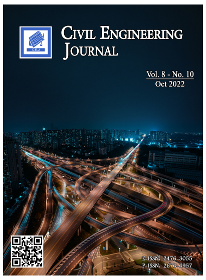
Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 8, No. 10, October, 2022



Assessing the Compliance of Extrusion Foamed Polystyrene Production with the Environmental Standards Requirements

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Received 17 June 2022; Revised 05 September 2022; Accepted 17 September 2022; Published 01 October 2022

Abstract

The development of modern construction requires the use of environmentally friendly building materials, including insulating materials, to ensure the energy efficiency of buildings and structures. The purpose of the work is relevant and was to develop a methodology for assessing the compliance of extruded polystyrene foam with environmental requirements. The problem is that the certification of such materials includes an examination of their physical and mechanical properties and does not allow assessment of materials' environmental aspects. A comprehensive approach to assessing the quality of extruded polystyrene foam is proposed, which ensures not only the technical level of material quality, but also compliance with environmental requirements. The research methodology is based on the environmental risks' identification at all stages of production and the determination of products environmental safety criteria. Each criterion is characterized by a set of indicators, among which a representative indicator is determined. A complex indicator is proposed for assessing the environmental safety of the production of extruded foamed polystyrene. The novelty of the work lies in the algorithm for calculating the material environmental friendliness complex criterion. The process model of the extruded polystyrene foam production analyses made it possible to establish representative indicators according to the products' environmental safety criteria. As a result of the analysis, critical operations were identified where environmental risks are likely, and representative indicators' limit values were set in accordance with regulatory documentation. Measures have been developed to minimize the release of harmful substances during each critical operation. To improve environmental management, the system for monitoring and assessing risks in the production of extruded foamed polystyrene has been optimized. As a result, a methodology has been developed for assessing the compliance of the production of extruded polystyrene foam with environmental requirements, which is necessary for product quality certification.

Keywords: Building Insulation Materials; Risks; Extruded Polystyrene Foam; Conformity Assessment; Environmental Standards.

1. Introduction

Nowadays, one of the most critical problems in the production of synthetic insulating building materials is the negative impact on the environment. The factors act on a global scale and require modern methods to minimize potential environmental risks [1-3].

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http://dx.doi.org/10.28991/CEJ-2022-08-10-018

Currently, environmental standards and norms are in place to prevent the negative impact of production factors when obtaining various materials and finished products. However, the standards are of a general nature and do not take into account the specifics of the production and materials' behavior at the various life cycle stages. The problem lies in the fact that the constant updating of the range of building materials from synthetic raw materials requires the timely development of a methodology for assessing production processes to ensure environmental requirements. The purpose of the work is to study environmental risks and develop a methodology for assessing the extruded polystyrene foam production's compliance with the environmental standards requirements. The relevance of the work is related to the need to introduce objective methods for assessing the environmental friendliness of synthetic insulating building materials during product certification and the introduction of effective systems for controlling harmful production factors.

The scientific novelty lies in the study of environmental risks in the process of obtaining extruded polystyrene foam and the development of the algorithm for calculating a comprehensive indicator of the material's environmental friendliness. The practical significance of the results lies in the development and implementation of the insulating building materials' environmental safety assessment methodology. The trends of recent years show a constant increase in the production of heat-insulating materials from extruded expanded polystyrene based on extruded expanded polystyrene (further XPS). As stated in the articles [4–6], the global market for extruded polystyrene foam insulation materials was estimated at $5.2 billion in 2019 and is projected to reach $7.9 billion by 2027, increasing by an average of 5.6% from 2020 to 2027.

The Russian market of XPS materials has a great growth and implementation potential in the conditions of climatic features of Russia. Synthetic insulation materials are the most important elements of building structures, as they ensure the energy efficiency of buildings and structures [7]. The use of heat-insulating XPS materials makes it possible to significantly improve and accelerate the construction technology of buildings and structures, as well as significantly reduce the costs of constructing new building structures [8–10]. Despite all the advantages of synthetic XPS insulation, there is a problem with its use in sustainable construction. There are three main reasons for this problem:

- In the production and sale of XPS insulation, mandatory quality assessment and certification is carried out only in terms of physical and mechanical properties (density, mass, thickness, thermal conductivity, porosity, etc.) and fire safety [11];
- Existing methods for assessing the building materials' environmental safety are limited to the examination of single indicators of toxicity or the release of harmful substances during the building's operation, this does not allow an objective assessment of the materials' compliance, structures and buildings with environmental requirements [12, 13];
- There are no systematized indicators for assessing the insulation XPS's environmental safety at all the life cycle stages, and above all at the stage of materials' production [11-13].

It should be noted the danger of harmful substances' release due to the possible destruction of the polymer [14]. This danger is largely associated with a violation of the materials' production process parameters in modern industries.

Much attention is paid to the study of the materials' environmental safety in scientific research [15-17].

However, the risk of harmful substances emission remains caused by possible degradation of the polymer [18-20]. It should be noted that this danger remains relevant even at production facilities modernized to meet environmental standards. Minimization of harmful impacts on the environment is possible by providing comprehensive measures:

- Prevention or reduction of pollutants emissions into the biosphere;
- Reduction (up to elimination) of production and consumption wastes;
- Reduction of energy and resource intensity during the production processes.

