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A Study on Appropriate Temperature of Phase Change Material applicable to Double Skin Facade System for Heating Energy Load Reduction

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Abstract

This study was conducted to apply a phase change material (PCM) to the inner skin part of a double skin facade to positively utilize natural solar heat so that a double skin facade may not only counteract external environmental changes but also positively introduce external natural solar energy, highlighting the advantages of a double skin facade. However, PCM is currently used by impregnating to a wall or a board of a building. Studies on the determination of an appropriate PCM temperature according to the applications are only conducted with respect to a wall or a board. Applying a PCM to an inner part of a double skin facade system involves variables such as impregnation method and appropriate temperature. These are the properties of a PCM, which are important variables directly affecting the room temperature depending on the mixing ratios and applications targets. This study was conducted with respect to window surfaces having a direct impact on the inside and the outside of a building to select a double skin facade system having excellent energy-saving performance and determine a PCM temperature which is applicable to a double skin facade, verifying the indoor energy-saving effect depending on the application of a PCM to the inner part of a double skin facade.

Keywords: *Energy Load Reduction, PCM (Phase Change Materials), Double Skin Facade*

1. Introduction

1.1. Background and Purpose of Study

Recently, energy consumption in Korea is increased by more than 10% each year, showing the highest increase rate in the world. Therefore, improvement of energy supply and management system is a critical national task. In addition, national energy policies are implemented in each country, as the energy consumption is increased. Energy consumption in a building is associated with the skin surface which is directly affected by the external environment. "Building skin," defined as the external part of a building which covers the inner volume of a building, has the function of accepting demands of the users in a building and mediating two spaces which are the interior environment and the exterior environment. However, skin surfaces of modern buildings are designed as full glass, giving a high-tech impression to a building. As a result, the indoor energy consumption is increased due to the external influences, and thus a building skin is an important factor in determining the annual energy consumption. Different from general building skins which passively change the indoor environment depending on the external climate conditions, a double skin facade system is a

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building skin actively counteracting the external environmental changes, enabling to reduce building skin load and indoor energy load. This study was conducted to apply a phase change material (PCM) to the inner skin part of a double skin facade system to positively utilize natural solar heat so that a double skin facade system may not only counteract external environmental changes but also positively introduce external natural solar energy, highlighting the advantages of a double skin facade. However, PCM is currently used by impregnating to a wall or a board of a building. Studies on the determination of an appropriate PCM temperature according to the applications are only conducted with respect to a wall or a board. Applying a PCM to an inner part of a double skin facade system involves variables such as impregnation method and appropriate temperature. These are the properties of a PCM, which are important variables directly affecting the room temperature depending on the mixing ratios and applications targets.

This study was conducted with respect to window surfaces having a direct impact on the inside and the outside of a building to select a double skin facade system having excellent energy-saving performance and determine a PCM temperature which is applicable to a double skin facade, verifying the indoor energy-saving effect depending on the application of a PCM to the inner part of a double skin facade.

1.2. Method of Study

The scope of this study was limited to unit households having a size which takes the largest portion in the apartment house units in Korea, and a mock-up model was prepared in that size in order to increase objectivity in evaluation the applicability. The data obtained from actual experiments were compared and analyzed to determine a PCM temperature appropriate to a double skin facade. A double skin facade system in which a PCM, not glass, was applied to the inner surface was installed to verify the installation possibility. The detailed procedures of the study are as follows:

First, in this study, prior to the determination of a PCM temperature appropriate to a double skin facade, the concept and types of double skin facade system as well as the concept and properties of PCM were investigated to select a double skin facade system to which a PCM may be applied and to determine a PCM temperature applicable to the double skin facade.

Second, a preliminary investigation was performed for the actual experiment of this study to set up the physical variables of the double skin facade system to which a PCM was to be applied. Before preparing a mock-up model for the actual experiment, an appropriate unit space was selected by analyzing the current status of the apartment houses in Korea.

