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Study Title: Floor Radiant Heating System with PCM

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ABSTRACT

This study deals with the application of PCM to the floor heating system. The results of this study are summarized as follows: (1) The existing, in Korea, floor heating system has the problem that a large amount of hot water and energy are consumed because of the low thermal storage performance of light weight aerated concrete and mortar. To solve this problem, we proposed a design of the floor heating system with PCM by applying PCM as a thermal storage material. That is, the floor heating system with PCM is constructed by applying floor construction materials in the order of the 210 mm concrete slab, 20 mm buffer material, 15 mm mortar, 10 mm PCM aluminum case, 55 mm mortar, and the floor finish. (2) The applicable melting point of PCM for the floor heating was calculated using the heat transfer model equation proposed in this study, and when the 5 mm wood floor finish was applied, the melting points of PCM products available were calculated to range from 32 ℃ to 39 ℃.

1. INTRODUCTION

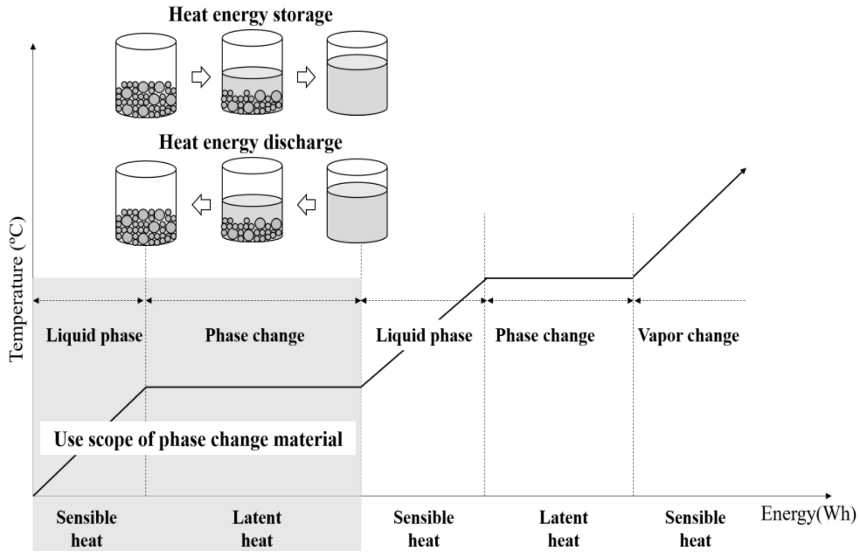
In Korea, multi-family residential buildings account for about 65% of residential buildings, and most of multi-family residential buildings use floor heating systems (Korean Statistical Information Service [KSIS], 2015). On the other hand, it is generally known that while dry construction methods are used in constructing the floor heating system in advanced countries (Drya et al., 2015; Muriel et al., 2016), concrete-based wet construction methods and hot water as a heat source are used in Korea (Lee et al., 2004). In particular, existing floor heating systems have low thermal storage performance and thus have the problem of energy consumption because of a sudden drop in the surface temperature of the floor when hot water supply is interrupted (Bai et al., 2012; Jeong et al., 2013; Jang et al., 2009).

Therefore, in this study, the design of a new floor heating system with PCM was proposed after analyzing the problem through investigation of existing floor heating systems.

