The wetland as an element of the roof garden

Alena Vargova[1*], and *Marian* Vertal[1]

[1]Department of Architecture Engineering, Faculty of Civil Engineering, Technical University of Kosice, Vysokoskolska 4, 04001 Kosice, Slovakia

Abstract. "Wetlands are among the most productive ecosystems that retain water, protect against floods, support biodiversity, purify water, retain nutrients, and stabilize local climate conditions. Based on the advantages of natural wetlands, constructed wetlands are created and often used for grey water treatment, called eco-purifiers or root purifiers. Because of the need to use the land space for other purposes, the idea of placing a wetland on the roof has been considered. The paper presents the wetland roof as a special variant of the green roof. It focuses on three wetland roofs that were created as part of the greenIZOLA project in Slovakia over the last two years. Moreover, it summarizes the knowledge gained from the operation of the wetland roof in the climatic zone of Slovakia."

1 Introduction

Stormwater runoff, overheating of cities, emergence of heated urban islands, climate change, and overheating of buildings, which subsequently have to be actively cooled become important issues nowadays. These problems are caused by rapid urbanization and the demand for development. It is becoming increasingly difficult to preserve as much greenery as possible, which is why green roofs have started to be used. Placing vegetation on the roof helps partially restore vegetation that has been built over. Many countries are taking a strong initiative to apply green roofs on new and existing buildings by way of reward or penalty [1]. They use them as an effective and practical tool in urbanization, which can retain a large amount of water and thereby delay the storm runoff of rainwater. At the same time, the retained water is used in the process of evapotranspiration, which creates a cooling effect on the building and the surroundings [1], thereby helping to reduce urban heat islands. The substrate and vegetation have a greater albedo than, for example, asphalt strips, at the same time the waterproofing layer is protected from UV radiation and climatic influences. In terms of greening, a vegetated roof can increase the abundance and diversity of birds, arthropods, and gastropods in the city compared to a conventional roof. Last but not least, such a roof also brings an aesthetic benefit to the building and its surroundings. Its premises can be used for relaxation and psychohygiene in a built-up city.

In the last 30-40 years, a modified version of the green roof, namely the wetland roof, began to spread. This roof is unique in that it has a permanent presence of water and uses wetland plants. An inseparable advantage, also the main selling point, is it can be used as a

* Corresponding author: alena.vargova@tuke.sk

root cleaner for gray cleaning water. Its existence was conditioned by the lack of space for the realization of ground root cleaners.

It is necessary that the roof and the whole building be adapted to create a fully functional wetland roof. Especially from the point of view of the building's statics and sanitary engineering. Wetland roofs can be implemented on flat and pitched roofs, on newly built and renovated roofs. The composition of a wetland roof resembles the composition of a simple extensive vegetation roof: (from bottom to top above the supporting or thermal insulation layer) waterproofing resistant to root overgrowth, growth medium, and vegetation. Moreover, there is water on the roof, which can be supplied by an irrigation system, or a direct source of water can be created on the roof - the water level.

A wetland roof, just like a green roof, brings benefits to the building, the surroundings, and the people. At the same time, the wetland roof has some advantages even more effectively, thanks to the permanent presence of water and wetland plants. Wetland plants are physiologically more active, more resistant, and, in combination with water, have a greater evapotranspiration process, which creates a cooling effect on the surroundings and the building. In Brunswick, installing a wetland roof over a cow barn reduced the barn temperature by 5K compared to a barn without a wetland roof. Thanks to high evapotranspiration, it can be 15-20 K cooler than other vegetation roofs and 30 K cooler than a classic bitumen roof. Moreover, the roof accumulates heat during the bottom and during the night hours protects the internal environment from a greater drop in temperature than the ambient temperature [2].