Third, to determine a PCM temperature appropriate to the double skin facade system with reference to the selected unit size, a basic double skin facade system was prepared and actual measurement data were obtained during a heating period. On the basis of the measurement results, the range of the PCM temperature to be applied to the double skin facade system was determined.

Fourth, to analyze the heat performance properties of the double skin facade system depending on the installation of the double skin facade system to which a PCM is applied with reference to the selected unit space and the PCM temperature, the PCM temperature which had previously been determined by analyzing the basic double skin facade system data was applied to the inner skin of the double skin facade system to prepare a total of seven different types of specimens. Data were measured for three days during heating period, and the measured data were compared and analyzed to certify the possibility of installing the double skin facade system to which a PCM was applied and to verify the indoor energy-saving effect depending on the PCM temperature appropriate for the double skin facade system as well as the appropriateness of the temperature.

2. Double Skin Facade System and PCM

2.1. Concept and Types of Double Skin Facade System

The concept of a double skin facade system is that one more skin is added upon a pre-existing skin to form an intermediate air space layer (thermal buffer layer) between the skins. A shade is installed in the intermediate air space layer to positively utilize external natural environment. A double skin facade system has high natural ventilation performance to always supply fresh air to the inside, since the double skins protects the inside from the influence of the exterior natural environment, allowing the windows to be freely opened and closed for natural ventilation. The intermediate air space layer forms a thermal buffer space so that the heating load may be reduced during winter season. In addition, the heated air in the intermediate air space layer is ventilated to the outside to reduce the air conditioning load. The two skins also protect the facade and the materials of a building so that the persisting period of construction materials may be increased. Furthermore, the intermediate air space layer having a certain width decreases direct solar ray during summer and a shade installed in the intermediate air space layer blocks the solar heat from being introduced to the inside.

Table 1. Types of Double Skin Facade System

Type		Features	
Box type double skin facade	Box type	- Double skins installed on vertical and perpendicular sections - Separated opening on the top and the bottom.	
		Pros	- Good privacy achieved - Easy window adjustment by users - Easy construction - Excellent indoor and outdoor noise shielding performance
		Cons	- Solar heat from the outside if not used properly.
Layered double skin facade	Corridor type	- Double skins are installed only on horizontal sections. - Openings on the top and the bottom of each layer for ventilation	
		Pros	- The intermediate air space layer may be used as a corridor or a resting place - Advantageous for solar ray reduction
		Cons	- Disadvantages for privacy - Noise easily transmitted to another room
Hybrid double skin facade	Box + shaft type	- Hybridization of layered double skin facade system (corridor ventilation) and curtain-wall type double skin facade system (shaft ventilation)	
		Pros	- The advantages of the two types may be used
		Cons	- Higher initial investment required
Curtain-wall type double skin facade	Shaft type	- Combination of the box type and the shaft type over a few layers - Applied to a building which is not very high due to the shaft height limitation	

		Pros	- High ventilation efficiency - Smaller number of openings. / Good soundproof effect
		Cons	- Many insulating materials are required for a shaft - Poor view by the shafts
	Full surface type	- Double skins are installed over a few layers without differentiating the vertical and horizontal sections - Good when there is a high level of external noise	
		Pros	- Lower initial investment
		Cons	- Rapid smoke diffusion in an event of fire - Noise easily transmitted to another room

As analyzed in Table 1, double skin facades are classified into five types. A box-type double skin facade system may be divided into vertical and horizontal sections, and have openings on the top and bottom. Since the box-type double skin facade system is good to achieve privacy, allows for the users to easily adjust the windows, and has excellent soundproof performance with respect to indoor and outdoor noise, it may be a double skin facade system appropriate for modern high-rise residential buildings to which a PCM may be easily applied.

2.2. PCM (Phase Change Materials)

A PCM refers a material which may absorb or release heat as its phase is changed from solid to liquid or reversely. A PCM is usually a substance having a melting point near room temperature and a medium having high thermal energy storage capacity. Figure 1 shows the energy flow through a PCM. A PCM accumulates sensible heat in solid state under the melting point to change the temperature and then accumulate latent heat without temperature change when it is melting to the point of being a liquid [1].

