San Francisco Living Roof Cost-Benefit Study

Summary Report . Draft 2 . June 8, 2016

Green Roof Cost-Benefit Study

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Section

Photo Credit Lisa Lee Benjamin

June 8, 2016

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Green Roof Cost-Benefit Study

Introduction and Methods

This study examines the costs and benefits associated with living roofs in San Francisco. It relies upon San Francisco-specific data where available, and makes use of a broad and robust range of regional, national and international sources where appropriate to fill in gaps in locally sourced knowledge.

The study makes certain assumptions to facilitate analysis and comparisons. See references section for more background on assumptions.

Building Types

- New Medium Office (3 storeys, 17,800 sf roof) – this configuration is based on the California Energy Commission (CEC) prototype model for this building type
- New Small Multifamily Residential (same scale as medium office used for direct comparison)

Baseline Roof

- White cool coating (this is the prescriptive code requirement for new non-residential buildings in San Francisco)

Living Roof

- 6” growing medium (soil), a semi-extensive depth chosen because this is the minimum depth that allows roofs to contribute to compliance with the SFPUC stormwater management ordinance
- Low-growing native and climate-adapted plants

The costs and benefits estimated include:

One-time Costs

- Installation

Recurring Costs

- Maintenance
- Irrigation
- Reroofing

One-time Benefits

- Avoided stormwater management equipment cost

Recurring Benefits

- Energy savings
- Carbon abatement
- Heat island mitigation
- Air quality improvement
- Noise abatement
- Biodiversity/habitat addition
- Biophilic amenity, productivity increase and decreased absenteeism from work
- Job creation
- Real estate effects (improved value in rent, absorption, tenant retention and risk reduction)

A range of other benefits can also be achieved, including access to open space, educational opportunities, food production and simple aesthetic beauty, but the value associated with these has not been included as they are very dependent on the specifics of individual roofs and users.

Analysis

A financial analysis was performed comparing costs and benefits associated with the living and baseline roofs over 25 years. The approach to this financial analysis differs somewhat from a typical one, in that it compares not just the two roofing systems in isolation, but a development package that includes a living roof with one that uses other means to comply with relevant regulations (primarily the SFPUC stormwater management ordinance).

Costs and benefits are then grouped according to the stakeholders to whom they accrue:

- Owners
- Tenants
- Owner-occupiers, and/or
- The Community

Benefits are generally estimated conservatively where there is doubt about what the value should be, so actual benefits are likely higher than shown. To further avoid overestimating benefits, in the case of community and real estate values, the tax value of the benefit to the City is used rather than the full value.

Green Roof Cost-Benefit Study

Living Roof Costs and Benefits

General Assumptions:			
Discount Rate, %	6.5%	Living Roof Size, sf	17,876
Investment Outlook, years	25	Site Size, sf	20,000
Living Roof Medium Depth	6"	Floors	3

Assumptions	Living	White		Living	White
Climate Zone	3		Electricity Price, $/kWh	$0.22	
Installation Cost, $/sf of roof	$31.52	$11.42	Natural Gas Price, $/therm	$1.50	
Replacement Premium, %	33.51%	20.0%	Avg Rent, $/sf/yr	$51.87	$51.38
Maintenance Costs, $/sf of roof	$0.46	$0.12	Avg Value, $/sf	$1,117.8	$1,112.4
Roof Life (yrs)	40	20	Average Vacancy, %	6.39%	6.45%
Disposal Costs, $/sf of roof	$0.12	$0.37	Cap Rate, %	3.73%	3.75%
Stormwater Surcharges, $/sf of roof (not used)	$0.00	$0.000	Absorption, months	5.9	6.0
Income Growth Rate	0.00%		Tenant Retention, months	52.8	52.6
Expenses Growth Rate	0.00%				

Variables - /sf of roof/yr unless noted	Living	White	Nominal Growth Rates	
Energy Equipment Cost, $/sf of roof (not counted)	$0.00	$0.00	Labor & Materials	4.9%
Stormwater Equipment Cost, $/sf of roof	$0.76	$9.08	Stormwater Costs	4.1%
BMP Maintenance Cost	$0.07	$0.24	Energy Prices	2.4%
Heating/Cooling Cost Premium	($0.07)	$0.00	Carbon (included in price)	0.0%
Embodied Carbon, tonnes of CO_2e/sf of roof	0.0006	0.00001	Community Benefits (Inflation)	2.5%
Reflectance + sequestration, metric tonnes of CO_2e	0.0002	0.0005	Rent, Absorb & Retention	3.0%
Carbon savings from heating/cooling savings	0.0004	0.0000	Living Roof Risk Contingency	2.5%

SF Soft Variables - $/sf of roof/yr	Living	White		Living	White
Internal Real Estate Impact (Living Roof on Green Building rent contribution)	$0.5	n/a	Biodiversity & Habitat	$0.03	n/a
			Air Quality	$0.11	n/a
External Real Estate Impact (Biophilia/Productivity)	$0.2	n/a	Heat Island Energy Savings	$0.00	n/a
			Heat Island Peak Shaving Savings	$0.20	n/a
Employment (Community Benefit)	$0.004	n/a	Noise Abatement	$0.04	n/a

Figure 1 – Key assumptions and findings for medium office

Individual Costs and Benefits

This section discusses each living roof cost or benefit that figured into the analysis and how its value was estimated. Table 2 summarizes all of the key assumptions and findings. Please see references section for a description of calculation data sources.

Stormwater

Stormwater performance of living roofs has been well-documented over the past 15 years through field monitoring studies and hydrological modeling.

To estimate the value of the stormwater management benefits of a living roof in San Francisco, we began with the SFPUC's compliance tool for the Stormwater Management Ordinance. Making the assumption that our 3-storey 17,800 sf footprint study building sits on a 20,000 sf lot, we sought to determine the most cost-effective way to meet SFPUC requirements with a living roof and without a living roof in both the combined sewer district and in the separate sewer district (MS4).

We found that, in the combined sewer district, the study building with a living roof complied with the ordinance without any additional stormwater management systems. The system that was needed for compliance without a living roof (a cistern) was estimated to cost $6.29 (normalized to cost per sf of roof).

In the MS4, the study building without the living roof required a more significant system to comply with both quantity and quality requirements. The modeled system included cisterns and rain gardens, and cost $13.73/sf of roof. The study building with the living roof still required a reduced-size additional system to comply, costing $2.03/sf of roof.

The weighted average of these two results gave an added stormwater equipment cost for the living roof case of $0.76/sf of roof, and for the white roof case of $9.08/sf of roof.