2. THE CONCEPT AND CHARACTERISTICS OF THE PHASE CHANGE MATERIAL (PCM)

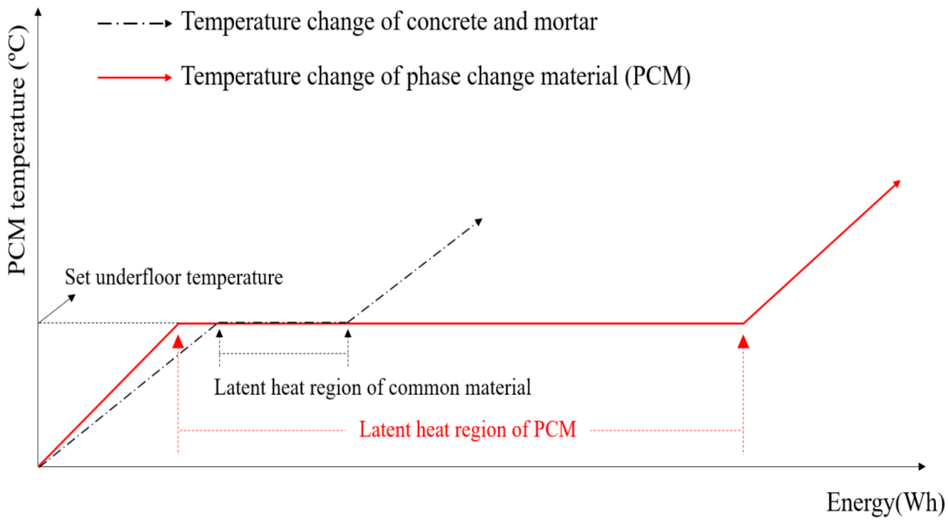
PCM is an energy storage medium that maximizes the thermal storage performance by artificially deforming the bonding form of the particles constituting the material. PCM stores heat while it is converted from a solid state to a liquid state (melting process) or from a liquid state to a gaseous state (evaporation process), and it releases heat during the reverse processes (liquefaction / solidification). The processes of thermal storage or heat release of PCM are shown in Fig. 2.1.

Figure. 2.1 Changes of the physical state of PCM by sensible heat and latent heat



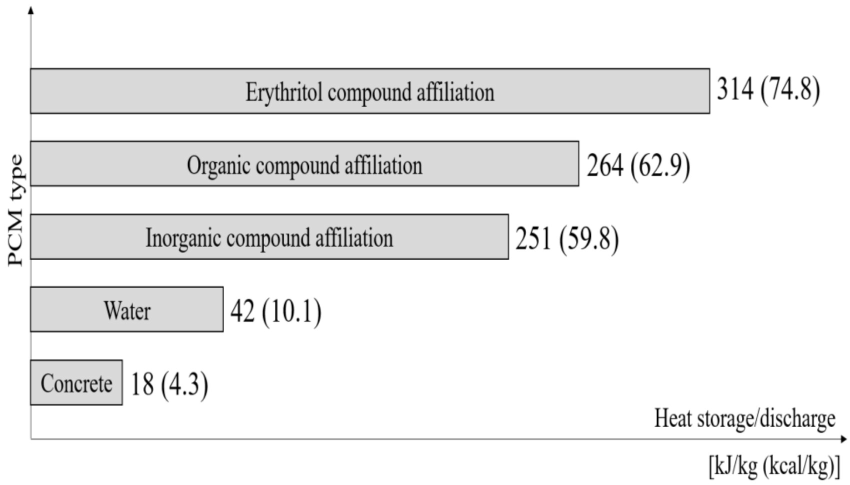
In addition, a key feature of PCM is that it artificially keeps the phase change process long enough to store a large amount of heat in the form of latent heat compared with sensible heat, as shown in Fig.2.2. The energy storage performance of PCM is excellent compared to other materials because the latent heat change period is considerably long.

Figure.2.2 Characteristics of sensible and latent heat of general materials and PCM



PCMs can be divided into three groups according to the kind of raw material and particle type: ① organic compound, ② inorganic compound, and ③ erythritol. There is a large difference in the phase change capability, energy storage, and emission performance among the three groups of PCM. The heat capacity data for each type are shown in Fig. 2.3.

Figure.2.3 Heat capacity according to the type of PCM



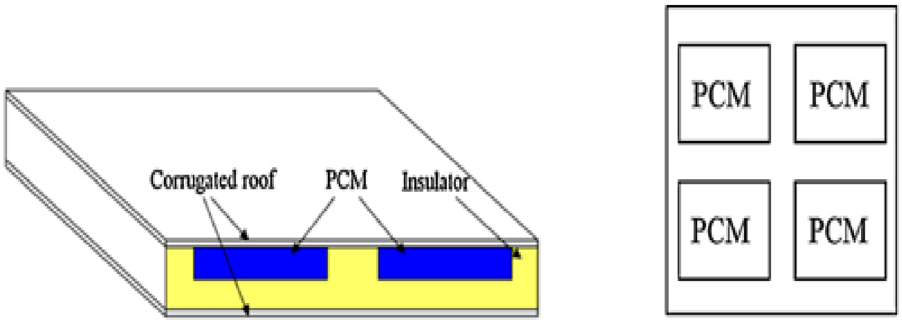
Meanwhile, since the PCM changed into a liquid state by the heat absorbed in the initial solid state has viscosity similar to that of water, it is impossible for PCM to maintain its shape in the process of phase change by itself. Therefore, in order to maintain PCM in a certain form, it must be used in a sealed container so that a phase change can occur in a stable condition. If excessive heat is supplied to PCM during the heat accumulation process after the container with PCM is inserted into the floor structure, the volume of the container itself may be expanded or destroyed due to an increase in the pressure in the container, and in this case, there is a high possibility that the PCM discharged from the container will be absorbed by the concrete or the mortar and it will cause cracks and decrease the strength.

