Estimating the Environmental Effects of Green Roofs

A Case Study in Kansas City, Missouri

United States Environmental Protection Agency

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Introduction

A green roof—also called a vegetated roof or eco-roof—is a roof with soil and plants placed on top of a conventional roof. Green roofs are growing in popularity, as they have proven to be a cost-effective strategy for creating more livable and sustainable cities.[1]

Integrating nature-based solutions like green roofs into the urban landscape can benefit the environment, public health, and society by:

- Reducing stormwater runoff.
- Lowering ambient air and surface temperatures and reducing the urban heat island effect.[2,3]
- Increasing building efficiency and reducing energy use for heating and cooling.[4]
- Reducing air pollution associated with heating, electric power generation, and temperature-dependent formation of ground-level ozone.[5]
- Achieving health benefits associated with reducing fine particulate matter ($PM_{2.5}$) air pollution.
- Improving psychological well-being through access to nature.[6]

How a Green Roof Captures Rainwater

A typical green roof system has a waterproof membrane, a drainage layer, and a lightweight soil populated with plants that absorb and temporarily store rainwater. This moisture returns to the atmosphere through evapotranspiration—the process by which water evaporates from the soil surface or transpires from plant stomata.

This case study uses the Kansas City metropolitan area, and specifically the city of Kansas City, Missouri (KCMO), to demonstrate the environmental and health benefits of green roofs.

Companies and municipalities are increasingly turning to nature-based approaches like green infrastructure to help protect people and infrastructure from extreme temperatures, severe storms, and chronic droughts. For example, city planners and stormwater managers are implementing green roofs and other green infrastructure practices as a cost-effective way to manage stormwater where it falls, reducing polluted runoff and keeping excess stormwater out of the sewer system while also creating a community amenity. By 2020, green roofs in KCMO could retain 29 inches of annual stormwater runoff if building developers and parking garage owners continue to install green roofs at the current growth rate.

The intended audiences of this case study are city planners, regional planning organizations, non-profits, environmental staff in governors' offices, and other state or local officials who want to learn about and be able to demonstrate that green roofs have multiple environmental benefits: providing stormwater management during wet weather events, lowering ambient air temperatures on hot summer days, and cleaning the air. This information may also be useful for stormwater management plans, for meeting National Pollutant Discharge Elimination System permitting requirements, or for Air Quality Management Plans, such as those that may be developed under EPA's Ozone and Particulate Matter Advance Programs.

The Science: How Green Roofs Benefit the Environment and Public Health

Stormwater Runoff

Green roofs retain rainwater long enough for the collected moisture to evaporate from the soil and rooftop vegetation (see Figure 1). During wet weather events, this helps prevent runoff from overwhelming sewers (and causing sewage to overflow into local streams and lakes), reduce basement backups, and lower treatment costs and energy usage for treating rainwater that enters KCMO's combined sewer systems.[a] Some green roofs are equipped to harvest rainwater as an alternative water supply for later use. Rainwater captured from green roofs is usually used for irrigation, flushing toilets, and for other non-potable purposes.

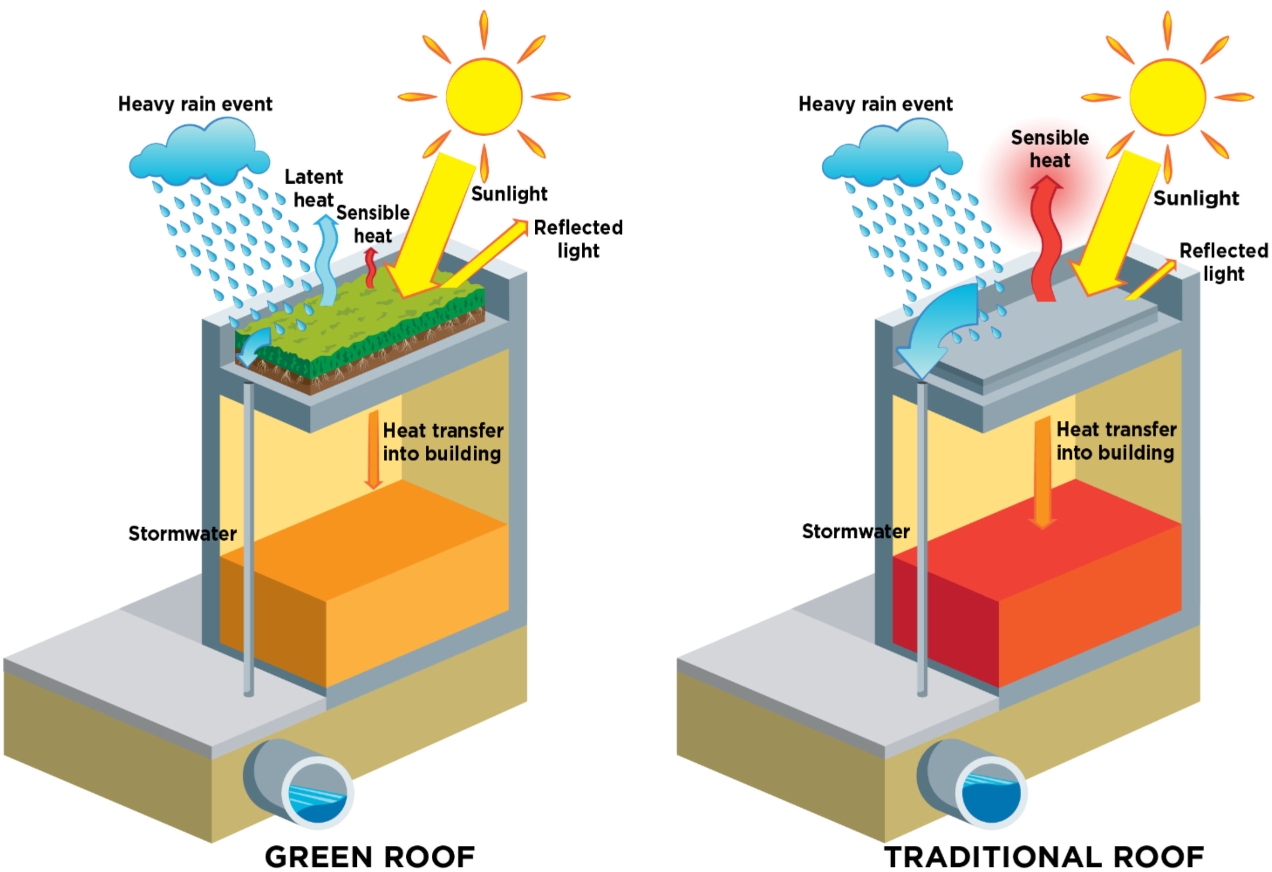


Figure 1. Heat exchange and water runoff of a green roof versus a traditional roof

[a] Stormwater retention is a function of size of storm events and length of preceding dry periods. Over a simulation year, the net water inflow may not balance outflow due to changes in soil moisture and saturation.