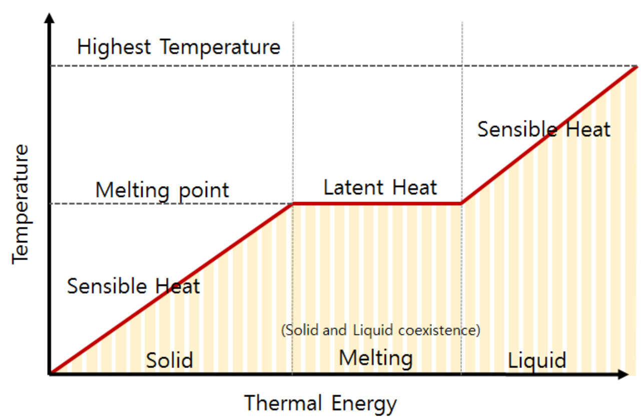


Figure 1. Concept of Energy Flow

2.3. Summary

This chapter discusses the concept and types of double skin facade. A box-type double skin facade system may be divided into vertical and horizontal sections, and have openings on the top and bottom. Since the box-type double skin facade system is good to achieve privacy, allows for the users to easily adjust the windows, and has excellent soundproof performance with respect to indoor and outdoor noise, it may be a double skin facade system appropriate for modern high-rise residential buildings. This chapter also discusses the concept and the thermal properties of a PCM. A PCM may be applied to a glass surface, but variables depending on the application targets and application methods should be considered to prepare alternatives in this regard.

3. Experiment Conditions for Actual Measurement Test to Determine Appropriate PCM (Phase Change Materials) Temperature

3.1. Actual Measurement Experimental Setup

Since a full glass surface is applied to the skin of modern high-rise residential buildings, a double skin facade system appropriate for high-rise residential buildings was applied in this study. A variety of variables, unit space size, and regional and temporal ranges were analyzed for the apartment house application of a double skin facade system to which a PCM was applied. However, not all these thinks may be taken into account to perform an experiment due to the difficulties and limitations.

In the experiment performed in this study, to investigate the possibility of installing a double skin facade system to which a PCM is applied to an apartment house and to determine the applicable temperature, the regional and temporal ranges, physical variables, and unit space size were set up as follows.

3.1.1. Regional and Temporal Ranges: The regions range of the measurement experiment performed in this study was set to be Seoul, Korea (N37°34', E126°57'). According to the average meteorological data of the Korea Meteorological Administration, the average air temperature in Seoul from 1981 to 2010 was 12.5℃, the coldest month temperature was −2.4℃ in January, and the warmest month temperature was 25.7℃ in August. The average annual rainfall was 1450.5 mm, and the average annual wind speed was 2.3 m/s (2014, Korea Meteorological Administration). The temporal range was for eight days from February 20 to 28 in 2014. To determine the PCM phase change temperature range to be applied to the inner surface of the double skin facade, an actual measurement experiment of the conventional double skin facade system was performed from February 21 to 22 in 2014 (48 hours) by measuring the indoor temperature.

3.1.2. Physical Variables: To apply a PCM to a double skin facade, a material different from that of the conventional double skin facade system was applied to the inner skin. While a PCM was applied to a concrete wall or board by impregnation in previous studies, it was inserted in this study since the impregnation into glass had some problems. In addition, to suggest the direction in which a PCM is inserted to glass, a PCM was inserted to polycarbonate which has a thermal transmission coefficient similar to that of a double glazing on the basis of the study by O [5] of Housing & Urban Research Institute on PCM-applied buildings. This was because the purpose of this study was not to determine the optimal material thickness. To obtain accurate data, a double-layered polycarbonate having a thickness of 16, the same as that of outer skin glass, was applied. Although the different opening operation methods for daytime and night time should be considered, the openings were closed due to the limitations of the actual measurement experiment with the mock-up model, assuming that an air conditioner is operated in the indoor space.