These measures are implemented at all production levels (see Figure 1).

Currently, various countries are implementing the environmental management systems. National standardization organizations often act as regulators (the main ones are presented in Table 1).

Table 1. National standardizing organizations and environmental standards systems

Country	Environmental management system	National standardizing organizations
Russia	National standards of Russia (GOST R), standards of the GOST R ISO 14000 series.	Federal Agency for Technical Regulation and Metrology (Rosstandart)
USA	American National Standard based on ISO 14000 (ASQ/ANSI/ISO 14000)	American National Standards Institute (ANSI)
China	Environmental management system ISO 14000 GB Environmental Standards	Standards Administration of China (SAC)
UK	BS 7750, EMAS and ISO 14000	British Standards Institute (BSI)
European Union	EMAS and ISO 14000	European Committee for Standardization (CEN)

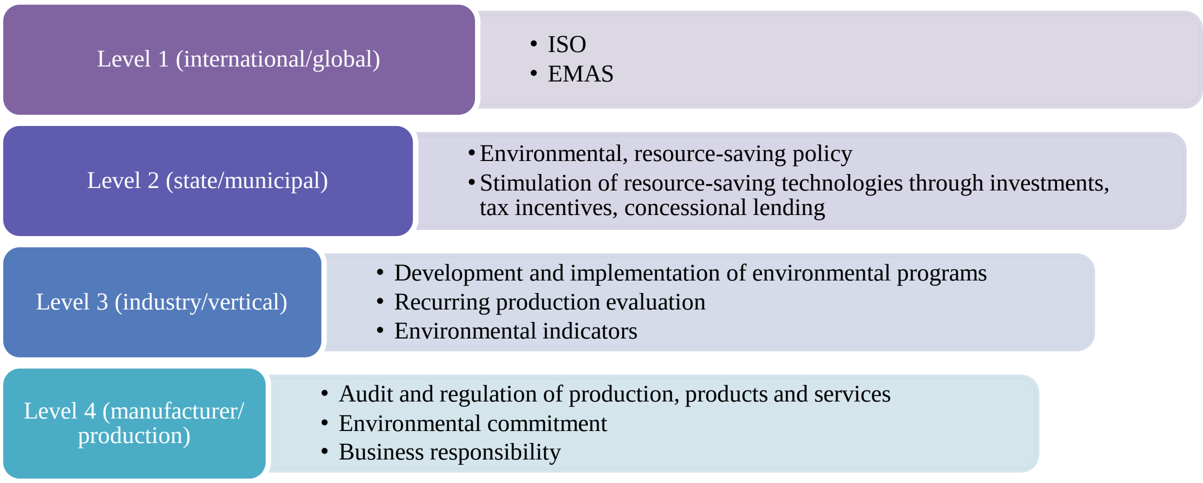

Figure 1. Measures to minimize harmful impacts on the environment

In Russia, the quality of insulation XPS materials is currently confirmed within the framework of mandatory product certification. Based on the regulatory documentation, a list of mandatory technical requirements for assessing the quality of the materials under study was compiled:

- Length, width, squareness, flatness;
- Thickness;
- Fire-technical characteristics;
- Durability;
- Dimensional stability at a given temperature and humidity;
- Deformation under certain compressive load and temperature;
- Compressive strength at 10% linear strain or ultimate compressive strength;
- Tensile strength perpendicular to the front surface;
- Creep under compression;
- Water absorption;
- Frost resistance;
- Vapor permeability;
- Harmful substances release.

However, the above indicators do not guarantee the environmental friendliness of insulation and require an expansion of the indicators list for an objective quality assessment. Currently, the compliance of XPS insulation with environmental requirements is carried out within the framework of voluntary certification. As of May 1, 2021, more than 500 voluntary certification systems are registered in the national standardization system of the Russian Federation. They assess technologies and products for compliance with environmental requirements. The complete register of systems is presented on the official website of the Federal Agency for Technical Regulation and Metrology of the Russian Federation (Rosstandart).

The main methods for assessing the safety of various building materials in accordance with Federal Law No. 384-FZ "Technical Regulations on the Safety of Buildings and Structures" and GOSTs are assessments by indicators of radionuclides natural activity, indicators of fire hazard and sanitary safety. However, this approach does not take into account the materials environmental safety at all the life cycle stages. In addition, the assessment of the environmental safety of XPS insulation is problematic due to the lack of a methodology for calculating the environmental criterion. There are also no estimated indicators that should take into account the production conditions and the specifics of the material behavior at all the life cycle stages. The environmental indicator should evaluate the safety of the material throughout its life cycle, and not just at the stage of its operation. Compliance of construction products with environmental requirements should confirm the safety of the material production for the biosphere. This gives the manufacturer an undeniable advantage in the market.

There are different approaches to assessing the environmental safety of building materials in world practice. Known methods of ecological preference provide for a preliminary assessment of the impact of products on the environment and humans based on a comparative analysis of various building materials with each other. It should be noted the relative nature of such an assessment based on ecological reasoning about the loads of materials during operation on the environment and humans. In addition, the choice of reference (base) material for comparison may be subjective and depend on the experts' opinion [21, 22].

