

Article

MgO-Based Board Materials for Dry Construction Are a Tool for More Sustainable Constructions—Literature Study and Thermal Analysis of Different Wall Compositions

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Abstract: Growing global environmental problems force us to think about their impact and search for ways to protect the environment. While the construction industry and the production of construction materials contribute to environmental pollution, they also offer great potential for addressing many environmental problems. Important opportunities exist in the use and processing of a whole host of industrial and construction waste and in the use of mineral resources. Among such mineral resources is magnesite, whose deposits in Slovakia are abundant. The current sustainability trends impose strict requirements on construction materials and products, favoring solutions with sufficient ecological and efficiency performance characteristics. With this focus on efficient and sustainable solutions in mind, the objective of this research was to analyze magnesium oxide construction boards, as they are the most commonly used construction product based on MgO. The specific MgO-based boards that were studied were applied in selected constructions built using the so-called dry method of construction and were compared with traditional material solutions. The research methodology is based on an analysis of computational models of the proposed variants to determine selected thermal-technical parameters. The analyses of external and interior structures presented in this work suggest that when boards based on MgO and traditional materials are used for coating constructions built using the dry method of construction, the former provide certain benefits in terms of energy accumulation, improving living comfort, and in terms of the fire resistance of constructions, improving overall safety. The conclusion of the presented article is devoted to discussions with works that addressed various perspectives on the application of MgO in the field of materials research. The findings from this analysis are beneficial especially in terms of expanding the knowledge in the area.

Keywords: dry construction; magnesite; MgO; thermal-technical properties; thermal resistance

1. Introduction

The technological progress of society has far-reaching consequences, and the globalization process significantly affects the state of the environment [1–4]. The construction industry contributes enormously to environmental degradation [5,6]. This means that sustainable construction is one of the main areas that can help address the global problem of climate change and contribute to sustainable global development [7–9]. Many studies focus on sustainable architecture and urbanism, integrated territorial development, the use of energy-efficient technology, heat loss reduction in buildings, etc. Less attention is dedicated to the topic of environmentally suitable construction materials. It is impossible to achieve an environmentally suitable construction without using ecological materials and products with a low carbon footprint [10], low emissions of hazardous substances, and higher biological stability.

Technological and social development results in population growth [11], uncontrolled use of natural resources and the urbanization of the environment [12]. The number of harmful emissions and waste is also increasing, while raw material resources are limited.

The sources of raw materials for construction and for infrastructure and industry development are limited in the same way as the sources of food and water for the growing global population [13]. This also applies to common raw materials for the production of construction materials and construction products. It is therefore necessary to change our approach to construction design. One option is to use secondary materials produced by other industrial activities. The aim is to reduce raw material extraction and the amount of waste accumulating in landfills [14]. The mass-produced waste that is a potential source of raw materials for the construction industry includes coal ash and waste sand from foundries.

There are currently efforts to apply so-called alternative raw materials, which are not only an environmentally more acceptable alternative to traditional materials (cement, lime, etc.), but also have other favorable properties for use in construction. In view of the availability of raw materials in Slovakia, it is magnesium oxide that appears to be a potentially exploitable raw material (MgO). Magnesium oxide (burnt magnesium) is the product of the thermal breakdown of magnesium carbonate (MgCO_3) [15]. Magnesium oxide occurs in nature as the mineral periclase, but is industrially obtained by thermal gelling of magnesite (MgCO_3). Magnesite refractory material containing MgO can be obtained from high purity magnesite ore by simple treatment and subsequent calcination at a temperature of 500–700 °C. Dolomite-based refractory materials are still widely used, especially in Europe. Thanks to its high melting point, chemical inertness and thermal stability, magnesium is the preferred material for the production of fire-proof materials used in high-temperature processes for steel, cement, lime, glass and non-ferrous metals [16]. The fire-proof materials industry is the biggest consumer of magnesium in the world. The metallurgical industry requires high-quality fire-proof materials that can withstand the heat of molten metal. Magnesite is a natural fire-proof material suitable for the metallurgical industry, as its key quality parameter is high thermal resistance. Other industries, i.e., the agriculture, construction, chemical, ceramics, pyrotechnics and environmental industry [17], have their own requirements on the properties of magnesium.

