


Article

# Phase Change Materials and Their Benefits in ETICS

Lubomír Sokola \* , Nikol Žižková, Vítězslav Novák and Aleš Jakubík

Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, Brno University of Technology, 602 00 Brno, Czech Republic; zizkova.n@fce.vutbr.cz (N.Ž.); novak.v@fce.vutbr.cz (V.N.); 198572@vutbr.cz (A.J.)

\* Correspondence: lubomir.sokola@gmail.com; Tel.: +420-737-434-843

Received: 16 October 2020; Accepted: 26 November 2020; Published: 29 November 2020



**Abstract:** Phase change materials (PCMs) are materials with the ability of absorption of latent heat based on a phase change. PCMs are able to store and release a large amount of energy at certain temperatures melting or freezing. The aim of the research is to verify whether this phenomenon (material) can be used within an external thermal insulation composite system (ETICS). This is particularly the usage of PCMs in the base coat. The research is focused on two main areas. The first area concerns the water condensation on the surface of the ETICS and the associated phenomenon of algae attack. The second area concerns the warming of ETICSs with the use of dark color shades. Practical experiments showed a positive effect of PCMs on the heat-storage properties of the ETICS base coat. It was also experimentally verified that the PCM sample did not condense water vapor on the sample surface compared to the reference sample.

**Keywords:** external thermal insulation composite system (ETICS), algae; phase change material (PCM), thermotropic material; thermography

## 1. Introduction

ETICS is the abbreviation for External Thermal Insulation Composite System. Typical system components are adhesive, thermal insulation material, anchors, base coat, reinforcement (usually glass fibre mesh) and finishing layer: finishing coat with a key coat (optional) and/or a decorative coat (optional) and accessories, e.g., fabricated corner beads, connection and edge profiles, expansion joint profiles, base profiles, etc. Thus, the attachment principle implies that the system does not have a continuous air gap. The aim of the system is to create an integral thermal insulation building envelope. The aim is not to allow the influence of weather conditions, especially water, on the structure of the building and to ensure the removal of water vapor in an adequately suitable way for the structure. The primary goal is to save energy when heating or cooling the building [1,2].

### 1.1. Heat Storage of ETICS

Polymer-modified mortar with reinforcement and primer together with plaster form the so-called ETICS base coat. The base coat is only a few mm thick and this thin ETICS surface is affected by a relatively large temperature change during the day in standard external conditions. Due to its small thickness it is also able to store only limited heat [3]. Limiting or shifting the effect of the temperature variation or a change in heat storage of the surface on the ETICS in the 0.2–0.9 °C range [4] can have an impact on several key things:

- Condensation of water vapor on the surface of the ETICS and associated biotic attack and so the necessity of algicidal protection (environmental burden) [5–11].
- Drying of water from the ETICS surface [12–15].

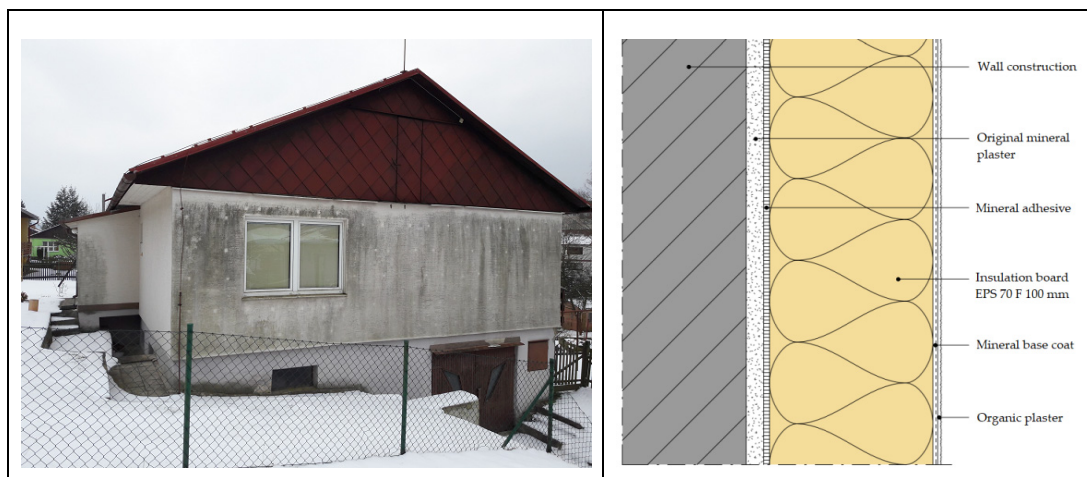
- ETICS overheating due to solar radiation, which mechanically burdens the thermal insulation system [16].

Within the ETICS we can focus mainly on two significant problems. One of them is a biotic attack on the facade [5–11], and the other is mechanical damage to the ETICS due to the effect of solar radiation [16].

### 1.2. Purpose and Impact of Biocides

The ETICS addresses two main impacts in terms of biocide use and the associated environmental burden. The first effect is health impact with effects on all living organisms, especially in the vicinity of the insulated building, i.e., in nearest surroundings of the building. The second is the impact of legislation and constant changes in the possibility of using effective biocidal substances in construction products, in other words, tightening up the legislation (prohibition of using active substances (biocides) for environmental reasons, etc.) [17].

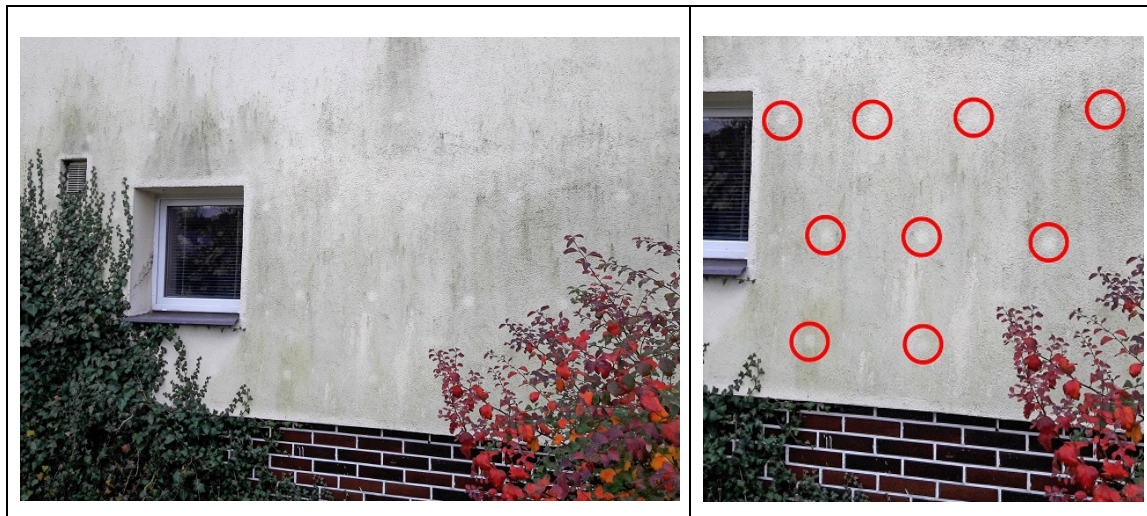
Basically, on the facade of the insulated building, air humidity condensation occurs, which then remains on the plaster surface for several hours. The thickness of the surface layer, the orientation of the walls to the cardinal points and the presence of living organisms near the walls (e.g., plants and trees) play a significant role. With a combination of these factors, there is the occurrence of algae and fungi. Especially the northern sides of insulated houses are intensively attacked [17,18]. This is apparent in Figure 1, which shows the northern wall of an insulated house in the town of Jeseník, Czech Republic.



