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Green Building Technologies that Use Plastic Pipe and Tubing to Function

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For

The Plastic Piping Education Foundation (PPEF)

and

Plastic Pipe and Fittings Association (PPFA)

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Beacon Mechanical
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Lubrizol
ML Concept Ltd
Radiantec
Radiantheat
Roto Rooter

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EXECUTIVE SUMMARY

Sustainability Edge Solutions is pleased to present this report compiling our review of selected green building, resource and life conserving systems and technologies that use plastic pipe and tubing to function. The report is primarily intended to be used by the plastic pipe and tubing industry to increase awareness about the increasingly important, integral role of plastic pipe, tubing and fittings for the proper functioning and environmental performance of these technologies, targeting the information needs of installers, designers, green builders, homeowners and commercial building owners and managers. It is our hope that the report will facilitate the evaluation, selection, design and implementation of these green technologies in construction of homes and buildings.

The report contains a chapter on residential and commercial application of each of the following eleven technologies:

1. Gray water reuse
2. Rainwater harvesting
3. Geothermal ground loops
4. Higher efficiency hot water distribution
5. Radiant heating
6. Solar hot water
7. Water efficient irrigation
8. Radon venting
9. Decentralized wastewater treatment
10. Central vacuum systems
11. Residential fire sprinklers

For each technology reviewed, information was compiled on:

- Description, benefits and limitations
- Energy and/or water savings potential for a hypothetical scenario, associated simple economic payback period and estimated CO_2 equivalent (CO_2e) greenhouse gas reductions
- Life safety impacts, where applicable
- Indoor environmental quality (IEQ) impacts, where applicable
- Materials used for piping, tubing, fittings
- Operating examples describing selected examples of installations
- Source Materials used for the literature review, including websites

The report highlights the use of plastic pipe, tubing and fittings in green building technologies. For those situations where plastic is preferred over non-plastic components for the identified green building technologies, the primary advantages cited generally included:

- Material flexibility and lighter weight, enabling greater design flexibility, ease of installation and lower installation time and cost;
- Durability and strength combined with chemical, weather and corrosion resistance and biological inertness, leading to effective performance and long service life in the field;
- Ease of color coding and marking to identify safe acceptable uses and applications;
- Cost-effectiveness in terms of manufacturing, transportation and ease of installation;
- Recyclability and recycled content improves end-of-life impacts;
- Extensive testing and compliance with nationally accepted consensus standards, third-party certification, and approval in building codes and regulations.

Recommended next steps for the plastic pipe industry are to:

1. Further characterize the environmental benefits of green building technologies that incorporate plastic pipe, tubing and fittings by conducting life cycle assessments of the plastic components utilized. This would build on life cycle inventory assessments already conducted by PPFA for certain plastic pipe products. The results of full life cycle assessment studies can promote adoption of these technologies for green building projects by highlighting their favorable influence on key environmental impact measures. They can also be used as a baseline for further improving manufacturing, transportation and installation efficiencies as well as end-of-life impacts, and enable the industry to respond effectively to opportunities and risks related to carbon management programs and regulatory schemes.

2. Conduct a more comprehensive economic analysis for the identified technologies using life cycle costing tools and determining net present value over the service life of the technology.

3. Develop and publicize in-depth, comprehensive case studies demonstrating the successful use of plastic pipe, tubing and fittings in a variety of green building installations.

INTRODUCTION AND BACKGROUND

The Plastic Piping Education Foundation and Plastic Pipe and Fittings Association engaged Sustainability Edge Solutions to review and report on the use of plastic pipe, tubing and fittings in green building technologies.

The green building movement in the U.S. has had a tremendous impact on generating widespread awareness of the impact of the built environment on the environment. Throughout their life cycle, the homes and buildings where we live and work contribute a significant proportion of the energy, water and materials consumed, and waste and greenhouse gases generated. Green buildings are not only more resource-efficient than conventional buildings, but they have many other beneficial impacts including greater occupant safety, comfort and wellbeing and less adverse impacts on site ecology and infrastructure.

The US Green Building Council (USGBC) states on their website that buildings in the U.S. are responsible for:

- 72% of electricity consumption,
- 39% of energy use,
- 38% of all carbon dioxide (CO_2) emissions,
- 40% of raw materials use,
- 30% of waste output (136 million tons annually), and
- 14% of potable water consumption.

Furthermore, according to EPA WaterSense:

- An American family of four can use 400 gallons (3,338 pounds) of water per day;
- On average, approximately 70% of that water is used indoors and about 30% is for outdoor uses;
- Nationwide, landscape irrigation is estimated to account for almost one-third of all residential water use, totaling more than 7 billion gallons per day;
- At least 36 states are anticipating local, regional, or statewide water shortages by 2013.

Properly designed and implemented green building technologies can result in significant reductions in energy and water consumption of homes and buildings and reduce associated greenhouse gas emissions and wastewater generation. Onsite storm water management practices can reduce the rate and quantity of storm water runoff and improve its quality as it returns to surface or groundwater sources.

Reducing onsite potable water consumption, especially hot water, in turn, reduces the energy and chemicals expended to treat, heat and distribute that water and to remove and process the resulting wastewater. This is a tremendous benefit to municipalities and utilities in terms of reduced operating costs and deferred capital expenditures for new or upgraded water supply and wastewater treatment facilities. As stated in “Rainwater: The Untapped Resource”, High Performing Buildings, Summer 2008, “Water treatment and delivery use 7-8% of the country’s energy.”

Other technologies primarily support enhanced health and well-being through enhancing indoor environmental quality by minimizing indoor concentrations of pollutants or mitigating risks to life safety and property damage.

State and local governments increasingly offer incentives for green buildings in the form of tax credits (income and property tax, sales tax), fast-tracking building permit approvals, utility subsidies, grants and loans. Innovative financing mechanisms are increasingly being made available to assist with capital costs of installing green building technologies, especially when favorable projected operating cost savings can be demonstrated.

Many of the commonly utilized green building technologies incorporate plastic pipe, tubing and fittings as integral components necessary for the required functional, environmental and safety performance.

This report summarizes our literature review and interviews with selected experts and industry representatives for the identified green building technologies. It is primarily intended to be used to increase awareness about the important, integral role of plastic pipe, tubing and fittings for the proper functioning and environmental performance of these technologies. The report provides information that can assist in the evaluation, selection, design and implementation of these green technologies in new construction of homes and buildings, targeting the information needs of installers, designers, green builders, homeowners and commercial building owners and managers.