The products for the metallurgical and ceramics industry consist of burnt magnesite clinker intended for the production of monolithic materials and steel aggregate cover protection, as well as for other applications. The products used in the chemical industry are intended for the production of chemicals based on magnesium [17]. For example, the CCM 78 product acts as a binder, where the number 78 indicates the magnesium oxide content in the powder. CCM 85 is intended for use in agriculture as a mineral ingredient for animals, providing health benefits thanks to its high magnesium content. It can also be used for the production of fertilizers in the chemical industry or for eliminating the effects of acid rain. In the construction industry, magnesium is used for the production of construction materials and components. Magnesium oxide boards (MgO boards) are large-sized structural boards, typically white. They are made from a natural and ecological material that does not pose a risk to health and does not release toxic substances. In general, MgO-based board composites are more resistant in terms of mechanical properties compared to traditional variants (e.g., gypsum boards, cement-particle boards and the like). From the point of view of processing technology, this aspect is also taken into account, because by differentiating the cutting and cutting of these products it is therefore not possible to use conventional hand-held cutting tools for cutting as with conventional board materials, but it is necessary to use mechanized electrical devices (for example electric circular saws and others) and appropriate personal protective equipment. The important advantages of magnesium oxide boards are that they are fire-proof, elastic, strong, frost-resistant, water-proof, ecological, anti-allergic, heat-reflective, healthy, and resistant to molds and rodents [18]. Their unique property is that they actively absorb CO_2 from the air throughout their life cycle, thereby continuously cleaning and improving the quality of the internal environment. Magnesium boards can be used virtually everywhere. They are used for ceilings, partitions, fireplaces, all types of internal and external wall lining, ventilated facades, creative ceilings, and wherever a building needs to be protected against fire, rotting or molds. According to an analysis of the MgO boards market for

2018–2023 [19], the global MgO boards market is divided into five main regions, i.e., North America (USA, Canada), Europe (United Kingdom, France, Germany, Russia), Asia and the Pacific (China, Japan, Australia), South America (Brazil, Argentina), and the Middle East and Africa (South Africa, Saudi Arabia). There are many manufacturers and even more suppliers in these regions. Each MgO board manufacturer has their own recipe for their product, which results in differences in properties. A magnesium oxide board is generally composed of Sorel cement, a magnesium oxide mixture, and other elements. The manufacturer Zhangjiagang Oriental Construction Material Co. [20] states that its magnesium oxide board is made from high-purity magnesium board, magnesium sulfate (MgSO_4), a magnesium chloride substitute (MgCl_2), a high-strength glass fiber mesh, perlite, and fabric. North American MgO LLC [21] states that its MgO board contains 67% MgO, 18% SiO_2 , 5% ash filler, 9% additives, and 1% glass fiber mesh.

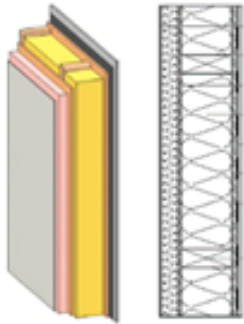
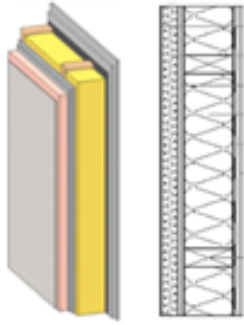
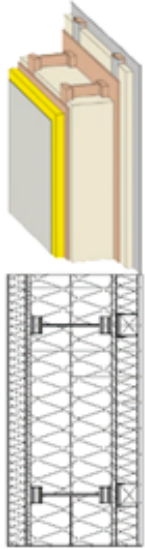
Dry construction is an efficient construction process in which construction elements are mechanically secured to the structure using a binding material [22,23]. It therefore dispenses with a construction binder, whose preparation requires water. It is the absence of water in the process that the term “dry” is derived from. Compared to traditional construction methods, dry construction has several advantages: the process is faster, without long technological breaks required for drying; a structure from structural boards is substantially lighter than partitions from bricks or other construction materials; the use of large-sized structures allows greater flexibility in terms of the placement, shapes and design of walls and lowered ceilings and produces less waste, which means a lower environmental impact and better thermal insulation, acoustic and fire protection properties compared to traditional construction technologies [24,25]. Despite their unquestionable advantages, dry construction is not a commonly used construction method in Slovakia. Its use is generally limited to interior structures such as partitions, wall lining, lowered ceilings, shaft walls, etc. The main obstacle to more extensive use is prejudice, leading to concerns about dry construction. As is the case with every system, dry construction has its potential disadvantages—it requires more planning ahead (future placement of heavy loads, inspection chambers, etc.) and there are stricter requirements on the workmanship and surface finish of the constructions.

With the above in mind, this work presents an analysis of the applicability of various material solutions for the dry method of construction of selected building structures. The analysis is focused on assessing the thermal-technical parameters of external and internal vertical wall structures with different lining materials. The composition of structures using MgO-based lining materials is also compared with traditional material composition. Another objective of the presented work is to survey and analyze the works published to date in the field of MgO application in construction that help raise awareness of the use of MgO in construction.

