Review Article
ISSN 2658-5553
Received: November 18, 2021 *Accepted: November 18, 2021* *Published: November 22, 2021*

Advantages, limitations and current trends in green roofs development. A review

Korniyenko, Sergey Valeryevich[1*]

[1] Volgograd State Technical University, Volgograd, Russian Federation; svkorn2009@yandex.ru (K.S.V.)
Correspondence: * email svkorn2009@yandex.ru; contact phone +79884912459

Keywords:

Green roof; Environment; Vegetation; Urban heat island; Heating; Cooling; Energy efficiency; Sustainability; Biopositivity

Abstract:

The green roof systems (GRS) seek to meet the environment and energy efficiency requirements in buildings, where inadequate performance is provided by the conventional roof systems. Some types of green roof have been commercially launched, but challenges, such as high initial cost, complex maintenance, and application limitations, prevent their widespread use. Most of these challenges can be overcome, but no GRS are likely to overcome all of them at once. This research reviews the advantages and disadvantages of green roofs and discusses the challenges associated with their utilization within buildings. The main consumer properties of green roofs have been systematized. The research makes the capabilities and limitations of the different GRS clearer for both architects and users, and discusses the challenges and promises facing developers and designers.

1 Introduction

The biggest challenge in building design is to optimize the use of natural energy to provide human comfort and consume less energy [1], [2], [3]. Within the target to reduce the energy demand of buildings and preserve the environment, innovative technical solutions have to be proposed and adopted [4], [5], [6], [7], [8], [9]. Among the systems available in the sustainable and bioclimatic architecture context, green (vegetated) roof technologies have been developed for approaching comfort and sustainability aspects [10], [11], [12], [13], [14], [15]. Green roofs are an effective contribution to resolving several environmental problems at the building and urban levels [8], [17], [18], [19].

Green roofs are complex systems, with a vegetation layer covering the outermost surface of the building envelope. An effective design may confer environmental and energy benefits [20], [21]. Also, the green roofs can be viewed as a tool to enhance aesthetic appeal of any building [22]. Compared to bland and utterly boring flat roofs, green roofs are more pleasant to experience or view from other buildings [23]. Comparing with a traditional black roof, many other advantages of a green roof can be noted, such as storm-water management [24], high water run-off quality [25], improving urban air quality [26], high thermal and acoustic performances [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], etc.

The main barrier relates to difficulties in performance quantification and evaluation of buildings with green roofs. There is a lack of holistic performance criteria based on testing, assessment and monitoring of green roofs systems. There are no best-practices assessing and documenting the performance of green roofs. Design and construction of buildings with green roofs tends to transcend multiple engineering disciplines, expecting a high degree of coordination among all the actors involved [37]. There is no evaluation of green roofs consumer properties. In addition, in the scientific literature, there is practically no data on the systematization of the main types of green roofs systems. This knowledge gap is significant and requires being addressed by the scientific community in order to simplify the evaluation of green roofs based on solid science.

As a contribution to addressing the mentioned barriers, the purpose of this research is to identify the gaps related to systematize the main consumer properties of green roofs systems, and to provide insights into current trends and future challenges in this domain.

2 Materials and Methods

Our research methodology combines mixed methods of research involving collecting, analyzing and integrating quantitative and qualitative research.

A literature review was conducted to identify elements found in scientific literature relevant to green roofs performance evaluation. In order to elaborate the review, Google Scholar, Scopus and Web of Science database searches were conducted. The aim here was to collect articles exploring studies which may have performed evaluation of green roofs. The literature review identifies and describes a knowledge gap on the assessment and systematization of consumer properties of green roofs systems.

The retrospective data analysis was carried out to identify real-world uptake using domestic and foreign construction experience. Based on a detailed analysis of the green roofs consumer properties, their properties were differentiated.

The integrated scientific approach in analysis of green roof performance has been suggested. This approach has been division into the following main steps: a) identify existing advantages; b) identify existing disadvantages and limitations; c) based on the analysis of disadvantages, formulate the study issues; d) based on the solution of these challenges, the suggestions to optimized roof system design can be developed.

The generic steps of these processes are presented in Figure 1.

