Improvement of Thermal Conductivity of Underlay Foam for Laminate Flooring to Reduce Heating Energy

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In recent years, research on low-energy building materials has actively progressed, with a growing interest in eco-friendly building. Strong interest has also been shown in the wooden flooring sector to improve the thermal conductivity of under floor heating systems. This study focused on improving the thermal transfer performance of radiant floor heating systems by enhancing the characteristics of the existing polyethylene underlay foam (PE foam). The thermal conductivity of the modified PE underlay foam (MPE foam) was increased by 48.1% compared with that of the PE foam. The theoretical heat flux was also calculated for the thermal conductivity, the results of which showed that the heat flux of the MPE foam was enhanced by 24.1%, compared with that of the underlay foam. To confirm the theoretical results, flooring systems were installed in the laboratory as a replica for the experiment. The velocity of thermal transfer for the laminated flooring used with the MPE foam was slower than the engineered flooring in which adhesive was used. However, the velocity of transfer was faster for the laminate flooring incorporating the PE foam. In addition, after the heating was switched off, the heat storage capacity of the laminate flooring with the modified PE foam was the highest among the tested samples.

Keywords: Wood-based materials; Laminate flooring; Energy conservation; Underlay foam; Polyethylene foam; High density fiberboard (HDF)

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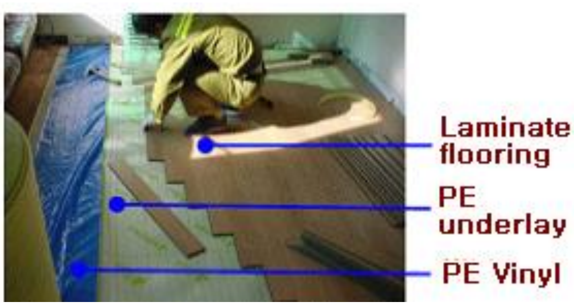
INTRODUCTION

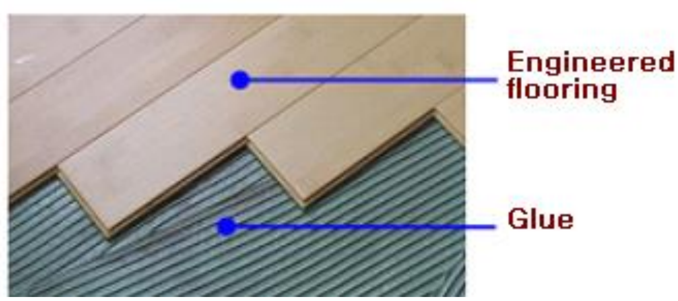
The Fourth Intergovernmental Panel on Climate Change (IPCC) Assessment Report, "Climate Change 2007," warns of threats to humanity's survival resulting from changes in the climatic environment, where global warming is no longer a distant problem, but one that requires our awareness as a serious threat today. The importance of such awareness requires full responses at national, regional, and global levels (Forsberg and von Malmborg 2004; Frank 2005; Seo *et al*. 2011). The growth rate of greenhouse gas emission *per capita* in Korea was the highest in the world from 1990 through 2004 (Chung *et al*. 2009). Moreover, 83% of the domestic greenhouse gas emissions were derived from energy use in the year 2004. Korea belongs to the second group of nations that required a mandatory reduction in greenhouse gas emissions, starting in 2013. Therefore, Korea is making particularly strident efforts to prepare for national measures to reduce the energy consumption and limit carbon dioxide emissions within the construction industry, which is responsible for over 40% of all carbon dioxide production.

To pursue sustainability in the construction industry, the existing development-focused construction activities must be transformed *via* a new paradigm, focusing on sustainable development through the adoption of sustainable policies by the government and the development and dissemination of sustainable construction technologies (Tae and Shin 2009; Chung *et al*. 2009). Buildings account for 20% to 40% of the total energy consumption in developed countries (Pérez-Lombard *et al*. 2008). In Korea, the energy consumption of buildings is more than 23% of the total energy consumption and, similar to other developed countries, this is increasing (Seo *et al*. 2011). With the increasing economic standards among Koreans, concerns about human health and the environment have been escalating because of the increasing demand for a wide range of flooring products. Among them, laminated flooring and plywood flooring have recently been improved for use in apartment building and various other building sectors.