2. Materials and Methods

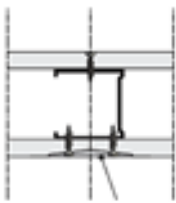
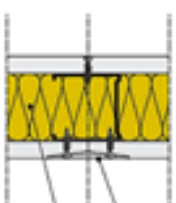
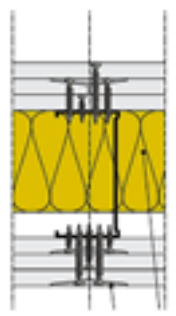
The samples examined in the research were the structural parts of external walls and interior partition walls containing various materials, built using the dry construction method. The compared variants were assessed in terms of selected thermal-technical parameters, i.e., their heat transfer coefficient and thermal resistance. The final heat transfer coefficient and thermal resistance values were obtained by modelling the individual structural parts and by calculation according to the STN-73 0540 [26] standard. For the calculation itself, AREA software (Svoboda software, 2017) was used, performing the calculation on the basis of standards STN-73 0540 [26]. Under boundary conditions, the following boundary conditions have been defined as also mentioned in the mentioned standard: heat transfer resistance $R_{si} = 0.13 \text{ (m}^2 \cdot \text{K)/W}$, $R_{se} = 0.04 \text{ (m}^2 \cdot \text{K)/W}$. The material composition of the assessed structural variants is presented in Tables 1 and 2. Various construction boards designed for dry construction were selected for the comparison, in addition to boards based on MgO, which were used for analyzing differences.

Table 1. Composition of the assessed design variants of exterior walls.

	Variant 1	Variant 2	Variant 3
A			
	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - thermal insulation EPS 100 mm ($\rho = 18 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 120 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - gypsum board 12.5 ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$)	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - thermal insulation EPS 100 mm ($\rho = 18 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 120 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - MgO board 12.5 ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$)	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - thermal insulation EPS 100 mm ($\rho = 18 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 120 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - clay board 12.5 ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$)
B			
	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - thermal insulation EPS 100 mm ($\rho = 18 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 120 mm ($\rho = 15 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - gypsum board 2 × 12.5 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$)	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - thermal insulation EPS 100 mm ($\rho = 18 \text{ kg/m}^3$) - MgO board 12.5 mm - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 120 mm ($\rho = 15 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - MgO board 2 × 12.5 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$)	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - thermal insulation EPS 100 mm ($\rho = 18 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 120 mm ($\rho = 15 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - clay board 2 × 12.5 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$)
C			
	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - mineral thermal insulation 70 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 150 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 30 mm ($\rho = 15 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - gypsum board 2 × 12.5 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$)	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - mineral thermal insulation 70 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 150 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 30 mm ($\rho = 15 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - MgO board 2 × 12.5 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$)	- mineral plaster 4 mm ($\rho = 500 \text{ kg/m}^3$) - mineral thermal insulation 70 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 150 mm ($\rho = 15 \text{ kg/m}^3$) - OSB 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 30 mm ($\rho = 15 \text{ kg/m}^3$) - vapor barrier ($\rho = 140 \text{ kg/m}^3$) * - clay board 2 × 12.5 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$)

Notes: EPS—expanded polystyrene, OSB—oriented strand board, *— $\lambda_e = 0.21 \text{ [W/(m}\cdot\text{K)]}$.

Table 2. Composition of the assessed design variants of interior walls.

	Variant 1	Variant 2	Variant 3	Variant 4
D 	- gypsum board 15 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$) - air cavity 50 mm - gypsum board 15 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$)	- cement chipboard 15 mm ($\rho = 1350 \text{ kg/m}^3$, $\lambda_e = 0.26 \text{ W/(m}\cdot\text{K)}$) - air cavity 50 mm - cement chipboard 15 mm ($\rho = 1350 \text{ kg/m}^3$, $\lambda_e = 0.26 \text{ W/(m}\cdot\text{K)}$)	- clay board 15 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$) - air cavity 50 mm - clay board 15 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$)	- MgO based board 15 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$) - air cavity 50 mm - MgO based board 15 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$)
E 	- gypsum board 15 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$) - thermal mineral insulation 70 mm ($\rho = 15 \text{ kg/m}^3$) - gypsum board 15 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$)	- cement chipboard 15 mm ($\rho = 1350 \text{ kg/m}^3$, $\lambda_e = 0.26 \text{ W/(m}\cdot\text{K)}$) - mineral thermal insulation 70 mm ($\rho = 15 \text{ kg/m}^3$) - cement chipboard 15 mm ($\rho = 1350 \text{ kg/m}^3$, $\lambda_e = 0.26 \text{ W/(m}\cdot\text{K)}$)	- clay board 15 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$) - mineral thermal insulation 70 mm ($\rho = 15 \text{ kg/m}^3$) - clay board 15 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$)	- MgO based board 15 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$) - mineral thermal insulation 70 mm ($\rho = 15 \text{ kg/m}^3$) - MgO based board 15 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$)
F 	- gypsum board 2 $\times$ 15 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 100 mm ($\rho = 15 \text{ kg/m}^3$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - gypsum board 2 $\times$ 15 mm ($\rho = 1200 \text{ kg/m}^3$, $\lambda_e = 0.58 \text{ W/(m}\cdot\text{K)}$)	- cement chipboard 2 $\times$ 15 mm ($\rho = 1350 \text{ kg/m}^3$, $\lambda_e = 0.26 \text{ W/(m}\cdot\text{K)}$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 100 mm ($\rho = 15 \text{ kg/m}^3$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - cement chipboard 2 $\times$ 15 mm ($\rho = 1350 \text{ kg/m}^3$, $\lambda_e = 0.26 \text{ W/(m}\cdot\text{K)}$)	- clay board 2 $\times$ 15 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 100 mm ($\rho = 15 \text{ kg/m}^3$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - clay board 2 $\times$ 15 mm ($\rho = 1450 \text{ kg/m}^3$, $\lambda_e = 0.353 \text{ W/(m}\cdot\text{K)}$)	- MgO based board 2 $\times$ 15 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - mineral thermal insulation 100 mm ($\rho = 15 \text{ kg/m}^3$) - OSB board 15 mm ($\rho = 650 \text{ kg/m}^3$) - MgO based board 2 $\times$ 15 mm ($\rho = 800 \text{ kg/m}^3$, $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$)

