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Abstract. Fashionable eco-friendly lifestyle increases the interest in green roofs. The subject of this article is to present problems as well as the benefits of using green roofs. The purpose of this article is to describe the advantages of using green roofs. The advantages are both ecological and what's very important today - also economic and aesthetic. In order to be objective, we also need to talk about the drawbacks of this type of construction investment. This study may be helpful in answering the question of whether it is worth following the new trend and using green roofs. The article makes it easier to consider all pros and cons.

1. Introduction

Part of the plot, which remains free of buildings, is called a biologically active area. It is an area with a natural surface arranged in a way that ensures natural vegetation. Investors are looking for solutions that will provide a compromise between the demand for buildings and the protection of the natural environment. Green roofs are a solution that meets the principles of this compromise, which give the opportunity to obtain valuable biologically active areas.

Research in the field of green roofs are not numerous. Among them: paper [1] presents a mathematical model yielding a representation of the dynamic thermal behaviour of actual green roofs. Several parametric sensitivity analyses have been carried out to assess the cooling potential of green roofs in summer. The main conclusion of these analyses is that green roofs do not act as cooling devices but as insulation ones, reducing the heat flux through the roof.

Paper [2] discusses the thermal effect of covering the building envelope with vegetation on the microclimate in the built environment, for various climates and urban canyon geometries. The climatic characteristics of nine cities, three urban canyon geometries, two canyon orientations and two wind directions are examined. The effects of temperature decrease on outdoors thermal comfort and energy savings are examined. Conclusions drawned on whether plants on the building envelope can be used to tackle the heat island effect, depending on all parameters taken into consideration.

Paper [3] it contains of research has been on the reduction of rainwater runoff for different types of roof greening. The derived empirical models allowed to assess the surface runoff from various types of roofs, when roof characteristics and the annual or seasonal precipitation are given. The application of the derived annual relationship for the region of Brussels showed that extensive roof greening on just 10% of the buildings would already results in a runoff reduction of 2.7% for the region and of 54% for the individual buildings.

Green roofs are a passive cooling technique that stop incoming solar radiation from reaching the building structure below. Many studies have been conducted over the past 10 years to consider the potential building energy benefits of green roofs and shown that they can offer benefits in winter heating reduction as well as summer cooling. Paper [4] highlights the situations in which the greatest building energy savings can be made.

The level of air pollution removal by green roofs in Chicago was quantified using a dry deposition model. Paper [5] showed 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%), PM10 (14%), and SO_2 (7%). The green roof can be used to supplement the use of urban trees in air pollution control, especially in situations where land and public funds are not readily available.

Paper [6] describes the life cycle environmental cost characteristics of intensive and extensive green roofs versus conventional roofs. The green roof design for the case study presented here is from an actual 1115 m^2 (12,000 ft^2) green roof project on a retail store in Pittsburgh, PA, USA. The study found that, for the Pittsburgh, PA climate, the energy use reduction that is realized because of the lower thermal conductivity of the roof due to the green roof growing medium is the critical factor in determining the relative magnitude of the environmental impact of the alternatives compared here.

Paper [7] attempts to evaluate the positive effects of vegetation with a multi-scale approach: an urban and a building scale. Monitoring the urban heat island in four areas of New York City, founded an average of 2°C difference of temperatures between the most and the least vegetated areas, ascribable to the substitution of vegetation with man-made building materials.

Green roofs have several environmental benefits, such as improving building energy efficiency. Paper [8] provides a comprehensive study of the impact of a green roof on building energy performance. A model of green roof thermal behaviour was coupled with a building code to allow the evaluation of green roof foliage and soil surface temperatures. Simulations were conducted for a single-family house with conventional and green roofs in a temperate French climate. The impact of the green roof on indoor air temperature and cooling and heating demand was analyzed.

Article [9] discussed various types of green roofs, components of a green roof, economic revenues, and technical attributes. Many general advantages and few general disadvantages of green roofs in one hand and pros and cons of green roofs with respect to energy utilization on the other hand are also synthesized.

