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Research Article

Theoretical Analysis and Comparison of the Thermal Performance, Construction Costs, and Maintenance Complexity between a Conventional and an Intensive Green Roof

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In this paper, a comparison between a conventional flat roof and an intensive green roof was made. Emphasis was on thermal conductivity of individual layers, the calculation of thermal resistance, and calculation of the thermal transmittance coefficient through both roof variants. The calculations for the two analysed roof variants were made for a building located in the town of Rijeka on the Adriatic coast. This paper also presents the construction technology comparison of the analysed roof variants. The construction cost was also analysed for both roof variants together with time needed for the execution of variant solutions. Finally, maintenance plans for both roof variants were presented in this paper. The results show that the construction costs of an intensive green roof are higher than the construction costs of a conventional flat roof and that the maintenance of the intensive green roof is more complex. On the other hand, the results of the analysis also show that constructing a green roof will result in more energy savings in the long term than in the case of constructing a conventional flat roof. In addition, there are several other benefits that go in favour of constructing an intensive green roof. Most prominent among those benefits are environmental and social benefits.

1. Introduction

New developments are often made at the expense of green areas [1] and green roofs are a sustainable solution to mitigate the effects of urbanization by replacing conventional roofs with vegetation and soil [2].

Today, the world is increasingly paying attention to sustainable construction due to increase in the consumption of energy and resources. In terms of environment green roofs are a better solution in comparison to conventional flat roofs [3]. Green roofs are and will continue to be components of construction that should not be overlooked [4].

Green roofs and green facades on buildings have been known for hundreds of years, but today they are increasingly attracting attention. More than 2,500 years ago, people built green garden shaped roofs on the roofs of their dwellings because they were aware of their insulation properties. However, the actual revitalization of this ancient concept was most clearly expressed by Friedrich Hundertwasser, pointing out that anything that lies horizontally under the open sky should belong to nature and that it should be possible to breathe in forest air in the city [5].

Modern green roofs draw their basic idea and concept from ancient builders; however, technological advancement has made modern green roofs far more efficient, practical, and more useful than their predecessors [6]. The first modern green roofs were constructed in Germany [6]. Recently, many countries (Sweden, Finland, Iceland, Denmark, and Norway) have seen a trend in the implementation of green roofs [7]. Recently, the coverage of green roofs in

Germany alone has increased by about 13.5 million m^2 per year, with green roof technology applied to about 10% of the total number of buildings [6].

Not only are green roofs and green facades a solution for the construction of new buildings but they can be an excellent solution for the reconstruction of existing buildings. Different authors assess the durability of green roofs and facades differently, ranging between 40 and 55 years [8]. As expected, application of green roofs is shown to be most suitable for buildings with reinforced concrete roof structures, as they can mostly withstand the additional burden posed by a flat green roof, which is precisely one of the obstacles to the application of green roofs [8].

Hidden oases on top of buildings around the world have become commonplace, namely, in the form of green roofs, by effectively using flat surfaces of buildings that have become gardens [9]. Green roofs are also called eco roofs, living roofs, or roof gardens, and they are basically roofs with plants on the top layer, originally built to improve the energy efficiency of buildings, but they also have many other advantages. In fact, their vegetation layer enables the photosynthesis process while their soil layer allows for the absorption of precipitation, which often results in an improvement of water runoff quality [4].

Since irrigation of vegetation on green roofs is necessary, notably during droughts, fog and dew water harvesting can be the answer to water shortages and they have the potential to be alternative water sources to urban water network supply. The productivity of fog harvesting is affected by wind velocity and type, shape, and wettability of the harvesting mesh, while the productivity of dew water harvesting along with wind velocity is also affected by relative humidity and dew condenser temperature [10].

Study [10] shows that fog harvesting mesh could increase stormwater management, decrease noise and air pollution, and create shaded areas to protect vegetation from direct sunlight.

The effect of urban heat island (UHI) explains why urban areas have higher temperatures than rural areas. The reason for this lies in darker colours of the final layers of flat roofs of buildings. Darker roofs absorb solar energy and can reach temperatures much higher than the ambient temperature [4]. This has a negative impact on energy consumption needed to cool down buildings. Rural areas are not exposed to this issue because of the vegetation given that trees and plants help control the temperature of the environment. The effect of urban heat island can be mitigated by the construction of green roofs in urban environments.

According to one of the definitions, the green roof is any open and vegetation planted area separated from the ground by a building or other structure [5]. They can mainly be divided into extensive and intensive green roofs [5, 9, 11]:

(1) Extensive green roofs are shallow and their soil (growing medium) is usually of lower quality and therefore they are only suitable for a limited number of plant species and use low demanding roofs, lawns, and gardens

(2) Intensive green roofs are often covered with high quality soil and more suitable for growing all plant species—high demanding roofs, lawns, and gardens

The thickness of the growing medium or substrate layer, amounting to about 30 cm, is considered to be crucial for this classification [7]. Extensive green roofs are lower priced with a limited choice of plants and a relatively thin layer of substrate and are designed to be almost self-sustaining and require minimum maintenance [12].

On an intensive green roof, however, various plant species can be planted [9]. Intensive green roofs require sufficient substrate depth and skilled workers for maintenance and irrigation. They are usually considered as roof gardens [12].

Extensive green roofs are lighter and suitable for large area roofs and the construction process itself is technically simple and allows application even on sloped roofs but the potential to improve energy performance and stormwater systems is relatively small [4].

Intensive green roofs enable the planting of different species and greater biodiversity, while creating additional space for different purposes on the building. Contrary to extensive green roofs, they have greater potential to improve energy performance and stormwater systems [4]. Their disadvantage is a higher construction cost and potential issues with the load bearing capacity structure on existing buildings.

Taking into account the extreme environment on roofs, the expected favourable vegetation characteristics for extensive green roofs are [6]

(1) Ability to withstand the conditions of dry periods
(2) Survive with a minimal amount of nutrients
(3) Possibility of a good ground cover
(4) As little maintenance as possible required
(5) Rapid plant propagation
(6) Short, soft, and noninvasive roots
(7) Phytoremediation (the ability of green plants to secrete and concentrate certain elements in the ecosystem, soil cleaning process)

Since green roofs have a positive effect on the reduction of indoor noise levels—although this has not yet been sufficiently researched, experts recommend constructing green roofs to the maximum extent possible within and around airports, factories, large garages, hospitals, schools, kinder gardens, shopping malls, and all locations where silence and temperature balance are applied as the main requirements. Green roofs can be constructed on any flat roof with proper waterproofing [9]. Out of all roofs with waterproofing in Croatia, only about 5% of them have green roofs, but the situation is improving because construction of green roofs has started on private houses and not only on hotels and shopping malls as was the case in the past [9].

Intensive green roof, type of green roof analysed in this paper, produces lower heat gain and loss and has better thermal performance due to the thicker level of substrate [4]. In addition, they also provide users an open, accessible space and a green environment within the building [12].

The aim and objective of this paper was to compare energy characteristics and cost and time estimate of the construction of a conventional flat and an intensive green roof by analysing characteristics and layers of both roofs located in the same climate and with the same surface area. Calculations were focused on thermal resistance and thermal transmittance coefficient through the building part. The analysis was intended to show the economic terms of construction, the construction time, and maintenance activities needed for both roof variants.