This initial stormwater equipment savings is by far the largest up-front direct savings associated with installing a living roof in San Francisco. Similar findings have been noted in studies of other cities with stormwater management ordinances, though the amount saved varies widely based on the nuances of each city's policy and on how the policy credits performance of the living roof. It may be advisable for SFPUC to review its treatment of living roofs in the calculator tools to ensure they accurately reflect current research results on living roof stormwater performance for rate, volume and quality. It appears the 2014-2015 tools may be somewhat conservative in their treatment of living roofs.

Figure 2 – San Francisco Stormwater Management Infrastructure. Top – Sewer System Improvement Plan shows major outlets and treatment facilities. Bottom – Municipal Separated Storm and Sanitary (MS4) Sewer Zones are shown in pink. Source: SFPUC

Energy

Energy performance of living roofs has been moderately well-documented over the past 15 years through field monitoring studies and energy modeling.

To estimate energy savings associated with living roofs in San Francisco, we began with the CEC prototype energy model for a medium office (3 storey building, 17,876sf roof), and a multifamily residential model of the same scale built using Title 24 defaults. We then ran the model with a black roof, a white roof and a living roof, accounting to the degree feasible for all major mechanisms of heat transfer to the interior that are impacted by the living roof, including conduction through the roof, thermal mass in the growing medium, roof albedo, and evapotranspiration leading to air temperature change in the rooftop microclimate (measured at the point of air intake in the air handling unit - AHU). The impact to rooftop microclimate is significant for building heating and cooling if HVAC equipment is located on the roof.

Office Energy Results

The modeling results suggest that a living roof is the best choice for energy efficiency in a medium office, contributing about a 3% whole building energy savings compared to a black roof and a 2% savings compared to a white roof. This translates to a10% heating savings compared to a white roof (7% vs black) and a 3.5% cooling savings vs white (18% vs black). Using the white roof case as the baseline since that is standard by California's Title 24 energy code, the living roof is expected to save about $0.046/sf of roof/year. Not surprisingly, the savings in San Francisco are at the low end of the energy savings values documented in the literature. That is likely due to our mild climate, with small overall heating and particularly low cooling loads, and the use of the white roof as the baseline.

To calculate the energy savings benefit used in the model, we took the modeled data and averaged in energy savings estimates from a few relevant sources with a lower weighting than the San Francisco-specific model. These other sources were literature aggregates from the GSA, Portland and LBNL studies, as well as field data from Kirstin Weeks's study of the Nueva School roofs in Hillsborough, CA. The weighted average came to $0.068/sf/year.

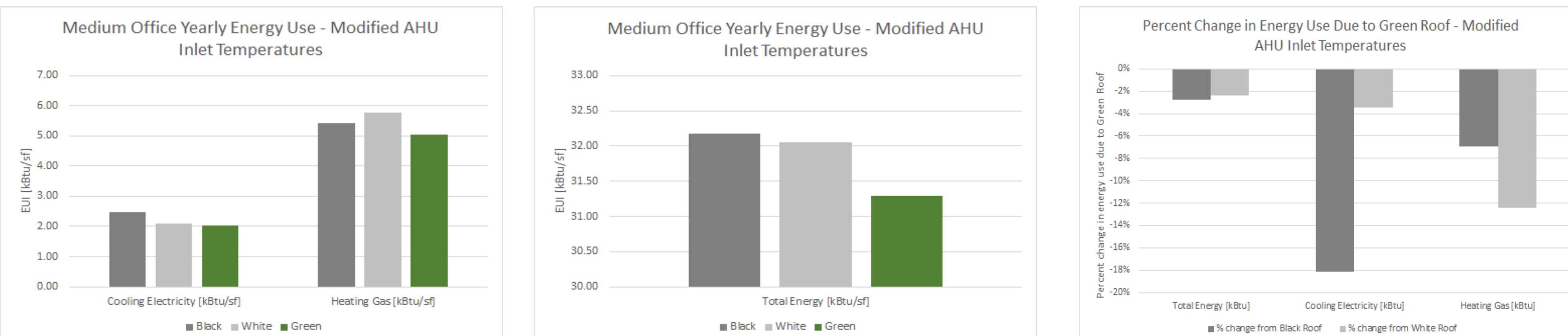

Figure 3 – Energy model analysis comparing black, white and living roofs in a medium San Francisco office building

Green Roof Cost-Benefit Study
Living Roof Benefit Descriptions

Carbon and Climate Change Impacts

Living roofs can impact carbon and climate in several ways, both positive and negative.

Like any surface, the albedo determines how much shortwave radiation is directly reflected back out of the atmosphere. So the color of a living roof surface matters, and lighter plants and soils perform better for global cooling (and better than black roofs, but generally not as well as white roofs). Living roofs by virtue of their typical components also require more energy to produce, and so have a higher embodied carbon.

On the other hand, living roofs are comprised of plants that sequester carbon as they grow. By virtue of building energy savings, living roofs also have a positive effect on carbon removal from the atmosphere.

Our calculations suggest that the impact of heating/cooling savings and sequestration are greater than that of albedo and embodied carbon, so a living roof has a small positive impact on carbon and climate change.

June 8, 2016

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Living Roof Benefit Descriptions

Heat Island Effect

Living roofs reduce the heat island effect through surface albedo, reduced surface temperature and evapotranspiration. The value associated with this is calculated by estimating modest reductions in surrounding building energy use and peak load.

Air quality improvement

Impact of living roofs on common smog-forming air pollutants, such as NOx, SOx, CO and PM10, comes directly through leaf and soil processes, as well as indirectly through energy and heat island effects. Value of benefits is estimated primarily through calculating the cost of alternative conventional means of removing these same pollutants, such as adding scrubbing at power plants (scaled down, as with other benefits and costs, to the quantity impacted by one square foot of living roof).

Noise abatement

A living roof can reduce sound transfer through the roof, primarily because of effects of the growing medium. The value of this benefit is estimated for only the top floor of the study building based on the literature, and is included in productivity and absenteeism benefits.

Biodiversity/habitat addition

Living roofs increase urban biodiversity, especially when designed to promote habitat value for species present in the vicinity who can access the roof. Value of biodiversity is estimated based on the cost of setting aside land for conservation in the Bay Area and nearby. Programs cited include the Big Sur Land Trust and the California Rangeland Trust.

Biophilic amenity

Biophilia is the inherent human affinity for other living beings, such as plants and animals, and for natural forms and patterns. Living roofs that are visible or accessible can enhance building occupants' wellbeing through biophilia. Value of this biophilic benefit is estimated through scaling documented impacts of natural views on office worker productivity and absenteeism. Value to the owner/tenant is conservatively calculated assuming 10% of building occupants access the roof for lunch, and it improves their productivity for one hour after lunch. Value to the community is calculated assuming four floors of neighboring buildings have a view of the roof, 50% cannot view it, and 50% already had a natural view of some kind. Potential reduced costs in health care or other ways to value wellbeing are not included, though studies have documented the value of natural views and biophilic design in the healing process.

