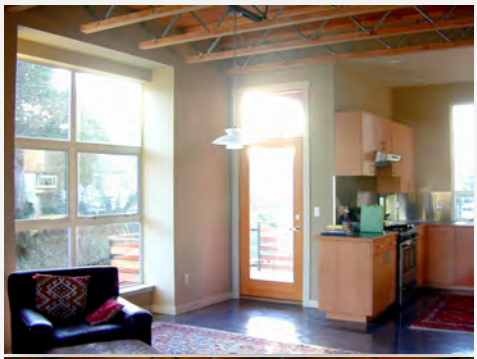

Kerby Street Homes

Four custom designed speculative "green" homes. These homes are sited on a narrow infill lot in North Portland and utilize a variety of advanced energy efficiency and renewable energy technologies (zonal hydronic heating systems, heat recovery ventilation and solar electric and solar water heating panels). Additionally, each home's porch features an ecoroof that can be irrigated by a rainwater harvesting system located under the driveway, while also using rainwater for toilet flushing.

Project Highlights

- **Rainwater harvest**
- **Ecoroof**
- **Radiant hydronic heating**
- **Heat recovery ventilation**
- **Low/no VOC materials**
- **Meets city density goals**

Portfolio Contents

- **Final Report**
- **Monitoring & Verification**
- **Case Study**
- **Construction pictures**

Portland Office of Sustainable Development
G/Rated Green Investment Fund

Grantee Final Report

2 6 2006

PROJECT INFORMATION

Name of Primary Contact:
Aaron Blake

Company:
Reworks, Inc.

Address:
P.O. Box 454, Corbett, OR 97019

(503) 695-3426 ph
(503) 695-6726 fax
reworks@cascadeaccess.com

PROJECT DETAILS

Project Name:
Kerby Street Homes

Project Owner:
Reworks, Inc., until January 1, 2006 when ownership was transferred to new homebuyers.

Project Addresses:
619 N Humboldt; 4905 N Kerby, 4911 N Kerby, 4917 N Kerby
Portland, OR 97217

Located on NWC of N Kerby Ave. and N Humboldt St. Near intersection of N Albina Ave. and N Alberta St.

Project Start Date:
May 16th, 2005

Project Completion:
Occupancy, December 8th, 2005

DESIGN AND CONSTRUCTION TEAM

Designers:
Aaron Blake, Christina Davis

General Contractor
Reworks, Inc.

Structural Engineer:
Scott Bowman, Angle Design

Mechanical Engineer
Shelter Products (Radiant floor system)

Building Details

Gross Floor Area:
1865 SF per house (heated space)
2144 SF per House (with garage)

8576 SF approximate gross total of all 4 houses

Building Type:
Single Family detached

Site Conditions:
Previously Developed (one SFR on 10,000 SF lot, demolished prior to Reworks purchase)
New Construction

Green Products and Materials:

1. Zonal Radiant Heat System. Projected performance: 30%-50% energy savings over a forced-air system. Dedicated hot water heater: Bradford White 40 gal. Direct Vent; 80% Recovery Efficiency; 38,000 BTU's; Model DS1-40S6BN; ISO9001 registered. Radiant system: Shelter Products, Inc. design; Precision Hydronic Products fabrication of mechanical modules; ISO9001:2000 certified.
2. Heat Recovery Ventilation System. Projected performance: Reduces airborne pollutants and excess moisture in the home. Recovers 60%-75% of the heat in the exhaust air. System Components: Venmar Solo 1.5; 80% efficient heat recovery ventilator; 150 watts, 120 v; Ultima Control Device allows for maximum control of unit with various exchange/filtration options; Pleated filter arrestance rate is 90-92%.
3. Rainwater Harvest System. Projected performance: Decrease in municipal potable water demand by 25% per year. System Components: 1500 gallon concrete cistern; Goulds 1/2 HP in-line shallow well pump model JRS5, !SO9001 registered; Flo-True roof washers at each downspout.
4. Pervious concrete driveway. Turfstone and SF Rima porous-pavers from Willamette Graystone. Both are traffic-rated and designed to comply with stormwater infiltration requirements.
5. Pre-wire for solar photovoltaic panels. One homeowner opted for the installation of a 2 KW system provided by Mr. Sun Solar. All of the homes are pre-wired for the future installation of solar PV panels. Mr. Sun Solar, in addition to installing the system, coordinates the tax rebate incentives for the homeowner. According to Mr. Sun Solar, lighting and appliances represent about 25% of a household's total electric load or approximately 2,500 kWh/yr. A 2 kW photovoltaic system would produce an average of 7 kWhr/day over the course of the year, with an annual savings of nearly 2,600 kWhr. This translates to a savings of approximately $180 annually.
6. Pre-plumb for solar hot water heating. All four homeowners opted for the solar hot water package. The Sol-Reliant water heating system is rated to save 2,450 kWh/yr.

This provides approximately 60% of the annual energy required to heat water and produces a savings of about $6 per occupant per month. Additionally, energy savings from a solar water heater are projected to keep an estimated 1,000 pounds of CO_2 per year from being pumped into the atmosphere by fossil fuel plants.

7. Ecoroofs over porches. Each house has two mini-ecoroofs, each approximately 50 SF in area. They are designed to reduce stormwater runoff by absorption, retention and the slow dissipation of rainwater. They also contribute to the livability of the project by providing greenery and a non-reflective roof surface when viewed from the upper floors of the houses. The roofs are lined with TPO membrane, use Tremdrain filter fabric beneath the soil medium, Pro-Gro rooftop soil blend for ecoroofs, and planted with a variety of sedums and other plants as recommended by Ecoroofs Everywhere.
8. Native Landscaping. Trees and plants are native species or species known to thrive in the average Portland climate and have a low water demand.
9. Drywell. Works in conjunction with the rainharvest cistern. When the cistern overflows, it drains into the drywell. Drywell also handles foundation drainage.
10. Low/no-VOC finishes and materials. We utilized formaldehyde-free MDF trim, fiberglass batt insulation, wheat-board cabinets, and wool carpet and recycled denim carpet pad. The interior paint finishes are a low VOC product from Benjamin Moore. Concrete floors are finished with Euco AquaCure acrylic, low VOC finish.

Green Venders and Suppliers Used:

1. Humabuilt; supplied wheat-board cabinetry.
2. Pacific Hydronics (formerly Shelter Products); supplied radiant floor materials and components.
3. Willamette Graystone; supplied rainwater cisterns, Turfstone and SF Rima pavers.
4. Pro-Gro materials; supplied eco-roof planting medium.
5. Dealer's Supply; supplied Tremdrain for eco-roofs.
6. Mr. Sun Solar; supplied and installed pre-wiring and pre-plumbing for solar PV and hot water systems, supplied and installed equipment for both systems.
7. Willamette Roofing; 50 year galvalume metal roof.
8. Flo-True; supplied roof washers for rainharvest system.
9. Wolcott plumbing and Bear Electric; connected and commissioned radiant floor systems and rainharvest systems.
10. EBS; supplied FSC certified Massaranduba hardwood, wool carpet and denim carpet pad, and Rais gas fireplaces.
11. Parr lumber; supplied formaldehyde-free MDF.
12. Bell Heating; supplied and installed HRV systems.
13. Spray-On Foam and Coatings, Inc.; supplied and installed Durafill foam in demonstration house
14. 5-J's Insulation Service; supplied and installed formaldehyde-free Johns Manville fiberglass insulation.

PROJECT HIGHLIGHTS

INNOVATIVE SUSTAINABLE TECHNOLOGIES AND PRACTICES

1. Speculative houses designed and built as wholly-integrated "green" homes; City density goals met with dense development, yet each house is considerably private while allowing maximum natural light and ventilation. House design and site plan an alternative to "skinny housing" yet designed with similar zoning parameters.
2. Rainwater harvest system captures and recycles 80%-90% of roof-discharged storm water.
3. Eco-roofs over porches provide stormwater management and enhance livability.
4. Radiant hydronic heating with a concrete thermal slab on two levels provides comfortable heat at a cost savings over conventional heating.
5. Whole-house ventilation system with heat recovery promotes occupant comfort and health by providing continuous air circulation and filtration.
6. Demonstration house uses sprayed-in foam insulation that is about twice as air-tight as a fiberglass batt-insulated home.
7. Houses are pre-wired and pre-plumbed for solar PV and hot water systems to make homeowner's choice to install these systems more cost-effective and convenient.
8. Rainscreen design for siding allows for moisture to escape the building envelope before it can do any damage to the wall cavity or create mold-related health problems.
9. Advanced framing of exterior stud walls reduces framing material usage without compromising structural integrity of building.
10. Low/no VOC materials and finishes used in the interior to promote healthy indoor air quality.

PROJECT COSTS

Design Fees	$27,000
Land Acquisition	$110,000
Site Clearing/Deconstruction	$ 0
Site Development	$45,871
Public Improvements	$10,800
Permits	$14,276
System Development Charges	$32,406
Construction Hard Costs	$740,775
Green Technologies	$190,497
Other Costs	$113,529
TOTAL	$1,285,154

PROJECT COST BY MEASURE

Measure: Architectural Design including all green features
Design: $27,000

Measure: Zonal Radiant hydronic systems including concrete slab floors
Materials: $22,625
Associated Labor: $13,420

Measure: HRV System
Equipment: $4,800
Associated Labor:$2,900

Measure: Pre-wire and plumb for solar panels and solar hot water
Associated Labor/Materials: $3,600

Measure: Native landscaping
Materials: $6,644
Equipment: $1,058
Associated Labor: $12,583

Measure: Rainwater Harvesting System and drywell
Materials: $8,986
Associated Labor: $10,160

Measure: Ecoroofs over all porches
Materials: $2,613
Associated Labor $4,682

Measure: Porous paver drive and walkways
Materials: $4,527
Associated Labor: $2,000

Measure: Low Flow toilets and shower heads
Materials: $1,200

Measure: 50yr recyclable metal roof
Materials: $5,000
Associated Labor: $8,200

Measure: Durafill spray in foam insulation in one house
Materials/Labor: $5,000

Measure: John Manville formaldehyde free fiberglass insulation 3 homes
Materials/Labor: $6,700

Measure: Fir cabinet systems w/wheat board interiors
Materials: $18,135
Associated Labor: $6,000

Measure: Pre finished bamboo flooring and stairs
Materials: $11,700
Associated Labor: $14,000

Measure: 100% wool carpet and denim pad
Materials: $10,453
Associated Labor: $3,511

Financial Savings and Benefits

Energy:

Hard Cost Savings and/or Cost Tradeoffs (per 4911 N Kerby):

Thermal Envelope (Durafill insulation)	$5,000
Radiant Hydronic Floor System	$9,011
Solar Hot Water system feeds Domestic Hot Water	$5,100
Solar PV System	$9,200
TOTAL	$28,311

Projected Operational Cost Savings: ~50% annually	$780/yr
Incentives: GIF Grant (builder assistance)	$3,500
Federal Tax Rebates (for Solar Systems)	$2,820
Energy Trust Rebates	$6,660

Water:

Hard Cost Savings and/or Cost Tradeoffs (per house):

Rainwater Harvest System	$4,786
Native landscaping/small yards	$5,071
Low-flow toilets and showerheads	$1,200
TOTAL	$11,057

Projected Operational Cost Savings: ~25% annually	$ -?-
Incentives: GIF Grant	$ -0-

Stormwater:

Hard Cost Savings and/or Cost Tradeoffs (per house):

Rainwater Harvest System/drywell	$4,786
Porous Paver Driveway and Walkway	$1,631
Eco-Roofs over porches	$1,823
TOTAL	$8,190

Projected Operational Cost Savings:	$ -0-
Incentives: GIF Grant	$212

Materials:

Hard Cost Savings and/or Cost Tradeoffs (per house):

HRV System	$1,925
50-year Metal roofing	$3,300
Pre-finished bamboo flooring and stairs	$6,425
Wool carpet and denim pad	$3,491
Wheat-board cabinets	$6,033
TOTAL	$21,174

Projected Operational Cost Savings:	$ -0-
Incentives: GIF Grant	$2,016

Environmental Benefits

Modeled Energy Savings:	-?-
Material Savings:	
Advanced Framing	15%
Projected Annual CO_2 Emissions Savings:	
Solar Hot Water System	1,000 lbs/yr
Projected Annual Water Savings:	25%
Construction Waste Diversion:	
Wood/Cardboard	90%
Metal/Plastic/Glass	80%
Projected Annual Reduced Rainwater Runoff:	100% of site area
Enhanced Habitat	26 new trees

Community Benefits:

New four-house development restored to a neglected, blighted corner an active, viable residential community. Formerly a vacant lot with safety and crime concerns, the new infill project transformed the corner into a showcase of sustainable building practices and appropriate land use. The newly occupied corner provides additional tax revenues to the county, deters criminal activity and improves safety, and with public improvements to the street such as new sidewalks and street trees also improves the livability of the neighborhood.

DESIGN AND CONSTRUCTION:

Speculative houses designed and built as wholly-integrated "green" homes

Pre-design: Goal was to create a radically different, sustainable, speculative infill project. Hours of research went onto figuring out the green features that we hoped to work into the design. Additionally, we consulted with a variety of green building experts and material suppliers to ascertain which building systems and materials we would incorporate into the design.

Design: The concept for the house was to create a single-family, contemporary "loft-style" house that incorporated an open floor plan for flexibility, exposed structure for aesthetics, and large windows to admit light and air. The structure was designed for simplicity, to utilize conventional materials in unique ways, and reduce the amount of materials needed. A lot of thought was given to how the houses relate to each other on the site and assuring privacy.

Construction: The objective was to build a market-rate home that offered exceptional design and a host of integrated green features. Process management and economies of scale in the building of four houses simultaneously helped in the success of completing the project in under seven months. We were less successful in meeting out budget goals, however, we were within a 10% contingency factor. The demand for the type of housing that we built far exceeded the supply and we discovered that the majority of people were attracted to the design overall as opposed to the green features specifically.

As the design/builder I found that my presence at all times during the construction process was critical to the success of the project, especially in an un-built design, as there were multitudes of questions and problems that needed solving.

Operation and Maintenance: The objective on the user end was to create a home that is virtually hands-free most of the time. We employed finishes and materials on the exterior that showed durability and low-maintenance characteristics. The mechanical systems are designed to be simple and easy to operate without constant adjustments to settings. Passive

solar heating and passive cooling are easily controlled by the occupants and require no maintenance.

Radiant Hydronic Heating with Thermal Slab

Pre-design: The objective in specifying a radiant hydronic in-floor heating system with a concrete thermal slab was to provide even, comfortable heat at a 30-50% energy savings over forced air systems.

Design: Pacific Hydronics (formerly Shelter Products) ran the energy analysis of the homes, designed the radiant system, and specified and supplied all of the components for the installation of the system. The house design required little adjustment to accommodate the system (unlike a forced air system) as the radiant system requires virtually no vertical chases or soffits. The system was designed to be closed-loop with a dedicated hot water heater and therefore non-potable. This facilitated the installation of the radiant loops by a non-licensed plumber.

Construction: Reworks installed PEX radiant loops once for the ground floor slab over R-15 rigid insulation and again for the second level slab over a visqueen vapor barrier. Both slabs were poured in place concrete, exposed. The plumbing contractor installed the valve center and manifolds in the mechanical room and made all of the connections.