Temperatures and the Heat Island Effect

Temperature management matters in cities, because buildings, roads, and other types of typical urban infrastructure absorb heat and can make cities much hotter than surrounding rural areas. This creates an "island" of higher temperatures in the region, a phenomenon known as the urban heat island effect.[2] Air temperatures in urban areas can be 1.8–5.4°F warmer than their surroundings during the day. In the evening, this difference can be much greater because the built environment retains heat absorbed during the day.

A large body of evidence shows that green roofs help to reduce local ambient air and surface temperatures in cities.[2] Green roof vegetation can shade buildings and increase evapotranspiration, which shifts a roof's energy balance (or "budget"). The net effect reduces the temperature of the roof and air directly above it during the day and at night. Factors that influence the energy budget of a roof (or the balance of incoming and outgoing energy flows) include latent and sensible heat exchange, shortwave and longwave radiation exchange, heat conduction, and thermal storage.

> Latent and sensible heat are types of energy released or absorbed in the atmosphere. Latent heat is felt as humidity. Sensible heat is felt as changes in temperature. Evapotranspiration cools the air.

Reducing temperatures and the heat island effect can lower people's risk of becoming ill or dying during an extreme heat event (e.g., a heat wave). Each year, hundreds of Americans die from extreme heat, and thousands more require medical treatment for critical illnesses such as heat exhaustion and heat stroke.[6]

Switching to a green roof decreases heat transmitted into buildings and re-emitted into the atmosphere. Lowering air and surface temperatures can also reduce the amount of energy needed to cool buildings, which in turn reduces demand for electricity and cuts the associated waste heat produced by air conditioning units as well as air pollution produced by power plants. In addition, lower ambient temperatures reduce the formation of ground-level ozone, as discussed below.

Building Efficiency

A green roof can increase building efficiency and help reduce electricity costs. The soil (growing medium) provides insulation and the vegetation shades the roof from solar heat, thereby lowering the temperature of the roof and the air directly above it. This in turn reduces the electricity demand for air conditioning in summer months. Studies have shown the insulating properties of green roofs can reduce the transfer of heat from a building's exterior to its interior through the roof (i.e., heat flux). Heat flux reduction depends on the building and roof insulation and moisture in a green roof's soil medium. Typically, it can lower the need for air conditioning load to cool a building[7] by 10 to 30 percent.

During winter, a green roof acts as an insulator and can reduce demand for heating. However, the insulating benefits are less significant when the growing medium is moist—typically the case in winter months.

Electricity savings depends on the local climate, building characteristics, and the design and maintenance of the green roof. By reducing demand for electricity within a building, a green roof can also reduce total demand on the regional electric power grid.

Air Quality

By lowering temperatures and reducing energy use, green roofs can help reduce concentrations of several pollutants that affect air quality, climate, and health.

Criteria air pollutants—such as particle pollution (often referred to as particulate matter or PM), ground-level ozone (O_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and lead (Pb)—lower air quality and can be harmful to human health.[b] Using fossil fuels to generate electricity increases levels of these pollutants in the atmosphere. Once emitted, some criteria air pollutants circulate widely, potentially for long distances.

A recent study by Fallman et al.[8] modeled the ozone reduction effects of green and cool (light-colored) roofs in Stuttgart, Germany.

Their 10-day study attributed a 5 to 8 percent decrease in ozone concentrations during an August heat wave to green roofs. A simulated green roof reduced ozone more effectively than a simulated cool roof due to an increase of shortwave reflection emitted from the higher-albedo cool roof. However, the current literature is limited, and few studies consider scenarios of green roofs and other green infrastructure changes in different regional climates.

Some "primary" air pollutants (e.g., PM, CO, SO_2, and NO_x), are directly harmful to people and the environment. Other "secondary" air pollutants form in the air when primary air pollutants and other precursor air pollutants, such as volatile organic compounds (VOCs), react or interact. For example, primary air pollutants such as NO_x and VOCs react under certain weather conditions to form ozone, a secondary air pollutant. Ozone is a principal component of photochemical smog that can cause coughing, throat irritation, difficulty breathing, and lung damage, and can aggravate asthma.[c] Another secondary air pollutant, $PM_{2.5}$, is of concern because of its prevalence and links with many respiratory and cardiovascular illnesses and death.[d]

Greenhouse gases, or GHGs—such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6)—trap heat in the atmosphere that would otherwise escape to space, and contribute to climate change. GHGs from natural sources help keep the Earth habitable, as the planet would be much colder without them.

Increasing GHG emissions changes the climate system in ways that affect our health, environment, and economy. For example, climate change can influence crop yields, lead to more frequent extreme heat waves, and make air quality problems worse. Methane, a potent GHG, also contributes to the formation of ground-level ozone, which is a harmful air pollutant and component of smog. GHGs accumulate and can remain in the atmosphere for decades to centuries, affecting the global climate system for the long term.

Green roofs can clean the air in three ways: by lowering temperatures, removing pollutants from the air directly, and preventing additional air pollution. When air temperatures decrease, the rate of

[b] The Clean Air Act requires EPA to set National Ambient Air Quality Standards for these air pollutants. EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally based criteria (i.e., science-based guidelines) for setting permissible levels.
[c] Tropospheric ozone also acts as a strong GHG.[9]
[d] Different components of $PM_{2.5}$ have both cooling (e.g., sulfates) and warming (e.g., black carbon) effects on the climate system.[10]

photochemical ozone formation goes down, lowering ozone production. Plant matter on a green roof can also absorb existing ozone near the rooftop through plants' stomata. By moderating building temperatures, green roofs help to reduce criteria air pollution and greenhouse gases associated with heating and cooling buildings, including pollution from electricity generation. Because of this, green roofs help society avoid and reduce a wide range of air pollutants, creating short-term and long-lasting benefits for the atmosphere and human health.