2. Literature Review of Conventional Flat Roofs and Green Roofs

A conventional flat roof is a structure composed of a series of layers of different materials and functions, which protect the underlying structure from water damage in addition to serving as a roof deck. External influence which presents the greatest risk to flat roof layers is moisture from rainwater [13]. In order to ensure rainwater drainage, flat roofs are designed and constructed with a slope from -5° to 5° [14].

Other external factors that can lead to damage or destruction of layers include snow and ice. Sudden changes in temperature during summer can cause small cracks in the material, ultraviolet rays can damage materials over time, and insolation and temperature oscillations (annual and daily differences) can cause additional stress in the roof structure. Internal factors include captured moisture (moisture generated during construction) which can also have an important impact, so care must be taken to ensure that it evaporates [15]. Flat roofs can be accessible to users (walk-through) or not accessible to users except for maintenance operations [14].

Regarding the arrangement of layers, they can be classified as single unirradiated (warm) roofs or double irradiated (cold) roofs. Single unirradiated (warm) roofs are composed of several layers laid on top of each other, and the position of the layers in the structure can be conventional, where all roof layers are protected by a final waterproofing layer [15] or inverted where the waterproofing layer lies beneath the thermal insulation. Thus, thermal insulation protects the waterproofing layer from expansion and contraction due to weather fluctuations (frost or solar radiation) and from damage caused by user foot traffic [16]. Double irradiated (cold) roofs are also composed of several layers laid on top of each other and the top layer is separated by irradiated space from other layers. The air space must be transversely ventilated with inlet and outlet openings. Cold roofs are seldom constructed due to being uneconomical and mainly in cases of increased insolation and higher indoor air humidity (>80%) [15].

Since flat roof is the most exposed part of the building, all layers placed on the load bearing structure of a flat roof have a vital role to protect and secure the integrity of the rest of the building [13].

Sloped concrete is a layer of lightweight concrete performed to achieve the required slope of the roof surface for the purpose of rainwater runoff. This layer is not needed when the load bearing structure is already inclined. Vapour barrier is a layer that prevents the penetration of water vapour through the load bearing structure into the thermal insulation layer and through to the waterproofing layer. The role of the thermal insulation is to reduce heat loss through the roof of the building during winter and to ensure the thermal stability of the roof in the summer. It also ensures the stationary of the diffusion flow of water vapour and reduces the thermal work of the load bearing roof structure. To prevent penetration of water in other layers of the roof and spaces below, a layer of waterproofing is placed and is usually made of synthetic, bituminous, and mineral materials. A protective layer is placed to protect the waterproofing layer from mechanical action and from the effects of insolation and thermal oscillations. The choice of a protective layer depends on whether the roof is a walk-through. If it is not a walk-through roof, the protective layer is most often applied with a pebble embankment (mechanical and insolation protection) or with protective coatings which do not provide mechanical protection. On the other hand, on walk-through roofs it is necessary to construct surfaces that, in addition to allowing movement, also protect other layers of the flat roof. The protective layer of the walk-through roof can be made of stone or ceramic tiles or cast asphalt [15].

Green roof is an open space covered in soil and vegetation at the building rooftop. Buildings have negative effects on local ecosystems and with installing green roofs to roof surfaces those negative effects such as carbon emissions and habitat reduction for plants and animals (reduction in biodiversity) can be alleviated while also reducing energy consumption of a building [17].

Green roofs can be generally classified as extensive, semi-intensive, and intensive [6].

Extensive green roofs do not greatly affect the load-bearing capacity of the structure given that they are characterized with a thin layer of substrate (less than 15 cm) and have little demands as far as maintenance [6] and the vegetation that grow on them. Given their thin substrate layer they are suitable for installation on both new and retrofitted buildings [3].

Extensive roofs can accommodate only a limited type of vegetation such as grass, moss, sedum, meadow plants and herbs, and succulents because of the thin layer of substrate [6]. They are not designed for walking but can be walked on for the purpose of maintaining the roof [18].

Semi-intensive green roofs are characterized with a fairly thick substrate layer (20–30 cm) and are in need of frequent maintenance and can hold small plants and shrubs as well as grass [6].

Intensive green roofs (type of green roof analysed in this paper) have greater weight and are characterized with a thick substrate layer (20–200 cm). They need additional structural support due to the increased load [3] and drainage and irrigation systems increase the technical complexity and costs but on the other hand they offer better insulation and energy performance as well as enhancing storm water management [4]. They can accommodate a variety of plants including shrubs and small trees due to the substrate layer thickness but they also require maintenance such as fertilizing, weeding, and watering [6]. Construction and installation of green roofs is a significant investment, but the cost varies depending on the green roof type. The cost of an intensive green roof is greater than the cost of a semi-intensive or an extensive roof. Extensive green roofs are prevalent for the sake of weight restrictions, costs, and maintenance of a building [6]. The construction of these types of roofs is technically simple and can be done on sloped roofs. They are fitting for sizable rooftops but their energy performance and storm water management potentials are low [4].

Green roofs are constructed with layers that enable vegetation growth and also provide protection to other roof layers [19]. Each layer affects the results of a green roof so they need to be selected appropriately in order to achieve the best outcome and results [7]. Components of a typical green roof are vegetation layer, growing medium (substrate), drainage-retention layer, membrane layer, which serves as a filter, and waterproofing layer [12] and in certain variants thermal insulation is also integrated [20]. Other layers, namely, the root barrier for protecting the waterproofing layer from plant roots and the irrigation system, are generally needed [4].

Vegetation is the topmost layer of the green roofs [6]. Apart from the aesthetic attributes, vegetation improves runoff quality [21], air quality [22], and thermal performance [23].

Experimental study [24] analysed various thermal impacts and water consumption of extensive green roofs in the Mediterranean climate. The results of the study showed that the fluctuations in temperature of a green roof decrease and that green roofs moderate the temperature of the roof surface especially during summer. Furthermore, study showed that green roofs aid in decreasing heat and electricity consumption during summer and winter months.

In choosing vegetation, location, precipitation intensity, humidity, wind, and sun exposure should all be taken into account [7]. Growing medium has an essential influence on vegetation growth and green roof performance [6] by providing support, nutrients, air, and water to vegetation [20]. Depending on the type of chosen vegetation, the substrate content varies. Percentage of organic content in substrate is higher for intensive green roofs than for extensive green roofs [12, 25]. Substrate needs to have an appropriate balance between weight, nutrients, thickness, and durability [12]. Substrate weight needs to be kept as low as possible, particularly in older buildings which were not constructed to house green roofs [6]. The filter layer separates the substrate from the drainage layer and prevents fine particles of the substrate from entering the drainage layer while upholding the integrity of the substrate and vegetation [20]. Drainage-retention layer offers a balance between air and water and it protects the waterproof membrane and improves thermal properties [6]. Furthermore, it manages water runoff and regulates retention and excess water drainage [20]. Waterproofing layer is vital because the wet soil and a high moisture content enhance the possibility of roof leakage [7]. If the waterproofing layer contains bitumen, asphalt, or organic materials there needs to be a root protection barrier [26]. Root barrier protects the structure of green roofs from vegetation roots as the perforation of the waterproofing membrane is avoided; hence this layer is significant in intensive green roofs [7, 12].