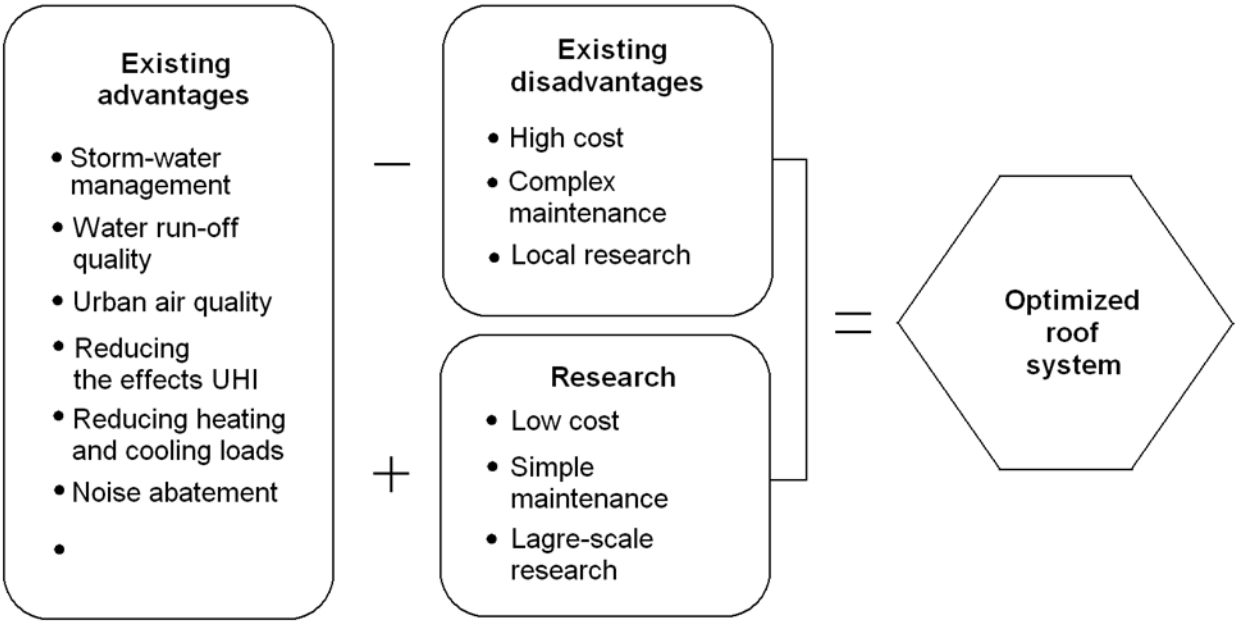

Fig. 1 – Agenda methodology

The main challenges of green roofs system have been summarized based on challenging ratio technique. This approach is generic and reflects the most important aspects in the design process.

3 Results and Discussion

3.1 Green roof elements

The green roof is a complex building component. Depending on the location and requirements, green roofs generally comprise of several functional elements as demonstrated in Figure 2.

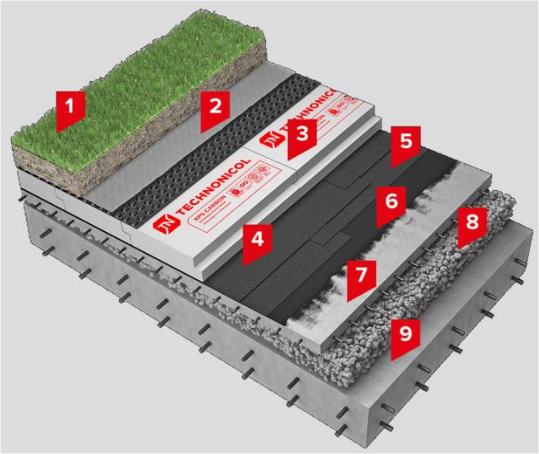

Fig. 2 – The elements of the flat green roof (scheme): 1 – plants and growth substrate; 2 – filter and drainage layers; 3 – insulation; 4 – protection layer ; 5 – water proofing membrane; 6 – primer bitumen layer; 7 – reinforced cement screed coat; 8 – light-weight expanded clay aggregates; 9 – slab

Fig. 3 – View of the sedum-tray garden roof

The green roof specification is listed in Table 1.

Table 1. Green roof specification

Elements	Requirements
Vegetation	Plants improve runoff quality, air quality and thermal performance; Plants must be adapted to withstand drought and frosts; Plants must survive even with minimal nutrients in the substrate and have good ground coverage; Short and soft roots of some plants (such as succulent species) prevents the penetration of roots into the roof deck; Plants retard weed growth as well as soil erosion when built on sloped roofs.
Growth substrate	It is important to keep the weight of substrate as low as possible; Substrate surface should not be exposed to direct sunlight and wind; Water holding capacity of substrate components is crucial for the survival of plants under drought conditions; Improved aeration and capillary properties of substrate are essential for plant growth.
Filter layer	The main function of a filter layer is to separate the growth substrate from the drainage layer, and there by prevent small soil media particles from entering and clogging the drainage layer below; Geotextiles fabrics are often used in green roofs; The filter fabric also acts as a root-barrier membrane for plants that have soft and short roots.
Drainage layer	Drainage layer provides an optimal balance between air and water in the green roof system; Drainage layer aids in removal of excess water from substrate to ensure aerobic substrate condition; Drainage layer protects water proof membrane and improve thermal properties of green roof; The basic type of drainage layer is drainage granular materials (such as light-weight expanded clay aggregates, crushed brick, expanded shale and coarse gravel); More efficient systems are drainage modular panels.
Insulation	Thermal protection
Protection layer	Moisture protection and root barrier
Typical roof design	Building component

The main advantages of green roofs are summarized below.

3.2 Existing advantages of green roofs

3.2.1 Storm-water management

Green roofs are known to retain rainwater and delay peak flow, thereby reduce the risk of flooding in urban areas [37]. When rain water enter green roof, a portion of water will be absorbed by growing substrate and retained in the pore spaces (Figure 4).

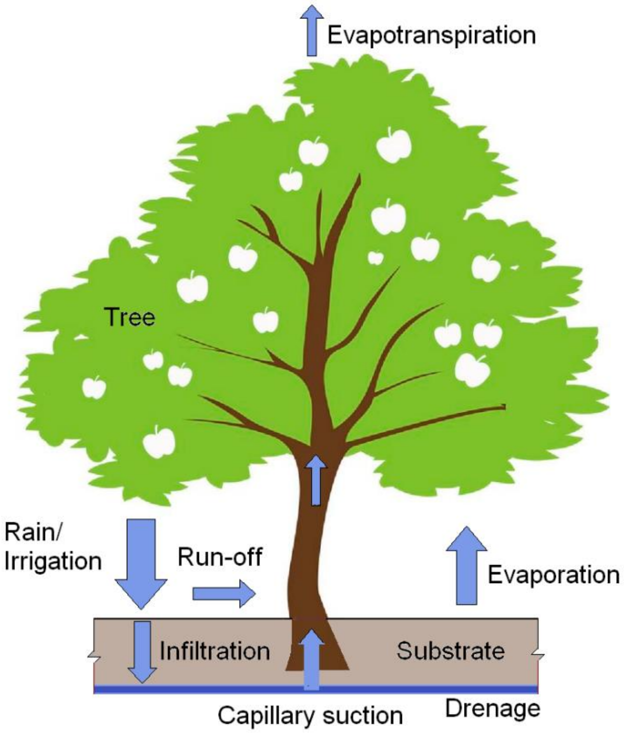

Fig. 4 – Water balance in the tree (scheme)