A few research focused on wetland roofs appear in the world to understand their interaction with the building and to make the design of such a roof more efficient (Tab.1). Research is mostly focused from a botanical and environmental point of view. In some research, the course of temperatures in the composition and their influence on the surroundings were partly monitored. Furthermore, experience from research is local, as most of the conducted research is in Germany, Vietnam, and Korea.

Table 1. Selected conducted research focused on the wetland roof.

Research location (Country)	**Subject of research**
Barn in Brunswick (Germany)	- Comparison of interior temperature in a barn with and without a wetland roof [1].
Family house (Israel)	- Gray water treatment and the wetland roof effect for energy savings during hot weather [2].
Seoul National University (Korea)	- Monthly evaporation and water level fluctuations in the wetland; plant survival rates after flooding and drought; biomass and C and N content in plants [3].
Ton Duc Thang University (Vietnam)	- Wastewater treatment using wetland roof systems [4].
Technical University in Brno (Czech Republic)	- Purification of gray water through the wetland and subsequent use of water for irrigation of green roofs [5].
Helmholtz Centre Leipzig (Germany)	- Rainwater supply without added fertilizer and with added fertilizer. - Longevity of wetland plants with intermittent irrigation, suitability of vegetation. - Hydroaccumulation, gray water treatment, cooling effects. - Transport/degradation of pollutants [6].

From the existing publications, the wetland roof appears to be a more advantageous modified green roof and suitable for our climatic conditions. However, the implementation of an in-situ experiment is key to the correct design of the structure and maintenance of a wetland roof in Slovakia. Therefore, an experimental wetland roof was considered, on which the course of temperatures in the individual layers of the composition will be monitored throughout the year. The aim of the paper is to present the genesis of the preparation and realization of the experimental wetland roof in Slovakia and to interpret the knowledge regarding the maintenance of this type of roof. Moreover, the paper focuses on the course of surface temperatures of a classic green roof and a wetland roof during typical hot summer days without precipitation.

2 Materials and methods

As part of the greenIZOLA project, which is aimed at the green conversion of a building located in an industrial zone [7], three wetland roofs were created. These roofs represent a sample, to verify the functionality of the roof and possibly optimize the initial design. One of the roofs is equipped with measuring infrastructure and is used for research purposes.

The experimental roof is located on the southern terrace of the fourth above-ground floor of the IZOLA Košice, s.r.o. building in Košice, Slovakia. According to Köppen–Geiger climate classification [8] the climate of Slovakia can be classified as Cfb Climate; a warm temperate humid climate with a warm summer.

The research is focused on comparing the interaction of the water element (wetland roof) and the classic green roof with the building over the course of the year using in situ measurements. Figure 1 shows the methodology of research, which is divided into three phases. The first phase consists of studying the available literature on the issue of wetland roofs, setting the research goal, consulting with vegetation specialists, placing the experimental roof, designing the roof, and choosing measuring devices. The realization of the experimental roof, implementation of measuring devices, calibration, and data collection itself during all seasons are parts of the second phase. The third phase consists of the analysis of the obtained data using complex tools of descriptive statistics and the subsequent interpretation of new knowledge for the scientific field, the educational sphere, and technical practice. Currently, the research is at the beginning of the third phase, when the gradually obtained information from the operation of the experimental roof is evaluated.