Notes: OSB—oriented strand board.

Types A–C have a composition that is commonly used in dry construction. All these types of external structures are designed as diffusely closed structures. Types A and B are contact insulated systems and type C has a similar design, except that its thermal insulation is thicker and is also fitted on the interior side of its structure. As for the external wall structures, the interior side of variant 1 is lined with a gypsum board, variant 2 is lined with a board based on MgO, and variant 3 is lined with a clay board. Types D–F are dry

construction structures designed for interior walls. Their variants are as follows: variant 1 is lined with a gypsum board, variant 2 is lined with a cement board, variant 3 is lined with a clay board, and variant 4 is lined with a board based on MgO. The primary sources of information (Tables 1 and 2) on the materials used and their characteristics came from the STN-73 0540 [26] standard, and the characteristics for MgO and clay-based materials came from specific manufacturers.

In view of the trend of sustainability and application of environmentally friendly raw materials in construction, a partial objective of the study was to analyze previously published works in the field of MgO application in construction. The analysis is presented in the discussion part, where the works are divided according to four areas, i.e., LCA, moisture properties, flexing, static and mechanical properties, and resistance properties.

3. Results and Discussion

3.1. Results

This chapter summarizes the analyses of the material variants of exterior and interior walls designed for dry construction. The analyses of the variants were focused on selected thermal-technical parameters of the structural parts of constructions. The results are summarized in Tables 3 and 4.

Table 3. Values of selected parameters (R and U) of the assessed design variants of exterior walls.

	Variant 1	Variant 2	Variant 3
A	6.555 *	6.561 *	6.568 *
	0.152 **	0.152 **	0.152 **
B	6.469 *	6.618 *	6.497 *
	0.154 **	0.151 **	0.153 **
C	7.683 *	7.697 *	7.711 *
	0.130 **	0.129 **	0.129 **

Note: (*—R [$\text{m}^2 \cdot \text{K}/\text{W}$]; **—U [$\text{W}/(\text{m}^2 \cdot \text{K})$]).

Table 4. Values of selected parameters (R and U) of the assessed design variants of interior walls.

	Variant 1	Variant 2	Variant 3	Variant 4
D	0.222 *	0.286 *	0.254 *	0.238 *
	4.504 **	3.496 **	3.937 **	4.201 **
E	1.894 *	1.958 *	1.926 *	1.910 *
	0.527 **	0.510 **	0.519 **	0.523 **
F	2.950 *	3.076 *	3.016 *	2.982 *
	0.338 **	0.325 **	0.331 **	0.335 **

Note: (*—R [$\text{m}^2 \cdot \text{K}/\text{W}$]; **—U [$\text{W}/(\text{m}^2 \cdot \text{K})$]).

The analysis of the composition of the external structures in the individual categories revealed certain differences. Types A–C, variant 3, lined on the interior side with a clay board (A3 R = $6.568 \text{ m}^2 \cdot \text{K}/\text{W}$; B3 R = $6.497 \text{ m}^2 \cdot \text{K}/\text{W}$; C3 R = $7.711 \text{ m}^2 \cdot \text{K}/\text{W}$), exhibited the best parameters among the compared variants. The second best was the variant lined on the interior side with a board based on MgO (A2 R = $6.561 \text{ m}^2 \cdot \text{K}/\text{W}$; B2 R = $6.618 \text{ m}^2 \cdot \text{K}/\text{W}$; C2 R = $7.697 \text{ m}^2 \cdot \text{K}/\text{W}$). The structure lined on the interior side with a gypsum board exhibited the worst parameters (A1 R = $6.555 \text{ m}^2 \cdot \text{K}/\text{W}$; B1 R = $6.469 \text{ m}^2 \cdot \text{K}/\text{W}$; C1 R = $7.683 \text{ m}^2 \cdot \text{K}/\text{W}$). Based on these values, it can be stated that the differences among the assessed variants are not striking in the case of single-layer lining. The differences grew as the thickness of the lining materials increased. The main advantage of using boards based on MgO is their resistance to high temperatures and fire. This means that if the bearing frame of a construction is lined with boards based on MgO, the construction is more fire-proof and

generally safer. This is also true of other parts of buildings, such as partitions, ceilings and floors.

