Effects of Decorative Veneer and Structure on the Thermal Conductivity of Engineered Wood Flooring

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This paper explores the thermal conductivity of engineered wood flooring, which is widely used in world market. The effects of decorative veneer type and structure on the thermal conductivity of engineered wood flooring were studied. Four decorative veneer types and three different structures of engineered wood flooring served as test specimens. All samples were placed in a laboratory simulating a heating system environment, of which the temperature should be measured three times every five minutes. The temperature differences between the upper and lower surfaces were as follows: cherry > maple > birch > eastern black walnut. Three types of structures also showed differences in temperature changes, based on five-minute observations. The larger the decorative veneer's density, the higher the thermal conductivity, and the faster the heat transferred, meaning less heat was lost. The thermal conductivity of three-layer engineered wood flooring, with decorative veneer made of sawn wood, exhibited the best properties. The second best of the three samples was the three-layer engineered wood flooring with decorative veneer made of thick veneer and plywood. Finally, a multilayered engineered wood flooring performed the worst. The engineered wood flooring for use in heating systems should be chosen for its larger density of decorative veneer made of sawn wood.

Keywords: Engineered wood flooring; Thermal conductivity; Decorative veneer; Structure of flooring

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INTRODUCTION

At one point in time, engineered wood flooring was widely used; as early as 1970, it gained popularity in Europe. Engineered wood flooring consists of sawn wood or plywood with a thin fancy veneer bonded onto poplar panels or plywood using urea-formaldehyde (UF) and melamine-formaldehyde (MF) resins as hot press adhesive (Kim and Kim 2006). In 1999, one-third of all wood flooring used in the United States was engineered wood flooring. Meanwhile, in the European market, almost 63.8 percent of wood flooring was engineered wood flooring (Blanchet *et al.* 2003). In China, with the rapid development of the construction industry, wood flooring output has been rising at rates ranging from 5 to 20 percent annually (Wang and Guo 2006). In 2013, the overall yield of Chinese wood flooring reached 397 million square meters. As for engineered wood flooring, which already occupied approximately one fourth of the flooring market, its output was as high as 90.7 million square meters. As engineered wood flooring exhibits a natural grain, provides a fine comfort level, and has good stability, its use has flourished in home renovation.

The performance capabilities of engineered wood flooring are put to the test when it is used in a radiant floor heating system. The heat for a radiant floor heating system is provided by hot water, which runs through an X-L pipe, an enclosed electric heating liquid pipe installed under cement mortar board (Kim and Kim 2005). The heating system controls consist of a central control and an indoor control (Olesen 2000). By using this heating system, Korean investigators made a comparison regarding the effect of the installation method on the thermal transfer characteristics of wood flooring. The investigators found that the velocity of thermal transfer for modified engineered flooring, which used adhesives, was faster than that of the laminate flooring, technically showing about 2 °C difference of temperature (Seo *et al.* 2014). They also found that the structure of the flooring, the structure of each component of the flooring, and form of the flooring, has a significant effect on thermal conductivity (Seo *et al.* 2011). In short, there are many factors that influence the thermal conductivity of wood floorings, such as density, structure, temperature, and moisture content of wood (Abdou and Budaiwi 2005; Yu *et al.* 2011; Pi *et al.* 2013). In order to improve the thermal conductivity of the flooring, Son *et al*. (2013) found that flooring panels should be thinner. Seo *et al.* (2012) found that improving the performance of adhesives for wood flooring also can improve thermal conductivity; it was found that using exfoliated graphite nanoplatelets (xGnP) or resin/xGnp composites as adhesive would increase the thermal conductivity.

This research focused on finding the effect of decorative veneer type and structure of engineered wood flooring on thermal conductivity. Improving the thermal conductivity of engineered wood flooring is an important method that saves energy and increases efficiency. Especially used in heating system, the engineered wood flooring is requested to present better thermal conductivity, which can reach the required temperature in the shortest time. Therefore, the goal of work was to provide technical support for improving thermal conductivity of engineered wood flooring used in heating system.