**Figure 1.** Algae on the facade of the External Thermal Insulation Composite System (ETICS) of a family house in Jeseník (CZ), north side. On the right side there is the composition of the system.

### 1.3. Biotic Attack on ETICS Facade:

Algae create an undesirable aesthetic effect on the facade surface. Most algae live in water, but some species also live in the air (*aerophytic algae*) and receive water in the form of rain or water vapor. Aerophytes are microscopic green or blue-green algae in our climate. On buildings, aerophytes live on wet and north-facing walls. If living conditions allow them, these microorganisms will multiply and form visible colonies (see Figure 2). Organic plasters, which form the surface layer of ETICS, are also suitable substrates [3,12,13].



**Figure 2.** Algae on the facade of the ETICS of a family house in the village Lipová-lázně (CZ) with visible anchor points without attack due to the thermal conductivity of the anchor, north side.

Three conditions must always be met to create a growth:

- Presence of algae.
- Sufficient moisture.
- Suitable substrate [3,12,13].

According to a study [19,20], the most common algae on facade plasters is an algae called *Cladosporium* spp.

The possibility of biotic infestation in connection with sufficient surface moisture depends on many factors such as ambient temperature, air flow and humidity, sunlight and orientation to the world sides and other factors. From this point of view, studies and research work were created focusing on the above-mentioned influences and the resulting possibilities of biotic attack on the facade and the growth of algae itself [5–13,18,21]. Thanks to this research, PCMs with the most suitable melting point of wax to reduce condensation on the ETICS surface were chosen for the practical part of our research, e.g., in the dissertation [18] the temperature of the façade surface in autumn 2007 (Brno, Czech Republic) was measured in the range between 0 and 30 °C. It was stated that the presence and retention of water on the surface of the ETICS is largely due to condensation on the facade compared to water in the form of rain. The spring and autumn months are especially critical due to temperature and relative humidity. Due to the limitation of humidity on the ETICS, it is therefore appropriate to prevent to a certain extent the possible condensation of water at temperatures between –5 and +30 °C [18].

The case study of EMPA (Swiss Federal Laboratories for Materials Science and Technology) was also very interesting. [4] The results of this study gave the initial idea of dealing with PCM in connection with biotic attack. Temperature measurements were made on the north facing facade of the building. The outdoor air temperature was 5.1 °C. The sky was overcast. In addition to surface thermometers, a thermovision camera was also used. Measurements revealed that the windowless facade parts affected by algae were only slightly warmer than ambient at 5.5 °C. The measurements confirmed that the algae occurred only in the coldest areas of the façade [4].

In a detailed examination of the areas covered with vegetation, the thermovision image revealed lighter spots. These spots hardly ever contained algae. ETICS metal anchors are located in the same place as these light spots. Thermovision measurements revealed that their influence as a thermal bridge caused a local increase of the facade surface temperature by 0.2–0.9 °C. This case study suggests that even a few tenths of a degree of Celsius can decide if the surface is attacked by algae or not. At only a slightly lower surface temperature, the moisture did not dry up quickly enough so that the water needed for algae growth was present. This explains the high susceptibility of ETICS to algae

occurrence and the need for biocidal protection; the better the thermal insulation capacity, the cooler the facade surface [3,4].

#### 1.4. ETICS Temperature Change Due to the Influence of Sunlight

In the past few years, companies have often met the requirements of investors to implement very deep dark shades on ETICS insulation systems, where expanded polystyrene (EPS) is an insulator and where the light reflectance is in the range of 10–12 HBW (Hellbezugswert), in other words, the proportion of reflected light from the total light radiation falling on the facade. In general, it is recommended for a contact thermal insulation system that this shade reflectance value be >25 [16].

For the HBW rating scale, a shade of white that represents 100% light reflectance and an HBW value of 0 is taken, then a shade of black that absorbs most of the sun's radiation. It should be noted that when exposed to facades with shades of less than 15 HBW by sunlight in the summer months, the light is converted into heat and the system is heated to more than 75 °C (measured on the ETICS in situ). However, if an EPS insulation system is used, the insulator temperature should not exceed 70 °C. In cases where the temperature is higher, irreversible changes in EPS occur and the insulation system ceases to function. It should be noted that the materials used in the thermal insulation system have different technical parameters and properties that are optimally balanced for certain temperatures. If the system subsequently cools down rapidly with a high surface temperature, e.g., due to hail, driven rain, etc., it is most likely that thermodynamic stress will cause cracks and splits and possibly the system will break off due to deflection of the boards from the substrate. The resulting defects also cause water entry to the system, where in winter months the formation of ice crystals causes relatively rapid destruction of surface treatments and subsequent irreversible damage to the ETICS [16,22].

#### 1.5. PCM Materials

In pure chemicals, three types of phase changes are possible: melting and solidification, vapor and condensation, and sublimation and desublimation. For technical reasons of the production, phase change between solid and liquid is the most useful. Materials that change state and thereby release or receive large latent heat are called PCMs (Phase Change Materials) and they are used in various fields [23,24].

Thus, PCMs are latent heat-absorbing materials based on phase change. At certain melting and freezing temperatures, the substance is able to absorb and then release a large amount of energy. Heat is absorbed and released when the material changes from solid to liquid and vice versa (the so-called phase conversion of the first kind) [25–27].