The current environmental certification system of various building materials applies an assessing methodology for the safety of a material for human health at the operational stage, that is, the sanitary-environmental aspect (EcoMaterial Basic). Radiological, electromagnetic, chemical, toxicological measurements and laboratory studies of materials are carried out. Methods for assessing the complex impact of the material and its production on the environment (EcoMaterial Green) have not yet been developed, and there are no criteria for assessing the environmental responsibility of the manufacturer (EcoMaterial Absolute) [23].

Currently, a national standards system is being formed, it presents environmental requirements, standards and methods of products evaluating. Criteria and indicators for confirm compliance with "green" products have been developed for components of modern paints and varnishes, additives in cement mixtures, binders for nonwoven materials (road construction), fiberglass products, adhesives for the production of high-quality paper and cardboard, industrial adhesives for furniture production, adhesive compositions for the medical industry, etc. [24]. There are no methods for XPS building insulation. In the next section, the authors propose an approach to assessing the environmental safety of heaters made of XPS.

This paper proposes a methodology for assessing the environmental safety of XPS building insulation based on the analysis of the production process model according to environmental criteria and representative indicators. Each criterion includes a set of indicators, among which a representative indicator is determined. Criteria and indicators are determined based on the identification of environmental risks at each stage of the production process. This approach will allow to assess the environmental safety of production and finished products (EcoMaterial Green) and optimize environmental management at the enterprise (EcoMaterial Absolute).

2. Materials and Methods

2.1. Characteristics of XPS Materials

In this study, the control points have been identified when it is necessary to confirm the compliance of the extruded polystyrene foam production process with the requirements of environmental standards. To do this, several international systems of environmental management have been analyzed the production as well located on the territory of the European part of the Russian Federation.

In the interstate standard GOST 32310-2020 (EN 13164 + A.1: 2015) "Thermal insulation products of extruded polystyrene foam for building. Specifications (Products made of extruded polystyrene foam used in construction [25]. Specifications)" it is stated that extruded polystyrene foam is a rigid heat-insulating material with a closed cellular structure, obtained by extruding polystyrene with the addition of foaming agents.

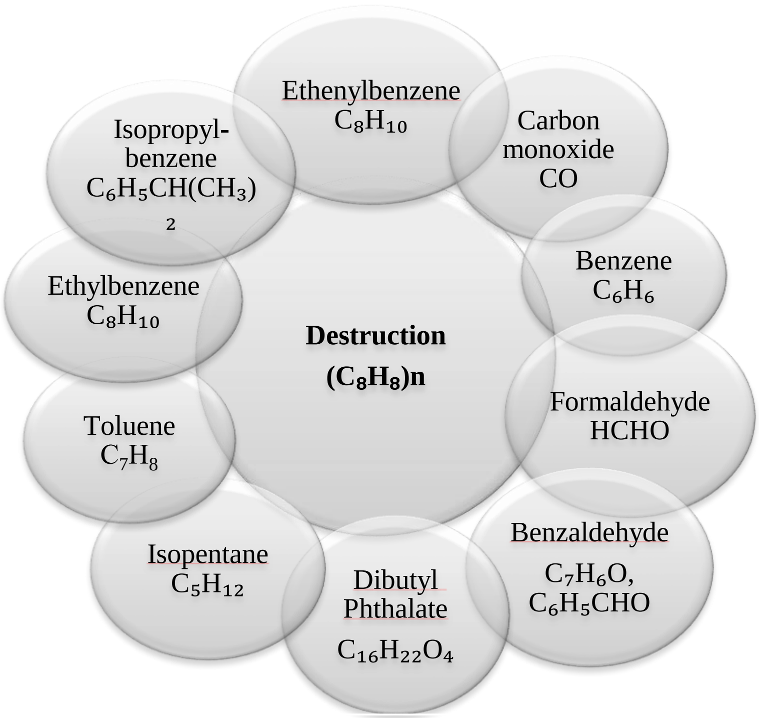

Figure 2. Harmful chemicals released during the polystyrene extrusion

The danger of polystyrene processing lies in the toxicity of decomposition products, which is associated with the destruction of polymer macromolecules at elevated temperatures. In the extrusion process of polystyrene, harmful substances are released [26, 27], they are shown in Figure 2. Properties characteristics of the extruded polystyrene foam (XPS) are presented in Table 2.

Table 2. Characteristics of extruded polystyrene foam (XPS)

Indicator	The value of the indicator
Strength	2-3.6 kgf/cm^2 at linear deformation; 10% and 4-7.1 kgf/cm^2 in static bending.
Volume weight	15-29 kg/m^3 - for insulation of walls, ceilings, etc. 30-36 kg/m^3 - for insulation of the foundation, floor, roof, etc.
Shrinkage	Absent in all operating conditions.
Thermal conductivity	0.026 W/m·Deg at 10 C.
Frost resistance	Loss of thermal resistance - 5% after 1000 freeze and thaw cycles. Temperature range -50 to +75 C.
Water absorption	⩽ 0.5% of volume within 30 days.
Vapor permeability	Vapor permeability coefficient 0.007-0.012 mg/(m•h•Pa).
Fire resistance class	G3-G4 (G3-normal flammability; G4-strong flammability). With the addition of fire retardants-G1 (low flammability).
Soundproofing	Impact noise reduction index - 25 dB.
Environmental friendliness	> 40 years subject to compliance with the installation technology.

