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Functional Adaptive Nano-Materials and Technologies for Energy Efficient Buildings

Analysis of ETICS State of the Art: An Update

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1. Introduction

This document provides an analysis of the state-of-the-art, the patent situation and literature of the ETICS market. It shows recent innovations in ETICS and the main components (including insulation material, foams, flame retardants, rendering and mounting systems).

2. Innovation in ETICS

First of all, the innovations concerning the ETICS as a whole system are presented. In the following, the relevant documents of the patent literature are listed (see Table 1).

The patent by Jablite describes an insulation panel with an air gap in between. A fan is used to draw air through the gap, this air is used to regulate the temperature in the house. In contrast to the aims in the FoAM-BUILD project, the air is not used to ventilate the façade. The combination of the insulation board with an air gap and a ventilation works as a heat exchange device.

The obtained temperature differences are however low, and the device has to have a large surface to exchange sufficiently high amounts of heat. This results in a high flow resistance that has to be overcome by the fan, and therefore in a relatively high energy consumption by the fan.
Table 1: Patent situation ETICS

It is questionable, under which conditions this system is efficient. Regarding the FoAM-BUILD project, it still can be an interesting method to obtain air that has a higher temperature than the ambient air for the drying of the façade.

Reference	Approach
EP000002778308A1, Jablite, 17.09.2014	Dynamic insulation boards with air gap within the insulation material
EP000002689894A2, Sto, 29.1.2014	New tool for fixing anchors, works as an extension put on anchors to meet the desired depth of the anchor
EP000001640521B2, Brillux, 21.01.2015	New procedure for fixing insulation plates

In cases, where a cooling of the house is needed, e.g. in late summer, this air can be used to dry the façade. However, for this case, the air can also be taken from inside the house. The proposed use of the ground heat in FoAM-BUILD would be a more constant source of warm air and this approach is therefore still preferred.

The other two patents by Sto and Brillux are presenting methods to reduce the error rate during the installation of the ETICS, one by defining the anchor depth and the other one by a new fixing method. However both approaches tend to be more time-consuming than the standard approach and therefore reduce the efficiency of the workers. In summary, these patents will not affect the FoAM-BUILD project.

The enquiry of the scientific literature brought results that are listed in Table 2 .

Reference	Title
V. Sulakatko, I. Lill, E. Liisma, Procedia Economics and Finance, Volume 21, 2015, Pages 297–305	Analysis of On-site Construction Processes for Effective External Thermal Insulation Composite System (ETICS) Installation
C. Fernandes, J. de Brito, C. Cruz, J. Perform. Constr. Facil., 2015	Thermal Retrofitting of Façades: Architectural Integration of ETICS
S. H. Cho; H. Y. Lee; J. S. Kang; Y. J. Lee; G. S. Choi, Materials Research Innovations, Volume 19, 2015, Pages S5-1049-1053	Evaluation on the thermal performance of external insulation system in apartment building remodelling
H. J. Choi; Y. M. Kim; G. S. Choi; J. S. Kang; S. E. Lee, Materials Research Innovations, Volume 19, 2015, Pages S5-1054-1064	Thermal resistance characteristics of film insulator with low-emissivity
Y. M. Kim; Y. J. Lee; G. S. Choi; J. S. Kang, Materials Research Innovations, Volume 19, 2015, Pages S5-1074-1076	Thermal performance of sandwich insulation system for apartment buildings according to the shear connectors and insulation

Table2: Scientific literature regarding ETICS

From this list, the most relevant for FoAM-BUILD are the publications from Sulakatko and Choi, that are described in the following. The paper by Sulakatko et al. analyses the error rate on-site while installing the ETICS. In particular in cold regions problems occur caused by the fact that many products, for instance mortar, need temperatures of above 5°C for curing. In case the temperatures are too low, air blowers are used to heat the wall. However this leads to a higher CO_2-uptake and therefore a higher shrinkage in the rendering. The cracks caused by this error can be avoided by using powder-accelerators in the mortar, which is investigated within the FoAM-BUILD project. (WP3)

The paper published by Choi et al. compares ventilated ETICS with non-ventilated ones. The ventilation is not performed on the outside façade however. The aim of this work is to decrease the condensation of water inside the building. Since the last report was published, progress was also made in terms of standardization regarding ETICS (Table 3).

