LIFE CYCLE COSTS OF GREEN ROOFS
- A Comparison of Germany, USA, and Brazil -

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Abstract - Within the last decades, the trend to ever larger dwellings and the increases in industry and traffic have resulted in the continuous growth of cities. The settlement surface in Germany has doubled within the last 40 years and present growth amounts to 1.1% per year. In the USA, the built on surface extends by 3% per year; in Brazil this number may be much higher. Together with increasing emissions, especially caused by traffic, industry and domestic burning, this increase in settlement surface has led to a noticeable impairment of the urban climate. The climate of cities, in comparison to the climate of open land, in most cases has negative effects on urban inhabitants. For example, sleep disturbances and heart disease may be more prevalent. The limited available space in cities makes roof gardens an attractive possibility to improve the urban situation. In Europe, green roof technology has become increasingly important within the last 20 years. In the USA, green roof technology started two years ago and is now growing rapidly. Use of green roofs in Brazil is infrequent, but there, as in all countries, a substantial benefit of roof planting is the economic gain. This work presents these advantages by comparing green roofs with other kinds of roofs. The work presented here is preliminary, and is to be continued in the context of a thesis (diploma). Our first results should be useful for planners, architects, builders, and other experts involved in roof greening. The authors are looking forward to receive detailed information to calculate the benefits as well as possible.

Life Cycle Costs

The following benefits of green roofs can be judged by financial criteria. Although in most cases, one benefit alone is not enough to justify the installation of a green roof, we have to examine the benefits separately:

1. extension of the life span of the underlying waterproof system
2. reduction of the stormwater runoff
3. improvement of thermal insulation
4. reduction of sound reflection and transmission
5. increase in property value

Costs

Together with the underlying roof waterproofing, an extensive green roof Installation in Germany at present costs approximately 85 $ per square meter. The costs are roughly twice those of a conventional roof. In the USA the costs are similar. In Brazil the costs are 30% of these values. Compared to generally in all three countries low-priced pre-fabricated or welded roofs, green roofs cost about three times more. The low-priced roofs, however, require replacement or major repairs after approximately 15 years, whereas green roofs will survive thirty or more years (Table 1).

35 years of experience with green roofs in Germany demonstrate the value of the roof planting as protection of the waterproofing membrane. A roof which is covered with planting can be expected to outlast a comparable roof without greening by a factor of at least two. Although modern green roof planting systems are not more than 35 years old, many researchers expect that these installations will keep 50 years and more. The old green roofs in Berlin demonstrate a life span of more than 90 years before they require important repairs or replacement. In Germany 90 years is a typical lifespan so it is the time base for the following text.

Table 1: Life cycle costs during the lifespan of different types of roofs in Germany (construction and repair costs, disposal and recycling costs – not including maintenance). Data is based on a estimated 90-year building life cycle with a 100 m² roof. Costs are calculated per m². (own generalised calculation of projects and publication)

Type of Roof	**Construction costs in $/m²**	**Repairs (interval in years)**	**Renovation after... years (average)**	**Renovations costs during life span ($)**	**Reconstruction RC /Disposal and recycling – costs: RECY ***	**Sum ($/m²)**
Bitumen roof	40	Every ten years	After 15 years	6 x 40 = 240	20 RC, 20 RECY	320
Gravel roof	50	Every 15 years	After 15 – 20 years.	About 200	25 RC, 25 RECY	295
Extensive green roof without PVC-products	90	-	Temporally only occasional renovation work	40	40 RC, RE -.-	170
Extensive green roof with PVC products	85	-	Temporally only occasional renovation work	40	40 RC, 20 RECY	185
Intensive green roof without PVC-Products	380	-	Temporally only occasional renovation work	At last in maximum up to 380 (the same cost as the building costs during the whole lifespan)	100 RC, RECY -,-	860
Intensive green roof with PVC-products	340	-	Temporally only occasional renovation work	340	100 RC, 40 RECY	820

Depending on environmental regulations, the charges could rise in the next years! A waterproofing layer is necessary. But the PVC-layer causes problems in production and in terms of recycling.