A notable example is a study published in Science documenting that surgery patients with planted views recovered 1 day faster and took half the painkillers compared to those with a view of a brick wall (Ulrich, 1984). Locally, UCSF Mission Bay was designed with living roofs intended to enhance the healing process and support practitioner wellbeing. The value estimate is thus quite conservative, especially when looking at certain parts of the City, such as central SOMA, where taller surrounding buildings would gain from living roof views.

Job creation

Living roofs create jobs for a range of professionals, including designers, manufacturers, installers and maintenance personnel. Job creation value for San Francisco is conservatively set equal to 90% of the average maintenance cost of the living roof minus the average maintenance cost of the baseline roof. This is the amount that would be paid to maintenance personnel (leaving out 10% assumed to be product/material purchases). Design, manufacturing and installation jobs have been left out of the estimate.

Real estate effects

Living roofs can improve the value of a real estate asset. The estimate of real estate value is based on San Francisco-specific real estate market characteristics, and uses literature and market knowledge to estimate likely increase in rent, faster absorption, tenant retention and risk reduction.

Living Roof Cost Descriptions and Sensitivity

First Cost

Living and white roof costs for actual built roofs in San Francisco as well as typical quotes from local installers and estimators were compiled. Because costs include or exclude a range of factors, these costs were then normalized to include the waterproof membrane, include installation costs, and exclude contractor markup. Because the sample size of data from San Francisco is fairly small, cost data from the literature for national averages were also included with a low weighting. The average living roof cost was $31.52, and costs ranged from $8/sf - $51.26/sf, with the lowest cost estimated in San Francisco at $22.50/sf. White roof costs ranged from $1.87/sf - $17/sf, averaging $11.42/sf.

Operations & Maintenance Costs

Like first cost, O&M costs were estimated primarily based on local pricing, but also including literature values due to limited local data. Irrigation costs based on local climate and water prices are included.

Maintenance costs for living roofs ranged from $0.16/sf - $1.13/sf, averaging $0.39/sf + $0.07/sf for irrigation water.

Roof Replacement Costs

Living roofs, when properly installed, make the waterproof membrane last significantly longer than in a conventional roof due to reduced strain from thermal expansion and contraction, and due to protection from physical damage. Roof replacement is assumed to be at 20 years for the baseline roof and at 40 years for living roofs based on the literature and typical warranties.

Sensitivity

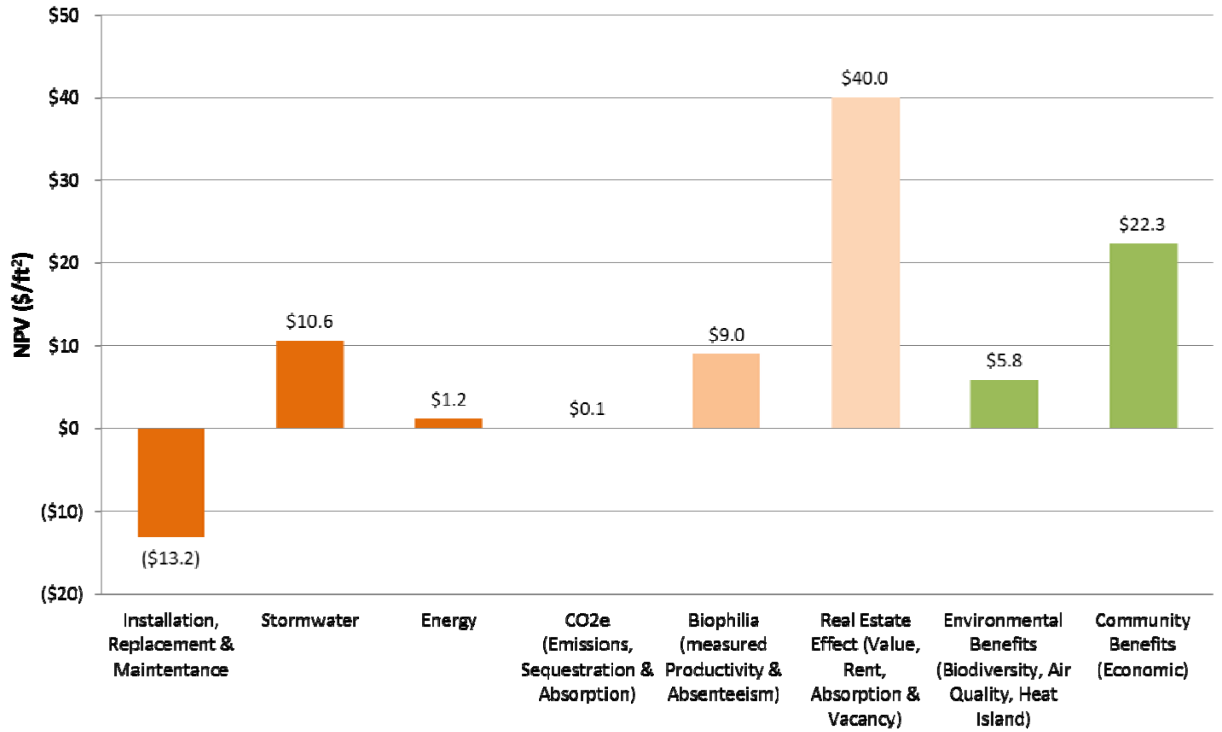
The sensitivity analysis shows that the Net Present Value (NPV) is most sensitive to first cost, roof life and discount rate, moderately sensitive to the cost of meeting the Stormwater Management Ordinance without a living roof and to maintenance cost, and somewhat sensitive to energy savings and risk contingency assumed.

Variable	Change in Total NPV per 1% Change in Variable
Installation Costs	12.2%
Roof Life	11.5%
Discount Rate	10.6%
Stormwater Equipment Cost	6.0%
Maintenance Costs	4.1%
Heating/Cooling Savings	0.9%
Living Roof Risk Contingency	0.9%

Figure 4 – sensitivity analysis of financial results to variables

Cost-Benefit Analysis Results - Office

When all the costs and benefit estimates are combined and accrue over a 25 year period (with discounting of future cash flows), we arrive at the values shown. Costs are roughly balanced out by savings in stormwater management equipment plus energy savings, with stormwater management being the most significant direct savings to the owner of a new building installing a living roof. Looking at these costs and benefits in another way, and broadening the lens, the largest potential value an owner stands to gain from installing a living roof comes from the living roof's effect on a building's cap rate and real estate value. But not all value generated by a living roof accrues to its owner. Tenants of the building who have access to or views of the roof gain biophilic benefits, estimated in terms of improved productivity and reduced absenteeism. Thus, a tenant or owner-occupier can be expected to have a clearly positive 25-year living roof NPV. Likewise, many living roof benefits accrue not primarily to the owner or occupier of the building, but to the environment and community at large. Views from neighboring buildings, improved urban climate, air quality and biodiversity offer significant value to the community that is not captured by the owner in a traditional financial equation.