Green roofs improve the sustainability performance of the built environment [3], especially in highly urbanized cities where green space is sparse or even nonexistent [1]. Compared to the conventional flat roofs, green roofs are more aesthetically appealing [6] and provide numerous economic, social, and environmental benefits. Those benefits are in line with the triple-bottom-line of the sustainability of green roofs. The main economic benefits of green roofs, despite being short-term inefficient in comparison to conventional flat roofs, include long-term savings in energy consumption (due to better thermal performance and reduction in cooling and heating demand in summer and winter), competitive life cycle costs (due to longer roof life), increases in facility values, and increases in building useable areas [3].

Green roofs add to the thermal insulation of roofs and reduce the transmission of heat in and out of the building which leads to energy savings. Various studies confirmed the cooling effect of the green roofs and their ability to reduce peak air temperature by an average of 3°C and reduce peak surface temperature by an average of 17°C. Reduction of surface temperature depends on climate conditions and the season with green roofs being most effective during the summer months [27].

Study [28] showed that in Italy, in the Mediterranean climate, green roofs reduce peak surface temperature by 20–30°C during summer and only 10–13°C during winter months. Furthermore, the reduction in temperature is highest when the weather is sunny but less so when the weather is cloudy or rainy [27].

Green roofs can provide a space that can be used for recreational activities and human interaction hence providing psychological and social benefits which is particularly significant in developed urban centres [7] and consequently adds to the value of the building.

There are numerous environmental benefits of green roofs, primarily stormwater management enhancement [3], thermal benefits, improved water and air quality, decreased noise pollution, extended roof life, aiding in restoring biodiversity, reduced heat island effect, and increased green space in urban environments [1].

Studies [29, 30] have shown that green roofs have a positive influence on the indoor thermal comfort levels and moderating roof temperatures. Green roofs lower the indoor temperatures in the summer and raise them during winter which leads to improving comfort levels for building occupants and saves on using HVAC system which then reduces CO_2 emissions. Other benefits also work in favour of green roof construction. In addition to already mentioned benefits of creating biodiversity and green space in highly urbanized cities, improved water and air quality, decreased noise pollution, and extended roof life one other major benefit is the reduction of the urban heat island effect.

Urban heat island (UHI) effect represents the difference in temperature between cities (higher temperatures) and the suburban and rural areas that directly surround them [31]. The main cause of UHI is urbanization and as a result decreased vegetation and evapotranspiration, increase in dark surfaces with low reflection of incoming radiation away from a surface, and increased anthropogenic heat production [32]. Green roofs can help mitigate the urban heat island effect by increasing vegetation with sufficient soil moisture for evapotranspiration and by increasing the reflection of incoming radiation away from a surface [17].

Green roofs reduce the risk of flooding by retaining rainwater and delaying peak flow. Substrate and vegetation will absorb and take up some of the rainwater and the rest of the water will enter the drainage layer where water will be detained. After the drainage space is filled the overflow will drain and the remaining retained water will be used by plants and vegetation or it will evaporate, which explains the runoff retention potential of green roofs. Substrate type and thickness, drainage element type and its capacity for storage, vegetation type and coverage, volume of rain event and time of previous dry period, and the slope of the roof all have an effect on the retention potential [6]. Green roofs reduce the variation of indoor temperature and decrease energy consumption [4]. Furthermore, substrate acts as the roofs added insulation [6]. Green roofs buffer acidic rain thus producing good quality stormwater runoff [6, 33].

During dry periods, especially in the summer, green roofs need water for irrigation. The amount of water consumption is affected by type of a green roof, type of climate, rainfall, type of vegetation, temperature, and humidity. Harvesting of rainwater and fog/dew water harvesting can be used to meet the irrigation needs of a green roof for the purpose of reducing the amount of water consumed from the water supply network [10].

Moisture capture in fog harvesting arises from direct contact with the surface and thus an efficient water removal is a determining factor for the performance of harvesting moisture. Moisture capture in dew harvesting is driven by the nucleation energy barrier to condensation on each surface, which is greatly influenced by the wettability of the surface where performance of harvesting moisture is better in more wettable surface [34].

Study [35] showed green roofs can also reduce noises from traffic. Green roofs aid in restoring biodiversity by offering a place for birds, insects, and plants. Air quality is improved as well by purifying the air from smog and holding of a number of polluting air particles and gases [6, 36]. Environmental benefits of green roofs are observed in new highly insulated buildings as well as retrofitted buildings where those benefits are even greater [4].

However, there are some shortcomings of green roofs. Green roof components are mostly made of polymer materials which are not environmentally friendly and cause pollution [7]. The disposal of these materials also causes environmental concern and extra costs, such as dismantling and transport to landfill [3].

Maintenance is an important part of the building's life cycle. The aim is to carry out as little maintenance as possible and as infrequently as possible but also ensuring and preserving the availability of service facilities and building elements as well as the whole building [37].

The objectives of building maintenance are to ensure that the buildings and their associated services are in a safe condition and that the buildings are fit for use, to ensure that the condition of the building meets all statutory requirements, to carry out the maintenance work necessary to maintain the value of physical assets of the building stock, and to carry out the work necessary to maintain the quality of the building [37, 38].

The various types of maintenance are preventive maintenance, scheduled maintenance, corrective maintenance, condition-based maintenance, emergency/unforeseen maintenance, predictive maintenance, deferred maintenance, and on-site/off-site maintenance [38, 39].

Preventive maintenance is performed in accordance with a predetermined maintenance plan created for each roof layer and their service life prediction (SLP) and it should be carried out regularly at fixed intervals [20]. The preventive maintenance activities are conducted to keep the facility in a desired state of repair [40]. Furthermore, by performing these activities, the probability of occurrence of failure is reduced and future sudden failure is avoided [37]. Reactive maintenance activities include replacement or repair of an element that has failed and cannot perform its required function. There is a large number of those activities and they are hard to predict because it is almost impossible to anticipate all possible failures [38].

The biggest challenge in maintenance is to determine the most appropriate maintenance strategy [41]. In order to secure sufficient performance and minimize costs, activities performed during the service life of the building should be chosen with care [20]. The performance of roofs relies on periodic monitoring, regular maintenance, and appropriate quality of roof materials [14, 42].

Conventional flat roofs require minimal maintenance if constructed properly and regular inspection and maintenance can extend the life of the roof.

Flat roofs are more inclined to degradation than pitched roofs because the lower slopes can cause water related problems. Poor maintenance coupled with the fact that roofs are exposed to all kinds of weather conditions has an immense influence on the durability of roofs thus reducing their service life. Therefore, roofs should be checked twice a year, taking note of any effects of seasonal change. Any small issues developing before they become a larger problem should be spotted and repaired in order to ensure that all the roof elements meet the functional requirements [14].

Roof inspection is a human activity; therefore keeping a photographic record of the state of the roof's top layer is beneficial to see the changes in condition over a certain period [43].

Apart from the top protection layer—ceramic tiles, all other layers are inaccessible and thus the inspection of each individual layer and damage detection is difficult, almost impossible [15].

