Refi Home

An owner-designed project on an infill lot in the North Mississippi neighborhood that kept total square footage down to 70% of an average home size -- an act that saved money by reducing material needs and the amount of space heated during colder weather. Other features include dual flush toilets, efficient building envelope, unfinished surfaces, reclaimed timbers and flexible space design.

Project Highlights

- Hydronic radiant heating
- Formaldehyde-free batt insulation
- Ecoroof
- Rainwater harvesting
- Reclaimed timber
- Bamboo flooring and cabinetry
- Recycled paint

Portfolio Contents

- Final Report
- Monitoring & Verification

- Project Website (External Link)

PROJECT INFORMATION

Name of Primary Contact:	Emily Réfi, AIA				
Company or Organization:	Emily Réfi, Architect LLC				
Address:	4522 N. Kerby Ave.				
City, State & Zip:	Portland, OR 97217				
Phone:	503.750.5669	Fax:		E-mail:	emilyrefi@gmail.com

PROJECT DETAILS

Project Name:	Refi House
Project Owner:	Karl + Emily Réfi
Project Address:	4522 N. Kerby Ave.
City, State, ZIP:	Portland, OR 97217
Date Project Started:	Construction started November 2005
Date of Completion:	Occupancy September 2006, Green measures completed April 2007
Building Certifications:	

Design and Construction Team

Architect or Designer:	Emily + Karl Réfi
General Contractor:	John Weed, WBS Construction Inc.
Landscape Architect:	Green roof plant list consultation by Jason King, LA, Greenworks
Structural Engineer:	Bob Grummel, Grummel Engineering
Civil Engineer:	
Mechanical Engineer:	design-build contractor: David Neketin HASCo
Electrical Engineer:	
Interior Designer:	
Green Building Consultant:	
Energy Modeler:	HASCo
LEED Consultant:	
Additional:	

Building Details

If building has mixed use, please include the sq. ft of each type of use

Gross Floor Area: 1600 s.f. heated + 400 s.f. basement/garage

Building Type

☒ Single-family Residential
☐ Multi-family Residential
☐ Commercial
☐ Industrial
☐ Institutional
☐ Mixed-Use
☐ Other (describe)

Site Conditions (check all that apply)

☒ Previously Undeveloped Land
☐ Previously Developed Land
☐ Brownfield Site
☐ Preexisting Structure(s)

Project Type

☐ Renovation
☒ New Construction
☐ Addition

Project Costs

Land Acquisition:	$77,000
Site Clearing/Deconstruction:	
Site Development:	$18,524
Public Improvements:	
Design Fees:	$2,159 structural engineering
Permits:	$6,060
System Development Charges:	$8,482
Construction:	$243,415
Green Technologies:	$34,907
Other Costs:	$4,638 survey, printing, special inspections, misc.
Total:	$395,185

Project Measure Matrix

In the following Matrix, as requested, please provide detailed information about all green products and materials identified in the Grant Agreement, Green Build1ing Practices and Features.

Green Building Project Measure Matrix

* indicates cost was included with "Green Technologies"

Product/ brand or Measure by Category	Model #	Vendor	Cost				Efficiency/ Equipment Ratings or Capacity	Certifications	Incentives, Credits, rebates, grants, etc…
			Design	Material	Labor	Equipment			
Energy									
Hydronic Radiant Heat:					$12,520*				
Gas water/space heater: Polaris	PG10 34-100-2NV	HASCo					96% efficient 34 gallon capacity		$340 tax credit
Aluminum trays for pex tubing: Thermo-Fin		HASCo							
Under slab rigid insulation: Owens Corning				price included w/ batt insulation					
Formaldehyde-free batt insulation: Certainteed				$4098					
Appliances:									
Refrigerator: Kenmore	#64933	Sears				$760	417 kWh/year	Energy Star	
Dishwasher: Kenmore	#16253	Sears				$400	368 kWh/year 1290 gallons/year	Energy Star	$50 tax credit
Clothes Washer: Frigidaire	# FTF530ES	Standard TV & Appliance				$481	142 kWh/year 8726 gallons/year	Energy Star	$115 tax credit
Other:									
Windows: Milgard	Aluminum thermally broken LoE, argon filled			$8060			picture units: U=.33 casement units: U=.43		
Ceiling fan: Harbor Breeze	56" titanium & brushed chrome	Lowes				$70*			
Water Efficiency									
Kohler-Sterling Dual Flush Toilets	Karsten Model #402028	Keller Supply		$530*			1.6 / 0.8 gallons per flush		
also see Rainwater Harvesting below									

Stormwater Management									
GREENROOF $7888* total					$4680				
Structure			$960	$400					
Colbond drain mat	Enkadrain 3611R	Atlas Supply		$640			40% PI recycled mat'l		
Flashings: TT&L Sheetmetal				$85					
ProGro growth medium	Intensive Blend	ProGro		$224					
Conveying truck delivery: EZ Grade					$250				
Plantings:									
Sedum cuttings		Squaw Mountain Nursery		$77					
Sedum plugs		Lowes Home Depot		$160					
Native plants		Bosky Dell Natives & Portland Nursery		$330					
Stepping Stones: Oregon Decorative Rock				$81					
RAINWATER HARVESTING $1245*			$350		$600				
recycled steel food storage drums		Craig's list		$175			(2) @ 55 = 110 gal		
Flotec utility pump	FP0F360AC	Lowe's				$120	1/12 HP, 350 gallons per hour		
Other:									
Vegetated bioswale plantings (other costs in site development)				$280*	$400*				
Permeable Concrete pavers: Mutual Materials	Turfstone				$2590*				
Materials and Resources									
Reclaimed timber stair treads: salvaged douglas fir		Endura Wood Products	$270*	$1144*	$1000*				
bamboo flooring material: Plyboo	vertical grain, amber color	Emerson/Crosscuts		$3470*	$4510				