In order to prevent such problems, it is important that the usage range of PCM should be limited so that the phase change process can be repeated in a way that the change from the solid state to the liquid state and the reverse process occur alternately, that is, melting and solidification take place alternately. In addition, there is a large difference in the latent heat storage and release performance depending on the type of PCM of each series, and the melting point of PCM is very diverse. Therefore, when using PCM, it is necessary to select and use the appropriate melting point and type of PCM on the basis of various thermal and physical environments of the system into which PCM is inserted and of the application area.

3. RESEARCH TRENDS AND FACTORS AFFECTING PCM APPLICATION IN BUILDINGS

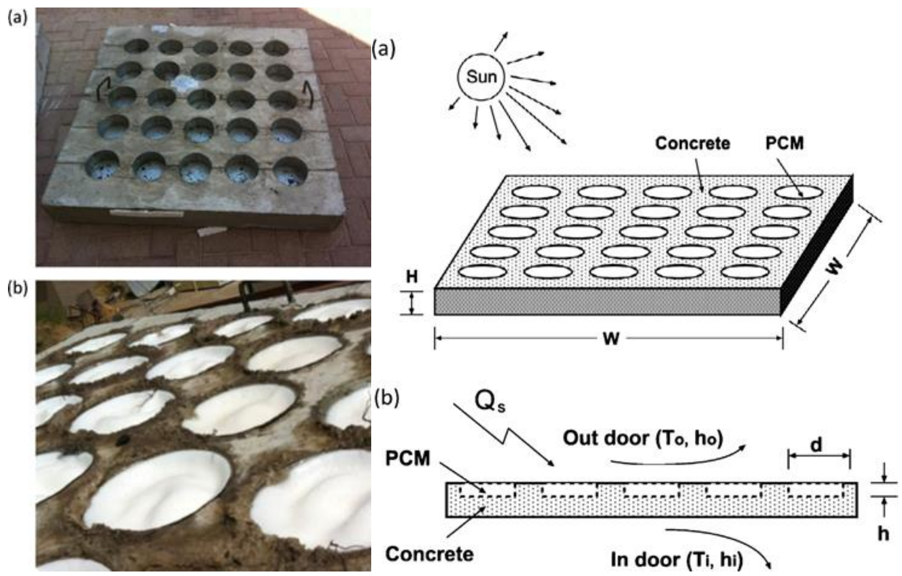
In this study, the research trends for application of PCM to buildings were analyzed. First, Chou et al. evaluated the thermal performance of the roof with the additional insulation material and PCM. His research results showed that the lower peak temperature was observed for the roof where both the insulation material and PCM were applied, and the energy reduction rate was about 52.7% for the insulated roof containing PCM (Fig. 3.1).

Figure.3.1 The insulated roof with PCM



Alawadhi et al. derived a research result of reducing the total heat flux by 39% by applying n-eicosane PCM in the form of a cylinder and cone in the concrete structure applied to the roof layer (Fig. 3.2).

Figure.3.2 The roof layer concrete structure with PCM



In addition, Kośny et al. conducted a study on the reduction of heating and cooling loads of the building by constructing a thermal storage layer on the roof layer of inclined solar panels by applying Bio PCM, and reported that the heat flow of the roof layer was reduced by 90%.

Based on the research results of the existing literature, the factors to be considered for PCM application in building construction were identified as shown in Table 3.1.