Report Structure
The report contains a chapter on each of the following technologies:

1. Gray water reuse
2. Rainwater harvesting
3. Geothermal ground loops
4. Higher efficiency hot water distribution
5. Radiant heating
6. Solar hot water
7. Water efficient irrigation
8. Radon venting
9. Decentralized wastewater treatment
10. Central vacuum systems
11. Residential fire sprinklers

For each technology studied, information was compiled on:

<u>Technology Overview</u>

Description, benefits, limitations, challenges, other impacts and considerations, barriers to adoption are summarized for residential and commercial applications of the technology.

<u>Energy and/or Water Savings</u> (as applicable)

Conservation statistics, economic analysis, installed costs, operating and maintenance issues, simple payback period estimates for a hypothetical scenario were summarized.

Energy and water savings were calculated using representative consumption figures and electricity, natural gas, and sample water and wastewater pricing for Florida, Minnesota and California.

Greenhouse gas reduction estimates per year expressed as CO_2 equivalent mass for an average household and an office building installation were estimated and are reported in the internationally accepted units of metric tonnes.

For radon venting and residential fire sprinklers, rather than energy and water conservation, general data such as additional lung cancer deaths per year that could be avoided, or the numbers of homes destroyed by fire, material waste and water waste (attributed to fire trucks as compared to sprinklers per incident) were explored. For central vacuum systems, potential indoor air quality improvement benefits are reported.

Life Safety Impacts (if applicable)

Safety and health impacts, statistics and benefits related to the technology are provided.

Indoor Environmental Quality (IEQ) Impacts (if applicable)

Health, comfort and quality of life impacts, statistics and risks and benefits related to the technology are provided.

Materials Used for Piping, Tubing, Fittings

Dominant piping, tubing and fitting materials used are listed, with emphasis on the use of plastic pipe, tubing and fittings, features, limitations, cost data, installation considerations, and additional environmental aspects. This information was compiled from a literature review as well as interviews with experts and individuals in selected organizations familiar with the technology in question. Recognizing that there are other viewpoints and technical and economic considerations that could be relevant to each particular situation, these responses were summarized and represent a limited selection of the following perspectives and viewpoints:

- manufacturers of the identified technologies
- manufacturers of piping systems and components used in those technologies
- system installers and contractors
- system owners and operators

A list of people and companies interviewed was maintained, but they have not all been quoted directly or named explicitly in the report.

Operating Examples

This section describes specific examples of installations of the individual technologies, including a brief overview of project intent, type of building, location, conservation estimates, costs, performance and testimonials. The selected examples of operating systems are listed for illustrative purposes only, and do not necessarily represent typical or common examples of the technology. Many of these sites incorporate additional green building technologies, products and practices that have a substantial impact on the associated environmental and economic benefits and impacts.

Source Materials

A list of sources (print and online) consulted for each green building technology is provided at the end of each technology chapter. Referenced materials include:

- regulations and standards
- government agency studies, reports, statistics, surveys, calculators
- industry association reports
- technical and environmental research studies and reports

- manufacturers' literature and websites
- marketing and product brochures
- green building rating systems
- energy and water utility data and pricing levels
- case studies and operating examples

Source materials used in the report are referenced in-text in abbreviated form within the body of each technology chapter, and in full at the end of each corresponding technology chapter.

The chapters on each technology are not to be considered complete or exhaustive reviews but summaries of the literature reviewed and of selected viewpoints. The general chapters of the report which apply to all of the technologies contain information that explains and qualifies this content, such as the methodology, assumptions and overall conclusions. The reader is cautioned that due diligence and independent verification must be exercised for design and safety considerations, compliance to codes and regulations, comparisons, specification or procurement decisions, political considerations as well as costs and economic analysis applicable to their specific context.

Energy and Water Savings Methodology

Energy and water savings achievable from implementing each green building technology were calculated from estimates of associated reduction in energy and/or water consumption and comparing it to a baseline consumption scenario for a building or home that uses conventional technologies. In order to ascertain total savings, the percentage savings was multiplied by the baseline energy or water consumed.

An exhaustive and comprehensive review of life cycle costs was outside the scope and timeframe of this study. Water and energy savings achievable and simple economic payback estimates for applicable technologies were limited to the savings achieved at the building or home site compared to conventional practices. Water and energy savings estimates based on the life cycle of the technology and/or electricity supply or municipal water-side impacts or other off-site impacts were also outside the scope of this study.

Technology costs and percentage energy and water savings achieved were compiled from data obtained from system manufacturers, government agency estimates, published case studies or operating examples that were current at the time of the review.

Due to the lack of empirical and representative information that could be applied consistently across all scenarios analyzed, a number of simplifying assumptions were made for the economic analysis. The analysis is intended to be used for illustrative purposes only and should not be used for comparative purposes or specific procurement decisions, as they will not be directly transferable to other projects and specific contexts.

The simple payback period, the time it takes to recover the initial investment cost with savings, was estimated for a hypothetical reference household or office building implementing the technology. Annual savings from energy and/or water consumption reductions were offset by annual operating and maintenance costs attributable to each technology, where available.

As energy and water use varies greatly depending on geographic location and seasons, the economic payback was estimated for current pricing levels for electricity, natural gas and water for Florida, Minnesota and California. All non-electricity fuel use was assumed to be natural gas for the purposes of this analysis.

Baseline energy consumption figures by state were obtained from the Energy Information Administration (EIA) tables. Baseline water consumption figures were obtained from the US Geological Survey (USGS) figures for water use in residences and commercial buildings by State.

Wastewater figures were derived assuming that the volume of wastewater generated is equal to the potable water consumption.

Water utilities have vastly differing rates and rate structures. Even within the same utility the various different districts served can have very different rates depending on the age of the systems, source of supply, labor force characteristics, etc. Some include fixed charges and wastewater charges and some report them separately. As a result, reliable statewide water and wastewater pricing was not readily available. For illustrative purposes, sample water pricing for Miami-Dade, Minneapolis and San Diego were used along with the state average consumption figures for Florida, Minnesota and California, respectively.

The mix of power generation types and their carbon-intensity varies from region to region, making it necessary to identify the conversion factor appropriate for the regional grid in question. For our analysis, the state residential and commercial consumption and pricing figures reported by the EIA are assumed to already take this into account. Greenhouse gas (GHG) emissions reductions estimates are reported in metric tons (tonnes) of CO_2 equivalent by applying the GHG conversion factors to the amount of energy saved.