Bamboo & Wheatboard cabinetry	custom	L&Z Wood Specialties		$3500*	$5000				
Ipe decking		Lakeside Lumber	included in flooring						
Recycled Paint: MetroPaint				$140					
Floor finish / sealer:BonaKemi	BonaSeal	Environmental Building Supply	included in flooring						
Construction and Demolition Waste Recycling									

PROJECT HIGHLIGHTS

Financial Savings & Benefits

Can any soft or hard cost savings be identified from installation of green measures? Please provide actual cost savings.	Advanced framing: $1450 framing material savings (10%) Metro paint: $140 material savings Wheatboard cabinets: $600 material savings over plywood
Can any operational cost savings from green measures be identified? Please provide actual or projected operational cost savings.	Energy: Projected 40% operational cost savings Water Efficiency: Projected 25% operational cost savings Stormwater management: Projected $68/year for Clean River Rewards

Environmental Benefits

Please be as specific as possible. Compare against code or a similar conventional building as relevant.

Modeled Energy Savings: *(Annual kWh or therms per sq foot)*	Energy: Pending M&V, projected 40% energy savings
Estimated Annual Water Savings: *(Annual savings in gallons per person)*	Water Efficiency: Pending M&V, projected 25% water savings
Construction and Demolition Waste Recycling: *(% recycled by weight or volume of total waste)*	Unknown
Estimated Annual Reduced Stormwater Runoff: *(% total permeable surface area of total site area)*	100% on-site stormwater management
Enhanced Habitat: *(% area of restored or new habitat of total site area)*	N/A
Other:	

Community Benefits

Can any specific community benefits be identified? Examples include educational opportunities, public access or community benefit programs.	Demonstrates a new style and expression of green infill construction. Featured on HGTV and Portland Monthly Magazine, emphasizing that modern design can be green and you don't have to break the bank. Educational outreach: '06 Build it Green tour, visited by U of O architecture students, held neighborhood open house. Used as a case study at ecoroof lecture at the 2007 Greener Home and Gardens show.

LESSONS LEARNED

Describe key outcomes from this project. How has the project changed from its original scope and why? Would you recommend the green technology or practice to other projects? Were there any policy, zoning or building code related issues that affected the project?	As our project evolved, necessity required compromise or scaling back some elements, but all aspects of the original vision are still present to a strong degree. While most of the material selections, systems and construction techniques would be adapted seamlessly to other projects, incorporating measures such as rainwater harvesting or a green roof require an extra level of design consideration, construction effort and ongoing maintenance that may be unrealistic or inappropriate for certain homeowners. That being said, these are some of the most personally rewarding and satisfying elements of our home. Building and zoning codes were easily met in our project, however we have seen many progressive designs sacrificed at the hands of a neighborhood association or a historic design standard. In our case, the biggest challenge we faced was convincing the bank that our design was not as “out there” at it first seemed to them. Hopefully the successful design, financing and completion of our project will in some way clear the path for other future would be homebuilders.

IMAGES AND GRAPHICS

Please attach drawings and photos that describe the project and the green technology or practice.

See drawings and images in included PDF file.

Questions? Please contact Kyle Diesner, 503-823-4166 at OSD. Thank you for taking the time to share what you’ve learned!

GIF Project M&V Plan and Report: Refi House

Prepared for:
Portland Bureau of Planning and Sustainability

July 23, 2009

Prepared by:
The Cadmus Group
Geosyntec

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1. Executive Summary

The Refi House in North Portland was designed by owners Karl and Emily Refi. The project received support from the Green Investment Fund (GIF) in 2005 for the home's green building materials. The owners wanted to use this opportunity to design a comfortable house with lowered resource usage by implementing features such as hydronic floor heating, daylighting, and an ecoroof. The Refi House is a two-story, single-family home that occupies approximately 1,355 square feet; it was completed in April 2007. This monitoring and verification report (M&V) focuses on the stormwater system and energy and water savings.

The house features a number of elements designed to reduce natural resource consumption, including recycled and non-toxic construction materials and Energy Star appliances. The primary innovation is a system that reduces stormwater runoff and provides water for all external irrigation. This system consists of an ecoroof on the first story to collect runoff from the second story roof, two rain barrels to capture runoff from the roof, a trench to collect overflow from the barrels, and grasscrete pavers.

Assessment of the stormwater collection system included a site inspection and an estimate of the reduction in stormwater runoff from the project site. Although a flow meter to measure water usage from the rain barrels had been installed, it eventually broke, so no data were available from it. Modeled stormwater retention was found to be nearly 80%. The system was installed to provide external irrigation, which is necessary in this climate between June and October. During these months, water offset may be as high as 584 gallons. Functionally, the stormwater system is well designed and appears effective at reducing runoff from the site.

The Refis implemented a number of energy saving features. Construction of the house incorporated measures that exceeded 2005 Oregon code, as well as an Energy Star clothes washer, refrigerator, and dishwasher. There is also a hydronic floor heating system that provides all space and water heating for the home, using a 95% efficient condensing water heater. The combined effect of all installed appliances and measures results in a 28.5% reduction in annual energy usage from a baseline house.

Water consumption is reduced through the installation of efficient appliances and fixtures. Three items yield water savings above the level required by current standards: the Kohler-Sterling dual flush toilet, the Frigidaire clothes washer, and the Kenmore dishwasher. All three of these were reviewed and analyzed to project associated annual water savings. Total water savings are estimated to be 5,617 gallons per year, which amounts to more than 12% of total baseline water consumption for the home.

As detailed in the report, the Refi House's green features and installed high-efficiency fixtures and appliances are functioning as expected.

