CALCULATION TOOL MULTIFUNCTIONAL ROOFS VERSION 3.0

Background Report on key figures

LIFE@Urban Roofs
Municipality of Rotterdam

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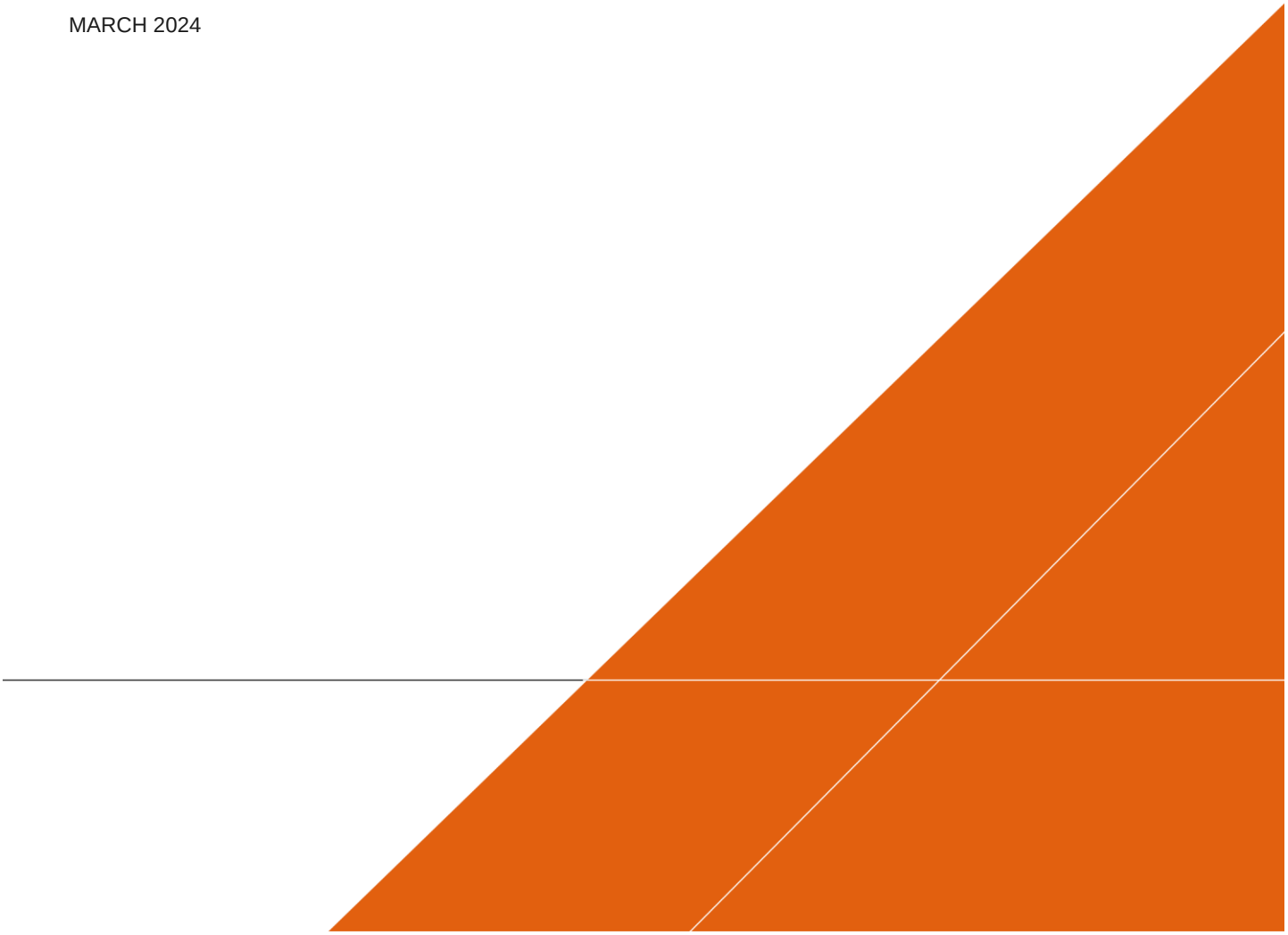

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Problem statement

In the urban environment, there is little room at ground level to tackle climate and water challenges. At the same time, a large amount of roof surface in the city remains unused. Roofs offer all kinds of opportunities for use and can make an important contribution to the living environment and quality of life in the city. This can be done in several ways by the construction of multifunctional roofs, such as a combination of a roof with planting (green function), water storage (blue function) and solar panels (yellow function).