Operation and Maintenance: Commissioning the system was a challenge due to the process of purging the lines of entrained air. Once this operation was complete, the system worked smoothly with minimal balancing required to evenly distribute heat throughout the house. The system works on thermostat controlled zone valves that regulate water flow through the lines. The homeowner needs only to set the temperature once during the season to establish a comfort level that is maintained at all times. This setting is usually cooler than a conventional forced air system as the radiant heat is concentrated where it is needed most and maintains a more even temperature throughout the house.

Heat Recovery Ventilation System

Pre-design: The objective in specifying a Heat Recovery Ventilation System was to improve occupant comfort and health, as well as control excess moisture in the home by providing continuous, filtered air exchanges of approximately 50 CFM.

Design: The Venmar HRV unit chosen for the job has a heat recovery efficiency of about 80% . The distribution system for the HRV is similar to a forced air duct system, but smaller and less complicated. Supply air was provided to each bedroom and the main living space. Return air was collected at the top of the stair volume to help aid in stack ventilation.

Construction: The actual implementation of the HRV system became problematic as it was discovered that the space allocated for the unit and the various duct connections was inadequate. After much troubleshooting, an access panel was installed to open one side of the space to allow for access to the unit. Accommodating the ductwork for the system required the creation of vertical chases as it was discovered that the sizing of the ducts was larger than anticipated.

Operation and Maintenance: Once installed, the system works effortlessly. The HRV is operated with a control that allows for various speeds (CFM's), filtration, and humidity settings. The user sets the unit to exchange air continuously at a low CFM for routine operation and adjusts the humidity control to eliminate condensation. The HRV is outfitted with a HEPA filter and a particulate filter to remove any air-borne allergens. These filters require replacement periodically.

Rainwater Harvest System

Pre-design: The objective of the rainwater harvest system is to divert all of the stormwater collected from the main roof of the house away from the City's combined sewer system and instead capture the rainwater for use within the house. This system is estimated

to divert 100% of the stormwater from the roof and through reuse, reduce the demand for municipal potable water by an average of 25% annually.

Design: The rainwater harvest system is simple in design and materials. The primary collection facility, the roof, is made of galvalume sheet metal. Gutters and downspouts collect the runoff and convey the water to an underground cistern. Before reaching the cistern a roof-washer diverts the first 10 gallons of flow as a means to "wash" the roof of any contaminants before the cistern is filled. The cistern has a capacity of 1500 gallons. Overflow is diverted to a drywell located beside the cistern. The cistern is connected to the house where reclaimed water is used to supply toilets and hose bibs. A one-half horsepower pump pressurizes the line and cycles on during a call for water. An in-line water meter measures the amount of water consumed in CUFT. The system is equipped with a sensor that reads when the tank is nearly empty and automatically opens a valve to allow municipal water to replenish the lines.

Construction: The most challenging aspect of installing the rainharvest system is that the system relies on the coordination of numerous trades and the installation takes place over the course of the entire project. This factor alone prevented the system from being fully completed and tested until the project was nearly finished. The trades involved in the creation of the system began with the excavators who excavated the pit in which the cistern and drywell were placed and who ran the underground plumbing that feeds the cistern; the plumbing contractor who installed the supply line from the tank to the house; the General Contractor who chose to install components of the cistern (riser, lid), run underground electrical to supply the float switch, as well as install the float switch, the roof washers, "non-potable" placards, and set the pump; the roofers who installed the standing-seam metal roof; and the gutter contractors who installed the gutters and downspouts.

Operation and Maintenance: The rain harvest system, despite it's many components, is relatively low-maintenance. The roof washers and the gutters are to be checked for debris and cleaned twice a year, and the cistern cleaned annually. The other components require no routine maintenance. The operation of the system is virtually hands free.

Solar Hot Water panels and pre-wiring for Solar Photovoltaic panels

Pre-design: The objective in pre-design was to provide a convenient way for the homeowners to install solar hot water and photovoltaic panels should they opt for the systems. A solar hot water system is rated to save 2,450 kWh/yr. A 2 kW solar photovoltaic system is rated to save 2,555 kWh/yr.

Design: The roof was designed to accommodate a 3 kW photovoltaic system, or a solar hot water system and a 2 kW photovoltaic system. Additional space in the mechanical area inside the house was created for the future installation of the components needed to operate the systems.

Construction: During the rough-in phase of mechanical systems, Mr. Sun Solar, Inc. ran copper piping and electrical wire from the roof to the mechanical room on the ground floor for the future installation of the solar arrays. Pre-wiring and plumbing assured that the systems were properly integrated into the house instead of retroactive installation that incurs the hassle and cost of retrofitting the systems after construction. At the very end of the project the solar hot water panels were craned onto the rooftop and secured to the standing seam roof. In the mechanical area, 80 gallon heat exchangers were set and plumbed to the domestic hot water tank. On one house, a 2 kW photovoltaic array was installed on the roof beside the hot water panels and hardwired to an inverter in the garage that sends the energy generated back to the grid.

Operation and Maintenance: These systems are designed to operate without routine maintenance. Occasionally, the solar collectors should be cleaned of dust and the fittings checked for any sign of leaks. The solar hot water system is closed loop; glycol is used as the medium for collecting heat from the solar panel and then exchanges its heat with the potable water in the heat exchanger. The levels of glycol will require monitoring and occasionally more glycol may be added.

Ecoroofs over front and rear porches

Pre-design: The objective with selecting ecoroofs for the porches was primarily to create awareness of ecoroofs and their application in residential design. The small size of the roofs limited their contribution to dramatic stormwater mitigation (that is handled mostly by the rainharvest system and to a lesser extent porous pavers) but instead gives the occupants a green roof-scape to gaze upon from various vantages in the home and reduces glare or heat gain from conventional roofing materials.

Design: The ecoroofs are designed as planter boxes using the guidelines established by BES and the non-profit Ecoroofs Everywhere. Hose bibs were provided at each roof for the installation of micro drip irrigation systems to help the plants establish roots.

Construction: The box is framed with conventional lumber and crafted to slope from 6" to 9" where at the lowest point there is a drain connected to a downspout. The box is lined with TPO rubber membrane and flashed along its edge. Along the sides that abut the house 1 1/2" drain rock is used to allow rapid drainage and to give an aesthetic boarder to the garden. A Tremdrain 1/2" drain mat with filter fabric was installed on top of the TPO followed by a light-weight soil medium supplied by Pro-Gro. Planted in this soil are sedums and wild strawberry.

Operation and Maintenance: The roofs will require watering during the dry months. A drip irrigation system on a timer will facilitate this requirement. The roofs will also require occasional weeding until the plants have grown to cover the entire surface. Watering needs will diminish over time as the drought-tolerant plants establish roots.

LESSONS LEARNED

Green building is not mainstream and not a major factor in homebuyers criterias or desires for purchasing, but we are educating people. Whereas all four homebuyers of the Kerby Street project had little or no exposure to green building each opted for the solar hot water system after learning of the environmental and long-term cost benefits.

Structural Insulated Panels were initially specified as the wall/thermal envelope for the houses, but after much research it was decided that SIPS were too complicated to coordinate into the construction process due to prohibitive material and labor costs, the lack of subcontractors who have experience and familiarity with the product or it's installation, and risks involving lead times and production challenges with out of state manufacturing facilities.

This project demonstrated that costs for installing green features is more expensive but I feel there are ways to mitigate increases in cost with long-term savings and more integration into the course of construction process. Whole house design strategies such as passive solar heating and passive cooling, access to natural light for living and working, improved building thermal envelope design (including advanced framing, spray-in foam insulation, high efficiency windows), rainscreens, and siting of the structure on the property to fully benefit from prevailing breezes and solar gain are relatively inexpensive ways to improve building performance. Mechanical systems such as the radiant floors, HRV, and rainwater harvest system proved to be costly in the short term as the subcontractors who installed them had little knowledge of the systems and their operation, hence labor was much more that expected.

Green Features that we would use again of recommend to other builders:

The advantages of spray-in foam seem to be increased thermal performance as tested air infiltration was nearly half that of a house insulated with fiberglass batts. The downside is the high cost of foam as compared to fiberglass.

Rainscreen under siding

Advanced framing and TJI floor and roof systems

Radiant floors (as long as tubes run in a concrete slab. Wall blowers don't heat as well.)

Rainwater harvesting (would be more cost efficient if reclaimed water could be used for washing machines or even potable uses). System is redundant since the required drywell is sized to handle all of the stormwater volume. This project featured one of the first wholly integrated, permitted residential rainharvest systems (per Senior Plumbing Inspector).

HRV system, as long as its designed to properly function within the space. One drawback is the redundant ductwork system that isn't shared with heating or A/C.

Porous paver driveway and walkway. Material is durable and maintains appearance. Works well to allow infiltration of stormwater. Can be less expensive than concrete as a surface.

Ecoroofs. Additional cost is worth the return on appearance and performance.

IMAGES AND GRAPHICS

See addendum

Final Report

GIF Project M&V Plan and Report: Kerby Avenue Homes

Prepared for:
Portland Office of Sustainable Development

April 18, 2007

quantec *Raising the bar in analytics™*

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Executive Summary

The Kerby Avenue homes project in North Portland was developed by Reworks, Inc., and received support from the Office of Sustainable Development (OSD) Green Investment Fund (GIF) in 2005. The project includes four residential units; each unit features 3 bedrooms and 2 baths and occupies approximately 1,865 sq. ft. This monitoring and verification report (M&V) focuses on energy usage at the site, water usage, and the effectiveness of on-site cisterns to capture rainwater.

The homes feature a number of elements designed to reduce natural resource consumption. These include a 1,500 gallon rainwater collection system, and other on-site water absorption amenities such as planters and porous pavers. Each home was built with two small ecoroofs; passive cooling with cross- and stack-ventilation; passive heating through solar gain and thermal mass in combination with a radiant hydronic heating system installed in the floor; low-VOC paint and sustainably harvested bamboo floors; and an 80% efficiency heat recovery ventilator and 80% efficiency filtration system. The units are also built with wiring and plumbing to support installation of photovoltaic panels (PVs) and solar water heaters. The final installation decision was left to the home owners; one owner installed a PV system and all opted for solar water heating.

An energy analysis was completed with the development of a detailed eQUEST model for one of the Kerby Avenue homes using architectural drawings. Portland State University provided assistance in developing the initial model. Quantec modified the initial model and calibrated it using billing data collected over one year to produce yearly consumption estimates (heating, lighting, etc.) consistent with the billing data. The next step was creating the counterfactual version of the calibrated model by using building characteristics based on the Oregon Energy Code. The final step was comparing the outputs of the two models to determine the specific end-use savings and global savings attributable to the homes as built. The energy analysis also included blower door testing and infrared monitoring.

Table 1 provides the checklist used for the site inspection and includes a detailed overview of the energy saving measures and other features of the project. Some of the exterior measures in the project include a rainwater collection system, which will recirculate rainwater for use in toilets and on-site irrigation, and two small ecoroofs for each unit. The majority of the building envelope was completed as designed. One change from the building design is found in the wall materials. The original plan called for structural insulated panels (SIPs) for each of the walls. In the end, the units were not completed with SIPs, but rather with more standard materials. This change resulted from higher than anticipated materials costs and a shortage of local expertise.

In addition to energy use, this report reviews the design concepts and impacts related to water consumption and stormwater treatment. In terms of water consumption, all appliances and fixtures were reviewed. Two appliances were found to be more efficient than required by current standards, the clothes washers and dishwashers.

Table 1 Checklist for Site Visit

Measure	Installed?	Comments
Exterior		
1500 ga.l rainwater harvesting system	Yes	
Ecoroofs over porches	Yes	Two small ecoroofs on each home
Recyclable standing-seam metal roof	Yes	50-year Galvalume metal roof
Fiber cement board siding with rainscreen	Yes	
Flo-true roof washer	Yes	
Landscape swales	Yes	
Porous pavers	Yes	
Landscape planters	Yes	
Landscaping with native plants and trees	Yes	Plant list was received; plants are native or thrive in local area
Sunshades on south and west windows	Yes	Only minimal blockage of the sun is due to sunshades
Building Envelope		
SIP walls; recycled cotton insulation in roof	No	Advanced wood framing with fiberglass in three homes; Durafill spray-in urethane foam in fourth home
Concrete slab on first floor	Yes	
One or two upstairs bedrooms - wall can be removed or inserted	No	There are two bedrooms upstairs and one bedroom downstairs. The walls are not removable though.
Third bedroom downstairs can be expanded into garage	No	
Daylighting in every room (windows and/or skylights)	Yes	Large windows in every room
Pre-finished bamboo stair and bathroom floors	Yes	
Passive cooling with cross- and stack-ventilation	Yes	
Low VOC and allergen-free materials and finishes used throughout interior	Yes	Reworks stated that paint was low-VOC Benjamin Moore and floors were finished with Euco AquaCure acrylic.
Passive heating through solar gain and thermal mass	Yes	Concrete slab confirmed on the first floor
Up to 50% fly ash in concrete foundation and floors	Yes	The concrete has 25% fly ash.
Other		
80% efficiency heat recovery ventilator	Yes	Venmar Heat Recovery Ventilator
80% efficiency filtration system	Yes	Venmar Heat Recovery Ventilator
Radiant hydronic heating system with concrete slab	Yes	
Low-flow showerheads	Yes	Masco - 2.5 gpm; meets current standard
Low-flow toilets	Yes	Kohler - 1.6 gpf; meets current standard
Water-efficient washing machines & dish washers	Yes	Verified with Reworks that homeowner installed
Prewiring & plumbing for installation of solar electric and hot water heating panels	Yes	
Solar water heater	-	Homeowners and Reworks are working together on this installation. All four homeowners are installing.
Solar photovoltaic (PV) panels	-	Homeowners and Reworks are working together on this installation. One homeowner installed.

Assessment of the stormwater collection system included a site inspection and review of the ecoroofs and stormwater systems. Our analysis included the storage rates and efficiency levels of the cistern system and estimation of the ecoroof runoff retention rates.

This report provides detailed information on the energy savings, water savings and reduced stormwater run-off resulting from the various design and measure installation for the Kerby Avenue homes. In order to analyze the performance of the homes, electric, gas and water billing information was collected following the first year of occupancy.

In terms of energy savings, the combined list of measures reduced electric consumption by 18.5% and reduced gas consumption by 13.5%. The largest single element contributing to these savings was the hydronic floor heating systems. Energy savings are summarized in Table 2.

Table 2 Reduced Gas and Electric Consumption

Installed Measure	Total House Percent Savings in Btu (Gas)	Total House Percent Savings in kWh (Electric)
Windows (U 0.36)	0.3%	0.1%
Hydronic Floor Heating	8.2%	13.5%
Infiltration Rate 1 (0.30 ACH)	1.5%	1.7%
nfiltration Rate 2 (0.18 ACH)	3.5%	3.6%
Solar Water Heating	4.5%	0%
ENERGY STAR Appliances	0%	5%
Total As-Built Model	13.5%	18.5%

Additional savings were observed for the home with an installed PV unit. In this case, the annual electric bill savings compared to the average consumption of the homes without PVs was observed to be roughly 34%.