Plastics Abbreviations

ABS — acrylonitrile-butadiene-styrene
CPVC — chlorinated polyvinylchloride
HDPE – high-density polyethylene
PE — polyethylene
PE-AL-PEX – polyethylene-aluminum-PEX metal/plastic composite
PEX — cross-linked polyethylene
PEX-AL-PEX – PEX-aluminum-PEX metal/plastic composite
PP — polypropylene
PVC — polyvinylchloride

1. GRAY WATER REUSE SYSTEMS

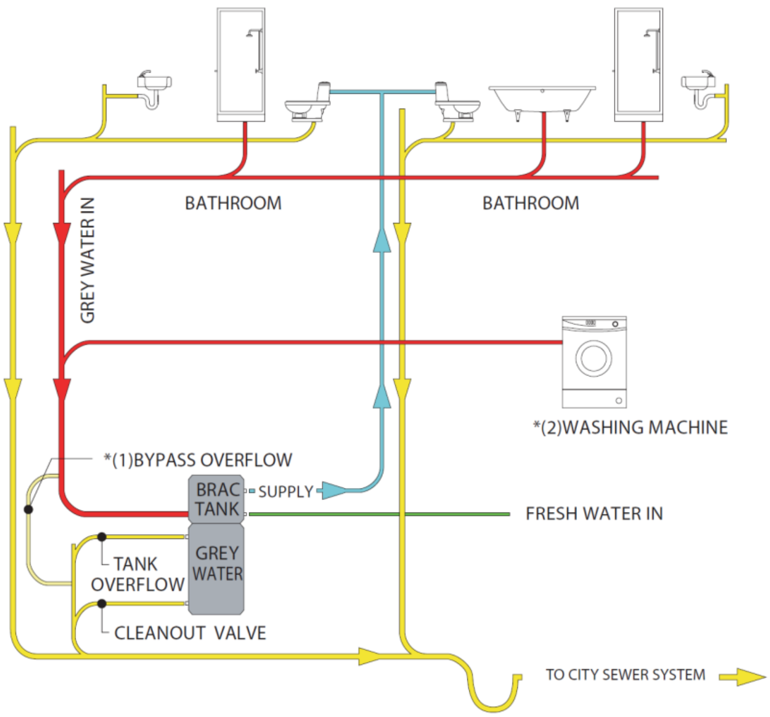
1.1. Technology overview

Wastewater produced in a home or business is comprised of gray and black water. Gray water consists of wastewater from bathroom sinks, bathtubs, showers, and clothes washers and typically accounts for 60% of the wastewater produced in homes. It contains significantly less pathogens and nitrogen than black water (water from toilet flushing, kitchen sinks, dishwashers and similarly contaminated sources) and therefore requires a lower level of treatment for reuse.

Gray water reuse systems separate the two streams of wastewater with dedicated waste piping systems (i.e., black water and gray water streams), collect and store the gray water, treat it as necessary and then distribute it to the outlets designated for non-potable water supply. The distribution is usually done under pressure, using a separate water distribution system. Such water is often referred to as on-site treated or recycled water and is considered non-potable, that is, not appropriate for human consumption or cooking.

Gray water reuse systems can be very simple and inexpensive (e.g., a three-way diverter valve and a tank installed under a bathroom sink or laundry tub that only collects and diverts gray water) or very complex and expensive (e.g., systems with electronic controls, disinfection, chlorination, ozonation, filtration, etc.). Systems can either be custom designed and built, or purchased as a package. Some manufacturers claim that their systems can produce water of drinking quality.

Generally, gray water reuse systems collect gray water through a three-way diverter valve, treat it using a sand filter or settling tank to remove coarse material such as hair, soap flakes, sand, and lint, retain it in a non-pressurized storage tank, and then distribute it under pressure to the non-potable outlets. The non-pressurized storage tank will have an overflow to divert excess gray water to a municipal or onsite drain line, and can also have a backup water supply in case there is insufficient gray water. The following figure illustrates a typical gray water reuse system.



Source: Brac Systems

In North America, acceptable uses of the non-potable water generally depend on local codes, but typically include sub-surface irrigation of lawns, trees and ornamentals, flushing toilets and urinals, and exterior washing. In other parts of the world the uses are much broader and may include showering, bathing, and even drinking.

Benefits

Gray water reuse systems offer significant reduction in potable water consumption and wastewater generation. Some manufacturers claim that such gray water reuse systems can save 30% to 40% of the annual water bill.

In addition to the water savings, other benefits derived from gray water reuse systems are as follows:

For users:

- Reduced water supply and sewer costs;
- Reduced volume and costs associated with wastewater generated onsite;
- In locations where there is no municipal water supply, reduced number of trips to haul potable water; and
- In locations where there is no municipal sewerage system, reduced number of trips to empty sewage holding tanks or reduced onsite wastewater treatment needs, adding to cost and space savings.

For municipalities and utilities:

- Reduced demand for municipally-treated potable and reclaimed water;
- Reduced overall energy-use associated with conveying and treating water (both potable and

wastewater); and

- Deferred and reduced capital investments in upgrading or expanding water and wastewater conveyance and treatment facilities.

Installation of gray water reuse systems in new construction is relatively simple as long as space is available for larger components such as a holding tank and filters because it is easy to separate gray and black water drain lines in new construction. Retrofitting one-story homes that have a crawlspace or basement foundation can also be relatively simple. However, the technical and economic feasibility of installing a gray water reuse system in an existing building should be examined on a case by case basis.

Limitations

There are a number of limitations and issues that should be considered when installing a gray water reuse system. For example, the quality of gray water varies depending on the source and care must be exercised to protect the health of the public. Additional gray water reuse systems considerations are listed below:

<u>Gray water sources:</u>

- Wastewater from the kitchen sink and dishwasher is not considered suitable for reuse, as it can contain high proportions of organic material, fats, caustic additives, and food scraps that can clog the piping.
- Laundry wastewater, while being the most accessible source of gray water, can vary in quality between wash loads and can be contaminated with lint, oils, greases, chemicals, soaps, nutrients and other compounds. For households with cloth diaper washing or communicable disease, the discharge is considered black water and care must be used to prevent its reuse. The State of California requires a method of switching the output of clothes washers for this reason.
- Wastewater from bathroom showers and sinks is sometimes not easily accessible because drain pipes are usually below the floor and very close to the toilet wastewater connection. In addition, the wastewater can be contaminated with soaps, hair, shampoos, toothpaste, lint, body fats, oils and cleaning products.

<u>Irrigation applications:</u>

- Gray water should not be used to irrigate root vegetable gardens, but it is considered safe for sub-surface irrigation of lawns, trees, and ornamentals.
- While high levels of nitrate and phosphate can be beneficial to many plants, landscaping plants should be selected with care, as some native and exotic plants do not tolerate the alkalinity or high phosphate content of typical gray water sources.

<u>Health concerns:</u>

- Use in ponds or for above-surface irrigation is usually prohibited due to the risk of mosquito breeding, contact with human skin and possible pathogen transfer, such as bacteria (e.g., fecal coliforms) and protozoan (e.g., Giardia).
- Bacteria and other microscopic organisms which feed on the nutrients in gray water may cause the wastewater to become septic after a day or two.
- High levels of nitrate and phosphate may be harmful to humans if ingested.

