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Organizational and technological solutions for installing polymer membrane roofs in subzero temperature conditions

In conditions of sharp cold spells, typical for Arctic and similar regions, the installation of roofing requires the use of special materials and technologies capable of maintaining their operational properties at sub-zero temperatures. This paper examines organizational and technological solutions related to the use of polymer membrane roofing systems, including PVC (polyvinyl chloride), TPO (thermoplastic polyolefin), and EPDM (ethylene propylene diene monomer) membranes. A comprehensive analysis is provided of the physical and mechanical properties of these materials, with emphasis on their frost resistance, elasticity, long-term watertightness, and durability under mechanical stress. Special attention is paid to the practical aspects of installation during the winter season, including weld temperature ranges, base surface preparation, storage and transportation conditions, and measures for ensuring installation quality under strong winds, precipitation, and limited daylight hours. The article identifies key challenges encountered during cold-climate roofing operations, such as reduced seam strength due to temperature deviations, increased defect rates from poorly prepared substrates, logistical complexities, and labor shortages. Technological procedures and process maps are presented that help mitigate these risks, including preheating methods, use of protective coverings, precise control of welding equipment settings, and targeted worker training. The article emphasizes the importance of an integrated approach to project design, logistics, and work organization to ensure the high reliability and long-term performance of polymer roofing membranes in freezing climates. The study concludes with a rationale for optimal solutions that align material properties with construction process requirements.

Keywords: *polymer membranes, PVC, TPO, EPDM, cold climate, roofing technology, seam sealing, mechanical fastening, hot-air welding*

Under the sharply continental climate of Siberia, characterized by prolonged frost periods, significant temperature fluctuations, and intense wind loads, the installation and operation of polymer roofing membranes require a reassessment of both design solutions and organizational and technological approaches. When calculating structural joints, it is necessary to consider substantial temperature variations ranging from $-40\text{ }^{\circ}\text{C}$ in winter to $+30\text{ }^{\circ}\text{C}$ in summer, which cause thermal expansion and contraction of the membrane, leading to stress concentrations at fastening points and welded seams [1]. An analysis of damage observed at specific facilities in Novosibirsk, Tomsk, and Krasnoyarsk indicates that the most vulnerable zones remain junctions with parapets, pipes, and expansion joints, where violations of seam welding technology or inadequate sealing layers result in delamination, cracking, and detachment of the membrane. Roofing installation technology under cold-weather conditions requires strict control of temperature regimes during storage, transportation, and installation of roll materials: at temperatures below $-15\text{ }^{\circ}\text{C}$, flexibility deteriorates, brittleness increases, and tensile strength decreases. Construction practice shows that improper adaptation of technology to weather conditions leads to loss of membrane watertightness already within the first years of operation. All of this forms the task of developing adaptive roofing installation technologies that include temperature-independent materials, modified seam welding methods, and a technical quality control system adapted to the conditions of Siberia and the Far North.

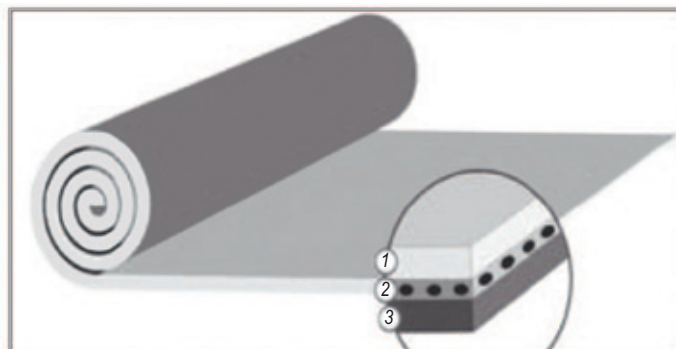
Polymer membrane roofing systems, especially those based on ethylene-propylene-diene rubber (EPDM), thermoplastic polyolefins (TPO), and polyvinyl chloride (PVC), are distinguished by a combination of high strength, durability, and installation efficiency [2]. EPDM membranes, manufactured as roll materials with a thickness ranging from 1.1 to 1.5 mm, demonstrate resistance to ultraviolet radiation and ozone, withstand temperature fluctuations from -40 to $+120\text{ }^{\circ}\text{C}$, and have a service life reaching 30–35 years. TPO membranes are characterized by high reflectivity, which reduces thermal loads on the roof, and exhibit excellent resistance to ultraviolet aging [3, 4]. Standardized tests confirm welded seam strength of up to 500 N/50 mm. Installation of such roofing systems is possible at negative temperatures (down to $-10\text{ }^{\circ}\text{C}$) using hot-air welding and special freeze-resistant sealants [5]. Modern polymer membranes have a mass of 1.2–1.5 kg/m², which reduces loads on load-bearing structures and simplifies installation. In addition to high installation rates (up to 600 m² per shift), these roofing systems demonstrate a low water absorption coefficient (less than 0.1 %), resistance to chemical substances, and resistance to biological degradation. In practice, this leads to reduced operating costs and an extended maintenance interval. Comprehensive studies confirm that the use of membrane systems makes it possible to achieve energy efficiency, minimize heat losses, and adapt roofing structures to severe climatic conditions. Laboratory aging data for PVC membranes also indicate [6] that at a temperature of $-20\text{ }^{\circ}\text{C}$, after 100 cooling-heating cycles, up to 12 % of welded joint strength