Reduced water consumption resulted from the installation of more efficient home appliances. Specifically, the Kerby Avenue homes were outfitted with high efficiency clothes washing machines and dishwashers. Total water savings were observed to be 9,950 gallons over the course of the year, or an average of 2,488 per home, as shown in Table 3. The total water savings ranged from 4% to nearly 15% of total water consumption for individual homes.

Table 3 Water Savings (gallons/year)

House	Appliance	Annual Water Savings, gal/year
1	Clothes washer: Fisher and Paykel Ecosmart GWL11	1,512
	Dishwasher: JennAir JDB1100AWS	209
2	Clothes washer: Maytag MAH2400	760
	Dishwasher: Frigidaire GLD2250RDC	209
3	Clothes washer: Kenmore 80 series	2,148*
	Dishwasher: Kenmore Elite 16289	417*
4	Clothes washer: LG WM1812CW	4,174
	Dishwasher: Frigidaire GLD2250RDC	521

Finally, the performance of the homes with respect to stormwater runoff reduction is notable. The estimated reduction in stormwater runoff for the four homes through use of the project cisterns, ecoroofs, and permeable pavers, is 6,500 ft^3 per year or an average annual reduction in stormwater runoff of about 40 percent. According to the project design, captured rainwater is used in the toilets and exterior hoses. Each of the rainwater harvesting systems was metered and monthly use of rainwater during 2006 was derived from data provided by the project builder. Rainwater usage ranged from 950 gallons (in March) to 2,400 gallons (in August). Each of the homes also has a drywell to infiltrate stormwater runoff that is not retained in the cisterns or ecoroofs. Due to the additional storage capacity of the dry well it is probably the case that only very large storms result in any stormwater runoff from the project site.

As detailed in the report, the Kerby Avenue homes' green features and installed efficiency appliances are functioning as expected. The result is four residential units with exemplary attributes for the conservation of electricity, gas, and water.

1. Project Description

General Project Characteristics

Reworks, Inc., the developer for this project, was established in 1999 as a development and design/build company incorporating innovative, healthy design with sustainable practices for constructing new buildings and renovating existing buildings. Reworks expressed their interest in experimenting with new, "green" materials and systems that reduce material consumption, incorporate recycling, and create highly energy-efficient buildings. Aaron Blake is the President of Reworks, Inc.; his wife, Christina Davis, is the Vice-President and Business Manager.

The project consists of four 3-bedroom, 2-bath homes, each 1,865 sq.ft., adjacent to each other in North Portland. The construction of all four homes is similar, though there are some differences in the green features incorporated in each.

This project was originally proposed to be completed in November 2005. It was actually completed in December 2005, and the owners took possession on December 8th of that year. Figure 1 shows three of the four units.

Figure 1. Finished Units

Proposed Green Features

The green features and practices that were originally proposed for the units in this project are listed in Table 4. Major green features originally proposed included the use of a cistern to capture rainwater for toilet flushing and irrigation, construction with structural insulated panels (SIPs), passive cooling with heat recovery ventilation, solar water heaters, and photovoltaic (PV) panels. A few of the features were dependent on decisions made by the buyers. All buyers elected to select solar water heating, for example, but only one chose to have a 2 kW PV system installed (though pre-wiring was provided for possible future installation in all units). Occupants also could select the type of washing machines that were installed.

As Table 4 shows, the developers planned to install some metering equipment and conduct tests to verify the performance of the buildings. Performance tests planned included blower door tests to measure air leakage, and infrared scanning to review the thermal performance of the construction and insulation.

Table 4. Green Features and Practices Initially Proposed

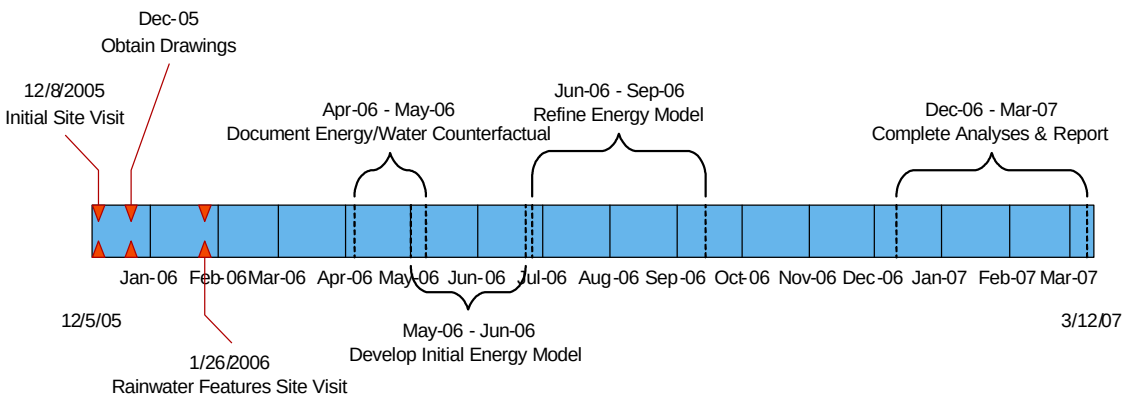
Exterior
Under-driveway 1500 gal. rainwater harvesting system for use in toilets and exterior hose bibs + meter (expandable to whole house in future)
Ecoroofs over porches
Recyclable standing-seam metal roof
Fiber cement board siding with rainscreen
Flo-true roof washer
Landscape swales
Porous pavers
Landscape planters
Landscaping with native plants and trees
Sunshades on south and west windows
Building Envelope
Structural Insulated Panels (SIPs) - (Expanded Polystyrene, EPS) core with 2 OSB outer shells
Concrete slab on first floor
Recycled cotton insulation
One or two upstairs bedrooms - wall can be removed or inserted
Third bedroom downstairs can be expanded into garage
Daylighting in every room (windows and/or skylights)
Pre-finished bamboo stair and bathroom floors
Passive cooling with cross- and stack-ventilation strategies
Low VOC and allergen-free materials and finishes used throughout interior
Passive heating through solar gain and thermal mass
Up to 50% fly ash in concrete foundation and floors
Other
80% efficiency heat recovery ventilator
80% efficiency filtration system
Radiant hydronic heating system with concrete slab
Low-flow showerheads
Low-flow toilets
Water-efficient washing machines
Prewiring & plumbing for installation of solar electric and hot water heating panels
Solar water heater
Solar photovoltaic (PV) panels
Metering / Measurements
Meter to measure kilowatt-hours of energy generated by PVs per month
Meter on rainwater supply to household
Infrared imaging to measure thermal insulation quality
Blower door testing to measure air infiltration
Monitor wood recycling weights to compare jobsite waste to Metro's average

M&V Scope and Schedule

In accordance with the priorities identified by the Office of Sustainable Development (OSD), the monitoring and verification (M&V) focus was on energy use, municipal water use, and cistern performance. Quantec, Portland State University, and Geosyntec performed the M&V for this project. Quantec focused on the review of the green features installed and contributed to the energy analysis and municipal water use analysis. PSU contributed to the energy analysis. Geosyntec had the lead for the analysis of the cistern performance and contributed to the municipal water use analysis.

Our schedule for M&V activities is shown in **Error! Not a valid bookmark self-reference.**.

Figure 2. M&V Schedule



2. Verified Green Features

Quantec, Portland State, and Geosyntec scheduled and performed a detailed site visit to verify that the green measures were incorporated into the housing units. As shown in the checklist in Table 5, we reviewed the measures listed in Table 4 to verify that they were present and properly installed.

Since the PV panels and solar water heater panels were being installed by the homeowners, Reworks indicated they would provide the necessary pre-wiring and plumbing for these systems. Quantec verified that the necessary equipment and wiring were in fact installed and that the homeowner could then easily integrate solar panels into the homes. After the homeowners had moved in, Quantec verified that one homeowner had installed PV panels, and that all had installed solar water heater panels.

For measures that involved the use of recycled material or environmentally-friendly products (e.g., low VOC paint), the measures were visually verified when possible. In other cases Reworks provided documentation or confirmed the use of the material or product.

One major change from the initial plans was the use of standard 2”x 6” studs, 24” o.c. framing and conventional insulation for wall construction instead of structural insulated panels (SIPs). This change in the plans was made because of the high cost of SIPs, lack of local contractors familiar with the technology, and concerns about the risk of working with out-of-state manufacturers. A related change was the switch in three of the houses from recycled cotton insulation to fiberglass in the attic, along with the use of fiberglass in the walls in place of SIPs. The fiberglass insulation used was formaldehyde-free. The fourth house used spray-in urethane Durafill open-cell spray-in foam instead of fiberglass for insulation.

Table 5. Checklist for Site Visit

Measure	Installed?	Comments
Exterior		
1500 ga.l rainwater harvesting system	Yes	
Ecoroofs over porches	Yes	Two small ecoroofs on each home
Recyclable standing-seam metal roof	Yes	50-year Galvalume metal roof
Fiber cement board siding with rainscreen	Yes	
Flo-true roof washer	Yes	
Landscape swales	Yes	
Porous pavers	Yes	
Landscape planters	Yes	
Landscaping with native plants and trees	Yes	Plant list was received; plants are native or thrive in local area
Sunshades on south and west windows	Yes	Only minimal blockage of the sun is due to sunshades
Building Envelope		
SIP walls; recycled cotton insulation in roof	No	Advanced wood framing with fiberglass in three homes; Durafill spray-in urethane foam in fourth home
Concrete slab on first floor	Yes	
One or two upstairs bedrooms - wall can be removed or inserted	No	There are two bedrooms upstairs and one bedroom downstairs. The walls are not removable though.
Third bedroom downstairs can be expanded into garage	No	
Daylighting in every room (windows and/or skylights)	Yes	Large windows in every room
Pre-finished bamboo stair and bathroom floors	Yes	
Passive cooling with cross- and stack-ventilation	Yes	
Low VOC and allergen-free materials and finishes used throughout interior	Yes	Reworks stated that paint was low-VOC Benjamin Moore and floors were finished with Euco AquaCure acrylic.
Passive heating through solar gain and thermal mass	Yes	Concrete slab confirmed on the first floor
Up to 50% fly ash in concrete foundation and floors	Yes	The concrete has 25% fly ash.
Other		
80% efficiency heat recovery ventilator	Yes	Venmar Heat Recovery Ventilator
80% efficiency filtration system	Yes	Venmar Heat Recovery Ventilator
Radiant hydronic heating system with concrete slab	Yes	
Low-flow showerheads	Yes	Masco - 2.5 gpm; meets current standard
Low-flow toilets	Yes	Kohler - 1.6 gpf; meets current standard
Water-efficient washing machines & dish washers	Yes	Verified with Reworks that homeowner installed
Prewiring & plumbing for installation of solar electric and hot water heating panels	Yes	
Solar water heater	-	Homeowners and Reworks are working together on this installation. All four homeowners installed.
Solar photovoltaic panels	-	Homeowners and Reworks are working together on this installation. One homeowner installed.

3. Energy M&V

Project and Counterfactual Characteristics

This project consisted of four homes with equal floor areas and similar floor plans and construction details. The primary goal was to create a typical model of one of the 3-story buildings and simulate the energy consumption of that building. Table 6 compares the energy-efficiency measures of the homes if they had been built to the Oregon code using conventional practice (the "counterfactual") with the measures as built.

Table 6. Comparison of Energy-efficiency Measures

Measure	Code Requirement (Counterfactual)	Project As-Built
Windows	U-value 0.40 (OR Code)	U-value 0.36
Wall Insulation	R-21 (OR Code)	R-21
Floor Insulation	R-25 (OR Code)	R-25
Ceiling Insulation	R-38 (OR Code)	R-38
Space Heating	Gas Furnace	Hydronic Floor Heating
Infiltration	0.40 ACH	0.30 and 0.18 ACH[1]
Solar Water Heating	None	Installed
Solar Electric (PV) System	None	2 kW PV System[2]
Energy Recovery Ventilator (ERV)	None	Installed
Appliances	Standard	ENERGY STAR Appliances

Our energy modeling approach is discussed next. When we analyzed the homes, it was not possible to model all the energy efficiency measures.

Analysis Approach

Our energy analysis approach started with the development of a detailed eQUEST model for one of the Kerby Avenue homes using architectural drawings. Portland State University provided assistance in developing this initial model. The next step was calibration of the model using billing data collected over one year to produce yearly consumption estimates (heating, lighting, etc.) consistent with the billing data. The third step was creating the counterfactual version of the calibrated model by using building characteristics based on the Oregon Energy Code. The final step was comparing the outputs of the two models to determine the specific end-use savings and global savings attributable to the homes as built.

The special features of these homes required unique analyses and provided useful insights into the energy-usage performance. For solar water heating, we were able to use the billing data to approximate the contribution of this system in each house. Energy generation data were available

[1] Earth Advantage blower door test results on two homes, one with standard batt wall insulation (0.30 ACH) and the other unit with spray-in Urethane insulation (0.18 ACH).

[2] PV system installed on only one home.

for the one home that had a solar electric (PV) system installed, so we were able to determine the contribution of the system. One home had spray-in insulation, which was shown with blower door testing to reduce the natural infiltration rate significantly. The limited scope of this study did not permit detailed analyses of all these unique features, but we were able to extract a considerable amount of useful information from the data available.

Description of Simulation Model and Other Analysis Tools

Energy Simulation Model

eQUEST is a public domain model supported as a part of the Energy Design Resources Program, which is funded by California utility customers and administered by Pacific Gas and Electric Company, San Diego Gas & Electric, and Southern California Edison, under the auspices of the California Public Utilities Commission.

eQUEST's calculation engine is the well-known DOE-2 model. DOE-2 is also in the public domain and is the most widely used and accepted building energy analysis program in the U.S. DOE-2 relies on building profile data, including building layouts, construction characteristics, energy usage behavior, conditioning systems (lighting, HVAC, etc.), and weather data to perform an hourly simulation of the building and to estimate energy consumption. In eQUEST, the energy-efficiency measure wizard allows users to explore various measure configurations while accounting for measure interaction effects.

Blower Door Testing

This test was planned as a way to determine the natural air leakage of these homes. It was proposed by the developer and was not a requirement of the M&V effort. This information is important in determining the energy consumption of the homes for heating and cooling and is a factor in the indoor air quality and longevity of the structure.

The test involves assembling a temporary frame in an exterior door, installing a large powerful fan and depressurizing the interior volume of the home. From the pressure difference between indoors and outdoors, the pressure at the fan opening, and the airflow rate through the fan, it is possible to calculate the overall air tightness of the home in terms of the natural air changes per hour (ACH). The tests were scheduled to be conducted on two homes by an Earth Advantage Technical Specialist. One home was insulated with conventional fiberglass insulation and the other had the spray-in urethane insulation.

Infrared Monitoring

The developer intended to conduct infrared monitoring of two homes, one with conventional insulation and the one with spray-in urethane. The purpose was to visually display the temperature profiles of the homes to identify variations in heat flux within each home and identify differences between the two homes monitored. These tests were not required as part of the scope of Quantec's M&V activities.

The developer conducted a search to identify a firm to perform the infrared scanning. After being unable to locate a contractor to do these tests, Quantec assisted with the search and was able to locate a company in Portland named MixZon, that had infrared scanning capabilities and was willing to conduct the tests at no charge.