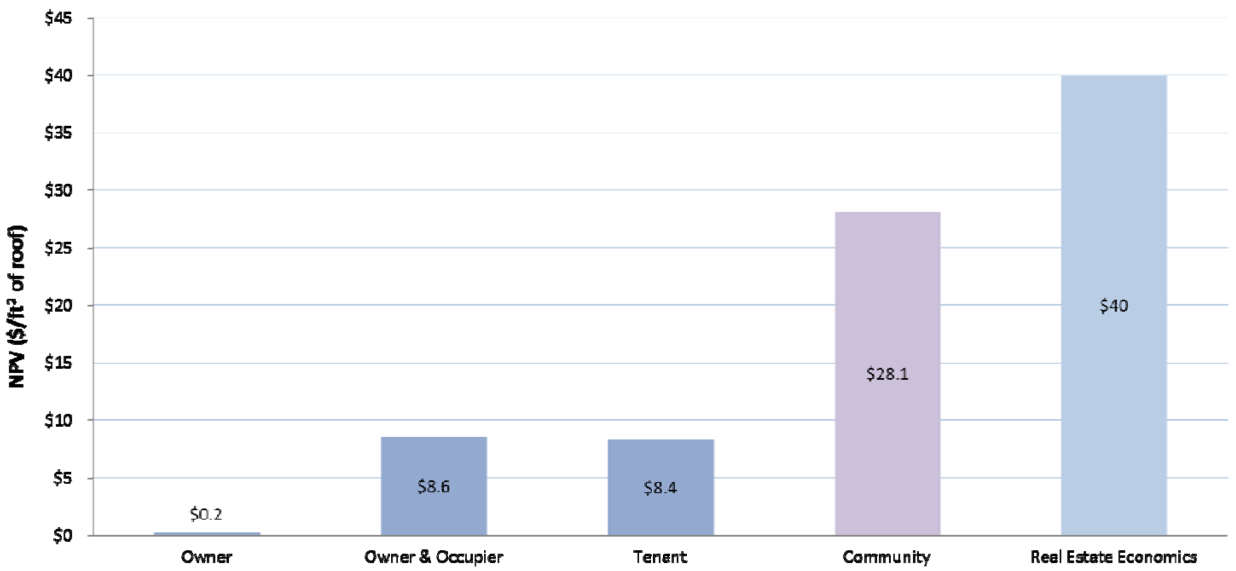


Figure 5 – summary of results for the medium office building

Cost-Benefit Analysis Results - Office

The stacked bar chart looks at these same figures in another way, with costs to each stakeholder broken out below the x axis, and benefits above the x axis. The dotted lines show the full estimated potential value to owners and owner-occupiers including real estate effects. For the owner-occupier, the calculation assumes that biophilic benefits accruing to the occupants are responsible for a portion of the real estate effect, so the added real estate value is reduced by the estimated value of the biophilic benefits.

Cost-Benefit Analysis Results – Office

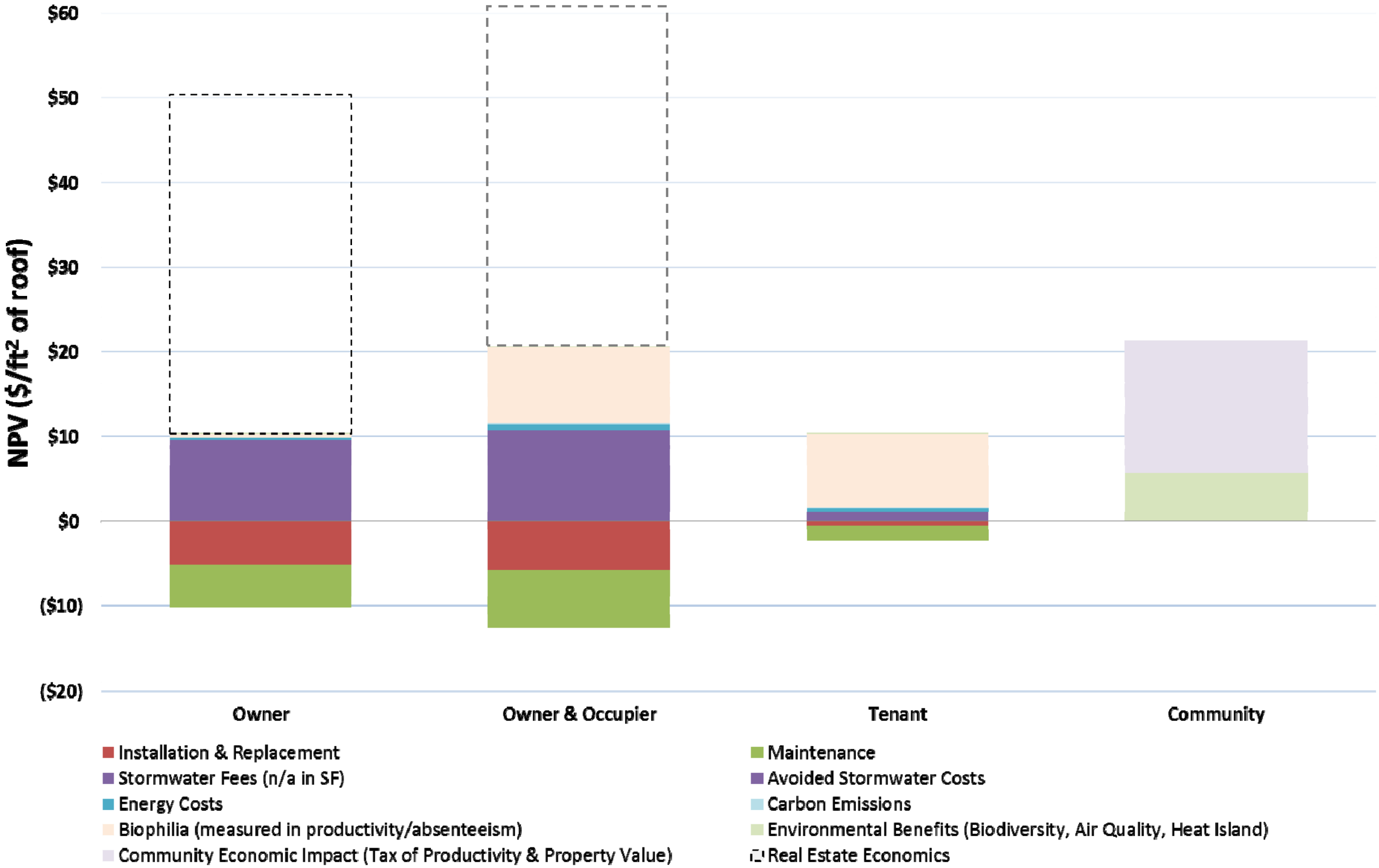


Figure 6 – stacked bar graph summary of results for medium office building

The study results for a multifamily residential building are similar to those found for the office. This section summarizes those results and highlights a few differences.