EXPERIMENTAL

Materials

For this research, the engineered wood floorings were provided by Dare (Jiangsu) Parquet Col, Ltd., which is located in Danyang of Jiangsu province in China. The floorings had three types of structure. As shown in Fig. 1, the first type of structure (Fig. 1A) consisted of 4 mm thick decorative face (upper) veneer, 9 mm thick poplar core boards, and 2 mm thick poplar back (lower) veneer. The second type (Fig. 1B) was composed of 4 mm thick face plates (which includes a 1.2 mm thick combination of decorative face (upper) veneer and three-layer plywood), with the remaining structure being identical to Fig. 1A. The third type (Fig. 1C) was made of 1.2 mm thick decorative face (upper) veneer, seven-layer core plywood, and 2 mm of poplar back (lower) veneer.

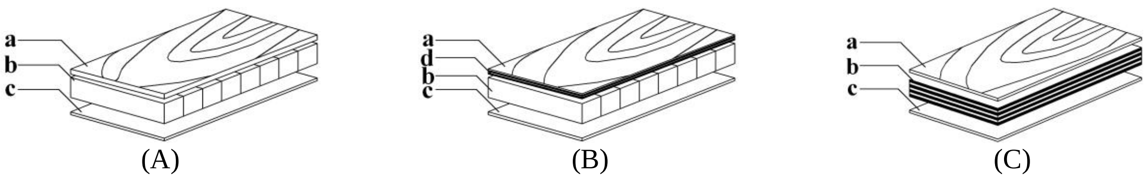

Fig. 1. Three types of structure (A), (B), and (C) of engineered wood flooring: (a) decorative face (upper) veneer, (b) core board, (c) back (lower) board, and (d) plywood

According to a study conducted by Seo *et al.* (2011), the thermal transfer performance of flooring is dependent on the material's thickness. As a result, all three types of engineered wood flooring possessed the same dimensions: 910 mm length, 125 mm width, and 15 mm thickness.

According to Yu *et al.* (2011), the transversal thermal conductivity of wood increases with the density, temperature, and moisture content. The specimens were prepared from four species of hardwoods, which are presented as a function of density. Therefore, four types of wood, with varying densities, were selected as decorative veneer for this study, as listed in Table 1. In order to avoid the influence of moisture content, the original moisture content was controlled within a certain range for all samples.

Table 1. Density of Four Different Decorative Veneers

Veneer Types	Density (g/cm^3)
Eastern black walnut	0.85
Birch	0.75
Maple	0.71
Cherry	0.61

Methods

Testing environment and equipment

The experiment was conducted in a laboratory simulating a heating system environment, which was manufactured by O.S. PANTO S.R.L (Italy). The type of model was SEF, and the control model was DKC18. Figure 2 shows the testing environment, in the laboratory, as described by Kim and Kim (2005). In the lab, a copper pipe was installed with a narrow pitch in a cement mortar. Hot water from a boiler was supplied to the floor coil, which was an X-L pipe underneath the floor surface. On the cement mortar, there was a layer of polyethylene foam. In addition, the laboratory was equipped with a humidifier, which regulated the overall humidity by spraying water vapor in the room (Fig. 2). Figure 3 shows the heat-transfer process.

