TECHNOSPHERE SAFETY
ТЕХНОСФЕРНАЯ БЕЗОПАСНОСТЬ

UDC 504.3.054
https://doi.org/10.23947/2541-9129-2025-9-2-136-145
Original Empirical Research

Green Roofs in Infill Development to Improve the Environmental Safety of Urban Areas

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Abstract

Introduction. When designing construction projects in urban areas, it is essential to protect the environment from dust pollution. This is particularly challenging in densely populated areas where the construction site is often surrounded by existing buildings and infrastructure. Successful implementation of such projects requires a thorough analysis of many factors, including weather conditions, environmental risks, and limited space for maneuvering. A crucial aspect of this process is the development of measures to control dust emissions during construction. Therefore, technological innovations in the field of eco-friendly roofing systems are becoming a key element of modern urban planning. As scientific research in recent years has shown, eco-friendly structures contribute to the rational use of urban space and significantly improve the environment. However, the results of these studies lack data on the effectiveness of green roof structures and vegetation on them in reducing dust pollution in residential areas. They are adjacent to already populated objects and the lack of space makes it impossible to completely protect urban residents from dust exposure. The aim of this work is to evaluate the effectiveness of green roofs to control the spread of dust in areas with active infill development and to develop our own green roof designs. The introduction of green roofs into residential construction not only improves the architectural appearance of neighborhoods, but also enhances the quality of the urban environment. The use of eco-friendly solutions in construction contributes to the modernization of the industry, making it safer for the environment and more comfortable for residents.

Materials and Methods. An environmental experiment was conducted as part of the large-scale construction of the Krasny Aksai residential complex in Rostov-on-Don. In March 2020, in the construction area and outside the site, employees of the contractor planted herbaceous plants of six species typical of the Rostov region. Each plant species occupied an area of six square meters, creating a total experimental area of 36 square meters. The methodology for determining the volume of dust deposits trapped by plants included sampling dust particles from the surface of plant leaves with a brush, which was performed twice a week from May to October 2020, during the active construction of a multi-storey residential building. Air samples were taken to measure dust concentrations using an electric aspirator PU-3E/12 and filters made from perchlorvinyl fiber AFA-VP10.

Results. The research showed that during the construction period with an easterly wind of 3–5 meters per second and humidity of 40%, the planted vegetation had a significant impact on air quality. There was a decrease in the concentration of PM10 dust particles above the green area by 10%, and at a distance of 10 meters from the vegetation cover, compared to the adjacent construction area, by 15%. Measurements of dust deposits over the growing season (May–October) revealed a significant dynamics: if at the beginning of the season (May–June) the amount of dust deposits on plants was a maximum of 0.42 mg/cm^2, then in the midst of the warm season (July–October) it reached 1.81 mg/cm^2. Financial calculations showed that traditional and green roofs were equally cost-effective over the long term (up to 40 years). To achieve this research goal, the authors have developed and implemented two types of constructive solutions for green roofs for public and residential buildings.

Discussion and Conclusion. Green roof structures can act as an effective barrier against the spread of dust in the air, especially in areas near infill development where there is a high concentration of suspended solids. To reduce this concentration in residential areas near infill development, it is recommended to install green roofs on terraces, rooftops, and substructures of buildings with windows and entrances located near the construction site. In order to curb the spread of suspended particles, it is also suggested that green roof installation be considered for low-rise buildings such as kindergartens, schools, and shopping malls. The decision on where to install these structures should depend on the overall urban development plan for the area or specific territory.