It can also be taken up by the vegetation and either stored in plant tissues or transpired back into the atmosphere [28]. A portion of water leaves the roof surface as a runoff. The remaining water passes through filter fabric and then enters drainage element. Due to potential to store water between pores (in the case of drainage granular materials) or compartments (in the case of drainage modular panels), water will be detained. After complete utilization of drainage space, the overflow will drain. The retained water inside green roof will evaporate or be used by plants during dry periods. It is the evaporated and transpired water that explains the runoff retention potential of green roofs. In general, the retention potential of any green roof depends on type and thickness of growth medium, type of drainage element and its storage capacity, type of vegetation and coverage, volume of rain event and time of previous dry period, and slope of green roof. Considering that most of the components that comprise green roof substrate are light weight volcanic materials, The moisture holding capacity of modern green roofs is usually high, since porous substrates and water-retaining drainage layers are often used.

Plants play a significant role in the runoff reduction depending on each plant’s capacity for water interception, water retention and transpiration. The average runoff retention of 65.7% can be achieved on an intensive green roof [37].

The water balance in the plant is the most important component of the water conditions during operation of the green roof. The water conditions in the plant include water losses during transpiration, water absorption, and water balance within the plants. So, the water balance in the plant is given by simple equation:

$$B = (A - E) + W, \tag{1}$$

where B is the water balance in the plant, A is the amount of water absorbed by roots, E is the liquid losses during transpiration (evapotranspiration) and W is the water reserves in the plant.

The simplicity of this equation is apparent; the main difficulty is to accurately determine the components A, E and W. The complex process of mass transfer in the plant is accompanied by energy transfer. The vegetation is closely related to the roof structure. Therefore, it is necessary to consider the processes of combined heat and moisture transfer in green roofs.

3.2.2 Water run-off quality

Green roofs retain pollutants thereby produce good quality storm-water run-off. Both green roof substrate and vegetation could act as a particle trap for dust and airborne particulates removing them from the rainwater. The substrate medium also performs as an ion exchange filter for nutrients and metals in the rain water. On the other hand, the discharge of nutrients from green roofs can be directly associated with the usage of fertilizers [37]. Conventional fertilizers cause higher nutrients concentrations in runoff. It is known that intensive roof pollute runoff significantly higher than extensive green roof due to higher substrate depth. However, compared to other environmental benefits, enhancement of water quality through green roofs needs extensive research.

3.2.3 Urban air quality

The green roof technology is a popular approach that could help to mitigate air pollution in urban environments and significant improves urban air quality. Urban air often contains elevated levels of pollutants that are harmful to human health and environment. Among several mitigation technologies, the ability of plants to clean the air is considered practical and environmentally benign technique. In general, plants mitigate air pollution through direct and indirect processes, i.e. directly consume gaseous pollutants through their stomata or indirectly by modifying microclimate. The research of He Y. et al. [23] demonstrated that a total of 1675 kg of air pollutants was removed by 19.8 ha of green roofs in one year with O_3 accounting for 52% of the total, NO_2 (27%), PM_{10} (14%), and SO_2 (7%). On the other hand, Johnson and Newton [10] estimated that 2000 m^2 of uncut grass on a green roof can remove up to 4000 kg of particulate matter. In a sunny day, a green roof may lower the CO_2 concentration in the nearby region as much as 2% [10]. Planting trees in urban areas have been shown to provide better benefits in mitigation of air pollution, consequently the intensive green roofs are more favourable in terms of minimizing air pollution than extensive roofs, owing to the possibility of installing small trees and shrubs.

3.2.4 Reducing the effects urban heat island (UHI)

The temperature of cities goes up as a result of urban heat island (UHI) which deteriorates comfort conditions of habitants. Green roofs can be viewed as a perspective technology to mitigate UHI effect i.e. to decrease ambient air temperature in urban areas. UHI intensifies the current energy issues of urban spaces not only in summer, but in winter. Green roofs are components that combat UHI and increase the albedo of urban areas. On the plants surface, the sensible heat flux is small because of the large latent heat flux by evaporation, although the net radiation is large. Green roofs repeatedly demonstrated functional and efficiency in reducing UHI and cooling the temperature of a particular area [31]. Berardi et al. [15] indicated that albedo of green roofs ranges from 0.7 to 0.85, which is much higher than the albedo of bitumen roofs (0.1–0.2). For comparison, white roof reflects 55–80% of incident sunlight [14]. Also these structures can increase the city’s albedo whereby, 0.1 increase of the albedo can decrease the average ambient air temperature around 0.3 K and decreases the peak ambient air temperature around 0.9 K [14], [16]. Likewise, some simulation studies demonstrated that green roofs may reduce the average ambient temperature between 0.3 and 3 K in city scale and reduce UHI effects [31]. Consequently, green roofs are very important in mitigation of UHI; the reflective strategies and vegetative methods are scientifically sound and effective [10].