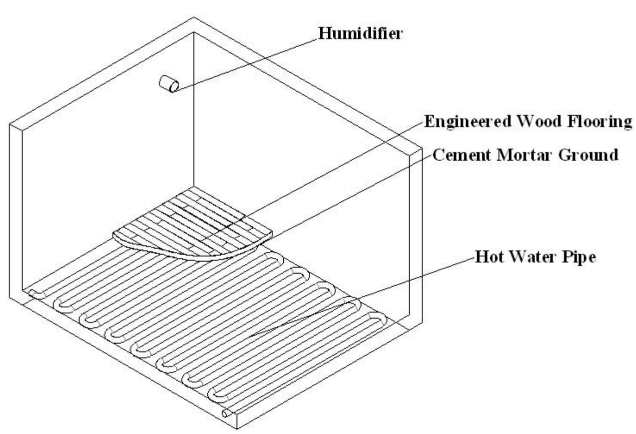

Fig. 2. The testing environment

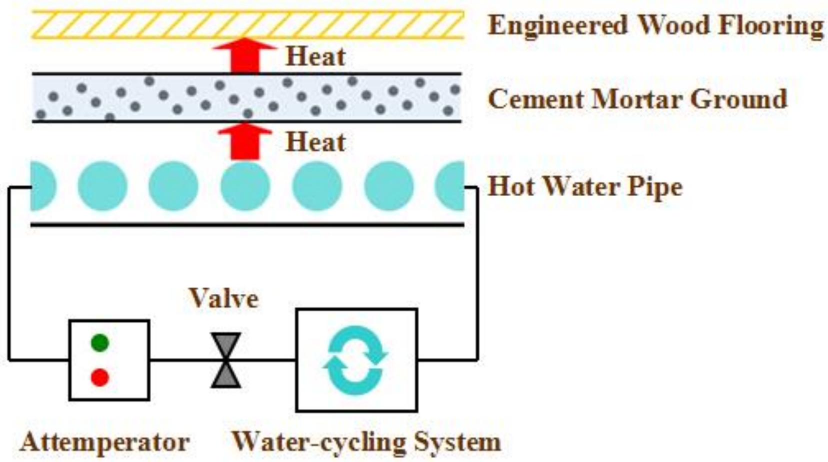

Fig. 3. The process of heat transfer

Thermal conductivity measurement

The thermal conductivity of the wood flooring was measured using a surface thermocouple thermometer, model DT-613, produced by CEM (Shenzhen, China). The temperature was simultaneously measured on the top and bottom surfaces of the engineered wood flooring with a NR-81533B probe (CEM). Table 2 shows the parameters of the thermometer.

Table 2. Parameters of the Surface Thermocouple Thermometer

Model	DT-613
Range of Temperature	-200 °C to 1372 °C
Resolution Ratio	0.1 °C
Error	0.5% ± 1 °C

Plan of the experiment

As Kang *et al.* (2003) have explored, the perfect flooring surface temperature ranged from 22.0 to 38.8 °C. The season in which this experiment was carried out was late autumn, where the outdoor temperature was typically 15 °C during the daytime. Hence, the set temperature for the laboratory environment was 35 ± 2 °C. On account of the heat loss during the hot water transfer through the cement mortar to the engineered wood flooring, the temperature of hot water was set to 40 ± 2 °C.

At first, the primary temperature on the top and bottom surfaces of each engineered wood flooring sample was measured and recorded. Then, the temperature control system of the laboratory was opened and the temperature set to 40 ± 2 °C. Four or five hours later, the indoor temperature was raised to the needed temperature. The temperature of the floor was also measured and recorded at 35.5 °C. Afterwards, all the samples were placed on the ground, in a flat orientation, with the decorative veneer facing upwards. The top and bottom surface temperature of each sample was measured three times every five minutes, and the average value recorded. The experiment was stopped when the variation was too small to detect differences in the final measured data compared to the previous data.

RESULTS AND DISCUSSION

Influence of Different Types of Decorative Veneer

Table 3 shows the values of the primary temperature (T_p), final temperature of the upper surface ($T_{f.up}$), final temperature of the lower surface ($T_{f.lower}$), average final temperature of the lower surface ($T_{f.lower.avg}$), and the temperature variation (T_v) between the final temperature of the upper surface and the average final temperature of the lower surface of the respective engineered wood flooring.