Keywords: green roofs, dust distribution, environmental safety of urban areas, fine dust, dust pollution

For Citation. Manzhilevskaya SE, Evtushenko AI, Mailyan DR. Green Roofs in Infill Development to Improve the Environmental Safety of Urban Areas. *Safety of Technogenic and Natural Systems.* 2025;9(2):136–145. https://doi.org/10.23947/2541-9129-2025-9-2-136-145

Оригинальное эмпирическое исследование

Применение зеленых крыш в точечном строительстве для повышения экологической безопасности городских территорий

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Аннотация

Введение. При проектировании строительных работ в условиях городской застройки важнейшим аспектом является защита окружающей среды от пылевого загрязнения. Особую сложность представляет организация работ в густонаселенных районах, где строительная площадка бывает зажата существующими зданиями и инфраструктурой. Успешная реализация подобных проектов требует тщательного анализа множества факторов: погодных условий, экологических рисков и ограниченного пространства для маневра. Принципиальное значение имеет разработка комплекса мер по контролю пылевых выбросов, возникающих в ходе строительных операций. Поэтому технологические инновации в области экологичных кровельных систем становятся ключевым элементом современного градостроительства. Как показывают научные изыскания последних лет, экологичные конструкции способствуют рациональному использованию городского пространства и заметно улучшают состояние окружающей среды, но при этом в результатах таких исследований отсутствуют данные, которые бы подтверждали, что конструкции зеленой кровли и растительный покров на них эффективны для снижения пылевого загрязнения в условиях точечной застройки, где источники пылевого загрязнения — строительные площадки — соседствуют с уже заселенными объектами и стесненность пространства не дает возможности полностью оградить жителей городов от пылевого воздействия. Цель данной работы — дать оценку эффективности использования зеленых крыш для борьбы с распространением пыли в районах активного точечного строительства, а также разработать собственные конструкции зеленой кровли. Внедрение зеленых крыш в точечное строительство не только преображает архитектурный облик городских кварталов, но и существенно улучшает качество городской среды. Применение подобных экологичных решений способствует общей модернизации строительной отрасли, делает её более безопасной для окружающей среды и комфортной для жителей.

Материалы и методы. В рамках масштабного строительства жилого комплекса «Красный Аксай» в Ростове-на-Дону был проведен экологический эксперимент. В зоне ведения строительных работ и за пределами ограждающих конструкций строительной площадки в марте 2020 года сотрудники подрядной организации высадили травянистые растения шести разновидностей, типичные для Ростовской области. Каждый вид растений занимал площадь в шесть квадратных метров, формируя общую экспериментальную зону в 36 квадратных метров. Методология определения объема пылевых отложений, улавливаемых растениями, включала в себя отбор при помощи кисти проб пылевых частицы с поверхности листьев растений, который производился два раза в неделю с мая по октябрь 2020 года, в период активного строительства многоэтажного дома точечной застройки. Отбор проб воздуха для определения концентрации в нем пыли производился с использованием электрического аспиратора ПУ-3Е/12 и фильтров из перхлорвиниловых волокон АФА-ВП10.

Результаты исследования. Исследования показали, что в условиях преобладающего восточного ветра (3–5 м/с) и влажности в 40 % в период производства строительных работ высаженная растительность значительно влияла на качество воздуха. Над озелененной зоной наблюдалось снижение концентрации пылевых частиц PM10 на 10 %, на расстоянии 10 метров от растительного покрова, по сравнению с прилегающей строительной зоной, — на 15 %. Замеры количества пылевого осадка в вегетационный период (май–октябрь) выявили существенную динамику: если в начале сезона (май–июнь) количество пылевых отложений на растениях составляло максимум 0,42 мг/см², то в разгар теплого сезона (июль–октябрь) оно достигало 1,81 мг/см². Финансовые расчеты показали, что при долгосрочной эксплуатации (до 40 лет) традиционные и озелененные крыши имеют одинаковую стоимость. Для достижения поставленной цели исследования авторами были разработаны и применены на практике два типа конструктивных решений зеленой кровли для общественных и жилых зданий.