Identification No.	Title
EN 13496	Thermal insulation products for building applications. Determination of the mechanical properties of glass fibre meshes as reinforcement for External Thermal Insulation Composite Systems with renders (ETICS)
EN 15824	Specifications for external renders and internal plasters based on organic binders
prEN 16382	Thermal insulation products for building applications - Determination of the pull-through resistance of plate anchors through thermal insulation products
prEN 16383	Thermal insulation products for building applications - Determination of the hygrothermal behaviour of external thermal insulation composite systems with renders (ETICS)
prEN 16724	Thermal insulation products for building applications - Instructions for mounting and fixing for determination of the reaction to fire testing of external thermal Insulation composite systems (ETICS)

Table 3: Scientific literature regarding ETICS

The EN 13496 was updated in December 2013 with modifications regarding the test evaluation and a more detailed definition of the sampling. The EN 15824 treats organic binders in plasters regarding the reaction to fire and the classification thereof, and prEN 16382 and prEN 16383 concern the determination of the pull-through resistance of plate anchors and the hygrothermal behaviour of ETICS. These documents just finished the enquiry stage, meaning that the final version is being prepared but the voting has not happened yet. The prEN 16724 is about the preparation of samples for tests concerning the reaction to fire like the SBI test. It is currently in formal vote stage, meaning that the final version is almost ready and the final voting will start soon.

3. Main components of ETICS

3.1. Insulation material

3.1.1. Thermal Conductivity/ EPS Nanofoams

Many of the activities regarding insulation materials aim for high performance materials on the basis of phenolic foam, polyurethane foam or aerogel mats. However these materials still have disadvantages like high costs, a high density or an energy consuming production process. An increasing activity was stated for the work on processes for nanofoams on the basis of polystyrene and other thermoplastic polymers. With these materials, the thermal conductivity is supposed to be significantly reduced by using the Knudsen effect. Therefore, cell sizes of about 100 nm are necessary. The update on this material will be the focus of this chapter, since the FoAM-BUILD project is aiming for EPS nanofoams.

Different approaches to obtain PS-based nanofoams from scientific literature are summarized in Table 4.

Reference	Title
C. Forest, P. Chaumont, P. Cassagnau, B. Swoboda, P. Sonntag, Progress in Polymer Science, Volume 41, February 2015, Pages 122–145	Polymer nano-foams for insulating applications prepared from CO_2 foaming
B. Notario, J. Pinto, E. Solorzano, J.A. de Saja, M. Dumon, M.A. Rodríguez-Pérez, Polymer, Volume 56, 15 January 2015, Pages 57–67	Experimental validation of the Knudsen effect in nanocellular polymeric foams
J.A.R. Ruiz, J.M. Tallon, M. Pedros, M. Dumon, The Journal of Supercritical Fluids, Volume 57, Issue 1, May 2011, Pages 87–94	Two-step micro cellular foaming of amorphous polymers in supercritical CO_2
A. Wong, L.H. Mark, M.M. Hasan, C. B. Park, The Journal of Supercritical Fluids, Volume 90, June 2014, Pages 35–43	The synergy of supercritical CO_2 and supercritical N_2 in foaming of polystyrene for cell nucleation
C. Gutiérrez, J.F. Rodríguez, I. Gracia, A. de Lucas, M.T. García, The Journal of Supercritical Fluids, Volume 88, April 2014, Pages 92–104	Preparation and characterization of polystyrene foams from limonene solutions
H. Ruckdäschel, P. Gutmann, V. Altstädt, H. Schmalz, A.H.E. Müller, Advances in Polymer Science, Volume 227, 2010, pp 199-252	Foaming of Microstructured and Nanostructured Polymer Blends
Z. Xing, M. Wang, G. Du, T. Xiao, W. Liu, D. Qiang, G. Wu, The Journal of Supercritical Fluids, Volume 82, October 2013, Pages 50–55	Preparation of microcellular polystyrene/polyethylene alloy foams by supercritical CO_2 foaming and analysis by X-ray microtomography

Table 4: Literature insulation materials

The first paper by C. Forest et al. gives an overview on the actual techniques used to produce nano-structured foams. Some of the described methods (e.g. supercritical CO_2 foaming of polymer blend systems) are also used and further developed within the FoAM-BUILD project. An overview on cell sizes that were reached with different materials and in different studies is given. Also a model for the calculation of the Knudsen effect is given.