Table 3. Variation in Temperature of Engineered Wood Flooring Decorated with Four Different Veneers

Structure	Veneer type	T_p (°C)	$T_{f.up}$ (°C)	$T_{f.lower}$ (°C)	$T_{f.lower.avg}$ (°C)	T_v (°C)
A	Eastern black walnut	11.1 (0.17)	32.2 (0.20)	35.4 (0.23)	35.3 (0.18)	3.1
	Birch	10.8 (0.21)	31.6 (0.29)	35.2 (0.25)	35.3 (0.18)	3.7
	Maple	11.1 (0.22)	31.8 (0.20)	35.6 (0.18)	35.3 (0.18)	3.5
	Cherry	11.2 (0.22)	30.9 (0.26)	35.5 (0.20)	35.3 (0.18)	4.4
B	Eastern black walnut	11.3 (0.19)	32.1 (0.22)	35.2 (0.18)	35.3 (0.18)	3.2
	Birch	11.1 (0.26)	31.8 (0.24)	35.4 (0.24)	35.3 (0.18)	3.5
	Maple	11.2 (0.20)	30.4 (0.23)	35.1 (0.19)	35.3 (0.18)	4.9
	Cherry	11.4 (0.16)	30.0 (0.22)	35.0 (0.21)	35.3 (0.18)	5.3
C	Eastern black walnut	10.8 (0.24)	30.8 (0.19)	35.6 (0.26)	35.3 (0.18)	4.5
	Birch	10.0 (0.29)	29.6 (0.28)	35.3 (0.24)	35.3 (0.18)	5.7
	Maple	10.5 (0.26)	29.4 (0.17)	35.2 (0.20)	35.3 (0.18)	5.9
	Cherry	11.2 (0.19)	28.9 (0.21)	35.1 (0.25)	35.3 (0.18)	6.4

The standard deviation values are in parentheses

As can be seen in Table 3, the sample's upper and lower surface temperatures rose with time. The lower surface temperatures for all the different decorative veneers were relatively close, because the temperatures typically approached the ground temperature. The average of all the samples' lower surface temperatures was 35.3 °C. The temperature variation for the engineered wood flooring decorated with eastern black walnut was the smallest, with birch being the second smallest. As for cherry, which served as decorative veneer, the temperature variation was the largest. Plainly stated, the heat loss rankings for the four types of decorative veneer, from small to large, were as follows: eastern black walnut, birch, maple, and cherry. Furthermore, the coefficient of thermal conductivity is proportional to the density of wood (MacLean 1941). The density of the four types of decorative veneer are as follows: eastern black walnut > birch > maple > cherry. Additionally, the thermal conductivity of four types of decorative veneer were as follows: eastern black walnut > birch > maple > cherry. The coefficient of thermal conductivity is inversely proportional to heat loss (Tritt 2004). Therefore, among the four types of wood densities for decorative veneer, the values of heat loss can be ordered: eastern black walnut > birch > maple > cherry.

Figure 4 shows the upper surface temperature trends for engineered wood floorings decorated with four different veneers. The values in the figure are based on Table 3 and the standard deviation when ranged from 0.14 to 0.31. The primary temperature (T_p) and final temperature of the upper surface ($T_{f.up}$) of different types of decorative veneer could be seen clearly in Table 3, the change values for every five minutes were shown in Table 4.