The analysis of the composition of the interior structures in the individual categories revealed certain differences. In the assessment of the interior walls, the focus was on examining their accumulation properties as a factor contributing to living comfort. The ability to accumulate energy is highly desirable in the case of interior structures, as constructions built using the dry method typically lack this characteristic. Types D-F, variant 1, lined with a gypsum board (D1 $R = 0.222 \text{ m}^2 \cdot \text{K/W}$; E1 $R = 1.894 \text{ m}^2 \cdot \text{K/W}$; F1 $R = 2.950 \text{ m}^2 \cdot \text{K/W}$), exhibited the best energy accumulation parameters among the compared variants. The second best was the variant lined with a board based on MgO (D4 $R = 0.238 \text{ m}^2 \cdot \text{K/W}$; E4 $R = 1.910 \text{ m}^2 \cdot \text{K/W}$; F4 $R = 2.982 \text{ m}^2 \cdot \text{K/W}$). Next was the variant lined with a clay board (D3 $R = 0.254 \text{ m}^2 \cdot \text{K/W}$; E3 $R = 1.926 \text{ m}^2 \cdot \text{K/W}$; F3 $R = 3.016 \text{ m}^2 \cdot \text{K/W}$), and the structure lined with a cement board exhibited the worst parameters (D2 $R = 0.286 \text{ m}^2 \cdot \text{K/W}$; E2 $R = 1.958 \text{ m}^2 \cdot \text{K/W}$; F2 $R = 3.076 \text{ m}^2 \cdot \text{K/W}$). Based on these values, it can be stated that the differences among the assessed variants are not striking in the case of single-layer lining used on interior walls. The differences grew as the thickness of the lining materials increased.

3.2. Discussion

There are many studies focused on the application of MgO in various composite materials and products. They primarily assess the life cycle of construction structural parts containing MgO and examine their fire-protection, moisture, mechanical, static and thermal-technical properties.

3.2.1. LCA

A study by Li et al. [27] focused on assessing the life cycle of an innovative structural insulation panel from magnesium oxide (MgO SIP) applied in a high-performance smart house in Vancouver. LCA compares six environmental impact indicators for MgO SIP, traditional SIP and a traditional stick-frame structure during the life cycle phases of extraction, production, transport, construction and operation. The results show that MgO SIP does not surpass traditional alternatives, mainly as a result of material transport over long distances. However, an LCA of hypothetical scenarios shows that MgO SIP has great potential to become more ecological than traditional alternatives when MgO is sourced and produced locally and when MgO SIP is designed without oriented strand board. Although the results depend on the context, studying hypothetical scenarios shows various ways of improving the environmental behavior of this innovative product. The findings in our work match the results of the study—especially the conclusion that the use of MgO is not always the most cost-efficient option, as limited availability on the market can increase procurement costs and overall construction costs. Likewise, the application of MgO may not be able to compete with traditional solutions in terms of certain parameters, such thermal-technical parameters.

3.2.2. Moisture Properties

A study by Nielsen et al. [28] examines the moisture properties of various types of MgO boards. All analyses were performed on MgO boards supplied by a Chinese manufacturer, with different thickness and based either on magnesium sulfate or magnesium chloride. The composition of the MgO boards was determined using X-ray fluorescence and energy dispersive X-ray radiation. The main difference was in their chloride and sulfate content. A test for moisture retention showed that both types of MgO boards absorbed excessive amounts of moisture from a moist environment, although the sulfate-based MgO boards absorbed less moisture from the environment than the chloride-based MgO boards. The MgSO₄ boards also stopped absorbing moisture when relative humidity reached 95% and their weight increased substantially when relative humidity was lower. These findings

were also confirmed in our research, which simulated the use of MgO on external and interior structures in dry construction.

A study by Rode et al. [29] also confirms that when relative humidity exceeds 84%, MgO boards start to absorb excessive amounts of moisture from the surrounding air. As such higher levels of humidity are typical in the places where exterior lining is to be used, it can be concluded that MgO boards are not a suitable product for this purpose. This is confirmed by the numerous failures recorded in recent years, where these boards leaked salty water, which damages the adjacent structural elements from wood or metal, eventually causing the MgO board to fall apart. These conclusions match the findings in our research, which simulated the behavior of MgO-based construction boards to show that they are more suitable for use on the exterior of buildings. This does not rule out the possibility of exterior use when their recipe is modified so as to make them more stable for such use.