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1 — reinforcing mesh; 2 — lower PVC component; 3 — upper PVC component

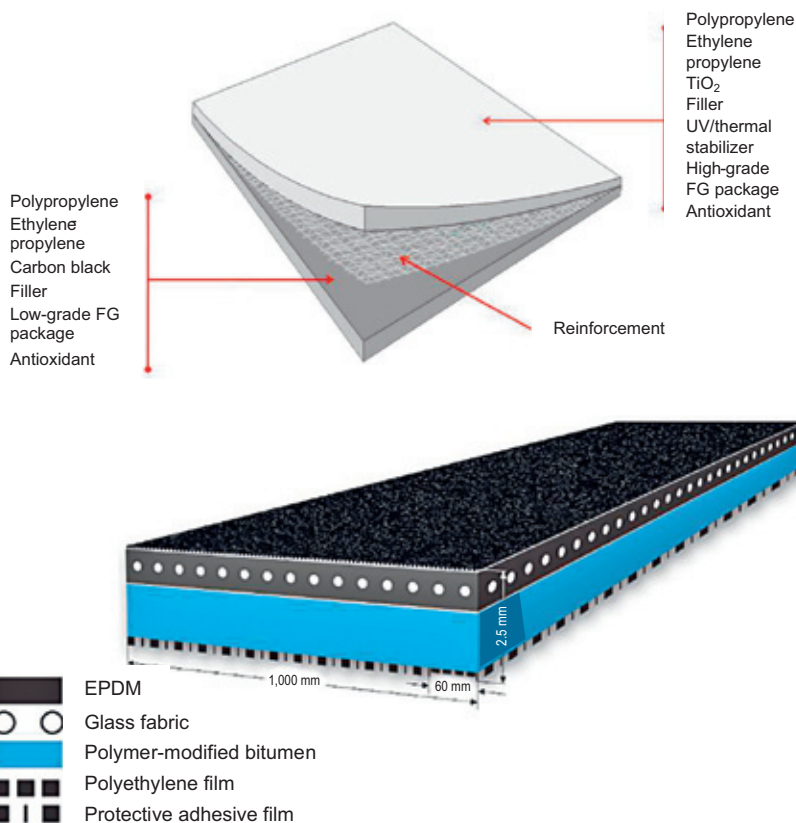


Fig. 1. Compositions of the main types of polymer membranes: PVC, TPO, EPDM [2–6]

is lost, and visual inspection reveals initial signs of microcracking at junction areas. The tests also showed that membranes based on thermoplastic polyolefins exhibit better shape stability at negative temperatures, whereas reinforced PVC membranes retain higher tensile strength (Fig. 1).

Problems arising during the installation and operation of roll and polymer roofing systems reflect systemic deficiencies at all stages, from design to quality control. The study establishes that up to 60 % of roll roofing systems in operation in Russia are in unsatisfactory condition, while more than 40 % of defects are caused by loss of watertightness and leaks [7]. The greatest difficulties occur in regions with negative temperatures: moisture penetrating into the structure freezes, increases in volume, and disrupts the integrity of the roofing system. In winter conditions of the Far North, frozen thermal insulation loses its thermal performance, and the roofing

system is subjected to microcracking due to thermal contraction. With the onset of the warm period, a vapor pressure effect develops; it has been recorded that when moist insulation is heated, the partial pressure can reach $0.2 \cdot 10^5$ Pa, which provokes blistering and delamination of roll materials. The key technological violations identified include installation of membranes on a wet substrate, improper detailing of junctions, non-compliance with the required thickness of the roofing assembly, incorrect temperature conditions during mastic application, and the absence of basic quality control measures. An additional risk factor is the low qualification level of contractors: roofing crews often lack the skills to work with modern PVC or TPO membranes, fail to ensure proper seam welding, and perform installation at inadmissible temperatures below -10 °C. A significant issue is also associated with the regulatory framework, as technical regulations have not been updated for decades and do not contain