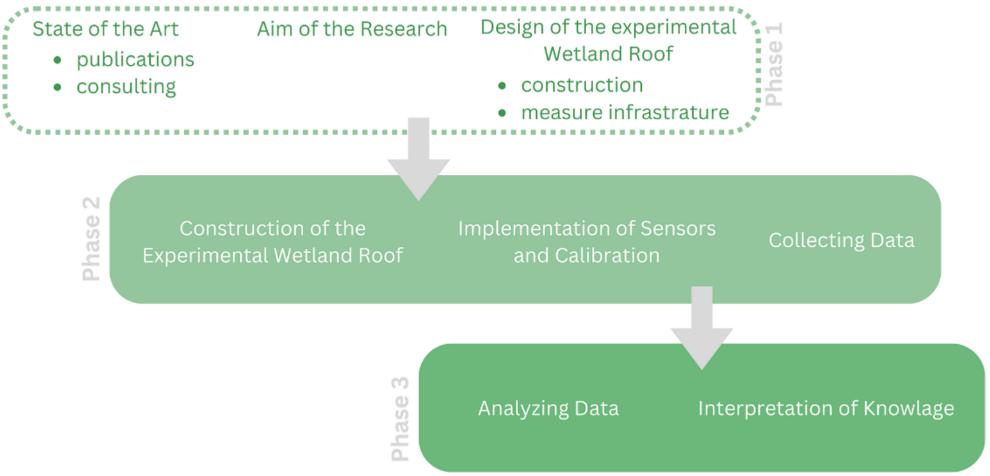

Fig. 1 Research methodology.

 https://doi.org/10.1051/e3sconf/202455001018

2.1 Design and implementation of a wetland roof in Slovakia

Based on the studied literature and consultation with a local botanist, a design of a prototype wetland roof was created, which should handle our climatic conditions and at the same time does not danger the statics and operation of the building.

In May 2022, the first wetland roof was made on the building, on the southern experimental terrace. On the second floor, on the north and west terraces, two more wetland elements were created in May 2023. For all three elements, the roof was finished with waterproofing resistant to root growth and the implementation procedure consisted of the same steps. The "body of the wetland" consists of a steel frame (Fig. 2 – A2, B2, C2), where polystyrene risers were installed around the perimeter. Subsequently, the space was lined with pond film, and a stone film was applied to the edges (on the wedges) (from an aesthetic point of view, but also to better hold the substrate mixture on the sides). The inside was filled with a substrate mixture, where vegetation was planted, and river gravel was poured between it. The last step was filling the space with water (Fig. 2 – A3, B3, C3).

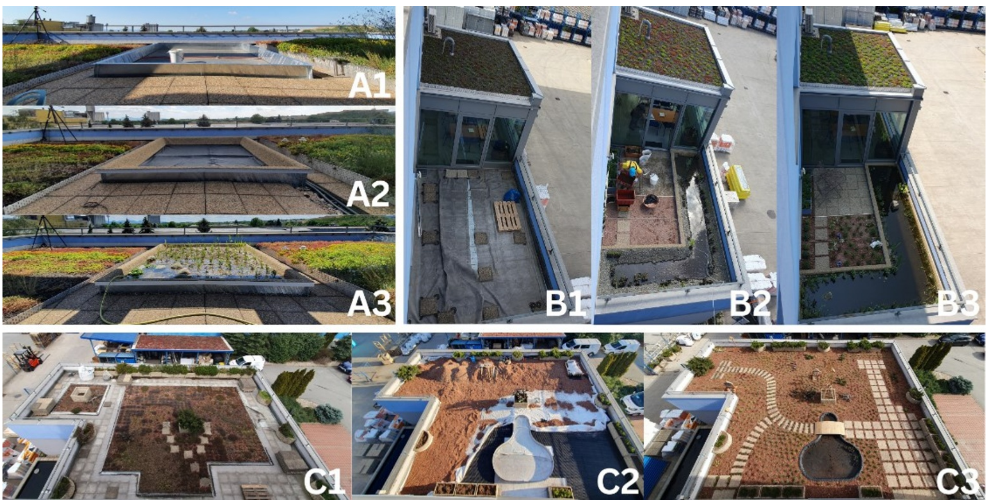

Fig. 2 Photos from the construction of wetland elements. A – the experimental wetland roof, B – the wetland on the western terrace, C – the wetland on the northern terrace; 1 – original state, 2 – installation of the "body" of the wetland, 3 – after completion.

