The Application of Recycled Plastic Insulation Materials in Constructions – Serbian Prospects

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Abstract
Plastic is one of the most popular and useful materials of modern times. However, its popularity is part of the problem: we now use about 20 times more plastic than we did 50 years ago. However, the lifespan of plastics can be optimized by reuse and recycling. As the space for landfilling is diminishing, recycling plastic has become an attractive alternative to final disposal.
The main objective of this paper is to present a novel thermal insulation building material for construction engineering made from recycled plastic. Based on conducted research, it can be concluded that Serbia has a relatively good level of activity in the recycling sector. In the plastic recycling process, PET flakes are produced, from which, through further processing, polyester fibre is gained whose further use in the production of insulation material is possible. Unfortunately, there is no factory in Serbia that currently produces this kind of insulation. All further analyses are based on recycled plastic insulation materials, which are developed and commercialized on the foreign market. The paper presents the technical characteristics of these materials in relation to the classical insulating materials and analyzes the economic and other factors affecting the possibility of employing these materials in the Serbian construction industry. The analyses results are that in terms of thermal and technical characteristics, insulation materials from recycled plastic do not lag behind conventional insulation materials. In terms of environment and human health impacts, there are no negative effects. The calculation demonstrates that a building envelope, which contains recycled plastic thermal insulation material, can reach low-energy and even more passive building standards. The initial cost of investing in thermal insulation returns within the first years of the exploitation period.

Key words
Plastics Waste, Recycling, Thermal Insulation, Energy Savings

1. INTRODUCTION

Plastics have become an inseparable and integral part of our lives. The quantity of plastics consumed annually all over the world has been growing phenomenally. Its low density, strength, user-friendly designs, fabrication capabilities, long life, light weight, and low cost are the factors behind such phenomenal growth. Plastics have been used in packaging, automotive and industrial applications, medical delivery systems, artificial implants, other healthcare applications, water desalination, land/soil conservation, flood prevention, preservation and distribution of food, housing, communication materials, security systems, and other uses. With such large and varying applications, plastics contribute to an ever-increasing volume in the solid waste stream.

The world's annual consumption of plastic materials has increased from around 5 million tons in the 1950s to nearly 100 million tons. [1]. We produce and use 20 times more plastic today than we did 50 years ago. This implies that on one hand, more resources are being used to meet the increased demand of plastic, and on the other hand, more plastic waste is being generated. In Serbia, as well as many other developing regions and even the regions with low economic growth, plastic consumption has increased much more than the world average due to rapid urbanization and economic development. The estimated quantity of plastic packaging waste in Serbia is 88 000 tonnes annually [2].

Due to the increase in generation, waste plastics are becoming a major stream in solid waste. Along with the extremely long periods required for natural decomposition, waste plastic is often the most visible component in waste dumps and open landfills. Plastic waste recycling can provide an opportunity to collect and dispose of plastic waste in the most environmental friendly way and it can be converted into a resource. Reuse of bulky wastes is considered the best environmental alternative for solving the problem of disposal. In most situations, plastic waste recycling could also be economically viable, as it generates resources, which are in high demand.

The growth in the use of plastic, as well as recycled plastic resources or products is due to its beneficial properties, which include: lighter weight, durability and longevity, resistance to chemicals, water persistence,

excellent thermal and electrical insulation properties, unique ability to combine with other materials like aluminum foil, paper, adhesives and comparatively lesser production cost.

There is a wide range of products made from recycled plastic, including: polyethylene bin liners and carrier bags, plastic bottles, flooring and window frames, *building insulation materials*, strapping band, video and compact disc cassette cases, fencing and garden furniture, fiber filling for sleeping bags and duvets, variety of office accessories, geotextile base for roads and landfills [3].

As the entire world today is facing two large problems, one being the shortage of energy and uncertainty in its supply and the other environmental pollution, developing a new generation of recycled plastic insulation materials for the green building industry becomes an imperative.

2. PLASTIC RECYCLING AND PRODUCTION IN SERBIA

In Serbia, there are a large number of processors of different types of plastic, primarily Polyethylene terephthalate (PET). Table 1 contains an overview of the five largest plastic recyclers, including materials and quantities, methods and collection scope, and production.