The radiant floor heating system, On-dol, has conventionally been used in Korea. Hot water from a boiler is piped to a floor coil, which is an XL pipe underneath the floor surface. The thermal storage mass consists of cement mortar, which replaces the traditional stone slab (Park *et al*. 1995; Yeo *et al*. 2003; Song 2005; Kim *et al*. 2008; An *et al*. 2010). Polyvinyl chloride (PVC) flooring and laminated paper flooring, treated with soybean oil, were traditionally the most common housing materials, but they are now beginning to be replaced by wooden flooring, especially in apartments (Suleiman *et al*. 1999). Wooden flooring has many advantages, such as hardness, durability, high resistance to fire, excellent appearance, and high latent heat. Two types of installation methods are used: adhesive and floating with polyethylene (Seo *et al*. 2011). Figure 1 shows the two types of installation methods. The average thermal conductivity is as follows: laminate flooring (0.115 W/mK) > solid-wood flooring (0.112 W/mK) > modified engineered flooring (0.111 W/mK) > engineered flooring (0.104 W/mK). Laminate flooring and solid-wood flooring have high density, as they are made of high density fiberboard (HDF) and thick solid wood, respectively. The thermal transfer performance depends on the flooring thickness and the installation method. The thermal conductivity of laminated flooring is higher than that of engineered flooring. However, flooring in which the adhesive installation method is used has a higher performance than that in which the floating installation method is used (Seo *et al*. 2011).



Laminate flooring Installation



Engineered flooring Installation

Fig. 1. Installation method of laminate flooring and engineered flooring

Polyethylene (PE) vinyl is used in laminated flooring, as shown in Fig. 1, where polyethylene underlay foam (PE foam) is used for floor leveling and for preventing moisture. However, the PE foam has a low density and offers poor heat conduction. Thus, in the winter, more heating energy is used compared with other types of flooring. Several researchers have studied a variety of PE foam types for building components, such as for roofing, flooring, and walls. Roels and Deurinck (2011) focused on the influence of the emissivity, changes of temperature, and heat fluxes of roof underlay foam on the global thermal behavior of sloped roofs according to climatic conditions. Moreover, Lindfors and Bjork (1997) studied the performance of various modern products intended for underlay in steep roofs. They tested for durability against thermal degradation and against water on the roof, and the effect of the combination of water, heat, and cold with natural ageing. The effect of water flowing over the installed products was also studied. In previous research, a mock-up was made to analyze the heat transfer analysis of wood flooring. From the research, it was confirmed that the heat transfer property of laminate flooring is lower than that of engineered flooring. The result of the heat transfer analysis of the wood flooring is shown in Fig. 2 (Seo *et al*. 2011).

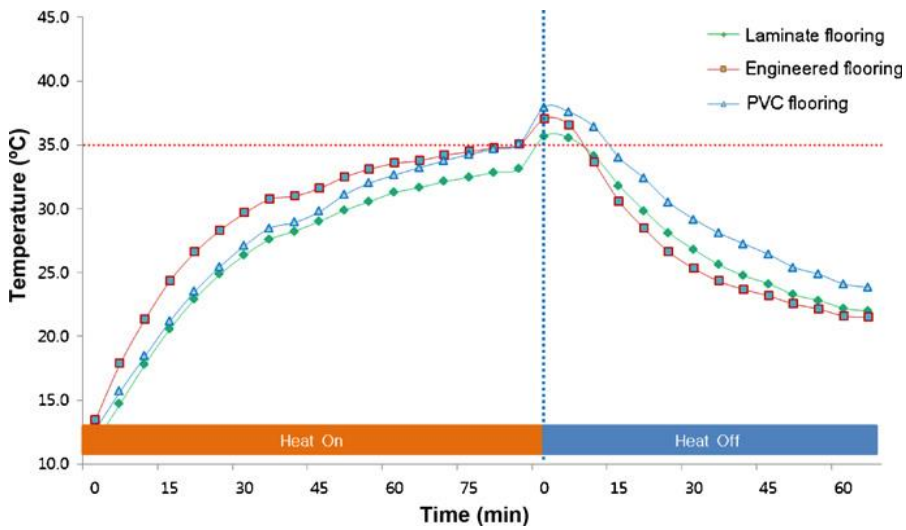


Fig. 2. Heat transfer analysis of wood flooring (Seo *et al*. 2011)

In this current study, the characteristics of the PE foam that were used with the laminated flooring installation were determined to seek improvement of the PE foam for an effective thermal transfer. Also, the modified PE (MPE) foam was compared with the PE foam, according to a mock-up test for thermal conductivity and effectiveness.