Barriers to adoption

Permit approvals may take longer because local regulators, code officials, sanitary engineers, inspectors and boards of health might not be familiar with gray water reuse systems. Lack of familiarity with such systems may also add to the overall costs, as some jurisdictions might require detailed drawings signed by a professional engineer.

Other impacts
One manufacturer indicated that because the resulting wastewater is no longer diluted with gray water, the strength of black water produced in buildings that have gray water reuse systems can be very high. This increased concentration and reduced flows can affect the performance of onsite septic systems and may have unforeseen impacts on existing wastewater lines.

1.2. Water Savings

Water Conservation Estimates
According to the American Water Works Association (AWWA), the daily indoor per capita water use in a typical single family home in the U.S. is 69.3 gal, broken down as follows:

Use	Gallons per Capita, per Day	Percentage of Total Daily Use	Gallons per Capita of Gray Water	Percentage of Gray Water
Baths	1.2	1.7%	1.2	3.1%
Clothes Washers	15.0	21.7%	15.0	38.8%
Faucets	10.9	15.7%	10.9	28.2%
Showers	11.6	16.8%	11.6	30.0%
Dishwashers	1.0	1.4%		
Toilets	18.5	26.7%		
Leaks	9.5	13.7%		
Other Domestic Uses	1.6	2.2%		
Total	**69.3**	**100.0%**	**38.7**	**100.0%**

Source: Compiled from data from Vickers, 2001

Our research revealed that water savings estimates vary between 8 and 20 gallons per day (gpd) per person, or 11,680 to 29,200 gal per year for a 4-person household. One manufacturer indicated that total water consumption in the typical 4-person household in the U.S. is 200 gpd and water savings derived from the use of a gray water reuse system are approximately 40%.

This level of savings can typically be realized if gray water is reused completely and its volume is sufficient to fully satisfy a particular need in place of potable water. Otherwise, as it has been observed and documented in the U.S. and Australia, gray water reuse systems can have a significantly reduced net benefit.

Economic Analysis
The total cost of a gray water system includes costs of the components, installation, operational and maintenance costs. There appears to be no “typical” project that could be used as a benchmark for estimations of gray water systems-related costs, as factors contributing to the overall cost vary significantly from case to case. The following table provides an indication of costs for gray water systems intended for residential and commercial applications in North America for several systems.

The table summarizes sample cost data obtained for different systems. It should be noted that the Equaris Household Water Treatment and Wastewater Recycling System is intended to produce drinking water for the household, hence its significantly higher capital cost.

Examples of Gray Water Reuse System Costs, USD				
Description	**System costs**		**Installation costs**	
	min	**max**	**min**	**max**
Brac residential systems	$1,800	$4,000		
Brac commercial systems	$6,500	$50,000		
Rough-in for a gray water system in a 2.5-bath home (Toolbase Services)			$325	$500
Equaris gray water (Wash Water) treatment system		$7,500		
Equaris Household Water Treatment and Wastewater Recycling System (H20RS)		$32,500		

Jurisdictions that allow gray water reuse systems sometimes require that the homeowner enter into a maintenance contract for the system, which would include water sampling and testing. Indications are that the monthly service contract fee would be between $35 and $60.

The 2006 Water and Wastewater Rate Survey published by the American Water Works Association estimates that the average combined charge across numerous counties and cities in the U.S. is $7 per 1,000 gal of fresh water and wastewater. The resulting potential cost savings for a 4-person household based on an estimated 40% reduction in water consumption and assuming a cost of water of $7 per 1,000 gal is $204 annually.

A simple analysis of economic payback for specific examples of residential and commercial gray water reuse systems resulting in a 40% reduction in potable water consumption was completed based on water pricing in Florida, California and Minnesota:

	Installed Cost, USD	**Economic Payback Period, years**		
		Florida	**Minnesota**	**California**
Residential	$4,000	negative	negative	negative
Commercial	$50,000	3.6	3.0	2.1

A negative payback period indicates that annual operating and maintenance costs are higher than estimated annual savings achieved.

See the Energy and Water Savings Methodology subsection within the Introduction and Background section of the report for a description of methodology used and limitations of this simple payback analysis. Appendix A contains the data, calculations and data sources used for the water savings analysis.

1.3. Materials Used (Piping, Tubing, Fittings)

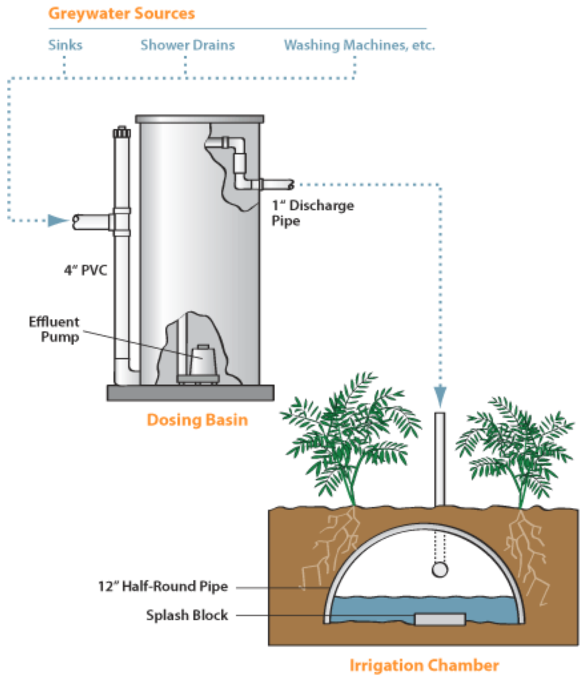
Pipe materials conventionally used for water distribution are generally considered suitable for water for reuse, including PVC, and HDPE, ductile iron, copper and steel (including stainless steel). Coated pipe, such as concrete lined DI pipe, may also be used. Plastic pipe is considered suitable for gray water reuse applications because it does not corrode with acidic or aggressive water. Purple colored PVC, CPVC and PEX is available to help identify non-potable water lines.

Piping used to collect and convey gray water to the holding tank is typically ABS, PP or PVC drain, waste, and vent (DWV). The amount of pipe and fittings used will depend largely on the layout of the home, the extent of the gray water collection (number of fixtures from which the gray water is obtained), and the type of system installed.

Similarly, the piping for the non-potable supply system can be PEX, PEX-AL-PEX, PE-AL-PEX, CPVC or copper. Again, the amount of pipe and fittings will depend largely on the layout of the home and the number of non-potable water outlets. In addition, if the gray water is distributed by gravity only, the distribution piping can also be ABS, PE or PVC DWV. The IPC 2009 allows the use of service piping, such as PVC and PE for this application.