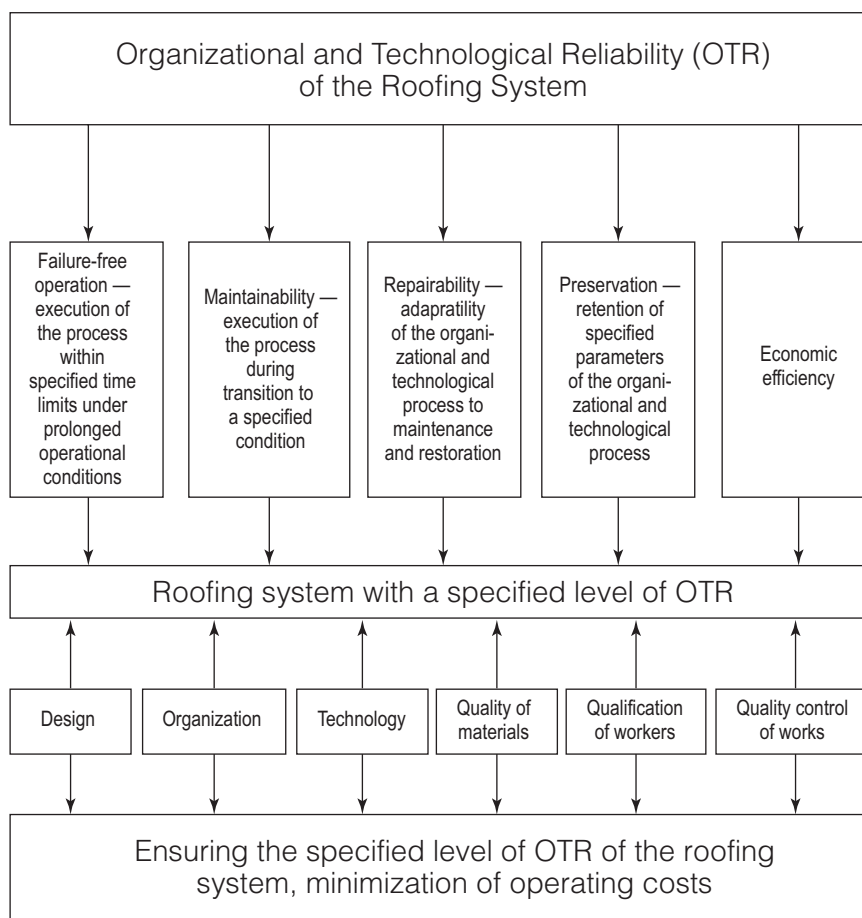


Fig. 2. Organizational and technological reliability of the roofing system [7]

requirements for the use of innovative roofing materials. As a result, contractors rely on internal guidelines provided by suppliers, which do not always account for the actual operating conditions in cold climate regions [8].

Polymer membrane roofing systems are increasingly used in construction due to their high technological efficiency, durability, and resistance to aggressive climatic impacts (Fig. 2). In cold regions, particular value is placed on the ability of PVC membranes to retain their physical and mechanical properties at low temperatures. The material thickness typically ranges from 1.2 to 2 mm, while the mass does not exceed 1.5 kg/m², which simplifies transportation and installation [9]. The membranes are reinforced with fiberglass, which increases their tensile strength. When installing roofing systems in northern regions, three main methods of membrane fastening are used: mechanical, adhesive, and ballasted. The mechanical method is considered the most versatile, as it can be applied at subzero temperatures and does not require the use of expensive adhesive compounds, the operation of which is limited to temperatures above +5 °C. In addition, membrane welding performed using automatic and semi-automatic equipment employs hot air at temperatures of up to 600 °C, making it possible to achieve a strong welded joint with a width of at least 35 mm without the risk of loss of watertightness.

