Economic-Environmental and Technological Assessment of ETICS

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Abstract. The current societal trend is to reduce energy consumption and emissions of substances harmful to human health and threatening the climate and biodiversity. Buildings account for 40% of total energy consumption in the EU, and the sector is growing steadily. Buildings also account for 36% of greenhouse gas emissions. It is therefore clear that the energy status of buildings plays a significant role in both the economy and people's lives. ETICS (External Thermal Insulation Composite System) of buildings is particularly beneficial in energy savings. However, the impact on human health and the environment is not investigated enough, both during construction and during the lifetime and demolition of the structure. Financial demands and thermal insulation properties are usually main criteria for the selection of the best insulation. However, the impact on the environment and public health should also be taken into account. The aim of the paper is to find the most suitable variants of thermal insulation using appropriate statistical methods considering all aspects. This means considering not only variables involving thermal, technical, operational, economic, but also health and environmental aspects. Products that are friendly to the health of the population and the environment also bring economic benefits, which are sometimes difficult to quantify.

Keywords: ETICS, economic assessment, energy savings, environmental impacts

JEL Classification: C89, Q51
AMS Classification: 65-00

1 Introduction

External thermal insulation compound systems (ETICS) of buildings are already well researched in terms of technology, thermal insulation and economics. The impacts of different types of systems on the environment and the health of the population have already been studied less thoroughly. There is almost no sophisticated decision-making process for selecting the specific variant for the particular building, considering all the above-mentioned aspects. There is a complete lack of quantification of the perception of the general public of different types of ETICS. The article will describe the decision-making process for finding the best (effective) solutions with consideration of thermal-technical, economic, health and environmental aspects.

Thermal insulation of buildings brings benefits to society as a whole, especially in energy savings. However, the risk of producing adverse effects on the environment and the health of the population is not negligible. The correct choice of a suitable variant and product should include an assessment not only of the thermal-technical, operational, economic but also of the health and environmental aspects.

When assessing environmental and health impacts, often only CO and sulphur emissions are assessed, and only quantitatively. The influence of other very dangerous chemical substances that are released during the production of ETICS components and subsequently also during the operation of the construction is investigated only very marginally. Maximum attention will be paid to this aspect and the individual variants will be carefully examined from this point of view as well.

The general public usually does not have enough quality data on the various available variants of ETICS. The chosen method of insulation should be perceived positively by the user, which will contribute to well-being and a high standard of living.

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2 Materials

The thermal-technical parameters of ETICS are provided by a layer of thermal insulation, which in thermal insulation systems can be formed by available insulation materials on the market. This is usually polystyrene foam, mineral fibre boards or lamellas, or materials based on polyurethane, polyisocyanurate or phenolic foam [13].

2.1 Styrofoam

Styrofoam is a light and rigid foam that is widely used in European construction, mainly as thermal insulation. It is also an excellent packaging material because its impact properties combined with its low weight make it a material suitable for countless uses. Expanded polystyrene is produced in two basic types, differing in production technology and properties: EPS (Expanded Polystyrene) and XPS (Extruded Polystyrene). Consumption of polystyrene in the Czech construction industry has been growing for a long time and in 2017 it repeatedly exceeded 60 thousand tons (compared to 1997, when the production of polystyrene for the construction industry was 10,000 tons). By 2030, according to EU legislation on circular economics, all plastics must be fully recyclable, including expanded polystyrene (EPS). Cut and pure polystyrene is fully recyclable. The cut polystyrene foam is then crushed and, depending on the degree of contamination, used further. Clean material without unwanted impurities can be repeatedly used for the production of new packaging or insulation. Contaminated polystyrene foam can be used for aerated concrete, aerated plasters, backfills or in the production of aerated bricks.