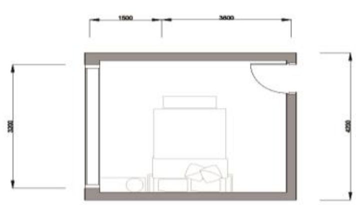
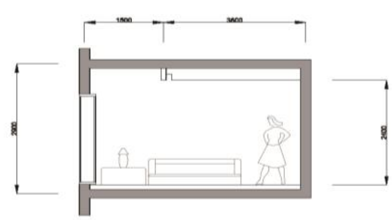
3.1.3. Unit Space Size: The current status of the apartment house size was investigated to determine appropriate unit space size. According to the statistics of the Apartment Residence

Environment in Korea, as of 2010, the supplied area of 99.0 ㎡ (30 pyeong) to 115.5 ㎡ (35 pyeong) accounted for the highest portion of 24.1% among the apartment houses. The ratio of the supplied area from 66.0 ㎡ (20 pyeong) to 82.5 ㎡ (25 pyeong) was 18.6%, and that of the supplied area from 82.5 ㎡ (25 pyeong) to 99.0 ㎡ (30 pyeong) was 16.6%. In addition, according to the house construction approval data of the house construction statistics as of 2013 for each house size, the ratio of houses having a supplied area from 60 ㎡ to 85 ㎡ was the highest as 42.4%. Therefore, the exclusive use space area of 84 ㎡ was chosen as an appropriate unit space size in this study. [9]

3.2. Materials and Structure of Actual Measurement Experiment

This study was conducted with apartment house of 84 ㎡, and the main bedroom was selected as a prototype unit, which was on the basis of the study on double-skin facade's cooling effects on indoor temperature of apartment's room conducted by Won et al. [3]. Table 1 shows the dimensions of a main bedroom of an 84 ㎡ apartment unit. The detailed dimensions are 4,200 mm wide and 3,600 mm deep. The balcony was 1,500 mm deep. The layer height and the ceiling height were 2,900 mm and 2,400 mm, respectively, in the unit space. The direction of the unit space was toward the South. The purpose of this study was to examine the indoor thermal environment according to the application of a double skin facade. The balcony was an extended type. Since the conventional double skin facades which have been applied in Korea had an intermediate air space layer which was about 1000 mm wide, it was difficult to set up the standards for an outer wall due to the possibility of raising a legal problem. The large width provided a disadvantage in an economic point of view. To countermeasure such a problem, the width of the intermediate air space layer of the double skin faced was determined as 200 mm to maximize the possibility of applying to the conventional outer wall surface on the basis of the study conducted by Lee (an empirical study on the development of double skin facade system coping with various climate conditions).

Table 2. Specifications of Unit Space [mm]

Type	Contents
Floor Plan	
Section	

As shown in Table 2, the mock-up model used in the actual measurement experiment was reduced in size to 1/6 of the selected unit space.

Table 3. Overview and Composition of Specimen

Type		Detail	
Model Size	Indoor	Width	700 mm
		Depth	600 mm
		Height	400 mm
	double-skin façade System	Width	700 mm
		Depth	200 mm
		Height	400 mm
Material	Foamed Polystyrene	Thickness	100 mm
		Heat Conductivity	0.034 W/mK
	Double Glass	Thickness	16 mm
		Visible Light Heat Ray from the Sun	Transmittance (81%)
			Reflectance (15%)
		Sheltering Coefficient	Transmittance (68%)
			Reflectance (12%)
		Thickness	0.86%
		Visible Light	3.19 W/m^2K
	Polycarbonate Double Plate Sheet	Thickness	16 mm(CL)
		Light Transmittance	79%
		Thermal Transmittance	3.0 W/m^2K
	PCM	General description: n- Octadencane (>97%) Application area: Latent heat storage material, Phase change material Molecular formula: $C_{18}H_{38}$	
Measurement System	Pyrheliometer Sensor	ML-020VM	
	Temperature/Humidity Sensor	SHT11	
	Surface Temperature Sensor	K-TYPE	
	Data Logo	TX-220	