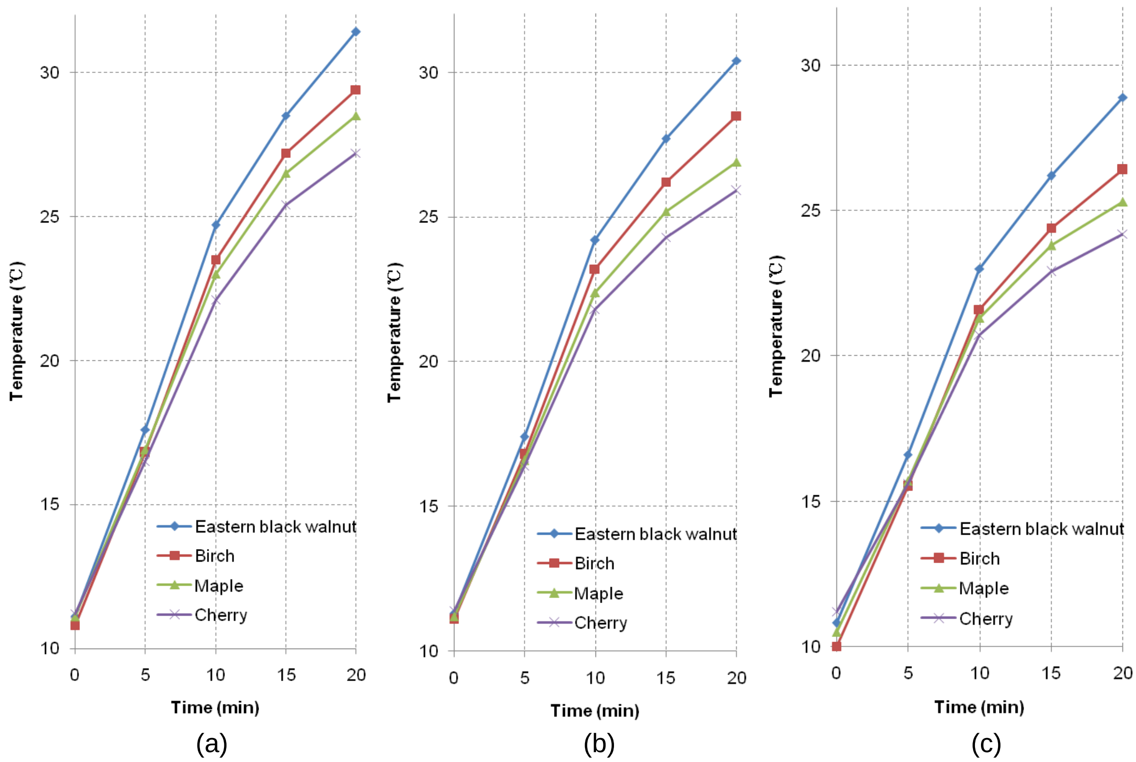

Fig. 4. The upper surface temperature trends for engineered wood floorings that were decorated with four different veneers: eastern black walnut, birch, maple, and cherry. (a) structure A, (b) structure B, and (c) structure C

In Fig. 4, comparing the final temperature of the four different decorative veneers, regardless of the structure, the results indicated that eastern black walnut shows the highest temperature, while cherry shows the lowest temperature. Furthermore, the greater the change, the faster the temperature rises. Table 1 indicates that the larger the density of the decorative veneer, the faster the temperature changes, and the better the thermal conductivity. As can be seen from Table 1 and Fig. 4, the density of the decorative veneers had a larger effect on the speed of the temperature increase. The distance between the molecules became shorter as the density increased (Carbó *et al.* 1980). As a result, the heat would be easier and faster to transfer. In addition, the macroscopic gap in the wood with a smaller density would be larger. These gaps are full of air, and the distance between the air molecules is larger than the component molecule of wood. The larger distance means the speed of heat transfer would be slower. Therefore, the results for the heat-transfer rate for the four different decorative veneer are ordered as follows: eastern black walnut > birch > maple > cherry.

Influence of Different Structures of Engineered Wood Flooring

As can be seen in Table 3, for decorative veneer made of eastern black walnut, the temperature variation of structure A was the smallest, followed by structure B, while structure C was the largest. This trend can also be seen for the other three decorative veneers. As a result, the heat loss for the three structures, from small to large, was as follows: structure A, structure B, and structure C.

There are various structures of engineered wood flooring, as shown in Fig. 1, and the different structures lead to different results for the thermal conductivity.