2. Project Description

General Project Characteristics

The Refi House project in North Portland was designed by architects/owners Karl and Emily Refi. The project received support from the Green Investment Fund (GIF) in 2005 for the home's green building strategies. The owners wanted to design a house with low resource usage by implementing such features as hydronic floor heating, stormwater management, and an ecoroof. Additional goals involved making the home comfortable and sustainable, so they designed a smaller home oriented for daylighting, with an open floor plan to minimize wall area. The house was built on a 5,000 square foot lot on North Kerby Avenue in Portland. Construction began in November 2005, and it was ready for occupancy in September 2006; all green measures were completed in April 2007. Figure 1 shows a photo of the Refi House.

Figure 1. Refi House, Front View

The following firms and team members were involved in this project:

- Owners: Karl and Emily Refi
- Architects: Karl and Emily Refi
- Contractor: John Weed, WBS Construction Inc.

- Structural Engineer: Bob Grummel, Grummel Engineering
- Mechanical Engineer: David Neketin, HASCo
- Landscape Architect: Jason Kin, LA, Greenworks

Proposed Green Features

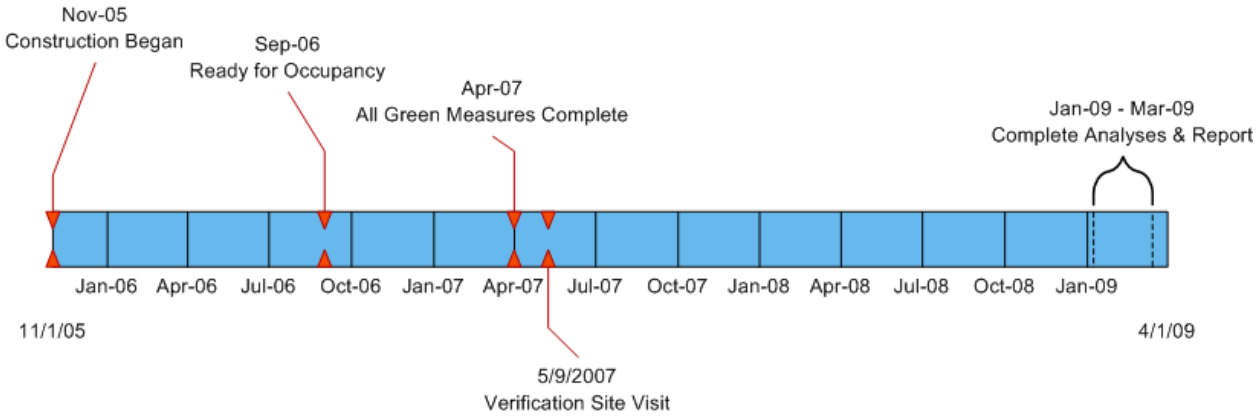
The focus of the proposed green features at the Refi House was on reducing water and energy demands in the home. The most aggressive measures involved managing stormwater runoff by capturing it for external irrigation, and using grasscrete pavers instead of concrete for the driveway. Sustainable and recycled building materials were used when possible. The wall area was minimized by designing the house with an open floor plan, which reduced building materials and improved daylighting and ventilation. Passive cooling via a shaft in the roof eliminated the need for any mechanical cooling. Finally, dual-flush toilets and Energy Star appliances for the dishwasher, clothes washer, and refrigerator were installed.

M&V Scope and Schedule

In accordance with the priorities identified by the Bureau of Planning and Sustainability (BPS), the monitoring and verification (M&V) focus was on energy and water usage, and rainwater capture and use. The Cadmus Group (Cadmus, formerly Quantec, LLC) and Geosyntec performed the M&V for this project. Cadmus focused on the review of the installed green features. Geosyntec led the analysis of the rainfall, runoff reduction, and harvested rainwater use.

Our schedule for M&V activities is shown in Figure 2.

Figure 2. M&V Schedule



3. Verified Green Features

Cadmus and Geosyntec scheduled and performed a detailed site visit to verify that the green measures were incorporated into the project. As shown in the checklist in Table 1, the measures listed in the Proposed Green Features section were reviewed and their existence and proper installation were verified.

Table 1. Checklist for GIF Measures and Installed Green Features

Proposed Measures	GIF Measure?	Installed	Comments
Exterior			
Rainwater harvesting system for irrigation of ecoroof and garden	Yes	Yes	Two 55-gallon barrel collection system used for irrigation
Grasscrete pavers for driveway	Yes	Yes	TurfStone concrete pavers used for driveway. Grasses and flowers planted in pavers.
Vegetated Bioswale	Yes	Yes	Overflow from rainwater harvest system drain into bioswale.
500 sq ft Ecoroof over 1-story portion of the house	Yes	Yes	4" to 5" growth medium provided by Pro-Gro. The ecoroof is partly shaded by 2-story and plant section designed to match site conditions.
Galvalume corrugated metal siding	No	Yes	Steel metal siding is recyclable.
Building Envelope			
Under slab insulation	Yes	Yes	Rigid board insulation installed under concrete slab area.
Day lighting	Yes	Yes	Reflective light shelves located in the kitchen.
Natural ventilation	Yes	Yes	Operable windows at wall top on second floor provide vertical air flow and others provide cross ventilation
Advanced Framing	Yes	Yes	24" on-center 2x6" construction.
High efficiency windows	Yes	Yes	Double pane windows, thermally improved metal, low-e, with argon
R-38 Ceiling / R-21 Walls	Yes	Yes	Batt insulation
Energy Efficiency			
Hydronic radiant floor in slab on 1st floor	Yes	Yes	Hydronic tubing located in slab.
Warmboard type hydronic radiant floor heating under bamboo flooring	Yes	Yes	Instead of Warmboard, Thermo-Fin aluminum tubing was used under bamboo flooring.
High efficiency condensing water heater	No	Yes	Polaris 50 gallon 95% efficiency water heater.
Other: Energy efficient lighting	No	Yes	Located throughout the house. Kitchen 9W CFLs.
Other			
Dual flush toilets (2)	Yes	Yes	Sterling dual flush toilet 1.6/0.8 gpf. Model# 402028
Reclaimed timber	Yes	Yes	Reclaimed fir treads.
Bamboo flooring	Yes	Yes	Vertical grain bamboo finish/sealer with Bonaseal.
Bamboo/ wheatboard cabinetry	Yes	Yes	
Fiber Cement Countertops	Yes	Yes (see comments)	Instead of fiber cement, concrete countertops were installed.
Metro Paint or Low VOC paint	Yes	Yes	Metro paint, white was used.
Recycled glass tiles for 260 sq. ft. of the bathroom floor and walls	Yes	No	Glass tiles installed but were imported and claimed to be about 30% recycled content, but this could not be confirmed.