Table 3.1 Factors affecting PCM application in buildings

type of factor	description
outdoor and surface temperature	The outdoor temperature and surface temperature are affected by the season and climate zone of the building to which PCM is intended to be applied. The outdoor and surface temperatures affect the layer to which PCM has been applied and produce a difference in the heat transferred to the internal structure.
phase change temperature	The determination of the phase change temperature is influenced by the outdoor temperature and surface temperature, and the target temperature is set according to the applied area. When applied outside the building, the outdoor temperature and surface temperature are important factors in determining the time of phase change, and when applied inside the building, the phase change temperature is determined considering the room temperature.
application area	The application area determines the phase change temperature and determines the temperature range to be maintained, especially when PCM is applied inside the building.
quantity (thickness) of PCM	The quantity of PCM determines the length of time during which the phase change takes place and affects the indoor and surface temperature maxima. The surface and indoor temperatures, which are affected by the amount of PCM latent heat from the time point at which the phase change temperature occurs, are kept constant unless the external heat supply is interrupted and the external temperature is cooled down to below the phase change temperature.

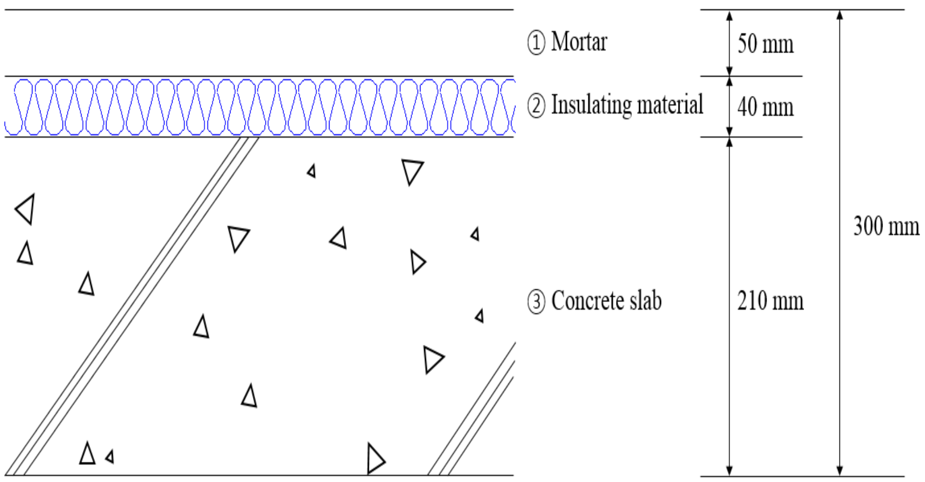
4. THE CONCEPT AND DESIGN OF THE FLOOR HEATING SYSTEM WITH PCM

4.1 The Concept of the Floor Heating System with PCM

PCM refers to a substance whose phase changes according to changes in the temperature, and has a property of accumulating thermal energy according to a thermal change. The main role of the aerated concrete used in the floor heating system is to store the heat energy supplied from the hot water and deliver it to the floor surface, but its thermal performance is known to be significantly low.

According to the regulations and standards related to floor heating system in Korea (Notice No. 2015-319 of the Ministry of Land, Infrastructure and Transport, Paragraph 3 of Article 49 of the Building Act, Paragraph 4 of Article 21 of the Housing Act, etc.) (Fig. 4.1), currently, for most of the apartment buildings in Korea, the 'standard floor structure' is constructed by applying construction materials in the order of the 210 mm concrete slab, 20 mm buffer material, 40 mm light weight aerated concrete, and mortar including a 40 mm hot water pipe (fig. 4.1).

Figure.4.1 The cross-section of the standard floor structure of domestic apartment buildings for over 30 households