In the third paper listed submitted by Ruiz et al., the two-step foaming of different polymer blends is described. A further developed process is used in FoAM-BUILD using modified polymer beads in a similar process with supercritical CO_2 for nucleation and a hot water bath for further reduction of density.

In the paper by H. Ruckdäschel et al., the importance of the blend morphology of polymer blend systems (PPE/PS/SAN/etc.) on the cellular morphology (cell density, cell size) of foams made of those blends is shown. Those relations are very important for the project as blending of polymers is seen as a key to reduce the cell size of polystyrene based polymer foams significantly. The influence of other blend systems on the foam morphology are being studied right now as it is expected to reach even lower cell sizes with other materials.

In conclusion, the actual literature review shows several approaches to develop nano-cellular foams. The most promising ones are to use supercritical CO2 for fine nucleation and foaming of polymer blends. Nonetheless the reached densities are very high. The FoAM-BUILD approach to have a modified two-step foaming process to reach lower densities then already achieved, does not need to be changed as it is an enhancement of the mentioned methods.

3.1.2. Flame retardants

Brominated flame retardants are the most common flame retardants used in EPS. Often, these materials are persistent, bio-accumulative and toxic (PBT) and release high amounts of volatile organic compounds. For this reason, the formerly mainly used brominated flame retardant, hexabromocyclododecane (HBCD) is on the Substances of Very High Concern list within the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) agreement and will be prohibited by the EU from the 21st of August 2015. As a result there is now a need to avoid brominated flame retardants in insulation materials in general.

The patent situation regarding flame retardancy in insulation materials is described in Table 5.

Reference	Approach
EP000002708668A1, Sto, 19.3.2014	Insulation plates with high flame retardancy by organic binder and flame retardant coating
EP000002743296A1, Sto, 18.06.2014	Insulation plates with high flame retardancy by organic polymer coating

Table 5: Patent situation insulation materials

These patents are not relevant for the FoAM-BUILD project since another approach is used. However they could become interesting in case there are changes in the project, so these patents should not get out of the sight.

Table 6 shows the published literature concerning non-halogenated flame retardants and the approaches in research.

Reference	Title
W. Hu, B. Yu, S.-D. Jiang, L. Song, Y. Hu, B. Wang, Journal of Hazardous Materials, Volume 300, 30 December 2015, Pages 58–66	Hyper-branched polymer grafting graphene oxide as an effective flame retardant and smoke suppressant for polystyrene
X. Chen, Y. Liu, S. Bai, Q. Wang, Polymer-Plastics Technology and Engineering, Volume 53, Issue 13, 2014, pages 1402-1407	Macromolecular Nitrogen-Phosphorous Compound/Expandable Graphite Synchronous Expansion Flame Retardant Polystyrene Foam
Y. Xia, R. Liu, X. Lyu, H. Zhang, Q. Wang, J. Guo, Y. Gong, Fibers and Polymers, October 2014, Volume 15, Issue 10, pp 2181-2185	Study on kenaf flame retarded by halogen-free flame retardant/HIPS composites
J. Liu, Z. Yu, H. Chang, Y. Zhang, Y. Shi, J. Luo, B. Pan, C. Lu, Polymer Degradation and Stability, Volume 103, May 2014, Pages 83–95	Thermal degradation behavior and fire performance of halogen-free flame-retardant high impact polystyrene containing magnesium hydroxide and microencapsulated red phosphorus
B. Wicklein, A. Kocjan, G. Salazar-Alvarez, F. Carosio, G. Camino, M. Antonietti, Nature Nanotechnology, Volume 10, 2015, pages: 277–283	Thermally insulating and fire-retardant lightweight anisotropic foams based on nanocellulose and graphene oxide