Energy Efficient Appliances			Model Number
Dishwasher	Yes	Yes	Kenmore Stainless Steel, 24" Model# 16253
Refrigerator	Yes	Yes	Kenmore Top-Freezer refrigerator, 18.9 cu.ft., Model# 64933
Clothes washer	Yes	Yes	Frigidaire front load washer, 3.1 cu.ft., Model# FTF530E

Exterior measures, stormwater system equipment, and efficient appliances were all visually verified. For measures that involved the use of recycled material or environmentally-friendly products (e.g., bamboo flooring), the measures were visually verified when possible. In other cases, the owner and contractor provided documentation or details on the measures that were installed and the rationale behind any changes.

All proposed measures were implemented and verified, with the exception of the recycled glass for the bathroom floor and walls. The company from whom the tiles were imported claimed 30% recycled content, but this could not be verified. Also verified were a number of sustainable, but non-GIF measures, such as corrugated metal siding on the first floor, a high efficiency condensing water heater, and energy-efficient lighting. Table 1shows all measures that were reviewed, and notes those that are not GIF measures.

4. Energy M&V

Project and Counterfactual Characteristics

Construction of the Refi House incorporated measures that exceeded 2005 Oregon code, as well as several Energy Star appliances. Table 2 below shows each envelope and HVAC energy-efficiency measure incorporate in this home and the code requirements. The Energy Star appliances were compared to the federal requirements from 2005 when the house was built. Three appliances that exceed these efficiency standards are the refrigerator, clothes washer, and dishwasher. The refrigerator is a Kenmore 64933 with a top-mounted freezer. The clothes washer is a front-loading Frigidaire FTF530ES with an energy factor of 0.64, which is 39% better than the federal standard of 0.46. The dishwasher is a Kenmore model 16253 with a modified energy factor of 1.97, a 56% improvement over the federal standard of 1.26.

Table 2. Comparison of Energy-Efficiency Measures

Measure	Code Requirement (Counterfactual)	Project As-Built
Windows	U-value 0.40 (OR code)[1]	U-value 0.33
Wall insulation	R-21 (OR code)	R-21A (equivalent to R-23)
Floor insulation	R-25 (OR code)[2]	R-30
Space heating	Hydronic floor heating, 78% efficient	Hydronic floor heating, 89% efficient[3]
Water heating	55.5% efficient for 34 gallon tank	83% efficient

Analysis Approach

The analysis approach for the efficient appliances was relatively straightforward. Energy savings were estimated from Energy Star calculators by comparing annual usage for the refrigerator, clothes washer, and dishwasher to baseline, non-Energy Star appliances with the same specifications.

The house was modeled using Energy 10 software to determine savings in heating costs resulting from the home being built above code with a hydronic heating system. The building plans were used to input the window and wall dimensions into the model. The values in Table 2 were used to create the as-built model of the Refi House and a baseline house built to code with standard insulation levels and window efficiency.

Hydronic heating was a challenge to model in Energy 10 because this system is not specifically an option in the Energy 10 HVAC menu. We specified the system available in Energy 10 that

[1] Standard practice is Energy Star (U-value 0.35) – Energy Trust of Oregon

[2] Oregon 2008 code raised the floor insulation requirement to R-30

[3] Although the Polaris water heater is rated at 95% efficiency, its space heating efficiency is rated at 89% and water heating efficiency at 83% by the Gas Appliance Manufacturers Association (GAMA) http://www.gamanet.org/

was most similar, and set the characteristics to represent a hydronic system. System efficiency was set to the code requirement of 78% in the baseline model and its GAMA rated 89% in the energy-efficient model.

The as-built Energy 10 model was calibrated to one year of post occupancy gas and electric bills. The calibrated model was then used to estimate energy consumption for the baseline home built to Oregon code.

Energy 10 does not provide the capability to model different water heating efficiencies. Consequently, we had to apply a secondary analysis to estimate water heating energy savings. To estimate the reduction in hot water energy usage as compared to the baseline model, we applied an annual water heating usage value derived from a conditional demand analysis Cadmus performed for new single-family construction as part of a recent Resource Potential Study for Puget Sound Energy. We assumed that the annual water heating loads were the same for Portland and the Puget Sound area. The calculations in the Puget Sound project estimated for an average household of 3.4 occupants that 304 therms were used for water heating annually. For the two-person occupancy at the Refi House, we applied a per occupant ratio to arrive at an estimated baseline annual water heating usage of 179 therms for two people.

We then applied the ratio of different efficiencies to estimate the change in usage from using the hydronic system. The current federal standard[4] equation for efficiency of a gas water heater is:

$$Efficiency = 0.62 - (0.0019 \times RatedVolume)$$

Using a rated volume of 34 gallons (the tank capacity of the Polaris water heater), we calculated a baseline efficiency of 55.5%. The Polaris water heater has an efficiency rating of 83%. If the efficiency ratio of 55.5% to 83% is applied to the above baseline of 179 therms, the Polaris water heater would only require 120 therms per year, for an annual reduction of 59 therms per year.

Results

The Energy Star refrigerator, dishwasher, and clothes washer all consume less energy than baseline, standard efficiency appliances. These appliances produced a total annual savings of 453 kWh, as shown in Table 3. Electric bills for the Refi House recorded 3,554 kWh used during the one year post-occupancy analysis period, indicating the Energy Star appliances resulted in an 11.3% reduction from a projected annual electric usage of 4,007 kWh without the Energy Star appliances.