People want to experience the benefits of multifunctional roofs (through usage, energy, water retention, etc.), but it is difficult to find parties willing to pay for these investments. This has several causes. The main reason is that the benefits of multifunctional roofs are not always clear. Not all benefits can be directly valued in Euro's, and they are often not immediately visible to all users or, more importantly, to the investor. The tool LIFE@Urban Roofs offers a solution to this matter. The social and financial costs and benefits are made visible with the multifunctional roofs calculation tool version 3.0, developed for LIFE@Urban Roofs Rotterdam, as part of the EU LIFE program[1].

1.2 The LIFE program

Within the framework of the EU LIFE program, the Municipality of Rotterdam has started the project LIFE@Urban Roofs in collaboration with several Rotterdam partners. The aim of the project is to develop methods to simplify investments in multifunctional roofs in the private and (semi)public sector. In addition, the EU program LIFE@Urban Roofs aims to share knowledge between cities and/or countries with similar issues.

1.3 Reading guide

The purpose of this background report is to explain the effects included in LIFE@Urban Roofs version 3.0, and the key figures used. In the following chapters you will read about:

- General principles and assumptions (Chapter 2).
- Explanation of the financial business case (Chapter 3).
- Explanation of the social cost-benefit analysis, including a description of the determination and valuing method of relevant impacts (Chapter 4).
- Key figures and assumptions used (Chapter 5).

Note: The calculation tool LIFE@Urban Roofs was prepared within the context of the LIFE program. The methodology and key figures described in this background report apply to this scope only. For additional questions or application elsewhere; please contact Arcadis or the Municipality of Rotterdam.

[1] Link to the European LIFE program

2 USING THE TOOL

2.1 The user

The tool is accessible to anyone interested in multifunctional roofs and who wants to make a first step in discovering their application. For the use of for municipalities, individuals, and enthusiasts alike. In the tool, default values are applied as much as possible. These values can be adapted to any specific case if desired.

The calculation tool multifunctional roofs provides insight into the financial business case and social costs and benefits of a multifunctional roof. For more information about multifunctional roofs; see this website of the Municipality of Rotterdam.

Since the delivery of the 1.0 version of the calculation tool in 2018, several parties have applied the tool. In 2021, the calculation tool was updated (version 2.0). The 3.0 version of the calculation tool in 2024 concerns another update and improvement of the tool. Parties that have used the tool in the past (including partners of the National Roofing Plan) have contributed to this update and improvement by providing feedback. The 3.0 version of the calculation tool multifunctional roofs was developed primarily to increase the accessibility and user-friendliness of the tool, while updating key figures and assumptions used in determining financial and social costs and benefits. The goals of the LIFE@Urban Roofs project have been the guiding principle during this process.

The 3.0 tool can be used as an incentive tool, but can also be used to inspire and inform about the application of multifunctional roofs. The purpose of the tool is to get a good first impression of the costs and benefits of a multifunctional roof, both financially and socially, with limited input. The calculation tool can thus be seen as a Quickscan and a first step towards a financial business case and social cost-benefit analysis (SCBA). The tool is accessible to anyone interested in multifunctional roofs, such as municipalities, individuals, or enthusiasts.

The calculation tool uses so-called default values as much as possible. These default values can be adjusted if required or desired.

2.2 Methods

The calculation tool is an Excel file consisting of five different sheets:

- Introduction sheet
  1. Current situation.
  2. New roof.
  3. Results.
- What's next?

The user is guided through the calculation tool step by step. The instrument is set up in such a way that it takes about 15 minutes to complete. To assist the user, as many default values as possible have been entered already. The user can modify these values, if desired. The user fills in all the yellow fields or leaves the pre-filled values as they are.

2.3 Types of multifunctional roofs

The calculation tool uses seven roof colors: green, blue, yellow, red, orange, purple and gray roofs; see Table 1 below.

Table 1 Description and effects of types of roofs included in LIFE@Urban Roofs

Rooftop type	Description and effects
Green roofs	Green roofs contribute to a green environment and are useful during extremely dry, hot, and wet weather. The positive effects of a green roof include: increase in biodiversity, avoided healthcare costs, prevented labor loss, water retention, and increase in property value.
Blue roofs	Blue roofs collect and store water. They play an important role during very wet or just dry weather. The positive effects of a green roof are water retention and possible reuse of the captured water
Yellow roofs	Yellow roofs generate renewable energy (from the sun). The positive effects are energy revenues for the owner, a reduction in CO2 from power generation, and improved air quality as fewer pollutants are required for power generation.
Red roofs	Red roofs have a social function. People can meet each other on this type of roof and there are exploitation opportunities on a red roof. Red roofs consist of commercial and social activities. Commercial activities bring costs and revenues, social activities only costs.
Orange roofs	Orange roofs are used for transport and mobility.
Purple roofs	Purple roofs are residential roofs, used for living.
Grey roofs	Grey roofs are for technical installations.