Table 6: Scientific literature flame retardancy

Overall, these papers do not seem to be of high relevance for the FoAM-BUILD project. The papers of Hu et al., Xia et al. and Lui et al. treat a more compact material than it is planned in FoAM-BUILD and therefore do not contain any additional relevant knowledge for the project. In the paper of Chen et al. necessary information about the foam density is missing, and it can be assumed that the high amounts of flame retardants used in this work lead to a relatively high density of the foamed material, which is not desired in the FoAM-BUILD project. The paper of Wicklein et al. describes a system that based on cellulose nanofibers, graphene oxide and sepiolite nanorods and has therefore no direct relevance for the EPS based foams in FoAM -BUILD.

3.2. Moisture problems on the external surfaces of the ETICS

Façades with ETICS are not heated by the warm temperatures inside the building and in addition have a low heat capacity compared to massive brick walls. Caused by this, façades with ETICS will cool down more easily, even below the dew point, especially during night and in autumn. As a consequence, condensation of water will occur which enables the algae and fungi to grow.

The concept of increasing the heat capacity is used in the patent by Knauf (see Table 7). Wood wool boards form the outer layer of the ETICS and cause a high heat capacity of the wall. Additional thermal insulation material could be brought between the inner and the outside layer.

A high influence of porosity and roughness on the growth of biofilms was shown by D'Orazio et al. (Table 8). This is caused by an increased water retention caused by the higher surface area. In the FoAM-BUILD project, the surface roughness can be varied by the use of different top coats. The result of this paper is that, especially for accelerated tests, it seems to be useful to use top coats with a high roughness to test the worst-case scenario.

The second paper by von Werder et al. utilized a fluorometric method to quantify the growth of algae on façades and therefore the resistance against the growth. This method could also be used in the FoAM-BUILD project to decrease the time needed for the interpretation of measurements regarding algae growth on the façade with ETICS.

Reference	Approach
WO002013164432A1, Knauf, 7.11.2013	Reducing the growth of algae and fungi by the thermal mass of wood wool boards

Table 7: Patent situation algae and fungi

Reference	Title
M. D'Orazio, G. Cursio, L. Graziani, L. Aquilanti, A. Osimani, F. Clementi, C. Yéprémian, V. Lariccia, S. Amoroso, Building and Environment, Volume 77, 2014, pages 20-28	Effects of water absorption and surface roughness on the bioreceptivity of ETICS compared to clay bricks
J. von Werder, H. Venzmer, R. Černý, Journal of Building Physics, Vol. 38 no. 4, 2015, pages 290-316	Application of fluorometric and numerical analysis for assessing the algal resistance of external thermal insulation composite systems

Table 8: Scientific literature biofilm growth on ETICS

3.3. Rendering system

The hygrothermal behavior of façades is an important parameter for the growth of biofilms (see previous chapter). One paper relevant for FoAM-BUILD was found about the influence of the orientation of the façade on the hygrothermal behavior. Barreira et al. performed an experimental investigation of the influence of wall orientation on surface condensation for a building with walls equipped with ETICS. The building was located in Porto, Portugal and the measurements were performed mainly during the year 2009. It was found that orientation of the façade has a major influence on surface condensation. More specifically for the building under study the west façade presented higher risk of condensation followed by the east, north and south façades. The paper provides experimental data for hygrothermal simulations and could be used for our model validation in case relevant weather data can be obtained (Porto, Portugal, year 2009).

3.4. Mounting system

Different innovations regarding mounting systems where described in Chapter 2: Innovation in ETICS.

Reference	Title
E. Barreira, V. P. de Freitas, Building and Environment, Volume 63, 2013, pages 31-39	Experimental study of the hygrothermal behaviour of External Thermal Insulation Composite Systems (ETICS)

Table 9: Scientific literature hygrothermal behaviour on ETICS

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