3.3. Preparation of the Actual Measurement Mock-up Model and Experiment

The actual measurement mock-up model was prepared by forming the bottom, walls, and ceiling with foamed polystyrene 100T and the inner and outer windows with 16 double glazing. The inner skin was prepared by inserting a PCM into a 16 mm multi-layered transparent polycarbonate. Table 4 shows the mock-up model preparation process. The actual measurement experiment was performed from February 27 to March 1, 2014.

Table 4. Fabrication Processes of Mock-up Test Model

1. Outer Wall Assembly	2. Double Skin system Installation	3. Silicon Process
		
4. Measuring Equipment Installation	5. Roof Assembly	6. Completion of Test Model
		

4. Determination of an Appropriate PCM Temperature Applicable to a Double Skin Facade

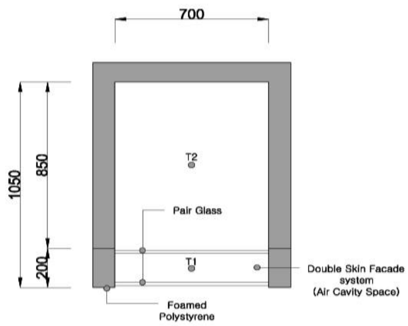
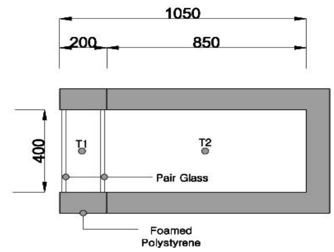
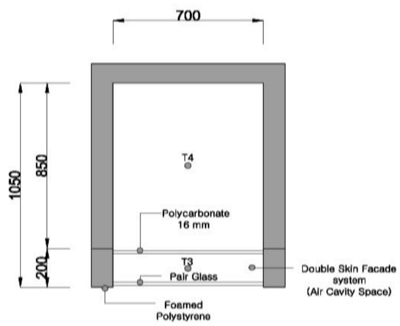
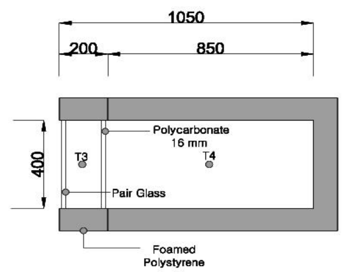
To determine the PCM phase change temperature range to be applied to the inner surface of the double skin facade, an actual measurement experiment of the conventional double skin facade system was performed from February 21 to 22 in 2014 (48 hours) by measuring the indoor temperature.

Table 5. Actual Measurement Values of the Indoor Temperature of the Double Skin Facade

Day	Type	Temperature[℃]			Humidity[%]
		Min.	Max.	Avg.	Avg.
2014.02.21	Cavity	-7.93	60.64	14.7	36.1
	Indoor	-6.42	45.39	11.6	33.9
2014.02.20	Cavity	-5.82	54.35	14.0	33.7
	Indoor	-5.33	41.83	10.8	31.2

Currently, a PCM is applied in the field of construction with reference to 18℃ in winter and 28℃ in summer. However, since the temperature in the intermediate air space layer and the indoor air was elevated to 40℃ through 60℃ and dropped to -5℃ through -7℃, as shown in Table 5, four different PCM phase change temperatures within the 18℃ to 28℃ range, which were 18℃, 24℃, 26℃, and 28℃, were applied to the inner surface to analyze the indoor thermal environment in comparison with that of the basic double skin facade. The PCM mixing ratio between hexadecane and octadecane, which were the key components of the PCM, was adjusted according to the temperature.

