An Assessment and Comparative Study of Modern Thermal Insulation Systems

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***Abstract* – The thermal protection and overall energy performance of a building are influenced by the gradual development of technical and energy requirements. This should be adapted into application of new thermal insulation materials and systems in construction. The paper deals with unconventional thermal insulation materials and systems that are mostly applied in buildings included in Modern Methods of Construction (MMC). Five types of thermal insulation systems or materials - Baumit openTherm, Knauf SMARTwall N C1, SATSYS ThermoUm, Knauf TP 435 B, and Aerogel Spaceloft - are assessed and compared to each other in a case study of a family house. Based on the comparison of the thermal insulation systems through multi-criteria decision-making method PATTERN, a significance ranking of the systems from construction cost, construction time, thermal conductivity, diffusion resistance and fire resistance point of view is determined.**

***Keywords* – Thermal insulation, thermal insulation system, façade, ETICS, construction cost, construction time, decision-making methods.**

1. Introduction

The energy consumption of a building undoubtedly greatly depends on the characteristics of its envelope. The thermal performance of external walls represents a fundamental factor to increase the energy efficiency of the construction sector [1]. Thermal insulation is definitely one of the best ways to reduce the energy consumption due to both winter heating and summer cooling and insulation materials play a significant role in this scenario. The selection of the proper material, its thickness and its position, allow obtaining good indoor thermal comfort conditions and adequate energy savings [2].

A thermal insulation is one efficient technology to utilize the energy in providing the desired thermal comfort by its environmentally friendly characteristics. The principle of thermal insulation is by the proper installation of insulation using energy-efficient materials that would reduce the heat loss or heat gain, which leads to reduction of energy cost as the result [3].

Wall insulation performance is a key factor affecting building energy consumption and indoor comfortable level [4]. Building envelopes have many details which can easily introduce thermal bridge due to limited space of insulation or incorrectly solved construction details [5].

Depending on the building's energy consumption structure, the thermal performance of the building envelope is the main factor affecting energy consumption, thus, the thermally insulated walls can reduce the energy consumption of the heating or air conditioning system [3].

For the buildings of today and the near future, several insulation materials and solutions, both conventional and unconventional, are used and will have to be used depending on the exact circumstances and specifications [6]. Therefore, it will be of major importance to know the limitations and the possibilities of all the insulation materials and solutions, i.e. their advantages and disadvantages.

Nano cellulose possesses a combination of properties suitable to produce ultralight, strong and flexible foams and aerogels for a rapidly growing range of applications. The research interest in nanocellulose-based foams and aerogels is recent but rapidly growing [7]. The combination of an ultralow density, tuneable porous architecture and outstanding mechanical properties makes them of interest for a

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wide range of applications including thermal insulation.

The use of aerogel technology in façades has potential to reduce thermal bridging and limit condensation [5]. Recent improvements in aerogel production have reduced the costs, making it possible to integrate the material in construction products such as insulation panels, transparent building components, and insulation plasters. New products can help reduce the thickness of the insulation compared, for example, to expanded polystyrene insulation products [8]. The development of special aerogel-based plaster systems together with optimal application methods for structured facades can contribute to the future success of respective solutions.

2. Materials and methods

To assess and compare the different modern thermal insulation materials and systems, a case study was conducted evaluating five different thermal insulation systems from five indicators' point of view. The indicators include construction cost, construction time, thermal conductivity coefficient, diffusion resistance factor, and resistance to fire. The case study has referred to a single-story family house (FH) without a basement, which is inhabited by a four-member family (Figure 1. and Figure 2.). The roof is hip, and the attic isn't intended for housing.