The most vulnerable element to degradation is the waterproofing layer [14]. Unfortunately, the damage to this layer is only noticeable when water has penetrated through all the layers of the roof and begins to moisten the inner surface of the ceiling. The exact place of water penetration through the waterproofing layer is almost impossible to determine. By going through the waterproofing layer water moistens the thermal insulation layer and consequently moistens the thermal insulation layer and reduces its intended role and causes problems with the drying of this layer after the repair of the waterproofing layer. The appearance of internal fungi and mould on inner surfaces of the border parts of the roof is the result of insufficient thermal insulation of the roof in those areas (thermal bridges). The problem can be solved by adding thermal insulation to those areas because this procedure does not require too much investment [15].

In order to secure a long life for any roof system inspections should be conducted twice a year and maintenance plan needs to be created [44].

Green roofs necessitate regular maintenance throughout their lifecycle [7]. Preventive maintenance like regular cleaning, repairs, or replacements will enhance the performance of green roofs [20].

Despite the common belief that they do not need regular irrigation or fertilizing to achieve maximum benefits, green roofs do in fact require watering and fertilization and furthermore, the vegetation, drainage, and substrate should be checked regularly [7].

The intensity of the required maintenance depends on the green roof type. Maintenance is minimal in the case of extensive roofs, where it is needed once or twice a year in the form of weeding, cleaning of the drainage system from debris, maintaining the irrigation system, and replacing plants if needed and invasive weeds must also be removed. Compared to the semi-intensive or extensive green roof types, maintenance of the intensive green roofs will increase and will entail pruning, disease, insect, and weed prevention or eradication, mowing, fertilizing, etc. [45]. Visual inspections are important to diagnose visible anomalies, for example, possible vegetation infestation or drainage system obstructions. Layers that cannot be visually inspected require other techniques, such as measuring superficial temperatures and moisture which indirectly informs on inner anomalies [20].

3. Methodology

In this paper, two variants of roof structures, conventional flat roof and intensive green roof, were analysed. The data used for the analysis and comparison of these two roofs are the cost and time estimate data for a building under construction. Calculations were made for a building located in the town of Rijeka on the Adriatic coast. The average monthly outdoor air temperature of the coldest month in the location in question according to meteorological data for the nearest climatically relevant meteorological station is higher than 3°C (Croatian costal climate zone), and the designed internal heating temperature is higher than 18°C, where designed internal heating temperature for residential units is 20°C during the heating season. An analysis of the components of both roofs was made, with an emphasis on thermal conductivity of individual layers, the calculation of thermal resistance, and calculation of the thermal transmittance coefficient through the building part. It was also analysed which roof is more economically viable in the stage of the construction. Intensive roof is the type of green roof chosen for the analysis.

The advantages of a green roof in relation to a conventional flat roof in terms of environmental and social benefits are also presented. Characteristics of green and conventional flat roofs are described, with particular attention paid to the characteristics of green roofs. Maintenance of both roof variants was analysed and a maintenance plan for each green roof layer and its service life prediction is shown.

3.1. Construction Technology of the Analysed Roof Variants. The two variants of roofs analysed in this paper, conventional flat roof and an intensive green roof, are set on a roof deck with a surface area of 550 m^2.

Roof layers of both variants are performed on a load bearing structure and a layer of sloped lightweight concrete base with the upper surface area incline of 2%, exposure class XC2, concrete class C30/37, with a reinforced mesh B 500 B, Q-28. It ensures the inclination of the roof surface towards the areas for storm water runoff (water catchments) and it is installed by using a concrete pump. Sloped lightweight is laid within the parapet so there is no need for formwork installation. After the concrete is pumped, it needs to be smoothed and prepared for installation of roof layers. Vapour barrier, thermal insulation, and waterproofing layers are set on a sloped lightweight concrete base in both analyses roof variants (highlighted grey in Table 1). Layers placed above them differ in both variants.

Figures 1 and 2 show the layers of the conventional flat roof and the intensive green roof.

Table 1 shows the layers, thickness, and characteristics of a conventional flat roof and an intensive green roof.

Vapour barrier prevents the penetration of water vapour from the building through the load bearing structure into the

Table 1: Conventional flat and intensive green roof layers (placed on a load bearing structure) characteristics and thickness (the table is structured by authors upon data collected from cost estimate for the building under construction).

Conventional flat roof				Intensive green roof			
	Layer	Thickness (m)	Material		Layer	Thickness (m)	Material
VI	Ceramic tiles	0.02	Ceramic tiles placed on standard pads	VIb	Vegetation	0.4	Shrubs
				VIa	Growing medium		Substrate
V	Filter layer	0.003	Geotextile	V	Filter layer	0.005	Geotextile filter layer SF 100 g/m^2
			$\varrho = 500\,\text{g/m}^2$	IVb	Drainage-accumulation	0.06	Accumulation cups filled with a dedicated mix
				IVa	Root protection	0.0025	Filter layer (with protection from roots)
IV	Waterproofing	0.002	ECB-based polymeric waterproofing tape	IV	Waterproofing	0.002	ECB-based polymeric waterproofing tape
III	Thermal insulation	0.18	Foam glass in hot bitumen	III	Thermal insulation	0.18	Foam glass in hot bitumen
II	Vapour barrier	0.01	Synthetic felt geotextile	II	Vapour barrier	0.01	Synthetic felt geotextile
I	Lightweight concrete	0.13	Upper surface area incline of 2%, exposure class XC2, concrete class C30/37, with a reinforced mesh B 500 B, Q-28	I	Lightweight concrete	0.13	Upper surface area incline of 2%, exposure class XC2, concrete class C30/37, with a reinforced mesh B 500 B, Q-28
	Load bearing structure	0.30	Reinforced concrete		Load bearing structure	0.30	Reinforced concrete

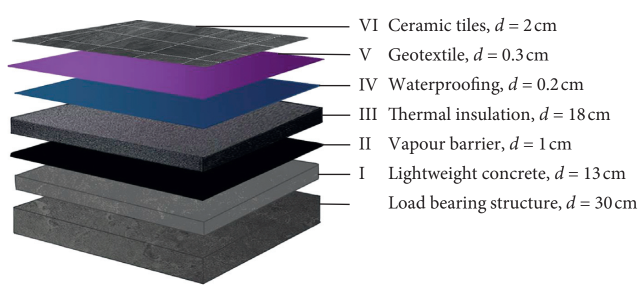

Figure 1: Conventional flat roof layers (the figure is created by authors upon data collected from cost estimate for the building under construction).