EXPERIMENTAL

Materials

In this study, the laminated floor and the engineered floor materials were provided by LOT Co. The laminate floor comprises a core of high-density fiberboard, while the engineered flooring is composed of plywood with a thin decorative veneer bonded onto the face of the plywood using urea- and melamine-formaldehyde resins as hot-press adhesives. PE foam is a sheet made of high-density PE, with admixtures and filling gas. It contains many air cells and has a low specific gravity. Also, the difference in foaming ratio causes a difference in the density of PE foams. This means that a low foaming ratio results in a high-density of PE foams. Table 1 shows the properties of the PE foam for the laminated floor construction. The properties of MPE shown in table 1 were measured after the punching process. As mentioned above, the laminate flooring with the PE foam used more heating energy in the winter. In this study, modified polyethylene underlay foam (MPE foam) was used for improving the heat transfer property of laminate flooring.

Table 1. Properties of PE Foam and MPE Foam

Samples	Foaming ratio	After process	Density	Thickness	Picture
PE foam	40x	None	22 kg/m^3	2 mm	
MPE foam	35x	Making hole	35 kg/m^3	2 mm	

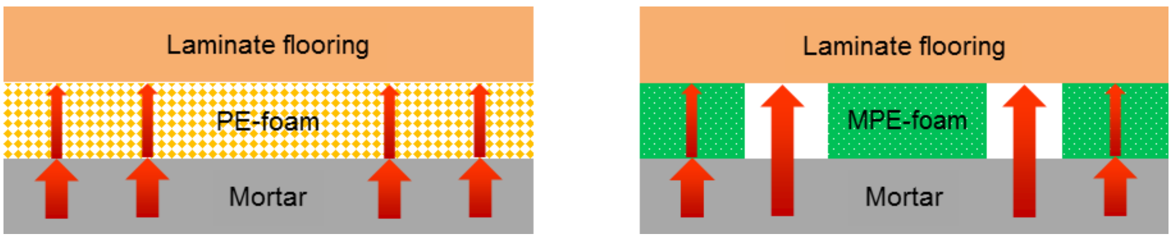


Fig. 3. Comparison of the heat transfer method between the PE foam and MPE foam

To enhance the thermal transfer performance of the PE foam, this study focused on the direct heat transfer through the punched parts of the PE foam. The punched parts were prepared by tension applied after cutting the PE foam at equal intervals. The diameters of the short side and long side of the punched holes of the MPE foam are 10 mm and 15 mm, respectively. In addition, the thickness of the MPE foam is 2 mm. The characteristics of the MPE foam are shown in Table 1.

The methods of heat transfer through the PE foam and the MPE foam are presented in Fig. 3. As shown in Fig. 3, the MPE foam has a suitable structure to transfer heat to the floor, with less density of material hindering the heat penetration.

Methods

The thermal conductivities of the PE foam and the MPE foam were measured using a Heat Flow Meter 436 (HFM 436/3/1, NETZSCH Gerätebau GmbH, Selb, Germany), according to ISO 8301 (1991). Heat Flow Meters (HFM) are exact, fast, and easy-to-use instruments for measuring the thermal conductivity (λ) of low conductivity materials such as insulation. The HFM is a calibrated instrument which performs tests according to ASTM C518, ISO 8301, JIS A1412, DIN EN 12664, and DIN EN 12667. A sample was placed between a hot plate and a cold plate, and the heat flow created by the well-defined temperature difference was measured with a heat flux sensor. The sample size was 300 mm x 300 mm, and the same thickness of the samples was used for all of the components of the laminated flooring structure, because the thickness of the PE foam was too thin to measure the thermal conductivity using a Heat Flow Meter 436. The quantities of the heat flux for the PE foam and the MPE foam were calculated in accordance with the equation for flat materials of KS F 2803 (1996), the standard practice for thermal insulation works. The surface heat transfer coefficient of 12 W/m^{2}K was used for KS F 2803. The equation is as follows,