Обсуждение и заключение. Конструкции зеленой кровли могут служить эффективной преградой для распространения пыли в воздушной среде, что особенно актуально для районов, расположенных вблизи точечных застроек, где отмечается значительная концентрация взвешенных веществ в воздухе. Для снижения концентрации взвешенных веществ в жилой зоне рядом с точечной застройкой монтаж конструкций зеленой кровли необходимо осуществлять на террасах, крышах, стилобатной части зданий, где окна и входные группы расположены рядом со строительной площадкой. В целях сдерживания распространения взвешенных частиц монтаж зеленой кровли должен быть осуществлен на малоэтажных зданиях, например, детских садах, школах, торговых павильонах — в зависимости от общей концепции градостроительного плана застройки района или конкретной территории.

Ключевые слова: зеленые крыши, распространение пыли, экологическая безопасность городских территорий, мелкодисперсная пыль, пылевое загрязнение

Для цитирования: Манжилевская С.Е., Евтушенко А.И., Маилян Д.Р. Применение зеленых крыш в точечном строительстве для повышения экологической безопасности городских территорий. *Безопасность техногенных и природных систем.* 2025;9(2):136–145. https://doi.org/10.23947/2541-9129-2025-9-2-136-145

Introduction. Modern cities are actively integrating new environmental solutions into their infrastructure, and green roofs have already become a traditional element of urban planning [1]. Recent studies have demonstrated that these structures significantly contribute to the efficient use of urban space and significantly improve the environment [2, 3]. The effectiveness of plant coatings in neutralizing pollutants, including PM0.5-PM10 has been confirmed by numerous studies [4, 5]. Today, green roofs are not considered as an innovative concept, but rather as a crucial part of strategies to improve urban ecosystems. Experts and the public are increasingly recognizing their contribution to enhancing the quality of life for citizens and restoring natural balance in urban areas [6].

Studies have shown that residential buildings significantly worsen the quality of air in cities, releasing harmful PM0.5-PM10 particles, which negatively affect the health of residents [7]. Therefore, architects and developers should consider green roofs as a standard element of construction projects [8]. The introduction of such eco-friendly solutions into everyday practice is becoming a key factor in ensuring the environmental sustainability and safety of modern urban planning [9].

The limited availability of natural resources in cramped urban spaces requires their rational use and functional expansion, which is especially important in the case of residential development and reconstruction of outdated buildings [10]. The strategy of replenishing such dwindling resources is the introduction of environmentally friendly and economically cost-effective architectural concepts, including green roofs [11]. These solutions minimize dust pollution in residential areas, have a beneficial effect on the quality of life of urban residents, and contribute to more efficient environmental management [12].

In an urban environment where space is limited, the transformation of standard roofing structures into ecological oases seems to be a perfect solution for the restoration of natural cover. This is particularly true when there are no other land use options available. A green roof is a multi-level structure that sits on the top of buildings [13]. It includes a base and a variety of intermediate elements, from waterproofing barriers to vegetation cover. All these layers function as a single mechanism that ensures the vital activity of flora on the roof and effectively replenishes the green areas lost during the construction process. The implementation of such projects requires detailed design and analysis of weight characteristics to ensure the reliability and stability of these innovative systems.

The research focus in the area of green roof systems is primarily on their ability to clean the air of such pollutants as SO_2, O_3, NO_2 and PM10 [14, 15]. Vegetation on roofs, like other urban landscaping elements, shows significant potential in reducing atmospheric pollution and harmful emissions by up to 35–100%. This has been demonstrated through research, and these environmental benefits have led to an increasing interest in green roofs worldwide.

The aim of this research is to evaluate the effectiveness of green roofs in reducing the spread of dust in urban environments, which is particularly important for areas with active infill development. To accomplish this goal, we have solved the task of identifying vegetation types that effectively collect dust, and developed designs for green roof systems that were suitable for installation in residential areas. Such environmental solutions contribute to the overall modernization of the construction industry, making it safer for the environment and more comfortable for residents.

Materials and Methods. The choice of an optimal location plays a key role in maximizing the benefits of green roof structures in the fight against PM2.5 and PM10 pollutants, given the difficulties with their installation. For Russian cities, there are specific parameters for determining the priority areas for the installation of these environmental structures. One of the most important factors is the location in a certain climatic zone according to the zoning scheme (Fig. 1) [16]. It is the correct location of green roofs that determines their effectiveness in reducing the concentration of harmful particles in the atmosphere.