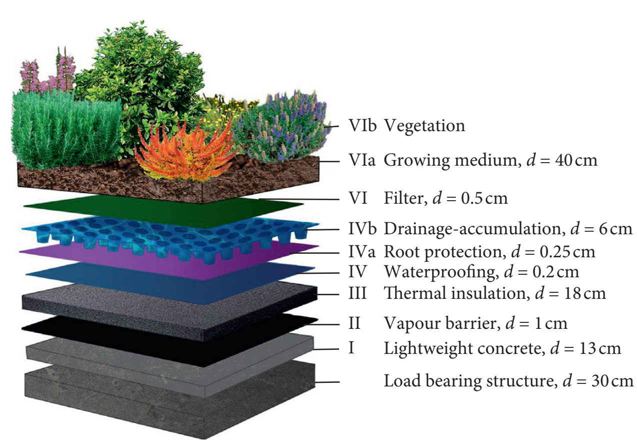

Figure 2: Intensive green roof layers (the figure is created by authors upon data collected from cost estimate for the building under construction).

thermal insulation layer through to the waterproofing and thus prevents or minimizes the permissible wetting of thermal insulation and the possibility of damage to thermal insulation and waterproofing layer. Vapour barrier, a layer of polymer modified bitumen insulation strips with an Al foil insert, is placed on the smooth and dry concrete surface. Thermal insulation layer reduces heat loss through the roof of the building during winter; it ensures the thermal stability of the roof during summer, ensures the stationary diffusion flow of water vapour, and reduces the thermal performance of the load bearing roof structure. Thermal insulation is a layer of foam glass in hot bitumen on which a layer of flexible waterproofing tape made of ECB (ethylene polymer bitumen) 2 mm thick is placed. Waterproofing layer is a one-piece waterproof membrane whose basic function is to protect all the layers of the roof. Foam glass and waterproofing are then welded to each other with hot air on the overlaps of at least 5 cm and raised at least 30 cm against the parapet.

In the case of a conventional flat roof, on top of the waterproofing layer a filter layer of geotextile with a thickness of 0.3 cm is installed to separate the final layer of waterproofing from the final roof tiling. Ceramic tiles placed on standard pads serve as a final and protective layer.

In the case of an intensive green roof, since waterproofing contains bitumen, which is an organic material, a filter layer with root protection is added to it. It is an elastomeric strip based on EPDM 2.5 mm thick, reinforced with glass cloth that has a self-adhesive layer with a separating foil on the underside. The width of the strip is 1 m and the fold and the weld must be welded at a 5 cm width. The drainage-accumulation layer is used for drainage and storage of a part of the excess water that is filtered from the substrate and it consists of accumulation cups 60 mm high, filled with a special mixture aggregate. Next, a filter layer of a 5 mm thick SF geotextile with good water permeability and resistance to rooting and sealing with small particles that are filtered from the substrate is placed. A layer of fertile substrate approximately 40 cm thick is placed on the filter layer. Substrate is a mixture of organic and inorganic components. It is permeable and retains moisture and air with a granulation of 0.06–16 mm. Vegetation is then planted, and the terrain is levelled and abundantly watered. An average of 1,5 shrubs were planted per m^2, including *Lavandula latifolia*, *Rosmarinus officinalis*, *Viburnum tinus*, *Calluna vulgaris*, *Cotoneaster danmeri*, *Santolina chamayparissus*, *Santolina virens*, and *Erica verticillata*.

The critical path method (CPM) is used to compare the time required for construction of both analysed roof variants. Critical path method is a tool used in project management for scheduling a set of project activities in planning and controlling all types of projects. It is an approach to project scheduling that breaks the project into several work tasks (activities), displays them in a flow chart, and then calculates the project duration based on estimated durations for each task. CPM is used to calculate operation parameters including earliest starting time, latest starting time, earliest finish time, latest finish time, maximum available time, and slack time. In many construction projects, delays may occur and, to ensure successful project performance, critical activities need to be defined. CPM defines activities on the critical path (critical activities, timewise) which is determined by identifying the longest stretch of dependent activities and measuring the time required to complete them from start to finish. Any delay in the critical activities delays the project completion overall time and the project should be managed to avoid delays in any of these activities [46]. Gantt chart is used to illustrate project activities. Gantt charts for conventional flat roof and intensive green roof were created using the Microsoft Office Project.

4. Results and Discussion

4.1. Construction Time Estimate Data of the Analysed Roof Variants. The critical path method (CPM) was used to compare the time required for the construction of analysed roof variants.

Figures 3 and 4 show Gantt charts for the conventional flat roof and intensive green roof analysed in this paper, respectively.

Gantt charts (Figures 3 and 4) show that the total construction time of a conventional flat roof is 18 days, and total construction time of a green roof is 23 days.

Time needed for execution of activities for the construction of lightweight sloped concrete layer, vapour barrier layer, thermal insulation layer, and waterproofing layer, which are the same for both variants of the roof, is 10 days. These activities include reinforcement mesh installation, concrete laying, synthetic felt geotextile installation, foam glass in hot bitumen installation, and ECB-based polymeric waterproofing tape installation.

Layers above the waterproofing are different in both analysed roof variants and their construction time differs. After the installation of the waterproofing layer of a conventional flat roof is finished, the duration of the geotextile instalment is one day, and the duration of the ceramic tiles installation is seven days. These activities are performed in a total of eight days. In the case of the green roof, after the installation of waterproofing, the activities for installation of the filter layer with protection from roots, installation of accumulation cups and filling of accumulation cups with a dedicated mix, installation of geotextile filter, substrate installation, and vegetation planting are performed. The duration of these activities is a total of 13 days. The connection between all activities is finish-to-start (FS) because the installation of each subsequent layer can start only when the installation of the previous one is completed; i.e., the activities are dependent. When installing the vapour barrier layer, for the activity of the synthetic felt geotextile installation, a lag time of three days is applied for the drying of concrete laid in the previous activity.

For the analysed roof variants, the construction time of an intensive green roof is five days longer than the construction time of a conventional flat roof. Since the analysed construction activities include only the construction of roofs, and not the construction activities of the whole building, all activities are critical because they are interdependent, and consequently any delays of any activities will delay the project completion overall time.

4.2. Energy Characteristics of the Analysed Roof Variants. Thermal transmittance coefficient (U (W/(m^2K))) is calculated for opaque building parts according to HRN EN ISO 6946: 2008 [41].

The maximum allowed value of the thermal transmittance coefficient for flat and sloped roofs above the heated space for the analysed building according to [41] is 0.3 W/m^2K, given the average monthly outdoor air temperature of the coldest month at the location in question is higher than 3°C (according to meteorological data for the nearest climatically relevant meteorological station) and that the designed internal heating temperature is higher than 18°C. Tables 2 and 3 show the values of thermal conductivity and thermal resistance and the thickness of each layer of the analysed conventional flat and intensive green roof.

Thermal resistance of each layer is expressed by

$$R = \frac{d}{\lambda}. \tag{1}$$

R (m^2K/W) is the thermal resistance of a layer, d (m) is the layer thickness, and λ (W/mK) is the thermal conductivity. Thermal resistance is correlated with the thickness of the layer through which the heat passes and is inversely proportional to thermal conductivity.

Thermal transmittance coefficient U (W/(m^2K)) is expressed by

$$U = \frac{1}{R_T}. \tag{2}$$

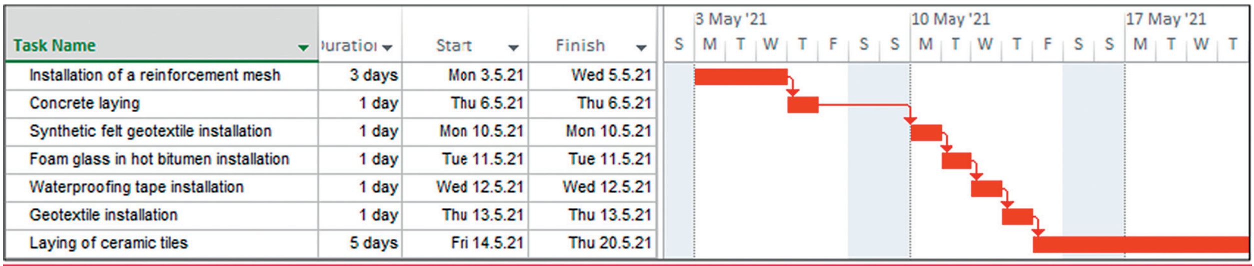

FIGURE 3: Conventional flat roof Gantt chart (the figure is created by authors upon data collected from cost estimate for the building under construction).