Different types of paraffins (PCMs) were tested. The PCMs utilized were purchased from Microtek Lab. The core is paraffin and the shell is a polymer (see Figure 3). These PCMs are all in microencapsulated form and physically have an appearance of a white powder.

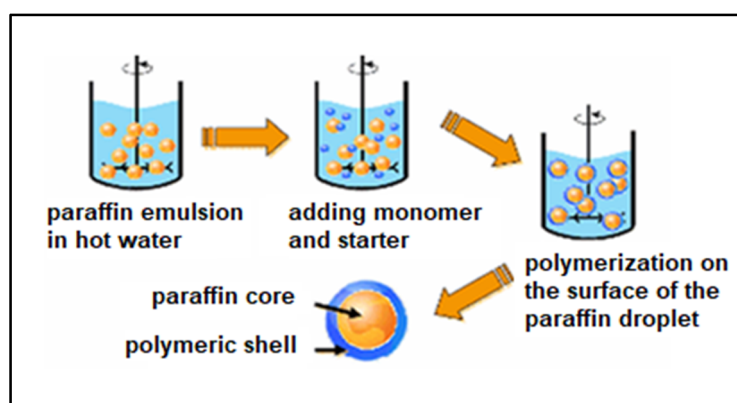


Figure 3. Micronal microcapsule production scheme [28,29].

Main criteria for the selection of PCMs are in Table 1.

**Table 1.** Main criteria governing the selection of Phase Change Materials (PCMs) [27,30–32].

Thermo-Physical Properties
<ul style="list-style-type: none"> <li>• Phase change temperature suitable for desired application, in the desired operating temperature range [30,32].</li> <li>• High latent heat of fusion per unit volume [30].</li> <li>• High thermal conductivity to assist in charging and discharging of PCM within the limited time frame [30].</li> <li>• High specific heat so that additional energy in the form of sensible heat is available to the thermal energy storage system [30].</li> <li>• PCM should melt completely (i.e., congruent melting) during phase transition so that the solid and liquid phases are homogenous [30].</li> <li>• Thermally reliable (i.e., cycling stability) so that the PCM is stable in terms of phase change temperature and latent heat of fusion and can be used in the long run [30].</li> <li>• Good heat transfer [32].</li> <li>• Small vapor pressure at operating temperature [32].</li> <li>• Favourable phase equilibrium and no segregation [32].</li> <li>• Complete melting [31].</li> </ul>
Kinetic properties
<ul style="list-style-type: none"> <li>• High rate of nucleation so as to avoid super cooling of the PCM in liquid phase [30,32].</li> <li>• High rate of crystal growth so that heat recovery from the storage system is optimum [30,32].</li> </ul>
Chemical properties
<ul style="list-style-type: none"> <li>• Chemically compatible with construction/encapsulated materials [30].</li> <li>• No degradation after large number of thermal (freeze/melt) cycles so as to assure long operation life [30].</li> <li>• Non-toxic, non-flammable and non-explosive so as to assure safety [30].</li> <li>• Corrosion resistant to construction/encapsulated materials [30].</li> <li>• Complete reversible melt/freeze cycles [32].</li> <li>• Chemical stability [31].</li> <li>• High freeze/melt stability [31].</li> </ul>
Environmental properties
<ul style="list-style-type: none"> <li>• Low environmental impact and non-polluting during service life [30].</li> <li>• Low embodied energy [32].</li> </ul>

## 2. Materials and Methods

### 2.1. Constituent Materials

#### 2.1.1. Ethylene-vinyl Acetate Copolymer

Redispersible powder is a water-redispersible vinyl acetate/ethylene copolymer powder produced by Dairen that is readily dispersible in water and forms stable emulsion. This material is soft and flexible, because of its relatively high ethylene content. Its glass transition temperature is below freezing point and average particle size is 90  $\mu\text{m}$ .

#### 2.1.2. Cement

Portland cement CEM I 42.5 R, manufactured in Czechia, was used as the binder in the research.

CEM I 42.5 R Portland cement is manufactured in accordance with EN 197-1 ed 2. It is a hydraulic binder in powder form manufactured by grinding together Portland clinker, calcium sulphate, additional constituent and additives.

### 2.1.3. Hydrated Lime

Lime hydrate CL 90-S in accordance with EN 459-1 was used in the tested recipes.

### 2.1.4. Calcium Carbonate

Calcium carbonate with a granulometry of 0.2–0.5 mm delivered from Omya was a component of the base coat.

### 2.1.5. Quartz Sand

Quartz sand with a granulometry of 0.2–0.8 mm was a component of tested formulations.

### 2.1.6. Cellulose Ether

A cellulose ether (methylcellulose derivatives) manufactured by Samsung was used in the mixes. This type of admixture extends the workability of fresh mortars and increases its retention capacity.

### 2.1.7. Rheological Additive Sepiolite

It is a powder additive that improves the system rheology. Sepiolite controls system flow and consistency, ensuring optimum distribution of solvents, fillers and other components. Sepiolite imparts thixotropic and pseudoplastic properties to the systems in which it is incorporated. This favours a suspending and thickening behavior, improving application and workability.

### 2.1.8. Hydrophobic Agents

A combination of zinc stearate and sodium oleate was used in the samples. Metallic soaps owe their outstanding position in building protection to their high specific surface area, as well as to their high water-repellent effect. By making them hydrophobic, the surface is coated over the total cross section, which guarantees that the mass will be water-repellent for several years. During the last few years, combination products have been used more and more as they guarantee a good incorporation and quick hydrophobic effect.

### 2.1.9. Reducing Agent Cr<sup>6+</sup>

Chromate reduction chemicals—Redox S10. Since 2005, cementitious products may contain a maximum of 2 ppm free chromium (VI) content. Even at low addition levels, Redox stannous sulphate (SnSO<sub>4</sub>) is a highly efficient chromate reducer. Redox has no influence on the final cement properties or on the workability of the system.

### 2.1.10. Fly Ash

Dětmarovice fly ash which was used in the research as the substitute of the cement and is a coal combustion product.

### 2.1.11. PCM

The core is purified paraffin and the shell is a polymer. Micronal is microcapsulated with highly crosslinked polymethylmethacrylate polymer and Nextek with aromatic thermosetting copolyester. The exact composition of PCM is the know-how of Microtek and is not publicly stated.

The following powder PCMs were used:

- *Micronal DS 5040 X* manufactured by Microtek (USA)

Powder, particle size: 50–300 μm; melting point of wax: 23 °C; group heat of fusion based on 1 g: ≥95 J/g; thermal stability: up to 200 °C.