For systems intended for subsurface irrigation, the irrigation chambers are typically PVC half-pipes, as shown in the Clivus system. 3" perforated plastic pipe can also be used. Gray water flows to a dosing basin, where it is collected and stored for not more than a day. A level switch activates the dosing basin's effluent pump or gravity siphon (where sufficient slope is available), and gray water is moved to the irrigation chambers. The irrigation chamber is a half PVC pipe with a diameter of 8 to12 in, placed within the root zone. The number of irrigation chambers and their lengths are determined by gray water volume, soil characteristics and site design. These gray water systems are always custom-designed.

Composting Toilets and Gray Water Systems



Source: Clivus Multrum Incorporated

1.4. Operating Example(s) and Testimonials

Operating Examples

Queens Botanical Garden, New York

Queens Botanical Garden (Queens, NY) was built to achieve LEED platinum standards. The complex hosts approximately 300,000 annual visitors on a 10-acre site. Its 16,000 ft^2 visitor/administration building reuses gray water for flushing all conventional fixtures. Other green technologies incorporated include a geothermal heating and cooling system, composting toilets, rooftop solar panels and a green roof.

Heart House, Maryland

Heart House, located in Maryland, is a 3-bedroom farmhouse and ecological retreat center with a Clivus composting toilet system and a gray water system for complete nutrient recycling, protecting the farmland and forests on the site from pollution. The flower beds are watered from a 90-ft irrigation chamber, while compost liquid is drawn from a storage tank by impulse sprinklers to fertilize the landscape.

Lewis Mill, Maryland

The Lewis Mill is an old grist mill which now houses a residence and several businesses. This mill is a demonstration site for the NutriCycle System, a waterless, composting toilet combined with a gravity gray water recycling system that provides a low cost and non-polluting alternative to septic systems or sewers. The only maintenance associated with the gray water system is to replace the nylon mesh screen filter once a year. During the winter, water flow is diverted to a second set of pipes located just below the frost line.

Testimonials
The following is a testimonial for gray water reuse systems from a Wash & Water user (Australia). Further information and details can be found in their website, which is listed in the references section.

I have been using the Wash and Water system since December 2006. With a five-person household, I wash one load per day on average. Knowing the huge amount of water I was wasting and that I didn't want my garden and lawn to die because of the drought and water restrictions, I started hosing the washing water directly from the machine onto the lawn. This only wrecked the pump in my washing machine! I found the solution with the Wash and Water system which has enabled me to stop wasting water and to keep my beautiful garden and lawn. Wash and Water is a cleverly-designed system which was easy to install – no plumber required – and easy to use. As well as the water from the washing machine, I catch rain water (when we get it) by placing the bin under the down pipe. I recommend a Wash and Water system to anyone who does not want to waste our precious water and who wishes to maintain a garden and lawn.
Helen, Kambah, ACT

1.5. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

2006 Water and Wastewater Rate Survey, American Water Works Association, Denver, Colorado and Raftelis Financial Consultants, Inc., Charlotte, North Carolina.

Brac Systems – Gray Water Recycling. http://www.bracsystems.com/.

Brandt, Peiffer A. 2006 Water and Wastewater Rate Survey Preliminary Results and Industry Trends. *Proceedings of the Water Environment Federation,* 71-80: 5884-5887(4).

Canadian Standards Association. CSA B128 Series-06 standard, Non-potable water systems

Clivus Multrum Incorporated. Composting Toilets and Graywater Systems by Clivus Multrum. http://www.clivusmultrum.com/.

Dr. Ing. Settimo Martinello. Save water system mod. v1. Casapassiva.com. http://www.casapassiva.com/en/houses/55_Save_water_system_mod_v1.php.

Equaris Corporation. The Equaris BMRC wastewater system. http://www.equaris.com/

Environmental Protection Agency: http://www.epa.gov/water/

Gray water: what it is…how to treat it…how to use it. http://www.graywater.com/.

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2. RAINWATER HARVESTING

2.1. Technology Overview

Rainwater harvesting systems collect or 'harvest' rainwater for commercial and residential use. The technology is adaptable to a wide variety of conditions and is used in the richest and poorest countries as well as in the wettest and driest regions of the world, and has been in use since ancient Greek and Roman times. Rainwater harvesting not only reduces potable water consumption, but is an effective strategy for managing storm water runoff rates - an especially important consideration in areas with combined sanitary and storm sewer systems.

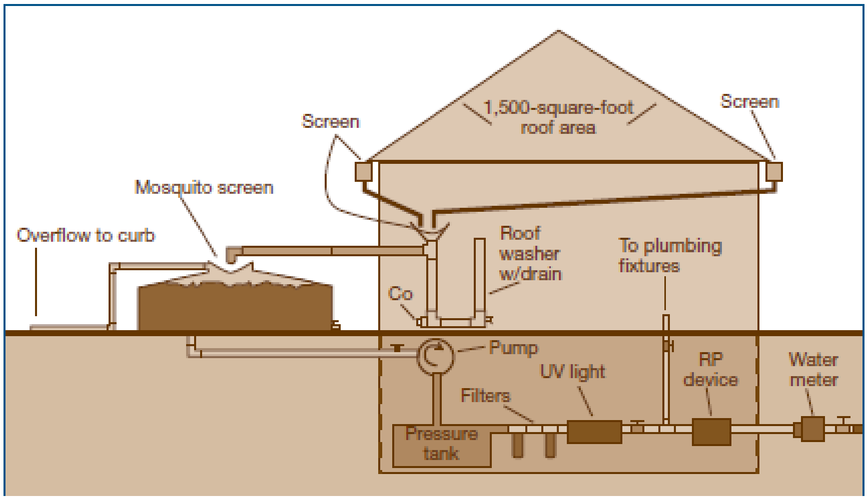
In developed countries, use of harvested rainwater generally includes irrigation, flushing toilets and washing laundry. However, in certain parts of the developed world such as Australia, New Zealand, Germany, and even in parts of the U.S. (e.g., California and Texas), rural households rely on rainwater as the only source of water for all household activities. On a global scale, harvested rainwater is also used for bathing and drinking, following appropriate treatment. In poorer parts of the world rainwater harvesting is often used where capital intensive and technically complex traditional water supply systems are not affordable. Rainwater may also be used for recharging the groundwater sources. On commercial building sites rainwater can be used for cooling-tower make-up water.

As water conservation grows in popularity, more people have begun to make their own domestic rainwater harvesting installations using DIY plans and construction information available on the Internet. These systems range from traditional and inexpensive technologies like rain barrels connected to existing gutters, leaders and roof systems to more complex systems depending on the degree of personal skill and preference. The installation effort generally depends on whether the roof or drainage system needs to be modified or replaced.

Other commercially available systems are extremely sophisticated, like some systems manufactured in Germany which incorporate computer management systems, submersible pumps, and links to gray water and main plumbing systems.