2.2. Methodology

As a result of the system of ISO 14000 standards analysis [28, 29] environmental requirements that XPS production should meet.

Further, environmental friendliness criteria are established to evaluate materials and technologies. The following criteria have been selected to evaluate the production of XPS materials:

- Resource Saving Products;
- Energy Efficiency;
- Waste Production;
- Environmental Protection;
- Environmental safety of technology.

Each criterion is defined by a set of characteristics and corresponding indicators. The classification of products and technologies as environmentally friendly consists in assessing one representative indicator from a set of indicators. A representative indicator best represents a characteristic or criterion of a product or technology. The list of indicators of products and technologies, including representative indicators and their numerical values, is established according to the standards for the relevant products and technologies [11, 30].

For example, according to the criterion "*Products resource saving*", a set of indicators from which a representative indicator is selected is presented in Table 3.

Table 3. Product indicators according to the criterion "Resource saving"

Criterion	Characteristics	Indicators from which a representative one is distinguished
Resource saving	Resource content	Mass of substance, material, product, product
	Resource intensity	Specific consumption of raw materials, materials in the manufacture of products, products
	Resource efficiency	Energy consumption during the operation of the product, products; coefficient of performance (COP) of the product
	Recyclability	The level of recyclability of objects (waste from it); resource intensity of object disposal (waste from it)

Similarly, the indicators and characteristics are determined for the remaining criteria. The criteria and indicators for assessing the production environmental safety of the XPS materials are presented in the Table 4.

Table 4. Requirements of environmental standards to produce insulating building materials based on extruded expanded polystyrene (XPS)

Criterion	Indicator	Indicator parameter
1. Environmental management	- Organization of the environmental management system (EMS) and its monitoring; - Optimization of design solutions; - Qualification requirements.	EMS policy; Staff learning & development.
2. Technological safety	- Compliance of technology with the requirements of industrial, environmental, sanitary, hygienic, and fire safety.	Yes/No
3. Resource saving	- Material consumption; - Energy intensity.	Consumption of raw materials kg; t

4. Energy saving; energy efficiency	- Energy intensity of production; - Loss of energy resources; - Indicators of efficiency of energy consumption; - Reduced energy consumption.	kW/t; %; %; kW
5. Quality of sanitary protection and waste disposal	- Total technological waste of all processes; - Increasing the amount of recycled waste; - Organization of storage areas for flammable materials and hazardous materials.	kg; t Yes/No
6. Environmental protection	- Reduction of emissions; - Assessment of the risk of hazardous events and measures to mitigate risks.	MAC, (mg/m^3)
7. Best available technology	- Manufacturing Technology Safety	Non-contact control sensors; Scrubbers

Legislative acts of the Russian Federation establish maximum allowed concentrations of pollutants both in the air of the working area (production) and in the atmospheric air of urban and rural settlements. Observing the temperature regime of melting polystyrene with additives, homogenization and mixing of the melt with foam agents allows keeping the release of harmful substances within the maximum allowable concentration (MAC). Based on these norms, the numerical parameters for each indicator were determined (Tables 3 and 4).

At the second stage, environmental risks are identified at all stages of material production. To do this, the production process is simulated, and control operations and control parameters (CPi control points) are set.

At the third stage, environmental criteria are calculated. For the calculation, a scoring system for assessing indicators for each control operation (control point CPi) is used. At each control point, the actual values of the parameters are evaluated on a two-point scale (0 or 1). The formulas for calculating the criteria are presented below:

- The resource saving criterion is calculated by Equation 1:

$$R_T = R_{T1} \wedge R_{T2} \wedge R_{T3} \tag{1}$$

- The energy efficiency criterion is calculated by Equation 2:

$$E_e = E_{eT1} \wedge E_{eT2} \wedge E_{eT3} \wedge E_{eT4} \wedge E_{eT5} \tag{2}$$

- The production waste criterion is calculated by Equation 3:

$$W = W_{T1} \wedge W_{T3} \wedge W_{T3} \tag{3}$$

- Environmental criterion is calculated by Equation 4:

$$Env = Env_{T1} \wedge Env_{T2} \tag{4}$$

- The technology safety criterion is calculated by Equation 5:

$$S = S_{T1} \wedge S_{T2} \wedge S_{T3} \wedge S_{T4} \wedge S_{T5} \tag{5}$$

Calculation of a complex indicator of environmental friendliness of production T is done by Equation 6

$$T = [H \vee R_T \vee E_e \vee W \vee Env] \wedge S \tag{6}$$

where T is the value of the criterion for classifying production as environmentally friendly, equals to 0 or 1; H is the value of the assignment criterion, equal to 0 or 1; R_T is resource saving criterion value equal to 0 or 1; E_e is the value of the energy efficiency criterion, equal to 0 or 1; W is the value of the waste criterion, equal to 0 or 1; Env is the value of the environmental criterion, equal to 0 or 1; S is the value of the technology safety criterion, equal to 0 or 1; "∧" is conjunction operator (AND); and "∨" is the disjunction operator (OR).