The Energy 10 model output and comparison of baseline water heating usage showed that the installed windows, higher floor insulation, advanced frame walls, hydronic heating system, and condensing gas water heater combined to have a significant effect on the gas usage. In comparing the as-built Refi House to the baseline model analyzed using Energy 10, total use declined from 810 therms to 554 therms, for a savings of 255 therms or a 32% reduction in gas

[4] http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/water_heater_fr.pdf

usage.[5] The space heating savings were estimated by subtracting the water heating savings, estimated as described above, from the savings estimated from the Energy 10 model runs for the baseline and as-built home.

Table 3. Energy Savings

Appliance/Measure	Annual kWh	Standard Annual kWh	Energy savings (kWh)	Energy Savings (therms)
Kenmore 64933 refrigerator	417	492	75	
Kenmore 16253 dishwasher	368	512	144	
Frigidaire FTF530ES clothes washer	142	376	234	
Building envelope and HVAC upgrades				196
Water heating savings				59
Total Annual Savings:			**453 kWh**	**255 therms**

The combined savings of all installed appliances and measures adds up to 453 kWh and 255 therms, equal to 21.9 MBtu combined end-use energy savings. The standard code baseline home would use 94.7 MBtu annually, so the energy savings in the efficient as-built house result in a 28.5% reduction in annual energy usage. Based on the Energy 10 model results, the higher efficiency building materials, better windows, and the efficient hydronic system produce the majority of the savings.

[5] The actual one year of post-occupancy gas bills totaled annual usage of 555 therms, which was insignificantly different from the calibrated model results for the as-built home.

5. Water M&V

As detailed previously, the Frigidaire clothes washer and Kenmore dishwasher are high-efficiency models. The other fixture that provides a significant contribution to water savings is the Kohler-Sterling dual flush toilet. This model allows the user to choose between a 1.6 gallon flush (equal to the current standard) and a more efficient 0.8 gallon flush.

Analysis Approach

For this analysis, the homeowner provided an estimate of the average number of clothes washer loads, dishwasher loads, and low-volume flushes per week. We obtained the 2005 requirements for these products and the ratings of the installed appliances. Water savings for the dual-flush toilet were estimated by multiplying the number of low-volume flushes per year times the difference in water usage of the low-volume and standard-volume flushes. Water savings for appliances were estimated by multiplying the number of clothes washer and dishwasher cycles per year by the difference in the water usage between the installed unit and a unit meeting the standard.

The owners provided their municipal water bills, which were used to compare the water savings from these appliances to the total consumption. The analysis was complicated by the interaction with the stormwater harvesting system, which provides a source of water for irrigation. Since the stormwater system was not metered to establish the rainwater capture rate, it was not possible to determine what percent of the home's water usage was saved through the efficient fixtures and appliances. Thus, we analyzed the calculated annual water savings in comparison to both the actual billing data and a baseline water use estimate of 62 gallons per day per occupant excluding any water use for lawn watering[6]. There were two people living in the home during the analysis period.

Results

The estimated water volumetric savings from use of the efficient appliances are shown in Table 4. Water savings ranged from approximately 600 to nearly 3,000 gallons per year by appliance. Overall savings were estimated to average 15.4 gal/day, resulting in a 15% reduction in the annual water consumption from would have occurred using standard efficiency fixtures. At an average of only 43 gallons per person each day, the Refi household consumed significantly less than the City of Portland residential baseline of 64 gallons per day per person[7]. The Refi House used an unknown volume of municipal water for irrigation. There is some seasonal variation in water usage, with higher consumption in normal garden irrigation seasons of spring and summer and lower consumption in the fall and winter, but the usage still falls well below the baseline. This leads us to conclude that the stormwater irrigation system is contributing to a reduction in

[6] http://permanent.access.gpo.gov/lps21800/www.epa.gov/safewater/wot/howmuch.html.
[7] Email from Jeff Sandberg, City of Portland Water Bureau, 4/29/09

water use. The reduction is estimated at 5.2 gallons per day based on the comparison to the average Portland residential water user.

Table 4. Water Savings

Efficient Device	Weekly Usage	Annual Water Savings (gal/year)	Total Water Savings (gal/year)	Actual Refi Billed Water Use (gal/year)	Portland Average Household Water Use (gal/year)
Dual flush toilet (low flow flushes 0.8 gallons)	60	2,122	5,617	31,665	46,720
Kenmore 16253 dishwasher	4	582			
Frigidaire FTF530ES clothes washer	4.5	2,913			

6. Stormwater M&V

As mentioned above, the Refi House includes several stormwater design features intended to reduce and reuse stormwater runoff. The following section summarizes those features and provides an evaluation of their effectiveness in the context of Portland area rainfall. The remaining sections describe the site visit, assessment of rainwater harvesting and runoff reduction, and conclusions regarding the overall stormwater system performance.

Stormwater Features and M&V Components

The two-story Refi House includes the following stormwater features:

- A 462 square foot ecoroof on the first story that receives runoff from the 810 square foot second story roof. The ecoroof soil depth is about 4 inches on average with a soil medium of Pro-Gro intensive blend.
- Two 55-gallon rain barrels that capture runoff from both rooftops.
- An 8 ft wide, 12 ft long and 1.5 ft deep infiltration trench receiving overflow from the rain barrels. The trench is not hydraulically connected to the City storm drain system.
- Grasscrete pavers in the driveway (215 square feet).

The above stormwater features are designed to eliminate nearly 100% of stormwater runoff from the 5000 square foot lot. The steps and landings at the front of the house constitute the only directly connected impervious area (113 square feet) on the lot. As described below, this project would have an effective imperviousness of approximately 32% without the stormwater features incorporated into the project design.