$$Q = \frac{\theta_o - \theta_r}{\frac{X}{\lambda} + \frac{1}{\alpha}} \tag{1}$$

where Q denotes heat flux; plain material (W/m^2), θ_o and θ_r are the internal temperature (°C) and outdoor temperature (°C), respectively, and X, λ, and α are the thickness (m), thermal conductivity (W/m·K), and heat transfer coefficients (W/m^2·K), respectively. Thermal transfer performance tests for the PE foam were conducted. A heat film was placed on 50 mm of extruded polystyrene (XPS) insulation; the PE foam and the MPE foam were then installed with the laminated flooring, following a practical construction method.

The adhesive used for the engineered flooring was also tested. The temperature of the heat film was set at 45 °C, and the heat travel times of both types, in relation to the temperature of the surface of the flooring at the start and finishing time, 35 °C, were compared.

RESULTS AND DISCUSSION

Thermal Conductivity

The thermal conductivity was measured in accordance with ISO 8301 (1991), the test methods for the thermal transmission properties of thermal insulation and the MPE foam, and the MPE foam that was adhered to the bottom side of the laminated floors. As shown in Fig. 4, the thermal conductivity of the MPE foam with laminate flooring was 48.1% greater than that of the PE foam. This is because the structure with the punched holes to transfer the heat directly is more capable of thermal conductivity. In particular, it is possible to effectively transfer heat to the surface of the laminated flooring by regularly eliminating the specific size of foam that hinders the heat transfer.

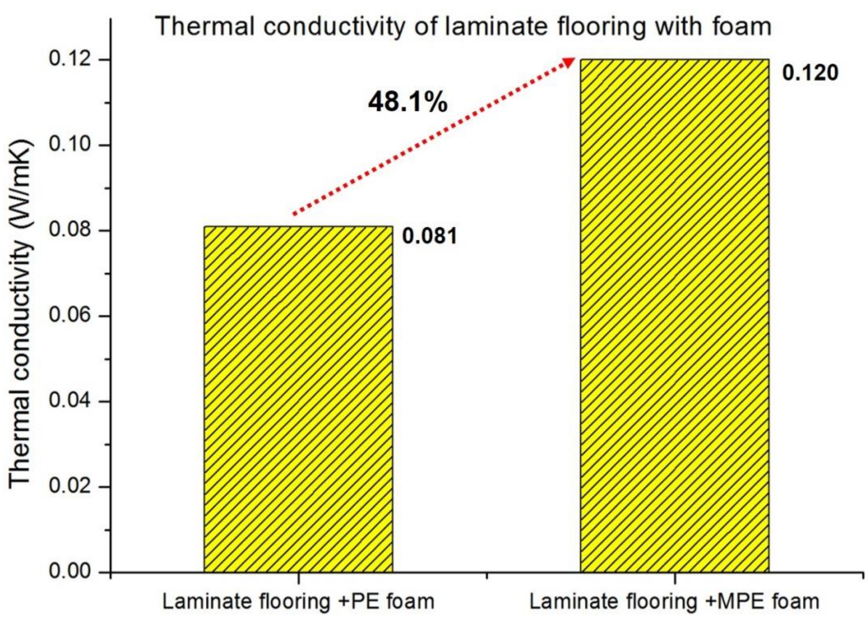


Fig. 4. Thermal conductivity of laminate flooring with PE foam

Table 2. Precondition of Computation Analysis

Floor heating Temperature	External ambient temperature	Thermal conductivity		Surface combined heat transfer coefficient
		Laminate flooring with PE foam	Laminate flooring with MPE foam	
45 °C	25 °C	0.081 W/m·K	0.120 W/m·K	12 W/m²·K (KS F 2803)

Heat Flux

The heat flux of PE foams was calculated following KS F 2803 (1996), and the surface of the laminated flooring and the conditions are presented in Table 2. With the above conditions, the heat flux of the PE foam and the MPE foam with laminated flooring can be calculated, as shown in Fig. 5. In other words, a difference was observed between the heat flux of the MPE foam with the laminate flooring and the PE foam. The difference was 23.29 W/m², and with respect to effectiveness, the MPE foam theoretically showed a 24.1% larger heat flux than the PE foam. Naturally, this will vary depending on the level of insulation and the usage characteristics in each case.