Table 1. Plastic Processors & Recycles in Serbia, Comparison Summary [4]

Company, Municipality	Materials	Quantities	Collection	Production
Greentech, Novi Sad	PET	Serbia 300 ton/month input; 250 ton/month finished product. Green Fiber Group: 5000 ton/month, 4000-4500 for Polyester Staple Fiber. Possible future investment in PE and PP lines in Serbia.	70% of all PET in Serbia passes through Greentech. Supply contracts & cooperation with all large operators. 100 containers in New Belgrade.	Serbia: PET flake. Polyester Staple Fiber. Strapping band.
Brzanplast, Batocina	All plastic, sorted, cleaned, granulated LDPE folio	2007: 3000 tons. 2008: 5000 tons. 2009: 3000 tons.	Private-sector collectors, some municipalities. Operate sorting line for all inputs. Four main suppliers 50%:	LDPE folio. Granulate.
Intercord, Subotica	PET PE PP Non-Plastics	2009: 1000 tons plastic.	Commercial & industrial clients. Subotica JKP. 40% collection ultimately provided by Roma (secondary sorting at landfill).	Granulates: PET, PE, PP
Deni Komerc, Nis	PET Biodegradable & recycled LDPE PP	PET: 600 kg/hour, 4000-5000 ton/year minimum. Current demand: 200-400 ton/month.	Municipalities & JKPs.	PET: flake, film, bottle-to-bottle. LDPE folio.
Saniplast, Gorni Milanovac	PET	50-60 ton/month	Municipalities & JKPs. 40 containers in Belgrade.	Pet flake.

On the basis of the data shown in Table 1, it can be concluded that Serbia has a relatively good level of activity in the recycling sector. Collectors and recyclers share a number of challenges, including: a lack of state subsidies and investment, as opposed to EU countries; lowered prices due to the global economic crisis; reduced quantities of materials, low prices and other factors; complex, slow and expensive administrative procedures, sometimes more complex than those in EU countries. Besides this, the market also has an insufficient supply of plastic secondary raw materials problem, and the absence of organised collection. This is evidented by the large capacities of most buyers and processors and the competition for raw material, primary PET packaging.

All the aforementioned companies (Greentech, Brzan Plast, Saniplast, Intercord and Deni Komerc) process PET and all of them have larger capacities and demand than production. In their production process, waste plastic bottles are sorted, shredded, washed, melted and pelletised. It is a two-stage process: the sorting is done manually and automatically with a manual polish, and the second stage is either direct melting of plastic and moulding into new shapes, or shredding into flakes followed by melting and processed into granulates or

Polyester Staple Fiber, whose further process in the production of insulation is possible. *All these companies sell PET flakes and export all produced materials as there is no factory in Serbia that can further process them.* [5]

Despite being stipulated by law, the existence of this production capacity is not the sole, sufficient condition for primary recycling in Serbia to function in practice. Plastics recycling in Serbia, in particular, would not be successful unless the proper infrastructure to collect the waste is put in place, the technology to economically reprocess the waste into new products is available and the establishment of markets for the cost-effective use of recycled products are developed.

3. NOVEL RECYCLED PLASTIC THERMAL INSULATION BUILDING MATERIAL

The development of new construction materials using recycled plastics is important to both the construction and the plastic recycling industries. The use of waste products in construction not only helps in reducing disposal problems but also makes it economical. Most of the insulation materials currently employed have been on the market for a long time and many are marginal insulators with poor durability or recyclability. It is well-known that plastics have low thermal conductivity, make excellent insulation materials, are extremely durable, and can be recycled.

As thermal insulation requirements continue to grow, the industry is under increasing pressure to meet these requirements and the ever more stringent thermal transmittance (U-values) demanded by them. Coupled with this is the common desire amongst developers to make optimum use of the generated plastic wastes and rid the world of the same.

Table 2 presents novel thermal insulation building materials for construction engineering made from recycled plastic, along with their chemical and physical properties, technical characteristics, areas of application, benefits in application and consumer prices on the market. The characteristics of recycled plastic insulation materials in relation to the classical insulating materials are given in Table 3.