In search of the most effective solution to reduce the energy consumption in buildings or minimize the contribution of the Urban Heat Island (UHI) effect, article [10] proposes a comparison between cool roofs and green roofs for several Italian cities that are representative of different climatic conditions.

Research centres around the world focus on the benefits and problems of green roofs. Research is carried out in test stations to help better understand and appreciate the benefits of this kind of roofing. This article discusses the problems and benefits of using green roofs. The benefits are many - both economical, ecological and aesthetic. There are however, also disadvantages.

2. Advantages of green roofs

The Waterproofing protection - extending the durability of the roof

The use of green roofs extends the durability of the building, which also means that its use is less expensive. With traditional roof covering, the annual temperature fluctuations reach up to 100°C, which greatly affects the durability of the materials from which the roof covering made. This necessitates frequent repairs and therefore increased operating costs. Green roofing protects waterproofing from overheating in summer and too low temperatures in winter. The annual temperature fluctuations with such solutions are only about 300°C, which is more than three times lower than in traditional roofs (Figure 1).

Figure 1. Temperature difference between green roof and traditional roof - Chicago City Hall [11].

This is confirmed by research conducted by, among others, Karen Liu, PhD, at the Canadian National Technical Research Centre. Measurements were conducted on the BCIT GNW campus, Vancouver, on a roof of approximately 100 m^2. The roof was divided into three parts, each with a different cover. The first one is the reference roof with traditional cover (REF) and the other two are green roofs: one covered with a 7.5 cm substrate layer (GR-1) and the other with a 15 cm thick substrate layer (GR-2). Temperature readings show that their daily fluctuations in waterproofing of green roofs were even several times lower than on the reference roof. This phenomenon is more evident in spring and summer. For these seasons, the average daytime fluctuation of the roof waterproofing temperature was about 5°C, while the traditional roof exceeded 40°C. Green roofs protect waterproofing against high thermal stresses and consequently significantly increase its durability.

Table 1 shows that the temperature of 20°C was exceeded on the reference roof in 257 days of the year (70% of days), whereas on green roofs temperature above 20°C was observed in 121 days - in the case of GR-1 cover, and only 68 days - in the case of GR-2 cover. Moreover, on the traditional roof temperatures above 600°C were observed (41 days), while on the green roof during this time it did not exceed 350°C [12].

Table 1. Temperature frequency. Source: own study based on [12].

Temperature greater than:	Green roof GR-1		Green roof GR-2		Reference roof REF	
	Number of days	Percentage of days	Number of days	Percentage of days	Number of days	Percentage of days
20°C	121	33	68	19	257	70
30°C	5	1	0	0	206	56
40°C	0	0	0	0	158	43
50°C	0	0	0	0	100	27
60°C	0	0	0	0	41	11

Such a large variation in the temperature recoded on both types of roof is a result, among other things, of the additional insulating masses in the form of the green roof layers. In addition, plants shade the roof and simultaneously absorb sunlight, using it to synthesize organic compounds. Evapotranspiration, i.e. evaporation of water from plant cells and soil, which contributes to lowering temperatures, is also important.

Green roof covering not only protects waterproofing against overheating and freezing and rapid temperature changes. It also provides protection against the damaging effects of wind, hail, UV radiation. Thanks to that, the layer lasts longer, does not require frequent repairs, which improves the economics of using the roof.

Thermal insulation

Another aspect of research conducted by the Canadian National Technical Research Centre was the comparison of the thermal insulation of green and traditional roofs (Figure 2). The diagram shows that the thermal insulation of both tested green roofs has similar values, but they differ significantly from the thermal insulation of the traditional roof. In summer and spring the flow of heat through the green roof is up to 80% smaller than in the case of the traditional roof. In winter and autumn the differences are no longer as significant, about 40%. Thanks to the green roof covering, the investor can save a great deal of money every year - on the costs of air conditioning in the summer and heating in the winter.