Experience in the use of polymer membranes for flat roofs of residential buildings demonstrates high efficiency both in new construction and in reconstruction projects (Table 1). Membrane roofing systems form a continuous waterproof layer with high frost

resistance, maintaining elasticity even at temperatures below –30 °C [10]. Depending on the structural characteristics of buildings and operational requirements, an inverted roofing system may be used, in which the waterproofing layer is protected by thermal insulation. This approach is especially important in severe climatic zones, where the membrane is additionally covered by insulation layers and a finishing surface (tiles, gravel), reducing the risk of mechanical damage. At the same time, ensuring the required reliability necessitates compliance with a minimum roof slope of 1 to 3 % to drain atmospheric precipitation, which is particularly critical under conditions of heavy snowfall. Design calculations assume that during intense precipitation up to 5 l of water per minute may fall on 1 m² of roof surface, which for an area of 500 m² corresponds to a load of 2.5 tons of water requiring efficient drainage through roof drains and stormwater systems. Under these conditions, the membrane must withstand repeated freeze-thaw cycles and exposure to ultraviolet radiation, which is achieved through the use of stabilizers and reinforcing layers.

A comparative analysis of roofing installation options shows that under climatic conditions with sharp temperature fluctuations, the highest efficiency is demonstrated by membrane systems installed using a mechanical fastening scheme with telescopic fasteners and automated welding [11]. Particular attention is paid to quality control of welded joints, including seam width, tightness, and the absence of overheated zones or lack of fusion, which are verified visually and by instrumental methods. Personnel training is also critically important: technological violations such as dragging

Table 1. Characteristics and technological requirements for the installation of polymer membrane roofing systems

| Characteristic | Description |
|---------------------------------------|---|
| Flexibility and elasticity | Membranes exhibit pronounced flexibility, allowing them to compensate for temperature fluctuations and maintain the continuity of the roofing layer under deformation |
| Resistance to ultraviolet radiation | Special additives in the membrane composition prevent degradation caused by solar radiation, thereby extending the service life of the roofing system |
| Durability | When all installation requirements are met, the service life of membranes can range from 25 to 30 years; however, violations of installation technology significantly reduce this indicator |
| Substrate preparation | The base surface must be clean, even, and free from sharp inclusions, as any defects may cause membrane damage and accelerated wear |
| Mechanical fastening | Installation of membranes using anchors or self-tapping fasteners compensates for thermal movements and is well suited for pitched roofing systems |
| Adhesive method | The use of adhesive mastics allows sealing of complex areas but requires strict compliance with temperature conditions and thorough preparation of the substrate |
| Ballasted method | Loose laying of the membrane followed by ballast loading using gravel or paving slabs is suitable for roofs with slopes up to 10°, but it creates additional structural load |
| Hot-air welding | Membrane sheets are joined using hot air, either manually or automatically. Welding parameters are selected individually depending on membrane type and weather conditions. Quality control includes visual inspection and strength testing |
| Consideration of climatic conditions | For severe winter conditions, frost-resistant materials are used, with particular attention paid to the strength of welded seams and reliability of fastenings under wind and snow loads |
| Compliance with safety requirements | When performing work involving hot air or adhesives, proper ventilation, use of personal protective equipment, and strict adherence to recommended temperature regimes are required |
| Importance of weld seam quality | Deviations in temperature parameters or improper welding speed may lead to incomplete fusion, overheating, or weakening of the joint, making the seam vulnerable to damage |
| Installation at negative temperatures | Laying membranes without preheating at temperatures ≤ 0 °C leads to loss of elasticity and crack formation. It is recommended to preheat the material to a temperature not lower than -10 °C prior to installation |

membrane rolls across the surface, failure to clean edges before welding, or installation of engineering systems without compliance with insulation requirements may lead to leaks and a reduction in the service life of the roofing system. To prevent these issues, the use of regulated quality control procedures is recommended, including seam probes, as well as maintaining a log of acceptance of concealed works. When these requirements are met, the service life of membrane roofs in cold climates can reach 40–50 years without the need for major repairs, provided timely maintenance and proper operation are ensured.

