conclude that the parquet material has lower K-Value compared to the marble flooring which means better insulation from the conditions outside and it also has higher R-Value which even be improved by increasing the thickness of the floor.As future work, we are planning to do field test study and to visit commercial office buildings and residential apartments with different installed flooring material to study in real-world what are the effects of different flooring material on the thermal comfort and indoor healthy environment and not focusing only on parquet and marble but also including other materials. In addition, we will study how thermal comfort could affect the employees' performance and productivity.

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