Well-Being

Access to nature, both directly and indirectly, can also help improve people's quality of life.[11] For instance, stress contributes to many chronic diseases, and studies show that direct access to nature can alleviate stress. Adding green design elements such as green roofs to the workplace can result in lower stress and irritability, higher productivity, and fewer employee absences.[12]

Green Roofs in Kansas City

How Kansas City Is Using Green Roofs

Kansas City is continually adding more green roofs to its city's skylines. According to the public Greenroof and Greenwall Projects Database[13] and EPA's conversations with local architecture firms, Kansas City has installed over 450,000 square feet of green rooftop from 1999 to 2015. KCMO has at least 16 existing green roof installations and at least three green roof projects under construction—a total of 19 green roof projects existing or in progress. The city government is integrating green roofs into some of its own capital improvement projects. If green roof annual growth continues at the existing rate of 10 percent, KCMO will top 700,000 square feet by 2020.

Kauffman Center for the Performing Arts[14,15]

Since 2011, the Kauffman Center for the Performing Arts, located in downtown KCMO, has been harnessing the benefits of green roof technology. At 4.4 acres, the center's green roof is one of the largest in the country, covering part of the building complex along with a parking garage. It is also the first permitted green roof stormwater detention facility in Missouri, which allows it to serve as a case study for the role green roof technology can play in public stormwater permitting. With three independent drainage systems, the green roof's surface is designed to retain water for its own needs, and its slope channels excess water into an underground cistern for reuse and recycling. The amount of water saved through this process is estimated to be equivalent to 84 percent of the city's annual irrigation demand and saves $56,000 a year in municipal water costs.

The Kauffman Center green roof also promotes a healthy local urban ecosystem. Ninety-five percent of the roof's landscape materials come from surrounding areas, and certain ground cover plants, such as switchgrass, provide food for local bird species. Moreover, the ground-level green roof is publicly accessible as an urban green space for city residents to enjoy. In 2013, Green Roofs for Healthy Cities awarded this project the Award of Excellence for its category.

Photo credit: Jeffrey L. Bruce & Company

Figure 2. Kauffman Center for the Performing Arts

Kansas City Central Library[16]

The award-winning green roof at the Kansas City Central Library, installed in 2004 as a retrofit, is as an example of how green roofs can simultaneously provide functional and recreational benefits. The installation is home to multiple landscape types that support native species, such as upland grasses, wetland, and Midwestern prairie. Meanwhile, the green roof's design elements enhance public life, as skylights and walk-on glass panels channel daylight to indoor patrons, and recreational elements like a giant chess set invite patrons to enjoy the green roof's outdoor setting.

Photo credit: Hex FX Aerials

Figure 3. Green roof at the Kansas City Central Library

Why Kansas City Is Using Green Roofs

Given city leaders' commitment to green infrastructure and their desire to improve local water and air quality, EPA worked with the Mid-America Regional Council (MARC)—the metropolitan planning organization for the Kansas City metro area—to create this case study to quantify the multiple benefits of green roofs that address environmental challenges.

In November 2016, MARC partnered with the architecture firm BNIM, Biohabitats, and BikeWalkKC to host a Green Infrastructure Charrette. More than 60 professionals and community members participated in an interactive workshop to prioritize green infrastructure goals, build local partnerships, and commit to implementing key strategies that connect citizens of KCMO with the surrounding natural environment. This group of environmental professionals, landscape architects, business developers, and city planners highlighted the need to preserve and protect drinking water, air quality, and ecosystems.

Water Quality and Stormwater Management

Since 2002, the city has discharged approximately 6.4 billion gallons of untreated sewage each year into local streams and rivers, including the Missouri River, Fishing River, Blue River, Wilkerson Creek, Rocky Branch Creek, Todd Creek, Brush Creek, Penn Valley Lake, and their tributaries.[17]

As part of a 2010 settlement with EPA, the City of KCMO agreed to make improvements to reduce its 5.4 billion gallons of annual combined sewer overflow discharges to comply with the Clean Water Act. These infrastructure improvements include a commitment to use green infrastructure to reduce stormwater runoff into the city's combined sewer systems.[17] Sewer overflows can pose risks to public health and sanitation, as well as damage city and private property. City planners began to incorporate green roofs to help control and prevent stormwater runoff that contributes to these overflows along with other mitigation measures. For example, the Kauffman Center for the Performing Arts green roof (see Figure 2) functions as a permitted stormwater detention facility.

Urban Heat Islands

In 2014, Kansas City was ranked one of the top 10 U.S. metro areas that experienced intense summer urban heat islands—measured as the greatest difference between average temperatures in rural and urban areas over an entire summer.[18] The Kansas City metro area was 4.6 degrees Fahrenheit warmer on average than the surrounding rural area during summer months—ranking it as the seventh largest differential in the United States. Green roofs can help alleviate the urban heat island effect.

Air Quality

Missouri and Kansas operate air quality monitors across the Kansas City metro area to ensure that businesses, states, and localities are doing their part to keep the air clean. While the monitors indicate that the KCMO area is successfully maintaining air quality below the National Ambient Air Quality Standards (NAAQS) for ozone and $PM_{2.5}$, as shown in Figure 4, community leaders are looking to measures like green roofs to reduce exposure to smog and keep the air clean.