Modern urban trends require a systematic approach to creating eco-friendly spaces in an urban environment. This task can be solved by developing affordable, cost-effective and technologically uncomplicated solutions. The criteria for implementation include location in urban centers with a population of more than 250,000 people, as well as the prerequisite that green areas make up at least 40% of the total area of the block [17].

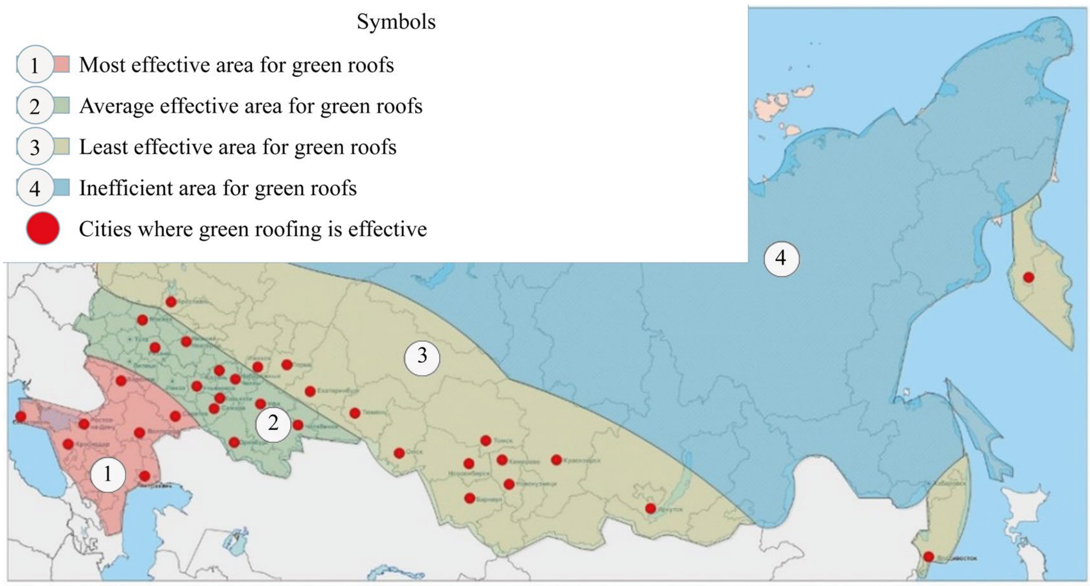


Fig. 1. Map of the territorial delimitation of Russia for optimal use of green roofs in various climatic conditions

During the construction of the Krasny Aksai residential complex in Rostov-on-Don, herbaceous plants of six varieties typical of the Rostov region were planted in March 2020 in the construction area and outside the site (Fig. 2). From May to September, during the construction of the monolithic frame of the building and the stone-installation works, 10 air samples were taken twice a week for 120 minutes at three control points according to the standard RD 52.04.893–2020[1] method — at the border of the construction site at 117 b, Beregovaya St., b. 5 (point A in Fig. 2), above the vegetation zone (point B in Fig. 2) and at a distance of 10 meters from the green zone, in the residential area of the Krasny Aksai residential complex (point C in Fig. 2). During the entire observation period, atmospheric parameters fluctuated: the air warmed up from +14 to +25°C, the wind reached 3–5 meters per second, and the relative humidity was from 30 up to 60%.

Fig. 2. Construction site of an infill development:
1, 2 — planting sites; A, B, C — control points for measuring the PM10 concentration

[1] RD 52.04.893–2020. *Mass concentration of suspended solids in atmospheric air samples. Method of gravimetric measurements.* Electronic Fund of Legal. and Regulatory and Technical Documents. (In Russ.) URL: https://files.stroyinf.ru/Data2/1/4293720/4293720281.pdf (accessed: 10.03.2025).