Figure 1. The model of the single-story family house

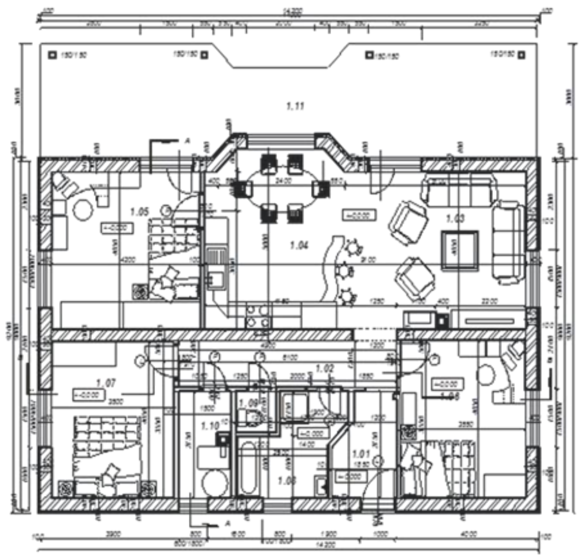

Figure 2. The ground-plan of the single-story family house

The house represents a medium size category. It is heated by natural gas. The bearing walls of the house are made of aerated blocks PORFIX. The structural layer of the walls is 300 mm thick. The house is situated in the town Gelnica. According to the standard *STN 73 0540-3 Thermal protection of buildings. Thermal performance of buildings and components. Part 3: Properties of environments and building products*, the temperature zone no. 3 of this region is -15°. The size characteristics of the house are presented in Table 1.

Table 1. The size characteristics of the family house

Characteristic	Size	Measure unit
Built-up area	132,74	m^2
Volume	508,20	m^3
Household area	60,90	m^2
Total living area	86,21	m^2
Height of the roof ridge from ±0,000	5,35	m

The external walls are made of 500 x 250 x 300 mm aerated concrete blocks Porfix. The internal surfaces are plastered by lime-cement stucco plaster, the external surfaces are plastered by lime-cement smooth plaster and are coated by façade paint Baumit. The windows and entrance doors are plastic. The ceilings are assembled from ceramic ceiling system Miako. The roof is coated by concrete roof system Bramac.

2.1 Studied thermal insulation systems

Five different thermal insulation systems were selected to be studied in the case of the presented family house. The selected systems are characterized by different technological processes of construction, different thermal and technical parameters.

Baumit openTherm insulation system

The ETICS (ETICS – External Thermal Insulation Composite System) Baumit openTherm consists of several layers that are in a specified order set solid applied to external walls. The breathable façade insulating panels are made of expanded polystyrene (EPS) in accordance with the standard *STN EN 13163 Thermal insulation products for buildings. Factory made expanded polystyrene (EPS) products. Specification.* It is specially designed for brickwork and similarly breathable masonry with very good thermal insulation properties.

Knauf SMARTwall N C1 insulation system

The ETICS is based on SMARTwall N C1 insulation boards made from mineral fibers bonded by modified synthetic resin. The SMARTwall N C1 board is a product with one-sided silicate spray coating. The boards are hydrophobized throughout the cross-section, thus any atmospheric humidity from surrounding environment is not absorbed by the boards. The SMARTwall N C1 boards are applied in ETICS for thermal, sound and fire insulation of external walls. The boards are glued and at the same time anchored to the wall.

Thermal insulating plaster SATSYS ThermoUm

The thermal insulation plasters ThermoUm of the Czech manufacturer of thermal insulation plastering composites SATSYS Technology were developed for plastering of brick, aerated concrete, concrete and other types of constructions. Due to low bulk density and low elastic modulus, the plasters can eliminate the volume changes of base construction. Thus, the plasters don't form any cracks. The grain size of the plaster is up to 2 mm. The new generation of ThermoUm insulating plasters are about four times lighter in comparison with common conventional plasters. Due to the excellent value of the thermal conductivity coefficient, the plaster belongs to extraordinary thermal insulating plasters.

Contactless ventilated Knauf TP 435 B thermal insulation system

The insulation product TP 435 B is made of mineral glass fibers. The board is one-sided coated by black non-woven fabric. Its thermal insulation properties and sound absorption properties are especially useful in the designs of lightweight external cladding systems, primarily as insulation of facade contactless ventilated thermal insulation systems. When applied to a construction, the product is installed with a black non-woven fabric in the exterior side. The black non-woven fabric minimizes cooling of the construction caused by airflow in a ventilated cavity.

Aerogel Spaceloft - ETICS Insulation system based on nanotechnologies

Spaceloft is a flexible, nanoporous, aerogel insulation composite. Due to its special properties, as extremely low thermal conductivity, high flexibility, higher compressive strength and vapor permeability, the Spaceloft insulation presents one from the ideal solutions of top thermal protection of buildings. Using the patented nanotechnology in the production of this insulation material, the Spaceloft has the best thermal properties and at the same time it is the product easy to process without negative environmental impact. The insulation blankets are produced mostly as 5 and 10 mm thick. The rolled blankets are on one side reinforced by a glass fiber mesh eventually the blankets are not reinforced. The role of the mesh is to eliminate plaster cracking.

