Net Positive Water: The Hafer Urban Frontier House

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The Urban Frontier House near downtown Billings, Montana, is an off-grid, net positive water home that provides an excellent illustration of how energy and water efficiency can be optimized when designing sustainable homes in urban settings. Billings averages 13.7 inches (348 mm) of rain annually and has temperatures in the teens during winter months. With the minimal rainfall and cold temperatures common in this high-desert climate, designing the Urban Frontier House to be comfortable and sustainable presented many challenges.

The Urban Frontier House is an example of how each element of a building, including stormwater collection and retention, water supply & treatment, water distribution, wastewater collection, wastewater treatment, water reuse, and water consumption, can be addressed with an emphasis on water conservation. These concepts should be integral in the future of sustainable building design.



Figure 1. The Urban Frontier House in Billings, Montana, illustrates how sustainable design principles can be applied in an urban setting to improve both water and energy efficiency.

Urban Frontier House Overview

The Urban Frontier House is a single-family home built on a former greyfield site near downtown Billings, Montana. The home serves as the main residence of Randy and Janna Hafer, owners of High Plains Architects. While attending Stanford University, Randy became overwhelmed with the desire to someday build a home that provided all the luxuries of traditional homes but was built and operated sustainably. His goals included changing current design and manufacturing practices so that the house would become a prototype for a healthier, more sustainable standard of residential construction. During that time, he developed a list of design parameters to incorporate:

#1 Urban Site – The Hafers wanted a building site within an urban setting, close to work and activities, and one in which all utilities and services were available, but in this case, unnecessary. They were able to identify a greyfield site for their future home just minutes from downtown Billings.

#2 Reasonable Budget – They wanted to build a home that was economical and within the range of traditional building expenses. The end product, the Urban Frontier House, came in at the higher end of the range for new local homes of similar size and quality.

#3 No Offsite Utilities – They wanted the building to be completely "off the grid" and totally self-sustainable. This revolutionary house has no mechanical heating or cooling system, no gas utilities, no city water or sewer service, no well or septic system, and no need to tie to the electrical grid.

#4 Comfortable – Comfort was imperative, especially when considering living through winters in Billings. The building would not be a success if it was not habitable year-round. Despite having no mechanical heating or cooling system, the house is very comfortable through all four seasons.

#5 Low-Maintenance – Maintaining a home and its mechanical components is necessary whether using traditional or sustainable building methods. Therefore, it was key that this home's maintenance needs were within the capabilities of a typical homeowner. As a result, the Hafers have found that the home does, in fact, require less maintenance then they would have expected.

#6 Easy-To-Operate Systems – Typically, a home's operational needs are not something an average homeowner wants to spend much time or money on. In order for a home to be truly sustainable, it has to be user-friendly. The systems in the house have turned out to be easy to operate and well within the capabilities of a typical homeowner.

#7 Replicable – It's tough enough to find the right materials to make a living building project happen and be fully off the grid. But adding the design criterion that the project must be replicable escalated the challenge. Yet, with the right material specifications and the growth of the sustainable building market, the replicability of this design is more of a reality than ever before.

#8 Scalable – The design and equipment selection for the home needed to be scalable. This meant that the systems could be reduced for smaller homes and small commercial buildings or scaled up to fit multi-family or larger-scale commercial designs. This is probably the simplest element of the design criteria developed so many years ago, as the various pieces of equipment specified are already available in a variety of sizes to meet all project needs.

As individual elements, the major design goals for the project may not have been difficult to achieve; combined, the challenge could seem unsurmountable. In this case, the architect/homeowners were not deterred and their dreams were solidified in 2016, when they finally moved into their off-the-grid home.

Details

The structure is located on a small urban infill lot seven blocks from the center of downtown. The Urban Frontier House contains 2,400 square feet (223 m^3) of living space that is heated and cooled passively, without traditional mechanical systems. Due to its super-insulated envelope made of overlapping structural insulated panels (SIPs), solar heat gain and heat produced by daily activity maintain a comfortable indoor temperature year-round. In the summer, the house is ventilated naturally with solar-powered skylights. During the frigid Montana winters, fresh air is circulated through the house using sun-warmed air from the garden room with help from a heat recovery ventilator.