Commercial rainwater harvesting systems can be purchased as a package or be custom designed and built. The components typically include (refer to illustration below):

- The catchment area or collection surface (the most common is the roof of the building; however, other surfaces such as courtyards, threshing areas, paved walking areas, rock surfaces and plastic sheets may also be used);
- A rainwater conveyance system (gutters, leaders, and pipes);
- Holding vessels (tanks or underground cisterns);
- A "first-flush" diverter roof-wash system (usually the first 10 to 20 gallons of rain are diverted from the cistern) to exclude large particles and pollutants that may have accumulated on the collection surface;
- A delivery system (pumps, pressure vessels, controls, and pressure piping; however, depending on local circumstances, a gravity system may be sufficient); and
- A treatment system (filter, UV disinfection, distillation or reverse osmosis system).



Source: Oregon State Rainwater Harvesting Smart Guide

There are an almost unlimited number of options for storing rainwater. The water storage tank usually represents the biggest capital investment element of a domestic rainwater harvesting system. It therefore requires careful design to provide optimal storage capacity while keeping the cost as low as possible.

For storing larger quantities of water the system will require a tank or an underground cistern. These can vary in size from 265 gal (1000 L) up to hundreds of thousands of gallons for large projects, but typically up to a maximum of 8,000 gal (30 m³) for a domestic system. The choice of system will depend on a number of technical and economic considerations such as:

- Space availability;
- Storage options available locally;
- Local traditions for water storage;
- Cost of purchasing a tank;
- Cost of materials and labor for construction;
- Materials and skills available locally;
- Ground conditions; and
- Whether the system will provide total or partial water supply.

The following pictures illustrate several examples of rainwater harvesting systems, including the filtration systems and complex control systems:

Source: Rainwater Connection

Source: Free rain Inc.

Rainwater harvesting systems are increasingly being incorporated into commercial and institutional buildings such as offices, schools and hospitals. Such buildings generally have large roof areas which present storm-water management issues, and collecting rainwater from them for reuse helps to alleviate those issues. In addition, commercial and institutional buildings have a high and potentially expensive demand for non-potable water, resulting in relatively short economic payback periods.

Warehouses and distribution centers, with their requirement for fleet vehicle washing are another excellent example of the cost-effective application of rainwater harvesting. In short, any building with a large roof and a high-demand for non-potable water can use rainwater harvesting to help alleviate storm-water management issues and achieve substantial savings on reduced consumption of municipal potable water.

Benefits
Rainwater harvesting systems can offer a significant reduction in potable water consumption. Some manufacturers claim that such systems can save 30% to 40% of the annual water bill.

In addition to allowing reduction in potable water consumption, rainwater harvesting systems:
- Provide free water, once the initial investment is recovered;
- Are generally a simple technology that can be a high-quality source of water, provided the system is well designed and maintained;
- Provide naturally soft water. Therefore, in hard water areas harvested rainwater is of superior quality than municipal water and does not build scale; and
- Allow construction of buildings in places where there is no municipal water supply or nearby aquifers, rivers or lakes.

In urban areas, rainwater harvesting:
- Mitigates urban flooding by reducing or controlling the amount of rainwater that goes into the storm sewers (i.e., helps reduce the impact of urban developments);
- Provides supplemental water for onsite use;
- Reduces water demand from municipalities, thereby reducing energy required to convey and treat water (potable and wastewater);
- Defers and reduces municipal capital investments for upgrading water and wastewater conveyance and treatment facilities;
- Increases soil moisture for urban greenery;
- Helps recharge the ground water table and improves the quality of groundwater (if the harvested rainwater is infiltrated back into the ground); and
- Allows growth of plants necessary for environmental stability by providing a ready supply of water for their survival.

Limitations and Other Considerations
There are issues, challenges and limitations that need to be considered for rainwater harvesting systems. For example, depending on the environment, water collected during the initial minutes of a rainfall usually contains airborne pollutants, windblown dust, particulates, pesticides, inorganic ions (Ca, Mg, Na, K, Cl, SO_4), and dissolved gases (CO_2, NO_x, SO_x).

Roof-wash may be achieved through a mechanism known as a “first-flush diverter” that sends the initial water flow to waste, removing large particles and pollutants that might accumulate on the collection surface. Regular inspection and maintenance of such devices is necessary.

Uncoated stainless steel, galvanized steel with a lead-free baked-enamel finish, or fiberglass roofs are considered the best choices for rainwater catchment surfaces. Most other roof materials have issues that need to be addressed and will likely require treatment of the rainwater, such as the following:
- When an old roof is used as the catchment area, if it is under tree branches, if the building

relies on wood heat, or if the air is too polluted there may be elevated contaminant or toxin levels.

- Roofs with wood shakes, concrete or clay tiles, or asphalt shingles can support unwanted biological growth such as mould or bacteria that will require treatment of the rainwater.
- Some materials, such as lead solder, treated wood, copper, or terne coating (terne is an alloy that contains 80% lead and 20% tin used to cover steel, to inhibit corrosion) can leach unwanted toxins into the rainwater.
- Asphalt shingles use copper as a fungicide, which may leach into the rainwater.
- Built-up tar and gravel roofs contain oils that are detrimental to the rainwater quality.

It is also necessary to consider local code requirements for rainwater harvesting systems. The following are some of the issues that need to be considered:

- Local building or health departments should be contacted before installing a rainwater harvesting system.
- Requirements and restrictions regarding water supply are not nearly as stringent as those governing water disposal.
- Some jurisdictions place rainwater in the same category as gray water, something that the rainwater harvesting industry disagrees with.
- Codes require an air gap between the municipal water supply and the rainwater system if municipal water feeds into a rainwater holding vessel as backup.
- Health departments require that cisterns be covered, to avoid mosquito breeding.
- Some municipalities restrict the use of harvested rainwater to irrigation only.
- Some municipalities require fully engineered plans, which can add up to $2,000 to the cost of a system.
- Certain jurisdictions, such as the state of Colorado, have restrictions on the collection and use of rainwater (i.e., state law says that the rainwater and storm water belongs to those who have the rights to the waterways).