3 EXPLANATION OF THE FINANCIAL BUSINESS CASE

3.1 Starting points and principles

In the financial business case, the costs (investment costs and management and maintenance costs) are set off against the revenues (for example, energy revenues or exploitation revenues). This is done by determining the Net Present Value (NPV) of the project; see also the text box below.

The NPV is a measure to represent the present value of an amount for a given vision year. NPV considers the time value of money and the risks associated with an investment. To determine the NPV, the present value of future expenditures (total investment costs and management and maintenance costs) is subtracted from the present values of all future receipts (revenues). Future costs and benefits are discounted to the base year, through which they become comparable.

The period of analysis can be altered in the calculation tool, ranging from 10 to 60 years. The default value is set at 40 years. The replacement periods of different types of roofs determine whether and when the investment costs of a new roof are included again in the period of analysis.

Net Present Value (NPV)

It is not possible to compare costs and benefits that occur in different periods. Investments are made at the time the project is implemented, while benefits occur later. Moreover, these effects are often not one-offs.

To compare all effects, the SCBA and the financial business case use Net Present Values. Using a discount rate, the future values of costs and benefits are discounted back to today (price level 2023). Because of the time value of money, a Euro now is worth more than a Euro later in time. In addition, there are risks that benefits will be lower in the future. These risks are also included in the discount rate.

The financial business case uses the discount rate used by the case owners. The SCBA used a real discount rate of 2.25%, as prescribed by the Dutch government. A discount rate of 2.9% was used for CO2 prices.

When the present value of the benefits is subtracted from the present value of the costs, the balance remains: the Net Present Value.

3.2 Costs and revenues

Costs

It is assumed that all costs are additional costs compared to the reference situation (i.e., regular maintenance). The costs in the financial business case consist of investment costs and management and maintenance costs.

Revenues

The most important revenues in the financial business case relate to yellow, blue, and red roofs. Various revenue items have been included in the financial business case:

Revenues	Explanation
Revenues related to exploitation red roof	Red roofs can have social and commercial functions. A commercial function can also concern a bar or restaurant. In that case, the revenues related to exploitation are included.
Revenues yellow roofs: • Revenues due to feedback energy yields (net metering) • Saving on energy consumption	Yellow roofs generate sustainable energy (solar panels). The energy yields that the roof produces through return and energy savings are expressed in Euros and are included as revenues.
Water reuse	Water retention on the roof can offer opportunities for water reuse and thus avoided costs for drinking water and avoided costs for an alternative retention facility.
Subsidies	Subsidies are included as revenue in the financial business case. It is assumed that subsidies are received in year 1.

4 EXPLANATION OF THE SOCIAL COST-BENEFIT ANALYSIS

4.1 Starting points and principles

To determine the social costs and benefits, the General Guide to Social Cost-Benefit Analysis (General SCBA Guide, Dutch) is followed as much as possible. This describes, in steps, what every SCBA should include according to current insights. The guideline was prepared by the Netherlands Bureau for Economic Policy Analysis (CPB) and the Netherlands Environmental Assessment Agency (PBL).

Please note that the calculation tool multifunctional roofs concerns a Quickscan of social costs and benefits. The calculation tool therefore provides a first indication of possible social costs and benefits of a multifunctional roof. This does not mean that all steps of an SCBA have been completed; see also the text box below.

For the determination of the NPV, the same basic principles and assumptions apply as described in the financial business case (see Chapter 3).

General Guide to SCBA

Strictly speaking, in accordance with the aforementioned General Guideline, carrying out a SCBA requires taking several steps, including an analysis of the underlying problem and developing several scenarios that could solve a specific problem. For example, the Municipality of Rotterdam could also reduce CO2 in ways other than rooftop solar energy, by making an extra effort to use energy-efficient transport.

However, this study focused solely on the social costs and benefits of multifunctional roofs because an analysis of alternative climate measures was not part of the scope of the study. In addition, multifunctional roofs contribute to the solution of multiple problems beyond the climate problem (biodiversity, water retention, heat stress, etc.), making it difficult in practice to develop alternatives that contribute to solving all of these issues as well.