The solar array is designed for roughly 6 kW with a vertical axis wind turbine to assist in energy generation. In order to minimize power conversion losses, the house utilizes its own DC microgrid, which powers all LED lighting, all ceiling fans, and pumps.

The rain falling on the roof of the Urban Frontier House is captured in the rain gutters, travels to the downspouts, and is directed into six rain barrels – three on the north side of the house and three on the south side – which are crafted from food-grade barrels that were originally used to ship pickled food overseas. This rainwater then runs through piping from the barrels underground and is collected in six 1,500-gallon (5,678-L) polyethylene rainwater tanks in the basement of the house. If the rainwater tanks in the basement are full, valves close off each tank, the water backs up, then it overflows out of the rain barrels onto the ground. The rainwater is treated with a 5-micron filter to remove sediment, a 0.5-micron carbon block cartridge to remove heavy metals, then disinfected with ultraviolet light.

The greywater is treated separately. It flows directly to an Orenco AdvanTex AX20RT Treatment System and is pressurized through a 5-micron filter and a 0.5-micron carbon block cartridge. Then, it is disinfected with ultraviolet light before filling the greywater pressure tank. After that, it is stored in a 1,500-gallon (5,678-L) tank for use in toilet flushing, clothes washing, dishwashing, and irrigation.

All of the house's organic waste is processed on-site by a Phoenix composter. The residents are careful with water usage but they do not scrimp. The faucets and showers have low-flow fixtures but meet the needs of the homeowners. All water is used at least twice and the Hafers have never come close to running out of water.