Vegetation layer

When selecting plant material, the extreme living conditions must be considered. (Table 2):

Table 2: particular conditions on green roofs

strong winds	risk of breaking, drying up of plants (winter)
shallow soils	drying of substrate and wind erosion
intense sun radiation	higher evapotranspiration, leaf damage by heat, increased frost susceptibility during winter
limited volume of growing medium	restricted growing

Maintenance, Durability

Table 3: Annual and life span costs of the time of 90 Years of inspections and maintenance for the different roof types (related to the 100m² roof example), data per m².

Type of roof	**Annual requirements**	**Lifespan cost per m²**	**Sum ($/m²)**
Bitumen roof	Optical inspection: only every five years, about 100 $ per roof inspection	0.2 (annual per m²) x 90	18
Gravel roof	The same as a bitumen roof!	“	18
Extensive green roof	Annual optical inspection and removal of tree seedlings, 100 $ per visit	1 x 90	90
Intensive green roof	8 times in a year, about 100 $ per visit	8 x 90	720

All roof planting requires maintenance (Table 3). Extensive greening is low maintenance, i.e. after desired surface coverage, irrigation is no longer necessary. Temporary drying is desirable. Weeds, particularly tree seedlings, should be removed regularly (1-2 x/year). A higher proportion of mineral content in the substrate will reduce the development of weeds and therefore also reduce maintenance expenditure.

Extensive roof planting should not be fertilized. Fertilizing of intensive roof gardens depends on the composition of the substrate and on the selection of the plants. Regular maintenance and observation of the plants is very important. For extensive greening with Sedum, no pruning is necessary. The plants of an intensive green roof require the same pruning measures as on a ground location. Roof waterproofing as well as the drainage systems are to be inspected regularly (2 x/year) and cleaned if necessary. Inspection and maintenance costs are affected to a large extent by local wages (Table 4). The labour costs in the USA amount to approximately 50% of German labour costs. In Brazil they may be no more than 10%.

Table 4: Minimum hourly wages

GERMANY	USA	BRAZIL
10.36 $	5.25 $	< 1$ (240 R$ / month)

Well-being

If roof planting in the past was predominantly intended for architectural reasons, then today it is regarded as a compensation for displaced nature. Surveys of the inhabitants of large cities showed that 70-80% of the population feels itself underprovided with green in the neighbourhood. A study of 25 large German towns concluded that in nearly all cities 40% of the urban surfaces are covered and sealed and in some cities even 50%. It is interesting that the portion of sealed surface nearly doubled in the past 30 years even though the population shrank.

Table 5: Ecological and human benefits of green roofs (x means a benefit exists; xx = high value, - means no benefit existing)

Type of roof	**Visual quality**	**Health and recreational benefits**	**Bio-diversity**	**Stormwater retention (av. retention and financial savings)**	**Energy savings**
Bitumen Roof	-	-	-	-	-
Gravel roof	-	-	-	-	-
Extensive green roof	X	X	X	75%, (15 $/m² for construction; 1,--/m² x a). 90.2 $/ /lifespan	X
Intensive green roof	XX	XX	X	100%, 90.2	X

One of the reasons for this is surely a rising requirement for each person's space. Nature moved to the periphery of the cities and a direct connection to nature for urban dwellers was made more difficult or completely lost. The greening of buildings in large towns and cities brings back a part of the lost nature to the citizens without requiring more space (Table 5).

Stormwater / Rainwater

Widespread impervious surfaces frequently result in an overloading of drainage networks and purification plants which in turn causes flooding and overspill of polluted wastewater into nearby bodies of water. To avoid these unpleasant and expensive consequences there are two possibilities: extension and enlargement of the sewer systems and purification plants, which is connected with high costs, or decrease and delay of the stormwater runoff. A suitable method to reduce the stormwater runoff is to plant green roofs (Table 6).

A green roof does have runoff. However it can be strongly reduced and delayed so that even in limited spaces, the infiltration of the surplus water on the property becomes possible. According to the FLL, the stormwater runoff of green roofs (10 cm soil) compared to non-green roofs is reduced by 50 %. Also in Germany these coefficients will be modified by new researches, but the administration actually uses in most cases the following old values.