4.2 Determination and valuation of relevant effects

In determining the relevant effects in the social cost-benefit analysis (SCBA), a distinction is made between effects that primarily accrue to owners/users of objects (private) and the social effects (public). The private and public effects are both reflected in the SCBA. The table below presents the effects included in the SCBA and the method of valuation. The following sources were consulted (see also the broader explanation of key figures in chapter 5 and the bibliography in chapter 0):

- General Guide to SCBA and the various SCBA instruments and workbooks (“MKBA werkwijzers”), such as Nature, Environment and Social Domain.
- Environmental Pricing Handbook CE Delft.
- Valuation of key figures from among others TEEB City 2019 (RIVM, 2019), the Water Damage Estimator, and RWS Economics.
- Similar SCBAs on green roofs.
- KNMI'14 climate scenarios.
- Other sources (see bibliography in Chapter 0).

Table 2 Costs and benefits that multifunctional roofs can generate.

Effect	Description	Valuation method
Costs		
Investment costs	*Additional* costs compared to the reference situation in € per m2 for each roof "color".	€
Management and maintenance costs	*Additional* costs compared to the reference situation in € per m2 per year per roof color.	€ per year
	Revenues / (Social) benefits	
Energy yields	Energy generated	kWh per year
	Energy yields in the SCBA consist of: - Energy revenues from power feedback/feed-ins - Energy savings through reduced consumption *Energy revenue feed-in* The user can decide whether net metering applies or not. This was chosen because of the lack of clarity regarding whether or not net metering will be phased out in the future (in the Netherlands). When it does apply, there is energy revenue: replacement consumption and supply back to the grid. It is assumed that the generated energy is for own consumption. If there is a surplus, it is delivered back to the grid. The price per kWh of electricity (excluding VAT/taxes) can be entered by the user, so that it is always up to date. When net metering does not apply, there is no energy revenue. This means that the energy revenues from feed-in/net metering will be €0. *Energy savings through reduced consumption* Energy yields in relation to energy consumption are determined by the amount of energy generated on the roof. This energy now does not have to be generated elsewhere, and thus ensures saving money.	€ per year
	Energy yields are also understood by expressing them in terms of number of households annually supplied with electricity.	Quantitative
Exploitation revenues red roof	*Possibility of exploitation*: the effects of the multifunctional roof are made clear by indicating the revenues of possible exploitation. This is expressed quantitatively.	€
Property/real estate value	The literature shows a range of 1.4-21% increase in property value due to greenery/green roofs. The following values are given as suggestions in the tool: • 1.4% property value increase for green roofs of 0-500 m^2 • 2.5% property value increase for green roofs of 500-1000 m^2 • 5% property value increase for green roofs of 1000-2000 m^2 • 7.5% property value increase for green roofs of 2000-3000 m^2 • 10% property value increase for green roofs of 3000-4000 m^2 • 12.5% property value increase for green roofs of 4000-5000 m^2 • 15% property value increase for green roofs of 5000-6000 m^2 • 17.5% property value increase for green roofs of 6000-7000 m^2 • 20% property value increase for green roofs of 7000-8000 m^2 • 21% property value increase for green roofs larger than 8000 m^2	€

Effect	Description	Valuation method
	In the tool, users can enter their own property value increase percentage based on this information. The increase in property value reflects the following underlying effects: aesthetic appreciation, noise reduction, productivity, and comfort. The assumption is that the increase in property value occurs once, in year 1. Disclaimer: property value appreciation is very location dependent. This calculation tool provides a first estimate. The exact determination of the possible increase in property value should be further investigated per location.	
Reputation and business climate	Effects on reputation and business climate are approached using multiple indicators: • Reputation of owner: does the project contribute to a green/innovative reputation of the property owner? This effect is described qualitatively. • Business climate of the neighborhood and city: does the project contribute to an improved business/settlement climate for residents and businesses? This effect is described qualitatively.	Qualitative
Water retention	For water retention, the physical measure is the number of additional m3 of water retention due to the project. This assumes shadow costs / avoided costs of an alternative retention facility (€415.4 per m3). The amount of water retention on a blue roof can be set manually. The default is set to 60 mm/L water per m2 (DakenPlan, 2024). It is assumed that a green roof stores 30 mm/L of water per m2.	€
	Water storage is additionally expressed as the number of filled rain barrels.	Quantitative
Water re-use	The collected water can be reused for personal use (for example, irrigation of a green roof). This leads to savings in tap water use. The size of this benefit in Euros depends on the current drinking water rate per m^3.	€
Water quality	Water storage on a multifunctional roof can lead to a reduction in the number of m^3 rainwater that reaches the water treatment plant through the sewer system, where it must be treated. Theoretically, this can reduce the energy and operating costs of water treatment. However, the effect of a green roof is zero in this perspective and is therefore not included in the SCBA. The same reduction in the number m3 of stormwater reaching the sewer can, in principle, locally reduce the number of sewage overflows to surface water. This benefits surface water quality. This effect is qualitatively considered.	Qualitative
Air quality: emissions	Energy generation on rooftops leads to a reduction in CO_2 emissions. This is valued, among other things, using the Handbook of Environmental Prices (CE Delft, 2023) and the Climate and Energy Outlook 2022 (PBL, 2022). The capture of CO_2 by green roofs is limited. The Environmental Pricing Handbook (CE Delft, 2023) contains environmental prices for more than 2.000 environmentally hazardous substances. The use of the environmental prices in the Handbook is	€