Table 2. Novel thermal insulation building material for construction engineering made from recycled plastic [6-10]

No	Insulation	Product Properties	Areas of Application	Thermal Conductivity [W/mK]	Water Diffusion Resistance Factor	Price [Eur/m^2] d=10cm
1	Recycled Fiber Loft Insulation	Manufactured from recycled plastic drinks bottles and fully recyclable; contains no glass fibre or other hazardous material; free from floating fibers; very easy and safe to handle without protective clothing or masks; Zero GWP (Global Warming Potential) and Zero ODP (Ozone Depleting Potential); unaffected by water; resistant to condensation and associated fungi and bacteria; unaffected by mildew and rot; resistant to insect attack; provides good acoustic properties; long term stability and durability; good thermal stability; low in density, compressible, resilient;	Suitable for lofts, timber frame walls, roofs and for external masonry walls with a cavity	0.0425	1.51	2.38-5.79
2	Home ECO Recycled Plastic Insulation		Designed for topping up existing insulation either between or over rafters	0.04	<1.0	NA[1]
3	Eco Warmth Insulation		EcoWarmth is designed for use in new and existing buildings	0.044	<1.0	NA
4	ISOTHERM Thermal Insulation		Suitable for roofs, ceilings, in walls, for geysers and pipes	0.045	<1.0	NA
5	Greenloft Roll Thermal Insulation		Suitable for roofs and ceilings	0.04	<1.0	NA

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[1] *Not Available on line*

Table 3. Characteristics of recycled plastic insulation materials in relation to classical insulating materials

Insulation Price: [Eur/m^2 d=10cm]	Raw Materials	Density [kg/m^3]	Health Problems	Environmental Aspects	Recyclable & Durability	Thermal Conductivity [W/mK]	Water Diffusion	Frost and Fire Resistance
[2]Eco Wool Insulation Price:2.38-5.79	Made from approximately 85%-90% recycled plastic bottles, the other 10%-15% being polyester to bind the insulation together	10-50	Itch free, non irritant, non allergenic; Manufacturing processes do not involve CFCs or HCFCs	No carbon emission into atmosphere. Eco Wool does not have Global Warming Potential and Ozone Depletion Potential	Fully recyclable; 50yeras+	0.040-0.044	Resistance Factor < 1.51 unaffected by water	High Frost resistant
Glass Fiber Insulation Price: 1.6	Made from molten glass, usually with 20% to 30% recycled industrial waste and post-consumer content	<130	Reasonably anticipated to be a human carcinogen [11]; generate pollutants during manufacturing	When melting does not discharge harmful gases; biodegradable	Fractional recyclable; 50yeras, providing maximum moisture to 3%	0.032-0.044	Resistance Factor > 1.00; Water Absorption >100%; high vapour permeability	Low Frost resistant; incombustible material
Petrochemical Foam Insulation Price: 4.07	Made from rock (basalt, diabase) or iron ore blast furnace slag. Some rock wool contains recycled glass	46-160	Possibly carcinogenic to humans [12]; generate pollutants during manufacturing	When melting does not discharge harmful gases; biodegradable	Fractional recyclable; 50years, providing maximum moisture to 3%	0.035-0.041	Resistance Factor >1.10	Low Frost resistant; incombustible material

Based on the data shown in the table above, it can be concluded that in terms of thermal properties, sound absorption and fire resistance, recycled plastic insulation materials do not lag behind conventional insulation materials, while on the other hand, they are resistant to frost, have a lower water absorption and vapour permeability.

The insulation materials presented in Table 3 do not generate pollutant during manufacturing and other chemical compounds that contain chlorine, hydrogen, fluorine, and carbon atoms. At the same time, they contain much more recycled materials and are fully recyclable. As the space for landfill disposal is diminishing due to its ever-increasing cost and with the increasing awareness about the environment, materials recyclability has become an important characteristic that should be met by modern materials. The Eco Wool Production process is improving and is expected to decline in the price of this product in the near future, so that in terms of economic viability will become serious competitors to conventional insulating materials.

It is worth noting that beside these materials, concrete materials incorporating recycled plastic aggregates can also be found on the market, designed to provide preferable thermal attributes and optimum energy performance in building construction. Such recycled aggregate concrete should satisfy both structural and thermal requirements as most concrete elements play dual roles as components of structural as well as thermal systems. These concrete materials would not be subject of this paper hereafter [13].

4. THERMAL INSULATION AS A KEY AREA FOR THE USE OF ENERGY EFFICIENCY MEASURES IN BUILDINGS DESIGN AND CONSTRUCTION IN SERBIA

The entire world is today facing two large problems. The first is a shortage of energy and uncertainty in its supply, and the second is environmental pollution, and climate change caused by excessive energy consumption.