- *Nextek 6D* manufactured by (USA)

Powder, particle size: 15–30  $\mu\text{m}$ ; melting point of wax: 6  $^{\circ}\text{C}$ ; group heat of fusion based on 1 g:  $\geq 170$  J/g; thermal stability: up to 250  $^{\circ}\text{C}$ .

- *Nextek 18D* manufactured by (USA)

Powder, particle size: 15–30  $\mu\text{m}$ ; melting point of wax: 6  $^{\circ}\text{C}$ ; group heat of fusion based on 1 g:  $\geq 190$  J/g; thermal stability: up to 250  $^{\circ}\text{C}$ .

#### 2.1.12. Polypropylene Fibres 4 mm

Polypropylene fibres increase the resistance of mortar and reduce hair and lattice cracks. Due to the PCM, it was necessary to use fibres to prevent microcracks in S3 P6D and S3 P18D formulations.

#### 2.2. Verified Mix Designs

In the final phase a total of four polymer cement mortar formulations were tested in Table 2. The individual formulations are distinguished by the type, amount of fly ash and PCM product. The PCM recipes below are the results up to three stages of testing. A set of physical-mechanical parameters required for base layer certification for the ETICS was tested. For this reason, there are differences not only due to fly ash and PCM, but also in other components of the recipe. Modifications were made so that the base layers met the required physical-mechanical parameters.

**Table 2.** Composition of the mortars analysed.

Input Materials	REF.	S2 P	S3 P6D	S3 P18D
	[%]	[%]	[%]	[%]
Water	21	21	40	40
Ethylene-vinyl acetate copolymer	1.800	1.800	2.100	2.100
Cement CEM I 42.5 R	22.000	16.000	20.000	20.000
Hydrated lime CL 90-S	1.800	1.800	1.800	1.800
Calcium carbonate 0.2–0.5 mm	65.899	55.917	21.500	21.500
Quartz sand 0.2–0.8 mm	8.000	8.000	10.000	10.000
Cellulose ether-HPMC	0.135	0.135	0.140	0.140
Rheological additive sepiolite	0.150	0.150	0.150	0.150
Zinc stearate	0.100	0.100	0.100	0.100
Sodium oleate	0.050	0.050	0.050	0.050
Reducing agent Cr <sup>6+</sup>	0.066	0.048	0.060	0.060
Fly ash Dětmarovice		16.000	16.000	16.000
Nextek 6D			28.000	
Nextek 18D				28.000
Polypropylene fibres 4 mm			0.100	0.100
SUM	100.000	100.000	100.000	100.000

#### 2.3. Test Methodology

A Testo 875-2i instrument was used for the measurements and the results were evaluated with Testo IRsoft software, version no. 4.5. The samples were 28 days old and the temperature and humidity of the environment during the measurement are given for individual measurements in Section 3. The resulting temperature is the average of the area of individual samples.

The same samples of finished samples were also tested using thermocouples and a data logger in a climate chamber. Data logger AHBORN set ALMEMO 2690-8AKSU, PT100 probes and ALMENO Control software were used. The purpose was to verify the suitability of the use of thermography and to verify its appropriate resolution. In the practical part, only selected outputs from thermographic measurements are presented.

Differential Scanning Calorimetry (DSC) analysis was used for the evaluation of latent heat thermal energy properties of the PCM.

### 3. Results and Discussion

#### 3.1. PCM Products Tested

The temperature removal behavior of the filler and thermotropic materials in the climate chamber (see Figures 4 and 5).

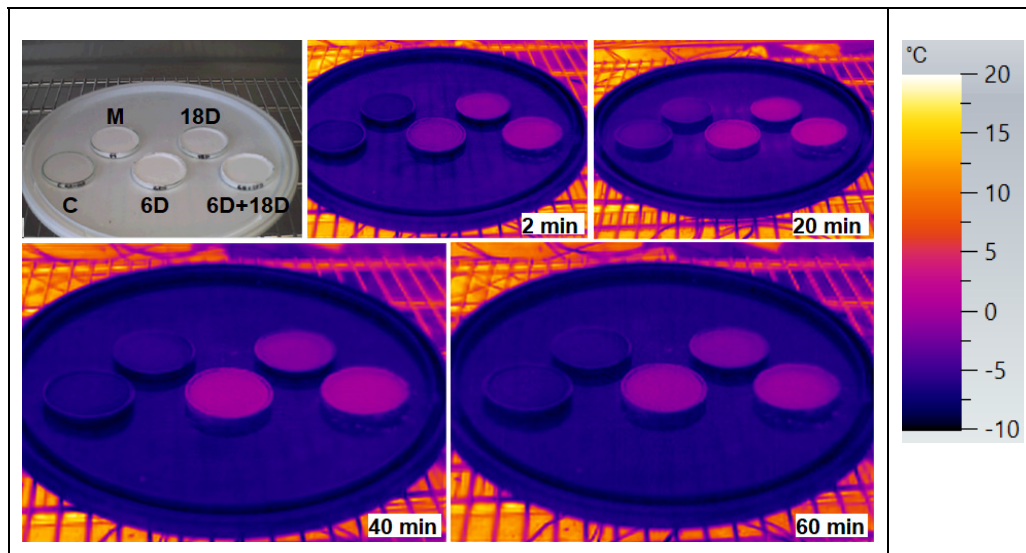


Figure 4. Thermal images during filler and PCM testing (from left: crushed limestone Carolith 0.2–0.5, Micronal DS 5040 X, Nextek 6D, Nextek 18D, Nextek 6D + 18D combination).