Key Energy Analysis Inputs, Assumptions, and Data

After the homeowners occupied their home for one year, Quantec requested a year's worth of utility billing data. Electric, gas and water billing data were collected from each unit. The energy billing data, electric and gas, were used to calibrate the eQUEST model according to the actual energy use of the home.

When reviewing the electric and gas billing data, it became apparent that one household had a significant increase in their annual energy usage compared to the other homes. The gas bills were three times higher in summer compared to the others, but comparable during the other seasons. After further investigation, the homeowner stated that the heating system was not turned off during the summer months.[3] Therefore, the hydronic heating system still operated during the cooler summer days and nights. In light of this information, we calibrated our model to the averaged billing data of three of the four homes, excluding the home with summer heating.

Additional data were collected from one unit that had installed a 2 kW photovoltaic (PV) array. The PV data were not able to be incorporated into the eQUEST model directly, but they provided a direct measure of the amount of utility supplied power offset by this system.

Project Model Development

Our team developed an eQUEST model of one of the Kerby Avenue homes. The inputs to the model were taken primarily from information provided by the architectural drawings supplied by Reworks. When no information was given, the Oregon Energy Code was used. All possible measures were included in the model when possible to represent the as-built building model.

Quantec collected the electric, natural gas, and water billing data for each home. As noted above, we used the energy billing data to calibrate the eQUEST model to produce approximately the same energy use as the average billing data. Once the model was calibrated, a baseline building model was created by extracting the energy-efficiency measures from the as-built model and rerunning eQUEST on the revised building design. The difference between the baseline and the as-built models represents the net energy savings for the modeled building.

Envelope Model Design

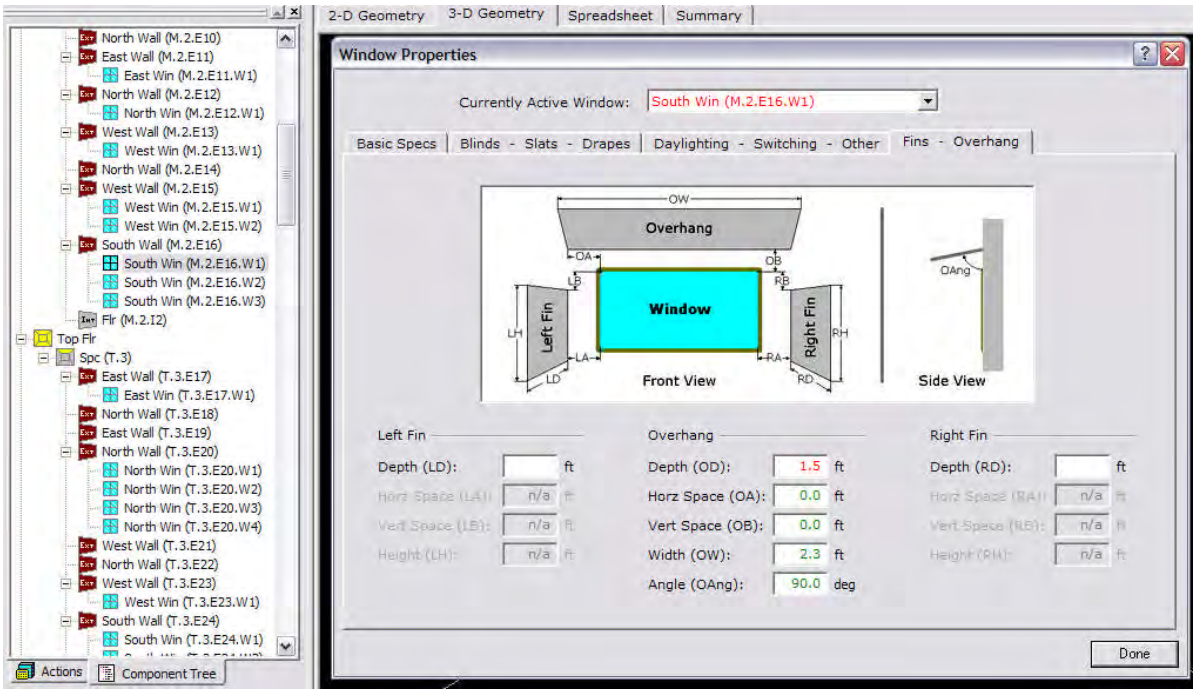
The eQUEST Schematic Design Wizard mode was used to input the basic design data. Multi-family low rise building type (exterior entries) was selected among the alternatives, since it is

[3] The homeowners were informed initially that the heating system should be turned off during the summer and the other owners did follow this practice.

closest to the detached single family building type. Building drawings were converted from a pdf document to Auto-cad and vertices were traced out into the eQUEST model. The total building area was calculated from total space including garage and divided evenly among the floors. U-value inputs of structures and fenestrations in the model were to building code standard unless and otherwise noted in the Kerby Avenue documentation.

After creating the building footprint and zoning, the building envelope parameters and building load data were entered. Then eQUEST's Detail Design mode was used to refine the input data and add additional features such as window overhangs. Figure 3 shows eQUEST's input display of the window overhang properties and building component tree.

Figure 3: eQUEST Detail Design mode



The following exterior design assumptions were made:

- Flat roof is considered instead of a ridged roof.
- Ground level walls were treated as fully above grade exterior walls instead of partial below-grade walls.
- Roof sky-lit area was not considered since it was less than 1% of total roof area.

The resulting envelope design is shown in Figure 4.

Counterfactual vs. As-Built

Once the basic envelope design was completed, the energy-efficiency measures were designed into the model. eQUEST cannot represent all the special technologies, such as hydronic heating, solar water heating, PV, or this building's particular ERV system. However, it was possible to

design assumptions into the model that best fit and represented most of these technologies. With the exception of the ERV system, all the stated technologies were incorporated into the eQUEST model. Table 7 presents the energy-efficiency measures that were designed in the as-built model.

Figure 4: eQUEST exterior view of Kerby Ave. model

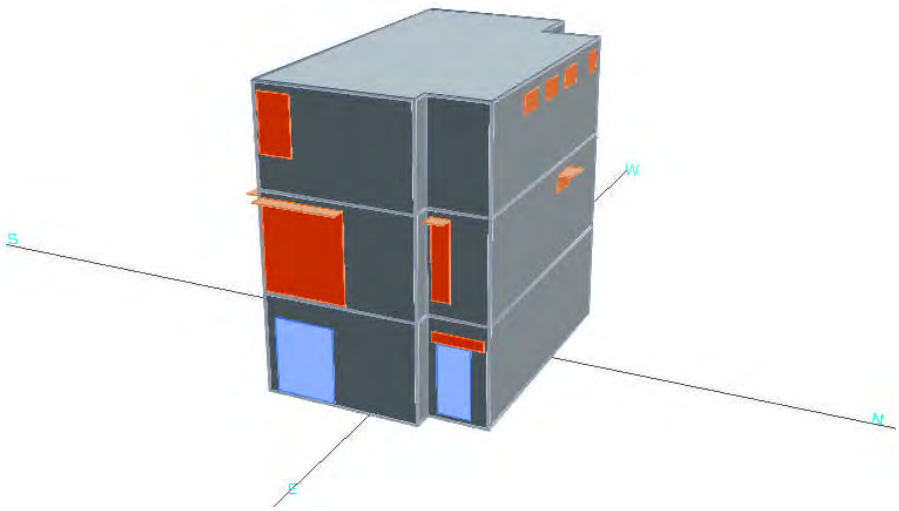


Table 7. eQUEST Model Inputs, Energy-efficiency Measures

Measure	Code Requirement (Counterfactual)	Project As-Built
Windows	U-value 0.40 (OR Code)	U-value 0.36
Space Heating	Gas Furnace	Hydronic Floor Heating
Infiltration Rate 1	0.40 ACH	0.30 ACH
Infiltration Rate 2	0.40 ACH	0.18 ACH
Solar Water Heating	None	Installed
Appliances	Standard	ENERGY STAR Appliances[4]

Results

Air Infiltration

Two of the project homes were tested using the blower door. One was insulated with conventional fiberglass insulation. The second one had Durafill sprayed-in urethane insulation, which the manufacturer claimed reduces air infiltration.

[4] ENERGY STAR appliances, entertainment systems, and office equipment were assumed to have 10% savings over the standard.

The home with fiberglass insulation was measured to have an infiltration rate of 6.1 air changes per hour (ACH) at 50 Pascals (Pa) of pressure.[5] This was converted to 0.30 ACH as the natural infiltration rate. The technician noted that he observed air leakage from around the wood stove flue pipe, the kitchen vent (the outside damper was not staying closed), and the big door in the great room. Minimal air leakage was noted around the windows.

For the home with Durafill insulation, the results were 3.5 ACH at 50 Pa and an estimated natural infiltration rate of 0.18 ACH. Thus, the measured infiltration rate was about 40% less than in the home with fiberglass insulation. The same leakage areas were noted in this dwelling with the exception of the kitchen exhaust vent.

The consequence of a lower infiltration rate is reduced energy consumption for space heating and cooling. This factor is included in most building energy simulation analyses. In addition, occupants of a house with less infiltration are likely to be more comfortable because of reduced drafts. However, less infiltration of outside air can aggravate internal air quality problems if sources are present in a building. The Oregon code does not have a specific infiltration requirement, but specifies infiltration control measures and practices instead. Based on the literature, these requirements should typically produce a natural infiltration rate of approximately 0.4 ACH.

Infrared Monitoring

The infrared scans were scheduled for January 9, 2007, to be conducted by Mr. Robert Doneker and his team from MixZon.[6] The first scans were attended by Quantec and representatives from OSD and the Energy Trust of Oregon. This scan encountered technical problems and the tests were repeated subsequently by the MixZon team alone.

Their equipment consisted of infrared and conventional video cameras mounted on a boom that can be raised to scan at various heights. Their equipment was originally designed for scanning effluent plumes, but was adapted for this application. A photo is shown in Figure 5.

One home with conventional insulation, as well as the home with spray-in urethane, were scanned on a day when the ambient temperature was at or below freezing. Two illustrative scans are shown in Figure 6 and Figure 7.

These scans show the top story of the two homes from the east-facing front. In both figures, the image on the left is a standard video view and the one on the right is the infrared scan showing the temperature profiles, based on the scale shown below the photo. All surfaces at or below freezing (0 ºC) are shown as black.

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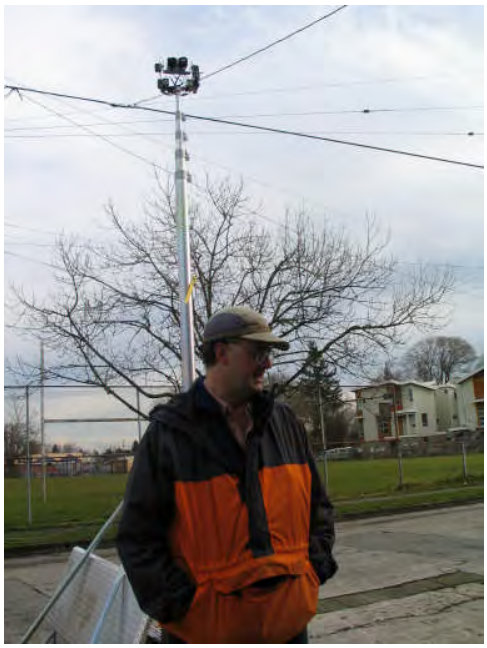
[5] This information was taken from a letter to Reworks from the Earth Advantage technician dated December 6, 2005.

[6] MixZon is located at 1033 SW Yamhill Street, Suite 301, Portland, Oregon 97205. The company's phone number is 503-222-1022 and their website URL is http://www.mixzon.com.

One interesting finding in both scans is the presence of a higher temperature area in the right section of each. This area is covered by cementitious siding open at the bottom and, unlike the area with conventional siding, it has no horizontal wood strips that would prevent vertical airflow under the siding. Consequently, one possible explanation for the higher temperature in this location is that a convection zone is established under the siding, and surface air is heated and rises along the wall under the siding. No further tests were done to verify this. It was not possible to identify any clear differences between the two types of insulation based on the scans.

Figure 5. Infrared Scanner on Boom



Energy Consumption

We used the eQUEST simulations to examine the effect of one energy-efficiency measure at a time. Table 8 shows each installed measure and its associated energy savings as a percent of total, baseline (counterfactual) natural gas and electric energy consumption.

There was little savings associated with the windows in our model, primarily due to the small change in U-value from the code requirement. The hydronic heating system was difficult to model, but we were able to model it based on anticipated savings in electricity due to the absence of a furnace fan and increased efficiency of the distribution system. The infiltration reduction had a noticeable effect on space heating, thereby reducing both natural gas consumption and the baseline furnace electric fan load. The solar water heating produced a 4.5% overall savings in gas consumption and roughly 23% savings in annual water heating (not shown in table). ENERGY STAR appliances, such as a dishwasher, refrigerator, clothes washer, entertainment systems, and office equipment, have an overall electric savings of 5%. The total as-built model savings are less than the sum of the savings from individual measures because of interactive effects, which are accounted for in eQUEST. The infiltration rate used for the total as-built model was 0.30 ACH.

eQUEST output provides energy consumption values for each of the end-uses as shown in Table 9. From the modeling procedure described above, the table is populated with values for the counterfactual and as-built models. Total natural gas savings were 13.5% of the counterfactual consumption and electricity savings, without including the PV system, were 18.5% of the counterfactual amount. It is essential to point out here the importance of operating the hydronic heating system properly during the non-heating system. The billing data revealed significantly higher summer gas consumption in the one house where the system ran during the summer months and these results were not included in our analysis. They emphasize the importance of proper operation of systems with which homeowners may not be familiar.