Stormwater monitoring and verification included:

- Site inspection
- Reduction in stormwater runoff from the project site estimation

The selection and design of stormwater features is based in large part upon the precipitation characteristics of the location where they will be used. The analysis of the stormwater system components in the following sections is based upon local, long-term rainfall records (1949-2006) from the Portland International Airport (PDX).

Portland area rainfall is generally of low intensity, but makes up for this with its frequency. Portland averages around 155 days of rain annually with the majority (~75%) of rainfall occurring during the fall and winter months from October through March. Over 55,000 hours of hourly rainfall data (measurements > zero) collected at PDX were analyzed to investigate rainfall intensities and the temporal distribution. Ninety percent of area rainfall is 0.08 inches per hour or less and over 99 percent of the analyzed rainfall data are 0.20 inches per hour or less. Average annual rainfall at PDX for the 5 years of data analyzed was 36.2 inches with a standard deviation

of 7.8 inches. Figure 3 displays the annual rainfall totals used in the analysis; Figure 4 shows the temporal distribution of Portland rainfall.

Figure 3. Portland Yearly Rainfall Totals (PDX Rain Gage)

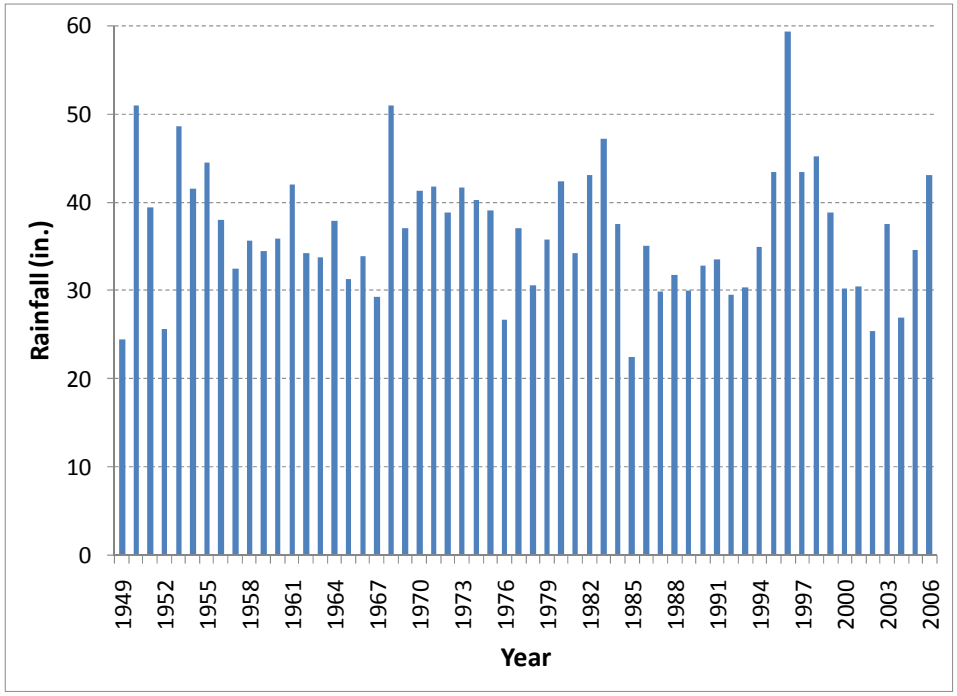
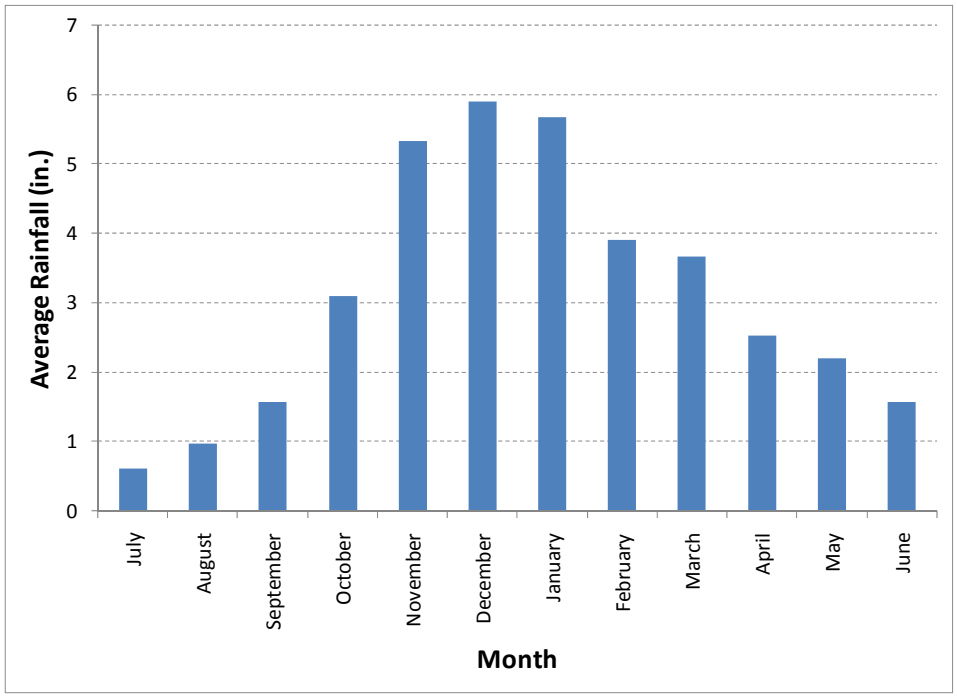


Figure 4. Portland Average Monthly Rainfall



Site Inspection and Stormwater System Photos

A site inspection of the project (Figure 5) was conducted on the afternoon of May 9, 2007. Figure 5 presents photos from the site inspection. The grasscrete paver driveway (Photo 1) appeared to be well established and the rain barrels (Photo 2) were connected to the roof downspout. The infiltration trench (Photo 3) and the ecoroof (Photo 4) had been recently planted, but appeared to be actively growing and healthy. The vegetation in the infiltration trench will ensure long-term performance by keeping the surface from "caking" and providing preferential flow paths along stems and roots. Overall, the stormwater system was well designed and appeared very effective at reducing runoff from the site.