Table 6: Stormwater runoff coefficient according to roof type

roofs without greening	green roofs with a slope up to 5°	Green roofs with a slope over 5°
roof surface > 3° slope: **1.0**	< 10 cm structure thickness: **0.5**	Independent of structure thickness: **0.7**
roof surface < 3° slope: **0.8**	10-25 cm structure thickness: **0.3**	
gravel roofs : **0.5**	20-50 cm structure thickness: **0.2**	
	> 50 cm structure thickness: **0.1**	

Many German municipalities are currently charging annual fees for stormwater which accumulates on impervious surfaces. Obviously conventional roofs are considered to be impervious surface. For green roofs, the runoff coefficient is used to determine how much runoff will be introduced into the public sewer and how much annual fee must be paid. Therefore green roofs help to store precipitation .

Thermal insulation

The thermal insulation of a green roof is based on different layers which reduce the energy passage. This insulating effect is not constant but dependent on the weather and influenced by the water content of the layers, the water flow in the drainage layer and the wind velocity. Therefore the calculation of the insulating effect is difficult. The factors which can influence the thermal protection can be divided into the factors of heat transfer and convection. During heat transfer, the thermal protection is essentially based on cavities in plates or substrate and on air in spaces between substrate components. As well, the air within the vegetation works as thermal insulation.

During heat transfer, the absorption and reflection of the long-wave radiant heat from the building plays an important role in thermal protection. The nocturnal heating of the soil layers due to the root is likewise apparent. The surface roughness of the sod layer as opposed to a smooth tar roof causes a decrease in convection losses. The wind energy is converted in stems, stalks, leaves, etc. into warmth. The saving of energy, in particular at low temperatures, is also connected with the displacement of the freezing point from the roof surface into the soil layer.

The coordination of all factors has an effect, as though the vegetation layer would have the same heat conductivity of expanded clay. After Roofscapes(2002), a 10 cm green roof layer is equivalent to 5 cm of a normal technical insulation material but this is only a draft point of view. . Thus the insulation values are improved by about 25 % with extensive greening. This improvement serves not only the thermal insulation in the winter, but also decreases the temperature of underlying rooms in the summer. Substantially lower temperatures (on average 3-4 °C, Roofscapes, 2002) were measured in underlying rooms after roof greening. For buildings in the tropics, this is surely a factor which would favour greening. Especially in Brazil, with its constant energy requirement mostly due to the many air conditioning systems, this reduction in temperature would bring advantages. But until now there still exists a gap of climate measurements under tropic conditions.

Noise Insulation

Without increase of the mass of green roof construction materials, an improvement of the insulation of airborne sound can be achieved by roof planting, since the large cavities of a gravel layer in greening material are avoided. If the green roof thickness increases, the insulation of airborne sound continues to improve. A substrate depth of 20 cm can improve sound absorption up to about 46 dB (A). This is in particular interesting within the range of approach lanes from airports. On low buildings in the effective range of altitude acoustic sources, such as in trade and industrial areas, green roofs possess special importance. Conventional roofs reflect the sound whereas green roofs absorb it. The noise level can be reduced by 2 to 3 dB (A) compared to gravel roofs (Koch &.Seitz, 1998). A green roof can thus be considered as element or alternative in structural noise control – but also here are until now only a few measurements done.

Increase in property value

On the international estate markets, the consequences of economic weakness are generally visible. The demand for office space has clearly diminished, which is expressed in low rental rates (Table 7). Only in prime urban locations do the price level and occupancy rate remain stable. Generally the market is dominated by falling prices and decreasing occupancy.

Table 7: rental rates of the largest cities (DEKA Immobilien Global (31.03. 2003):Semi-annual report)

	GERMANY (Berlin)	USA (New York)	BRAZIL (Saõ Paulo)
Vacancy rate %	8	9	15
Top rents / m² / per year	300 $	550 $ (55 sq.ft.)	200 $

Table 8: Different roof types and their rental advantages (in $ /m²) (x = obligatory) (1): The calculation of rental rates in Germany is regulated; an additional 1/4 of the normal rent is allowable for terraces and roof gardens. For example, an average rent: 10,- ($ /m²)/4 x 12 Month x 90 Years. The rent of this roof garden is similar to an additional room in the flat of 25 m²!)