2.2 Determination of insulation thickness in thermal insulation systems

The thickness of insulation in the five compared insulation systems was for the family house determined based on demands on thermal resistance of the walls according to the standard *STN 730540-2 thermal protection of buildings. Thermal performance of buildings and components. Parts 2: Functional requirements.* The determination was supported by recommendations of competent professional construction companies and recommendations of insulation systems manufacturers. The thickness of insulation in the different thermal insulation systems is presented in Table 2.

Table 2. The thickness of insulation in thermal insulation systems

No.	Type of insulation	Thickness
1	EPS board – Baumit openTherm	140 mm
2	Mineral fibres board - Knauf SMARTwall N C1	140 mm
3	Thermal insulating plaster SATSYS ThermoUm	40 mm
4	Mineral fibres board - Knauf TP 435 B	100 mm
5	Insulation blanket - Aerogel Spaceloft	10 mm

The target recommended thermal resistance value is R = 6.50 [m^2K/W)]. The target recommended value of heat transfer coefficient is for U = 0.15 [W/m^2K].

The estimation of the cost of different thermal insulation systems involved in the case study was made through the software Cenkros 4, the most widely used construction and economic software in Slovak construction industry. It includes national recommended prices of construction processes that are essential for estimation of the construction cost. Similarly, the construction time of each variant of thermal insulation system in the family house was estimated. Based on the comparison of the thermal insulation systems through multi-criteria decision-making method PATTERN, a significance rank of the systems from construction cost, construction time, thermal conductivity and fire resistance point of view is determined.

3. Results and discussion

In Table 3, the total construction cost of thermal insulation system in the family house are presented. The costs are estimated for all the five variants of presented thermal insulation systems. Moreover, the costs are calculated per 1 m^2 of each thermal insulation system. Similarly, the construction time of each variant of thermal insulation system in the family house is determined and presented.

Table 3. The estimated construction cost and construction time of studied thermal insulation systems

No.	Thermal insulation system	Construction cost	Cost per 1 m^2	Construction time	Thickness
1	EPS board – Baumit openTherm	7 182 EUR	47,88 EUR	239,12 hours	140 mm
2	Mineral fibres board - Knauf SMARTwall N C1	6 551 EUR	43,67 EUR	230,48 hours	140 mm
3	Thermal insulating plaster SATSYS ThermoUm	6 970 EUR	46,47 EUR	242,81 hours	40 mm
4	Mineral fibres board - Knauf TP 435 B	11 155 EUR	74,36 EUR	356,69 hours	100 mm
5	Insulation blanket - Aerogel Spaceloft	16 606 EUR	110,70 EUR	269,22 hours	10 mm

From the results of the study of thermal insulation systems from construction cost point of view is evident that thermal insulation system Aerogel Spaceloft based on insulation blankets is the most expensive. Similarly, the system Knauf TP 435 B, based on mineral fibers boards, belongs to rather expensive thermal insulation systems. The cost-related thermal insulation systems are Knauf SMARTwall N C1, Thermal insulating plaster SATSYS ThermoUM and Baumit openTherm with construction cost from 6 500 to 7 182 EUR in the case study. Regarding the analysis from construction time point of view, the biggest time saving is evident in SMARTwall N C1 thermal insulation system. As it is clear by the results of the study, the system Knauf TP 435 B is the most time consuming. To compare the studied thermal insulation systems through multi-criteria decision-making method PATTERN, in addition to construction cost and construction time, three other indicators were considered: thermal conductivity coefficient, diffusion resistance factor and reaction to fire. All the mentioned evaluation criteria are summarized in Table 4.

Table 4. The evaluation parameters of the studied thermal insulation systems

No.	Thermal insulation system	Indicator 1 Construction cost [EUR/m^2]	Indicator 2 Construction time [hours]	Indicator 3 Thermal conductivity coefficient [W/mK]	Indicator 4 Diffusion resistance factor	Indicator 5 Reaction to fire
1	EPS board – Baumit openTherm	7 182	239,12	0,040	10,000	3,000
2	Mineral fibres board - Knauf SMARTwall N C1	6 551	230,48	0,034	3,500	1,000
3	Thermal insulating plaster SATSYS ThermoUm	6 970 E	242,81	0,085	8,000	1,000
4	Mineral fibres board - Knauf TP 435 B	11 155	356,69	0,034	1,000	1,000
5	Insulation blanket - Aerogel Spaceloft	16 606	269,22	0,013	5,000	2,000