Each plant species planted in the area of the site occupied an area of six square meters, forming a total experimental area of 36 square meters. All the selected plants had a high dust absorption capacity, which was a key criterion in their selection for this study (Fig. 3) [18, 19].

Fig. 3. Herbaceous plants characterized by high efficiency of dust deposition:
a — Agrostis stolonifera; *b* — Lavandula angustifolia; *c* — Festuca rubra; *d* — Plantago lanceolata;
e — Sedum album; *f* — Festuca festina

The methodology for determining the amount of dust deposited on plants involved taking 50 measurements twice a week in the morning. Dust particles were collected from the surface of plant leaves using a brush. The process took place during the period of active construction of a multi-storey residential building, that is, from May to September 2020. The collected material was carefully transferred into a pre-weighed container for further evaporation and weighing. After collecting samples from each plant species, laboratory treatment was performed: the liquid was evaporated and the sediment was dried until the mass stabilized. Using these recorded indicators, we were able to calculate the specific dust concentration — the number of milligrams of dust collected per square centimeter of plant leaf surface. The results of particle deposition on the leaves of the studied plants can be seen in Figure 4.

Air sampling to determine dust concentration in it was carried out using an electric aspirator PU-3E/12, which was tested, and filters made of PVC fibers AFA-VP10. Preliminary tests of this measuring equipment in a wind tunnel showed that the measurement error during a one-time experiment did not exceed 12%, which met the requirements of RD 52.04.893-2020.

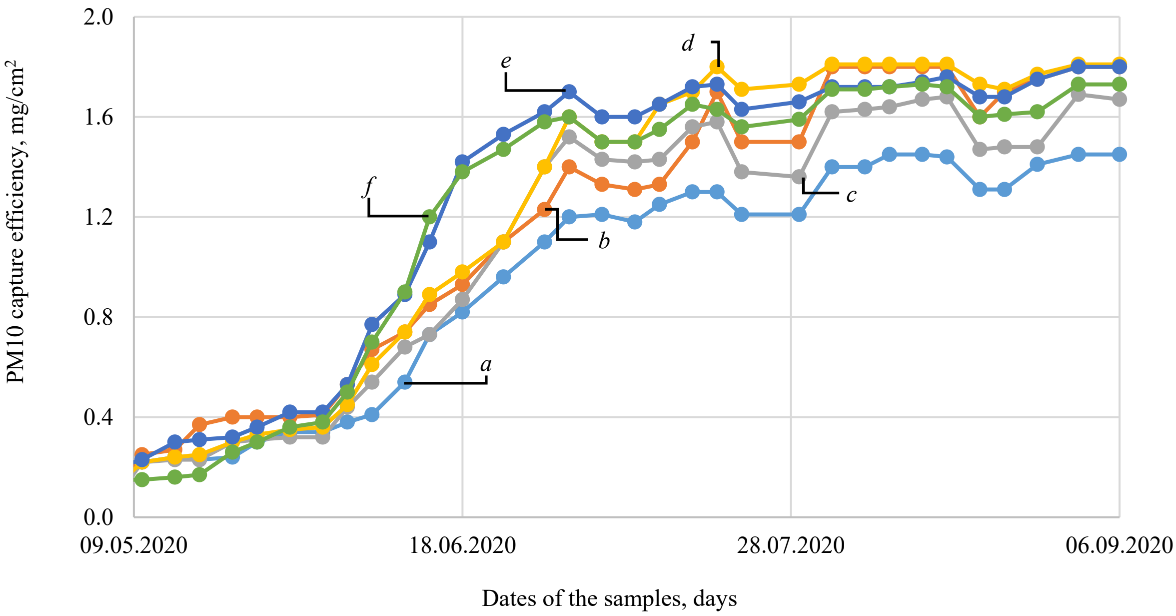


Fig. 4. Density of PM10 dust deposition on plants in the zone of infill development:
a — Agrostis stolonifera; *b* — Lavandula angustifolia; *c* — Festuca rubra;
d — Plantago lanceolata; *e* — Sedum album; *f* — Festuca festina

Results. The analysis of measurements showed that in conditions of prevailing easterly wind (3–5 m/s) and an air humidity of 30–60% during the period of work, the planted vegetation significantly affected the air quality. Above the landscaped area, there was a decrease in the concentration of PM10 dust particles from construction work from an average of 10 (humidity — 30–35%) to 20% (humidity — 35–60%), and at a distance of 10 meters from the vegetation cover, compared with the adjacent construction area, from an average of 15 (humidity — 30–35%) up to 30% (humidity — 35–60%).