Figure 5. Stormwater M&V Inspection

Photo 1: Refi House w/ Grasscrete Driveway

Photo 2: Rain Barrels

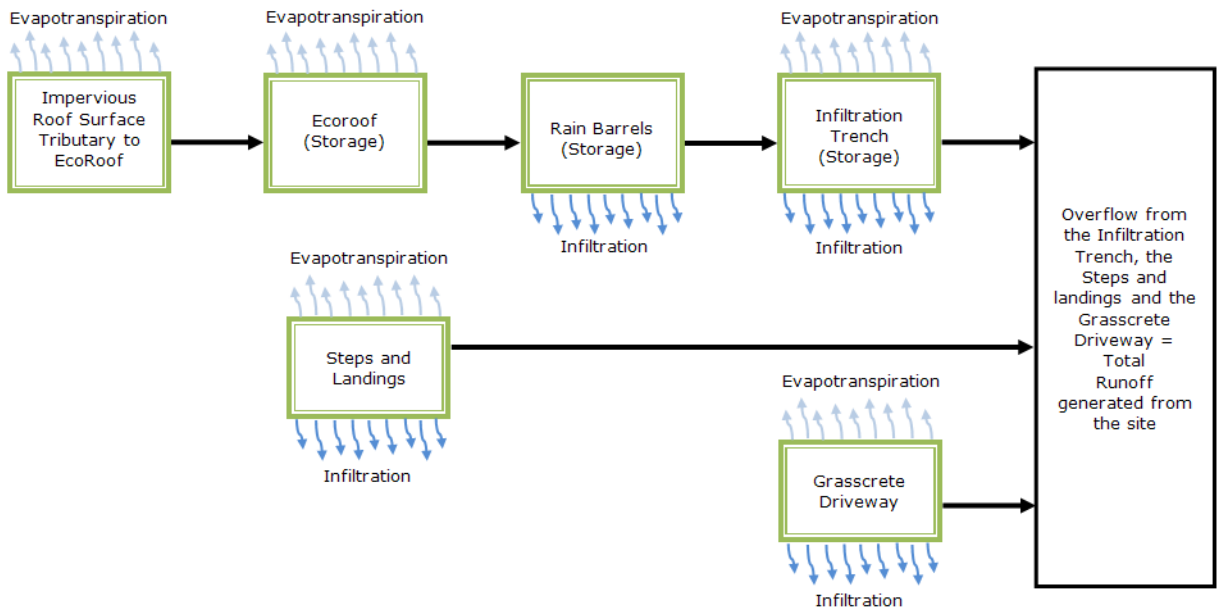
Photo 3: Infiltration Trench

Photo 4: First Story Ecoroof

Components of the Stormwater Management System

Each component of the system was modeled as shown below in Figure 6 using dimensions of the site features described above. While each component of the system was modeled as an individual entity, the analysis was conducted on the system as whole.

Figure 6. Schematic of System Modeled



Impervious roof
All runoff from the impervious roof surface is directed to the ecoroof. A very small portion of the rain is temporarily stored and evaporated from this impervious surface.

Ecoroof
The ecoroof not only captures rain that falls directly on it, but also receives runoff from the second story impervious roof. A Pro-Gro soil medium was used in the ecoroof and has an average soil depth of four inches. The soil medium is assumed to have a moisture-retaining capacity of approximately 30 percent based on a soil with good water retention (Brady and Weil, 2003), which corresponds to an estimated capacity of 1.2 inches of water storage depth. The ecoroof was simulated as an impervious surface in the model (since water can only be stored in the soil pores and cannot be lost to infiltration) and the available storage depth was assigned with the depression storage model parameter.

Rain Barrels
Rainwater captured by the two 55-gallon barrels is used for landscape irrigation and other non-potable uses (e.g., car washing). A Flotec utility pump is used to provide pressurized flow with enough pressure to water the ecoroof. The owners installed a flow meter to monitor the water usage from the rain barrels. However, the device did not provide accurate readings (presumably due to the low flow/low pressure of the system) and the meter eventually broke from being exposed to the elements.

Without water use data it is difficult to estimate the contribution of the rainwater harvesting system had on the total water use reduction. Since the barrels overflow to an infiltration trench that is not hydraulically connected to the storm drain system, the runoff reduction is expected to be significant even if no rainwater was captured and used. The retention of rainwater in the soils of the ecoroof and the temporary detention in the rain barrels slows the runoff rate to the infiltration trench and allows for increased infiltration volume. A conservative drain rate of 2-weeks was assumed for the rain barrels. While it is recognized that during the winter these barrels may not be emptied at this rate, the small storage volume relative to the estimated runoff volumes will not significantly impact the site hydrology. The infiltration trench, as discussed below, has a much larger impact on site hydrology.

Infiltration Trench
Overflow from the rain barrels is directed to an infiltration trench with a total volume of about 144 gallons. A storage capacity of 30 percent (~43 gallons) was assumed for the infiltration trench. The infiltration trench is intended for temporary storage while the runoff infiltrates into the ground and it will flood when its capacity is exceeded. Estimates analyzed for the infiltration rate were 0.2 in/hr, which represents a poorly maintained infiltration trench over time, and 2 in/hr, which represents an ideal infiltration trench with high infiltration rates (close to the maximum hydraulic conductivity obtained from the NRCS). While not hydraulically connected to the City storm drain system, the amount of flooding is considered runoff from the site. Evaporation from the infiltration trench was included in the analysis.