The current housing stock in Serbia was built according to old energy regulations, in conditions of relatively cheap electricity and the insufficient application of building thermal protection regulations. These

[2] *The little symbol have the following meanings, respectively: The product achieved an A or A+ rating in the BRE Green Guide to Specification; Product contains recycled material and can be recycled; Product can be used as part of a recognised system to comply with relevant requirements of Approved Document L/E/B; Manufacturing processes do not involve CFCs or HCFCs; Ozone Depletion Potential Manufacturing processes do not contribute to ozone depletion; Global Worming Potential Manufacturing processes do not contribute to global worming; These products meet the Greenworks sustainablity credentials*

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buildings are large consumers and do not stand up to new world trends in protecting the environment and reducing carbon dioxide emissions.

In Serbia there is large technical potential for saving energy and implementing energy efficiency measures in building design and construction, when the following facts are considered:

- Houses and flats built before 1970 have almost no thermal insulation, as there were no heat protection requirements and regulations. Average heat losses in these buildings mainly range from 200 to 250 kWh/m^2 annually.
- Buildings built before 1987 have inadequate thermal insulation, only 2-4 cm. Heat losses in these buildings are often greater than those in older buildings, built before 1970, and come to 300 kWh/m^2 and more annually.
- More than 75% of buildings were built before 1987, and these buildings have the largest potential for savings, up to 80% of energy.

Activities to raise energy efficiency by increasing thermal protection of buildings should focus on buildings built before 1987.

We have to bear in mind that only 2% of construction projects relate to the construction of new buildings, that over 86% of money goes on existing buildings and that over the next 30 years more than 139 billion m^2 of commercial buildings need to be renovated [14].

Emphasis is placed on the fact that the largest savings are made through greater thicknesses of thermal insulation. If a wall is not insulated at all, the minimum recommended thickness of insulation is 10 cm, but if there is already a thin layer of insulation, then the actual condition needs to be inspected, and then it is either replaced with new insulation or the existing insulation is added to with at least 10 cm of new thermal insulation. In order to achieve a low-energy building standard (40kWh/m^2/annually to 15kWh/m^2/annually), the thickness of the insulation in exterior walls ranges from 15 cm to 30 cm, Figure 1.

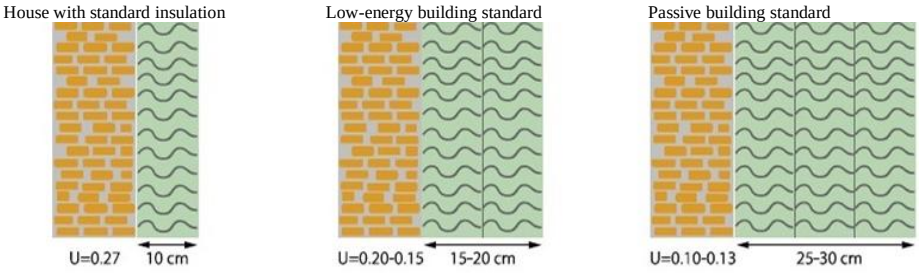


Fig 1. Thickness of thermal insulation for different building standards [15]

Ensuring the technical requirements in terms of choice of material and thickness of the thermal insulation layer, in order to achieve the energy efficiency of buildings, is only one of the conditions, which must be met on the road to achieving low-energy building standards.

In 2011, the Government of the Republic of Serbia adopted the Regulations on the Energy Efficiency of Buildings [16], which regulates energy properties and the method of calculating the thermal properties of high-rise buildings, as well as the energy requirements for new and existing buildings. These Regulations will begin to be applied as of 30 September 2012. In terms of heat insulation and the conditions, which the building envelope must meet, the Regulations prescribe the maximum values of the thermal transmittance coefficient of construction materials, as it is shown in Table 4.

Table 4. Largest permitted values of the thermal transmittance coefficient U_{max}[W/m^{2}K] for elements of the thermal envelope of a building [16]

Description of element/system in contact with external air	Existing buildings U_{max}[W/m^{2}K]	New buildings U_{max}[W/m^{2}K]
Exterior wall	0.40	0.30
Flat/sloping roof above the unheated space	0.40	0.30
Flat/sloping roof above the heated space	0.20	0.15

The thermal insulation material itself, according to the SRPS.U.A2.020 standard [17], must meet the condition that its heat conductivity coefficient is $\lambda < 0.06$ W/mK.

Bearing in mind the aforementioned thermal and technical characteristics of insulation material obtained from recycled plastic, whose heat conductivity coefficient is within the boundaries of 0.040 W/mK $< \lambda <$ 0.044

W/mK, it can be concluded that in terms of thermal characteristics it meets the condition contained in the SRPS U.A2.020 standard [17] that it is a true thermal insulating material.