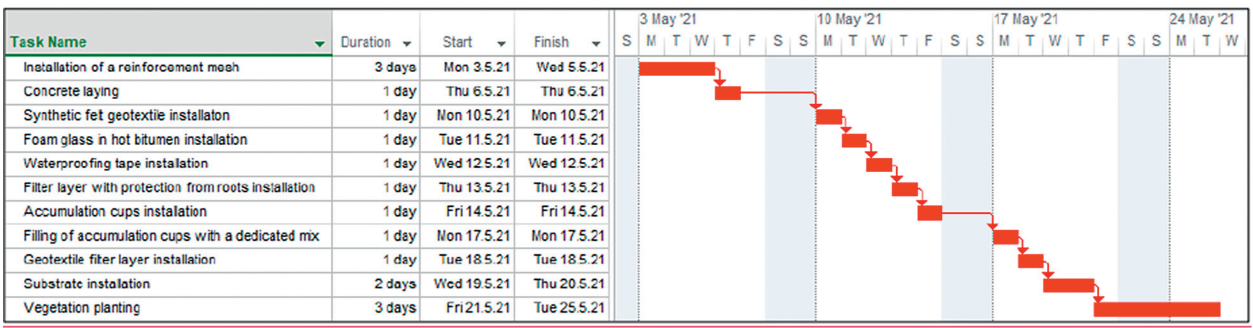

FIGURE 4: Intensive green roof Gantt chart (the figure is created by authors upon data collected from cost estimate for the building under construction).

TABLE 2: Thermal resistance of layers of a conventional flat roof (the table is structured by authors upon data collected from cost estimate for the building under construction).

Material type	Thickness d (m)	Thermal conductivity λ (W/mK)	Thermal resistance R (m^2K/W)
Ceramic tiles	0.02	1.3	0.02
Geotextile	0.003	0.19	0.02
ECB-based polymeric waterproofing tape	0.002	0.26	0.01
Thermal insulation, foam glass in hot bitumen	0.18	0.045	4.00
Synthetic felt geotextile, vapour barrier	0.01	0.19	0.05
Lightweight concrete	0.13	0.55	0.24
Reinforced concrete (roof deck)	0.30	2.6	0.12

TABLE 3: Thermal resistance of layers of an intensive green roof (the table is structured by authors upon data collected from cost estimate for the building under construction).

Material type	Thickness d (m)	Thermal conductivity λ (W/mK)	Thermal resistance R (m^2K/W)
Substrate	0.4	0.27	1.48
Geotextile filter layer SF 100 g/m^2	0.005	0.2	0.03
Accumulation cups filled with a dedicated mix	0.06	0.13	0.46
Filter layer (with protection from roots)	0.0025	0.2	0.01
ECB-based polymeric waterproofing tape	0.002	0.26	0.01
Thermal insulation, foam glass in hot bitumen	0.18	0.045	4.00
Synthetic felt geotextile, vapour barrier	0.01	0.19	0.05
Lightweight concrete	0.13	0.55	0.24
Roof deck	0.30	2.6	0.12

R_T (m^2K/W) is the total resistance to heat transfer through the bulkhead and is expressed by

$$R_T = R_{si} + R_n + R_{se}. \quad (3)$$

R_{si} (m^2K/W) is the internal surface resistance to heat transfer, Rn (m^2K/W) is the sum of the resistance of all layers, and Rse (m^2K/W) is the external surface resistance to heat transfer.

Tables 4 and 5 show the values of thermal transmittance coefficient for conventional and green roofs. Both roof variants meet the minimum thermal protection and the maximum allowed values of the thermal transmittance coefficient.

In this analysis, both values of the thermal transmittance coefficients for the two analysed roof variants meet the required value of amounting less than 0.3 W/m^2K [41] which is maximum allowed. The calculated value of thermal transmittance coefficient is 0.22 $W/(m^2K)$ for the analysed conventional flat roof and 0.15 $W/(m^2K)$ for the analysed intensive green roof. By comparing the calculated values of the thermal transmittance coefficient as a main parameter for describing the thermal performance properties of building's external envelope, it can be concluded that the construction of an intensive green roof will lead to energy savings. All layers from the roof deck up for both analysed roof variants were considered in the calculation for the purpose of comparing the roofs.

According to [40, 41], thermal transmittance coefficient calculation for roofs takes into account only the layers which are on the side of the room up to and including the waterproofing layer; therefore thermal properties of layers placed above the waterproofing layer have no influence on the value of thermal transmittance coefficient. Furthermore, it is necessary to conduct further research on the impact of green roofs on energy benefits.

Since the thermal transmittance coefficient (U) is a main parameter for describing the thermal performance properties of building's external envelope, by comparing the calculated U-values for the two roof variants it is concluded that the construction of an intensive green roof will lead to more energy savings than the construction of a conventional flat roof.

If damage is not addressed in time bigger damage may occur which can cause higher repair costs and might reduce the functionality and safety of the building.

In addition, according to literature, the mitigation of the urban heat island effect is one of the most prominent benefits of the construction of green roofs. Numerous analyses found in literature also show that green roofs, in comparison to conventional flat roofs, contribute to the preservation of the environment and have numerous environmental benefits and affect the life of users in a positive way and also add to the value of the building which is worth taking into account.

In the study [47] building energy use was simulated and a bottom-up LCA was conducted assuming a 50-year building life. The key property of a green roof is its low solar absorptance, which causes lower surface temperature, thereby reducing the heat flux through the roof [47]. Savings in annual energy use are just over 1%, but summer cooling load is reduced by over 6% and reductions in peak hour cooling load in the upper floors reach 25% [47]. This study showed that, by replacing the common flat roof with a green roof, environmental impacts are reduced by between 1.0 and 5.3% [47]. This study [47] also revealed how the highest environmental impacts are associated with the use phase and this phase accounts for more than 50% of the total environmental impact. Comparative analysis studies between green roofs and conventional roofs indicated the green roofs as sustainable options over conventional roofs and encourage the use of recycled materials in green roofs as a sustainable option for construction [48]. Study [49] shows how green roofs can reduce atmospheric pollution from 35% to 100% where intensive green roofs, like the one presented in this study, would help mitigate the environmental impacts more than extensive green roofs or conventional flat roofs.

4.3. Construction Costs Comparison of the Analysed Roof Variants. The data used for the construction cost analysis of the two analysed roofs is the cost estimate data for actual buildings under construction. For that reason, construction costs for both roofs, conventional flat and intensive green roof, are grouped as they are stated in project documentation. All prices include the supply and transport of materials as well as their installation. Total construction costs and construction costs of one square meter of a conventional flat and intensive green roof are presented in Tables 6 and 7.

The construction costs of the analysed conventional flat roof are presented for each layer separately, in contrast to the construction costs of the analysed intensive green roof, where the costs for lightweight concrete and vegetation are presented separately and the construction costs of other layers are combined.