Table 6. Overview of Each Type of Specimen [mm]

Type	Floor Plan	Section
Type-1 (Basic)		
Type-2 (PCM temperature : 18℃)		
Type-3 (PCM temperature : 24℃)		
Type-4 (PCM temperature : 26℃)		
Type-5 (PCM temperature : 28℃)		

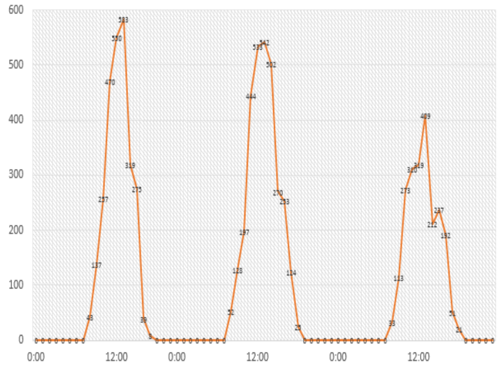
To determine the PCM temperature applicable to a double skin facade system and to compare the indoor thermal environment, a total of five types of mock-up models were prepared including the basic double skin facade system and other four models to which outer skins having different PCM phase change temperatures were applied. The first one was the conventional double skin facade system type (Type-1: Basic Type). The second to fifth models were those to which different PCM phase change temperatures were applied: 18℃ (Type-2), 24℃ (Type-3), 26℃ (Type-4), and 28℃ (Type-5).

5. Experiment Results

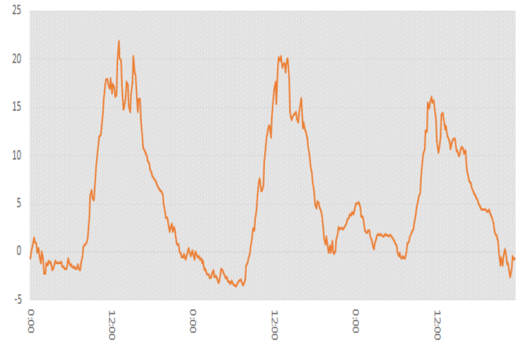
The analyzed measurement experiment results were the data measured in a ten-minute interval for three days from 00:00 on February 2 to 23:59 on March 1, 2014.

5.1. Climate Data during the Experiment Period

The average highest temperature of the external space during the experimental period was 23.2℃, and the average lowest temperature was − 3.6℃. The relative humidity was 69% in average. The maximum solar radiation was 659 W/㎡. Figure 2 and Table 6 show the climate data for the three days during the experiment period.



Isolation [W/㎡]



(b) Outdoor temperature [℃]

Figure 2. Climate Data during the Experimental Period

Table 7. Climate Data during the Experimental Period

Type	Temperature [℃]※※			Humidity [%]※※	Isolation [W/㎡]※※	Sunshine Duration [hr]※	Cloud Cover [10%]※
	Avg.	Min	Max	Avg.	max		
02.27	5.9	-2.7	23.2	67	654	5.4	4.8
02.28	4.8	-3.6	20.8	68	604	4.3	6.3
03.01	5.0	-2.8	16.9	70	423	1.0	8.1
Average	5.2	-3.0	20.3	69	560	3.6	6.4

Note)※Survey Data
※※Korea Meteorological Administration

5.2. Test Measurement Data

Measurement results with the mock-up models: The temperature of the intermediate air space layer and the indoor space of the five types of mock-up models during the experiment period are shown in Table 7. The measurement values are different each day because the experiment was performed under natural climate. The lowest temperature values might have been varied due to the effect of the external air temperature. The highest temperature might have been varied due to the external temperature which was also affected by the variation of the solar radiation depending on the fine dust concentration and the amount of clouds.