After comparison of the studied thermal insulation systems through multi-criterial decision-making method PATTERN, an order of optimal solution for the family house insulation was stated. By the five before mentioned indicators, the thermal insulation system Baumit openTherm based on EPS boards (140 mm thick) was in the decision-making process settled as the best solution for the family house in the case study. The family house insulation by the thermal insulating plaster SATSYS ThermoUm got only a little worst placement (2nd place) in the comparison process. Other thermal insulation system as potential solutions of the house insulation have been placed in the following order: the system Knauf SMARTwall N C1 based on mineral fibers boards – 3rd place; the system Aerogel Spaceloft based in insulation blankets – 4th place; and the contactless ventilated system Knauf TP 435 B based on mineral glass fibers boards as the least appropriate solution for the family house in the case study from the studied indicators point of view.

The results of the comparison of the studied thermal insulation systems through multi-criteria decision-making process PATTERN are presented in Figure 3.

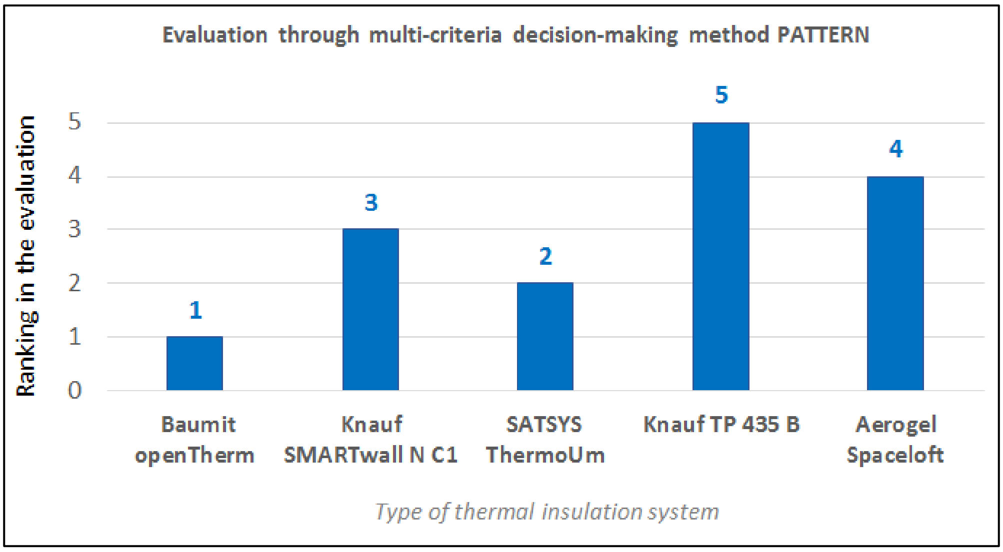

Figure 3. The significance ranking of the studied thermal insulation systems

4. Conclusion

The process of construction materials selection presents a central stage for planning sustainable and stable buildings. The application of a proper assessment method can be a powerful resource for designers and builders, assisting the decision process and supporting an assertive choice.

The case study presented in the paper has dealt with selection of an optimal solution for thermal insulation of the family house. Five different thermal insulation systems were assessed and compared to each other from five different indicators point of view. By comparison of the studied thermal insulation systems through multi-criterial decision-making method PATTERN, the ranking of the systems in terms of construction cost, construction time, thermal conductivity coefficient, diffusion resistance factor and reaction to fire was determined.

Based on the mentioned assessment results, the ETICS Baumit openTherm based on EPS boards is the best solution for the family house given in the case study. High vapor permeability of grey insulation boards, improved method of anchoring, high vapor permeability, elasticity and weathering resistance of white adhesive squeegee belong to the most significant benefits of this high tech system. The high vapor permeability of the thermal insulation system helps maintain optimal moisture in the interior.

The ETICS Insulation system based on nanotechnologies – Aerogel Spaceloft – which can be currently included in the Modern Methods of Construction (MMC), doesn't belong to the best solutions for the family house from the studied indicators point of view. The results of the case study have indicated that despite an excellent thermal conductivity coefficient, it is difficult to recommend this high tech technology as an optimal solution for every builder or client of family houses. The system suffered because of high construction cost. Several studies that have been conducted in the Institute of Construction Technology and Management in Faculty of Civil Engineering of Technical University of Košice demonstrated that low construction cost shouldn't be generally included into the benefits of the MMC.

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