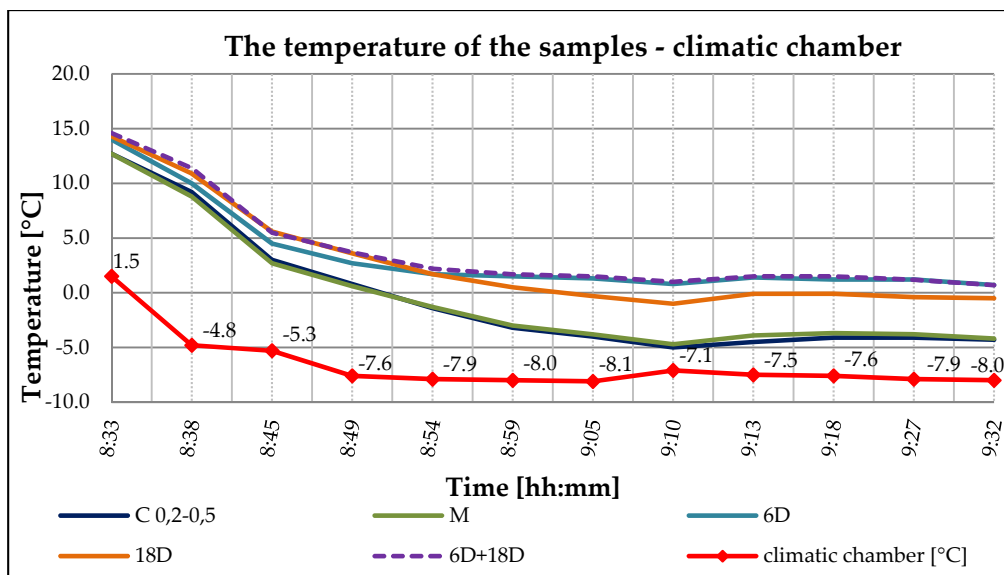
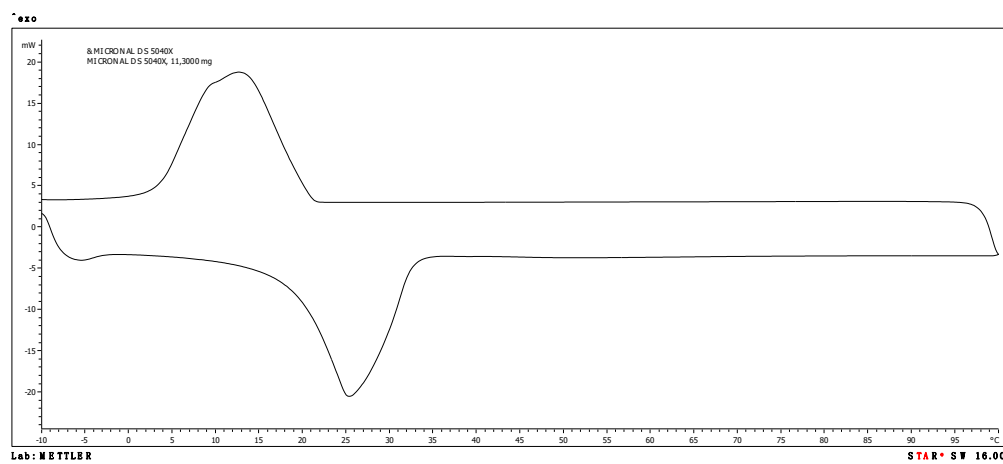


Figure 5. Evolution of temperature of filler and thermotropic materials placed in climate chamber.

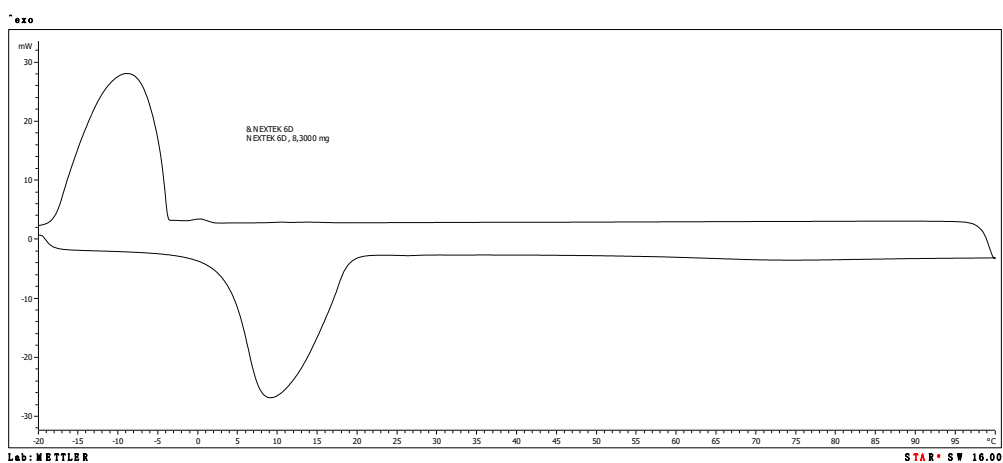
The samples tested with a thermal camera were standard filler Carolith 0.2–0.5 (crushed limestone), PCM Micronal DS 5040 X (M), Nextek (6D), Nextek (18D) and their combinations (6D + 18D) (see Figure 5). The specimens were placed in a climatic chamber at a temperature of 12 °C and a relative humidity of 50% for 24 h. At the start of the test, the temperature in the climate chamber was lowered to −12 °C and the temperature development of the test samples was monitored for 1 h. The ambient temperature dropped to −8 °C within 20 min and remained at this level until the end of the measurement. It is clear from Figure 5 that PCM Micronal was close to Carolith in its behavior, as

the wax was no longer activated due to the previous storage of the sample at a temperature of 12 °C. Micronal acts like a standard filler, without any benefit in terms of heat release, which was assumed due to the wax adjustment exclusively for the interior (thermal comfort in the rooms). On the other hand, Nextek specimens showed the ability to release heat at 12 °C despite previous storage. Sample 18 D fulfilled its function until the sample temperature was close to 2 °C, then due to the properties of the wax, the temperature gradually decreases (see Figure 5). It is interesting to activate the wax even after storage, which is below the guaranteed melting temperature point. Sample 6D had a time lag compared to sample 18D, which on the other hand showed the ability to perform PCM function below 2 °C. The last sample was a 50:50 Nextek 6D and 18D combination. The result of this combination is that it is very efficient and allows you to take advantage of both products and their settings. This combination is then effective to a greater extent and covers a significant proportion of normal outdoor temperatures. The above tests have shown that PCM from Nextek can be used in exterior materials and their thermo-technical properties.

Differential Scanning Calorimetry (DSC) analysis was used for evaluation of the latent heat thermal energy properties of the PCM (see Figures 6–8 and Table 3).