Measurements of the amount of dust deposition during the growing season (May–September) revealed the following dynamics: if at the beginning of the season (May–June) the amount of dust deposition on plants was a maximum of 0.42 mg/cm^2, then at the height of the warm season (July–September) it reached 1.81 mg/cm^2. The dynamics of changes in the amount of dust deposition on plants was explained by the fact that during the measurement period, plants grew at the beginning of the growing season, then the area of vegetation increased, but at the same time, the dust deposition formed on the leaves could be blown into the air by the wind at a speed of 3.5 m/s and higher. In the period from July to September, the vegetation surface area was already at its maximum. The process of active dust deposition was also influenced by the fact that dew formed on plants in the first half of the day, and the volume of green mass of plants, which allowed dust deposits to accumulate on the leaves, prevented external sources of exposure (wind, precipitation) from sweeping the dust deposits onto the ground or into the air. Figure 5 shows the dynamics of changes in the PM10 concentration during the study period at three control points for measurements (construction site, vegetation area, residential area).

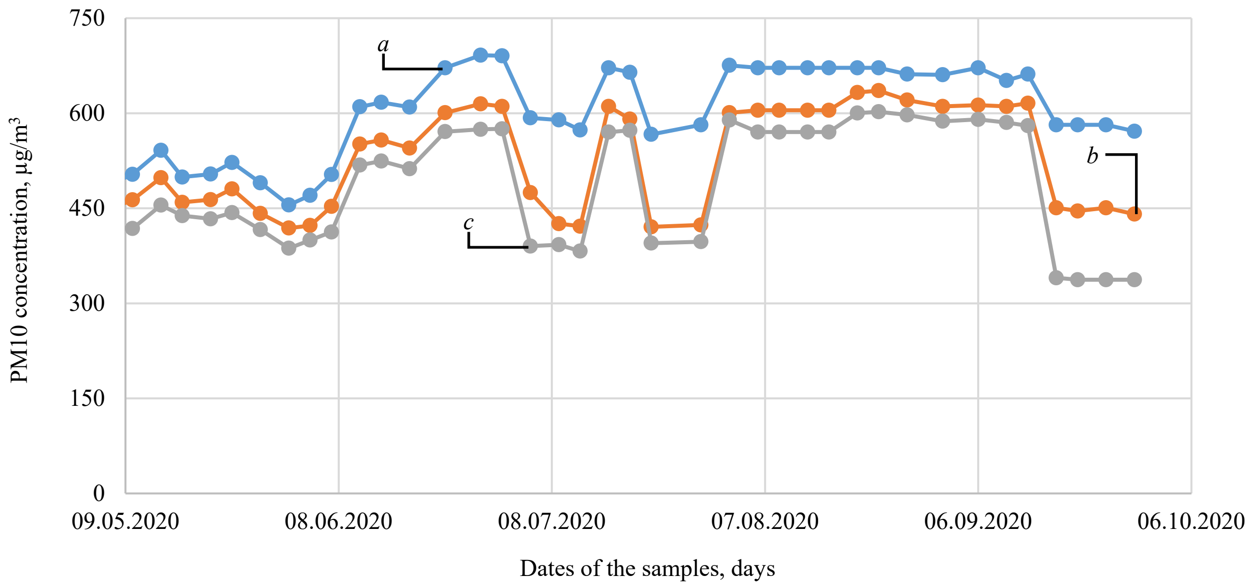
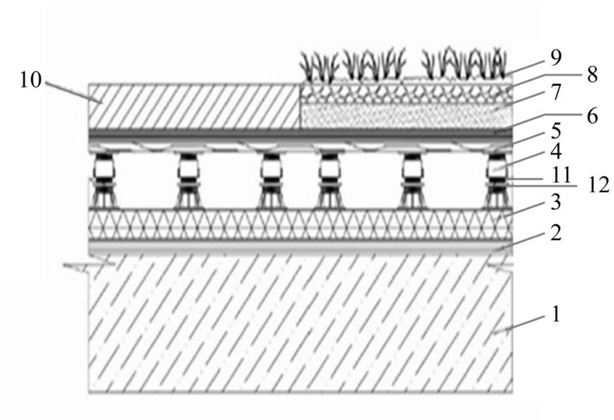