Grasscrete
Instead of paving the driveway, it was constructed using grasscrete, which allows a portion of the rainfall to infiltrate rather than running off into a storm drain. This was modeled as a pervious area with a saturated hydraulic conductivity representative of a sandy loam (0.43 in/hr) to represent the porous base material typically used for these BMP types. This saturated hydraulic conductivity is higher than that of the loam soil present in the area according to NRCS (0.13 in/hr). Evaporation from the grasscrete was included in the analysis.

Steps and landings
An estimated 113 square feet of steps and landings are the only directly connected impervious area on the lot and were included in the model. While some of the rain that fell on the steps and landings evaporated, the remaining runoff was included in the estimates of the total runoff generated on the site.

Overall System Performance

To determine the effectiveness of the stormwater management system installed at the Refi House, four scenarios were modeled in SWMM to estimate the amount of runoff captured (percent capture) and either evaporated or infiltrated by the system. In all the scenarios, the surface area of the modeled portion of the site was the same. A baseline model with a loam soil was run to estimate the amount of runoff that might be expected from the site if none of the stormwater management system had been installed. That was followed by three additional models that provided for a range of conditions that might exist on the site with the stormwater management system installed. The scenarios modeled are shown in 5.

Table 5. Scenarios Modeled in SWMM for Refi House

Stormwater Management System included?	Assumed infiltration rate of trench (in/hr)	Time to empty rain barrels	Estimated Percent Runoff	Increase in Volume Retained
No	N/A	N/A	83.7%	N/A
Yes	0.2	No water removed from barrels	7.4%	76.3%
Yes	0.2	2 weeks	6.8%	76.8%
Yes	2	2 weeks	5.1%	78.6%

The model runs show that implementing the stormwater management system described above is estimated to have increased the percent of rainwater retained on the site by approximately 76 to 79 percent, on average. These results assume the infiltration trench and the grasscrete driveway are regularly maintained by raking the surfaces and promoting vigorous vegetative growth to ensure the soils remain open for infiltration.

Conclusions

Based on the assessment above, the ecoroof, infiltration trench, and grasscrete driveway of the Refi House appear to be providing significant runoff volume reductions from the site. The rain barrels do not significantly contribute to this runoff volume reduction due to their small storage capacities, but they can provide domestic water use offset. If the cisterns were used year round and consistently emptied every two weeks, the potential for savings is up to 2,400 gallons annually. The owners intended them to provide water for external irrigation, which is necessary during the summer months of June through September. If the rain barrels were consistently emptied every 2 weeks during these months, domestic water use offset could be as high as 584 gallons. Finding alternative uses for captured rainwater during the wet season or increasing the capacity of the harvesting system could significantly increase the domestic water use offset. Overall, the system effectively reduces the amount of runoff being generated from the site and appears to be functioning as intended.

7. Construction and Demolition Waste

Starting with GIF projects funded in 2006, awardees were required to submit to Cadmus the material description, weight, and disposal or recycling receipts for all C&D waste. This project was funded in 2005, and therefore, this requirement did not apply.

Appendix A: Stormwater/Rainwater Modeling

Modeling Introduction

The U.S. EPA Storm Water Management Model (SWMM) is a public domain watershed model that is widely used for modeling hydrologic and hydraulic processes affecting runoff from urban and natural drainages. The model can simulate all aspects of the urban hydrologic cycle and is particularly appropriate for analyzing hydrologic effects of development and stormwater Best Management Practices (BMPs) on surface runoff, infiltration, and evapotranspiration.

SWMM was designed for continuous rainfall and runoff simulation such that long-term, hydrologic and hydraulic analyses could be performed. The continuous simulations allow for an evaluation of the long-term average performance of stormwater features. As such, SWMM was used to model the hydrologic effectiveness the stormwater management system at the Refi House. Hourly precipitation data collected at the Portland International Airport from January 1949 through 2006 were used as the precipitation input for modeling the roofs, directly connected impervious surfaces and the stormwater management system. Only areas thought to have a large impact on the stormwater system installed on this site were included in the analysis (i.e., other pervious areas of the site were omitted as these areas are essentially unchanged from the previous undeveloped condition).

Rain Barrel Modeling

SWMM requires input of many model parameters, however the parameters that are central to this analysis are: rainfall, evaporation, infiltration rates and rain barrel emptying rates. The primary model assumptions are:

- Rainfall: historic rainfall data collected at the Portland International Airport is a reasonable representation of the rainfall amount and variability at the project site. Long-term continuous simulation modeling is believed to provide more accurate estimates of average annual performance than using average annual rainfall depths or a design storm event with a 1-year recurrence interval.
- Evaporation: Table contains the raw pan[8] evaporation data and the adjusted values used in the model. The pan evaporation data are used as the basis for estimating evaporation. A pan coefficient of 0.8 was selected based on information in the Handbook of Hydrology (Maidment, 1993). Evapotranspiration is water loss through evaporation directly from the soil or surface storage and transpiration losses from plants.
- Infiltration rates: site-specific infiltration rates are not available so information regarding the local soils was obtained from the Natural Resources Conservation Service (NRCS). The most limiting layer of the Latourell soils (clay loam) in the area near the Refi House

[8] An evaporation pan is a large, screened metal dish containing water used to measure actual water loss. This data is converted to an estimate of water loss (evaporation of evapotranspiration) through the use of a pan coefficient. The data was obtained online from http://www.wrcc.dri.edu/htmlfiles/wetevap.final.html

have hydraulic conductivities between 0.57 and 1.98 in/hr, according to the NRCS. The information on soil characteristics was used to estimate a range of infiltration rates for the trench and to assign soil characteristics to define the infiltration under the grasscrete.

- Rain barrel emptying rates: these were unknown and were estimated to be between no emptying and a very low rate of two weeks to empty both barrels.

Table 6. Evaporation Data

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Pan data	1.1	1.5	2.2	3.1	4.7	5.8	7.5	6.1	3.9	2.1	1.3	1	40.30
80% of pan data	0.88	1.2	1.76	2.48	3.76	4.64	6	4.88	3.12	1.68	1.04	0.8	32.24

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