At the final stage, a decision is made to confirm the production compliance with the environmental standards requirements and the possible issuance of a conformity certificate. If the T-complex criterion is equal to 1, then such products and production (technology) are classified as environmentally safe.

3. Results

The analysis object is a plant in the European part of the Russian Federation that produce building heat-insulating materials (XPS boards for insulating building facades). Environmental requirements were determined on the basis of international and Russian standards for environmental management systems. The requirements set includes technical and operational requirements for the finished products quality and environmental requirements for production processes (Table 5).

Table 5. Requirements for materials based on XPS

Mandatory requirements	Environmental requirements
1. Technical requirements 1.1. Thermal resistance and thermal conductivity	1. Environmental management
1.2. Length, width 1.3. Thickness	2. Resource saving
1.4. Fire-technical characteristics 1.5. Durability	3. Energy saving and energy efficiency
2. Operational requirements 2.1. Dimensional stability at temperature and humidity	4. Sanitary protection quality and waste disposal
2.2. Compressive deformation and temperature 2.3. Compressive strength	5. Environmental protection
2.4. Tensile strength 2.5. Compression set	6. Life safety technology
2.6. Water absorption, vapor permeability 2.7. Frost resistance 2.8. Release of harmful substances	7. Best available techniques and their safety

To identify environmental risks, a model of the process of obtaining materials from XPS is constructed. The production of extruded polystyrene foam (XPS) plates is a complex technological process [31-33]. The main stages of XPS materials production are presented in the form of a graphical model in Figure 3 [34, 35]. Environmental risks have been identified at all stages of the process of obtaining material, and a comprehensive system of product quality control and environmental risks in the process of obtaining XPS has been developed (Figure 3).