Fig. 5. Dynamics of changes in the PM10 concentration during the construction period:
a — point A, construction site; *b* — point Б, vegetation area; *c* — point B, residential area

To achieve the aim of this research, the authors have developed innovative, resource-efficient and practical green roof designs that can be incorporated into the planning stage of residential developments. These designs can easily serve as a tool for reducing the negative impact of dust emissions during construction, whether it is the construction of new buildings or the renovation of the existing structures for various purposes.

The first mobile green roof structure was developed with the possibility of its dismantling for the winter period. Patent No. 191863U1 was registered for this type of roof [20]. The structural elements of such a roof were a combination of reinforced concrete slab, durable anti-rot roofing felt, adjustable Forest Style supports made of high-strength propylene (with the possibility of building up due to an additional nozzle of 60 mm), as well as Ondulin double-layer asphalt concrete coating. Figure 6 provides the structural scheme of the green roof and the implementation of this structure at the facility after reconstruction in Rostov-on-Don.



Green roof design for installation on public buildings

1 — Reinforced concrete floor slab;
2 — Covering layer of roofing felt;
3 — Thermal insulation layer;
4 — Adjustable supports;
5 — Ondulin lining layer;
6 — Waterproofing layer;
7 — Drainage layer;
8 — Ground;
9 — Green spaces;
10 — Decking;
11 — Galvanized studs;
12 — Locking nut

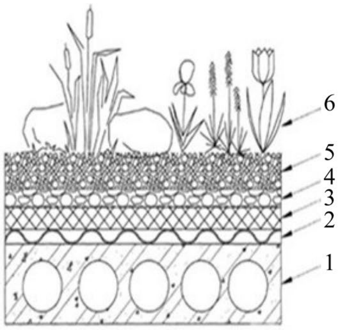
a)

b) *c)*

Fig. 6. Design solutions of green roof for public buildings: *a* — design scheme; *b* — object for the green roof structure implementation — business center “League of Nations”
(91, Suvorova St., Rostov-on-Don; *c* — implemented green roof design solutions

The second type of structure is intended for residential buildings, winter gardens and terraces. This system is characterized by simple dwsign, cost-effectiveness, high thermal insulation, and moisture protection. Patent No. 163334U1 [21] was registered for the utility model. The vegetation layer is planted in the final stage of the project. It is placed along the perimeter of the green areas of the structure. The installation of this type of roof involves the use of two types of coatings: one for the side section, which allows for year-round use of the green roof, and the other for the central area, where a swimming pool or café can be located, for example.