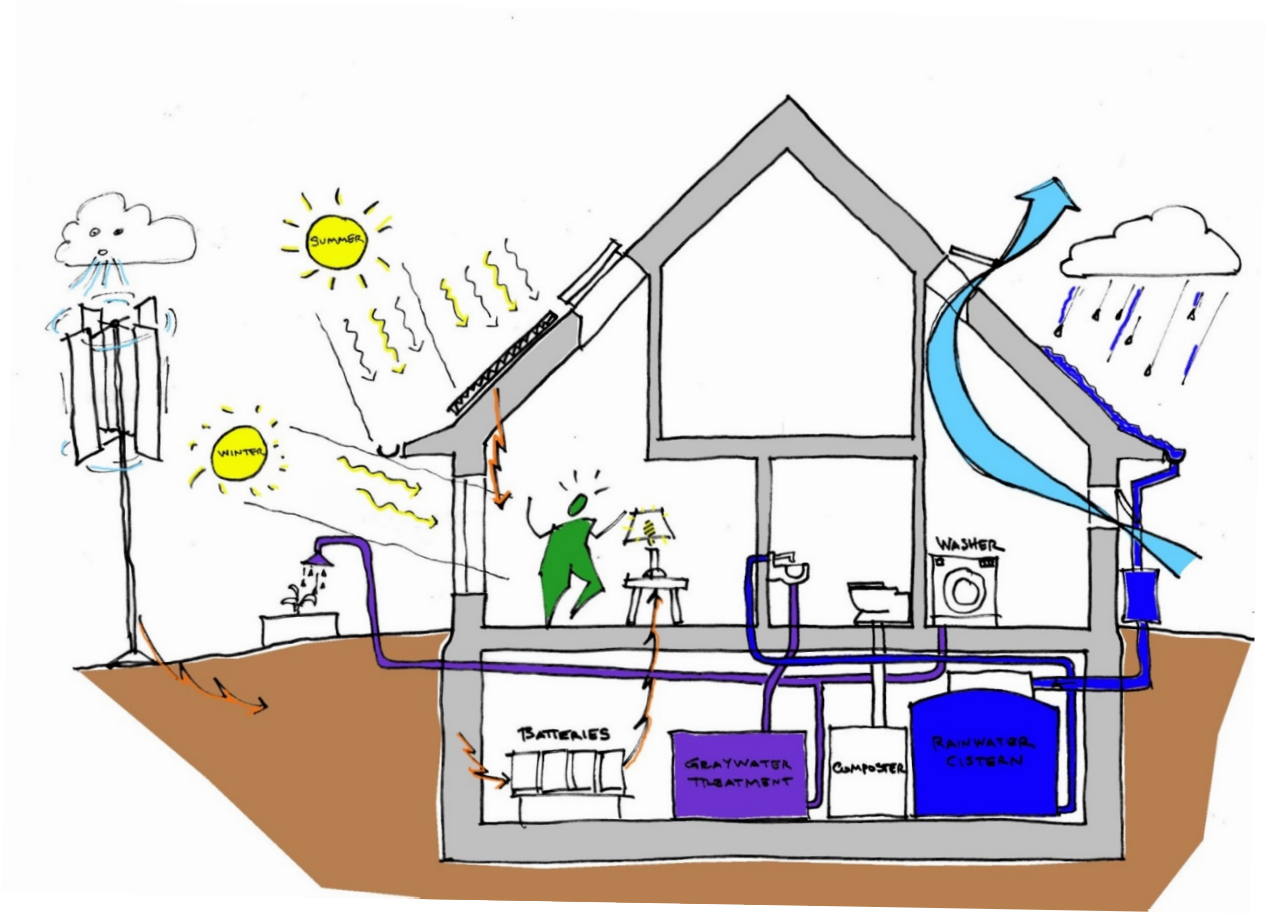


Figure 2. Rainwater and greywater are captured and treated on-site to meet household water demands.

All the toilets drain into the Phoenix composter located in the basement, which is manufactured by Advanced Composting Systems in Whitefish, Montana. The composting system needed to be designed to be somewhat invisible, which is atypical for most available composting options. The

Phoenix system requires very little maintenance and has allowed residents and guests to use the toilets in the traditional fashion.

Urban agriculture is an important component of the Living Building Challenge,[i] a certification program for sustainable design and building practices. In addition to the 4-season garden room, the Urban Frontier House aims to cultivate the vast majority of the yard for food production. By producing a large portion of their food, the owners will enjoy a nutritious and convenient supplement to their diet. Irrigation needs are provided by greywater and rainwater systems.

Capital and Operational Expenses

Due to the cost for connection to water and sewer services, as well as construction costs required to make the connections, the capital cost of purchasing and installing equipment necessary to collect and use rainwater, treat and reuse greywater, and compost solids was similar to that of traditional utility services.

At the moment, operational expenses are minimal because Randy Hafer operates all of the systems himself. Energy is generated onsite, so there have been no electrical expenses, either. Randy estimates that he is spending around 15 minutes per week to operate all of the water and wastewater components, which includes loading kitchen scraps into the composter and monitoring the operation of each system's components.

Equipment Selection & Sourcing

The Living Building Challenge requires that the equipment be sourced as locally as possible. With the additional requirements for all water sources to be located on-site, there were specific systems that would be necessary, such as the composting system. The greywater system and water control panel were sourced by Orenco Systems out of Sutherlin, Oregon. The rainwater tanks were sourced from Roto-Molding in Caldwell, Idaho, and the rain barrels were sourced from Upcycle Products in Morris, Illinois.

Certifications

High Plains Architects' Urban Frontier House is certified Leadership in Energy & Environment Design (LEED) for Homes Platinum and is pursuing Living Building Challenge and Passive House certifications. The goal of the Living Building Challenge, the most rigorous green building certification program in the world, is to create market change towards a more healthy and sustainably built environment.