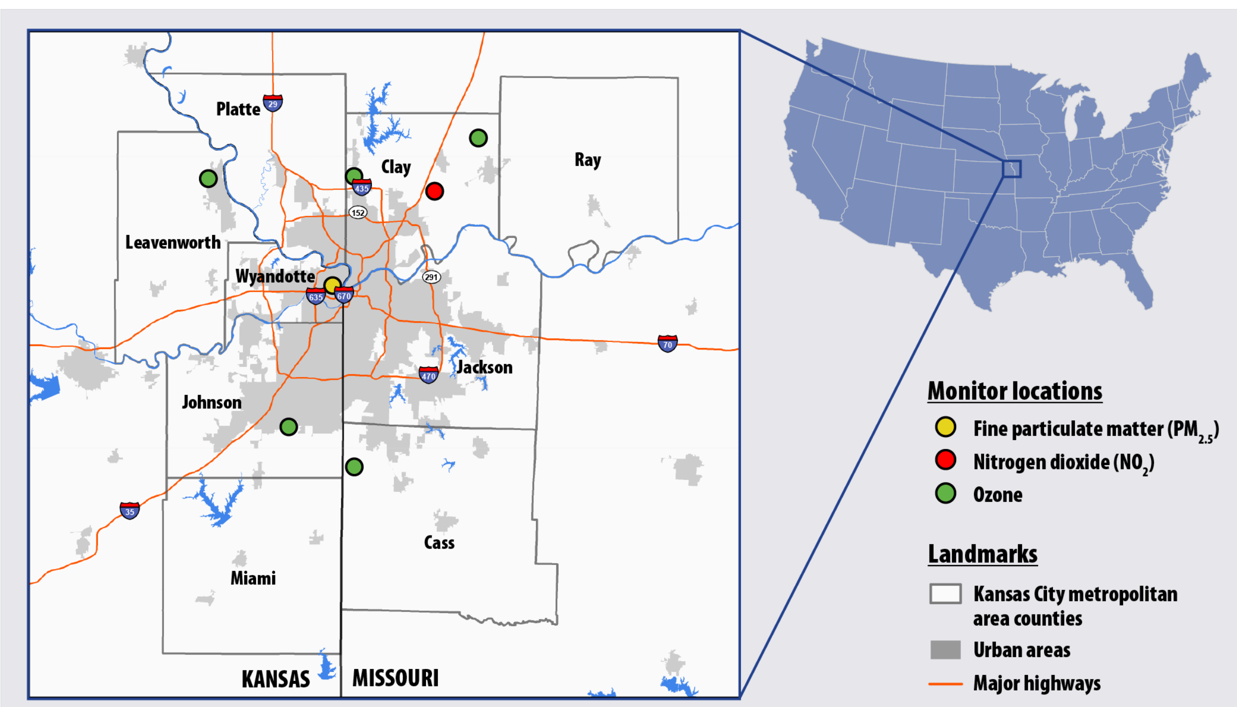


Figure 4. Air quality monitoring stations in the Kansas City metro area

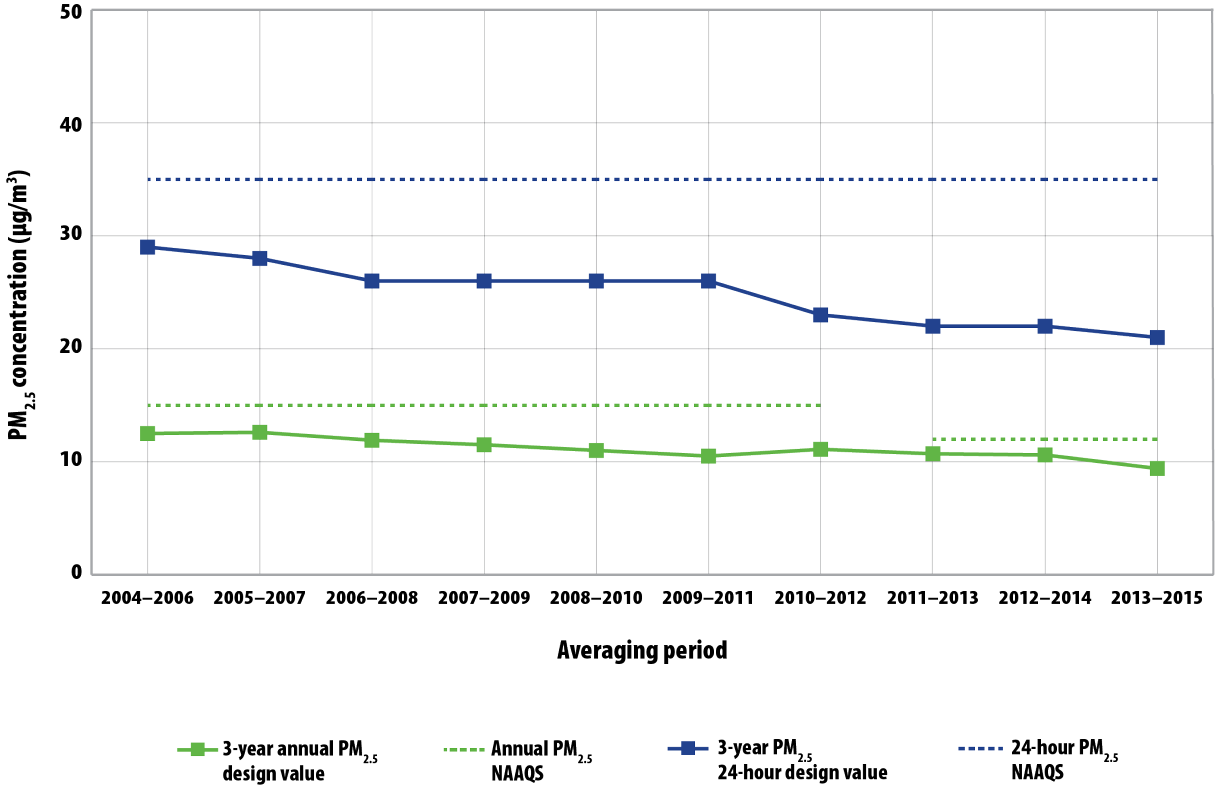
Reducing ground-level-ozone (smog)[e] is an important public health objective for KCMO. KCMO's 8-hour ozone values are trending downward, and the current 3-year design value (68 parts per billion) is below the 2015 ozone NAAQS of 70 parts per billion, as Figure 5 shows.[f]

ppbv: parts per billion by volume
The dotted line indicates the NAAQS, which was lowered to 70 parts per billion in 2015.

Figure 5. Ozone concentrations in the Kansas City metro area

Keeping fine PM levels below the NAAQS is another important public health priority for KCMO leaders. The Kansas City metro area is currently maintaining $PM_{2.5}$ concentrations below the national standard. Air quality monitoring data show that the metro area is in attainment of both the annual $PM_{2.5}$ NAAQS (with a design value of 9.4 micrograms per cubic meter) and the 24-hour $PM_{2.5}$ NAAQS (with a design value of 21 micrograms per cubic meter) for the most recent 3-year period, 2013–2015 (Figure 6). Green roofs can help KCMO stay in attainment and continue to meet these important air quality standards.