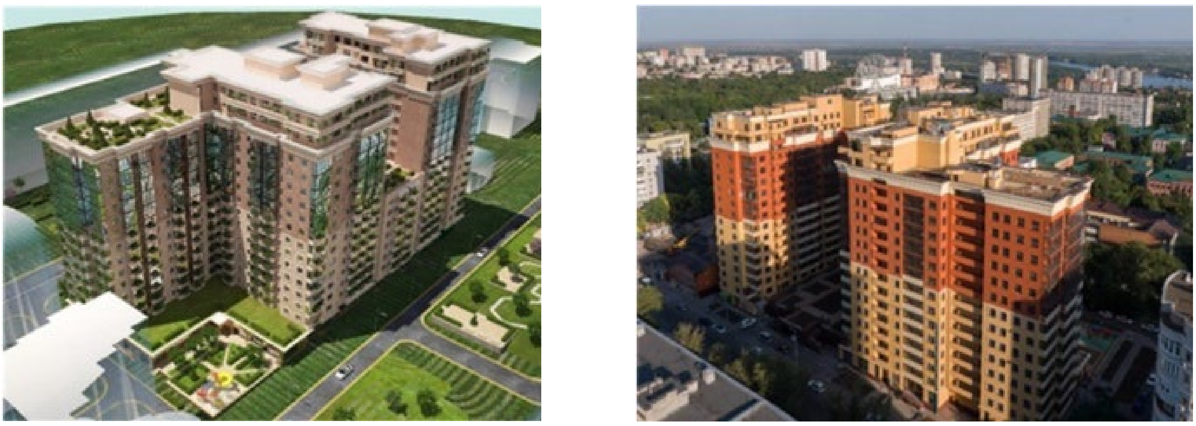
Figure 7 shows the developed design of the second type of green roof, which consists of a reinforced concrete floor slab, filter and vegetation layers. Ondulin is used as a protective element. The structure is additionally equipped with a layer of anchors in the ground. The implementation of this design solution at an urban development facility is also presented.



Green roof design
for residential buildings

1 — Reinforced concrete slab;
2 — Ondulin protective layer;
3 — Thermal insulation layer made of expanded polystyrene;
4 — Filter layer made of peat and/or gravel;
5 — Fixing soil mixture;
6 — Plant layer containing a substrate with plants

a)



b) c)

Fig. 7. Green roof design solutions for residential buildings: *a* — design scheme; *b* — object for the implementation of a green roof structure in design solutions (Zhemchuzhina Dona residential complex; 240, Maxim Gorky Str., Rostov-on-Don);
c — implemented green roof design solutions

The cost of these green roof structures starts from 4,200 rubles per square meter. Financial calculations show that with long-term operation (up to 40 years), traditional and green roofs have approximately the same cost. At the same time, investments in the installation of green roof systems for the League of Nations business center amounted to only 1.3% of the total reconstruction budget. In the case of the Zhemchuzhina Dona multi-apartment high-rise residential complex, the share of costs for the development of design solutions, installation and landscaping of the roof amounted to 4% of the total construction costs of the facility.

Discussion and Conclusion. The research conducted by the authors proves that the creation of vegetation cover is a fairly effective barrier to the spread of dust pollution from infill construction. The efficiency of dust collection can reach an average of 10 to 20%, depending on the air humidity level. At the same time, it is important to choose the right plants for the green roof and arrange it well in order to maximize the effect of dust suppression, which will significantly increase the environmental safety of residential areas in residential buildings. The two types of constructive green roof solutions developed by the authors, which are applicable for the reconstruction of buildings and the construction of new facilities, make it possible to create a comprehensive protection of the urban area from one of the most harmful sources of dust emissions in the urban environment — the construction site. Although the introduction of such technologies requires additional financial investments, they are offset by a decrease in the incidence of workers from harmful effects of dust by about 15%. This leads to a corresponding reduction in the cost of construction work and labor savings, while providing a higher level of protection for both workers on the construction site and residents of nearby areas.

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Claimed Contributorship:

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AI Evtushenko: carrying out calculations, design of a scientific article.

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Conflict of Interest Statement: **the authors do not have any conflict of interest.**

All authors have read and approved the final manuscript.

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Заявленный вклад авторов:

С.Е. Манжилевская: формирование цели и задач исследования, проведение расчетов, подготовка текста, формирование выводов.

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Конфликт интересов: **авторы заявляют об отсутствии конфликта интересов.**

Все авторы прочитали и одобрили окончательный вариант рукописи.

Received / Поступила в редакцию 02.04.2025
Reviewed / Поступила после рецензирования 29.04.2025
Accepted / Принята к публикации 05.05.2025