A study by Aiken et al. [30] highlights the considerable differences among magnesium oxychloride boards from different manufacturers. It also examined the mechanism of the desorption phenomenon observed on magnesium oxychloride boards. The probability of the occurrence of desorption on a specific board is likely to be associated with these factors: firstly, its chemical composition, achieved by using the right amounts of raw materials and by the purity of the raw materials, secondly, its physical properties, such as porousness, which determine how easy it is for moisture to enter and permeate the board, and finally, the use of phosphorus, which can help protect the 5-phase phase against dissolving. There were significant differences among the boards in terms of their composition, physical properties and performance in a humid environment. It is apparent that not all boards with magnesium oxychloride are the same, and in actual operating conditions the better-performing boards have potential to prevent the failures that occurred in the authors' research. Our analyses confirm that the properties of construction boards based on MgO vary depending on the recipe, i.e., different manufacturers declare vastly different parameters, with the differences often reaching tens of percentage points. The MgO plate analyzed by us showed these basic density parameters 800 kg/m³ (thickness 12.5 mm). In contrast, the density in this work Aiken et al. [30] was as follows: 686–1113 kg/m³ (thickness 9 mm), 1032 kg/m³ (thickness 11 mm), 998 kg/m³ (thickness 12.5 mm), which is only confirmed by our statement.

Gravit et al. [31] note that the use of boards from magnesium oxide may cause the corrosion of steel frames and the growth of molds on wooden details. The authors provide information from foreign sources about the negative effects of the use of MgO boards. They conclude that it is necessary to provide a clear classification of magnesium boards and define technical requirements that will lead to a standard global formulation. Their claims support our conclusions. Boards based on MgO may initially appear to be good as fire-protection insulation, but the main problem is that their ability to diffuse water vapor is poor, which may cause the corrosion of the various materials lined with these materials.

A study by Hansen et al. [32] examined the moisture absorption and desorption curves for MgO boards. The study concludes that MgO boards must not come into contact with a moist environment. When relative humidity exceeds approximately 84%, drops of salty water start forming on the surfaces of MgO boards and the water is absorbed into the wooden structures connected with the boards, which may lead to the spread of molds on the wood. MgO boards are also susceptible to the growth of molds, as they contain organic material. When an MgO board is exposed to high levels of moisture, resulting from the dissolution of the salts it contains, it will fall apart at some point. These findings match the findings in our research, where we identified many favorable properties, but the poor ability to diffuse water vapor is a certain disadvantage of this material solution and its application. Specifically, this meant that, compared to other compared materials, MgO-based boards showed significantly worse diffusion properties, which directly affects the passage of air humidity through the structure. Ultimately, moisture remains trapped in

the structure or in the interiors of the building, which can be considered a negative factor. As is also confirmed in the work Hansen et al. [33] where it is examined.

A study by Jays et al. [33] examined the consequences of the action of relative humidity that increases the risk of corrosion of the metal joining materials on MgO boards. Various commercially available samples of MgO boards were examined in an environment with controlled relative humidity and during contact with various metal joining elements. It was found that different products absorbed water differently and that coloration varied according to the composition of the metal joining elements. Coloration and absorption were not a problem when relative humidity was low (75%), but were apparent on all MgO boards when relative humidity was high (97%).

A study by Nghana and Tariku [34] was focused on the potential of boards from American clay and magnesium oxide (MgO) to control humidity. The research was a field study, monitoring two buildings with different operating scenarios. One of them was treated as a reference building and its interior was lined with boards based on gypsum, a material commonly used in construction. The other building was treated as a test building and was lined with boards based on clay and boards based on MgO. Checks to ensure that the buildings were operationally identical were followed by three tests to simulate the interior surface finish of the building, the effects of ventilation and the level of occupancy. It was found that the boards based on clay had better potential for controlling humidity than gypsum, particularly when the actual surface conditions were compared. The experiments also showed that the potential of MgO boards to control humidity is comparable to that of gypsum, and that lining with MgO boards supports humidity control.

3.2.3. Flexing, Static and Mechanical Properties

A study by Smakosz and Kreja [35] was focused on comparing the results of flexing and compression tests in a mathematical model and the results of flexing and compression tests in real conditions. The examined sample consisted of expanded polystyrene lined with MgO boards. The results matched the results from the mathematical model. The research showed that while the use of averaged properties of polystyrene delivers satisfactory results, such an approach is unreliable due to significant dispersion of the values for MgO boards. Instead, the analysis used upper and lower limits, which resulted in a numerical results spectrum rather than a single curve.

Zheng et al. [36] built a chipboard structure from magnesium cement to test its mechanical strength, water resistance, thermal stability, and non-flammability. The results showed that this board had excellent properties. It exhibited good thermal stability and reliability. The maximum pyrolysis residue was 55.82%. A fire resistance test (CONE) showed good fire retardation performance.

Smakosz et al. [37] performed a flexural analysis of a composite insulation panel (CSIP) with boards from magnesium oxide and an expanded polystyrene core (EPS). An advanced non-linear FE model was created in the ABAQUS environment. This allowed the inclusion of the material's bi-modularity to significantly improve the accuracy of the calculation results and of failure mode prediction. The parameters of the material model describing the non-linear range were identified in an analysis of laboratory tests and in their numerical simulations performed on CSIP rays of three different lengths subjected to three-point and four-point flexing. The model was validated by comparing the calculation results with the experimental results for the panels with a natural scale. The strong correlation between these two types of results showed that the proposed model could effectively support the CSIP design process.