**Figure 6.** Differential Scanning Calorimetry (DSC) curves—cooling and heating curve of Micronal DS 5040X.



**Figure 7.** DSC curves—cooling and heating curve of Nextek 6D.

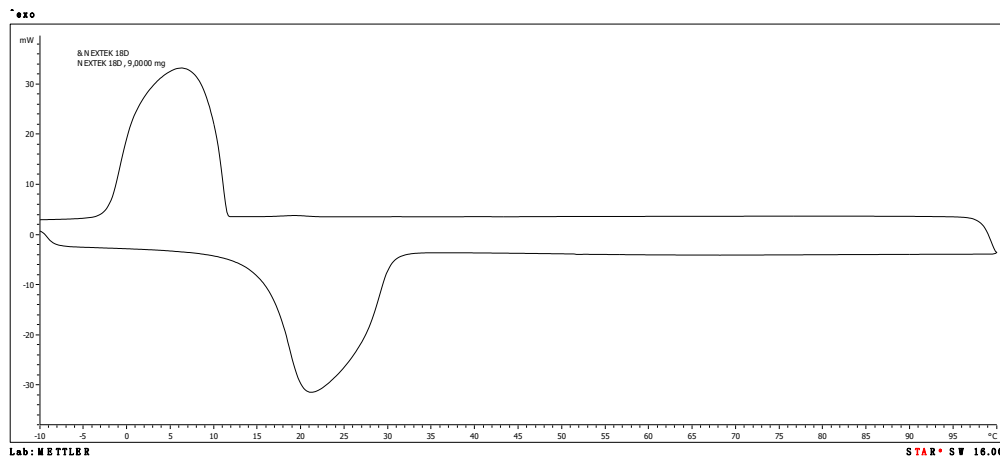


Figure 8. DSC curves—cooling and heating curve of Nextek 18D.

Table 3. Latent heat thermal energy storage properties of the used PCM.

Materials	Heating		Cooling	
	$T_m$ [°C]	$\Delta H_m$ [J/g]	$T_c$ [°C]	$\Delta H_c$ [J/g]
Micronal DS 5040 X	24.79	56.71	13.46	77.98
Nextek 6D	8.51	166.53	-7.89	160.69
Nextek 18D	20.52	165.83	7.12	184.07

The crystallization temperatures ( $T_c$ ), melting temperatures ( $T_m$ ), crystallization enthalpies ( $\Delta H_c$ ) and melting enthalpies ( $\Delta H_m$ ) obtained from the DSC are reported in the Table 3. With regard to the outdoor use of PCMs, Nextek 6D and Nextek 18D materials were selected for further experimental work.

### 3.2. ETICS Base Coat with PCM Test on Insulator

Evolution of temperature of base coat with PCM on exterior insulator (see Figures 9 and 10).

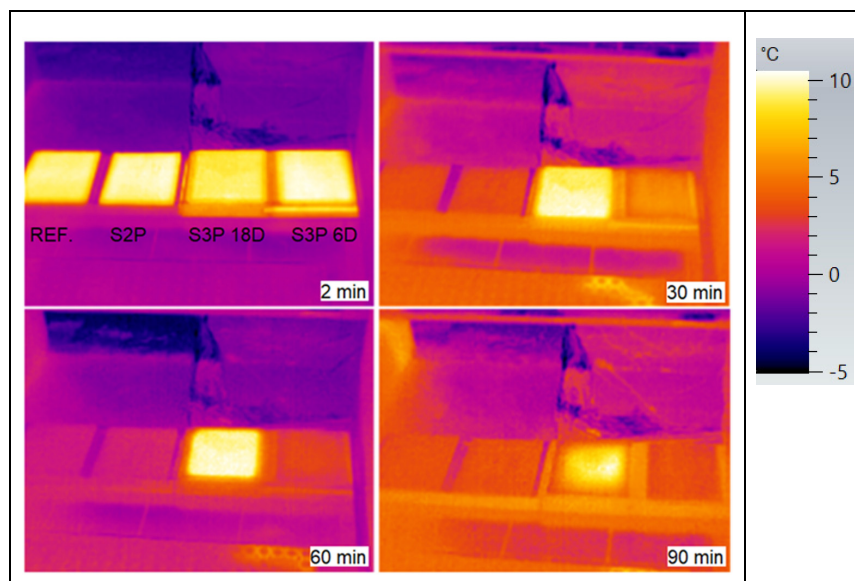


Figure 9. Thermal images of test specimens (from left: reference base coat, base coat with fly ash, base coat with fly ash and PCM Nextek 18D, base coat with fly ash and PCM Nextek 6D), exterior 1 °C and 58% humidity.

The samples used in the test were standard base coat (REF.), a co-developed base coat with a high temperature fly ash (S2P) and a base coat with PCM and fly ash (S3P 6D and S3P 18D). In samples S3P 6D and S3P 18D, the filler (Carolith 0.2–0.5) was replaced by the above-mentioned thermotropic material. The samples were placed in a laboratory environment at 23 °C and 50% relative humidity. Later they were placed outdoors at a temperature of about 1–2 °C and a relative air humidity of 58% and the temperature was measured for 2.5 h (see Figure 10). The samples were protected from direct sun exposure. The results show that the temperatures of both PCM-free base coats dropped to 2 °C after about 25 min, while the S3P 18D base coat reached a similar level, after about 90 min (see Figure 10).

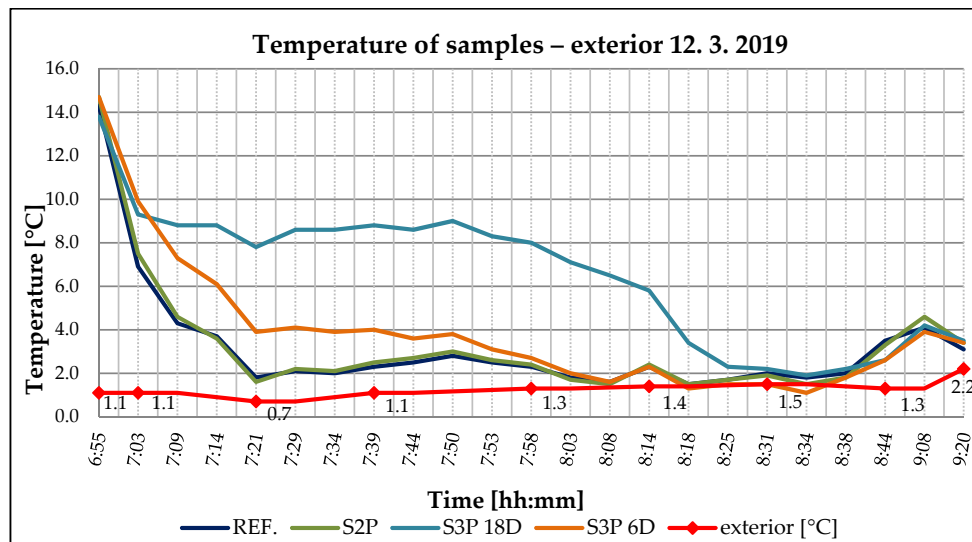


Figure 10. The development of the temperature of the PCM-containing base coat applied to the insulator, the samples placed in the exterior.