In the conditions of the Far North, the installation of polymer membrane roofing systems requires special organizational and technological solutions that take into account both low temperatures and high wind loads. Within one technical solution, a flat non-accessible roof system using a bitumen-polymer membrane with a thickness of 1.5 mm was analyzed¹. Thermal insulation consisted of two layers of mineral wool boards with densities of 160 and 80 kg/m³, respectively, providing a heat transfer coefficient of less than 0.16 W/m²·°C. A vapor barrier layer based on bitumen-polymer mastic was applied with heating, which allowed adhesion to be maintained at temperatures down to -15 °C. Installation was carried out mechanically using telescopic dowels, while seam welding was performed by automated hot-air equipment at a controlled temperature of 500–600 °C, forming a strong welded seam with a width of 35 mm. Work organization followed the “thermal contour”

¹ Technological Map for a Flat Roofing System on a Profiled Base with Mineral Insulation and PVC Membrane. URL: https://nav.tn.ru/cloud/iblock/343/RF_S_PK_TN_TEKHKARTA_Tekhnologicheskaya_karta_na_dvukhsloynnyu_krovlyu_iz_naplavyalemykh_iz_RBM.pdf

principle: installation of insulation and membrane was performed in sections not exceeding 100 m² per day, with immediate completion of all layers to prevent precipitation ingress and freezing. It was noted that when these technological parameters are observed, the system maintains tightness and thermal performance even under winter operating conditions with temperatures down to -35 °C and wind loads up to 1.2 kPa. Special attention was given to personnel training: welders underwent preliminary certification, and quality control was carried out using vacuum testing devices and visual inspection of welded seams.

In another roofing installation technology based on PVC membranes (Fig. 3) adapted to low-temperature conditions, the process included rolling out the sheets, mechanical fastening along the perimeter and overlap zones, and hot-air welding using automated equipment². The optimal welding temperature was 520–560 °C, with a feed speed of 2.5–3.5 m/min, resulting in a seam width of 35–40 mm. It was noted that to achieve effective seams under sub-zero temperatures, installation must be performed with preheating of the joint area and preliminary drying of the substrate. In particular, at a temperature of -10 °C, the heating time must be increased, and welding must be accompanied by mandatory seam density control using air pressure testing or manual peel testing. The importance of adapting work schedules to climatic conditions was also emphasized: shift duration is limited to 4–5 hours, with mandatory breaks for technical inspection of equipment and worker warming. To improve organizational and technological reliability, the use of

² Technological Map for the Installation of Roofing Systems with Polymeric Membranes and Mechanical Fastening on a Reinforced Concrete Base. URL: <https://isoroc.ru/sites/default/files/2024-02/>

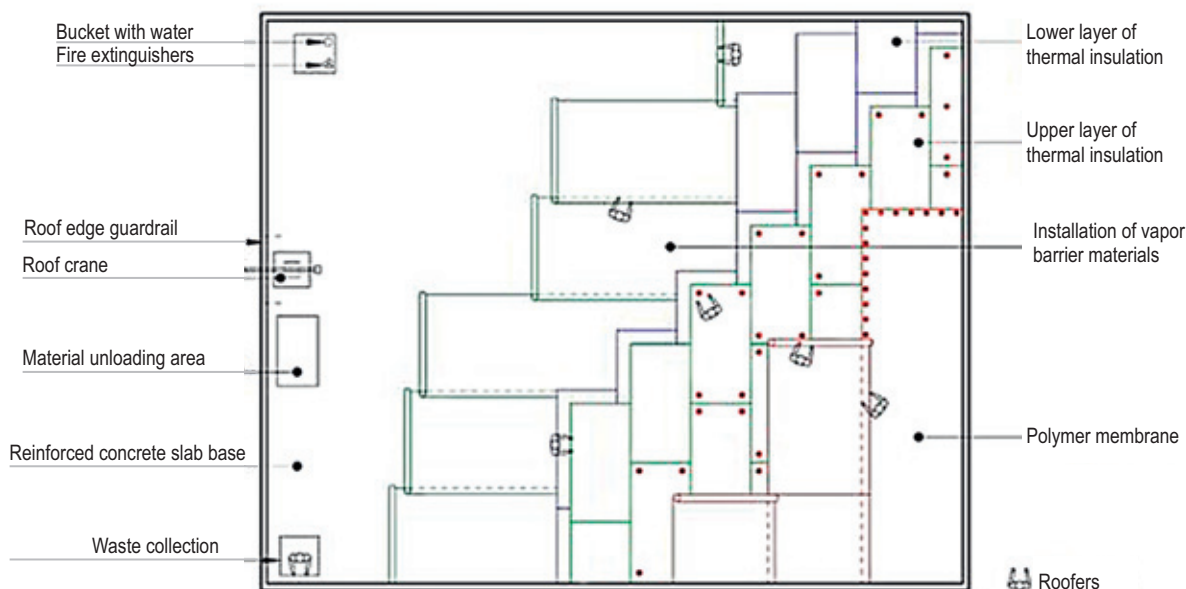


Fig. 3. Layout of workplace organization during the installation of PVC membrane roofing