Figure 6. Scan of Home with Conventional Wall Insulation

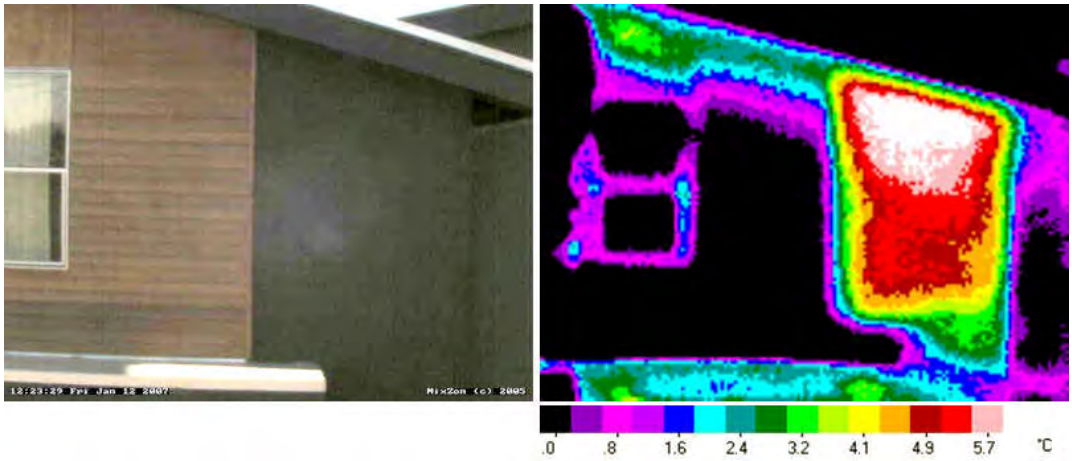


Figure 7. Scan of Home with Spray-in Urethane Insulation

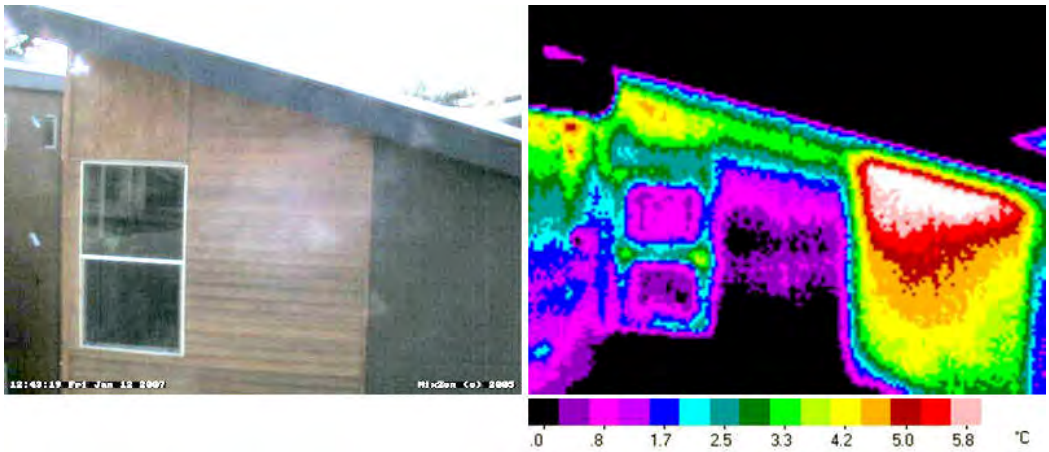


Table 8: House Percent Savings per Measure

Installed Measure	Total House Percent Savings in Btu (Gas)	Total House Percent Savings in kWh (Electric)
Windows (U 0.36)	0.3%	0.1%
Hydronic Floor Heating	8.2%	13.5%
Infiltration Rate 1 (0.30 ACH)	1.5%	1.7%
Infiltration Rate 2 (0.18 ACH)	3.5%	3.6%
Solar Water Heating	4.5%	0%
ENERGY STAR Appliances	0%	5%
Total As-Built Model	13.5%	18.5%

A detailed output of the eQUEST models of monthly energy consumption by end-use can be found in Appendix A:

Table 9. Energy Analysis Results

End Use	Baseline Usage (MBtu/year)	As-Built Usage (MBtu/year)	Energy Savings (MBtu/year)	Energy Savings (% of Total)
Space Heating	81.3	71.8	9.5	12%
Water Heating	18.6	14.6	4	22%
Total Gas	99.9	86.4	13.5	13.5%
End Use	**Baseline Usage (kWh/year)**	**As-Built Usage (kWh/year)**	**Energy Savings (kWh/year)**	**Energy Savings (% of Total)**
Plug Loads and Misc. Equipment	3,909	3,518	391	10%
Total Electric	7,786	6,347	1,439	18.5%

PV Generation

One of the four houses has a 2 kW PV utility-tied system, which includes a solar electric array, inverter, and meter. The most recent data provided by the homeowner was accumulative kWh generated since installation. At the time, the PV system had been installed for roughly 14 months and had produced 2,498 kWh. That equates to an average of 6 kWh/day, with an estimated annual production of 2,170 kWh. This system is performing very well and is typical for an optimality oriented 2 kW PV system in Portland. Using our as-built model of the total electric energy consumed, the potential electric bill savings compared to the average consumption of these homes is roughly 34% annually.

4. Water M&V

Project and Counterfactual Characteristics

We reviewed all the water using fixtures and appliances in these homes to determine which ones exceeded the requirements of the applicable standards. Although all fixtures such as faucets, showers, and toilets were low-flow devices, none were more water efficient than required by the standards.

The two appliances that exceeded the requirements of the standards were the clothes washers and dishwashers. Table 10 shows the appliances in the four homes, the water-efficiency requirement of the standards, and the actual rated efficiency of the appliance.

Table 10. Water Efficient Appliances

House	Appliance	Water Efficiency Standard	Actual Water Efficiency
1	Clothes washer: Fisher and Paykel Ecosmart GWL11	MEF = 1.04 WF = 13 40 Gal/Cycle	MEF = 1.91 WF = 8.5 25.5 Gal/Cycle
	Dishwasher: JennAir JDB1100AWS	EF = 0.46 9 Gal/Cycle	EF = 0.60 5 Gal/Cycle
2	Clothes washer: Maytag MAH2400	MEF = 1.04 WF = 13 27 Gal/Cycle	MEF = 1.78 WF = 0.59 12 Gal/Cycle
	Dishwasher: Frigidaire GLD2250RDC	EF = 0.46 9 Gal/Cycle	EF = 0.60 5 Gal/Cycle
3	Clothes washer: Kenmore 80 series	N/A	N/A
	Dishwasher: Kenmore Elite 16289	EF = 0.46 9 Gal/Cycle	EF = 0.62 5 Gal/Cycle
4	Clothes washer: LG WM1812CW	MEF = 1.04 WF = 13 40 Gal/Cycle	MEF = 1.89 WF = 4.5 13 Gal/Cycle
	Dishwasher: Frigidaire GLD2250RDC	EF = 0.46 9 Gal/Cycle	EF = 0.62 5 Gal/Cycle

Analysis Approach

Given the small number of appliances that exceeded the standards in these homes, the analysis approach was quite straightforward. We worked with Reworks to obtain an estimate from each household on the average number of clothes washer and dishwasher loads per week.

We also obtained the requirements of the standards for these products and the ratings of the appliances actually installed. Water savings were then estimated by multiplying the number of cycles per year of the clothes washer and dishwasher times the difference in the water usage of the installed unit and a unit just meeting the standard.

Reworks also provided the monthly municipal water meter readings and flows of water supplied from the cistern to the household. These data were obtained for the first year of occupancy. This

information allowed us to compare the water savings from these appliances to the total consumption.

Results

The water savings from use of the energy-efficient clothes washers and dishwashers are shown in Table 11. The water savings ranged from about 1,000 to nearly 5,000 gallons per year, or from 4% to nearly 15% of total water consumption (without the efficient appliances).

Table 11. Water Savings

House	Appliance	Loads/Week	Annual Water Savings, gal/year	Total for Both Appliances, gal/year	% of Annual Water Use (without efficient appliance)
1	Clothes washer: Fisher and Paykel Ecosmart GWL11	2	1,512	1,721	4.0%
	Dishwasher: JennAir JDB1100AWS	1	209		
2	Clothes washer: Maytag MAH2400	1	760	968	4.7%
	Dishwasher: Frigidaire GLD2250RDC	1	209		
3	Clothes washer: Kenmore 80 series	2	2,148*	2,566	8.9%
	Dishwasher: Kenmore Elite 16289	2	417*		
4	Clothes washer: LG WM1812CW	3	4,174	4,695	14.7%
	Dishwasher: Frigidaire GLD2250RDC	2.5	521		

*No data were available on these models so we used average savings per cycle from others.

5. Stormwater M&V

Introduction and Purpose

As mentioned above, the Kerby Avenue project included several stormwater treatment and control features intended to reduce and reuse stormwater runoff. This chapter summarizes those stormwater features and provides an evaluation of their effectiveness. The stormwater features included in the project are described in the next section, followed by a brief description of Portland area rainfall. The remaining sections describe the site visit, analysis of cistern and ecoroof performance, assessment of project stormwater runoff reductions, and conclusions regarding the stormwater system performance.

Stormwater Features and Rainfall

Each of the four Kerby Avenue homes included the following stormwater features:

- A 1,500-gallon underground cistern serving the main 1,000 square foot roof area
- Two small ecoroofs on the patio awnings totaling 100 square feet
- 325 square feet of permeable pavers on the walkway and driveway

The four homes occupy lots with a total area of 10,000 square feet. One lot is approximately 3,300 square feet with the three lots on Kerby Avenue occupying just over 2,233 square feet each. As described below, this project would have an effective imperviousness of approximately 56% without the stormwater features incorporated into the project design.

Stormwater monitoring and verification included:

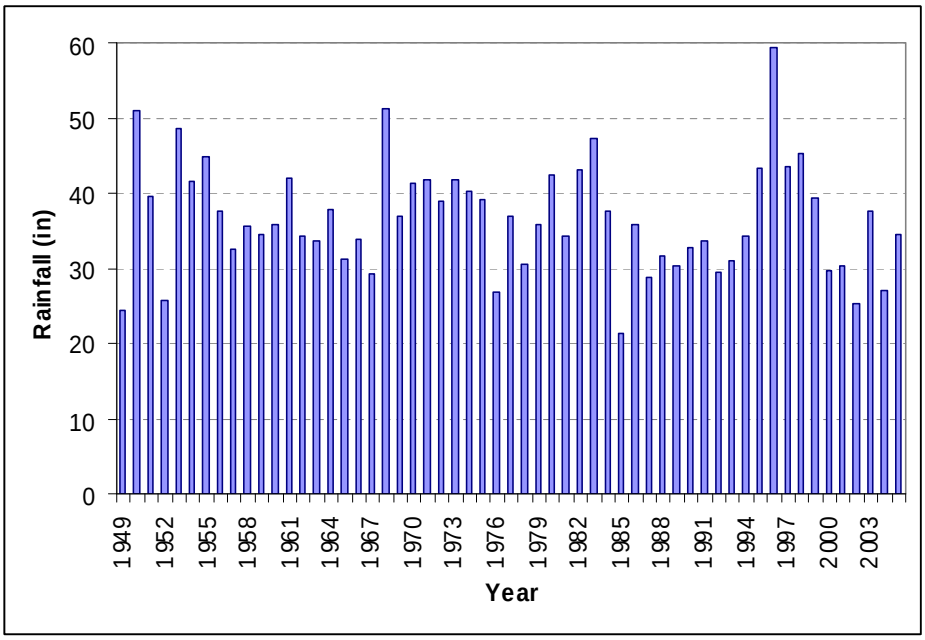
- Site inspection
- Rainwater harvesting system assessment
- Ecoroof assessment
- Reduction in stormwater runoff from the project site

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 rainfall data collected at the Portland International Airport (PDX) from January 1949 through December 2005.

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. Nearly 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 less than 0.08 inches per hour and over 99 percent of the analyzed rainfall data are less than 0.20 inches per hour. Average annual rainfall at PDX for the 56 years of data analyzed was 36.6 inches with a standard deviation of 7.3 inches. Figure 8 displays the annual rainfall totals used in the analysis; Figure 9 shows the temporal distribution of Portland rainfall.

Figure 8. Portland Yearly Rainfall Totals (PDX Rain Gage)



Site Inspection

A site inspection of the project (Figure 10) was conducted in the afternoon of January 28, 2006. Light to moderate rainfall occurred during the inspection of the structural stormwater controls, ecoroofs, and permeable paver driveways.

The permeable paver driveways (Photo 3) appeared to infiltrate all rainfall during the site visit and showed no signs of surface runoff. The ecoroofs (Photos 4 and 5) had a small trickle of flow down the drainage chain (Photo 6) during the visit. Appreciable rainfall occurred the morning of the site visit, which wetted and likely saturated the ecoroofs. The amount of water trickling down the drainage chain from the ecoroofs appeared to be less than the amount of rain falling on the ecoroofs. All four driveways and all eight ecoroofs of the Kerby Avenue homes appeared well-constructed and functioning properly as of the site inspection.

Figure 9. Portland Average Monthly Rainfall

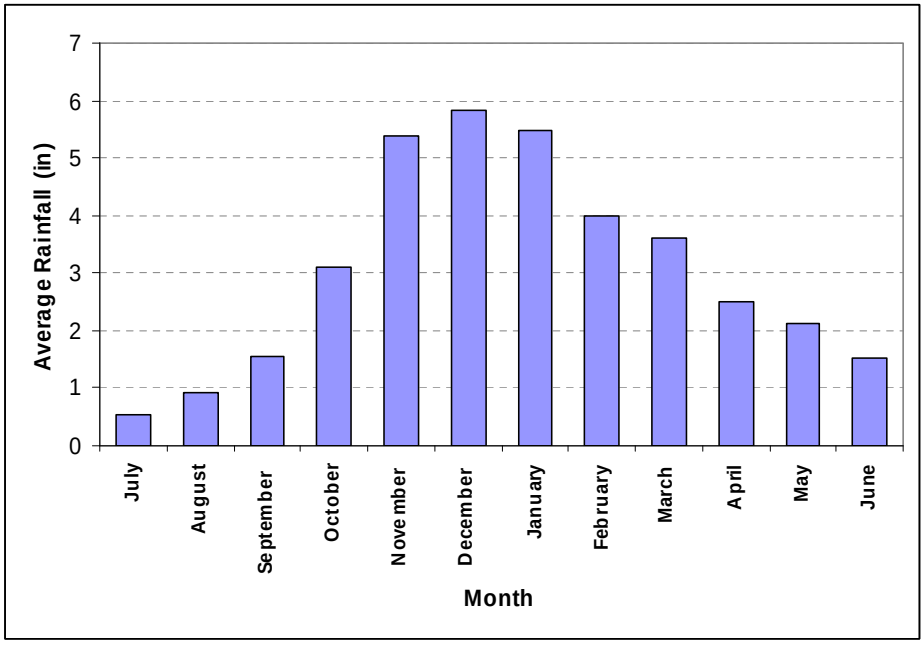


Figure 10. Stormwater M&V Inspection

Photo 1: Kerby Avenue Homes

Photo 2: Homes 3 and 4

Photo 3: Home 3 Permeable Paver Driveway

Photo 4: Home 2 Ecoroof

Photo 5: Typical Ecoroofs

Photo 6: Ecoroof & Drainage Chain

Rainwater Harvesting System Assessment

Each of the Kerby Avenue homes has a 1,500-gallon rainwater-harvesting system that collects rooftop runoff for use in the toilets and exterior hoses after the first 10 gallons of runoff is diverted to the storm drain (Photo 6). Each of these rainwater harvesting systems is metered, and monthly use of rainwater during 2006 derived from data provided by the project builder is shown in Table 12.