[e] "Smog" and "ground-level ozone" refer to the results of chemical reactions in the atmosphere caused by NO_x and VOCs in the presence of strong sunlight.
[f] NAAQS require the 8-hour ozone standard, annual $PM_{2.5}$ standard, and 24-hour $PM_{2.5}$ standard to use a 3-year design value to determine whether an area is in attainment.



µg/m³: micrograms per cubic meter

The dotted lines indicate the NAAQS, which are currently 12 µg/m³ (annual) and 35 µg/m³ (24-hour).

Figure 6. $PM_{2.5}$ concentrations in the Kansas City metro area

Methods

In collaboration with KCMO staff, a local green roof architect, and MARC, and in consultation with the Missouri Department of Natural Resources and the Kansas Department of Health and Environment, EPA developed a case study to demonstrate the environmental and health impacts of green roofs using credible, free, and easy-to-use tools for estimating multi-media effects. Specifically, EPA estimated green roof impacts related to:

- Stormwater retention.
- Heat exchange, evapotranspiration, and corresponding heat island reduction.
- Building electricity demand and cost savings.
- Changes in emissions from the electric power sector.
- Monetized health benefits from improved air quality.

The goal of this illustrative case study is to lay out an analytical framework that a state or municipal government can use when assessing the effects of green roofs. Rather than focusing on one green roof installed on a particular building, EPA estimated the magnitude of impacts from the total coverage of green roofs in KCMO for a future year, 2020. EPA used historical growth rates and existing green roof data to ascertain the area of rooftop that could plausibly have green roofs installed by 2020.

Analytical Process

EPA began by defining the purpose of the analysis, assessing available tools, and developing a methodology that can be replicated in other U.S. locations where data are available. Figure 7 provides an overview of this methodology, which consists of five main steps:

1. Obtain local data.
2. Project green roof growth (in square feet, or ft^2)—in this case, through the year 2020.

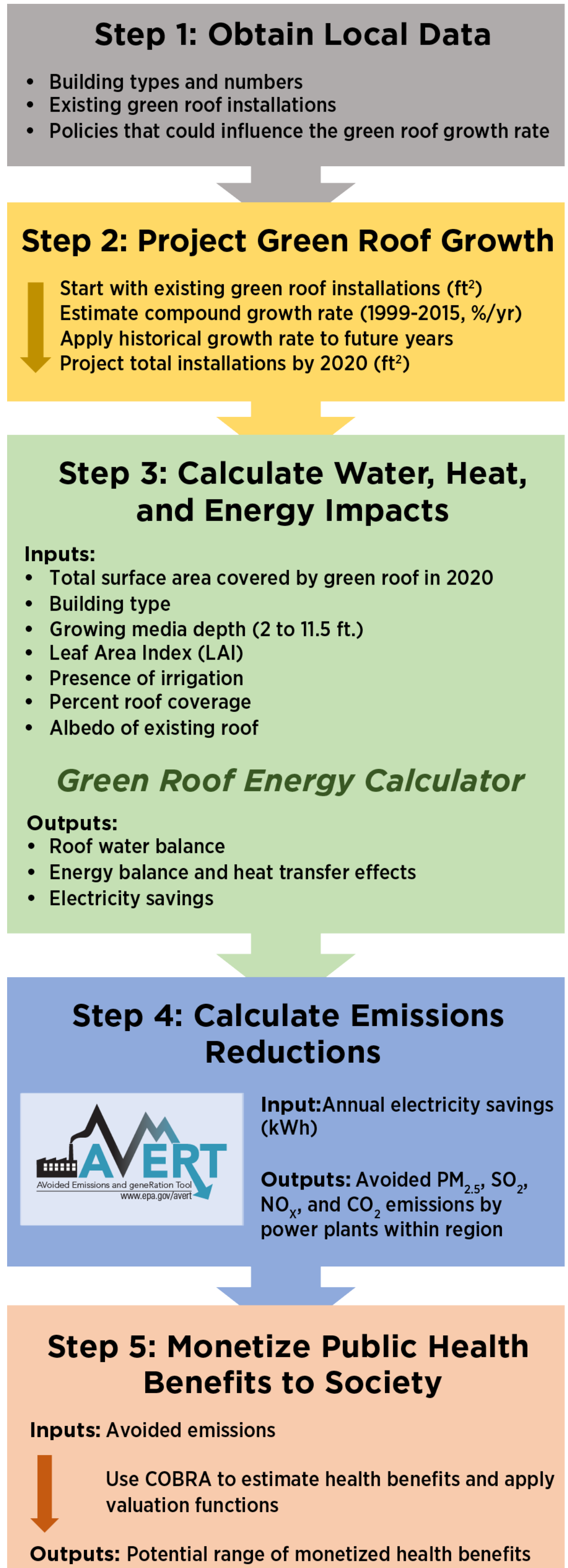


Figure 7. Analytical framework for estimating environmental effects of green roofs

3. Calculate water, heat, and energy impacts using the Green Roof Energy Calculator.
4. Calculate emissions reductions, based on energy savings, using EPA's AVoided Emissions and geneRation Tool (AVERT).
5. Monetize public health benefits to society, using EPA's Co-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool.

Many factors influenced the chosen analysis and results, including the intended audience, the available tools, and financial resources. Because the intended audience for this technical resource is broad—policymakers interested in reducing stormwater overflow events, advocates for urban heat island reduction, state environment departments, municipalities, and metropolitan planning organizations—EPA chose an analysis that could offer value to a variety of audiences and used a set of tools that are readily available, peer-reviewed, and free. These tools determined the types of input datasets and assumptions EPA needed to complete the analysis—in this case, a set of local input data and reasonable assumptions about green roof characteristics and future green roof installations. The next section discusses the tools EPA used for this analysis.