3.2.5 Reducing heating and cooling loads

Green roofs are known to improve building energy efficiency by reducing energy used for cooling and heating [23], [25], [27], [28], [35], etc. These are passive construction systems for energy savings. They reduce energy demand in buildings through improvement of building thermal performance under different environmental conditions.

In a Mediterranean to continental climate, green roofs can reflect 27% of the solar radiation, absorb 60% of it through photosynthesis and transmit as much as 13% of the remainder to the growing medium [35], [28]. Field measurements conducted during summer in Japan showed that green roofs can decrease the surface temperature of the roof from about 60 °C to 30 °C [10]. A study in Greece revealed that green roofs reduce the energy utilized for cooling by 48% with an indoor temperature reduction up to 4 K [10].

Green roofs protect roof membrane from extreme heat, wind and ultra violet radiation. Due to the presence of vegetation and thick substrate layer, the daily expansion and contraction of the roofing membrane can be avoided.

Improvement of thermal performance is basically due to increment of shading, better insulation, and higher thermal mass of the roof system [37]. The plants shade the roof and provide transpiration cooling. Surfaces under shrubs, trees and turfs demonstrated better thermal performance and low heat gain in comparison to surface under bare hard roofs over a typical day [38] (see Table 2).

Table 2. Results of heat gain and heat loss per meter square for various roof tops [38]

Top surface	Total amount of heat gain over a day (kJ/m^2)	Total amount of heat losses over a day (kJ/m^2)
Shrub	0	104.2
Turf	29.2	62.1
Tree	15.6	53.3
Bare soil	86.6	58
Hard surface	366.3	4.2

Thermal properties of various green roof substrates are listed in Table 3.

Table 3. Thermal properties of various green roof substrates under dry condition [4]

Sample	Bulk density (kg/m^3)	Heat storage capacity (J/(kg·K))	Heat conductivity (W/(m·K))
Substrate 1	788	873	0.138
Substrate 2	922	760	0.145
Substrate 3	1360	773	0.196
Substrate 4	545	748	0.199
Substrate 5	376	724	0.158

The thermal and energy benefits of green roofs depend on many factors, including the thermal and moisture properties of the green roof substrate. Thermal conductivity values of various types of substrates can be measured through steady-state and transient techniques under moisture conditions. Specific heat capacities of the green roof substrates can be also measured with a transient technique. As a rule, steady-state measurements demonstrate more consistency than transient measurements [30]. Thermal conductivity and heat storage capacity are differed among substrates, as demonstrated in Table 3. The substrate thermal conductivity increased when moisture content varies, ranged from 0.13 to 0.75 W/(m·K) [30]. The experimental values of substrates samples allow calculating the thermal transmittance (U-value) or thermal resistance (R-value) in steady-state, the heat accumulation, and the dynamic thermal response under a daily thermal oscillation (the thermal stability coefficient and time lag) for green roofs.

The research team from the University of Córdoba, Southern Spain, reported that annual reductions of energy gains and losses were obtained in the three green roofs, with annual average reductions of 66% and 63%, respectively, compared to the traditional black roof. These results were mainly related to the composition of the substrates, their capacity to retain water and the quantity of vegetation in each plot. This study indicates that the use of green roofs contributes significantly to reduce the energy demand of existing buildings under warm climatic conditions.

Most field studies evaluating green roof performance have been conducted in warmer climates with few studies of full-scale green roofs in cold regions. The work of Schade et al. [27] demonstrate the heat flow and thermal effect of an extensive green roof versus a black bare roof area on a highly insulated building (passive house) in the sub-arctic town of Kiruna, Sweden. Measured temperature and heat flux values were consistently higher and more variable for the black roof than the green roof, except during the snow-covered winter months when the responses were similar. Snow is a peculiar filter that equalizes fluctuations in temperatures and heat flux on a low-isolated building. The cumulative heat flux showed that the net heat loss was greater through the black than the green roof, but the values remained low. Overall, the study confirms that the energy benefit of a green roof on a highly insulated building in a subarctic climate is low.

In Russia, no long-term experimental analysis of thermal performance of green roofs was carried out. The main barrier relates to difficulties in performance quantification and evaluation of buildings with green roofs.

3.2.6 Noise abatement

Green roofs reduce noise from road, rail and air traffic. Increasing the thickness of the substrate increases the total weight of the roof, which leads to improved airborne noise insulation. The plants and green roof substrate absorb impact noise, such as “rain hammer”. Also, sound waves are partially absorbed due to the diffraction of sound on the surface of the roofs. The green roofs improve the acoustic performance of buildings. This improvement happens because green roofs provide additional mass, low stiffness and induces damping effects. The biggest modification on the final acoustic absorption and insulation capability (about 20 dB when the 80 mm samples of substrates) was produced by increasing the water content of the system from 10% to 30% RH. On the contrary, the conditioning at 90% RH does not procedure significant differences of the final acoustic behavior of the substrates [32]. However, research studies on the acoustical benefits of green roofs are rather limited. It is also worth noting that the sound performance of green roofs is more pronounced in low-rise buildings, because growing layer should be exposed to the direct urban sound field to be an effective absorptive surface [10].

The identified advantages create the necessary conditions for the further development of green roofs.

3.3 Existing disadvantages of green roofs

3.3.1 High cost

First and foremost hindrance factor is the high cost of green roof [39]. Installation of green roof requires significant investment and the cost varies with type of green roof, location, labor and equipment. Maintenance of a green roof is not directly related to energy but it is one of the parameters of its life-cycle analysis. In addition to the above, operation, maintenance and ultimate disposal incur additional cost. The installation cost of green roofs is 27% higher than that of conventional roofs [10]. However, considering the benefits over the life time (40 years) of the green roof, the net present value of the green roof is about 25% lower than that of a conventional roof. Imported green roof components often lead to high installation cost or possible failure due to non-compatibility issues. It was determined that disposal costs correspond to only 4.6% of the total costs (36.1% initial capital cost and 59.3% maintenance cost) [10].