Table 12. Monthly Rainwater Use

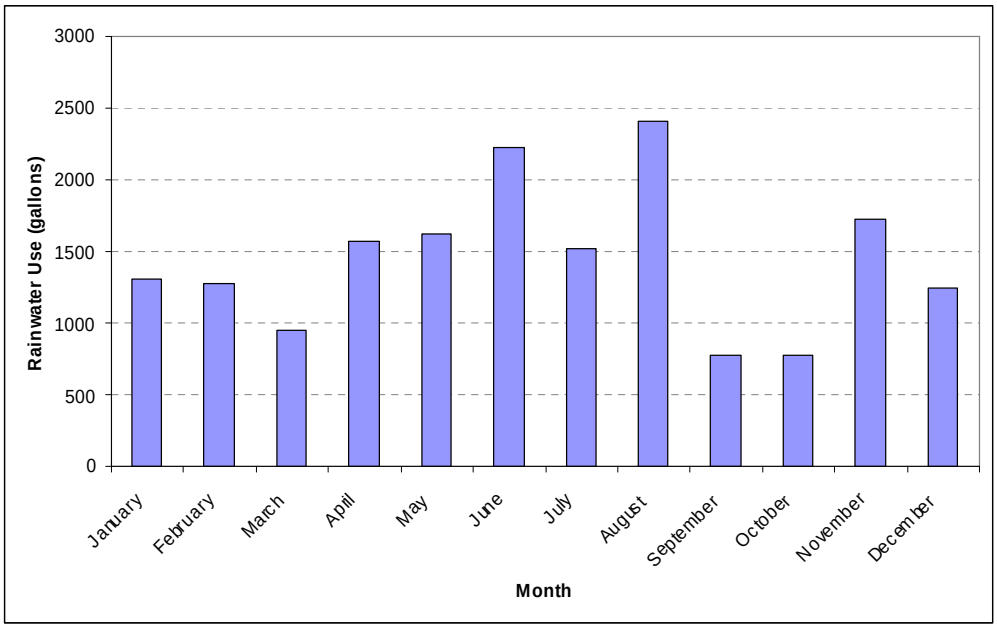
House	Rainwater Use by Month, 2006 (Gallons)											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	374	247	254	180	726	1182	681	763	30	187	441	374
2	262	322	217	434	292	329	262	486	224	284	426	277
3	239	322	202	434	224	284	224	411	359	307	404	426
4	434	389	277	524	381	434	352	748	165	07	456	165
Total	1,309	1,279	950	1,571	1,623	2,229	1,518	2,409	778	778	1,728	1,242

Initially it was believed that less harvested rainwater would be used during the months of August and September due to emptying of the cistern in July, and less available rainfall during the drier months of the year. The monitoring data in Table 12 indicate that appreciable rainwater use is occurring throughout the year even during the summer months due to the relatively large storage volume of the cistern and the fact that some rainfall occurred during the drier months. Rainfall during 2006 totaled about 43 inches, which is about 6 inches above normal. The water use rates in Table 12 would have been met by a typical year's rainfall of 36.6 inches; therefore, the wetter-than-normal year does not affect our assessment. The combined rainwater harvesting of the four cistern systems totaled 17,400 gallons; total rainwater use is plotted by month in Figure 11.

An average emptying rate was estimated from the data in Table 12. First the total water use for 2006 was calculated for each of the four homes, then this volume was converted from cubic feet to gallons and divided by the 1,500 gallon cistern volume to calculate the number of cistern volumes used by each home during 2006. Results ranged from a low of 2.5 cistern volumes for Home 3 to a high of 3.6 for Home 1, which has the largest lot and may have had the highest irrigation use. The volume of harvested rainwater (expressed as cistern volumes) was then averaged (2.9 volumes) for the four homes and converted to an average emptying rate expressed in weeks by dividing 52 weeks by 2.9 cistern volumes, giving an average of 18 weeks over the year to use one full cistern volume of rainwater.

[7] The meter readings indicated a small negative value for October, and water use was assumed to be negligible for the month.

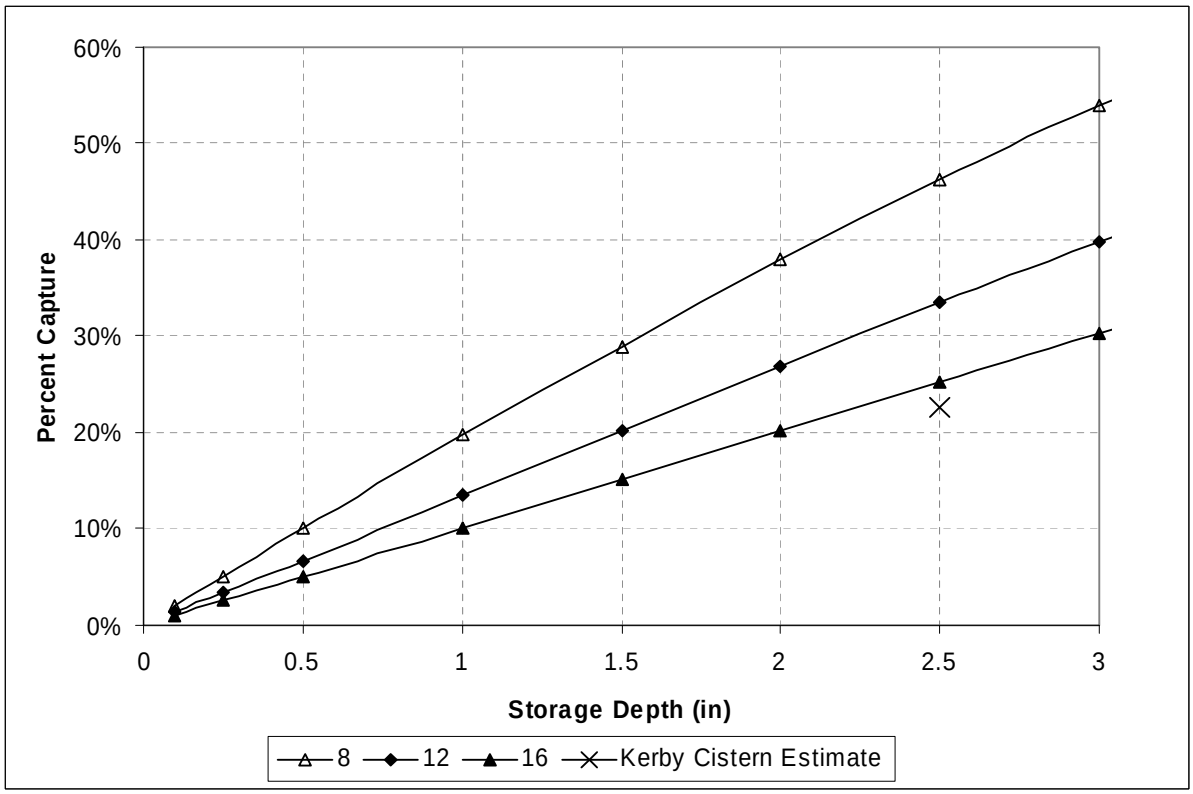
Figure 11. Total Rainwater Use During 2006



The available storage volume of each cistern is 1,500 gallons (200 ft^3), which is equivalent to a 2.4 inch (0.2 ft) storage depth over the approximately 1,000 ft^2 roof of each unit (calculated from as-built plans, including the ecoroof area). However, due to the ecoroofs returning nearly half of the rainfall back to the atmosphere (as shown later), this gives an equivalent roof area of about 950 ft^2 with an effective storage depth of 2.5 inches. Figure 12 shows average annual percent capture as a function of storage depth for three cistern emptying rates of 8, 12, and 16 weeks and the estimated annual average performance of the Kerby Avenue cisterns. Details of the cistern modeling are provided in the technical stormwater modeling Appendix B:. The storage volume of the cisterns used for the project is fairly large relative to the usage rate. Extrapolating from the capture estimate of the 8-, 12-, and 16-week emptying rate model results gives an average annual capture estimate of about 21%[8] for the Kerby Avenue project. This estimate agrees well with the monitoring data for 2006, during which about 19% of available runoff (based on 43 inches of rainfall) was captured in the cisterns. An average annual capture rate of 20% for the cisterns is used in the following stormwater reduction analysis.

[8] The 10 gallon first-flush bypass of the cistern system was not simulated in the modeling as this level of detail is beyond the scope of work. Excluding this feature will contribute to a slight overestimation of rainwater capture, on the order of one percent, as this volume is assumed routed into the cistern rather than bypassing the system.

Figure 12. Cistern Capture Efficiency



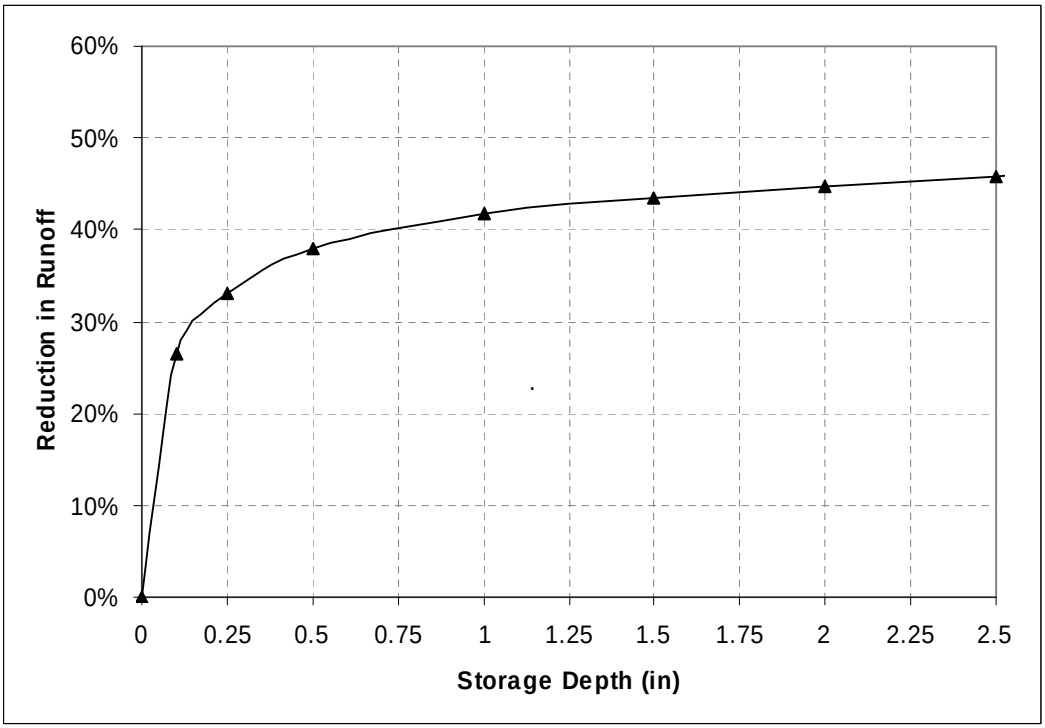
Each gallon of harvested rainwater replaces a gallon of city water that would have to be purchased. While cost analysis of the rainwater system was not part of the Kerby Avenue homes M&V, inspection of the rainwater use in Table 12 indicates that the systems are functioning properly and are expected to result in substantial savings on water bills in addition to a 20 percent reduction in stormwater runoff from the roof area draining to the cisterns.

Ecoroof Assessment

Each of the Kerby Avenue homes has two small ecoroofs totaling approximately 100 square feet. Modeling similar to the cistern modeling was conducted to evaluate ecoroof performance. Details of the ecoroof modeling are provided in Appendix B:.

The ecoroofs incorporated into the Kerby Avenue project contain on average about seven inches of soil medium. 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, 2002), giving an estimated water storage depth of approximately two inches. Figure 13 shows the results of the ecoroof analysis, which indicates that a 45 percent reduction in stormwater runoff is likely achieved by the ecoroofs (i.e., 45 percent of precipitation is evaporated and transpired back to the atmosphere).

Figure 13. Ecoroof Runoff Reduction



The ecoroofs drain to the rainwater harvesting system, so the remaining 50 percent or so of rainwater that results in runoff from the ecoroofs is routed to the cistern, and an appreciable fraction is reused for domestic and irrigation water needs.

Site Reduction in Stormwater Runoff

In order to estimate the effect of the stormwater management system on reducing stormwater runoff, an average annual stormwater runoff volume was estimated for the project, as if it did not have the stormwater features, using the Rational Equation (Novotny and Olem, 1994):

$$Q = R_v \times I \times A \tag{1}$$

where

Q = runoff (cubic feet),

I = rainfall (3 feet annual average),

A = drainage area (square feet), and

R_v = mean annual runoff coefficient (dimensionless).

The runoff coefficient is a unit-less value that represents the expected fraction of rainfall that results in runoff. It is primarily a function of the amount of impervious cover in the urban watershed. The runoff coefficient was calculated using the Simple Method (Schueler, 1987), a linear runoff coefficient equation based on a wide range of stormwater-monitoring data which is suitable for this level of analysis.

$$R_v = 0.90 \times (\textit{impervious fraction}) + 0.05$$

We estimated the impervious fraction of the entire Kerby Avenue homes project without the stormwater features to be 56 percent, based on the roof, driveway and sidewalk area, resulting in a runoff coefficient of 0.55. Therefore, the total runoff volume is estimated as 16,600 cubic feet[9] on an average annual basis for the entire project without the stormwater components included. As shown previously, the cistern systems result in approximately 20 percent capture of rainfall runoff. The estimated impervious area runoff coefficient, the average annual capture efficiency (see stormwater modeling Appendix B:), and the rooftop area were used to calculate the average annual runoff volume harvested of 2,100 ft^3 per year for the four combined systems. A similar calculation was made for the volume of runoff prevented by the ecoroofs at around 540 ft^3, on average, per year, and the permeable pavers prevent approximately 3,800 ft^3 of stormwater runoff in an average year. The expected reduction in stormwater runoff from using the project cisterns, ecoroofs, and permeable pavers, therefore, is 6,500 ft^3 per year, or an average annual reduction in stormwater runoff of about 40 percent.

Each of the Kerby Avenue homes also has a drywell to infiltrate stormwater runoff that is not retained in the cisterns or ecoroofs. Due to the additional storage capacity of the dry well it is probably the case that only very large storms result in any stormwater runoff from the project site.

Conclusions

The external stormwater features (driveways and ecoroofs) of the Kerby Avenue homes are functioning properly and result in practically all rainfall infiltrating through the permeable drive and walkways and a large portion of rainfall falling on the ecoroofs being returned to the atmosphere. The rainwater harvesting systems are also functioning as intended, resulting in appreciable reduction in stormwater runoff from the rooftops of the project. The only practical way to improve the performance of the Kerby Avenue homes stormwater system would be to utilize harvested rainfall at a higher rate in order to increase the rate at which available storage volume is generated within the cisterns. Use of the collected rainwater provides the additional benefit of reduced purchases of City water, helping offset the costs of the collection system.

While a modeling assessment of the drywell performance is outside the scope of this project, the drywell was constructed to meet the City of Portland standards and is expected to prevent stormwater runoff from leaving the project site except during very large storm events. The stormwater volume reductions achieved with the ecoroofs and cisterns when combined with the expected performance of the drywell should result in stormwater volume reductions even higher

[9] Runoff = 0.55 × 3 ft rain × 10,000 sq. ft. = 16,620 cubic feet of runoff

than the LEED goal of 30 percent reduction (US Green Building Council, 2005). The Kerby Avenue homes project has effectively met the commitments made to incorporate effective stormwater controls into the project.

References

Brady, N.C., and R.R. Weil. 2002. *The Nature and Properties of Soils.* New Jersey: Prentice Hall.

Novotny, V. and H. Olem. 1994. *Water Quality Prevention, Identification, and Management of Diffuse Pollution.* New York : Van Nostrand Reinhold.

Schueler, T. 1987. Controlling Urban Runoff, A Practical Manual for Planning and Designing Urban BMPs, Metropolitan Washington Council of Governments.

U.S. Green Building Council 2005. Green Building Rating System for New Construction & Major Renovations Version 2.2.