The difference between the three wetland elements is in the shape, orientation, ratio of substrate and water, distribution of the substrate, and the vegetation. The first experimental wetland roof on the fourth floor is oriented to the south side with an area of 10.7 m^2 (Fig. 3 – A). The thickness of the substrate mixture layer is 120 mm. Due to the slope of the terrace, the water level in the wetland is uneven. Only wetland plants that are found in Slovakia were applied since this is a pilot roof. The experimental roof has built-in measuring devices (Chapter 2.2). The wetland roof on the western terrace is L-shaped with an area of 11.3 m^2 and is oriented to the west (Fig. 3 – B). Moreover, it is partly shaded by an extension from the south side. The substrate is unevenly distributed and foreign plants that could survive in our climate were also planted. In this case, the wetland is replenished with excess water from the roof of the extension. The wetland element on the northern terrace with an area of 7.7 m^2 (Fig. 3 – C) contributes to the diversity of the biodiverse green roof. Most of the day, the building casts a shadow over the wetland. Combined vegetation of domestic and foreign species was also planted in the unevenly distributed substrate. The wetlands on the second floor are used exclusively for visual comparison - they are not equipped with a measuring infrastructure. In the framework of visual comparison, the state of vegetation, the spread and dominance of species and the possible occurrence of fauna are observed.

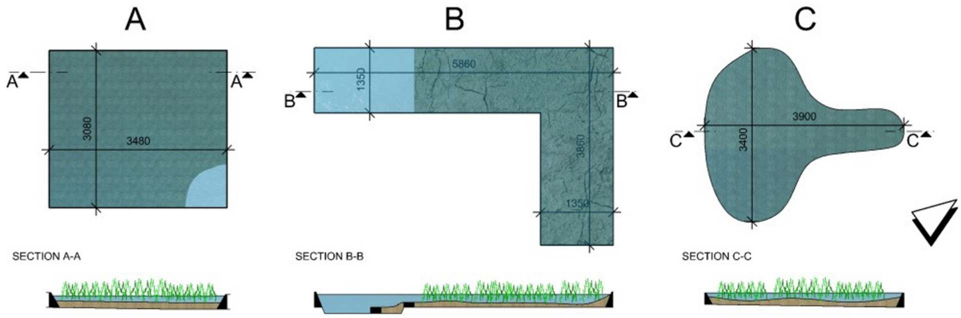

Fig. 3 Schemes of three wetland elements on the building (floor plan shape and section).

2.2 Measurement infrastructure – southern (experimental) terrace

The first experimental wetland roof was made on an already existing experimental roof. This roof was divided into three test segments: a green roof with a substrate thickness of 120 mm (TS I.); a reference roof with a gravel layer (TS II.); and a green roof with a substrate thickness of 240 mm (TS III.). In May 2022, the test segment TS II. (representing the reference roof) was replaced by the composition of the wetland roof. The roof was already equipped with a certain measuring infrastructure, and when the segments were replaced, it was supplemented with additional measuring devices. Currently, the roof is equipped with a CGR4 pyrgeometer, an Ahlborn FLA 628 S pyranometer, and an Ahlborn FMD760 weather station for recording external climate parameters (temperature and relative air humidity, atmospheric pressure, wind speed and direction, solar radiation intensity, amount, and intensity of atmospheric precipitation). Thermocouples Pt 100 for recording the course of temperatures (under the ceiling slab; under the thermal insulation; on the waterproofing layer; in the substrate; on the surface of the substrate) and plates for measuring the heat flow density (under the ceiling slab and on the waterproofing layer) are installed in every three test segments.