3.3.2 Complex maintenance

Maintenance of green roofs is another important barrier that confuses building owners. Green roof needs constant watering, at least during drought climates, and occasional fertilization which in turn promotes weed growth and thus require regular maintenance check. In order to decrease irrigation interval, the plant selection often limited to a few succulent species.

Any roof has the potential to leak. Leakage protection is particularly important for green roofs in which the substrate is often in a saturated wet state.

Restrictive maintenance procedure is need for green roof.

In general, extent and frequency of maintenance depends on the type of green roof. For extensive green roof, relatively simpler tasks such as plant protection, drainage check and weed removal are sufficient. On the other hand, intensive roofs require detailed maintenance operations. Irrespective of the type of green roof, weeding presents serious and time-consuming maintenance operation. It is also recommended to explore materials that can replace the current use of polymers, especially in filter and drainage layer, to enhance overall sustainability of green roofs.

3.3.3 Local research

Research on green roofs performance is local; therefore there is significant knowledge gap which prevents green roof to gain more popularity than it is now.

Research on green roofs is restricted to only few countries in Europe, America and Asia. Hence, the only option for other countries is to import green roof components, which usually results in high cost or ultimate failure due to adaptability issues. Considering that each country has different climatic condition and form of urbanization, local research is utmost important for success of green roofs. It is important to prepare growth medium using locally available materials and screen native plants for eventual success of green roof. In addition, life-cycle and cost-analysis should be performed.

The existing disadvantages of green roofs constrain widespread practical application of these building components.

3.4 Quantification of green roofs

The main challenges associated with the demonstrated green roof system have been summarized in Table 4.

Table 4. Roof systems and the associated challenges

Challenge	Green roof system (GRS)	White roof system (WRS)	Black roof system (BRS)
Storm-water management	Very high	Low	Low
Water run-off quality	High	Low	Low
Urban air quality	Very high	High	Low
Reducing the effects UHI	High	Very high	Low
Reducing heating loads (in winter)	High	High	High
Reducing cooling loads (in summer)	High	Very high	Low
Noise abatement	Very high	High	High
Initial cost	Very high	High	Low/Medium
Technology	Complex	Medium	Simple
Maintenance	Complex	Medium	Simple
Research	Local	Mid-scale	Large-scale
Positive image	Very high	High	Low

For comparison, black roof and white roof systems also have been considered [40], [39], [41]. For the purpose of comparison, the degree of challenge has been assigned a numerical value, regardless of the relative weight of each one (see Table 5). In this rating the minimum numerical value of each point is 1; maximum numerical value of each point is 4. The minimum numerical value is assigned when the challenge is not resolved (or poorly resolved). The maximum numerical value is assigned when the challenge is completely resolved. The maximum numerical value for all points is 48.

Table 5. The challenging ratio of the roof systems

Challenge	Green roof system (GRS)	White roof system (WRS)	Black roof system (BRS)
Storm-water management	4	1	1
Water run-off quality	3	1	1
Urban air quality	4	3	1
Reducing the effects UHI	3	4	1
Reducing heating loads (in winter)	3	3	3
Reducing cooling loads (in summer)	3	4	1
Noise abatement	4	3	3
Initial cost	1	2	3.5
Technology	1	2	4
Maintenance	1	2	4
Research	1	2	3
Positive image	4	3	1
Total	**32**	**30**	**26.5**

The data from Table 5 is visualized as shown in Figure 5.

Figure 5 show that the challenging ratios, which are the sum of all degrees of the challenging values, demonstrated maximum value for green roof system in comparison with white roof and black roof systems, which indicate that the green roofs are more promising to overcome the challenges and become widely used in warm climates. The main drawback is their limited applications due to the initial cost, installation difficulties and complex maintenance. The limited research is another major challenge for application of green roofs in different climates.