Effect	Description	Valuation method
	recommended by the Dutch government. In the tool, benefits were determined for saved emissions of CO_2 and air pollutant emissions (VOC, particulate matter, NO_x, SO_2). Rooftop energy generation further leads to a reduction of NO_X, SO_2, VOCs and particulate matter. This is also valued using, among others, the Handbook of Environmental Prices (CE Delft, 2023), the Climate and Energy Outlook (PBL, 2022) and TEEB 2019 (RIVM, 2019).	
Capture of fine particulate matter and other substances	Green roofs capture a limited amount of particulate matter and other substances. This effect was valued using the deposition rate in cm/s in Euros. TEEB 2019 was used for this purpose (RIVM, 2019).	€
Heat stress	The effects on heat stress from multifunctional roofs are determined by: • Albedo effect: reflection of sunlight (assuming a black roof in reference situation). • Increased cooling (in the building). • More evaporation: cooling the environment (blue roof). In other words, heat stress manifests itself in two ways: the effect on energy inside the building (albedo and cooling) and the effect on energy outside the building (cooling the environment through evaporation). According to the literature, the cooling effect saves 3 to 75% on air conditioning (in summer); figures vary (Groen Kennisnet, z.d.) (Papa Green, z.d.) (Regionaal Energieloket, z.d.). In addition, how big this effect is and thus how big the accompanying energy and cost savings are, depends on e.g. whether a green roof is properly irrigated, what kind of vegetation is on it, and whether a blue roof is properly "filled" (Powerly, z.d.) (Solar Sedum, 2022) (Wong, Chen, Ong, & Sia, 2003). Hence, a multifunctional roof can provide cooling, but this depends on several factors. Because of these uncertainties, the effect on heat stress/cooling has not been quantitatively valued in this calculation tool. If this is to be valued, in addition to certainty about the factors described above, knowledge about energy consumption and energy costs specifically for air conditioning is also required. The effects on cooling outside the building (cooling the environment) is taken into account in the *Health* effect (see below). The effect that heat stress has on physical and mental health is monetized under the *Health* effect. The remaining effect related to heat stress is described qualitatively.	Qualitative
Health (physical and mental)	The health effect was approached from two underlying effects: • *Avoided healthcare costs*: 0.835 fewer patients per 1000 inhabitants with 1% more green space within a 1 km radius of the home; €917 per patient (RIVM, 2019). It is assumed that the range of positive health effects for roofs includes a radius of 200 meters instead of 1 km. Therefore, 0.835/5 =0.167 fewer patients per 1000 residents within a 200-m radius is assumed. This 0.167 patients per 1000 residents is then corrected to the number of patients per X number of people facing the roof. Finally, this is then multiplied by the €917 healthcare cost per patient. • *Prevented loss of labour:* €6,679 per patient (RIVM, 2019). The health effect includes both physical and mental health effects. The effect of heat stress is also included. This €6,679 is multiplied by the number of patients per X number of people facing the roof.	€

Effect	Description	Valuation method
Social cohesion	For this effect, it is described whether the project leads to additional opportunities for people meeting (at ground level or on the roof) and less crime due to more green space.	Qualitative
Biodiversity contribution according to the nature points system	Based on the type of green roof and the area of greenery of the installed roof, the number of nature points were determined using a nature point system. Additional information on the nature point system can be found in section 4.3.	Qualitative
Contribution to BREAAM credits	Based on the BREEAM methodology, the extent to which the construction of the multifunctional roof contributes to the realization of sustainable buildings with minimal environmental impact is assessed. Consider, for example, improving water quality or promoting social cohesion in an area. Based on the overall BREEAM score, this can be made qualitatively clear. Additional information about the BREEAM system can be found in Chapter 4.4.	Qualitative
Housing	Purple roofs lead to additional m² of living/residential space. Adding residential space does come at a cost.	Quantitative
Mobility	Orange roofs can contribute to improved mobility. Adding orange roof surface does come at a cost.	Quantitative

4.3 Nature point system

The nature point system is used to determine how many points can be gained for multifunctional roof. A developer or architect can choose from a list of green roofs when creating their design. Points are assigned to those different roofs. For example, the construction of a biodiverse roof is good for 3 points, the construction of a sedum roof earns 2 points, and the installation of an insect stone, for example, gives 1 point. The calculation tool includes a selection of nature points; see Table 3 below.