mobile thermal shelters and temporary heated enclosures at the joints of installation sections was proposed, allowing stable temperature conditions to be maintained and preventing uneven quality of welded joints.

In the considered roofing installation technology using a polymer EPDM membrane, particular attention is paid to ensuring high-quality installation under subzero temperature conditions³. In harsh climatic environments, especially at temperatures below -10°C , one of the key solutions is the use of membranes with internal reinforcement made of a polyester mesh, which provides high resistance to tensile loads up to $850\text{ N}/50\text{ mm}$. Installation is carried out over mineral wool insulation with a low thermal conductivity coefficient ($\lambda \leq 0.038\text{ W}/\text{m}\cdot\text{K}$), which makes it possible to reduce heat losses through the roofing assembly. The membrane is fixed mechanically using telescopic fasteners with a spacing of no more than 200 mm along the perimeter and 300 mm in the field area, which is particularly critical under wind loads typical of northern regions. Seams are welded with hot air at a temperature of $500\text{--}600^{\circ}\text{C}$, with mandatory quality control of the welded joint performed visually (uniform dark line) and using a test probe. At the work organization stage, strict temperature regulation is an essential requirement: membrane rolls must be stored in a heated space for at least 12 hours at a temperature not lower than $+10^{\circ}\text{C}$ before installation, and welding is carried out with adjustments based on a temperature chart that defines welding parameters depending on ambient temperature. In addition, a multi-stage quality control system is implemented, including verification of substrate preparation, weather conditions, welding quality, and compliance with fastening technology. The application of this technology significantly reduces the risk of installation defects and extends the service life of the roofing system to up to 30 years, even under extreme climatic conditions.

Under subzero temperature conditions, reliable installation of roofing systems using polymer membranes requires a special approach to organizational and technological solutions (Table 2). One such solution is the application of mechanically fastened TPO

membranes followed by hot-air welding of seams⁴. To ensure coating strength at low temperatures down to -25°C , the use of equipment with automatic control of temperature, feed speed, and welding pressure becomes a critical requirement, as it prevents the formation of defective seams. The document indicates that the optimal welding temperature range is from $+480$ to $+540^{\circ}\text{C}$ at a speed of $2.5\text{--}3.5\text{ m}/\text{min}$. Installation is carried out using a sectional laying technique, where membranes are rolled out and temporarily fixed, after which seams with a width of $30\text{--}35\text{ mm}$ is welded. To ensure roof tightness under Far North conditions, the mandatory use of a vapor barrier layer (for example, bitumen-impregnated fiberglass mat) and thermal insulation with a thermal conductivity coefficient not exceeding $0.033\text{ W}/(\text{m}\cdot^{\circ}\text{C})$, arranged in two layers, is required. The membrane is fastened to the base through all layers of the roofing assembly using telescopic fasteners installed at a spacing of no more than 300 mm along the perimeter and 500 mm in the central zone of the membrane sheet. Special attention is given to sealing junctions, corners, and roof drains, where an additional reinforced tape is used and welded along the perimeter of the connections. Quality control is performed using peel tests and visual inspection of welded seams. The necessity of strict compliance with temperature requirements for storage and transportation of materials (not lower than $+5^{\circ}\text{C}$) is emphasized, as well as mandatory preheating of membrane rolls in an insulated module prior to installation.