Most of the costs and benefits of the living roof relate only to the external environment and community, and are thus the same between an office building and a residential building of the same size. Exceptions include:

Real Estate

Parameters specific to multifamily residential buildings in San Francisco were used. The estimated living roof value is lower than for commercial, but still high compared to other study parameters.

General Assumptions:				
Discount Rate, %	6.5%		Living Roof Size, sf	17,876
Investment Outlook, years	25		Site Size, sf (roof	20,000
Living Roof Medium	6"		Floors	3

SF Assumptions, annual where applicable:	Living	White		Living	White
Climate Zone	3		Electricity Price, $/kWh	$0.22	
Installation Cost, $/sf of roof	$31.52	$11.42	Natural Gas Price, $/therm	$1.50	
Replacement Premium, %	33.51%	20.0%	Avg Rent, $/sf/yr	$32.91	$32.60
Maintenance Costs, $/sf of roof	$0.46	$0.12	Avg Value, $/sf	$667.7	$664.5
Roof Life	40	20	Average Vacancy, %	4.26%	4.30%
Disposal Costs, $/sf of roof	$0.12	$0.37	Cap Rate, %	3.73%	3.75%
Stormwater Surcharges, $/sf of roof (not used)	$0.00	$0.000	Absorption, months	1.0	1.0
Income Growth Rate	0.00%		Tenant Retention, months	36.2	36.0
Expenses Growth Rate	0.00%				

SF Variables - $/yr/sf roof	Living	White	**Nominal Growth Rates**	
Energy Equipment Cost, $/sf of roof	$0.00	$0.00	Labor & Materials	4.9%
Stormwater Equipment Cost, $/sf of roof	$0.76	$9.08	Stormwater Costs	4.1%
BMP Maintenance Cost, $/sf of roof	$0.07	$0.24	Energy Prices	2.4%
Heating/Cooling Costs, $/sf of roof	($0.05)	$0.00	Carbon (included in price)	0.0%
Embodied Carbon, tonnes of CO_2e/sf of roof	0.0006	0.00001	Community Benefits (Inflation)	2.5%
Reflectance + sequestration, metric tonnes of CO_2e	0.0002	0.0005	Rent, Absorb & Retention	3.0%
Carbon savings from heating/cooling savings	0.0004	0.0000	Living Roof Risk Contingency	2.5%

SF Soft Variables - $/yr/sf roof	Living	White			
Internal Real Estate Impact (Living Roof on Green Building rent contribution)	$0.3	n/a	Biodiversity & Habitat, $/sf of roof	$0.03	n/a
			Air Quality, $/sf of roof	$0.11	n/a
External Real Estate Impact (Biophilia/Productivity)	$0.2	n/a	Heat Island Energy Savings	$0.00	n/a
			Heat Island Peak Shaving Savings	$0.20	n/a
Employment (Community Benefit)	$0.004	n/a	Noise Abatement	$0.04	n/a

Figure 7 – Key assumptions and findings for small multifamily

Energy

For small multifamily residential, modeled energy savings in San Francisco are lower than for a medium office building. Of primary influence is the baseline assumption of no cooling system, as well as the assumption that there is not a heating unit located on the roof (so rooftop microclimate does not have a direct impact). Estimated heating energy in the living roof case is reduced by less than 1% compared to a white roof, and is about 2% higher than for a black roof. In the model, we have taken the white roof as baseline and have used a $0.0007/sf/year savings for the living roof case. This is a very small savings, but doesn't impact the overall financial picture much because there is a low sensitivity to energy savings in this study.

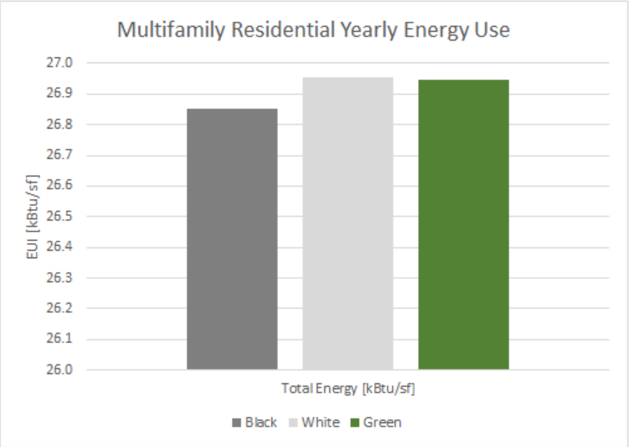
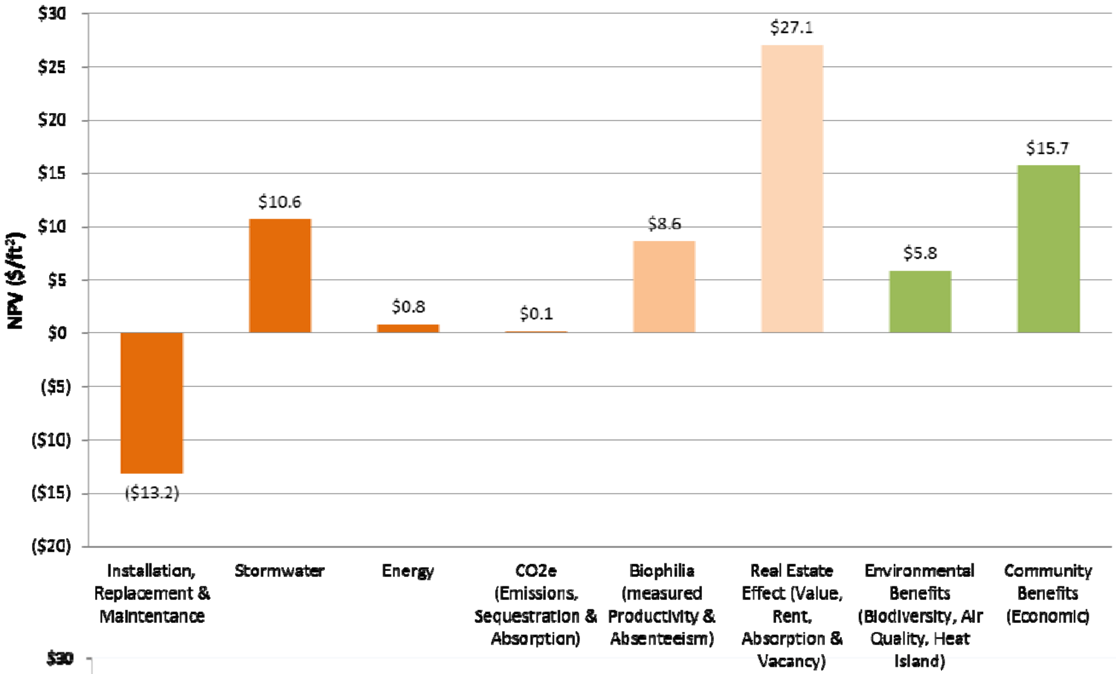