### 3.3. ETICS Base Coat Test with PCM on Insulator—Solar Effect

Evolution of sample temperature on exterior direct sunlight (see Figures 11 and 12).

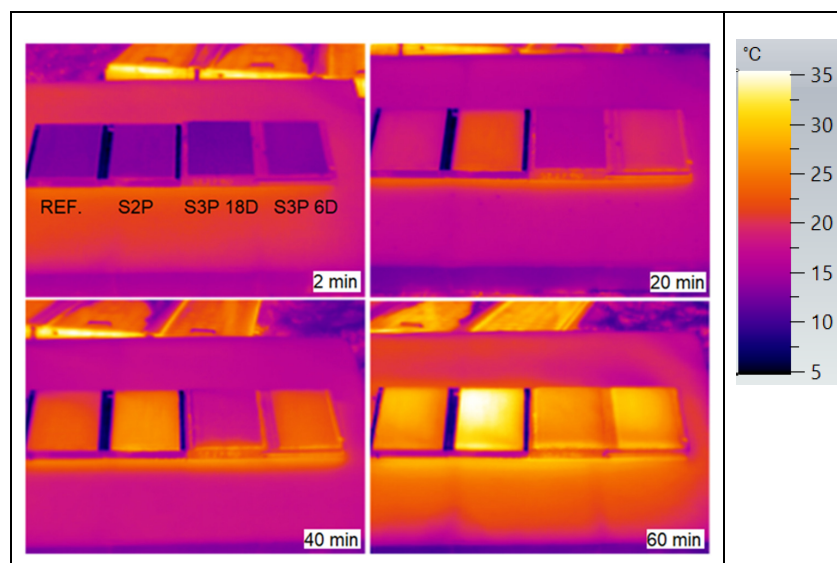


Figure 11. Thermal images of test specimens (from left: reference base coat, base coat with fly ash, base coat with fly ash and PCM Nextek 18D, base coat with fly ash and PCM Nextek 6D), exterior 1 °C and 58% humidity.

As outlined in the last test, Figure 12, the base coat samples were tested outdoors for one hour at a temperature of about 9 °C and 68% relative humidity. The ambient temperature dropped to 5.8 °C within 1 h of measurement. The results show us the effect of direct sunlight on the sample for about 40 min and subsequent clouding. The figures show that the surface temperatures of the PCM-free sample have a faster temperature rise than the PCM samples, where the increase is gradual. The best result was the PCM Nextek 18 D sample again. At 12:01, clouds shaded the samples and temperatures dropped again, which caused a sharper fall for a sample without PCM. The results thus show that the thermal behavior of the PCM material is more gentle on the thermodynamic stress of the ETICS and limits the possibility of micro-cracks. Thus, the rise and fall of the base coat temperature is moderated by the PCM.

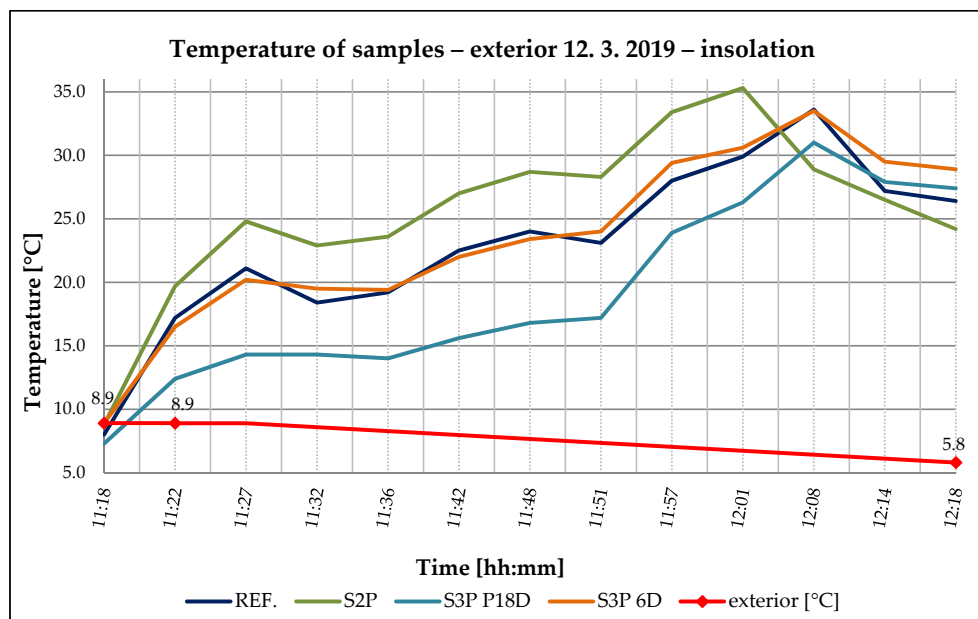


Figure 12. Evolution of temperature of samples placed in direct sunlight.

The experimental verification of the condensation on the ETICS is shown in Figure 13.