Tools Used

In assessing potential tools for this analysis, EPA looked for free, credible, already available tools that could estimate the multi-media effects of green roofs in a city like KCMO. EPA chose to use three tools for this analysis: the Green Roof Energy Calculator,[g] EPA's AVERT,[h] and EPA's COBRA.[i]

The national Green Roof Energy Calculator, co-developed by the University of Toronto and Portland State University with Green Roofs for Healthy Cities, has annual building energy performance datasets for more than 100 North American cities. This free online tool compares the estimated annual energy performance of a commercial or residential building with a green roof against the estimated performance of the same building with a conventional roof. These comparisons allow non-experts to obtain quick estimates of how green roof design decisions might affect building energy use. The built-in assumptions of the online calculator originate from a more complex whole-building energy simulation model, the Department of Energy's EnergyPlus model, and actual measurements of roof surface data, soil moisture, and other variables from specific green roofs that have been studied. This combination of direct measurements and modeling data drives the tool's estimates of heating, ventilation, and air-conditioning energy use.

EPA used the Green Roof Energy Calculator to compare the electricity savings, heat flux, evapotranspiration, and net stormwater runoff of a building with a green roof against existing office buildings and apartment buildings with conventional roofs.[j]

[g] The Green Roof Energy Calculator can be found at the following link: https://sustainability.asu.edu/urban-climate/green-roof-calculator/
[h] AVERT can be found at the following link: https://www.epa.gov/avert
[i] COBRA can be found at the following link: https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool
[j] Medium-sized office buildings are generally those that have three to five floors and are 53,630 ft^2. Medium-sized apartment buildings have four to six floors and are 33,600 ft^2.

EPA then took the electricity demand savings from the Green Roof Energy Calculator and entered the kilowatt-hour savings into AVERT.[k] AVERT can estimate the avoided NO_x, SO_2, $PM_{2.5}$ and CO_2 emissions at power plants due to lower demand on the electricity grid. AVERT divides the country into 10 regions (KCMO is in the Lower Midwest region) and produces county, state, and regional results in pounds or tons, per month or per year. In this case study, EPA calculated annual emissions avoided at power plants throughout Kansas and Missouri due to a 2020 projected green roof installation scenario in KCMO.

Next, EPA used COBRA to estimate the monetized health benefits likely to result from the emissions reductions from the green roof scenario. COBRA includes a reduced-form air quality model (i.e., a relatively simple air quality model) to estimate how changes in emissions in a given county can affect ambient air quality in the surrounding region. It also includes functions to estimate how changes in ambient air quality impact health outcomes, such as premature mortality, hospitalizations, nonfatal heart attacks, asthma exacerbations, and lost work and school days.

Step 1. Obtain Local Data

The first step in the process is to ask local green roof architects and municipal, state, and regional planners for locally based information on 1) the types and number of buildings in the area with existing green roofs, 2) any buildings undergoing green roof construction, and 3) policies in place that provide incentives for green roofs that could affect the future growth rate of green roof installations.

To complete the analysis for Kansas City, EPA obtained data on building types and numbers from MARC, which maintains GIS datasets and maps of existing buildings in the nine-county Kansas City metro area. MARC supplied EPA with the number of existing buildings in eight of the nine counties and aggregated the total rooftop area (ft^2) for six distinct building types.[l] This information helped EPA determine the number of rooftops that could potentially be converted to green roofs. EPA gathered information on existing green roof installations from city government officials and local green roof architects. Based on information EPA collected from the Greenroof and Greenwall Project Database[13] and conversations with local architecture firms, EPA found that KCMO has at least 16 existing green roof installations with vegetation covering 450,000 ft^2 of rooftop. The average vegetative coverage per rooftop for these projects is 60 percent. The City of Kansas City also has three green roof projects under construction, making a grand total of 19 green roof projects existing or in progress within the metro area.

While KCMO does not have a green roof policy or direct incentives on the books, it does have policies that can indirectly support future green roof installations. The KCMO 2008 Climate Protection Plan[19] recommends promoting green roofs. In January 2017, plans for a $75 million development featuring apartments, a boutique hotel, and greenspace on top of a parking garage in Westport received strong support from the City Plan Commission, a Kansas City citizens advisory group.[20]

[k] AVERT uses gigawatt-hours for energy savings impacts. EPA rounded its inputs up to 1.0 gigawatt-hour of savings and assumed savings affected 100% of all hours for this case study.

[l] The six building types within MARC's GIS dataset for this project are commercial, condo, industrial/business park, multi-family, office, and public/semi-public.

In addition, recent energy and water use benchmarking requirements, under the City Council's Energy Empowerment Ordinance (June 2015) will be helpful in assessing building electricity consumption data, both before and after a green roof installation. The ordinance requires owners of large buildings to benchmark and report their energy and water usage by May 1st of 2016, 2017, or 2018, depending on their building type.[21] These data, combined with green rooftop direct measurements (such as heat flux and evapotranspiration estimates) and simulated estimates from the national Green Roof Energy Calculator, are expected to provide a more comprehensive dataset for future study.[m]

Table 1. Green roof calculator inputs

Input	KCMO Value
Total surface area of green roofs in 2020	734,826 ft^2
Building type	Existing office buildings
Growing media depth (2–11.5 inches)	4 (typical for the type of vegetation in the Kansas City area)
Leaf area index (LAI)	5 (typical for extensive green roofs)
Whether there is irrigation	No irrigation
Percent roof coverage	100%*
Albedo of existing roof	Dark (0.15)

* The user may choose to enter either total roof coverage or total *green* roof coverage. EPA entered 100 percent as the total known amount of green roof coverage. If EPA had used total roof area and estimated what percentage of that area was "green," the average coverage for Kansas City's green roofs would have been 60 percent of total roof area.

Step 2. Project Green Roof Growth

After collecting local data, the next step is to establish a 2020 green roof projection scenario. For Kansas City, EPA analyzed green roof installation data from 1999 to 2015 and calculated a historical compound annual growth rate of 10.3 percent. EPA then applied this growth rate over a 5-year period, starting with the total amount of green roof area installed in 2015. Figure 8 shows actual green roof installations and projected growth of KCMO's green roofs from 1999 to 2020.

[m] Note that attributing the energy savings to one measure can be difficult if other changes in energy efficiency, behavior, or occupancy are occurring at the same time. Using a model such as the Green Roof Energy Calculator in conjunction with measuring green roof heat flux, evapotranspiration, and actual energy consumption offers a way to cross-reference the energy impacts associated with green roofs.