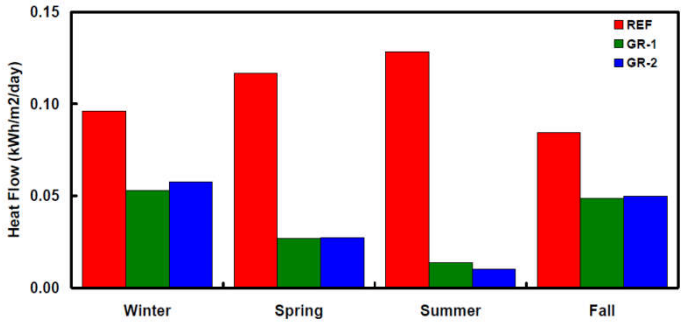

Figure 2. Average daily heat flow through the roof at particular times of the year [13].

Biologically active area

Another way to reduce the cost of a construction investment, or even the possibility of its implementation on a very limited area, is to install a green roof that is considered by the law to be biologically active. At present times the price of building plots are high, so it may be more profitable for an investor to purchase a smaller plot and green the roof of the planned building instead of purchasing a larger one and having the ability to build up the same area. In addition, in urban agglomerations, investors are forced to operate on a very small area where their planned building would not meet the required greening ratio if not for the possibility of creating a biologically active area on the roof. According to the Regulation of the Minister of Infrastructure on the technical conditions to be met by buildings and their location, we can count 50% of the area of the terrace and the roof space as a biologically active area, however their area cannot be less than 10 m^2. In summary: By using a green roof, you can build a larger building while maintaining the required area ratio of the biologically active area. Often this is the main reason for building buildings with green roof covering in cities.

Growing on the roof

Another advantage of green roofs is the ability to use them for growing flowers, herbs, vegetables or fruits. The Fairmont Hotel in Vancouver has allocated nearly 200 m^2 of roof space to be a garden, the produce from which is used in the hotel restaurant. The cost of producing vegetables, fruits and flowers is much lower than the cost of purchasing them. You do not have to pay for the transportation and storage of these products. This brings about $20,000-25,000 of savings per year. In addition, the plants are always fresh and available at all times, and the garden is part of an advertising campaign and a kind of attraction of the hotel.

Prestige

Another advantage of green roofs is their undeniable marketing value. A building covered with such a roof gains prestige, its attractiveness increases, which translates into its price and demand in the real estate market. In the case of industrial buildings and office buildings, a green roof attracts interest and gives a positive image of the company or institution that applied it. This does not translate into financial value, but builds the prestige of the company. It testifies to its care not only for economics but also for the environment.

Place for recreation

City dwellers feel the need for contact with nature. In order to enjoy its beauty they are often forced to travel considerable distances. This possibility is often limited for both temporal and financial reasons. Green roofs on the buildings in which they live allow them to interact with nature at any time of the day without having to travel long distances. They will not replace a real green forest, but at least give a semblance of one.

Stopping and purifying rain water

Green roofs help solve the problem of overloaded sewage networks. Rapid rainfall and the use of materials causing rapid outflow of rain water in more and more areas often causes the flooding of streets, from which storm sewers are unable to remove the excess. According to Paweł Kożuchowski [14]: "While the water runoff coefficient [ψ] from the conventional roof surface equals 1, its value for the green roof is three times lower and equals 0.3." Rain water that has to filter through several layers of a green roof to reach the sewer on its way is stopped by the substrate, the drainage and storage layer and absorbed by the vegetation. The amount of water retained by the green roof depends on the time of the year, the depth and the humidity of the substrate. The design of the roof is also important: the number of layers, the slope and the type of plantings. However, this type of roof always retains a significant part of the precipitation.

The use of green roofs can significantly reduce rain water drainage. Another plus is that less water is directed to the sewage treatment plant, so there are some savings here as well. In some countries where you pay for the drainage of rainwater, green building administrators are exempt from this part of the fee. In addition, green roofs clean the rain water. They can intercept harmful elements like lead and cadmium, even in 90%.