The nature point system is used by, among others, the municipality of The Hague and the Covenant Climate-adaptive Building Zuid Holland (Gemeente Den Haag, 2020). For a small project (500m² footprint) 2 points are requested on facade and roof. For a medium project (<2000 m²) 4 points, and for a large project (>2000 m²), 6 points.

Table 3 Recorded nature points (Gemeente Den Haag, 2020)

Nature points	
1	Green roof with sedum (>5-7cm)/30%
2	Green roof with sedum, grass, and herbs (>7-15cm)/30%
3	Green roof with (sedum), grass and herbs, dwarf shrubs and shrubs (15-30 cm)/30%
4	Green roof with (grass), herbs, dwarf shrubs and shrubs (30-50 cm)/30%
4	Green roof with herbs, dwarf shrubs, shrubs, and trees (>50 cm) /30%
4	Only for high-rise buildings (> 50m): at least 100% of the footprint of the urban layer is returned as horizontal outdoor spaces such as roof gardens. At least 40% of this must be designed with greenery that contributes to biodiversity

4.4 BREEAM

BREEAM stands for Building Research Establishment Environmental Assessment Method and is used in more than 80 countries worldwide. The method was originally developed by the Building Research Establishment (BRE). BREEAM-NL has been the certification method for a sustainably built environment since 2009. This method allows projects to be assessed on integral sustainability. BREEAM-NL has four labels.

With the label BREEAM-NL Area, an entire area is assessed for sustainability. This can be a redevelopment of existing areas, but the certification of new area developments is also possible. The sustainability label addresses various themes such as heat stress, climate adaptation and health by improving local air quality and social cohesion. That makes BREEAM-NL Area *(BREEAM-NL, 2018)* the yardstick for sustainable area development in the Netherlands. Multifunctional roofs can contribute to this. The calculation tool includes a selection of the credits from BREEAM. These can be found in Table 4.

Disclaimer: the contribution of BREEAM points is an indication, no rights can be derived from the score.

If desired, the contribution to credits BREEAM can also be examined at the building level by the user himself.

Table 4 Recorded BREEAM-credits in the tool

Credit	Description
SYN 5	Encourage managerial and/or financial participation of users in the area to increase their involvement with and responsibility for the area.
SYN 6	Encourage collaborative and financing structures among stakeholders to increase the feasibility of sustainability ambitions in the area.
BRO 3	Encouraging local generation of renewable energy.
BRO 4	Reducing the use of drinking water in the area.
RO 7	Maintain and enhance biodiversity and ecological value and function at local and regional levels and sustainably preserve them.
RO 8	Encourage intensive land use to minimize land use for development.
RO 11	Minimizing flood risk in the area after development.
RO 12	Preventing damage to the built environment and vital and vulnerable functions due to extreme precipitation events.
RO 13	Promoting an optimal system for the transportation (people) and transportation (products) needs of an area and its surroundings with the lowest possible environmental impact.
WELL 2	Promoting social cohesion in the area.
WELL 3	Improving the quality of the environmental experience.
KLI 1	Promoting a good outdoor thermal climate for users and preventing heat stress.
KLI 3	Optimizing local air quality.

5 APPLIED KEY FIGURES

The table below presents the key figures and assumptions used from the calculation tool multifunctional roofs version 3.0.

Category	Effect / assumption	Key figure	Unit	Source
General	Discounted costs and benefits (excluding CO_2 emissions) (default value, adjustable)	2,25	%	Discount rate Dutch government (RWS, z.d.)
	Discount rate CO_2 emissions	2,9	%	Discount rate Dutch government (RWS, z.d.)
	Period of analysis[2] (default value, adjustable)	40	Year	-
	Price level	2023	Year	Consumer Price Index 2023 (CBS StatLine, 2024)
	All costs and benefits/revenues do not include VAT/taxes			
Costs				
Additional **Investment costs multifunctional roofs** [3,4]	Replacement cost[2] regular roof	45	€ / m²	Homedeal Roofing (Homedeal, 2024) Adjustable by user of the tool
	Replacement period / lifespan regular roof[5] . In addition, it is assumed that the replacement period of a regular roof increases with the installation of a green sedum roof. Instead of 20 years, it then becomes 60 years (simultaneously with the green roof).	20	Years	
	Investment cost of blue roof	100-150	€ / m²	(Gemeente Rotterdam, z.d.) Poster: Water on green roofs (Amsterdam Rainproof, 2024) Assumption; expert judgment Adjustable by user of the tool
	Replacement term / lifespan blue roof	30	Years	
	Investment cost (solar panels) yellow roof	470	€ / panel	Solar Plan Knowledge Centre (Zonneplan, 2024) Homedeal: The price of solar panels (Homedeal, 2024)
	Replacement period / lifespan (solar panels) yellow roof	25	Years	