The total construction cost of the lightweight concrete for both roof variants is 9.224,93 Eur. The total cost for the construction of all other layers of the conventional flat roof is 39.440,50 Eur which is 71,71 Eur/m^2, while the total cost for all other layers of the intensive green roof is 78.996,50 Eur which is 143,63 Eur/m^2.

Total construction cost of a conventional flat roof is 48.665,43 Eur which is 88,48 Eur/m^2, while the total cost of the intensive green roof is 88.221,43 Eur which is 160,40 Eur/m^2.

Comparative construction costs analysis shows that the construction costs of an intensive green roof are 81.30% higher compared to a conventional flat roof.

Although the analysis shows that the construction costs of the analysed intensive green roof are much higher than the construction costs of the analysed conventional flat roof other benefits can tip the scale in favour of the intensive green roof. Those benefits include better stormwater attenuation, thermal benefits, water quality enhancement, noise reduction, and air pollution mitigation. They give protection to the roof membrane from heat, wind, and

Table 4: Thermal transmittance coefficient—conventional flat roof (the table is structured by authors upon data from cost estimate and [41]).

Internal surface resistance to heat transfer	External surface resistance to heat transfer	Sum of the resistance of all layers	Total resistance to heat transfer through the bulkhead	Thermal transmittance coefficient
R_{si} (m^2K/W)	R_{se} (m^2K/W)	R_n (m^2K/W)	R_T (m^2K/W)	U ($W/(m^2K)$)
0.1	0.04	4.44	4.58	0.22

Table 5: Thermal transmittance coefficient—intensive green roof (the table is structured by authors upon data from cost estimate and [41]).

Internal surface resistance to heat transfer	External surface resistance to heat transfer	Sum of the resistance of all layers	Total resistance to heat transfer through the bulkhead	Thermal transmittance coefficient
R_{si} (m^2K/W)	R_{se} (m^2K/W)	R_n (m^2K/W)	R_T (m^2K/W)	U ($W/(m^2K)$)
0.1	0.04	6.39	6.53	0.15

Table 6: Conventional flat roof construction costs (the table is structured by authors upon data collected from cost estimate for the building under construction).

Layer	Unit of measure	Quantity	Unit price (Eur)	Total cost (Eur)
Ceramic tiles	m^2	550	18,47	10.158,50
Waterproofing	m^2	550	15,83	8.706,50
Protection layer	m^2	550	3,96	2.178,00
Thermal insulation and vapour barrier	m^2	550	33,45	18.397,50
Lightweight concrete	m^3	71.5	129,02	9.224,93
Total cost				48.665,43
Total cost per m^2				88,48

Table 7: Intensive green roof construction costs (the table is structured by authors upon data collected from cost estimate for the building under construction).

Layer	Unit of measure	Quantity	Unit price (Eur)	Total cost (Eur)
Vegetation	m^2	550	4,10	2.255,00
Growing medium				
Filter layer				
Drainage and storage				
Protection layer	m^2	550	139,53	76.741,50
Waterproofing				
Thermal insulation				
Vapour barrier				
Lightweight concrete	m^3	71.5	129,02	9.224,93
Total cost				88.221,43
Total cost per m^2				160,40

ultraviolet radiation and furthermore, they can increase the aesthetic of a building [6].

4.4. Maintenance and the Proposed Roof Maintenance Plan. Maintenance is important to ensure the functionality and safety of the building and also the longest possible service life of the building as well as its parts. In that regard, maintenance plans are constructed for both the conventional flat roof and the intensive green roof.

Table 8 shows a maintenance plan for the conventional flat roof analysed in this paper with a service life prediction for each layer (SLP) and maintenance actions and their frequency.

In the analysed conventional flat roof ceramic tiles are placed as the top protection layer of the roof which is directly exposed to visual inspections. Maintenance plan shown in Table 8 predicts twice a year checks of state of cleanliness and checks for any cracks or any other damage should be carried out with the same frequency. Build-up of leaves, twigs, and dirt (mould, algae) that always collects on a roof, no matter what time of year, should not be allowed to the point where it begins to block gutters and creates water pooling. Trees positioned close to the building, which increases the

Table 8: Maintenance plan for the conventional flat roof layers and their service life prediction (SLP) (the table is structured by authors upon data from [20] and authors own assessment).

Layer	SLP (years)	Maintenance action			Frequency
		Visual	Monitoring	Preventive	
Ceramic tiles	30–40				
Check of state of cleanliness (dirt, debris)		x			2/year
Check for any cracks or any other damage		x			2/year
Replacement or major repair				x	After 40 years
Filter layer, geotextile	30–40				
In exposed areas, check for any damage		x			
Replacement or major repair				x	After 40 years
Waterproofing	30–40				
In exposed areas, check of detachments, loss of adherence, rips		x			2/year
In exposed areas, check of moisture or biological colonization		x			2/year
In situ campaigns to assess watertightness			x		Every 5 years
Local repairs				x	When necessary
Deep inspection, scheduling of the next one				x	After 10 years
Replacement or major repair				x	After 40 years
Thermal insulation	30–40				
In situ campaigns to assess heat fluxes and temperature values			x		Every 5 years
Local repairs				x	When necessary
Deep inspection, scheduling of the next one				x	After 10 years
Replacement or major repair				x	After 35 years
Load bearing structure	40–60				
Check of excessive deformation, cracks		x			1/year
Check of blistering, moisture stains, infiltrations		x			2/year
In situ campaigns to assess structural stability and serviceability			x		When necessary
Local repairs				x	When necessary
Deep inspection, scheduling of the next one. Eventual replacement or major repair				x	After 40 years
Replacement or major repair				x	After 60 years

likelihood of debris falling onto the roof, should be trimmed when possible to lower the number of times of the removal of build-up of leaves and twigs, etc. Ceramic tiles as well as the filter layer beneath them should be replaced or majorly repaired after 40 years since their service life prediction is between 30 and 40 years.

Maintenance plan predicts visual checks of the waterproofing layer such as rips, detachments, moisture, or biological colonization in exposed areas twice a year. Repairs should be carried out when necessary and the layer should be inspected after 10 years and replaced or majorly repaired after 40 years. Thermal insulation layer with the service life prediction of 30–40 years should be replaced or majorly repaired after that time. Heat fluxes and temperature values should be assessed every five years and when necessary local repair should be carried out. As shown in the maintenance plan in Table 8, load bearing structure should be checked for excessive deformation and cracks and for blistering, moisture stains, and infiltrations once a year and twice a year, respectively. Local repairs of this layer should be carried out when necessary as is the case with all the layers. Service life prediction for the load bearing structure for this analysed conventional flat roof is 40–60 years. After that time major repairs or replacement is predicted to occur.

Maintenance plan for each intensive green roof layer analysed in this paper and its service life prediction (SLP) is shown in Table 9.

Maintenance plan shown in Table 9 considers all layers of an intensive green roof and is further divided in maintenance elements for each layer. Visual, monitoring, and preventive maintenance actions as well as their frequency are assigned to every maintenance element.