Figure 8 – energy model summary for the small multifamily residential building

Biophilia and Productivity

It is more challenging to monetize biophilic benefits to residents than to office employees. Clearly there is a benefit to a tenant if a living roof is accessible, but it cannot be directly translated via salaries into the budget of the building owner/tenant. Research directly linking access to a living roof to reduced health care costs and other quantifiable wellness metrics would be valuable. Lacking that, we have made the rough assumption that, for economic benefits accruing to the City, residents with a living roof on their building have a similar benefit to employees who have a living roof on their office building. Those who use it experience an increase in productivity at work whose value accrues to their employers and then to the City via payroll tax. We have also made the even more rough assumption that the wellness value to individual tenants/homeowners is similar to the value employers gain. Thus we have held the biophilic value constant between the office and residential analyses.



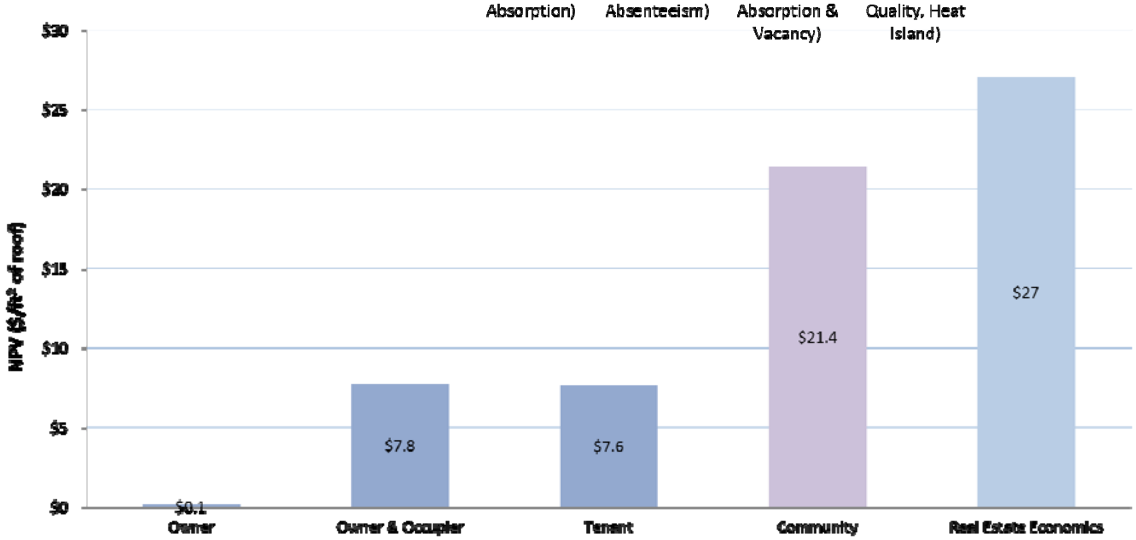


Figure 9 – summary of results for the small multifamily residential building

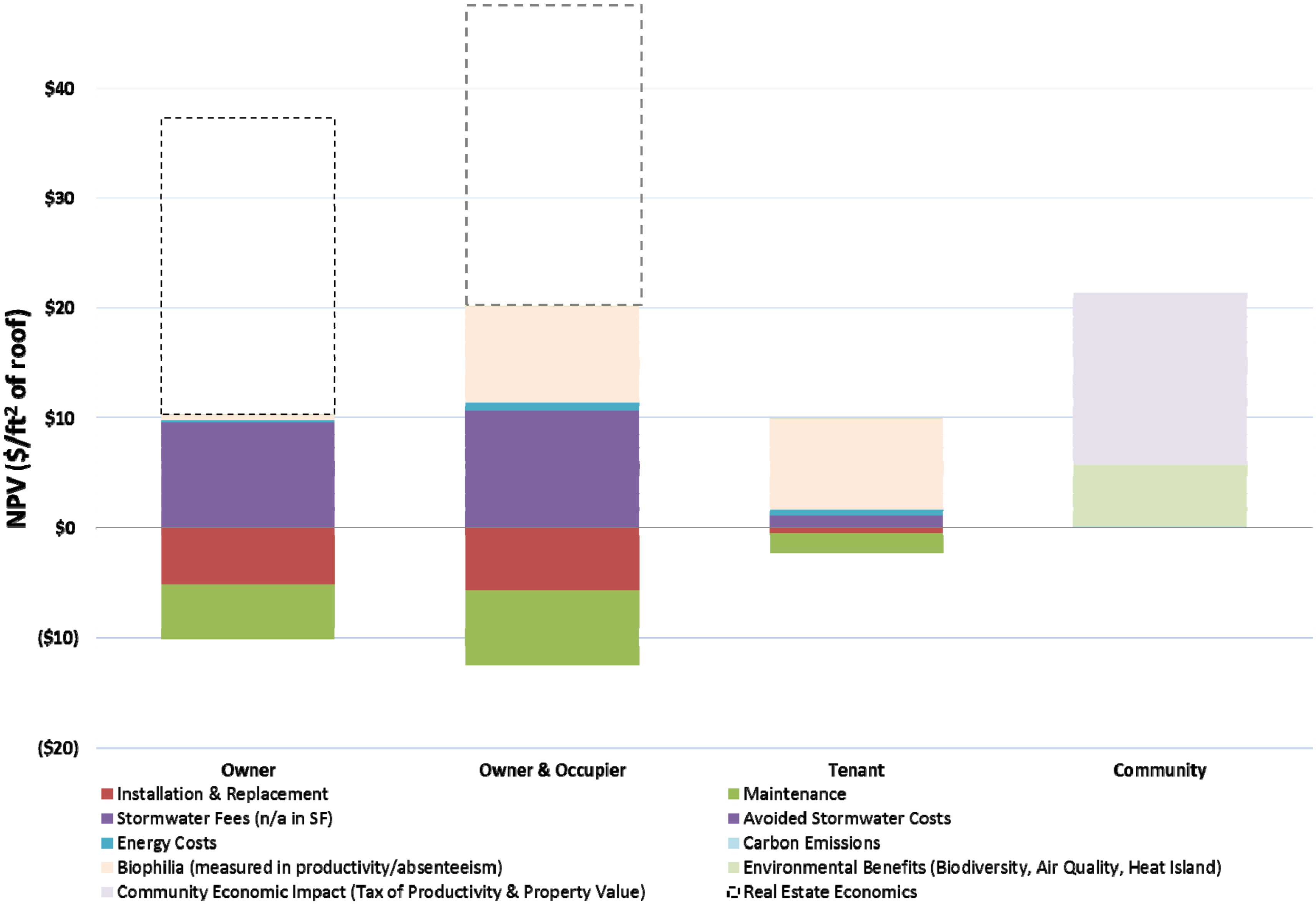


Figure 10 – stacked bar graph of results for the small multifamily residential building

Conclusions

City Scale Benefits

If policy and/or market factors were to result in a significant increase in living roof area in San Francisco, how much benefit could the city community expect to receive?