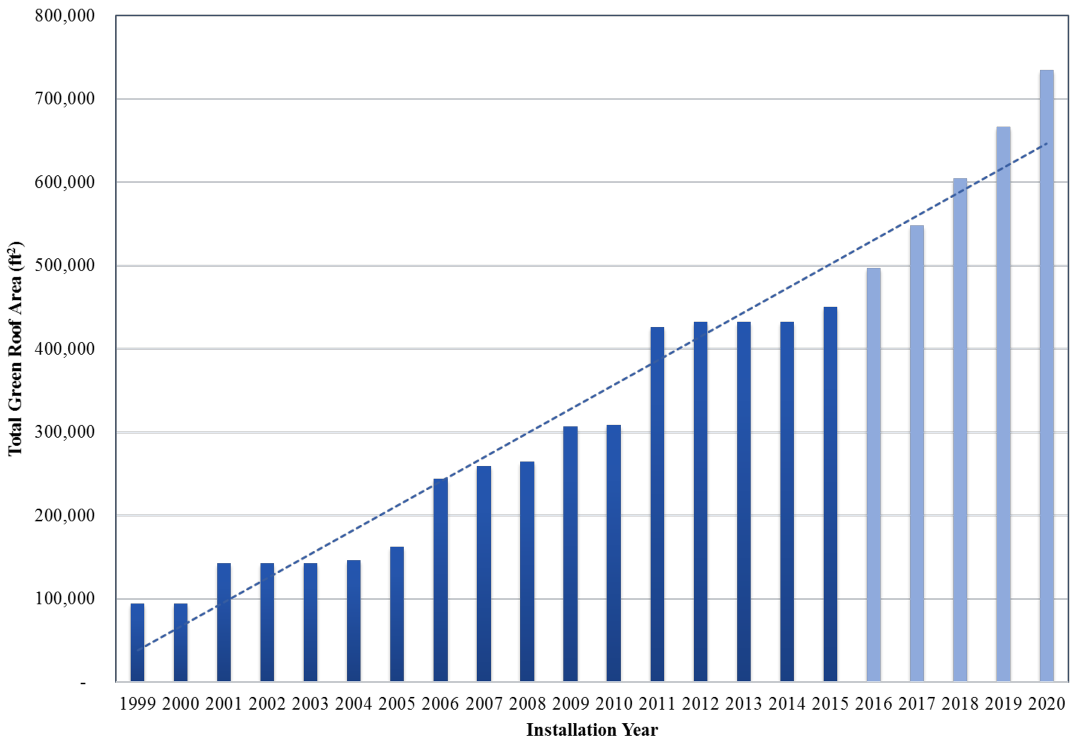


Figure 8. Green roof installations and projected growth in KCMO, 1999-2020

Step 3. Calculate Water, Heat, and Energy Impacts

After estimating the total square footage of green roof installation in 2020, the next step is to enter the information into the Green Roof Energy Calculator. Typical green roof characteristics are also needed to run the calculator. EPA consulted with the developer of this tool and a related journal article to determine what green roof characteristics to enter into the calculator for Kansas City.[4] In other cases, more relevant local data may be readily available.

Table 1 presents key inputs that EPA gathered to run the Green Roof Energy Calculator.

Step 4. Calculate Emissions Reductions

The next step is to take the energy savings from Step 3 and input them into AVERT to determine avoided emissions of air pollutants from power plants. Kansas City is in AVERT's Lower Midwest region, which includes Kansas; western Missouri; Oklahoma; and parts of Arkansas, Louisiana, New Mexico, and Texas. Table 6 (under "Results," below) shows annual avoided emissions for the entire Lower Midwest region as a result of green roofs in KCMO.

Step 5. Monetize Public Health Benefits to Society

The final step is to quantify the dollar value of the avoided health effects due to the avoided emissions from power plants. The county-level emissions reductions of $PM_{2.5}$, NO_x, and SO_2 estimated within AVERT's Lower Midwest region were entered into COBRA to estimate the public health benefits. The emissions reductions from AVERT were entered into COBRA at the county level for the Fuel Combustion from Electric Utilities emissions tier one, using the 2017 emissions baseline.[n] COBRA includes valuation functions to estimate the monetary value of the benefits of reducing emissions. The default health impacts and valuation functions in COBRA are consistent with the ones used in EPA Regulatory Impact Analyses.[22]

[n] Note that COBRA does not include a 2020 emissions baseline, but this analysis assumes that the 2017 baseline is representative for 2020.

Results

This section provides results from the Green Roof Energy Calculator, AVERT, and COBRA.

The Green Roof Energy Calculator estimates the following metrics:

- Annual roof water balance.
- Average latent heat exchange to urban environment.
- Average sensible heat exchange to urban environment.
- Building electricity savings and electricity cost savings.

AVERT estimates the following information:

- Annual and monthly $PM_{2.5}$, NO_x, SO_2, and CO_2 emissions impacts.
- Annual electric power generation impacts.
- Regional, state, and county-level estimates.

COBRA estimates the following changes between baseline and control scenarios:

- Changes in air quality (i.e., PM concentration).
- Corresponding health effects (incidence and monetized values).
- Estimates of the economic value in the number of cases for each health effect.

Water Balance: Runoff from Roofs

The Green Roof Energy Calculator shows that green roofs typically retain stormwater runoff better than conventional roofs during wet weather (Table 2). For this Kansas City scenario, green roof systems could retain up to 29 inches of stormwater per year on average.[o] Instead of running off into storm drains, this water is absorbed by soil and plants on the roof and eventually returned to the air through evapotranspiration directly above the roof's surface.

Less runoff helps prevent stormwater from overwhelming sewers and causing overflows of sewage into local waterbodies, reduces basement backups, and lowers treatment costs by reducing energy usage needed to treat rainwater that enters KCMO's combined sewer system. Because water balance dynamics are sensitive to growing media composition, compaction, and soil saturation, net water runoff results should be considered an order-of-magnitude estimate.

Table 2. Annual roof water balance for KCMO

	Conventional Roof Balance (Inches)	Green Roof System Balance (Inches)
Precipitation	32.3	32.3
Evapotranspiration	N/A	31.4
Net runoff	32.3	3.3

[o] If the total green roof area is only a fraction of the total surface area of the city, then the effective runoff reduction at the city scale would be smaller.