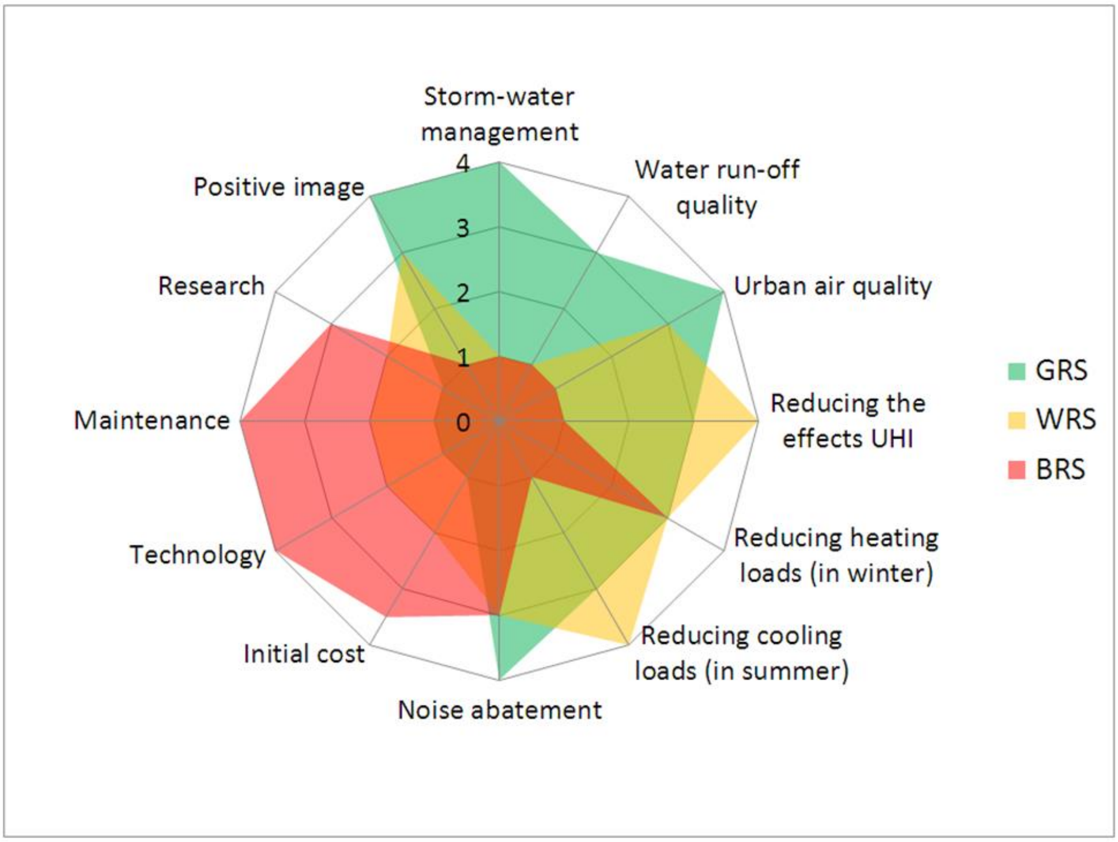

Fig. 5 – The challenging ratio chart of the roof systems

The data obtained above correlate with data provided by the research team from the Lawrence Berkeley National Laboratory, USA [39]. According to these data, owners concerned with local environmental benefits should choose green roofs, which offer built-in storm-water management and a “natural” urban landscape esthetic. At the same time, owners concerned with global warming should choose white roofs, which are more effective than green roofs at cooling the globe. The authors strongly recommend building code policies that phase out dark-colored roofs in warm climates to protect against their adverse public health externalities.

3.5 Future research

In summary, we propose three main aspects to improve the performance of green roofs.

The first aspect is reduction in the cost of green roofs. The locally available plants and substrate medium must be adapted to use in green roof systems. It is crucial to reduce the capital and operating costs of green roofs. The use of import substitution green roof technologies is highly recommended. It is important to keep the interdisciplinary research in close cooperation of architects, designers, biologists. The selection of plant and substrate type for green roofs should be performed according to the local climatic conditions and nutrient availability as well as the impact of plant on the ecosystems. The green roof costing assessment must be applied at all stages of the life cycle of buildings.

The second aspect is simplification of the maintenance procedure of green roofs. This is main practice aspect. Water-proofing is fundamental for success of any green roof. It is a pre-requisite during any green roof installation to prevent leaks. It is very difficult to find leaks through the waterproofing layer of the roof, which is covered with insulation and growth substrate. A single drop of water leakage in roof often considered as a failure of green roof. The detailed research on sustainable materials for roof membrane is required. These materials should be more reliable and durable, at the same time should produce less environmental impact during its life cycle. Plant watering must be minimized. The use of artificial intelligence modeling to optimize green roof irrigation is efficiency [24].

The third aspect is increase role of scientific research of green roofs performance under various climates. Comprehensive study on the performance of green roofs in winter, mid-season and summer for different climates is highly recommended. The effectiveness of this study is particularly high in summer, when the green roof as a passive technology is often used for reducing cooling load. To solve this issue, the combined heat and mass transfer simulation, based on new models in heterogeneous structures of large-scale extensive green roofs, and comprehensive long-term experimental analysis of these elements in various climates must be carried out. The result of this issue is new efficient design solutions of green roofs.

Building or energy usage regulations are also another valuable “tool” in this regard.

At the same time, it should be emphasized that green roofs can act as an important building component to create more sustainable, biopositive and energy efficient buildings. Hybrid Photovoltaic (PV)-green roofs is a new trend that provides benefits of green roofs as well as improve PV electrical yield [10]. Green roofs cool the surface and ambient air which in turn improve the performance of PV cells. PV panels also counter help green roofs by shading the parts of surface and thereby reduce the sun exposure and high evaporation rates normally experienced on green roofs. Green roofs could utilize grey water from laundry, bathroom and kitchen activities as an irrigation source. Grey water usually rich in nutrients hence minimize fertilization requirement of green roof.

4 Conclusions

Based on a review of literary sources and analysis of scientific data, the main consumer properties of green roofs were systematized. The green roof elements and the requirements for them were considered in detail. Key advantages of green roofs are storm-water management, water run-off quality, urban air quality, and reducing the effects urban heat island. Other benefits of green roofs are reducing heating and cooling loads and noise abatement. The identified benefits create the necessary conditions for the further development of green roofs. On the other hand, the existing disadvantages and limitations of green roofs, such as high cost, complex maintenance and local research, constrain widespread practical application of these building components. In summary, three main aspects to improve the performance of green roofs have been suggested. These include: reduction in the cost, simplification of the maintenance procedure and increase role of scientific research of green roofs performance under various climates. Green roofs can act as an important building component to create more sustainable, biopositive and energy efficient buildings. Thus, the green roof technology is fully response to modern challenges. This is a progressive technology of the near future.

5 Acknowledgements

I would like to thank Doctor of Philosophy, Professor Boris Navrotskiy for discussion and valuable comments on this work.