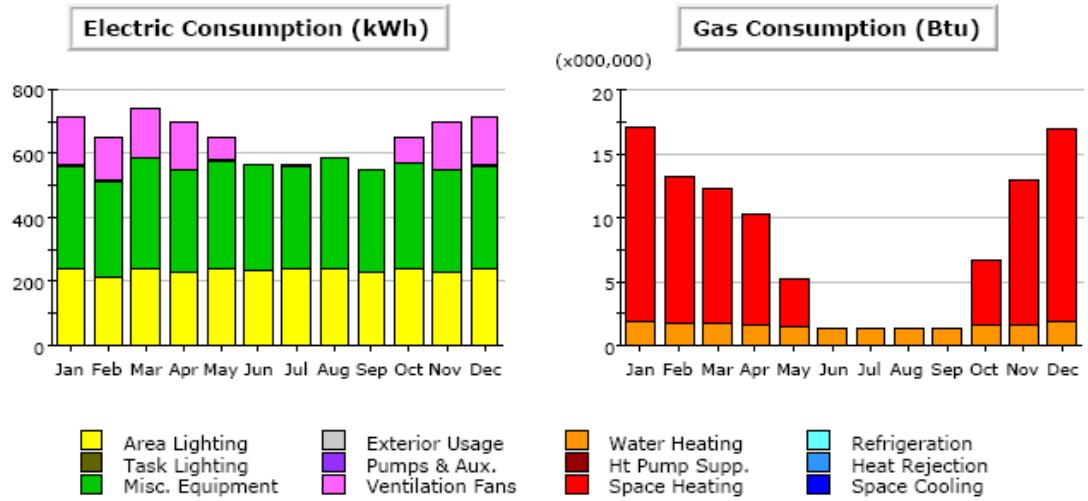
6. Construction and Demolition Waste

Starting with GIF projects funded in 2006, awardees were required to submit to Quantec 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: eQUEST Monthly Energy Consumption by End Use

eQUEST outputs are presented below for the counterfactual and as-built homes, respectively.

Project/Run: KERBY_BASELINE_Counterfactual - Baseline Design Run Date/Time: 03/10/07 @ 18:04



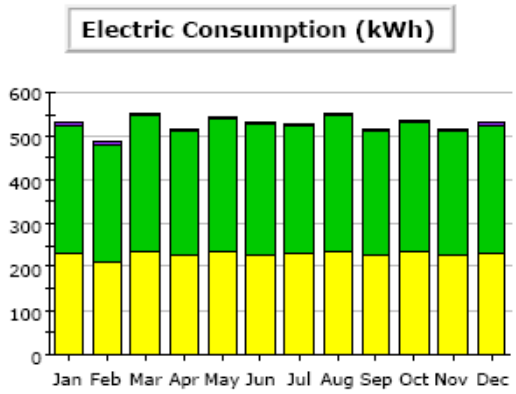
Electric Consumption (kWh)

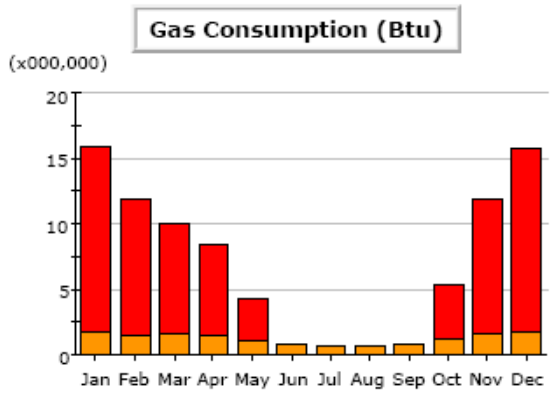
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	154.1	139.2	154.1	149.1	74.4	-	-	-	-	79.7	149.1	154.1	1,053.8
Pumps & Aux.	4.2	3.4	3.5	3.3	3.4	3.3	3.4	3.4	3.3	3.4	3.5	4.2	42.3
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	324.0	298.7	343.5	317.7	337.0	330.7	324.0	343.5	317.7	330.5	317.7	324.0	3,908.8
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	234.5	213.1	238.7	227.9	237.3	230.6	234.6	238.7	227.8	235.9	227.9	234.5	2,781.4
Total	716.8	654.4	739.7	698.1	652.0	564.5	561.9	585.5	548.8	649.5	698.2	716.8	7,786.3

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	15.25	11.44	10.57	8.67	3.81	-	-	-	-	5.23	11.28	15.06	81.30
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	1.90	1.67	1.70	1.54	1.49	1.37	1.30	1.25	1.34	1.53	1.64	1.86	18.58
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	17.15	13.10	12.27	10.22	5.30	1.37	1.30	1.25	1.34	6.75	12.92	16.91	99.87

Project/Run: KERBY_Measure_Complete - Baseline Design Run Date/Time: 03/09/07 @ 12:14





Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

Electric Consumption (kWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	4.9	3.8	3.9	3.6	3.7	3.6	3.7	3.7	3.6	3.7	4.0	4.9	47.3
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	291.6	268.8	309.1	286.0	303.3	297.6	291.6	309.1	285.9	297.4	285.9	291.6	3,517.9
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	234.5	213.1	238.7	227.9	237.3	230.6	234.6	238.7	227.8	235.9	227.9	234.5	2,781.4
Total	531.0	485.8	551.6	517.5	544.3	531.8	529.9	551.5	517.3	537.1	517.8	531.0	6,346.6

Gas Consumption (Btu x000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	14.18	10.36	8.42	7.08	3.08	-	-	-	-	4.23	10.28	14.15	71.78
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	1.71	1.49	1.53	1.38	1.09	0.77	0.70	0.69	0.79	1.22	1.56	1.70	14.62
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	15.89	11.85	9.95	8.46	4.17	0.77	0.70	0.69	0.79	5.45	11.83	15.85	86.40

Appendix B: Stormwater Modeling

Modeling Introduction

The 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, including rainfall, infiltration, evapotranspiration, surface and subsurface flow, hydraulic routing through the drainage network, and detention storage. The model is particularly appropriate for analyzing hydrologic effects of development because the model takes into account the effects of precipitation, topography, land use (accounting for any change in impervious cover), soils, and storage and treatment by 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 a direct frequency and duration analysis of flows in individual sub-watersheds and main-stem hydraulics. Hourly precipitation data collected at the Portland International Airport from January 1949 through 2005 were used as the precipitation input for the cistern modeling.

SWMM was used to model the effectiveness of a wide range of cisterns for harvesting rainwater. The range of cisterns modeled was extensive so that all cisterns associated with the Portland Office of Sustainability GIF M&V project would be represented by the model results, which could be used to evaluate cistern performance as additional projects are completed.

Cistern Modeling

Cistern Model Parameters and Assumption

SWMM requires input of many model parameters, however three parameters are central to this analysis: rainfall, cistern storage volume, and the cistern emptying rate. 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 sites. 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.

- Storage volume: The cistern storage volume was normalized to a depth over the cistern drainage area so that model results could be applied to a wide range of cistern sizes and drainage areas. A wide range of storage sizes was simulated.

- Emptying rate: Water is not withdrawn from a cistern at a constant rate; however it would be difficult to predict variability in water withdrawals even if the SWMM model could simulate variable outflows, which it cannot. Therefore, the cistern emptying rate was simplified to an average monthly outflow for modeling purposes. A wide range of outflows was simulated.

The model parameters described in Table 13 represent the area draining to the cisterns. Model controls such as output and print controls[10] or time steps are not listed in Table 13; only those model parameters that represent physical characteristics are included.

Table 14 contains the raw pan[11] evaporation data which is referenced in row 2 of Table 13 and the adjusted values used in the cistern modeling. The pan evaporation data are used as the basis for estimating evaporation for the cistern modeling. A pan coefficient of 0.8 was selected based on information in the Handbook of Hydrology (Maidment, 1993). The pan evaporation data in Table 14 are also the basis for the evapotranspiration for the ecoroof modeling described in the following section. Evapotranspiration is water loss through evaporation directly from the soil or surface storage and transpiration losses from plants.

[10] Model output controls are used to select how often model results are output (i.e. how many model time steps between output), while the print controls are used to select which information is printed and for which model nodes.

[11] 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.

Table 13: Drainage Area Parameters (simulated with the SWMM Runoff Block)

Drainage Area Parameters	Parameter Description	Value	Source / Rationale
Infiltration	The infiltration rate is used to define the saturated hydraulic conductivity of the soil (permeable surface).	Not applicable	The drainage area was assumed to be 100% impervious to simulate a rooftop.
Evaporation	The monthly evaporation rate of rainfall from depression storage.	80% of pan data	Pan evaporation coefficient of 0.80 used for pan evaporation data[12] shown in Table 14.
Area (ac)	The area of the rooftop.	0.23	Modeled a 10,000 ft^2 square drainage area
Width (ft)	The width of the rooftop.	100	
Length (ft)	The length of the rooftop and the maximum overland flow length of runoff. A longer length results in a longer travel time for runoff and slightly higher evaporation loss.	100	
Imperviousness (%)	The percent of the drainage area that is covered by impervious surface; in this case 100% to simulate a rooftop.	100	
Slope	The slope of the rooftop.	0.02	Based on professional judgment and values recommended in the SWMM Manuals (James and James, 2000).
Manning's Impervious	The Manning's coefficient used to calculate the velocity of overland flow on impervious surfaces.	0.02	
Manning's Pervious	The Manning's coefficient used to calculate the velocity of overland flow on pervious surfaces.	Not applicable	
Depression Storage Impervious Surface	The average depth of depression (i.e. puddles) storage over the impervious surface.	0.01	
Depression Storage Pervious Surface	The average depth of depression (i.e. puddles) storage over the pervious surface.	N/A	

Table 14: 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	40.3
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

[12] Portland pan evaporation data obtained online from http://www.wrcc.dri.edu/htmlfiles/westevap.final.html

Table 15 lists the parameters used to simulate the storage and release of harvested rainwater by the cisterns. Cistern modeling was conducted to represent all 156 possible combinations of cistern parameters from the twelve storage depths and thirteen emptying rates that were simulated.

Table 15: Cistern Parameters (simulated with the SWMM Storage Treatment Block)

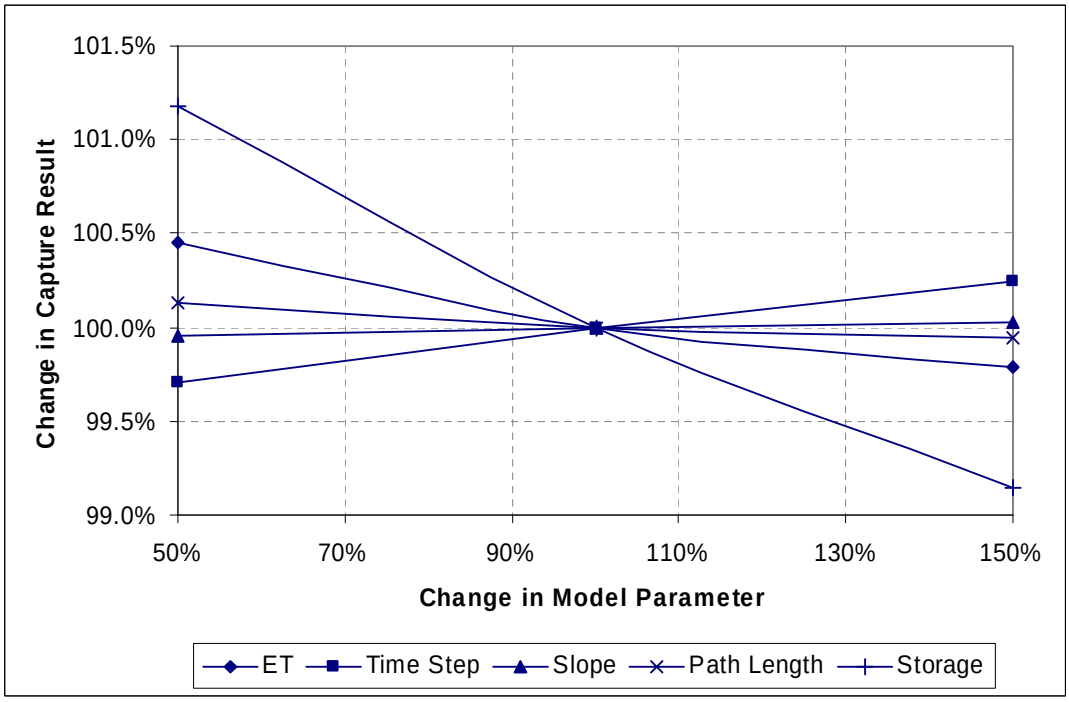
Cistern Parameters	Parameter Description	Value(s)	Source / Rationale
Evaporation	Evaporation from the cistern system.	Not simulated	Closed system with little vapor loss
Maximum inflow (cfs)	The maximum inflow rate to the cistern.	100	Inflow value was set very high so bypass would only occur when cistern was full.
Storage Volume - Depth (in)	The cistern storage volume divided by the roof area draining to the cistern. This is the normalized storage volume expressed as a depth of storage over the drainage area.	0.1, 0.25, 0.5, 0.75, 1, 1.5, 2, 3, 4, 5, 6, 8	Wide range of values to encompass any reasonable cistern sizes
Emptying Rate (weeks)	The emptying rate of the cistern expressed in weeks.	0.25, 0.5, 0.75, 1, 1.5, 2, 3, 4, 5, 6, 8, 12, 16	Wide range of values to encompass all anticipated water use rates

Sensitivity analysis was conducted to determine whether the drainage area model parameters have a significant effect on the cistern capture results. Sensitivity analysis was not conducted for the cistern parameters as the few parameters representing the cisterns were already varied for the modeling or the variables were not appropriate for simulation (e.g., evaporation). The parameters varied for the sensitivity analysis were: evaporation rate[13] (ET) time step, slope of the drainage area, runoff path length[14] and impervious surface depression storage. These five model parameters were varied by ± 50% and the model result compared to the result obtained for the reference value. Results of the sensitivity analysis are shown in Figure 14. For example, decreasing the evaporation rate by 50% resulted in an increase in modeled stormwater capture of 0.4% (a change in capture result to 100.4% of the base level shown in Figure 14). Model results varied by less than 1.5% for all variations in the sensitivity analysis, indicating that the effect of varying these parameters was insignificant compared to the effect of the rainfall input and cistern sizing.

[13] Evaporation or evapotranspiration which includes transpiration from plants in addition to evaporation losses.

[14] This is the actual length the runoff travels before entering a simulated pipe to the cistern; longer flow lengths result in slightly higher time for evaporation to occur.

Figure 14. Sensitivity Analysis Results



Cistern Model Results

Results for the cistern model runs are shown in Figure 15 with the emptying rate in weeks shown in the key. These results will be used to estimate the average annual fraction (i.e., percent capture) of runoff volume captured by the cisterns incorporated into the various GIF projects. In instances where the best estimate of cistern size and/ or emptying rate of a cistern used for a GIF project does not agree with the values modeled, interpolation of model result will be used to provide an average annual capture efficiency of the cistern.

Ecoroof Modeling

Ecoroof Model Parameters and Assumptions

Modeling the ecoroof performance was analogous to the cistern modeling in that the most sensitive model parameters are the effective storage depth of the ecoroof (how much water it can retain) and the rate at which the ecoroof dries out, thus creating storage capacity for subsequent rainfall (equivalent to the emptying rate of a cistern). Table 16 lists the parameters used in the model to simulate the ecoroofs. The ecoroofs were simulated as impervious surface in the model and the available storage depth was varied with the depression storage parameter. Modeling impervious surface with a storage depth is analogous to modeling the ecoroofs as if all the rainfall infiltrates, which is a reasonable assumption considering the low rainfall intensities in the Portland area and the high rate of infiltration of ecoroof soils.