Heat Exchange

Latent heat is what we feel as humidity. Table 3 shows latent heat exchange from green roofs, measured in watts per square meter of surface area (W/m^2). Because latent heat exchange does not occur on a conventional roof, the results of the green roof calculator show "not applicable" (N/A) for conventional roofs.

Table 3. Average latent heat exchange to the urban environment for KCMO roofs

	Conventional Roof (W/m^2)	Green Roof System (W/m^2)
Annual average	N/A	57.4
Summer average	N/A	66.9
Summer daily peak average	N/A	214.8

Sensible heat is the temperature difference between the rooftop surface and the surrounding air. The Green Roof Energy Calculator estimates lower sensible heat exchange values (W/m^2) for the green roof versus the dark conventional roof because the green roof produces higher levels of latent heat (Table 4). In other words, green roofs create a cooling effect because sensible heat exchange decreases as latent heat exchange increases, shifting the rooftop's energy budget.

Table 4. Average sensible heat exchange to the urban environment for KCMO roofs

	Conventional Roof (W/m^2)	Green Roof System (W/m^2)
Annual average	51.8	27.2
Summer average	92.7	33.4
Summer daily peak average	348.5	90.3

Energy Savings

The Green Roof Energy Calculator estimates the building energy consumption savings due to the insulating and cooling effects of a green roof. These results are based on a green roof module developed in the Department of Energy's EnergyPlus building energy simulation software. Table 5 shows the amount of electricity savings, cost savings (lower electricity bills), and natural gas savings for the KCMO green roof scenario, which reflects the total savings from green roofs installed across KMCO.

Table 5. Annual building energy consumption savings for total green roof systems in KCMO

Electricity savings	601,502 kilowatt-hours
Electricity cost savings	$41,587
Gas savings	2,930 therms

Lower Emissions

Table 6 shows annual avoided emissions for the entire Lower Midwest region as a result of green roofs in KCMO. As a result of more green roofs installed in KCMO, Table 7 shows county-level emissions reductions in Kansas and Missouri, where AVERT estimates that nine counties have electric generating units. These nine counties would experience reductions totaling 734 pounds of SO_2, 384 pounds of NO_x, and 269 tons of CO_2 avoided in 2020. The remaining reductions would take place in other states in the Lower Midwest region.

Table 6. Annual avoided air pollutants across the Lower Midwest AVERT region as a result of KCMO green roofs

Air Pollutant	Total Avoided Air Pollutant Emissions in 2020 (Annual)
SO_2	2,690 lbs/year
NO_x	1,800 lbs/year
$PM_{2.5}$	90 lbs/year
CO_2	1,150 tons/year

Table 7. Annual avoided air pollutants in Kansas and Missouri counties

Geographic Location (County, State)	Avoided Air Pollution from Power Plants in 2020			
	SO_2 (lbs)	NO_x (lbs)	$PM_{2.5}$ (lbs)	CO_2 (tons)
Pottawatomie, Kansas	120	110	10	120
Sedgwick, Kansas	—	40	—	10
Shawnee, Kansas	50	10	—	10
Wyandotte, Kansas	70	40	—	10
Greene, Missouri	60	30	—	20
Henry, Missouri	150	50	10	30
Jackson, Missouri	140	60	10	30
Platte, Missouri	N/A	20	—	20
Scott, Missouri	60	10	—	10

Estimated Health Benefits

The county-level emissions reductions from AVERT's Lower Midwest region were entered into COBRA to estimate the range of monetized health benefits. COBRA reflects reductions in premature mortality, hospital admissions, emergency department visits, asthma exacerbation, respiratory symptoms, acute bronchitis, and missed days of school or work. Based on these reductions in adverse health outcomes, COBRA estimates a range of economic benefits to society from $35,500 to $80,500 (in $2017 using a 3 percent discount rate) in 2020. Public health benefits from reducing NO_x as an ozone precursor are not included.

Uncertainty of Results

There are inherent uncertainties associated with the modeling results of this case study. Like any modeling exercise, it involves a mixture of direct measurements, reasonable methodological assumptions, and data probabilities to arrive at the estimates. Nonetheless, EPA used these models because they are freely accessible, provide credible estimates, have been extensively cited in peer-reviewed literature, and/or were benchmarked against empirical data and/or more sophisticated models.

The analysis also involves simplifying assumptions that affect the case study's results. First, green roof projections of future green roof installations in KCMO assume a continuation of historical growth trends. Second, due to the interconnectedness of the electricity grid, not all of the avoided emissions within the Lower Midwest region would necessarily affect the Kansas City area. In addition, because $PM_{2.5}$ and precursors are regional pollutants, not all of the health benefits from avoided emissions would accrue to residents of KCMO or neighboring communities.

These results should be considered a first-order approximation intended to provide a ballpark estimate of the benefits of green roofs in KCMO. They are not meant to be used for regulatory purposes to comply with the U.S. EPA's Clean Water Act combined sewer overflow regulations or NAAQS established under the Clean Air Act.

Conclusions

Green roofs can contribute to KCMO's environmental and livability goals—to mitigate the urban heat island effect, maintain clean air and water, and lower energy costs in buildings—while greening the urban landscape. As this methodology demonstrates, city planners, environmental regulators, and other practitioners can estimate the environmental and public health benefits of green roofs using free, credible, accessible tools. Because of the multiple benefits green roofs provide, they are gaining traction from a diverse set of stakeholders and businesses.

Interested parties nationwide can apply these methods and point to other evidence-based studies to estimate the value of green roofs and other green design practices in their areas. Using this methodology to quantitatively demonstrate the benefits of green roofs provides tangible data to decision-makers who have the power to implement green roofs as a strategy for achieving local environmental and public health goals.

Aside from quantifying the benefits of green roofs, cities are pursuing ways to encourage green roof adoption, including voluntary incentives and regulatory mandates. According to Green Roofs for Healthy Cities, the North American green roof industry experience an estimated 10.3% growth in 2016 over 2015. Many cities have enacted policies that encourage green roof development through rebate programs, tax incentives, or fast-track permitting programs.[23] Cities that have implemented these policies—including Washington, D.C.; Toronto, Ontario; Philadelphia, Pennsylvania; Seattle, Washington; and Chicago, Illinois—also reported the largest square footage of green roof installations in 2016.[24]

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