Thermal Transfer Performance

The heat transfer performance testing of the PE foam and the MPE foam was conducted to compare the surface temperature of the samples. The two types of PE foam were installed using practical floor components with insulation. In addition, in the case of the adhesive used in the engineered floor, urea-melamine-formaldehyde resin was used to install the finished flooring. Testing equipment was fabricated to measure the thermal transfer characteristics of the plywood flooring and two types of PE foam were installed laminate floorings. Insulation panels were installed on the floor and a suitable under-floor heating system was installed on the insulation panels. The tested radiant floor heating (ONDOL) system was modernized, with a gas boiler installed instead of using forest and briquette fuel. Hot water from a boiler is supplied to a floor coil consisting of X-L pipes underneath the floor surface (Seo *et al*. 2011). However, because of the difficulty in gaining detailed control of the surface temperature when using hot water supplied from a boiler, small area heating panels (850mm×1700mm) were used for easy installation. The flooring materials were installed on the heating panels depending on the actual installation: adhesive or floating with polyethylene insulation. Five temperature sensors were set on each flooring material. The data logger used was a midi LOGGER GL800 by Graphtec.

The results of the heat transfer performance of the three types are shown in Fig. 6. Thermal transfer performance tests were conducted with the process of starting with the heat on, and then switching the heat off when the surface temperature of the samples reached 35 °C. The order of the heat travel times for the heating to reach 35 °C of the surface temperature of the flooring were 23 minutes for the engineered flooring, 33 min for the MPE foam with the laminate flooring, and 38 min for the PE foam with the laminate flooring. From these results, the MPE foam with the laminate flooring showed less heat transfer performance than that of the engineered flooring, but it was better than the PE foam and the MPE foam with the laminate flooring, which reached 35 °C of the surface temperature 5 min earlier than the other flooring materials. On the other hand, after the heating was switched off, the order of the cooling travel time to reach 35 °C was the engineered floor, the PE foam with the laminate flooring, and then the MPE foam. This means that the laminate flooring with MPE foam successfully maintained the thermal energy compared to the laminate flooring with PE foam. This indicates that the laminate flooring has a larger heat storage capacity than that of the engineered flooring. Moreover, the MPE foam with the laminate flooring showed a larger heat storage capacity than that of the PE foam with the laminate flooring, due to the arrangement of the air layer in the punched parts of the MPE foam.