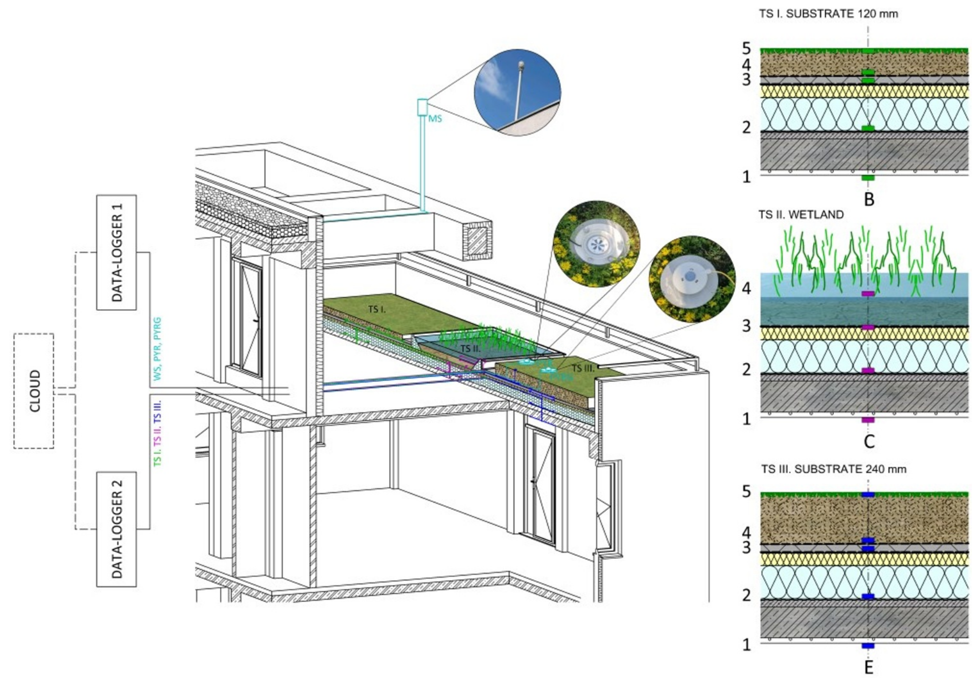

Fig. 4 3D section of the southern experimental roof with the connection of measuring infrastructure.

All the measuring devices are connected to the data loggers, which are located in the room next to the roof (Fig. 4). The measurements take place as a two-circuit with minute recording, the first circuit records external parameters and the second circuit records selected physical quantities in the layers of individual segments.

3 Results

Realized wetland roofs bring new knowledge not only from the point of view of the synergy of vegetation units with the building and the surroundings but also information about their necessary maintenance and possible optimization of the design and equipment of the roof.

3.1 Wetland roof maintenance

The first experimental wetland roof has completed its first year-round operating period (Fig. 5), based on which it was possible to monitor the maintenance required by the roof in our climate. This roof is not completely maintenance-free, it is necessary to perform certain actions, not on a daily basis, but seasonally, in some cases monthly. Figure 5 shows the state of the wetland on the roof in four seasons.

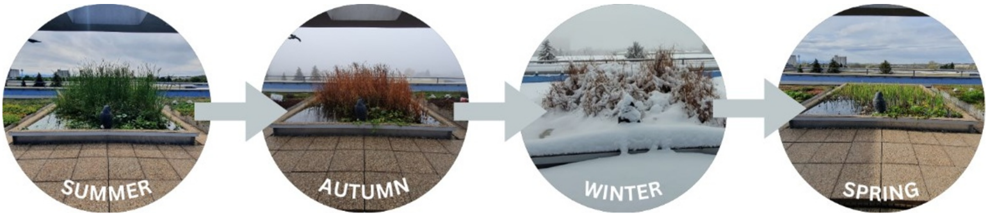

Fig. 5 Annual cycle of the experimental wetland. Summer 2022, Autumn 2022, Winter 2023, and Spring 2023.