At the current rate of development, we might expect to see roughly 21 million square feet of roof built per year in the near future in San Francisco. If we assume the better roofs ordinance results in 25% of those roofs installing living roofs (over 15-100% of their roof area), then, using the office results, this study suggests that the city community could expect the following benefits:

1-7% of city roofs living after 5 years

$15 - 100 million of tax revenues in the first 5 years from improved property and biophilic value

60,000 – 385,000 tonnes carbon emissions avoided or sequestered over 15 years, a critical period for reducing the anticipated impacts of climate change, equaling:

- the sequestration of 3,600-24,000 acres of forest
- The energy used by 400-2700 homes
- 800-5400 cars off the road

Policy Implications

The results show that owners, occupants and the community all stand to gain significant net value from the installation of a living roof. Owners tend to bear all costs for living roofs, even though the community receives many of the benefits. Because a traditional cost-benefit equation (omitting real estate effects and biophilia benefits) does not show a strong return on investment at this time, San Francisco is unlikely to see as rapid an increase in living roof area as would be preferred for community benefits.

This result suggests a role for incentives or other policy measures to drive more rapid uptake of living roofs in San Francisco than the market would tend to provide independently.

Conclusions

Trends over Time

If policy and/or market factors result in growth in the living roof industry in San Francisco, the cost-benefit equation will change. Costs will tend to decline due to competition and economies of scale. For example, one of the most mature living roof markets in the world is Switzerland. When modern living roofs were first introduced there in the 1990s, they often cost upwards of $20/sf (premium above typical roofing). Today, a living roof mandate has been in place for 25 years in Zurich and 15 years in Basel, and typical construction methods have evolved and in many cases simplified. The typical living roof cost has dropped to only $3/sf above typical roofing. The 1990s price was already lower than typical US prices today because the Swiss norm had already shifted to seeding roofs, whereas most US projects use a much more expensive model of planting pregrown plants.

Interestingly, the typical premium for living roofs in San Francisco today is almost identical to the Swiss 1990s cost. If the San Francisco market saw a similar rate of decline in living roof price, the price would come down to about $16/sf in 5 years and $11.50/sf in 10 years. Assuming a white roof with the minimum required stormwater management equipment to meet SFPUC requirements cost the same at that point, the living roof would be nearly cost-neutral in 2026 (premium of about $3/sf), and would have a 25-year NPV of about $14/sf for an owner-occupier, not counting real estate effects.

It is worth noting, however, that other market factors could change and influence the payback equation. Also, real estate premiums would tend to decline as living roofs became more common and thus less of a distinguishing feature.

Figure 11 – a $3/sf living roof recently installed in Switzerland, where many years of supportive policy and system simplification have led to significant decreases in first cost

Direct Sources and Calculation Details

The sources for the information used in the cost-benefit analysis are specific to San Francisco where feasible, though sources that are applicable but not local are also used. A notable source used when non-local data was not available or not needed was, “The Benefits and Challenges of Green Roofs on Public and Commercial Buildings,” a comprehensive review of US-based living roof performance research and cost information published in 2011 by the United States General Services Administration (referred to henceforth as GSA Study). Multiple inputs were sought for each variable and then weighted to generate averages that fairly represent costs or benefits. A list of the sources used in the cost-benefit model is below:

Building Size and Type

The roof and building size used in this study were taken from the CEC Medium Office prototype model used for energy calculations. The two building types, midrise office and multifamily residential, were chosen as representative of much of the new construction anticipated in the near future in San Francisco.

Installation costs

Because costs include or exclude a range of factors, roofing costs were normalized to include the waterproof membrane, include installation costs, and exclude contractor markup (meaning that we asked sources for installed costs, added average white roof cost to any living roof cost figures known or believed to exclude the membrane, and reduced by 15% costs known or believed to include contractor markup). Because the sample size of data from San Francisco is fairly small, cost data from the literature for national averages were also included with a low weighting. Individual roof costs received a lower weighting in the average than typical costs given by installers, assuming the latter represents costs for many roofs.

Sources include:

Typical San Francisco Bay Area pricing (each received weighting of 5 in the average)

- Habitat Gardens
- Jensen Landscaping
- Webcor
- Columbia Green
- Nibbi Bros
- Arup cost estimators
- SFDPW (typical costs for white roofs only)

Typical national pricing (each received weighting of 2 in the average)

- GSA Study average
- LBNL Study average
- Walmart Study pricing
- USGBC green roof briefing
- Roofmeadow/Charlie Miller

Individual San Francisco project pricing (4 commercial/public projects, 2 residential, each received weighting of 1 in the average).

- SFDPW
- Rana Creek

Maintenance costs

Like first cost, maintenance cost is also a weighted average.

Sources include:

- Habitat Gardens (weighting of 5)
- Jensen Landscaping (weighting of 5)
- USGBC green roof briefing (weighting of 1)
- GSA Study average (weighting of 2) - also provided the only white roof maintenance number

Discounting Rate and Investment Outlook

The discounting rate (6.5%) and investment outlook (25 years) were selected to match those used for the San Francisco cost-benefit study for solar Photovoltaics (PV).

Roof Life

Roof life assumptions were taken from the multiple sources of the GSA Study.

Carbon Dioxide (CO2)

CO2 performance is calculated as a combination of direct sequestration by living roofs, reduced power plant emissions due to building energy savings, and reduced power plant emissions due to impact on heat island effect.