In the text that follows, the key parameter of heat protection of a building or part of a building, the thermal transmittance coefficient of construction materials U [W/m^{2}K] will be calculated, according to the methodology and criteria prescribed by the Regulations on the Energy Efficiency of Buildings [16], for facade walls with thermal insulation made from recycled plastic. For the chosen building envelope models, a detailed cost estimate and a comparative technical-economic analysis of the results obtained will be carried out.

4.1. Technical-economic Analysis of the Characteristic of the Building Envelope with Recycled Plastic Thermal Insulation

Facade walls, which enclose or protect interior spaces of buildings, are the parts of a building that are exposed to a large number of different impacts; therefore, they always have to meet a great many requirements – primarily construction physics requirements.

Variants of walls made from hollow clay blocks, which are the most common in Serbia, have been chosen for the analysis. The calculation of the thermo-technical characteristics of sandwich walls made with hollow clay blocks was done for three different thicknesses of the layer of thermal insulation made from recycled plastic d=10/20/30cm, and with an exterior material of solid brick d=12cm.

Table 5. Thermo-technical characteristics of walls for different thicknesses of thermal insulation material

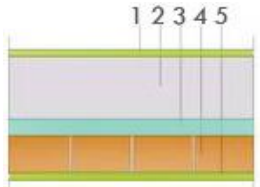
FACADE WALLS MADE FROM HOLLOW CLAY BLOCK (25+10/20/30+12)						
Graphical display of layers	Layers		d (cm)	Σ d (cm)	U-value (W/m^{2}K)	G (kg/m^2)
	1.	Tabby	2.00			
	2.	Clay block	25.00			
	3.	Eco Wool	10.00 20.00 30.00	**51.00** **61.00** **71.00**	**0.278 standard** **0.164 low-energy** **0.116 passive**	**572** **582** **592**
	4.	Solid brick	12.00			
	5.	Mortar	2.00			

Table 6[3]. Detailed cost estimate for the building envelope for different thicknesses of thermal insulation material

Facade Wall		**Sandwich Wall (25+10+12)**		**Sandwich Wall (25+20+12)**		**Sandwich Wall (25+30+12)**	
		Thickness (cm)	U-value (W/m^{2}K)	Thickness (cm)	U-value (W/m^{2}K)	Thickness (cm)	U-value (W/m^{2}K)
		51,0	**0,278**	**61,0**	**0,164**	**71,0**	**0,116**
Activity	**Resources**	(Eur/m^2)		(Eur/m^2)		(Eur/m^2)	
Clay masonry block	Labour	16,73	4,58	16,73	4,58	16,73	4,58
	Material		12,24		12,24		12,24
Brick masonry + thermo insul.	Labour	15,92	3,21	18,97	3,53	22,03	3,85
	Material		12,70		15,44		18,18
Plastering	Labour	8,92	5,76	8,92	5,76	8,92	5,76
	Material		3,17		3,17		3,17
Smoothing	Labour	0,93	0,70	0,93	0,70	0,93	0,70
	Material		0,23		0,23		0,23
Total[4] (Euros/m^2)		**42,49**		**45,55 (+7,2%)**		**48,60 (+14,4%)**	

[3] *Exchange rate formed on March 1st 2012 year: 1Eur = 110,25 dinars*

[4] *The cost estimate does not include income coefficient - φ.*

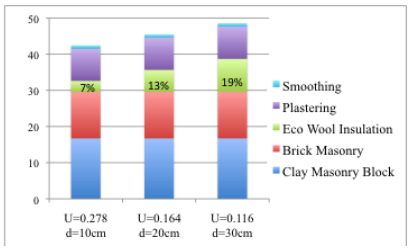


Fig. 2. Comparison of cost for building envelope for different thicknesses of heat insulation material