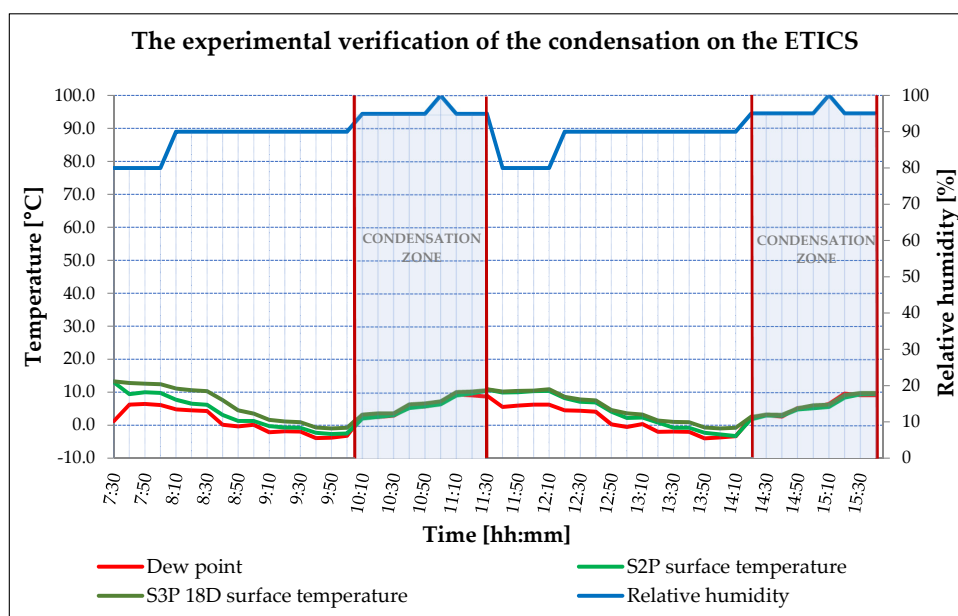
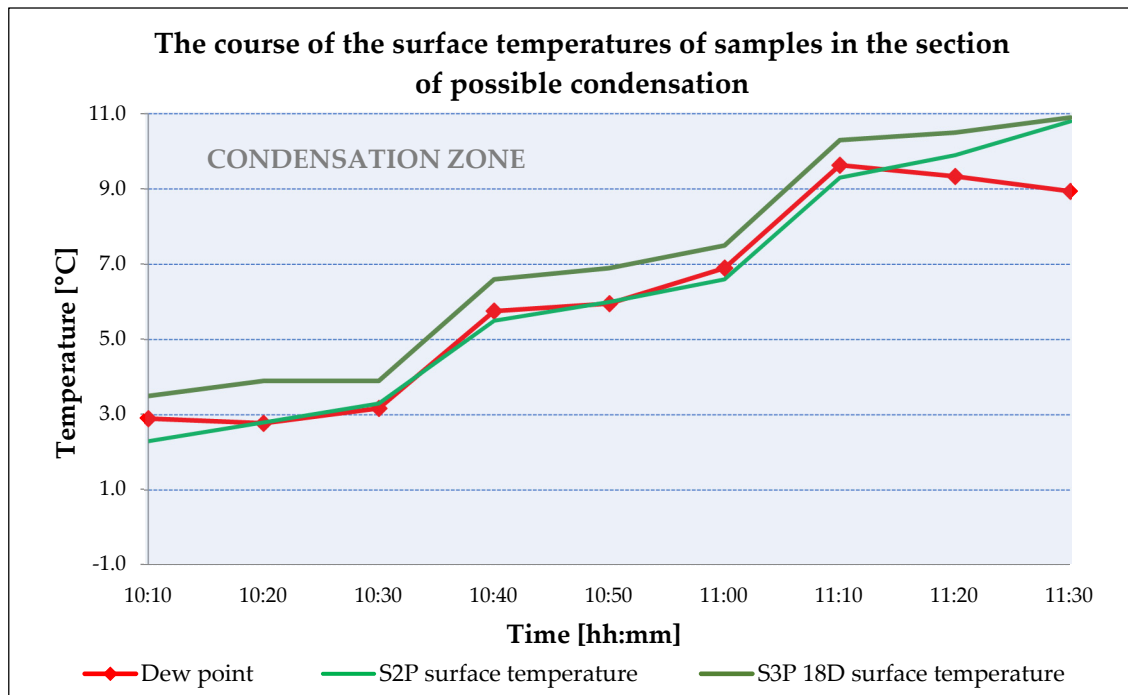


Figure 13. Development of ETICS surface temperature and susceptibility to condensation.

The systems were measured within 8 h and two complete cycles of cooling and heating the samples. The beginning of the measurement started at 12 °C. The resulting measurement showed different sample behavior and the surface temperature of the sample with PCM S3P 18D decreased less than in the case of the sample without PCM (S2P). In the condensation zone, this difference is better seen (see Figure 14).



**Figure 14.** The course of the surface temperatures of samples in the section of possible condensation.

The performed experiments confirmed that the surface temperatures of the S2P sample in the condensation section meet the conditions for condensation of water vapor on the surface. The temperatures of the sample S2P correspond to dew point temperatures in the condensation section (see Figure 14). In the case of the S3P 18D sample, thanks to the use of PCM, it was possible to keep the surface temperatures above the temperature of possible condensation, and thus, condensation on the ETICS surface did not occur. One PCM sample (S3 18D) was 0.2–1.0 °C away from the possibility of condensation and that agrees with a previous study [4]. These results were crucial for verifying the functionality of PCM technology within the ETICS system. The theoretical assumptions concerning the use of PCM in ETICSs and their influence on the possible condensation of water on the surface were verified. According to the authors in previous studies [16,27,28], condensation moisture has a high proportion of algae and mold growth on facades.

#### 4. Conclusions

Microcapsules with different wax settings (melting point) were used during the test. The Micronal product was used mainly in initial tests to verify the performance of this material within the ETICS base coat. Subsequently, other products that have a melting point more suitable for outdoor use were tested. Due to the weather conditions in Central Europe, the most suitable type was considered Nextek 6D. This hypothesis was not confirmed and the more suitable type for temperatures between 0 °C and 30 °C was Nextek 18D. The required wax properties for Nextek 6D began to show up at temperatures close to 0 °C and below. The 18D has proven to be the more appropriate choice in the required temperature range. A 50:50 combination of 6D and 18D was used in the last test. This combination ensured the use of PCM features on a larger scale and eliminated certain limitations of both types of PCM. Functional use is expected in the range of –6 to +30 °C. This temperature covers most of the calendar year.

The above-mentioned results have shown that the use of PCM for the protection of ETICSs has very interesting results and may bring environmental benefits (biocidal product reduction) and it also supports the durability of ETICSs due to reduced thermodynamic stress of the facade.

For further research, it seems to be best to use a combination of these two materials. The aim of the research is to utilize PCMs and at the same time to meet all the physical-mechanical parameters of the ETICS base layer according to The European Assessment Document (EAD) requirements. The long-term follow-up of two types of ETICS is intended as the final stage of the research: a standard system and new system with PCM and without biocidal protection.

**Author Contributions:** Conceptualization, L.S. and N.Ž.; methodology, L.S.; formal analysis, L.S.; investigation, L.S., N.Ž., V.N., A.J.; resources, L.S.; data curation, L.S.; writing—original draft preparation, L.S.; writing—review and editing, L.S.; supervision, N.Ž.; funding acquisition, L.S. and N.Ž. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** This paper has been worked out under the project No. FAST-S-20-6370 “Development of vacuum insulation based on by-products”, supported by the Ministry of Education, Youth and Sports under the “Specific research” at Brno University of Technology.

**Conflicts of Interest:** The authors declare no conflict of interest.

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