After planting the vegetation, it is advisable to help the plants by adding fertilizer to the water (organo-mineral fertilizer with humic acids). Algae may develop, which will gradually settle. In the case of a large overgrowth, it is necessary to remove these algae. During warm days without precipitation, it is necessary to check the water level (or water source) more regularly to avoid completely drying out. It is optimal to have a system installed that informs about a water drop. Wetland plants are resistible during the dry season, but even they have their limits. If the visible water level is lost, the vegetation still has a source from the accumulated water in the substrate mixture. However, if there are no precipitations, it is advisable to top up the water at a certain time. During the fall and winter, the wetland roof can make do with the water left on the roof and moisture from the surrounding area. Besides, wetland plants obtain nutrition from emissions, dust, and precipitation from the surrounding area. In winter, the vegetation goes into hibernation and ice can form on the surface of the wetland. For this reason, the structure must be flexible, to avoid degradation caused by forming the ice. In the case of using an irrigation system, the system must be switched off when the temperature drops below 3°C. During the period when there is an ice shell on the wetland, it is advisable to cut the vegetation at least 5 cm above the surface of the ice. Thus, the vegetation has space for new flowering in the spring. In the spring, the vegetation blooms anew. It is also necessary to control the spread of individual types of planted vegetation. Some plants can be more penetrating and thus oppress other species, eventually causing complete extinction.

3.2 Surface temperatures of vegetation units

A typical summer period without precipitation was analyzed when the outside air temperature grew above 30°C. The graph shown in Figure 6 represents the course of surface temperatures on a green roof with a substrate thickness of 240 mm (TS III.) under the vegetation and a wetland roof (TS II.) under vegetation and water. The red curve shows the course of outdoor air temperatures, the dark blue course of surface temperatures on the TS III substrate (Fig.4 position 5), and the light blue course of temperatures in the water of the wetland roof (Fig.4 position 4) in °C. Solar radiation intensity is shown in gray at the bottom of the x-axis in W/m^2.

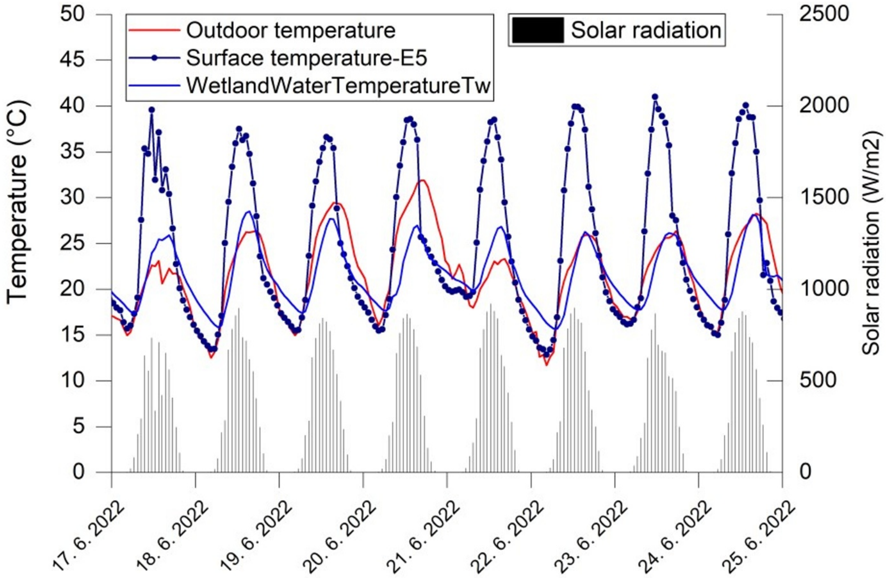

Fig. 6 Measured fluctuations of outdoor air temperatures, surface temperatures of test segment II. (green roof) and test segment III.(wetland roof) and amount of solar radiation for the period July 17 to July 24, 2022.

During the analyzed 8 days (July 17, 2022 to July 24, 2022), the maximum daily air temperature was around 32°C, and the lowest daily air temperature was 12°C. Only for 2 days the maximum daily air temperature dropped below 25°C. During these days, there was zero precipitation.