Table 4. Change in Temperature for the Three Structures of Engineered Wood Flooring

Veneer type	Structure	Temperature variation every 5 min (°C)											
		5	10	15	20	25	30	35	40	45	50	55	60
Eastern black walnut	A	6.5	7.1	3.8	2.9	0.5	0.1	-0.2	0.3	0.4	-0.2	0.1	0.0
	B	6.1	6.8	3.5	2.7	0.4	0.5	0.2	0.3	0.3	0.1	-0.1	0.0
	C	5.8	6.4	3.2	2.7	0.4	0.3	0.3	0.4	0.2	0.2	0.2	-0.1
Birch	A	6.0	6.7	3.7	2.2	0.5	0.6	0.3	0.3	0.1	0.2	0.1	0.1
	B	5.7	6.4	3.0	2.3	0.6	0.3	0.6	0.3	0.3	0.5	0.2	0.2
	C	5.5	6.1	2.8	2.0	0.7	0.6	0.5	0.4	0.4	0.5	0.2	-0.1
Maple	A	5.8	6.1	3.5	2.0	0.6	0.7	0.7	0.4	0.5	0.3	0.1	0.0
	B	5.4	5.8	2.8	1.7	0.8	0.7	0.5	0.5	0.5	0.4	0.2	-0.1
	C	5.2	5.6	2.5	1.5	0.8	0.6	0.8	0.8	0.6	0.3	0.1	0.1
Cherry	A	5.3	5.6	3.3	1.8	0.8	0.7	0.7	0.5	0.3	0.3	0.2	0.2
	B	5.0	5.4	2.5	1.6	0.9	0.8	0.8	0.7	0.6	0.4	-0.2	0.1
	C	4.4	5.1	2.2	1.3	1.0	0.8	0.7	0.8	0.6	0.5	0.2	0.1

- Represents a reduction in temperature; the standard deviation of these values ranged from 0.17 to 0.39

Table 4 shows the change in the upper surface temperature due to the flooring structure. The surface temperature for the three different structures rose due to the rising temperature of the lab environment. In the range of 10 min to 20 min (during which the temperature exhibited an obvious upward trend), it can be found that the temperature variation for structure A was the largest, followed by structure B, while structure C was the smallest, as shown in Table 4. At the same time (5 min), take eastern black walnut for instance, the temperature variation of structure A, B, and C are 6.5 °C, 6.1 °C, and 5.8 °C, respectively, in the first five minutes, and thus the large temperature variation means results in superior thermal conductivity (Callaway 1959).

It turns out that the saw-cut decorative veneer made of wood sheet, namely structure A, exerted the best performance for thermal conductivity among all three structures. This may be because the engineered wood flooring of structure A is compact in relative terms, and the adhesive for all samples are the same, so that the gap between the plies is small. As a result, it reduced the heat loss during the transferring process from air to plies. On the other hand, the density for the three structures are ranked as follows: structure A > structure B > structure C, as mentioned, the coefficient of thermal conductivity is proportional to the density of wood (MacLean 1941). Therefore, the thermal conductivity of the three structures are ranked as follows: structure A > structure B > structure C.

Figure 5 shows the temperature upward trends for the different engineered wood flooring structures. The values in the figure are based on Tables 3 and 4. The standard deviation ranged from 0.12 to 0.28. The first 20 min (during which the temperature rose steadily), the surface temperature of structure A rose the fastest, as shown by its biggest slope. Meanwhile, the temperature of structure C rose the slowest, as it has the smallest slope. Thus, the thermal conductivity of the three different engineered wood flooring structures were as follows: structure A > structure B > structure C.