2.2 Mineral and glass wool

Mineral wool is actually a fleece made by pressing fibres made from minerals. Stone thermal insulation is produced at high temperatures by pulping basalt or gabbro basalt in a kiln and forming these fibres into mats or boards. Stone wool is non-flammable, so it is used in constructions with increased requirements for fire safety - fire dividing strips in contact thermal insulation systems, constructions with higher fire resistance, etc.

Glass wool is produced from new glass or by recycling and pulping container glass. The molten glass is blown into fibres and formed into plates or mats. The use of glass wool is similar to stone wool. In the case of mineral wool, phenol-formaldehyde resins, which are carcinogenic, have previously been widely used in the manufacture. Compared to natural materials, non-natural materials have worse disposal options. Mineral fibre recycling is very difficult. This is due to the specific production of this building material. Recycling is only possible during production from waste material. This recycling can be divided into three types: reuse without modification, regeneration to the same product or use in the production of building materials.

2.3 Polyurethane

Polyurethane is a polymer that is produced by the polyaddition of diisocyanates and di- or polyhydric alcohols to form a carbamate (urethane) bond. Polyurethane and polyisocianurate foam (PUR) are used in addition to casting and spraying directly on the construction site and for the production of board materials. The boards can be produced by cutting from blocks formed by free foaming or in moulds. A big problem for the environment is expanded gases - CFCs (HCKW, HCFC), which were used in the past. The expanding gases bound in the pores slowly escape, for their half-lives the time is about 100 years. A large part of CFCs, which can still get into the air, falls on foams for thermal insulation in construction. Therefore, polyurethanes must be disposed of in a special way. In modern household waste incinerators, CFCs are practically completely destroyed. Polyurethane is an insulating material with the most complex and energy-intensive production process. Environmental stress and the risk of poisoning occur during production. Polyurethane is a typical product of so-called hard chemistry. Inputs for the production of polyurethanes are obtained from crude oil.

2.4 Phenolic foam

Phenolic foam is a material obtained by foaming phenol formaldehyde resins. The foamed blocks are then cut to the required dimensions. The boards are provided with an aluminum layer to improve the thermal-technical parameters of the material. The disadvantage of this insulation is the high price and is not recommended for insulating damp substrates (soaked masonry, damp concrete).

2.5 The blown cellulose

The basic component in the production of thermal insulation material blown cellulose is recycled paper. Using special technology, it is divided into cellulose fibres, which are then enriched with other ingredients.

2.6 Long shavings of wood

Long shavings of wood is a 100% natural material without chemicals and dyes. The fibres are usually 2 mm thin, 30 cm long and do not contain dust or chips. Before they are rolled into balls and wrapped, the dirt is shaken off with a special machine.

3 Impacts on human health, the environment and the availability of natural resources

Climate changes include systematic changes in the global atmosphere, which is inextricably linked to the hydrosphere, pedosphere and biosphere. The Earth maintains its thermal balance thanks to the delicate balance between the incident shortwave solar radiation and the emitted infrared, longwave radiation that escapes from the Earth's atmosphere. Gases present in the atmosphere, such as water vapor, carbon dioxide, methane, and others, allow sunlight to pass to the Earth's surface, but reflect the infrared radiation emitted by the Earth's surface partially back to Earth. The term "greenhouse effect" has been used for this phenomenon. The most important greenhouse gas is water vapor. The current concentration of CO2 is probably the highest in the last 20 million years, the concentration of CH4 is probably the highest in the last 420 thousand years and the current concentration of N2O has not been exceeded for at least the last thousand years [6]. The impact of CO2 on climate change is currently being intensively studied. In particular, the quantification of its impact and the quantification of anthropogenic climate change remain unclear.

The following environmental aspects were taken into account in the present study: Primary Energy Input (PEI), Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication (EP), Depletion of Stratospheric Ozone (ODP) and Photochemical Oxidation Potential (POCP) [12].