Figure 15. Percent Volume Captured vs. Storage Depth for Various Weekly Emptying Rates

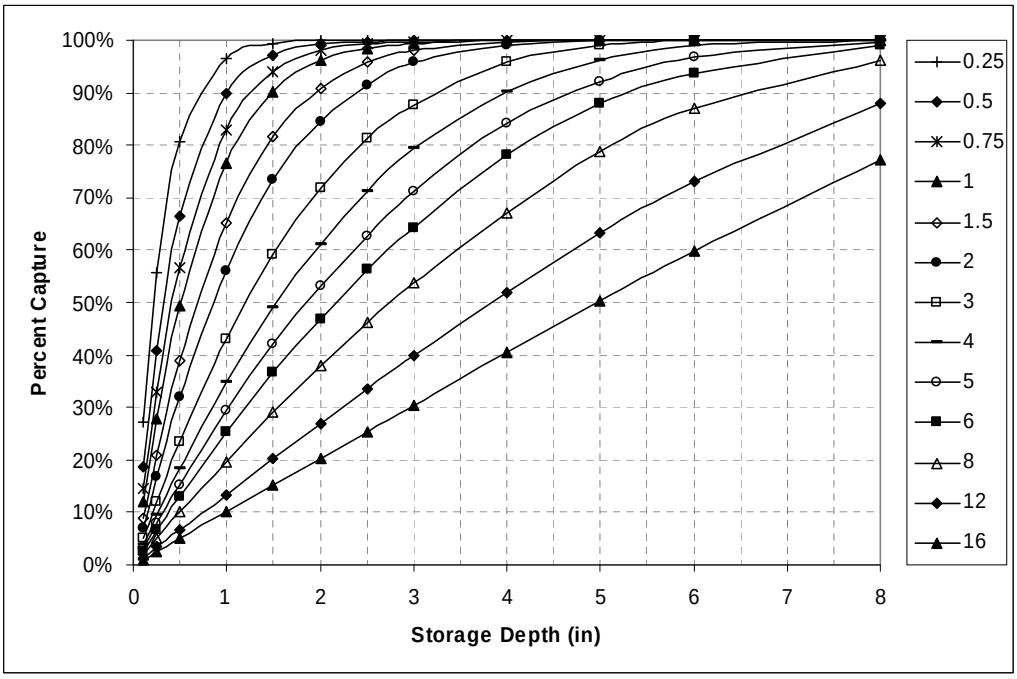


Table 16. Ecoroof Parameters (simulated with the SWMM Runoff Block)

Drainage Area Parameters	Parameter Description	Value	Source / Rationale
Infiltration (in/hr)	The infiltration rate is used to define the saturated hydraulic conductivity of the soil (permeable surface).	n.a.	Ecoroofs modeled as if all rainfall infiltrates
Evaporation	The monthly evapotranspiration rate of rainfall from the ecoroof.	80% to 160% of pan	Pan evaporation coefficient of 0.80 to 1.6 used for pan evaporation data[15].
Area (ac)	The area of the ecoroof.	0.23	Modeled a 10,000 ft^2 square drainage area; while this is larger than most ecoroofs the larger area contributes to model stability
Width (ft)	The width of the ecoroof.	100	
Length (ft)	The length of the ecoroof and the maximum overland flow length of rainfall. The model was set up to simulate infiltration of all rainfall.	100	
Imperviousness (%)	The percent of the drainage area that is covered by impervious surface. The ecoroof model was set up using a value of 100% with soil moisture storage represented with the impervious depression storage parameter. This is analogous to simulating 100% infiltration	100	

[15] Portland pan evaporation data obtained online from http://www.wrcc.dri.edu/htmlfiles/westevap.final.html

Drainage Area Parameters	Parameter Description	Value	Source / Rationale
	in the model.		
Slope	The slope of the ecoroof.	0.02	Based on professional judgment and values recommended in the SWMM Manuals (James and James, 2000).
Manning's Impervious	The Manning's coefficient used to calculate the velocity of overland flow (if any) on impervious surfaces.	0.02	
Manning's Pervious	The Manning's coefficient used to calculate the velocity of overland flow (if any) on pervious surfaces.	Not applicable	
Depression Storage Impervious Surface (in)	The average depth of depression (i.e. puddles) storage over the impervious surface, used in this case to represent the moisture storage capacity of the ecoroof soil.	0.1, 0.25, 0.5, 1, 1.5, 2, 2.5, 3	
Depression Storage Pervious Surface (in)	The average depth of depression (i.e. puddles) storage over the pervious surface.	Not applicable	

A wide range of evapotranspiration rates was used in the ecoroof analysis to represent possible variation in the transpiration of plants used in ecoroof design and to provide a wide range of results for comparison with a local ecoroof study.

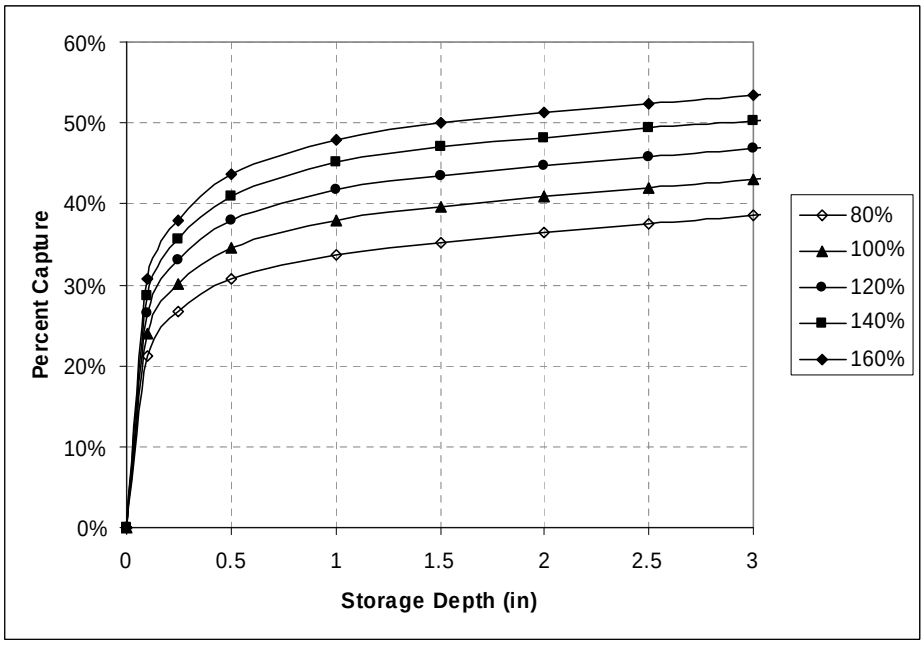
Ecoroof Model Results

Results for the 70 ecoroof model runs are shown in Figure 16 with the evapotranspiration (ET) pan coefficient used shown in the key. These results will be used to estimate the fraction, on an average annual basis, of rainfall returned to the atmosphere by the ecoroofs incorporated into the various GIF projects. In instances where the best estimate of ecoroof size and ET rate used for a GIF project does not agree with the values modeled, interpolation of model result will be used to provide an average annual effectiveness of the ecoroof.

Model results were compared to a study conducted by the City of Portland Bureau of Environmental Services. The study[16] monitored the performance of the Hamilton Building ecoroof and found that this ecoroof on top of high rise apartment building achieved a reduction in stormwater runoff of 54 percent over the two plus years of monitoring. The Hamilton ecoroof averages about 4.5 inches of soil medium; assuming a water retention ratio of 0.3 this would provide an effective storage depth of about 1.5 inches for the Hamilton ecoroof. Ecoroof model results in Figure 16 indicate an ecoroof effectiveness ranging from 36 percent using a pan ET coefficient of 0.8, to 50 percent when using an ET coefficient of 1.6. The ET coefficient of 1.2 is the recommended default value for all ecoroofs, unless there is compelling evidence that the ecoroof of interest has higher or lower ET due primarily to the vegetation used. Ecoroof model results for a storage depth of 1.5 inches and an ET coefficient of 1.2 give a predicted average annual reduction in runoff of 44 percent. While this result is about 10 percent less than observed

[16] Hamilton ecoroof study available at http://www.portlandonline.com/shared/cfm/image.cfm?id=78405

Figure 16. Ecoroof Performance



in the Hamilton ecoroof study, the Hamilton ecoroof is expected to have higher ET rates due to wind effects resulting from the ecoroof location on top of a high rise building. This would be expected to result in higher runoff reductions. The ecoroof model results when compared to the Hamilton study are reasonable, although the results may be slightly conservative. Using the ecoroof modeling results to predict ecoroof performance will result in realistic and potentially slightly conservative estimates of the average annual reductions in stormwater runoff.

References

James, W. and R. C. James 2000. Hydrology: A Guide to the Rain, Temperature and Runoff Modules of the USEPA SWMM4. Computational Hydraulics International, Ontario, Canada.

Maidment, D.R. (ed.), Handbook of Hydrology. McGraw-Hill Inc., New York, NY (1993).

KERBY STREET HOMES

Making Speculative Green Homes a Success

How does a developer successfully create an attractive, sustainable development on a small infill lot in one of Portland's inner neighborhoods? Ask Aaron Blake of Reworks. He transformed an underdeveloped 10,000 square-foot lot with safety concerns into a showcase of green building practices. The new homes and associated sidewalks and street trees have improved the livability of the neighborhood and helped advance city and regional goals for density and development.

Using Liquid Sunshine to Reduce Water Use

Each of the Kerby Street Homes features a rainwater harvesting system. This system reduces water use by approximately 25 percent. Developer Aaron Blake noted that the most challenging aspect of installing the rainwater harvesting system was coordinating the numerous trades people involved in the installation.

First, excavators dug the pit for the cistern and drywell; next the plumbing contractor installed the supply line; then the general contractor installed the cistern and electrical system; after which the roofer installed the standing-seam metal roof; and finally the gutter contractor installed the gutters and downspouts that fill the cistern.

Using Real Sunshine to Reduce Energy Use

The Kerby Street homes were built as a speculative development, but all four were sold to homebuyers during the construction phase. Before construction was completed, Mr. Blake explored solar options with future owners. All the homeowners expressed an interest in solar, so Mr. Blake worked with Mr. Sun Solar to pre-wire the homes.

During the rough-in phase of mechanical systems, Mr. Sun Solar, Inc. ran copper piping and electrical wire from the roof to the mechanical room on the ground floor for the future installation of the solar arrays. Pre-wiring and plumbing assured that the systems were properly integrated into the house instead of retroactive installation that incurs the hassle and cost of retrofitting the systems after construction.

At the end of the project, the solar thermal panels were craned onto the rooftop and secured to the roof. In the mechanical area of each home, an 80-gallon solar storage tank with a heat exchanger was set and plumbed to the domestic hot water tank. On one house, a 2 kW photovoltaic array was installed on the roof beside the hot water panels and hardwired to an inverter in the garage that sends the energy generated back to the grid.

Find more City of Portland resources for healthy living at www.portlandonline.com/bps

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These features were attractive to homebuyers due to their potential for significant long-term savings. Blake reports that these homes sold for higher prices than similar sized new homes in the area.

These systems require very little long-term maintenance. Occasionally, the solar collectors should be cleaned of dust and the fittings checked for any sign of leaks. Similarly, the rainwater harvesting system, despite its many components, is relatively low-maintenance. The roof washers and the gutters need to be checked for debris and cleaned twice a year, and the cistern cleaned annually. The other components require no routine maintenance and operation of the system is virtually hands-free.

Energy-Saving Heating and Cooling Systems

The Kerby Street Homes also feature a combination of both innovative and relatively simple energy saving systems. In addition to high-quality insulation and passive solar design elements, the radiant hydronic in-floor heating system with a concrete thermal slab provides even, comfortable heat, with a 30-50 percent energy savings over a forced-air system. The homeowner needs only to set the temperature once during the season to establish a comfort level that is maintained at all times. Blake reports that the homeowners have said they are pleased with the way the comfort and energy savings offered by the heating systems.

Another energy saving system is heat recovery ventilation (HRV). The intent of the HRV is to provide fresh air to a space, while using the exhaust air to preheat the intake air. The HRV is operated with a control that allows for a range of settings that control speed, filtration, and humidity. The user sets the unit to exchange air continuously at a relatively low speed for routine operation and adjusts the humidity control to eliminate condensation. The HRV is also outfitted with a HEPA filter and a particulate filter to remove any air-borne allergens.

Other Sustainable Features

The homes feature a variety of other sustainable elements:

- Green (vegetated) roofs over each porch.
- Fiber cement siding installed over a rain screen system.

- 50 percent fly ash added to concrete foundation walls.
- Driveways with pervious pavers to reduce water runoff.
- Low/no-VOC finishes and materials: Formaldehyde-free MDF trim, wheat-board cabinets, bamboo treads and flooring, and wool carpet and recycled denim carpet pad, as well as low VOC paint.
- Use of sprayed-in foam insulation in the demonstration home that is about twice as air-tight as a fiberglass batt-insulation.

Energy and Water System Financial Savings and Benefits

Costs	
▪ Thermal Envelope (Durafill insulation)	$5,000
▪ Radiant Hydronic Floor System	$9,011
▪ Solar Hot Water system	$5,100
▪ Solar PV System	$9,200
▪ Rainwater Harvest System	$4,786
▪ Native landscaping/small yards	$5,071
▪ Low-flow toilets and showerheads	$ 1,200
TOTAL	$39,368
Offsetting Grants and Rebates	
▪ Incentives: GIF Grant (builder assistance)	$3,500
▪ Federal Tax Rebates (for Solar Systems)	$2,820
▪ Energy Trust Incentives	$6,660
TOTAL	$12,980
Projected Operational Cost Savings	
▪ Heating -approximately 50% annually	$780/year

Resources and Suppliers

Reworks, Inc. ▪ *www.reworksinc.com*

Energy Trust incentives ▪ *www.energytrust.org*

Parr Lumber ▪ *www.parr.com*

Pacific Hydronics ▪ (no local Web site)

Wolcott Plumbing ▪ (no Web site)

Bear Electric ▪ *www.bearelectric.com*

Willamette Graystone ▪ *www.willamettegraystone.com*

Mr. Sun Solar ▪ *www.mrsunsolar.com*

Bell Heating ▪ *www.bellheating.com*

Project Partners

EnergyTrust of Oregon

Environmental Services City of Portland
working for clean rivers

Portland Water Bureau
FROM FOREST TO FAUCET

Ecoroof "Tremdrain" drainmat and drain rock border

Ecoroof ; detail of drain

Finished Interior showing exposed ceiling, radiant concrete floors

Finished Interior showing passive solar heating, wheatboard cabinets

FSC certified hardwood balcony

Completed project!

Setting the Cistern

Water and electric lines run into house

Radiant floor tubes on ground floor

Radiant floor tubes on main floor

Cistern connected to drywell

Float switch located inside cistern

Radiant Floor distribution system

Radiant Floor distribution system; circulating pump, expansion tank

Rainharvest pump and distribution system

Rainharvest system; detail of relay switch

Radiant Floor manifold center

Blower Door Test

Spray-in Durafill insulation

Framing; TJI roof structure

Framing; Advanced framing of exterior walls, plywood

Siding with Hardiplank and rainscreen