Sonkar et al. [38] presented a comprehensive experimental and analytical study of the axial performance of sixteen steel wall panels (CFS). It was a detailed examination of the effect of double-layer magnesium oxide insulation (MgO) on the axial strength of CFS (applied to one side or both sides). The effects of various parameters, such as screw spacing, the details of joints and the number of lining layers, on the axial strength of CFS wall panels were also studied. It was found that the analytical results matched the experimental results.

A study by Dewangan et al. [39] was focused on examining steel frame wall panels (CFS) with MgO board lining and the effect of parametric variations on the strength of the wall panels. A total of 49 samples were analyzed in the study. It was found that the strength of a wall panel with a pin spacing of 600 mm, a screw spacing of 150 mm and a sides ratio of 1:1 was 45% greater than that of a wall panel with a bare frame with the same specification. The study also compared the strength-related properties of a wall panel with MgO lining with wall panels with GB and OSB lining. OSB lining for high levels of stress is comparable to MgO lining. It was found that HDOSB boards were stronger than MgO boards when pin spacing was 500 mm and when screw spacing was 150 mm. These findings match the findings in our research, where it was observed that the lining from OSB boards had better stability than the boards based on MgO. To secure a structure axially, it is better to use OSB boards, while MgO boards are better as the final lining layer, when, for example, better fire resistance of the structure needs to be ensured.

A study by Manalo [40] analyzed the structural behavior of a new prefabricated wall system made from hardened fiberglass-reinforced polyurethane foam (PUF) and magnesium oxide boards. Cross-sectional flexing, compression and shear tests were performed on complete wall samples. The results of the experiments showed that the behavior of composite walls is determined by the strength of the MgO board. Full interaction between the solid PUF and the MgO board was achieved by using peroxide glue. During the shear test, single- and double-panel systems exhibited similar rigidity and strength. The use of vertical anchor screws increased shear strength by almost 15%, but did not improve shear rigidity. The results confirmed the potential of this composite wall system for use in a modular apartment structure.

A study by Aiken et al. [41] was focused on analyzing commonly used test methods for assessing the performance of construction boards. The authors compared the relatively new magnesium-based boards and traditional boards. Physical, mechanical and durability-related properties were examined. The conclusion was that the magnesium-based boards exhibited relatively good flexing strength and absorption properties, comparable to other types of boards. Magnesium-based boards performed well when subjected to repeated soaking and drying, and to repeated freezing and unfreezing. The impact on the flexing strength of the MgO-based boards was relatively minor, similar to that of the flexing strength of fiber-cement boards, and less severe than the impact on the flexing strength of gypsum boards. In contrast to the MgO-based boards analyzed by us with density parameters of 800 kg/m^3 and $\lambda_e = 0.22 \text{ W/(m}\cdot\text{K)}$, similar MgO-based boards in Aiken et al. [41] a different parameter in the density range $993\text{--}1092 \text{ kg/m}^3$ and $\lambda_e = 0.02\text{--}0.21 \text{ W/(m}\cdot\text{K)}$, which suggests different recipes and compositions.

3.2.4. Resistance Properties

A study by Rusthi et al. [42] analyzed the details of thermal properties tests and fire resistance tests of LSF wall systems (Light Steel Frame) lined with MgO boards with different configurations. The thermal properties tests performed on the two types of MgO boards showed that MgO boards lose a large amount of weight at increased temperatures, approximately 50% and 40% of the initial weight, whereas gypsumboard loses 15% of weight when used in a standard way. The fire resistance tests showed that MgO boards bend and crack. The study showed that the fire resistance of the LSF system lined with an MgO board depends on the type of MgO board with its weight loss properties, details of joints and the spacing of pins. A correctly designed and manufactured MgO board has potential to offer a higher level of fire resistance.

Martins et al. [43] note that large-sized construction boards are elements used in dry construction, particularly in construction systems such as light steel frame (LSF). In Brazil, boards from Portland cement and synthetic fibers are used extensively. They also have unsatisfactory hydro-thermal properties, low dimensional stability and high thermal conductivity. The authors analyzed magnesium boards with better dimensional stability and lower thermal conductivity, although such magnesium oxide boards are not currently

produced in Brazil. Their comparison analyses and thermal performance measurements were based on spectrophotometer tests for calculating solar radiation absorption, infrared thermography for determining the surface temperatures of the LSF panels, and on internal and external temperature assessments. The results showed that boards based on magnesium can improve the thermal performance of a construction's environment. These findings match the findings in our research, where positive thermal resistance properties of MgO boards were highlighted. Regarding the properties of MgO plates used in the mentioned work of Martins et al. [43] worked with boards that had these properties of density 960–1120 kg/m³, which was different from our work where the board analyzed on the basis of MgO had a density parameter of 800 kg/m³. However, when comparing thermal conductivity parameters, these differences were not as different as Martins et al. [43] reported a value of 0.18 W/(m·K) and we reported a value of 0.22 W/(m·K) in our work.