The warm season had a significant effect on the course of surface temperatures of the green roof. Since this is a period without precipitation, the roof did not have enough water to cool the roof surface using the evaporation process. The graph shows a gradual increase in the sinusoidal course of temperatures during the longer duration of drought and heat. The surface temperature reached a peak of 41°C on 23.06.2022. After reaching the air temperature maximum, the surface temperature began to cool. During the evening, the accumulated temperature was gradually transferred to the surroundings, thus cooling the surface. In some cases, it even cooled below the temperature of the outside air.

However, the temperature course of the wetland roof was significantly smaller than that of the green roof. Maximum daily temperatures ranged from 25°C to 28°C. Only in two cases, the temperature of the wetland roof was higher than the outside temperature, and when the air temperature dropped below 25°C.

The graphs clearly show that the wetland roof, due to the permanent presence of water, has significantly lower temperatures on the surface than the green roof, which is not irrigated. In some cases, it has a temperature almost twice as high as that of a wetland. In terms of creating cooler surface areas, a wetland roof is more advantageous.

4 Conclusion

Wetland roofs are an achievement of the last 30-40 years. However, there are few such roofs, and researches are mostly focused from a botanical and environmental point of view (Germany, China) nowadays. For the optimal design and implementation of the wetland roof in our climate, three wetland elements were created on the terraces of the IZOLA Košice, s.r.o. building. One wetland roof is equipped with a measuring infrastructure, the remaining two wetland roofs are used for visual comparison and as a design complement to the roof. The wetland roof appears to be a suitable modified variant of the green roof for our climatic conditions. After a year of operation, the roof is thriving and there has been no loss of vegetation. Moreover, a wetland roof is just as advantageous as a green roof, even more advantageous in some cases. Since its surface is covered by water, the surface temperatures are significantly lower than the surface temperatures of the green roof during hot days without precipitation. However, the wetland roof is not completely maintenance-free, it is necessary to check the water level, or allow water in, remove unwanted vegetation, and cut back the vegetation in winter. During the summer of 2022, it was necessary to add water to the wetland roof four times. Realized wetland roofs create space for a multidisciplinary connection of technical and natural sciences. As such cooperation is required in the creation of elements of green infrastructure. With the help of in situ measurement, it is advisable to examine the wetland roof in terms of the suitability of plant species, the impact of the wetland on the building structure, the impact of the wetland on the surrounding environment, the rate of CO_2 capture, the rate of gray water purification.

This work is supported by project no. 101056201 SECOVE – "Centers of professional excellence for sustainable energy" co-financed by the Erasmus+ program of the European Union and the project of the Ministry of Education of the Slovak Republic VEGA 1/0492/23 "Transformation of existing buildings into sustainable buildings - the ecological potential of flat roofs".

References

1. Zehnsdorf A. et. al, Wetland roof as an attractive option for decentralized water management and air conditioning enhancement in growing cities. Water **11**, (2019)
2. Wetland roof – Israel. [online] Available: www.greenroofs.com/projects/wetland-roof-israel/ [cit.12.9.2023]
3. Song U. et. al, Wetlands are an effective green roof system. Build Environ, Vol. **66**, pp. 141-147, (2013)
4. Vo T.D.H. et al, Improvement of septic tank effluent and green coverage by shallow bed wetland roof system. Biodeterior Biodegradation, Vol. **124**, pp. 138-145, (2017)
5. Petreje M. et al, Performance study of an innovative concept of hybrid constructed wetland-extensive green roof with growing media amended with recycled materials. J Environ Manage, Vol. **331**, pp. 117-151, (2023)
6. Helmholtz Zentrum für Umweltforschung, Sumpfpflanzendächer. Projekt Forschungsgründach. (2019)
7. Čakyová K. et al., *The concept of the green industrial zones*, in Proceeding of the 3rd International Scientific Conference EcoComfort and Current Issues of Civil Engineering, EcoComfort 2022, 14-16 September 2022, Lviv, Ukraine (2022)
8. World Maps of Köppen-Geiger climate classification. [online] Available: https://koeppen-geiger.vu-wien.ac.at/present.htm [cit.12.5.2024]