3.1 Depletion of stratospheric ozone

The depletion of stratospheric ozone (ODP) allows greater penetration of solar UV radiation on the earth's surface, which negatively affects human health, the quality of the natural environment, natural resources and human creations. The release of chlorinated and brominated organic compounds into the atmosphere, especially CFCs, CFCs, HCFCs, carbon tetrachloride, 1,1,1-trichloroethane, halons and methyl bromide, leads to increasing concentrations of chlorine and bromine atoms in the stratosphere. A common feature of these substances is their relative stability. Through the transport mechanisms of the atmosphere, these substances enter the stratosphere, where they are decomposed by higher intensities of UV radiation and release chlorine and bromine atoms. In addition to halogenated hydrocarbons, N2O and methane emissions also contribute to the decomposition of ozone. Ozone decomposition occurs by chemical reactions on solid particles in the stratosphere. The extremely low temperature over Antarctica leads to the condensation of water and nitric acid to form polar stratospheric clouds. In the presence of such particles, reactions leading to ozone decomposition are accelerated [3].

3.2 Human toxicity

Human toxicity expresses the adverse effects of substances emitted into the environment on human health. There are a large number of different adverse effects of substances, from acute toxicity to mutagenicity, teratogenicity, nephrotoxicity, etc. These are effects that are of different chemical and biological nature. The category indicator is the Acceptable Daily Intake (ADI) [3, 11, 12].

Human activities release a significant amount of inorganic respiratory substances into the air: SO2 coal combustion, CO2 combustion processes in general, NOx transport, CO combustion processes, HCl chemical production, HF chemical production or dust particles from combustion processes. Due to atmospheric flow and the resistance of these substances to decomposition, these substances have also been found in places on Earth where they have never been produced or applied [6].

3.3 Ionizing radiation

Ionizing radiation or radiation (radioactivity) includes the adverse effects of the release of radioactive substances into the environment as well as direct exposure to radiation, for example in building materials. Two types of emission fluxes play a role in the category of impact of ionizing radiation. Firstly, there are emissions of radioactive materials into the environment and secondly, it is direct radiation into the environment, not linked to the specific release of radionuclides (building materials).

So far, environmental noise pollution has been relatively rarely mentioned. However, increased noise levels have been shown to have an adverse effect on the health of the human population. Adverse effects of noise on animals have also been observed. More information on the development of noise pollution can be found on the European Environment Agency portal.

The main cause of photooxidants is the increased concentration of ozone, nitrogen oxides and Volatile Organic Compounds (VOCs) in the atmosphere, especially in places with lower air exchange, such as cities or valleys. In addition to ozone, we consider peroxoacetyl nitrate (PAN) to be the main toxic photooxidants, as well as hydrogen peroxide, the hydrogen peroxide radical, and other radicals which are formed as intermediates in oxidation reactions [3].

3.4 Acidification

Acidification is the process of acidification of the soil or water environment caused by an increase in the concentration of hydrogen cations that have entered the environment by atmospheric precipitation of emissions of sulphur dioxide, nitrogen oxides and ammonia. Substances causing acidification are SO_2, NO_x and NH_x, acids (HCl), H_2S. Lowering the pH of water and soil has far-reaching consequences. These are mainly the death of mountain forests, acidic surface water without fish, groundwater with a high content of toxic metals released from soils and rocks [3, 10, 12].

3.5 Eutrophication

Eutrophication (usability) is the process of increasing the content of nutrients in surface waters and soils. It is a natural phenomenon which, as a result of human activities, has exceeded an acceptable limit in the affected ecosystems. A visible consequence of eutrophication is the overgrowth of surface freshwater and seawater with aquatic cyanobacteria and algae. The primary consequences of eutrophication are disruption of the oxygen and light regime of water bodies, disturbance of the ecological balance by supporting fast-growing organisms at the expense of slow-growing ones, production of cyanobacterial toxins and loss of drinking water resources [3, 8, 10].