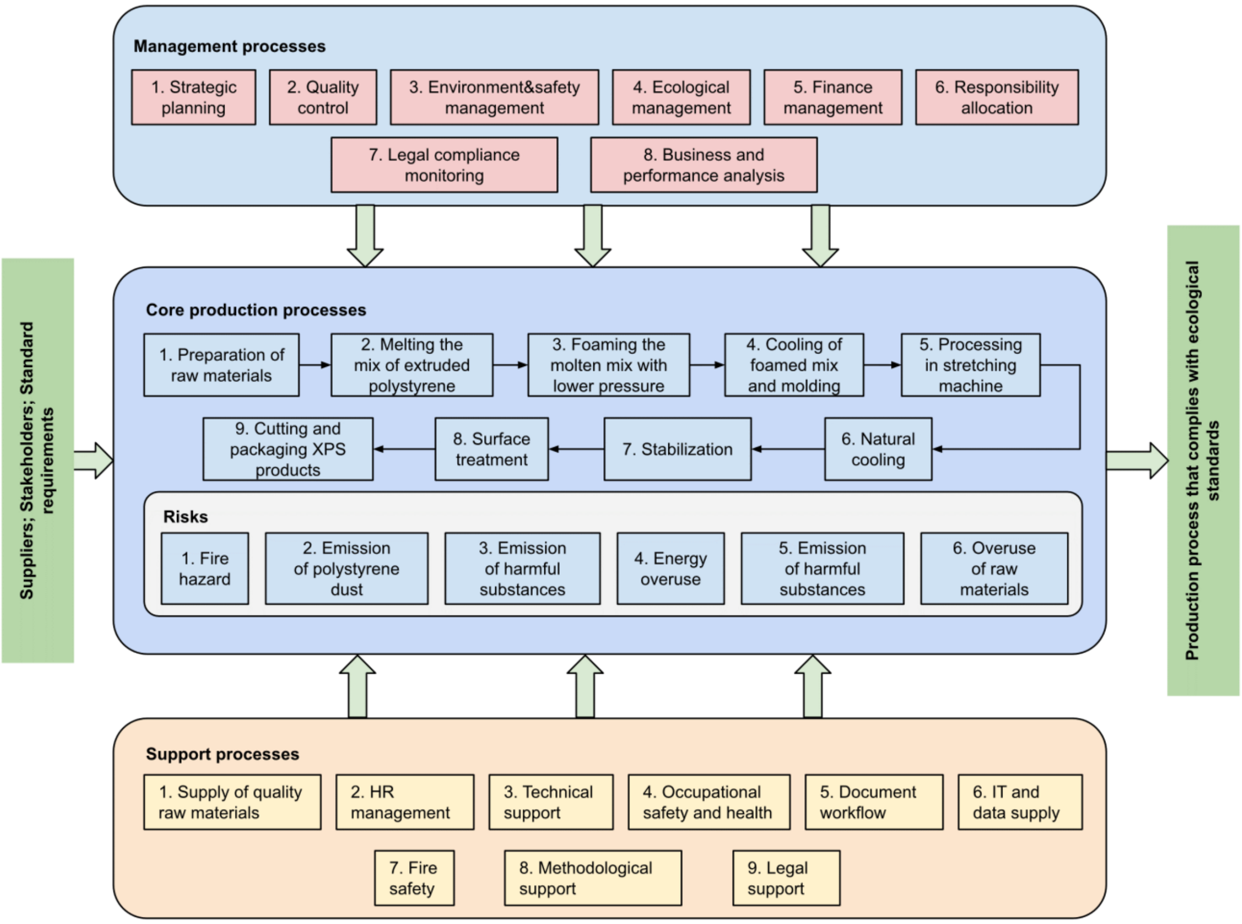

Figure 3. XPS manufacturing process model

The novelty is to improve the environmental management system and optimizing the control and management of environmental risks at all stages of the production cycle (hereinafter referred to as CPi control points). This ensures the environmental safety of finished products at all the life cycle stages. A new quality control system for the production of XPS materials with indication of control points CP_1 ... CP_{12} ("red stars") is shown in Figure 4.

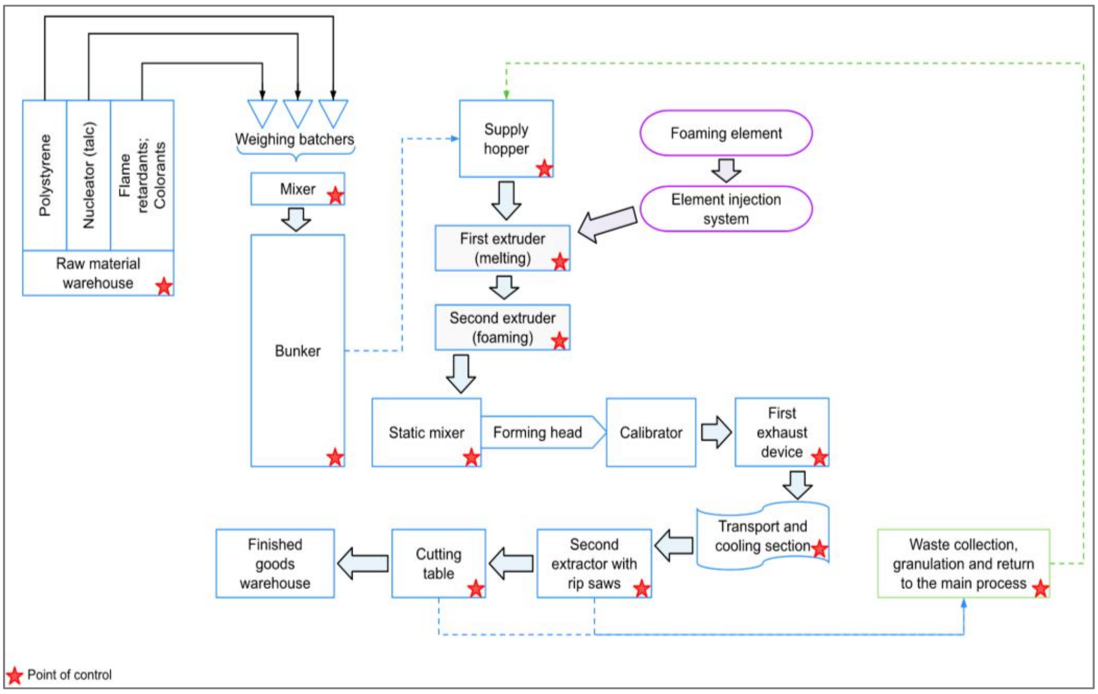

Figure 4. Quality control scheme: CP1 ... CP12 - environmental control operations (control points)

The developed control scheme (Figure 4) makes it possible to determine a set of indicators according to the criteria for assessing the environmental safety of production and products and to establish representative indicators. The significant influence on a possible spike of the pollutant's concentration can be exerted by such technological process parameters as the dosing accuracy of components and the temperature regime during polymer extrusion. To exclude the temperature excess and prevent the destruction of the polymer, in which hazardous substances are released [9, 10], it is necessary to control the humidity, mass, and volume of the polymer mass supplied for processing.

As granulated polystyrene is a combustible material particular attention should be given to the places of storage (warehousing) of raw materials. Polystyrene dust forms an explosive compound when interacting with air. Moreover, decomposition products of polystyrene, including styrene, are toxic. With an increase in maximum allowed concentration they can harm human health (irritation of the mucous membranes of the nose, eyes, larynx, dysfunction of the central nervous system, liver, spleen, bone marrow, lymphatic system, etc.) [36-38]. Further, according to Equations 1 to 6, the criteria for environmental safety of production of materials (products) from extruded foamed polystyrene at critical technological operations were calculated (red control points, Figure 4). The numerical values of the selected indicators are limited by the maximum permissible values that are established in the regulatory documents in force on the Russian Federation. An analysis of the results of calculating the criteria is presented in the next section (Table 6), where the control points are designated as CP1…CP12.