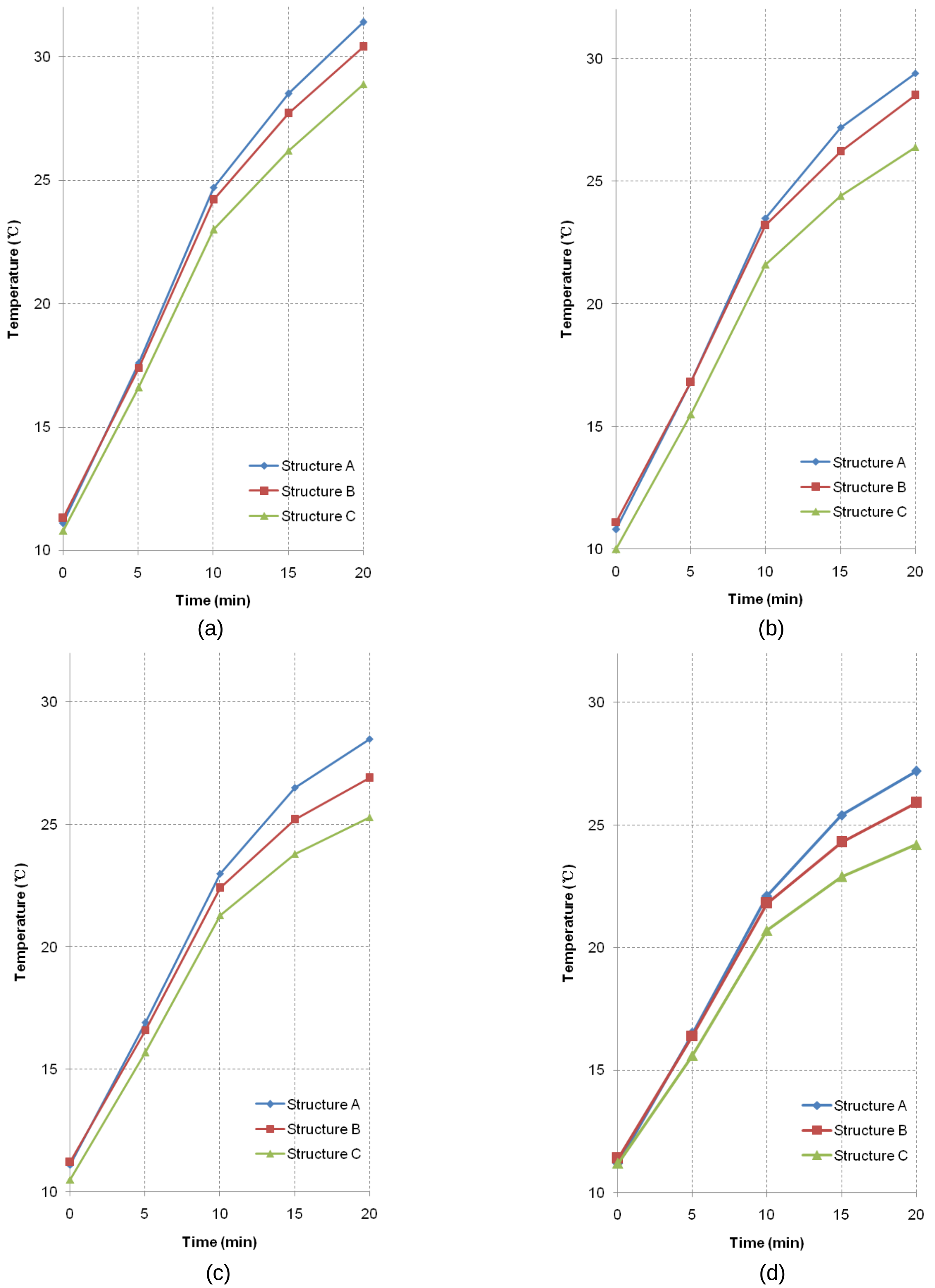

Fig. 5. The temperature uptrend of different engineered wood flooring structures: (a) Eastern black walnut, (b) Birch, (c) Maple, and (d) Cherry

CONCLUSIONS

1. Comparing engineered wood floorings that have the same structure, but different decorative veneers, it was found that the larger the decorative veneer density, the better the thermal conductivity and the faster the temperature transfer, resulting in less heat loss.
2. The flooring structure of samples with the same decorative veneer also had an influence on thermal conductivity. The thermal conductivity of three-layer engineered wood flooring with decorative veneer, made of sawn wood, exhibited the best properties. Then, the three-layer engineered wood flooring with decorative veneer made of thick veneer and plywood exhibited the second best properties. However, the thermal conductivity of multilayer engineered wood flooring showed the worst performance.
3. In conclusion, the engineered wood flooring should be chosen for its larger density of decorative veneer made of sawn wood for use in heating systems.

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