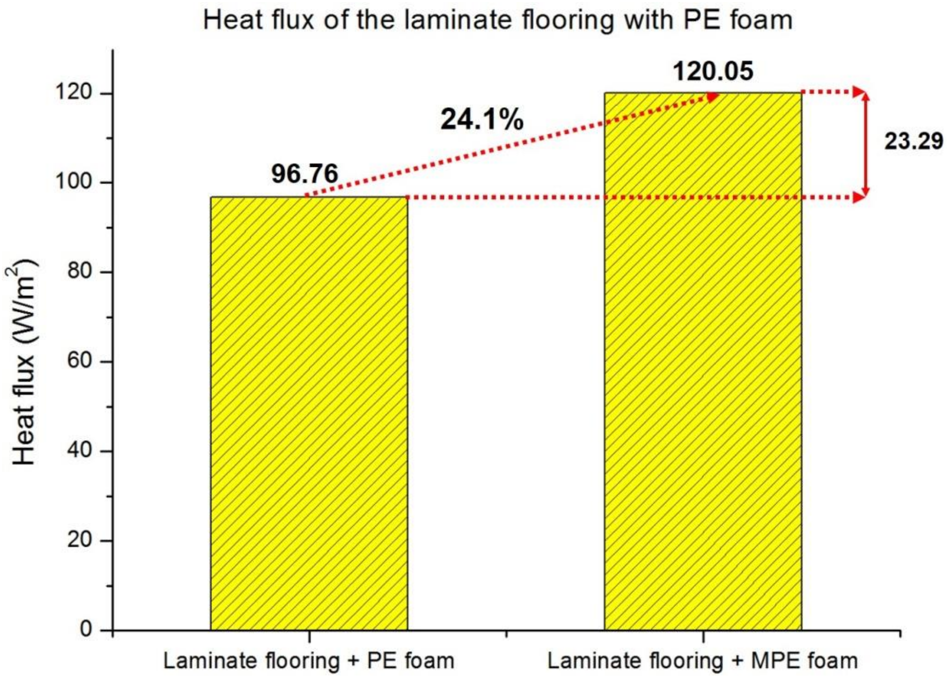


Fig. 5. Heat flux of the laminate flooring with PE foam

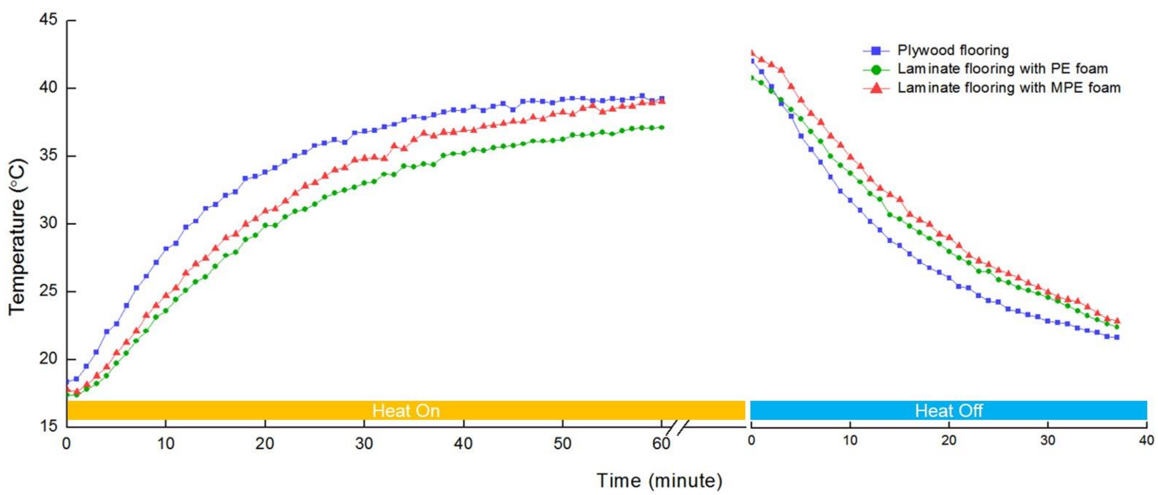


Fig. 6. Thermal transfer and latent heat performance of laminate flooring with PE foam and engineered wood flooring

CONCLUSIONS

1. The thermal conductivity of PE foam with laminate flooring was 0.081 W/m·K, and that of MPE foam with laminate flooring was 0.12 W/m·K. Therefore, the modified flooring showed 48.1% increased thermal conductivity compared to the PE foam with laminate flooring.
2. As a result of the theoretical calculation of the heat flux for flat-shaped samples at 12 $W/m^2 \cdot K$ of the heat transfer coefficient on the surface, the MPE foam with the laminate flooring will have a 24.1% larger heat flux than that of the floor of the PE foam at 45 °C of the heat source temperature.
3. A test for the thermal transfer performance of the PE foam through the laminate flooring from the heat source to the surface was conducted. The travel time to reach 35 °C of the surface of the flooring was measured. The travel time of the MPE foam with the laminate flooring was 33 min, and that of the PE foam with the flooring was 38 min. This result showed that the MPE foam had improved the thermal transfer performance by as much as 5 min.
4. The travel time of the engineered flooring in which adhesive was used was 23 min under the same conditions as the laminate flooring tests, which was 10 min faster than the MPE foam with the laminated flooring. Therefore, the thermal transfer performance of the MPE foam with the laminated floor was less than that of the engineered flooring because of the difference in the construction method. After the heating was switched off, the heat storage capacity of the flooring for the MPE foam was the largest amongst the samples because of the air layer in the punched parts in the MPE foam.

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