Table 6. Checkpoints for green technology in the production of XPS materials

Control Points	Environmental standard requirement	Controlled parameter and its value
CP #1 - Raw material warehouse CP #2 - Weighing batchers	Technology security Resource saving	Temperature regime, <= 25 °C Humidity in the warehouse, <75% Extraction of polystyrene dust, MAC = 5 (mg/m^3) Fire safety, Fire Safety Inspection Act
CP #3 - Bunker CP #4 – Supply hopper	Technology security Resource saving	Fire safety, Fire Safety Inspection Act Emission of dust and polystyrene fumes, MAC = 5 (mg/m^3) Emissions of pollutants, Permission to release harmful pollutants
CP #5 - First extruder CP #6 - Second extruder	Technology security	Melting temperature, 180-200 °C Foaming temperature, 90-100 °C Temperature during homogenization, 180-200 °C Emissions of pollutants: ethenylbenzene, MAC - 0.42 g / kg of products carbon oxide, 20 (mg/m^3); benzene, 5 (mg/m^3); formaldehyde, 0.5 (mg/m^3); benzaldehyde, 5 (mg/m^3); dibutyl phthalate, (mg/m^3); isopentane, 300 (mg/m^3); toluene, 50 (mg/m^3); ethylbenzene, 50 (mg/m^3); isopropylbenzene, (mg/m^3); carbon dioxide, 9000 (mg/m^3).
	Energy efficiency	Energy consumption and losses, kWh Reduced energy consumption, kWh (%)

CP #7 - Static mixer CP #8 - First exhaust device CP #10 - Second exhaust device	Technology security	Cooling temperature, 85-95 °C Emissions of pollutants, according to MAC Fire safety, Fire Safety Inspection Act
	Waste	Presence of residues in the mixer, none
CP #9 – Transport and cooling section	Energy efficiency	Energy consumption and losses, kWh Reduced energy consumption, kWh (%) Increasing the efficiency of energy infrastructure, implementation of energy efficient equipment
CP #11 - waste collection CP #12 - cutting table	Waste	Places for waste collection and storage, compliance with the rules of waste storage and disposal Waste management, technical report Waste collection, technical report
	Technology security	XPS Dust, MAC = 5 (mg/m^3); Fire safety, Fire Safety Inspection Act

The idea of the methodology for assessing the compliance of the production of extruded foamed polystyrene with the requirements of environmental standards can be described as follows. At the first stage, a model of the production process has been developed. As a result, the control points within the entire production cycle have been identified as well as environmental risks at each control point. It allowed to combine a comprehensive system to control and prevent the occurrence of environmental risks in the process of XPS production.

4. Discussions

The proposed method is an improved tool for assessing the production environmental safety. The results of the calculation of environmental safety criteria make it possible to create an effective environmental management system at the enterprise and optimal control at all the production cycle stages. The authors proposed to identify critical technological operations when receiving products (CP*i* control points), at which limit values of representative indicators are set.

One of the most critical problems today is the lack of practical tools for the implementation of the greening of production. The authors of the article proposed to identify vulnerable points of the technological process in the production of groups of homogeneous products. This will allow:

- To timely detect hazardous production areas;
- To strengthen the monitoring and control at all stages of the technological process;
- Reduce or eliminate the negative impact on the biosphere.

The model of the XPS production process based on a risk-based approach (Figure 3) and the identified control points (Figure 4) has allowed to develop a set of measures to ensure the environmental safety of XPS production. It is proposed to build 11 control points into the production cycle to ensure the compliance with the requirements of environmental standards (Table 4).

In the production process of manufacturing XPS materials, 12 critical operations were identified and, accordingly, 12 control points (CP1…CP12) were established to ensure environmental requirements (Table 6). Optimization of the production control system allows to reduce or eliminate the negative impact on the biosphere. To determine the *T*-criterion according to Equation 6, the criteria R_T, E_e, W, Env, S were previously calculated for all control points (Table 4), respectively, according to Equations 1 to 5.

The preliminary calculation of the environmental safety criteria R_T, E_e, W, Env, S according to Equations 1 to 5 revealed inconsistencies in a number of representative indicators at control points (CP1...CP12). And the complex criterion according to Equation 6 is not equal to 1. Further, measures have been developed to ensure the production of XPS materials meets environmental requirements in Table 7. Based on the identified control points, the measures to ensure that XPS production complies with the requirements of environmental standards have been developed.

Table 7. Measures to ensure the environmental safety of the products production with XPS

Control point (CP)	Conditions for ensuring environmental safety of production
CP #1	Fixed places of emission of harmful substances; The presence of exhaust ventilation; Temperature, humidity, dust control sensors; The presence of dust and gas filters; Systematic measurement of maximum allowed concentration; Systematic measurement of air passing volume; Compliance with fire safety.