[2] The replacement period determines whether and when the investment costs of a new roof/new roof feature are included again in the analysis period of the SCBA.
[3] These are additional costs to the regular cost of the roof. Thus, in the cost-benefit analysis, we assume *additional* costs over regular roof management. However, with multifunctional roofs, the replacement period of the regular roof becomes longer. This leads to a benefit. The assumption is that this benefit occurs at the time of the regular replacement period.
[4] This is a default value that can be adjusted by the user of the calculation tool.
[5] This is a default value that can be adjusted by the user of the calculation tool.

Category	Effect / assumption	Key figure	Unit	Source
				Adjustable by user of the tool
	Assumption replacement time / lifespan red roof	30	Years	Homedeal Roofing (Homedeal, 2024) Adjustable by user of the tool
	Investment cost of green roof (sedum, natural roof, garden roof, respectively)	50, 75 and 90	€ / m²	Poster: Water on green roofs (Amsterdam Rainproof, 2024) Adjustable by user of the tool
	Replacement term / lifespan sedum roof	60	Years	
	Replacement term / lifespan natural roof and rooftop garden	30	Year	
	Investment cost of red roof	200-500	€ / m²	(Gemeente Rotterdam, z.d.) Expert judgment Adjustable by user of the tool
	Red roof replacement period / lifespan	30	Years	
	Investment costs orange, purple and grey roofs	Resp. 200, 500 and 50 (minimum) as default, but adjustable	€ / m²	(Gemeente Rotterdam, z.d.) Adjustable by user of the tool
Additional **Management and maintenance costs roofs** [6,7]	Regular roof	4	€ / m² per year	Homedeal Roofing (Homedeal, 2024) Adjustable by user of the tool
	Blue roof	1	€ / m² per year	Homedeal: Roof maintenance prices (Homedeal, 2024) Adjustable by user of the tool
	Yellow roof	3,50	€ / panel per five years	Solvari: Solar panel maintenance (Solvari, 2024) Adjustable by user of the tool
	Green roof	1,20 - 1,80	€ / m² per year	Milieu Centraal Adjustable by user of the tool
	Red roof	10	€ / m² per year	Expert judgment Adjustable by user of the tool

[6] These are additional maintenance costs to the regular maintenance costs for the roof underlayment.
[7] This is a default value that can be adjusted by the user of the calculation tool.

Category	Effect / assumption	Key figure	Unit	Source
	Orange, purple, and grey roofs	3% of investment cost as default, but adjustable (6, 15 and 1.50 euros, respectively)	€ / m² per year	Adjustable by user of the tool
Living / Residential	Assumption energy consumption per household	3,400 as default, but Adjustable	KWh / year	Milieu Centraal Adjustable by user of the tool
	District/neighbourhood typology	-	-	District typology according to Climate Impact Atlas (Klimaateffectatlas, ESRI, 2024) To be filled in by user of the tool
	Current WOZ/property value[8]		€	WOZ value counter (Rijksoverheid, 2024) To be filled in by user of the tool
Energy Returns and Yields	Energy yield per panel	-	Wp	To be filled in by user of the tool
	Solar panel dimensions Assumption number m^2 per panel depends on roof pitch. • With a slab roof, 100% of the space can be used. • For a slightly sloped roof, 80%. • Sloping roof 60%. • Very sloping roof 40%.	Default value at 2.5, but adjustable	m²	Adjustable by user of the tool Solar Plan Knowledge Centre (Zonneplan, 2024) Homedeal: The price of solar panels (Homedeal, 2024) Solar panel yields (Zonnepaneleninformatie, z.d.)
	Correction factor efficiency panels	Default value at 0.9, but adjustable	-	Can be customized by tool user
	Price KWh electricity (excluding VAT)[9] . It is assumed that the energy generated is used for own consumption. If there is a surplus, it is delivered back to the grid.	-	€ / kWh	To be filled in by user of the tool Voltasolar Knowledge Centre (Voltasolar, 2022)

[8] The results can be differentiated according to the amount of residential units involved in the building. For now, it is up to the user whether the desire is there to do this; if it is known what kind of building it is and how many residential floors there are, you can determine the WOZ value yourself and differentiate the results.