References

1. Kalamees, T., Lupíšek, A., Sojková, K., Mørck, O.C., Borodinecs, A., Almeida, M., Rovers, R., Op’Tveld, P., Kuusk, K., Silva, S. What kind of heat loss requirements NZEB and deep renovation sets for building envelope? CESB 2016 - Central Europe Towards Sustainable Building 2016: Innovations for Sustainable Future. 2016. (October 2019). Pp. 137–144.
2. Environments, U. Healthy , Intelligent and Resilient Buildings and Urban Environments. 7th International Buildings Physics Conference, IBPC2018. 2018. (Septemvber 2018). Pp. 6.
3. Borodinecs, A., Prozuments, A., Zajacs, A., Zemitis, J. Retrofitting of fire stations in cold climate regions. Magazine of Civil Engineering. 2019. 90(6). Pp. 85–92. DOI:10.18720/MCE.90.8.
4. Coma, J., de Gracia, A., Chàfer, M., Pérez, G., Cabeza, L.F. Thermal characterization of different substrates under dried conditions for extensive green roofs. Energy and Buildings. 2017. 144. Pp. 175–180. DOI:10.1016/j.enbuild.2017.03.031.
5. Gaujena, B., Borodinecs, A., Zemitis, J., Prozuments, A. Influence of building envelope thermal mass on heating design temperature. IOP Conference Series: Materials Science and Engineering. 2015. 96(1). DOI:10.1088/1757-899X/96/1/012031.
6. Dimdina, I., Krumins, E., Lesinskis, A. Indoor Air Quality in Multi-Apartment Buildings before and after Renovation. Construction Science. 2015. 16(1). Pp. 3–10. DOI:10.1515/cons-2014-0006.
7. Andreas, E.L., Ackley, S.F. On the differences in ablation seasons of Arctic and Antarctic sea ice. 1982. 0469(December). DOI:10.1175/1520-0469(1982)039<0440.
8. Baranova, D., Sovetnikov, D., Borodinecs, A. The extensive analysis of building energy performance across the Baltic Sea region. Science and Technology for the Built Environment. 2018. 24(9). Pp. 982–993. DOI:10.1080/23744731.2018.1465753. URL:

https://doi.org/10.1080/23744731.2018.1465753.
9. Millers, R., Korjakins, A., Lešinskis, A., Borodinecs, A. Cooling panel with integrated PCM layer: A verified simulation study. Energies. 2020. 13(21). DOI:10.3390/en13215715.
10. Vijayaraghavan, K. Green roofs: A critical review on the role of components, benefits, limitations and trends. Renewable and Sustainable Energy Reviews. 2016. 57. Pp. 740–752. DOI:10.1016/j.rser.2015.12.119.
11. Sailor, D.J. A green roof model for building energy simulation programs. Energy and Buildings. 2008. 40(8). Pp. 1466–1478. DOI:10.1016/j.enbuild.2008.02.001.
12. Moody, S.S., Sailor, D.J. Development and application of a building energy performance metric for green roof systems. Energy and Buildings. 2013. 60. Pp. 262–269. DOI:10.1016/j.enbuild.2013.02.002.
13. Feng, C., Meng, Q., Zhang, Y. Theoretical and experimental analysis of the energy balance of extensive green roofs. Energy and Buildings. 2010. 42(6). Pp. 959–965. DOI:10.1016/j.enbuild.2009.12.014. URL: http://dx.doi.org/10.1016/j.enbuild.2009.12.014.
14. La Roche, P., Berardi, U. Comfort and energy savings with active green roofs. Energy and Buildings. 2014. 82. Pp. 492–504. DOI:10.1016/j.enbuild.2014.07.055.
15. Berardi, U. The outdoor microclimate benefits and energy saving resulting from green roofs retrofits. Energy and Buildings. 2016. 121. Pp. 217–229. DOI:10.1016/j.enbuild.2016.03.021.
16. La Roche, P., Yeom, D.J., Ponce, A. Passive cooling with a hybrid green roof for extreme climates. Energy and Buildings. 2020. 224. DOI:10.1016/j.enbuild.2020.110243.
17. Korniyenko, S. V., Kozlova, O.P., Astafurova, T.N. Increasing habitat sustainability in residential areas of the first mass series. IOP Conference Series: Materials Science and Engineering. 2019. 687(5). DOI:10.1088/1757-899X/687/5/055012.
18. Korniyenko, S. V, Astafurova, T.N., Kozlova, O.P. Housing in a Smart City. IOP Conference Series: Materials Science and Engineering. 2021. 1079(2). Pp. 022050. DOI:10.1088/1757-899x/1079/2/022050.
19. Korniyenko, S. V., Astafurova, T.N., Kozlova, O.P. Energy Efficient Major Overhaul in Residential Buildings of the First Mass Series. IOP Conference Series: Materials Science and Engineering. 2020. 753(4). DOI:10.1088/1757-899X/753/4/042039.
20. Quezada-García, S., Espinosa-Paredes, G., Escobedo-Izquierdo, M.A., Vázquez-Rodríguez, A., Vázquez-Rodríguez, R., Ambriz-García, J.J. Heterogeneous model for heat transfer in Green Roof Systems. Energy and Buildings. 2017. 139. Pp. 205–213. DOI:10.1016/j.enbuild.2017.01.015.
21. D'Orazio, M., Di Perna, C., Di Giuseppe, E. Green roof yearly performance: A case study in a highly insulated building under temperate climate. Energy and Buildings. 2012. 55. Pp. 439–451. DOI:10.1016/j.enbuild.2012.09.009.
22. Zhou, L.W., Wang, Q., Li, Y., Liu, M., Wang, R.Z. Green roof simulation with a seasonally variable leaf area index. Energy and Buildings. 2018. 174. Pp. 156–167. DOI:10.1016/j.enbuild.2018.06.020.
23. He, Y., Yu, H., Dong, N., Ye, H. Thermal and energy performance assessment of extensive green roof in summer: A case study of a lightweight building in Shanghai. Energy and Buildings. 2016. 127. Pp. 762–773. DOI:10.1016/j.enbuild.2016.06.016.
24. Tsang, S.W., Jim, C.Y. Applying artificial intelligence modeling to optimize green roof irrigation. Energy and Buildings. 2016. 127. Pp. 360–369. DOI:10.1016/j.enbuild.2016.06.005.
25. Ávila-Hernández, A., Simá, E., Xamán, J., Hernández-Pérez, I., Téllez-Velázquez, E., Chagolla-Aranda, M.A. Test box experiment and simulations of a green-roof: Thermal and energy performance of a residential building standard for Mexico. Energy and Buildings. 2020. 209. DOI:10.1016/j.enbuild.2019.109709.
26. Andenæs, E., Kvande, T., Muthanna, T.M., Lohne, J. Performance of blue-green roofs in cold climates: A scoping review. Buildings. 2018. 8(4). DOI:10.3390/buildings8040055.
27. Schade, J., Lidelöw, S., Lönnqvist, J. The thermal performance of a green roof on a highly insulated building in a sub-arctic climate. Energy and Buildings. 2021. 241. DOI:10.1016/j.enbuild.2021.110961.
28. Porcaro, M., Ruiz de Adana, M., Comino, F., Peña, A., Martín-Consuegra, E., Vanwalleghem, T. Long term experimental analysis of thermal performance of extensive green roofs with different substrates in Mediterranean climate. Energy and Buildings. 2019. 197. Pp. 18–33. DOI:10.1016/j.enbuild.2019.05.041.
29. Zirkelbach, D., Mehra, S.R., Sedlbauer, K.P., Künzel, H.M., Stöckl, B. A hygrothermal green roof