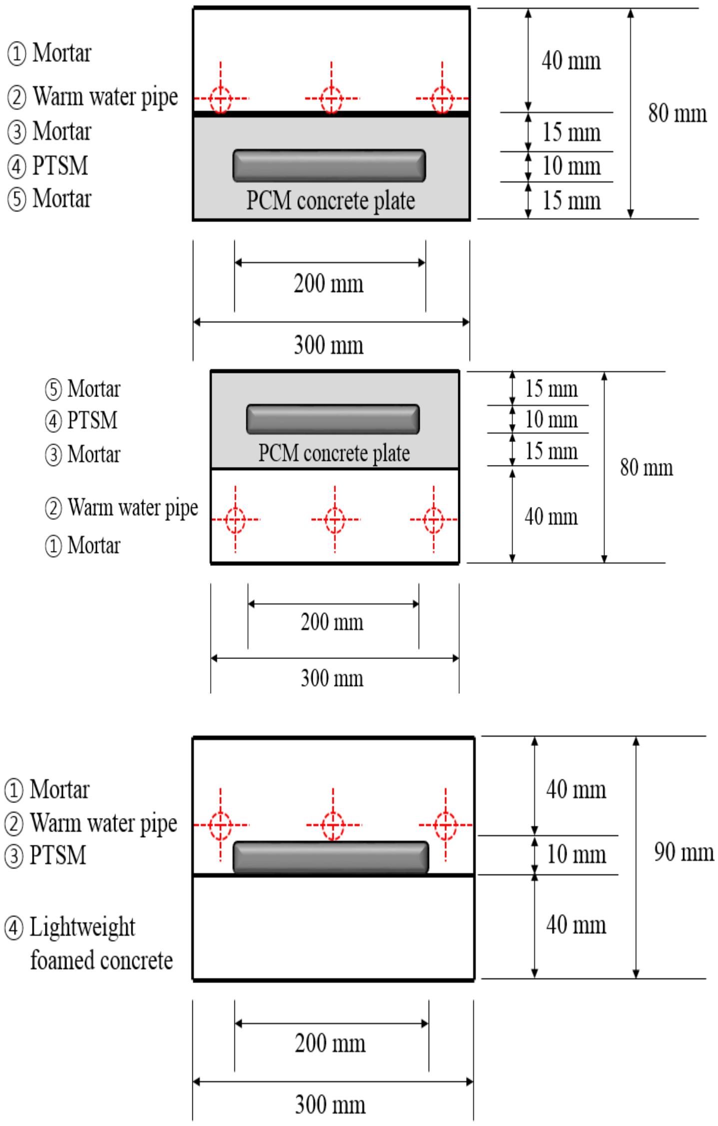
In other words, the materials of the floor heating system using light weight aerated concrete and mortar have a disadvantage of consuming a lot of hot water and energy in order to maintain the floor surface temperature set for indoor heating because the thermal storage performance is very low. In addition, due to the high specific heat of light weight aerated concrete and mortar, the preheating load for reaching the set temperature from the natural temperature and the floor surface temperature is considerably high, so the initial energy consumption for preheating at the time of heating is also very high.

Therefore, in order to improve the thermal performance of the floor heating system, it is necessary to insert a phase change material (PCM) having excellent latent heat storage capacity between the existing floor concrete and finishing mortar to improve the thermal storage performance

4.2 The Model Design of the Floor Heating System with PCM

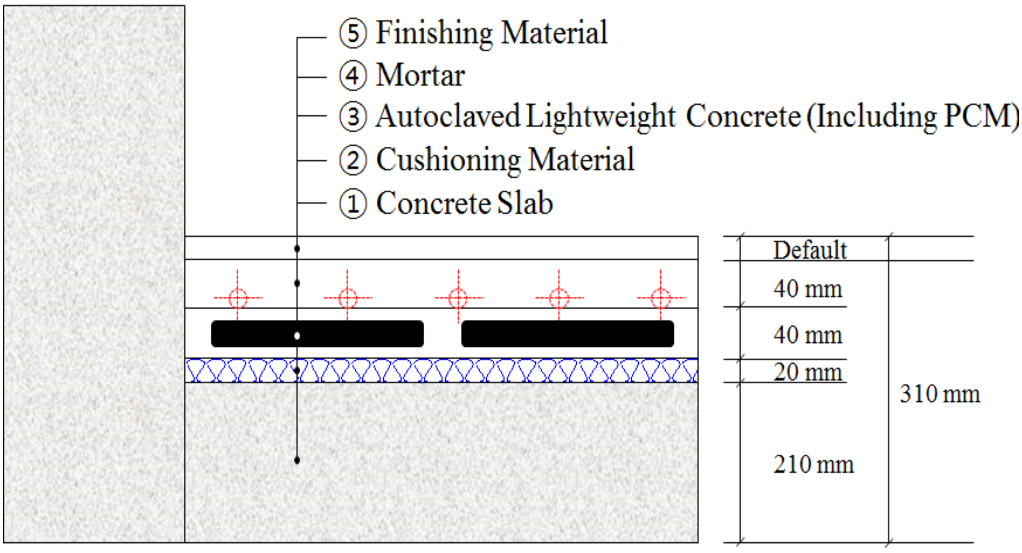
The model of the floor heating system using PCM can be classified into the following three types. In fig. 4.2, for Model 1, PCM concrete plate is inserted into light weight aerated concrete. In case of Model 2, light weight aerated concrete is removed, both upper and lower layers are placed with mortar and the hot water pipe is inserted into the lower part. In such cases, it would be possible to meet domestic legal standards (the legal standards for the floor impact noise prescribed by the Ministry of Land, Infrastructure and Transportation). In the case of Model 3, the PCM is inserted into the finishing mortar. This structure increases the floor thickness because both the hot water pipe and PCM are inserted.