Fire protection

Green roofs were used as a barrier already in the 19th century, in German industrial districts, where close buildings created a fire hazard. On roofs with intensive greening, planting takes place on a thick substrate layer and often irrigation is also used. Thanks to that, plantings are protected from both fire and heat radiation, i.e. they are flame retardant. Extensive roofs are such where the substrate layer exceeds a thickness of 3 cm and contains no more than 20% of organic components. With larger planting surfaces, it is necessary to create barriers about every 40 m, e.g. using gravel strips. In addition, it is necessary to lay gravel strips, about 50 cm wide, in front of walls with holes, and in front of holes in the roof itself, to prevent the spread of fire. The use of this type of cover increases the safety of the residents, as it protects against fire to a certain extent.

Reducing urban heat islands

Another problem of urban agglomerations, which can be partly solved with green roofs, is the effect of heat islands. This is a phenomenon of the occurrence of higher temperatures in city centres than on their outskirts. This is due to the accumulation of sources of heat pollution and increased radiation. Effective radiation of energy by urban areas is hampered by their specific building development. Much of the heat radiating from the streets and building walls is absorbed by the surrounding buildings. This is conducive to the large heat capacity of building materials and reduced

wind speed in the dense, urban development. This leads to the accumulation of solar energy delivered to the city during the day and its release at night. The greatest temperature difference between the city and the countryside is observed during clear, cloudless nights. In large cities in America, in favourable weather conditions, these differences are as high as 12°C, while in European cities they usually reach 10°C. In Poland, a well-developed urban heat island reaches an intensity of 5-8°C [15]. Heat islands have a negative impact on the human body. On hot days, they reduce the comfort of living in the city, cause the phenomenon of mugginess, dyspnea, can lead to overheating of the body in older people. The green areas in cities are increased in order to reduce the impact of heat islands. Lawns, squares and parks are set up, and green roofs in places lacking space. In summer this has an effect on lowering the air temperature. Plants shade the substrate, resulting in less sunlight reaching it. This decreases both the absorption and the subsequent heat release. In addition, green areas collect less sunlight than streets and buildings during the day. They also contribute to the increase of air humidity and its circulation. This greatly improves the comfort of living in the city.

Air purification

In cities where air pollution is particularly high, vegetation plays a very important role (Table 2). The air is cleaned, moisturised and ionised thanks to vegetation.Plants stop dust and dirt, absorb CO_2, SO_2, O_3, NO_X, and produce oxygen. Pollution in a park can be as much as 20-40% lower than in other areas of the city. The area of about 1.5 m^2 covered with unmown grass produces as much oxygen per year as the annual requirement of one person. Consequently, there should be as much vegetation as possible in the city. Unfortunately, development conditions do not always favour the establishment of many parks or squares. Green roofs, where the planted vegetation could perform the same function, could be a valuable addition.

Table 2. The effect of grass roofs on air quality.
Reductions in contaminants and monetary impact [13].

	CO	NO_2	O_3	PM_{10}	SO_2	$USD
Mg per 109.386 ha of green roof area per year	0.35	1.6	3.14	2.17	0.61	42.106

Biodiversity

Green roofs in cities where there are fewer parks and green areas provide space for local fauna and flora. Of course, they must be properly designed - the substrate should be enriched with local soil and its layer should be varied in thickness. Planted plants should be of the type found in the given area. It is advisable to place branches, boughs, stones on the roof, enriching the biodiversity. Such a roof can be a place of rest for migratory birds and also a natural insect environment. In the era of great care for the environment, this feature of green roofs is quite important.

Noise

Noise is considered to be a factor that significantly impairs the comfort of life. It has a negative impact on people. It may cause fatigue, distension, headache, nausea, sleep disorders. The degree of its impact depends on intensity, frequency and duration. Green roofs provide a barrier to noise - sounds are partially absorbed and dissipated. The substrate suppresses the lower frequency noise and the upper frequencies are blocked by the vegetation. A green roof with a substrate layer with a thickness of 12 cm can reduce noise by 40 dB. By increasing the thickness of this layer to 20 cm, the result of 46 - 50 dB is achieved [16]. This way, traffic noise is somewhat reduced.