CO2 Data Sources include:

- Getter, K.L., Rowe, D.B., Robertson, G.P., Cregg, B.M., Andresen, J.A., 2009b. Carbon sequestration potential of extensive green roofs. *Environmental Science and Technology 43 (19),* 7564-7570.
- Average San Francisco emissions factors for the electricity grid (http://carma.org/region/detail/5391959)
- Average carbon intensity of the US natural gas grid (www.carbonneutralcalculator.com)
- Data from energy section of this study

Biodiversity and habitat

Value of biodiversity is estimated as the cost per square foot of setting aside land for conservation in the Bay Area and nearby. The range of values per sf for conservation in perpetuity are $0.01/sf - $0.27/sf. The annual rate found is $0.09/sf/yr.

Sources include:

- The Big Sur Land Trust
- The California Rangeland Trust

Heat island

The heat island calculation combines an estimate of building energy savings in surrounding buildings (conservatively allotted to only one floor of four neighboring buildings) and a power plant peak load shaving value.

Sources include:

- Acks, K. (2006). *A Framework for Cost-Benefit Analysis of Green Roofs*: Initial Estimates. in Green
- Roofs in the Metropolitan Region: Research Report. C. Rosenzweig, S. Gaffin, and L. Parshall (Eds.) Columbia Center for Climate Systems Research and NASA Goddard Institute for Space Studies

CO_2 Offset Savings

CO_2 Offsets per sf of roof	Living	Black	White
Aged Albedo	22%	5%	55%
Change in Albedo	17%	0%	50%
Emitted CO_2 offset (tonne per 100 m^2 per 20 years)	4.0	0	10.0
Emitted CO_2 offset (tonne per sf year)	0.0002	0.0000	0.0005

Figure 12 – Summary for three roof types of components in calculation for offset CO_2

Heat Island

Savings in collective energy of surroundings	0.10%	energy savings
Typical energy of a building	1.6	kWh/sf
Total Savings	114	kWh
Average SF cost of energy	$0.220	$/kWh
	$0.01	$/sf of roof
Peak load shaving value	$600	$/kW
	$0.00	kW/sf of roof
	$0.20	$/sf of roof

Figure 13 – Summary of components of heat island reduction calculation

Air quality

Air quality value of a living roof is calculated by first determining the estimated air pollutant removal attributable to a living roof based on research, and second estimating the cost of a conventional means of eliminating the same quantity of each pollutant. Pollutants considered include NOx, PM10, SOx and CO.

The air quality assumptions were taken from the multiple sources of the GSA Study, including the following:

1. Clark, C. Adriaens, P., & Talbot, F.B. *Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits.* University of Michigan
2. Niu, H., Clark, C., Zhou, J., & Adriaens, P. (2010) Scaling of Economic Benefits from Green Roof Implementation in Washington, DC. *Environmental Science Technology*
3. Casey Trees Study (DC) Based on the cost on installing selective catalytic reduction on a 10MW natural gas turbine
4. A.H. Rosenfeld, H. Akbari, J.J. Romm and M. Pomerantz. (1998). Cool communities: strategies for heat island mitigation and smog reduction. *Energy and Buildings 28*:51-62

Air Quality

NO_2 Benefit per sf for reduction (city-wide)	$0.042	$/sf of roof
NO_x	$1,440	$/Mg
	0.00	Mg/sf
	$0.0589	$/sf of roof
NO_x	0.10	kg/1000sf/yr
	$6,500	$/ton
	$0.0008	$/sf of roof
Average of NOx	$0.0404	$/sf of roof
Urban Heat Island effect on NOx	0.10	change in temp
		change in NOx/degree
	16.7	reduction
	1.7	multiple of NOx savings
	$0.07	$/sf of roof due to urban heat island effect on NOx
PM10	0.26	kg/1000sf/yr
	$4,000	$/ton
	$0.001146	$/sf of roof
SOx	0.04	kg/1000sf/yr
	$1,500	$/ton
	$0.000002	$/sf of roof
CO	0.10	kg/1000sf/yr
	$870	$/ton
	$0.000096	$/sf of roof
	$0.11	$/sf of roof

Figure 14 – Air quality improvement breakdown by pollutant

Green Roof Cost-Benefit Study
References and Calculations

Stormwater

To estimate the value of the stormwater management benefits of a living roof in San Francisco, we began with the SFPUC's compliance tool for the Stormwater Management Ordinance. Making the assumption that our 3-storey 17,800 sf footprint study building sits on a 20,000 sf lot, we sought to determine the most cost-effective way to meet SFPUC requirements with a living roof and without a living roof in both the combined sewer district and in the separate sewer district (MS4).

Sources include:
1. SFPUC Stormwater Compliance Tool

Real Estate

The primary focus of this study relates to costs and cost savings; but real estate and community economics are full of additional factors that could be influenced by the presence of a green roof. For real estate, this includes rent (income), cap rate (risk), vacancy, absorption, and retention. In order to account for these, a novel approach was used by which a green premium was identified and averaged from several reports (4.5%).

This premium was then multiplied by a hypothetical contribution of a green roof—which used percentage of related LEED points and comparison of green cost premium to green roof cost premium to get 22%. So these two together yielded a "green roof premium" of 0.96%. Using this number, market specific metrics such as average cap rate, rent, etc. were modified and the annual financial contribution was estimated.
The end result was a $2.37/sf of roof/year benefit for having a green roof. Taken over the 25 year life and discounted, that results in an NPV of $40/sf of roof accruing to the owner.

Sources include:

1. Average Cap Rate for Class A Office = 3.75%, which came from CBRE (link)
2. Green Building Rent Premium = 4.5%, from Institute for Building Efficiency (link) & several other reports found here: link
3. Average Rent for Class A Office = $51.38, from LoopNet (link), Colliers (link), BOMA (link), and Kidder Mathews (link)
4. Average Expenses for Office = $9.66, from BOMA (link)
5. Average Vacancy for Office = 6.5%, from CBRE and Colliers (link)
6. Average absorption for Office = 6 months, Arup assumption
7. Average Lease Length = 52.6 months, from Grubb & Ellis (link)
8. Probability of Renewal = 42%, from MIT Study (link)

Economic Value to the Community

Economic value potentially generated by living roofs does not accrue only to the owner, but also to members of the broader San Francisco community. This value is comprised primarily of three factors: taxes generated from increased productivity, land value, and employment for green roof maintenance. The productivity estimate leveraged studies that found that every square foot of green roof visible could elevate the productivity of people in the viewing area by $3.21 per square foot. Similarly, the real estate impact previously explained was leveraged to suggest that the surrounding real estate value with views would be increased by $21/sf, which used the premium and capitalized it. Finally, 90% of the projected maintenance cost premium over standard roofing were assumed to be labor costs equal to salaries paid for generated jobs. The taxes that would be generated from these three factors were found and then summed to yield $1.18/sf of roof/year to the community.

Sourcess include:

1. SF payroll tax rate = 1.5%
2. SF property tax rate = 1.164%
3. Sources cited for real estate economics, productivity, and maintenance.

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ARUP

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