Vegetation layer maintenance is divided into post-planting phase (1 and 2 years), maturation phase (2 and 3 years, until vegetation covers approximately 90% the roof area), and maintenance phase (from year 3 or 4). Visual inspections include check of vegetation health and state of cleanliness. In postplanting phase check of vegetation health should occur four times a month while during maturation and maintenance phase those activities should be carried out two times a month. Pest control is to be performed preventively when necessary so that infected plants can be spotted in time and measures or replanting or treating the

Table 9: Maintenance plan for the intensive green roof layers and their service life prediction (SLP) (the table is structured by authors upon data from [20] and authors own assessment).

Layer	SLP (years)	Maintenance action			Frequency		
		Visual	Monitoring	Preventive	After planting	Maturation	Maintenance
Vegetation	—						
Check of vegetation health		x			4/month	2/month	2/month
Check of state of cleanliness		x			2/month	2/month	2/month
Pest control				x	When necessary		
Infesting/dry vegetation removal				x	6/year	6/year	12/year
Debris collection				x	1-2/year	1–2/year	1-2/year
Watering				x	1–3/day	1/day (summer)	1/day (summer)
Control of shrubs anchors				x	1/year	1/year	1/year
Fertilization				x	4/year	2/year	2/year
Pruning, reaping				x	—	1/year	1/year
Replacement of erosion protection				x	—	When necessary	
Seeding or replanting				x	When necessary	1/year	
Substrate	-						
Check of settlements, shrinkage, saturation		x			1-2/year	1–2/year	1-2/year
Substrate adding/levelling				x	—	When necessary	
Scarifying/soil aerating				x	—	1/year	2/year
Drainage, accumulation	10–35						
In situ campaigns and local pools to assess wet areas			x		Every 5 years		
Local repairs				x	When necessary		
Deep inspection, scheduling of the next one. Eventual replacement or major repair				x	After 10 years		
Replacement or major repair				x	After 35 years		
Waterproofing membrane and root protection	30–40						
In exposed areas, check of detachments, loss of adherence, rips		x			2/year	2/year	2/year
In exposed areas, check of moisture or biological colonization		x			2/year	2/year	2/year
In situ campaigns to assess watertightness			x		Every 5 years		
Local repairs				x	When necessary		
Deep inspection, scheduling of the next one				x	After 10 years		
Replacement or major repair				x	After 40 years		
Thermal insulation	35						
In situ campaigns to assess heat fluxes and temperature values			x		Every 5 years		
Local repairs				x	When necessary		
Deep inspection, scheduling of the next one				x	After 10 years		
Replacement or major repair				x	After 35 years		
Load bearing structure	40–60						
Check of excessive deformation, cracks		x			1/year		
Check of blistering, moisture stains, infiltrations		x			2/year		

Table 9: Continued.

Layer	SLP (years)	Maintenance action			Frequency		
		Visual	Monitoring	Preventive	After planting	Maturation	Maintenance
In situ campaigns to assess structural stability and serviceability			x		When necessary		
Local repairs				x	When necessary		
Deep inspection, scheduling of the next one. Eventual replacement or major repair				x	After 40 years		
Replacement or major repair				x	After 60 years		

plants can be done. In postplanting and maturation phase the removal of infested or dried vegetation should occur six times a year and more often in the maintenance phase when those actions should be carried out each month. As part of the preventive actions, once or twice a year debris should be collected. Watering depends on the vegetation phase and while vegetation is still in seed stage and after implementation phase watering should occur more often. Hence, it should occur up to three times a day during implantation phase, and once a day during the summer in later phases. Other preventive actions include fertilization, pruning and reaping, and seeding or replanting for which the frequency of their actions is shown in the maintenance plan in Table 9. Some actions should also be scheduled after floods or storms. Substrate layer should be visually checked for settlements and shrinkage and saturation once or twice a year. When necessary substrate should be added and soil aerating should be carried out once or twice a year during phases of maturation and maintenance as part of preventive maintenance. Drainage-accumulation layer with a service life prediction of up to 35 years should be locally repaired when necessary and after ten years a deep inspection should be carried out. Actions and frequency shown in the maintenance plan for all other layers of the analysed intensive green roof (waterproofing, thermal insulation, and load bearing structure) are the same as the actions and frequency of the same layers for the analysed conventional flat roof and are maintained as explained earlier in this paper.

From the presented maintenance plans for the analysed two types of flat roofs, conventional flat roof and intensive green roof, it can be concluded that green roof maintenance is more complex and by extension will be more costly. Although both roofs have some layers in common and thus their maintenance is the same, the layers of a conventional flat roof above the waterproofing layer are filter layer and the protective layer of ceramic tiles which are easier to maintain than in the case of an intensive green roof where the layers above the waterproof layer (root protection, drainage-accumulation, filter layer, growing medium, and vegetation) are more demanding because it is necessary to carry out more maintenance activities with higher frequency.

The life cycle of all roof components (layers) of both roof variants can be expanded by proper repair at an early stage of damage and maintenance according to a maintenance plan with defined set of activities that must be carried out at a specific time. Otherwise, bigger damage may occur, which, if not detected in time, can cause higher repair costs and at the same time, it might reduce the functionality and safety of the building.

5. Conclusion

Green roofs are a sustainable alternative to conventional flat roofs and there are multiple benefits in the construction of green roofs over the construction of conventional flat roofs, according to previously published literature. In this paper, intensive green roof and conventional flat roof are the two types of roofs analysed in terms of thermal performance, construction costs, and maintenance complexity. The two analysed roof variants are located in the town of Rijeka on the Adriatic coast and therefore are in the same climate conditions, Mediterranean climate. The data used for the analysis and comparison of these two roofs are the cost and time estimate data for a building under construction. The results of the analysis of the two roof variants have shown that the construction cost of an intensive green roof is 81.30% higher than the cost of a conventional flat roof.

Maintenance is also more complex in the case of an intensive green roof. Maintenance plan with defined set of activities for both analysed roof variants must be carried out as planned so that any repair needed can be done at an early stage of damage.

It is concluded that although the construction costs of an intensive green roof are higher which makes them short-term inefficient because of the greater investment and longer period of return of investment, and maintenance is more complex, the construction of an intensive green roof leads to more energy savings and other noneconomical benefits such as improved water and air quality, decreased noise pollution, extended roof life, restoring biodiversity, and an increase of green space in urban environments. Although initial (construction) costs are a big challenge in green roof construction, it is the position of the authors that lower construction cost and simpler maintenance should not be the only factor when deciding on the type of roof to be built on a particular location. With the advancement of construction technology and the development of new materials with better properties, we can expect that in the future green roofs will have an increasing advantage, regardless of the initial cost, because the benefits of green roofs over conventional flat roofs will be even greater, especially in today's world where we are trying to minimize environmental pollution and overurbanization.

First limitation of this study is the fact that it is focused only on intensive green roofs in the Mediterranean climate. But this was on purpose because previous study showed how intensive green roofs help mitigate the environmental impacts better and stronger than extensive green roofs or conventional flat roofs. Further research regarding this case study will be directed on thermal simulation of intensive green roof after completing extensive data collection regarding outdoor and indoor climate and energy use. Afterwards simulation can be performed on other types of green roofs and in different climate zones. The only aspect of results presented in this case study that is hard to validate on short term is a part of maintenance plan since it refers to a period of time longer than 5 years.

Data Availability

The textual and calculation data used to support the findings of this study are included within the article. The MS Project data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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