Aesthetics

The undeniable aesthetic qualities of green roofs are very important. In some cases, for example, in the Faroe Islands, slanted, grass-covered roofs have been used, which not only do not spoil the beauty of the surroundings, but emphasise it. In the cities, roof gardens make the landscape more beautiful and varied. They surprise us with greenery among all the concrete and glass. Many of them are even tourist attractions, such as the roofs of the Rockefeller Centre in New York or the Warsaw University Library. In Vienna, tours are held at the Hundertwasser House, where not only the roof is green, but the greenery pours out of the windows. The added advantage of such solutions is that they bring joy to the eyes of residents of neighbouring buildings. These gardens are also attractive because of the panoramic view of the city. They are an interesting element of urban development and reduce the negative effects of urbanization. As we can see, among others, in the "Green Spaces, Better Places" report [17], green spaces have a positive impact on quality of life, bringing social, economic and environmental benefits.

The market of green roofs in Poland is just developing. Designers and investors are increasingly relying on this type of solution, so it can be concluded that the advantages of this type of roof have been recognised. The benefits of using green roofs are confirmed by numerous scientific studies, although mostly from outside of Poland. Due to lack of domestic research, designers are forced to rely on German or American experiences. Although the latter do not always correspond to our climatic conditions, they are still convincing in promoting the use of these types of roofs, indicating their superiority over traditional ones in terms of ecology, comfort, and economics. The advantages of green roofs vary and depend on many factors. They will vary depending on whether the roof is flat or slanted, whether it is intensively or extensively green. There are different expectations for roofs covering buildings in cities and different in other areas. In every case, however, we can distinguish a whole range of advantages, but unfortunately we can also find disadvantages.

3. Disadvantages of green roofs

High cost of construction

The biggest disadvantage of green roofs is their cost, far exceeding the cost of traditional roofs. This is because of their specific design. It consists of many more layers than the traditional roof, and in addition they are made of expensive, often imported materials. We also need to consider the cost of developing an additional design of such roof cover. The price of the roof also depends on the type of roof - intensive greening demands greater financial investment. The cost of construction of any building consists of the costs of labour, materials and equipment. A green roof, in addition to the layers identical to a traditional roof, has a few extra ones, which causes more material to be used for its construction, thus increasing the financial outlay. It is important to note that these materials are expensive, must be of the highest grade, and often more reliable, imported materials are used. Tables 3 and 4 mention these specific, additional materials used to construct the green roof and their average net prices. Two types of roofs are considered: extensive and intensive, which also allows to show the price difference between these roofs. The study was based on commercially available solutions from companies engaged in introducing and distributing green roof technologies on the Polish market.

Table 3. Materials for an extensive green roof.
Source: own study.

Layer	Net price [PLN/m^2]
Substrate 6 cm	21
Filtration non-woven	4
Drainage mat	46
Spill absorbent protective mat	13
Anti-root foil	13
Total	97

Table 4. Materials for an intensive green roof.
Source: own study.

Layer	Net price [PLN/m^2]
Substrate 25 cm	103
Filtration non-woven	4
Drainage mat	98
Spill absorbent protective mat	30
Anti-root foil	15
Total	250

It can be seen that the greatest price variation is due to the amount of substrate used and the type of drainage planned. Note that the price of 1 m^2 of one and the other roof will be higher than the tables indicate, because the material consumption factor should also be taken into account. Foils and geotextiles are counted with the required overlap and turning up against the wall, and for the substrate the compaction and mineralization factor is assumed. The price of vegetation, which will be applied to particular roofs, is not included, but is not low, especially in the case of intensive greening. The costs are also increased by the required additional components such as drains, gutters, inspection chambers, gravel strips, not to mention structural landscaping. They must be calculated individually depending on the size of the roof, its shape, location and intended use. A complete material inventory would make it difficult to make a comparative assessment of the cost of 1 m^2. When calculating the cost of such a roof, the labour price should also be taken into account, which may also be high due to the degree of difficulty. To make an accurate green roof price calculation, we need to know its size, type, location and to breakdown the costs into three separate groups: materials, labour, equipment.