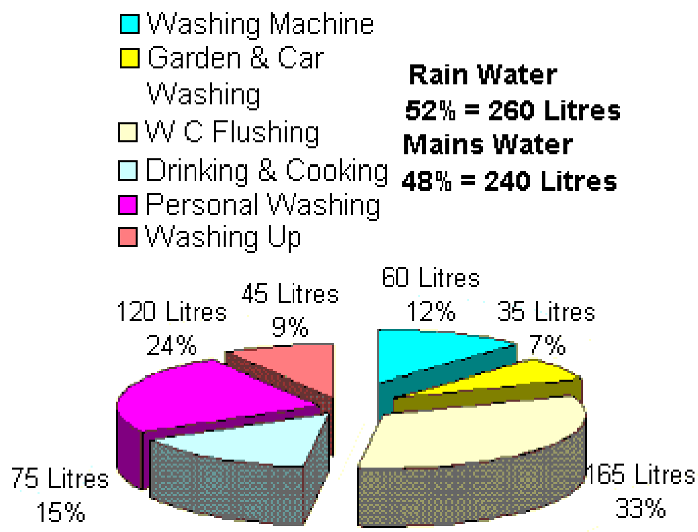
There are also other water quality considerations cited by experts, such as:

- Harvested rainwater may need to be analyzed from time to time. There is a need for universities and academia to get involved in testing the water (research).
- When rainwater is going to be used for drinking purposes, a reverse osmosis filtration system is needed. In this case, system components need to be chosen to comply with local code requirements and NSF standards for materials in contact with potable water.

2.2. Water Savings

According to ML Concept Ltd., depending on normal usage, a savings of 30 to 50% of the drinking water in houses and up to 80% in a business or commercial building is achievable.

Freerain Ltd., a UK-based rainwater systems specialist, reports a savings of approximately 50% of the typical municipal potable water consumption as shown by this pie chart:



Source: Freerain Ltd, UK.

In general, a typical 1,000 ft^2 roof can provide more than 600 gal/yr of rainwater for every inch of rainfall. In the Raleigh area, the average rainfall is 3 to 5 in per month (36 to 60 in/yr); therefore, the rainwater harvest for a typical 1,000 ft^2 ranges from 22,000 to 60,000 gal/yr. This can easily cover the amount of water needed for irrigation, washing cars and flushing toilets each year in a typical home in the U.S.

According to a technical bulletin on rainwater harvesting by Southface:

> The average U.S. household uses 146,000 gal of water per year with up to 50% of water going towards landscaping during summer months. Installing a rainwater harvesting system is one way to reduce outdoor water use by collecting water during the rainy season that can be used during droughts. By capturing water on a 1,500 ft^2 roof, a family could reduce their water bill by 50% and save 43,000 gal of water per year.

System losses such as evaporation or leakage need to be considered when conducting conservation estimates from a rainwater harvesting system.

Economic Analysis

The initial cost varies significantly depending on the chemical qualities of the rainwater, the catchment area material and the end use of the water, which determines the energy consumption and cost of treatment. A complete system (not including the catchment area) can cost $20,000, with sophisticated filtering and purification components. By contrast, a simple rain barrel system used for watering plants may cost only $200. Commercial systems will cost more depending on size and requirement, but will have a much quicker payback period.

Interviews conducted with various providers of rainwater harvesting systems revealed that:

- The cost of a system can range anywhere from $200 (for a rain barrel) to $50,000 and is determined mostly by its storage capacity (i.e., tank size).
- Aesthetics have a significant impact on the cost.
- The quality of the water and the intended end use is required for design. If it is for drinking purposes, a reverse osmosis filtration system is recommended.

- Filters for gravity systems can remove suspended particles as small as 150 μm, and even finer filtration can be achieved in pumped systems.
- The cost of piping, in a typical $5,000 system, is about $600.
- Operating and maintenance costs are as follows:

Other factors that affect the cost of rainwater harvesting systems are:

- Local plumbing labor rates.
- Whether it is new construction or retrofitting an existing building.
- Whether the system will provide total or partial water supply.
- If the roof material needs to be improved, the cost of the system can increase by $2,000 to $4,000.
- If the rainwater system uses pumps for pressurizing the distribution system, the operating costs can be between $600 to $720 per year ($50 and $60 per month).
- Annual maintenance for sediment cleanup and possible filter replacement can cost up to $420, and will also depend on the distance to the maintenance provider.

For smaller systems, the annual operating and maintenance costs can offset water savings achieved, resulting in a negative payback. Systems are most cost-effective in places where the water supply is of poor quality, unreliable or expensive. In areas not served by a municipal water supply, in drought-prone areas, or where there are local watering restrictions, installing a rainwater harvesting system can be a convenient and economical option. In regions where the municipal water quality is questionable, treated rainwater can be a solution.

Some jurisdictions offer tax credits for installation of rainwater harvesting systems. Arizona, for example offers a one-time tax credit of 25% of the cost of the system up to a maximum of $1,000. Builders are eligible for an income tax credit of up to $200 per residence constructed with a water conservation system installed.

In general, rainwater harvesting systems have higher initial costs than buying water from a central water supplier, and the decision on whether it is a viable investment should be determined on a case by case basis. The largest cost component of the system is for the cistern. Several sources indicated that payback period ranges from 1 to 6 years, but the actual payback period will ultimately depend on the initial system cost, collection area and efficiency, treatment needs and water usage.

For illustrative purposes only, a simple analysis of economic payback for specific examples of rainwater harvesting systems resulting in a 50% reduction in potable water consumption was completed based on water pricing in Florida, California, and Minnesota:

	Installed Cost, USD	**Economic Payback Period, years**		
		Florida	**Minnesota**	**California**
Residential	$5,000	negative	negative	41.7
Commercial	$20,000	1.2	1.0	0.7

A negative payback period indicates that annual operating and maintenance costs are higher than estimated annual savings achieved.

See the Energy and Water Savings Methodology subsection within the Introduction and Background section of the report for a description of methodology used and limitations of this simple payback analysis. Appendix A contains the data, calculations and data sources used for the water savings analysis.

2.3. Materials Used (Piping, Tubing, Fittings)

Plastic pipe and tubing is considered suitable for rainwater harvesting applications because it does not corrode with acidic or aggressive water. Rainwater harvesting systems typically use PVC or PE pipe rated for potable water. However, piping for the catchment portion is sometimes PVC DWV (not rated for potable water). Purple colored PVC, CPVC and PEX is available to help identify non-potable water lines.

Interviews with manufacturers revealed that no other piping materials are commonly used in the systems and the cost of the piping is about 10% of the cost of a typical $5,000 rainwater harvesting system.

2.4. Operating Example(s) and Testimonials

Operating Examples

U.S. National Volcano Park, Hawaii

At the U.S. National Volcano Park, rainwater systems were built to supply water for 1,000 workers and residents of the park and 10,000 visitors per day. The Park's rainwater harvesting system includes the rooftop of a building with an area of 1 acre (0.4 ha), a ground catchment area of more than 5 acres (2 ha), storage tanks with two reinforced concrete water tanks with 1,000,000 gal (3,800 m3) capacity each, and 18 redwood water tanks with 25,000 gal (95 m3) capacity each. Several smaller buildings have their own rainwater systems as well. A water treatment and pumping plant was built to provide users with good quality water.

Northern Guilford Middle and High School, North Carolina

The rainwater harvesting system has a 360,000 gal (1,350 m3) cistern with a flat top that is also being used as a basketball court. The system can fulfill 80 to 90% of the school's water demand and retains reserve water for fire protection.