Gnanachelvam et al. [44] note that wall systems from shaped steel pins (LSF) lined with various types of wall boards are now used more extensively for various purposes. Using standard fire resistance tests, the authors examined the thermal properties of selected wall boards and the fire resistance of non-bearing LSF wall systems lined with various types of wall boards, such as gypsum boards, magnesium sulfate boards, vermiculux boards and fiber-cement boards. The results showed that the gypsum boards had the best fire resistance, while the fiber-cement boards had the poorest fire resistance. The thermal properties test showed that the magnesium sulfate boards lost a large amount of weight, i.e., 43%, at increased temperatures, while the gypsum boards lost 23% of weight due to dehydration. Standard fire resistance tests of LSF walls showed that the use of magnesium sulfate boards reduces the fire resistance of LSF walls, which is accompanied by the formation of cracks. The findings produced by the study of the thermal-technical properties of MgO boards were similar to those in our research, but were not identical. This is due to the fact that different manufacturers use different recipes for the production of MgO boards, which results in different properties.

A study by Ye et al. [45] was focused on analyzing the fire resistance requirements on walls in multistory steel structures (CFS), where the walls were lined with double-sided double-layer boards. The lining materials for these walls included gypsum boards (GWB), Bolivian magnesium boards (BMG) and calcium silicate boards (CSB). Cyclic stress tests were performed on six walls, which determined their shear capacity. Factors such as lining material, side ratio, pin parts and pin spacing were considered. The results showed that the walls lined with Bolivian magnesium boards had the best strength, as the wall boards of the front-facing layer significantly exceeded the nominal value of the current standard. On the other hand, the walls lined calcium silicate boards to form the front-facing layer exhibited fragility with poor strength.

A study by Chen et al. [46] was focused on analyzing various panels and external insulation for improving the fire resistance of bearing CFS wall systems used in mid-rise buildings. Experiments were performed on six CFS wall samples with aluminum-silicon insulation, which was placed outside the CFS frame between the two layers of boards on the side of the fire rather than in the hollow space. The experiments included five types of panels, namely gypsum boards, Bolivian magnesium boards, oriented strand boards (OSB), light concrete boards (ALC) and mineral wool boards. It turned out that the CFS wall systems lined with Bolivian magnesium boards or ALC boards had better fire resistance than those lined with gypsum boards and OSB. It is therefore recommended that gypsum boards should be replaced with Bolivian magnesium boards to serve as the base layer, and that OSB should be replaced with ALC boards to serve as the external wall panels of CFS systems for use in mid-rise buildings. The wall compositions assessed in the study were similar to those analyzed in our research, although it is thermal-technical properties that were assessed in our research.

In general, stabs affected by increased humidity are more prone to biocorrosive defects, for example due to algae, fungi and the like [47–49]. In this respect, it is important to apply diffuse open systems for better removal of increased moisture.

Based on the analysis of the existing literature in this area, it can be stated that the application of MgO in construction has its special characteristics. Magnesium oxide boards are superior to other boards in terms of their resistance to fire, acoustic and thermal insulation properties, resistance to water and moisture, ability to reflect infrared light, their flexibility and strength, resistance to pests, mold, rotting and rodents, and in terms of their antiallergic and ecological properties. Thanks to their properties, they are safe for human health and create a safe and healthy internal environment. The analyses of external and interior structures presented in this work suggest that when boards based on MgO and traditional materials are used for coating constructions built using the dry method of construction, the former provide certain benefits in terms of energy accumulation, improving living comfort, and in terms of the fire resistance of constructions, improving its overall safety.

4. Conclusions

Innovations are a necessary part of everyday life in the modern world. This trend is also seen in the construction industry. This requires focusing on introducing new and more efficient solutions. Product innovations naturally result from the development of new materials and from their potential to improve the existing technologies and work procedures. To improve the efficiency of construction processes, the dry construction method is now used more extensively. Large-sized construction boards from various materials are an integral part of such solutions. They allow a wide range of applications (walls, partitions, floors, roofs, lowered ceilings) and use a wide range of materials. This work analyzed the properties of a relatively new and innovative construction board based on magnesium. Many sources highlight its numerous advantages that represent an improvement on the performance of traditional gypsum and wooden construction boards (with respect to fire, molds and pests, acoustic comfort and thermal resistance, strength-related parameters, especially tensile and impact strength, health safety, moisture resistance, as well as weight and flexibility). On the other hand, the price of these boards seems to be an obstacle to their more extensive use. Based on the analysis of the exterior and interior structures, it can be stated that the use of MgO boards for lining structures built using the dry construction method brings certain benefits compared to traditional materials, especially in terms of energy accumulation (improved living comfort) and fire resistance (improved overall safety).

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