CP #2	The presence of exhaust ventilation; Monitoring the operation of weighing equipment/dispensers; Systematic measurement of maximum allowed dust concentration; The presence of dust and gas filters.
CP #3	The presence of exhaust ventilation; Temperature and humidity control sensors, emergency sensors; Systematic measurement of air passing volume; Systematic measurement of maximum allowed concentration; Compliance with fire safety.
CP #4	The presence of exhaust ventilation.
CP #5 CP #6	The presence of exhaust ventilation; Main air ducts (leakage detection), air removal through exhaust ventilation systems; Temperature and humidity control sensors, emergency sensors; Systematic measurement of maxed allowed harmful pollutants concentration; Installation of a scrubber to clean the air from harmful pollutants, filtration, purification of used water.
CP #7 CP #8 CP #10	The presence of exhaust ventilation; Local suction system; Main air ducts (leakage detection), air removal through exhaust ventilation systems; Temperature and humidity control sensors, emergency sensors; Systematic measurement of maximum allowed harmful pollutants concentration.
CP #9	The presence of exhaust ventilation and emergency sensors.
CP #11 CP #12	The presence of exhaust ventilation; Local suction system; Main air ducts (leakage detection), air removal through exhaust ventilation systems; Aspiration equipment, bag cassette filters, bunkers, etc.; Emergency sensors; Systematic measurement of maximum allowed harmful pollutants concentration; Compliance with fire safety.

Table 7 data analysis allows to implement effective measures that guarantee the environmental safety of production and products. In real time conditions, it is necessary to introduce a scrubber cleaning system that allows removing particulate matter and other pollutants from the air up to 99.9% [39]. In the future, it will be necessary to create bunker-type production facilities. This will make it possible to exclude pollutants from emissions. Implementation of measures using the latest developments in scientific and technological progress will allow:

- To minimize the emission of harmful (polluting) substances;
- To implement the tasks of global environmental security;
- To plan creating bunker-type production facilities.

For the new production control model, the criteria R_T, E_e, W, Env, and S for critical operations (control points CP1-CP12, Tables 6 and 7) were calculated using Equations 1 to 5. The final calculation of the complex criterion T of environmental safety using Equation 6 showed the following results. Provided the measures into the technological process (Table 7) at operations CP1-CP12 (Table 6), the calculated value of the complex criterion T = 1. Therefore, the production of XPS material will meet environmental requirements, and the products will be environmentally safe.

5. Conclusions

The results made it possible to develop new approaches to assessing the conformity of building materials made from extruded expanded polystyrene (XPS). Well-known methods of XPS material certification evaluate the quality of physical and mechanical properties according to technical standards. This approach does not guarantee the environmental safety of the production process and does not meet the requirements of green building construction. The research methodology is based on the identification of environmental risks at all stages of production and the determination of criteria for the products' environmental friendliness. An integrated approach to assessing the quality of XPS material production is proposed. The methodology consists of calculating a complex criterion for the environmental safety of the XPS material production. This ensures the quality of the material and the environmental safety of the production process. Each criterion is characterized by the indicators set, among which a representative indicator is determined. The complex criterion calculating algorithm of environmental safety in the production of XPS materials is proposed. The process model analysis of extruded polystyrene foam production made it possible to establish representative indicators for environmental safety criteria. Critical operations have been identified, where environmental risks have been identified, and limit numerical values of representative indicators have been set in accordance with regulatory documentation. For each critical operation, measures have been developed to minimize the release of harmful substances. As a result, the model of the control system has been optimized for all critical production operations.

Measures have been developed to reduce environmental risks in the production of XPS materials. The calculation of environmental safety criteria for production confirms the effectiveness of the implementation of measures to reduce environmental risks. The methodology also made it possible to determine a rational way to modernize the production of environmentally friendly XPS materials. It is promising to create a bunker-type production that provides recycling of polymers and does not emit harmful substances into the environment. Cleaning systems in bunker production operate on the principle of cyclic cleaning and the return of resources to the production process without release into the biosphere. The improved methodology increases the objectivity of the environmental safety assessment of XPS material production when certifying the quality of construction products. In the future, it is necessary to continue the environmental safety research in a wider range of insulation building materials. This will expand the list of environmental safety criteria. This will contribute to the creation of a universal methodology for assessing the environmental safety of insulation materials of various compositions and properties.

To sum up the results and outcomes of the presented research, the following statements can be made:

- Based on the analysis of environmental standards, specific requirements for heat-insulating material production with extruded foamed polystyrene have been identified.
- Based on a risk-based approach, a process model for extruded polystyrene foam production has been developed, and the main environmental risks have been identified.
- A methodology for assessing the compliance of XPS production with environmental requirements based on the identification of control points has been proposed. Control parameters have been set for each control point. It allows for the control and prevention of the release of harmful substances at all stages of the process, including the partial degradation of the polymer.
- For each identified control point, measures have been developed, and their implementation ensures that XPS production meets the requirements of environmental standards.
- The prospects for the modernization of XPS production based on the creation of bunker-type production facilities that do not emit harmful substances into the environment have been determined. Suggested cleaning systems in bunker production should operate on the principle of cyclic cleaning and the return of resources to the production process without release into the biosphere.

6. Declarations

6.1. Author Contributions

Conceptualization, L.L., and T.S.; methodology, L.L.; validation, T.S., L.K., and L.N.; formal analysis, D.K. and E.B.; resources, L.N. and E.B.; data curation, T.S.; writing—original draft preparation, L.L.; writing—review and editing, L.N. and D.K.; visualization, L.L.; supervision, L.K.; project administration, L.N. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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