Type of roof	Waterproofing is required	Higher rent	Value in higher rent
Bitumen roof	X	-	-
Gravel roof	X	-	-
Extensive green roof	X	- (perhaps)	- reduction of stormwater fee
Intensive green roof	x	Yes	2.700,-- (1)

Ignoring the other benefits, green roofs are an architectural advantage. In new projects they can be considered as substantial elements of the entire landscape. Still more important, they can change traditional roofs into "roof landscapes" and this could lead to an economic advantage with the letting and the sales of buildings (Table 8). In many cases they can also be used in order to create passive recreation areas for employees and inhabitants. Often this value alone can justify the installation of a green roof.

Results

In the long-term, green roofs are more economical than non-greened roofs (Table 9, Figure 1). The same results are also found by another author (Haemmerle, 2002). The extensive green roof is inexpensive, with high visual quality ("beautiful"), and if all the additional advantages are calculated, the cost-benefit ratio will be rise further.

Roof gardens are not possible on all buildings, but if the construction allows a roof garden, a higher value of the flat is one consequence.

Many ecological benefits are still difficult or impossible to calculate, but the numbers provided here should help to make the decision for both types of green roofs easier.

What about in the US and Brazil?

In the US, roof gardens are becoming more and more fashionable. There is no regulation of the rental rates as in Germany, but the better quality of the flats also has a consequence on the price.

In Brazil, people prefer roof flats with green terraces because of the garden views. In tropical climates the life outside requires open green spaces. Many examples in Rio Sul demonstrate the same results!

Table 9: Total cost – benefit overview of the estimated lifespan of 90 years in \$ per m²

Type of roof	**Construction, inspection and disposal/recycling costs (from Table 1, \$)**	**Total maintenance (from Table 3, \$)**	**Financial benefits / increased rental income (Table 5 + Table 2, \$)**	**Total costs (-) or total profit (+) per m² (Column 2 + 3 –5, \$)**
Bitumen roof	320	18	- -	338,00 -
Gravel roof	295	18	- -	313,00 -
Extensive green roof without PVC products	170	90	90,2	169,80 -
Extensive green roof with PVC products	185	90	90,2 –	184,80 -
Intensive green roof without PVC products	860	720	90,2 + 2.700,00	1.210,20 +
Intensive green roof with PVC-Products	820	720	90,2 + 2.700,00	1250,00 +

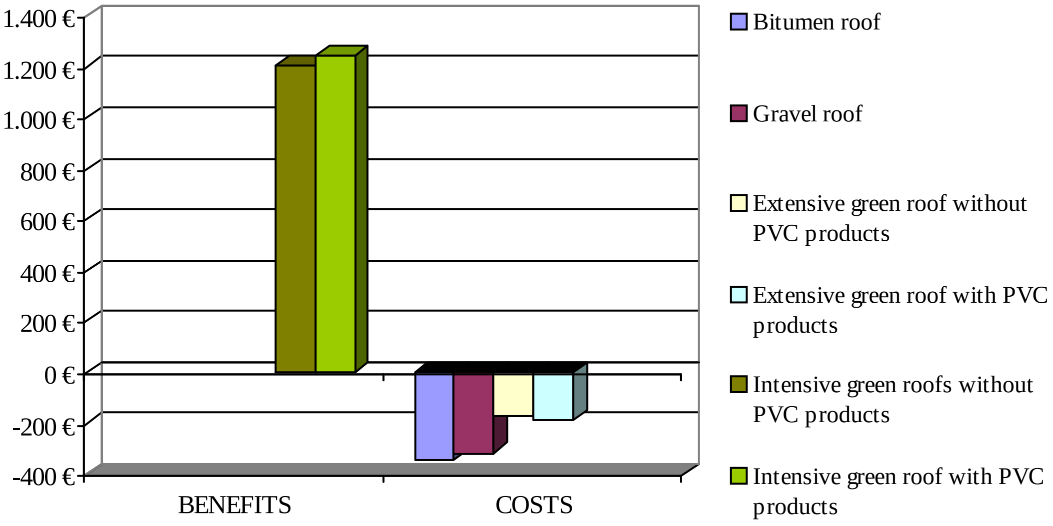

Figure 1: A first total cost – benefit overview of the estimated lifespan of 90 years in $ per m²

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