[9] Under the following assumption: the price for delivering back electricity is equal to the price for purchasing electricity.

Category	Effect / assumption	Key figure	Unit	Source
Property / Real estate value[8]	The literature shows a range of 1.4-21% increase in property value due to greenery/green roofs. The following values are given as suggestions in the tool: • 1.4% property value increase for green roofs of 0-500 m^2 • 2.5% property value increase for green roofs of 500-1000 m^2 • 5% property value increase for green roofs of 1000-2000 m^2 • 7.5% property value increase for green roofs of 2000-3000 m^2 • 10% property value increase for green roofs of 3000-4000 m^2 • 12.5% property value increase for green roofs of 4000-5000 m^2 • 15% property value increase for green roofs of 5000-6000 m^2 • 17.5% property value increase for green roofs of 6000-7000 m^2 • 20% property value increase for green roofs of 7000-8000 m^2 • 21% property value increase for green roofs larger than 8000 m^2 In the tool, users can enter their own property value increase percentage based on this information. The increase in property value reflects the following underlying effects: aesthetic appreciation, noise reduction, productivity, and comfort. The assumption is that the increase in property value occurs once, in year 1. Disclaimer: property value appreciation is very location dependent. This calculation tool provides a first estimate. The exact determination of the possible increase in property value should be further investigated per location.	1.4-20%, but adjustable	% of the WOZ value	Can be adjusted by users of the tool International Journal of Environmental Research and Public Health. (Veisten K. Y., 2012)
Water retention blue and green roofs	Shadow costs / avoided costs of an alternative retention facility	415,4	€	Expert judgement Arcadis (2024)
	Standard water retention green roof. The amount of water retention on a blue roof can be set manually.	30	mm/L per m2	Climate adaptation subsidy (Gemeente Rotterdam, 2024)
Water reuse	Drinking water tariff. The collected water can be reused for personal use (e.g., irrigation of a green roof). It is assumed that this could lead to avoided costs.	-	€ / m^3	To be filled in by user of the tool; current drinking water tariff

Category	Effect / assumption	Key figure	Unit	Source
Capture of particulate matter and other emission substances	Unit correction	3,1536	Cm / s to kg / ha / year	TEEB City Tool (RIVM, 2019)
	Deposition Rate Fine Dust Green Roofs	0,33	Cm / s	
	Social value Particulate matter	45,22	€ / kg	
	Deposition Rate Nitrogen Dioxide Green Roofs	0,5	Cm / s	
	Social value Nitrogen dioxide	35,18	€ / kg	
	Deposition Rate Sulphur Dioxide Green Roofs	0,72	Cm / s	
	Social value Sulphur dioxide	25,24	€ / kg	
	Deposition Rate Ozone Green Roofs	0,75	Cm / s	
	Social Value Ozone	4,24	€ / kg	
CO_2 emissions and air quality (other emissions)	Avoided emissions • CO_2 • NO_X • SO_2 • VOS • Fine dust	 0, 56 0,00071 0,00039 0,00056 0,00003	 kg/kWh kg/kWh kg/kWh kg/kWh kg/kWh	KEV (PBL, 2022) (CE Delft, 2015) (CE Delft, 2015) (CE Delft, 2015) (CE Delft, 2015)
	Environmental Pricing • CO_2 • NO_X • SO_2 • VOS • Fine dust (PM10)	 0,13 29,9 57,5 2,73 69,3	 Euro/kg Euro/kg Euro/kg Euro/kg Euro/kg	Environmental Pricing Handbook 2023. (CE Delft, 2023)
Health (physical and mental)	Fewer patients per 1000 inhabitants, within 1km	0,835	patients at 1% more green	TEEB City Tool (RIVM, 2019)
	Avoided healthcare costs	917	€ per patient	TEEB City Tool (RIVM, 2019)
	Preventing loss of labour	6.679	€ per patient	TEEB City Tool (RIVM, 2019)
	Assumption: Fewer patients at 1000 population, within 200m	0,167	Patients at 1% more green	TEEB City Tool (RIVM, 2019)
	Assumption: Fewer patients at 1000 population, within 2000m (depending on number of people facing roof)	0,02505	Patients at 1% more green	TEEB City Tool (RIVM, 2019)

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COLOPHON

CALCULATION TOOL MULTIFUNCTIONAL ROOFS VERSION 3.0
BACKGROUND REPORT ON KEY FIGURES

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