Figure.4.2 The design model of the floor heating system with PCM



The floor heating system with PCM refers to a floor heating system constructed by applying such a phase change material to the existing floor heating system. In other words, it is a modified structure of the conventional floor concrete layer and it is constructed by placing a layer of 15 mm thick mortar on a 210 mm thick concrete slab and a 20 mm thick buffer material, inserting a 10 mm thick PCM, and then placing a layer of light weight aerated concrete of 15 mm and mortar of 40 mm (total thickness of mortar: 55 mm) (Fig. 4.3).

Figure.4.3 The proposed model of the floor heating system with PCM

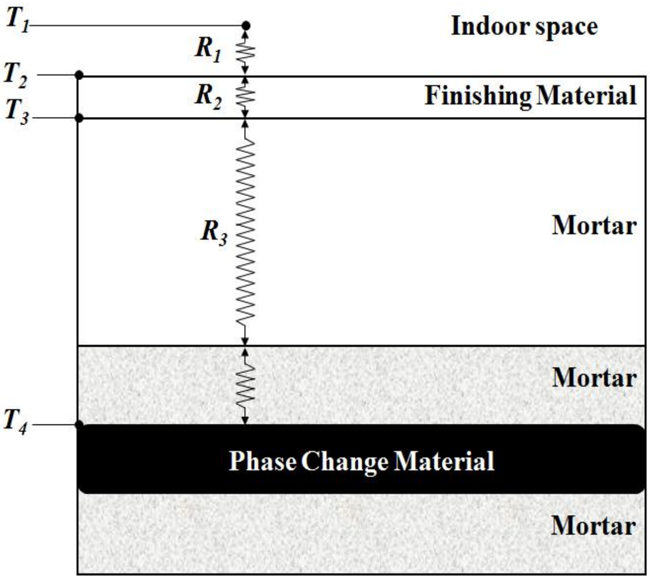


5. TEMPERATURE RANGE OF THE FLOOR HEATING SYSTEM WITH PCM

5.1 The Heat Transfer Model of PCM Floor Radiant Heating

Analysis of previous domestic studies showed that the range of the comfortable temperature of the floor surface for indoor heating is 28℃ to 31℃. In order to apply PCM to the floor heating, the melting point of PCM which can maintain the floor surface temperature for heating should be determined, and a heat transfer model for the floor structure should be established for this purpose. Fig. 5.1 shows a heat transfer model that can expect the range temperature of PCM for floor heating.

Figure.5.1 The heat transfer model for PCM floor heating



5.2 The Melting Temperature Range of PCM Floor Heating

The heat transfer model was set up under the condition that latent heat is released from PCM after assuming that the heat supplied from the hot water pipe has been fully stored in the PCM. Therefore, the initial boundary conditions were assumed to be the room heating temperature T_1 and PCM Melting Point T_4 (the temperature at which it remains constant: the temperature at which latent heat release occurs), and if the thermal properties of all the materials are given, the surface temperature of each material can be calculated by the following equations (1) - (3) (Cengle, 2006).

$$R_{total} = R_1 + R_2 + R_3 \tag{1}$$
$$T_3 = T_4 - (Q \times R_3) \tag{2}$$
$$T_2 = T_3 - (Q \times R_2) \tag{3}$$