3.6 The ecotoxicity

The ecotoxicity impact category includes the toxic effects of emitted substances on water, soil and sediment ecosystems. These are not only toxic effects on individual organisms, but on ecosystems as a whole. The direct consequence is not only a reduction in natural wealth, but also a reduction in the quality and abundance of natural raw material resources.

Groundwater resources are depleted faster than their yield, resulting in salt water penetration in coastal areas or local pollution intrusions. The limited availability of raw material resources may lead to an increase in international tensions in the future [3]. Technologies requiring less water should be used as a matter of priority.

4 Economic aspects

The price of the examined materials was determined as the average price offered in the region of South Moravia. The prices of individual materials vary by region and are, of course, variable over time. Prices can also be affected by special prices and free shipping offers. When searching for the best variants for a specific building in a given place and at a given time, it is necessary to update the prices. Economic losses caused by damage to human health and negative effects on the environment are not quantified. They are included in the analysis through environmental variables.

5 Data and analysis

As mentioned above, in addition to economic and technical criteria, social and environmental aspects were also considered. Price was taken as an economic variable, the technical properties are described by thermal resistance. The social aspect is described by the quantity SI (Social Impact), which we obtained by our own survey (questioning). The last six variables represent the environmental aspects. Environmental data were retrieved from Czech database Envimat [4, 7].

	Outputs			Inputs					
Thermal insulation	**Price**	**Thermal resistance**	**SI**	**PEI**	**GWP**	**AP**	**EP**	**ODP**	**POCP**
	Kč/m^2	m^2 K/W	Range 0-10	MJ/(m^2.a)	kg CO_2 eq/ (m^2 a)	g SO_2 eq/ (m^2 a)	g $(PO_4)^{3-}$eq/ (m^2 a)	g R-11 eq/ (m^2 a)	g C_2H_4 eq/ (m^2 a)
EPS	450	7,50	9	37,826	1,516	5,364	0,918	4,75E-05	2,432
XPS	690	7,50	8	28,954	1,146	4,018	0,904	2,65E-05	0,461
Rock wool	868	7,75	8	8,012	0,450	3,317	0,726	2,20E-05	0,177
Glass wool	770	8,75	7	25,499	0,838	3,902	1,481	1,35E-04	0,312
PUR	870	10,00	5	23,824	1,163	4,867	1,314	5,74E-06	0,226
Blown celulose	558	7,75	6	4,429	0,228	1,801	0,396	2,51E-05	0,076
Shavings of wood	897	13,80	9	1,422	0,077	0,388	0,206	5,98E-06	0,020

Table 1 Inputs table

To determine which of the studied materials are effective with respect to all considered variables, we used DEA analysis, specifically the BCC model (see [2] for details). We used environmental variables as inputs because we want to minimize them. We used technical and economic variables as outputs, which we want to maximize. We therefore considered the price with a negative sign. The results are shown in the following table.

Thermal insulation	EPS	XPS	Rock wool	Glass wool	PUR	Blown celulose	Shavings of wood
Efficiency	1,000	0,474	0,306	0,235	0,168	1,000	1,000

Table 2 Table of results

Three types of thermal insulation are effective, namely EPS, blown cellulose and wood wool. The other four are ineffective. XPS, glass wool and polyurethane foam work ineffectively mainly due to high values of ecological characteristics. Glass wool has worse results compared to XPS because it has a lower SI rating and is more expensive. Polyurethane foam is the worst, although one environmental indicator has the lowest, so in other ecological indicators it approaches the maximum values, it is the worst evaluated in terms of SI and, moreover, it is relatively expensive. Stone wool does not come out efficiently mainly due to the price, in other respects it is roughly on average.

6 Conclusion

DEA proved to be a suitable mathematical tool for finding optimal materials for ETICS with consideration of all aspects, not only technical-economic, but especially environmental. In practical use, it is necessary to update the prices of materials. For the final decision, it is also necessary to take into account the specific climatic conditions, the detailed composition (layers) of the ETICS and the construction to which the EICS will be applied.

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