Table 8. Test Measurement Data

Type		2013-02-27			2013-02-28			2013-02-29			Test Period		
		Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.
Cavity	Type-1	0.6	50.6	15.3	-0.9	45.9	13.4	2.4	30.6	11.0	0.7	42.4	13.2
	Type-2	4.5	37.0	15.5	0.2	35.0	13.6	2.8	26.7	11.6	2.5	32.9	13.6
	Type-3	2.7	39.8	16.1	-0.1	38.0	13.5	3.0	27.8	11.4	1.9	35.2	13.7
	Type-4	1.2	42.1	15.6	-0.8	40.3	13.2	2.5	28.9	10.9	1.0	37.1	13.2
	Type-5	1.1	43.4	15.6	-1.0	41.4	13.0	2.3	29.4	10.7	0.8	38.1	13.1
Indoor	Type-1	1.1	38.8	13.1	-0.9	45.9	13.4	2.8	22.6	9.8	1.0	35.8	12.1

	Type-2	4.8	22.3	12.9	0.9	19.9	11.0	3.3	16.3	10.2	3.0	19.5	11.3
	Type-3	2.8	22.6	12.5	-0.1	20.1	9.8	3.0	16.6	9.1	1.9	19.8	10.4
	Type-4	1.3	24.4	11.9	-0.7	22.1	9.3	2.5	17.2	8.5	1.0	21.2	9.9
	Type-5	1.6	25.0	12.4	-0.2	23.4	9.8	2.8	18.0	8.8	1.4	22.1	10.3

The average values of the highest temperature and the lowest temperature for the three days during the experiment period were compared as follows: Type-1 (Basic Type) showed the highest temperature of 42.4℃, followed by 38.1℃ of Type-5 (PCM temperature 28℃). The indoor temperature was the highest as 35.8℃ of Type-1 (Basic Type). The lowest temperature measured at the intermediate air space layer was the lowest as 0.7℃ in Type-1 (Basic Type), followed by 0.8℃ of Type-5 (PCM temperature 28℃). The lowest temperature measured at the indoor space was the lowest as 1℃ in Type-1 (Basic Type) and Type-4 (PCM temperature 26℃), followed by 1.4℃ of Type-5 (PCM temperature 28℃).

6. Conclusion

This study was conducted to apply a phase change material (PCM) to the inner skin part of a double skin facade system to positively utilize natural solar heat so that a double skin facade system may not only counteract external environmental changes but also positively introduce external natural solar energy, highlighting the advantages of a double skin facade. However, PCM is currently used by impregnating to a wall or a board of a building. Studies on the determination of an appropriate PCM temperature according to the applications are only conducted with respect to a wall or a board. Applying a PCM to an inner part of a double skin facade system involves variables such as impregnation method and appropriate temperature. These are the properties of a PCM, which are important variables directly affecting the room temperature depending on the mixing ratios and applications targets. This study was conducted with respect to window surfaces having a direct impact on the inside and the outside of a building to select a double skin facade system having excellent energy-saving performance and determine a PCM temperature which is applicable to a double skin facade, verifying the indoor energy-saving effect depending on the application of a PCM to the inner part of a double skin facade.

Since the temperature in the intermediate air space layer and the indoor air was elevated to 40℃ through 60℃ and dropped to -5℃ through -7℃, four different PCM phase change temperatures within the 18℃ to 28℃ range, which were 18℃, 24℃, 26℃, and 28℃, were applied to the inner surface to analyze the indoor thermal environment in comparison with that of the basic double skin facade. The analytical results showed that the mock-up model having the PCM temperature of 18℃ showed the best performance with reference to the indoor temperature on the day and during the night in winter. The different of the indoor temperature was little among the mock-up modeling having the PCM temperatures of 24℃, 26℃, and 28℃. Different from the conventional double skin facade, application of the PCM to the inner skin of the double skin facade system in winter reduced the temperature difference between day and night, maintaining the indoor temperature with a range for a certain period of time. This shows the energy flow pattern in which the PCM accumulates the solar heat introduced from the outside during the day time and releases the latent heat to the inside for a certain period of time. However, there is an unresolved problem that the PCM temperature applied in the field of construction during summer is 28℃ and thus the temperature is different between winter and summer. In future studies, a PCM temperature may be set up for summer season so that the appropriate PCM temperature may be applied not only in winter but also in summer.

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