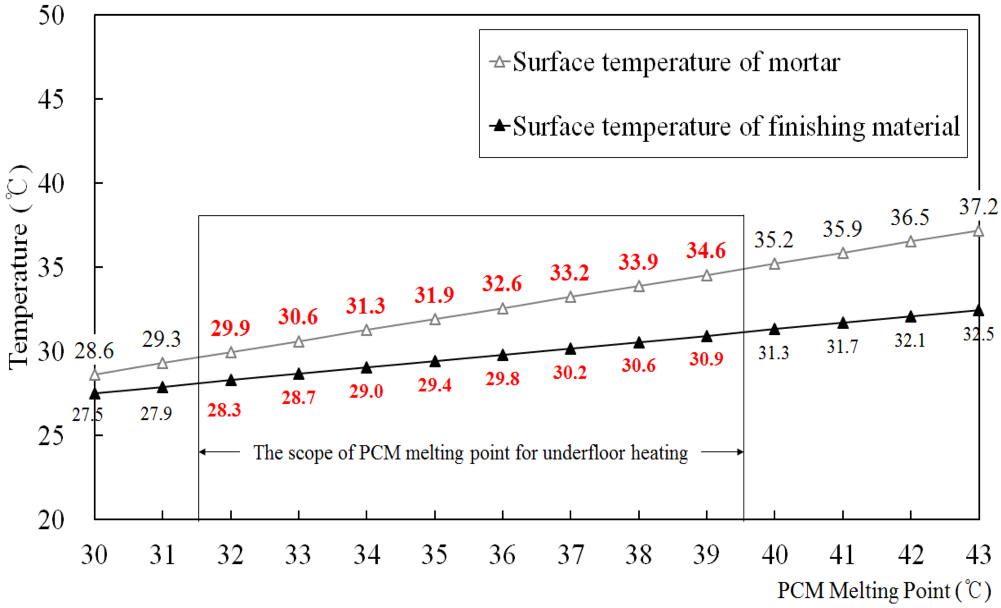
Here, R_{total}, R_1, R_2, and R_3 are the total heat transfer resistance from the PCM to the heating space (℃/W), the heat transfer resistance of the mortar (℃/W), the heat transfer resistance of the floor finish (℃/W), and the total heat transfer resistance of the floor surface (℃/W).

T_1, T_2, T_3, T_4, are the indoor air temperature, the surface temperature of the floor finish, the top surface temperature of the mortar, the surface temperature of PCM.

In the initial conditions, for the indoor heating temperature T_1 and the floor surface temperature T_2 for apartment buildings, 26℃ and 28-30℃ were applied, respectively, according to the results of recent research conducted (Akihiro et al., 1999). In addition, it is assumed that the floor finish has thermal conductivity of k=0.16 (W/m・K) and 5 mm thick laminate flooring is applied (Kim, 2014).

The calculation results of the PCM Melting Point, which satisfies the range of 28 ℃ to 30 ℃, which is the range of the floor surface temperature for indoor heating under these conditions, are shown in Fig. 5.2.

Figure.5.2 The melting temperature range of PCM floor heating



That is, the PCM Melting Point satisfying the floor surface temperature of 28-30 ℃ for indoor heating was calculated to be 32-39 ℃. In addition, when the temperature of PCM was 32-39 ℃, the surface temperature of the floor finishing material (T_2 in Figure 3) was 28.3-30.9 ℃, and the top surface temperature of the mortar (T_3 in Figure 3) was 29.9-34.6 ℃. That is, when inserting the PCM with the temperature of 32 ℃ in the floor structure, the surface temperature of the mortar was determined to be 29.9 ℃, and the surface temperature of the floor finish was calculated to be 28.3 ℃.

6. CONCLUSION

This study proposed a new floor heating system design by applying PCM to the floor heating system. In particular, the optimal temperature of the floor heating system with PCM was suggested. The results of this study are summarized below. (1) The existing floor heating system has the problem that a large amount of hot water and energy are consumed because of the low thermal storage performance of the light weight aerated concrete and the mortar. The PCM floor heating system is constructed by applying floor construction materials in the order of the 210 mm concrete slab, 20 mm buffer material, 15 mm mortar, 10 mm PCM aluminum case, 55 mm mortar, and floor finish. (2) The applicable PCM Melting Point for floor heating was calculated using the heat transfer model formula proposed in this study, and as a result of analysis, the applicable PCM temperature was determined to be 32-39 ℃ when a 5 mm wood floor finish was applied.

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