Meeting the "LEED for Water Efficiency" standard[ii] requires an evaluation of outdoor usage and indoor efficiency. Outdoor water use must be eliminated or reduced by a calculated 30% less than the predetermined national average through the use of drought-tolerant site design and water conservation. Meeting the indoor water use prerequisites required reduced-flow water fixtures.

Specific baselines have been developed for water efficiency, based on fixtures within the building envelope. The specification of fixtures to meet the reduced baseline is the simplest and least costly of all of the water requirements. Additionally, appliances must meet the required standard as set forth in the "LEED for New Construction" specification.[iii]

Living Building Certification (LBC) requires meeting specific elements for water conservation, along with energy and other elements that are labeled "petals." The water-specific petal requires the following elements to be achieved:

Water Source - One hundred percent of the project's water needs must be supplied by captured precipitation or other natural closed-loop water systems, and/or by recycling used project water, and must be purified as needed without the use of chemicals.

Water Reuse - All stormwater and water discharge, including grey and black water, must be treated onsite and managed either through reuse, a closed loop system, or infiltration.

Although the descriptions within the water petal do not look daunting, they can be a challenging element to overcome. As Randy and Janna Hafer's goal was to meet the highest possible standard for sustainability, pursuing LBC was the obvious choice for their project. This required full reuse systems and integrated design concepts for a truly off-the-grid solution.

Regulatory Issues

In the state of Montana, the regulatory environment is more open to new ideas than many other areas of the country. Regulators in the state have a lot of experience with decentralized solutions and systems that generate their own water, so it was not so far "outside the box" for them to comprehend what this project was trying to achieve. The Hafers were required to get an exception so they would not have to hook up to the city sewer. Luckily, they had a public works director who was very supportive and traveled to the state capital to get the variance approved. There is a caveat: if the systems didn't work as designed, the Hafers had to agree to connect to city services.

Statistics & Seasonal Variations

With 9,000-gallons (30,069 L) of rainwater storage and an average rainfall of 13.7 inches (348 mm) per year, the large roof requires three inches (75 mm) of rain to fill the tanks. Water levels in the rainwater tanks have not been lower than the 7200-gallon (27,255-L) mark, which occurred during the winter when there was no rainwater collection due to winterization issues. Those issues have since been corrected. All of the water is used twice, and the greywater system has reduced the overall rainwater usage to roughly 10 gallons (38 L) per person, per day. The bulk of the greywater is reused for laundry and dishwashing and is heated through a 4-gallon (15-L) water heater. In hindsight, the rainwater storage volume could be much less. Seasonal

variations in rainfall have not caused an issue and are not expected to. An added bonus is that the rainwater tastes amazing. It's truly the purest and most direct source of potable water in the world.

Maintenance

Minimal maintenance has been required after the first two years of operation. Once a week, the composter requires about five minutes of maintenance involving food scraps, bulking material, and wetting water along with a hand churning. The material from the composter has yet to be removed and may not need to be removed for up to five years. The particulate filter for the greywater system was changed after roughly a year, although it may not need to be changed so frequently. The rainwater particulate filter requires changing roughly every 6 months, which is less than expected. There are very few parts of the systems that require maintenance, and this maintenance is simple enough that an average homeowner could perform it.

Conclusion

The water management system at the Urban Frontier House provides an elegant balance between rainwater collection and treatment, greywater reuse, and solids composting. Thanks to low-volume fixtures and water-conscious residents, the volume of water consumed is a quarter of the industry standard. Using rainwater models based on annual precipitation in Billings of around 13.7 inches (348 mm), the designers oversized storage vessels to ensure availability of potable water during the driest months. Greywater reuse has allowed for minimal potable water consumption and is the key to the net positive results.

The Urban Frontier House's water management system provides a vision of the future. In this future, our homes produce more resources than required, our buildings are comfortable without wasted consumption, and the health of our communities is improved. Creating regenerative communities is not some science-fiction script. It's a reality today, at no greater expense than traditional building standards.

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[i] https://living-future.org/lbc/basics/
[ii] https://new.usgbc.org/leed
[iii] Ibid.