model to simulate moisture and energy performance of building components. Energy and Buildings. 2017. 145. Pp. 79–91. DOI:10.1016/j.enbuild.2017.04.001.
30. Pianella, A., Clarke, R.E., Williams, N.S.G., Chen, Z., Aye, L. Steady-state and transient thermal measurements of green roof substrates. Energy and Buildings. 2016. 131. Pp. 123–131. DOI:10.1016/j.enbuild.2016.09.024.
31. Qaid, A., Bin Lamit, H., Ossen, D.R., Raja Shahminan, R.N. Urban heat island and thermal comfort conditions at micro-climate scale in a tropical planned city. Energy and Buildings. 2016. 133. Pp. 577–595. DOI:10.1016/j.enbuild.2016.10.006.
32. Fabiani, C., Coma, J., Pisello, A.L., Perez, G., Cotana, F., Cabeza, L.F. Thermo-acoustic performance of green roof substrates in dynamic hygrothermal conditions. Energy and Buildings. 2018. 178. Pp. 140–153. DOI:10.1016/j.enbuild.2018.08.024.
33. Tian, Y., Bai, X., Qi, B., Sun, L. Study on heat fluxes of green roofs based on an improved heat and mass transfer model. Energy and Buildings. 2017. 152. Pp. 175–184. DOI:10.1016/j.enbuild.2017.07.021.
34. Arkar, C., Domjan, S., Medved, S. Heat transfer in a lightweight extensive green roof under water-freezing conditions. Energy and Buildings. 2018. 167. Pp. 187–199. DOI:10.1016/j.enbuild.2018.02.056.
35. Bevilacqua, P., Mazzeo, D., Bruno, R., Arcuri, N. Experimental investigation of the thermal performances of an extensive green roof in the Mediterranean area. Energy and Buildings. 2016. 122. Pp. 63–79. DOI:10.1016/j.enbuild.2016.03.062.
36. Karachaliou, P., Santamouris, M., Pangalou, H. Experimental and numerical analysis of the energy performance of a large scale intensive green roof system installed on an office building in Athens. Energy and Buildings. 2016. 114. Pp. 256–264. DOI:10.1016/j.enbuild.2015.04.055.
37. Saadatian, O., Sopian, K., Salleh, E., Lim, C.H., Riffat, S., Saadatian, E., Toudeshki, A., Sulaiman, M.Y. A review of energy aspects of green roofs. 232013.
38. Bowler, D.E., Buyung-Ali, L., Knight, T.M., Pullin, A.S. Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning. 2010. 97(3). Pp. 147–155. DOI:10.1016/j.landurbplan.2010.05.006.
39. Sproul, J., Wan, M.P., Mandel, B.H., Rosenfeld, A.H. Economic comparison of white, green, and black flat roofs in the United States. Energy and Buildings. 2014. 71. Pp. 20–27. DOI:10.1016/j.enbuild.2013.11.058.
40. Gao, Y., Shi, D., Levinson, R., Guo, R., Lin, C., Ge, J. Thermal performance and energy savings of white and sedum-tray garden roof: A case study in a Chongqing office building. Energy and Buildings. 2017. 156. Pp. 343–359. DOI:10.1016/j.enbuild.2017.09.091.
41. Korniyenko, S. V. Multifactorial forecast of thermal behavior in building envelope elements. Magazine of Civil Engineering. 2014. 52(8). DOI:10.5862/MCE.52.4.