From the presented tables and figures, it can be observed that the price per square meter of finished exterior sandwich wall increases in line with the change in the thickness of the heat insulation, and at the same time improved thermal characteristics of the building. By placing thermal insulation in a 10 cm thick layer, the finished wall has a thermal transmittance coefficient of U=0.278, which is less than U_{max}=0.3 for newly-built buildings according to the Regulations on the Energy Efficiency of Buildings [16]. A building envelope obtained in this way is in the category of energy efficient performance. If we continue to increase the thickness of the insulation material, we get a building envelope that has a coefficient of U=0.164, which is the category of low-energy buildings. In order to meet the passive building standard, the building needs to have a 30 cm thick thermal insulation layer. As far as price is concerned, by transitioning from an energy efficient envelope to a passive building standard, the price changed by 14.4%, 6,11Euros/m^2, and just by 7.2%, 3,05 Euros/m^2 of the surface area of the envelope with the transition from low-energy to passive building standard. According to rough division in terms of savings achieved in a low-energy house, only 40 kWh/m^2/year is used for heating, which is equivalent to 2.7 litres of heating oil per m^2 annually. A passive building goes one step further – consuming just 15 kWh/m^2/year, which is equivalent to consuming 1 litre of heating oil per m^2 annually. Since the price of heating oil in Serbia is today 1,28 Euros per litre (150 dinars per litre[5]), the annual saving is 1,92 Euros/m^2 of the area of the building by transferring from low-energy to the passive building standard. With this short analysis it can be seen that the increased initial investment in thermal insulation is returned within a period of three years.

Each of the analyses conducted have their own weight and importance, and in aggregate provide the most favourable solution. Which characteristics will have the dominant role when selecting the material depends on the desired effect. The desired effects can be short-term economic effects, i.e. savings during construction, or the quality of the heat protection, as well as the quality of the built building itself regardless of the price, which is more profitable in the long term, but requires a larger initial investment. The most optimal solution is the one that is a combination of all these factors.

5. CONCLUSIONS

The use of a new generation of recycled plastics as insulation materials for the green building in the Serbian construction industry could are achieved significant environmental, economic and technical effects. The most significant of these are:

ENVIRONMENTAL ASPECTS

1. The level of recycling increases and with it the first principle of the waste management hierarchy is met: prevention of the creation of waste and a reduction in the use of resources.
2. Drastic reduction in communal waste, which must be transported to sanitary landfills, whereby the life of the landfill is extended and the exhaustion of natural resources and emissions from landfills are reduced.
3. Reduction of harmful gas emissions.

ECONOMIC ASPECTS

4. Private sector participation in the recycling process in various forms satisfies numerous economic goals: provision of investment capital, lower need for subsidies, rise in employment, etc.
5. Prices of natural gas, crude oil, coal, and nuclear fuel have tripled in the past five years. As these prices continue to increase, turning recycled plastics into green insulation becomes even more attractive financially.

TECHNICAL ASPECTS

6. Over 75% of all buildings in Serbia do not have adequate thermal insulation or none at all. Thermal insulation should be seen as an essential design component in terms of maximum thermal protection and energy efficiency of buildings.

[5] *Exchange rate formed on Jun 1st 2012 year: 1Eur = 116,92 dinars*

7. In terms of thermal and technical characteristics, insulation materials from recycled plastic do not lag behind conventional insulation materials.
8. In terms of impacts on the environment and human health, there are no negative effects.
9. Insulation material from recycled plastic satisfies condition regarding the thermal conductivity in the SRPS U.A2.020 standard [17] that it is a true thermal insulation material.
10. The calculation demonstrates that a building envelope which contains this thermal insulation material, and with a thickness of only d=10cm, meets the condition in terms of the maximum U-values of the thermal transmittance for the exterior wall of a newly-built building and/or an existing building, according to the Regulations on the Energy Efficiency of Buildings [16].
11. By increasing the thickness of the thermal insulation layer to 20cm or 30cm, low-energy and passive building standards are reached respectively.
12. The initial cost of investing in thermal insulation returns within the first three years of the exploitation period.

6. THE FUTURE OF RECYCLED INSULATION MATERIALS IN SERBIA

The manufacture of mineral wool and fiberglass insulation is energy intensive. Any materials that can be recycled, without requiring the melting of input materials, can save large quantities of energy. Prices of natural gas, crude oil, coal, and nuclear fuel have tripled in the past five years. As these prices continue to increase, recycling becomes even more attractive financially.

With growing concerns about global warming, recycling is a way to reduce energy use for the manufacture of construction and building materials. When the manufacture of recycled insulation materials is combined with the increases in energy efficiency realized by thermal insulation in buildings, the contributions to a more sustainable society can be large. One of the long-term goals of the Serbian Waste Management Strategy for the Period 2010- 2019 [18] is increasing the rate of the re-use and recycling of packaging waste to 25% of its quantity. In the next 7 years in Serbia, new recycling projects likely will be developed and commercialized. The Serbian insulation industry has the potential to take part in these projects and develop a new generation of recycled plastic insulation materials, which will increasingly contribute to a more sustainable society.

Acknowledgments

This research was funded in part by the Serbian Ministry of Education and Science project no. TR37009.

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