The reviewed materials and technologies for installing polymer membrane roofing systems have shown that their performance under subzero temperature conditions is largely determined not only by the properties of the materials themselves, but also by well-structured organizational and technological solutions. Successful application is possible only through an integrated approach that includes adaptation of installation technologies to climatic conditions, strict quality control of works, preliminary preparation of substrates, and compliance with temperature regimes at all stages. The identified problems, including a shortage of qualified personnel and an underdeveloped regulatory framework, limit the possibilities

³ Installation Manual for EPDM Membrane. URL: <https://construction-engineer.ru/wp-content/uploads/2021/07/Инструкция-по-монтажу-ЭПДМ-EPDM-мембраны.pdf>

⁴ Installation Instructions for TPO Roll Waterproofing Membranes from Sika. URL: <https://construction-engineer.ru/wp-content/uploads/2021/03/Инструкция-по-укладке-рулонной-гидроизоляции-из-ТПО-мембран-от-компании-Sika.pdf>

Table 2. Composition of operations and control procedures for polymer membrane roofing systems

| Work Stage | Requirements for Parameters | Method and Scope of Inspection | Controlled Indicators |
|---|---|---|--|
| Inspection of welding equipment before work start | Equipment must be technically sound and ensure stable welding temperature and speed | Visual inspection and functional check of the equipment prior to commencement of work | Equipment operability, heating stability |
| Visual inspection of the welded seam | The seam must be even, without pores, swelling, folds, burn-throughs, or delamination | After completion of welding, a visual inspection of the seam condition is carried out | Integrity and external appearance of the welded joint |
| Manual non-destructive seam test | After complete cooling, the seam must not delaminate; in case of rupture, the material should tear outside the seam | The seam is manually gripped and sharply stretched to assess adhesion strength | Uniformity of the joint, absence of delamination |
| Tensile strength test | The rupture location must occur in the base membrane, not along the seam line | The seam is torn manually or using tools, and joint strength is recorded | Strength and reliability of the welded seam |
| Control of the applied weld bead | The deposited material bead must have uniform thickness without excess or deficiency | During welding, visual inspection of bead shape and uniformity is performed | Uniformity and correct geometry of the deposited layer |
| Airtightness check of the welded seam | The seam must be completely airtight, preventing air penetration | Pressurized air is supplied into the welding channel using a compressor, followed by pressure testing | Airtightness of the seam |
| Vacuum leak test | No air leaks should be detected in the seam | A foaming solution is applied, and a vacuum bell is used to detect defects by bubble formation | Presence or absence of leaks in the welded joint |

for widespread and reliable use of modern membrane roofing systems in northern regions. At the same time, the potential of such systems remains high, and further research and development should focus on improving installation technologies, quality control tools, and methods for adapting roofing solutions to extreme climatic conditions.

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Организационно-технологические решения по устройству кровель из полимерных мембран в условиях отрицательных температур

В условиях резкого похолодания, характерного для арктических и приравненных к ним регионов, устройство кровельных покрытий требует применения особых материалов и технологий, способных сохранять эксплуатационные свойства при отрицательных температурах. В статье рассматриваются организационно-технологические решения, связанные с применением полимерных мембранных кровель, включая системы на основе ПВХ (поливинилхлорид), ТПО (термопластичные олефины) и ЭПДМ (этилен-пропилендиен-мономер). Проведен всесторонний анализ свойств и

характеристик этих материалов, с акцентом на их устойчивость к морозам, эластичность, способность сохранять герметичность и стойкость к механическим нагрузкам. Особое внимание уделено практическим аспектам монтажа кровельных систем в зимний период, включая температурные режимы сварки швов, особенности подготовки основания, допустимые условия транспортировки и хранения, а также мероприятия по обеспечению стабильности укладки в условиях сильного ветра, осадков и ограниченной световой активности. Также выделены ключевые проблемы, возникающие при реализации подобных работ: снижение прочности соединений при нарушении температурного режима, рост числа дефектов из-за некачественной подготовки основания, трудности в логистике и нехватка квалифицированных кадров. В статье представлены технологические карты и приемы, позволяющие минимизировать риски в процессе

монтажа, включая использование предварительного прогрева, применение тентов и временных укрытий, контроль над параметрами сварочного оборудования и обучение персонала. Подчеркивается необходимость комплексного подхода к проектированию, логистике и организации производства работ, направленного на обеспечение высокой надежности и долговечности полимерных кровель в условиях отрицательных температур. В результате обоснованы оптимальные решения, сочетающие свойства материалов и требования к технологии монтажа.

Ключевые слова: полимерные мембраны, ПВХ, ТПО, ЭПДМ, холодный климат, кровельные технологии, герметизация швов, механическое крепление, сварка горячим воздухом

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