Big weight

Another downside to a green roof is its weight. It is much higher than a traditional roof. For this reason, the structure must have increased load capacity, which again increases its weight. The weight of 1 m^2 of the lightest extensive green roof made with special lightweight substrate is about 40 kg, which is roughly the same as the traditional tile-covered roof. This is a special case, as the weight of this type of cover usually ranges from 150 kg/m^2 to 250 kg/m^2 when gravel drainage is used. Intensive green roofs are much heavier. This is due to the greater number of substrates used and the weight of the taller plants (shrubs, trees), as well as the structural landscaping. It is assumed that the weight can

range from 300-400 kg/m^2 up to 800 kg/m^2 in the case of fully usable intensive green roofs. The excessive load of the green roof often makes its installation on an existing building impossible.

The need for systematic care and associated costs

Each roof has different requirements, depending on the plants planted. Expansive green roofs are less absorbent and expensive - the plantings are cheaper and after the acclimatization period require less care. It is enough to remove weeds on average twice a year and check the flow capacity of water receivers. Intensive green roofs are much more expensive to maintain. Plants must be systematically watered, fertilized and nurtured. They often require the care of a specialist gardener to ensure that they grow properly, are protected against diseases, pests and weeds. In addition, it is necessary to maintain good technical condition of the drainage system. Drains, gutters and gravel strips have to be systematically controlled.

Flaws caused by errors

Green roofs are also accused of such disadvantages as leakage, condensation of water in the thermal insulation layer, or moulding of their bottom surface. These are not disadvantages, but rather the results of errors made during the design or construction of the cover. The specificity of green roofs, the fact that they constitute a type of water storage, causes that even the slightest deviations result in big losses. Thoughtful design and professional and careful construction ensure the reliable use of such roofs.

4. Conclusions

Green roofs have been appreciated by humans since almost always [18]. Initially they only constituted protection against unfavourable weather conditions, but over time humans began to notice more and more value and possibilities of using this kind of roof cover. Their properties are studied by many researchers. Numerous studies and experiments allow us to confirm the advantages of green roofs. Not only do they protect from heat or cold, but they also have a major impact on improving the living conditions and functioning of the human body, which is not unimportant to one's health. They allow for leisure, recreation and contact with nature even in tightly-built cities. They protect against their bustle and reduce pollution. Green roofs create a good microclimate and, in addition, neutralise the effect of urban heat islands. Green roofs are not only very useful for the environment, they also have many aesthetic qualities. They improve the appearance of cities, give a chance to beautify the ugly, unused roofs of many buildings. It happens, however, that they are being built for other reasons, namely economic ones. Because they are considered as biologically active areas, they allow for the maximum use of the space reserved for development. They also provide savings in the operation of buildings themselves. These are not, of course, all the advantages of green roofs, just the most important ones.

Compared to the many advantages, the disadvantages of green roofs are very few. However, they are quite significant. The biggest and most discouraging one to investors is their high cost. Although traditional roofs are cheaper, in many ways green roofs are a better option. However, when making such investments, we must remember that they should be professionally designed and built. Even the smallest mistakes can have fatal consequences later on. The most dangerous are: leaks, dampness, moulding. Removing them is troublesome and costly. Unfortunately, we can encounter such errors in Poland. Green roofs have only been built in Poland for a dozen or so years. We still lack the experience, understanding of their specificity, and above all the diligence of implementation. Over time, this situation should improve. The green roof market is starting to grow and the interest in this type of roofing is increasing. Architects are coming up with increasingly bold visions of buildings which utilize greenery. We can assume that the history of green roofs is not yet closed, and the list of their advantages is not yet exhausted.

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