Station Place Housing Tower, Portland, Oregon

Station Place, a 13-storey affordable housing tower, flushes 76 toilets on seven floors using a 20,000 gal tank. Expected annual water savings are 250,000 gal.

Ersson Residence, Portland, Oregon

In 1996, Portland's first permitted rainwater harvesting system was built to supplement residential water needs. The system was designed to harvest and purify rainwater for all of the household's water-related needs, except during long dry summers, when the homeowners switch back to city water. The 1,500-gal system collects 27,000 gal a year, effectively providing enough water for 9 months of the year. The system cost around $1,500.

Bacon Residence, Portland, Oregon

In 2002, a state-of-the-art 3,400-gal system that provides water for all household uses, including drinking water, was installed. The system collects and stores enough water for all the homeowner's water needs for 10 months a year and cost $7,000 to design and install.

Testimonials

Vesuvius Bay Road, Salt Spring Island, BC (obtained from the Rainwater Connection website):
"Many people don't want to face the fact that water will be a serious problem on this island. Since water is essential to my life – I decided to invest $5,000 and my labor to ensure a supply of water for my garden or for domestic use in times of drought. The garden produces a wide range of tomatoes, vegetables, and fruits including a fine crop of apples (MacIntosh, Gravenstein, and Red Northern Spy). Our golden plum tree held a bumper crop this year and the large crop of strawberries were eaten fresh or made into jam. The three cherry trees were left for the birds.

With some professional advice, I developed a plan to take advantage of this natural resource. I installed fascia boards under all my eaves, and large eave troughs. These were linked by down pipes and plastic pipe through coarse and fine filters to three 2,400 gal tanks. An electric pump and pressure tank pumped the water from the lower tank to a soaker hose in the garden. By the beginning of March, my system was complete. By July, I had 7,000 gal in my tanks."

From *Pulteney Street Plumbers* in March 2009:
"We were complete novices in the area of domestic water conservation, though we were keen to look at eco-friendly alternatives as we undertook an extensive build and renovation project on a house. Chris started by explaining the basics, for example the difference between gray water recycling and rainwater harvesting. Rainwater harvesting struck us as a comparatively simple and often overlooked way of saving a vital resource. They assessed our building and site with us, and advised us on a size and type of system that would suit our needs. When the quotation arrived from the supplier, they took us through it, explaining the details clearly. They gave us an estimate of the overall costs involved for our budget, which proved to be accurate when we eventually went ahead with the installation. In the end we felt we had a good working understanding of the system and the cost so we could make an informed choice. Pulteney Street Plumbers communicated effectively (and patiently!) but we never felt pressured into a hasty decision. Their expertise and support were reassuring and helped us take a leap into the unknown and go for it! The installation and commissioning went smoothly, and the system has been functioning without a hitch for over a year. It now seems to us that rainwater harvesting should be designed into any new build and where possible, fitted to existing buildings. And you definitely feel good when it rains..."

2.5. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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3. GEOTHERMAL ENERGY SYSTEMS

3.1. Technology Overview

Geothermal ground source heat pump systems use the renewable source of natural heat, heat storage capacity and relatively constant temperature of the earth (45 to 75ºF just a few feet below the Earth's surface) or groundwater to provide energy-efficient space heating and cooling or preheating domestic hot water. In effect, the ground acts as a heat source in the winter and as a heat sink in the summer. Geothermal systems are more efficient than gas or electrical heating and are therefore considered more environmentally-friendly than other heating and cooling options. Geothermal energy systems can be used for new or existing buildings and homes of virtually any size or lot in any region of the U.S. if sufficient piping can be installed for the site configuration and footprint.

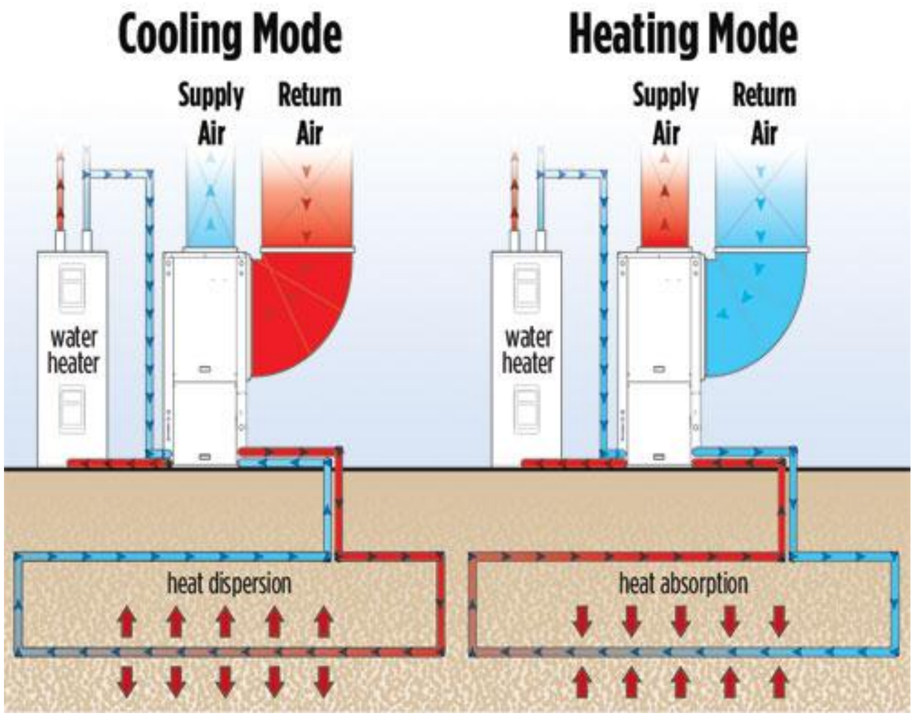
Geothermal energy systems consist of the indoor heat pump equipment, a ground piping loop, and a flow center to connect the heat pump and the loop. The ground loop, which is invisible after installation (it is buried or submerged), allows for the exchange of heat energy between the earth or groundwater and the heat pump.

The heat exchange fluid is pumped through the ground loop, where it either disperses heat to the ground in the summer or absorbs heat from the ground in the winter. The fluid is circulated through a heat pump, transferring heat to a forced air or radiant heating system in the winter and extracting heat from the building and dissipating it via the ground loops in the summer.

The diagram below illustrates a geothermal ground loop system supplying hot water to a radiant floor heating system.

Source: Pro Star Mechanical Technologies Ltd.

The diagram below illustrates the typical components and operation of a geothermal ground loop system providing space heating and cooling via conventional air ductwork.



Source: Blackwell Heating & Air Conditioning, Inc.

Special heat pump features include variable speed blowers and multiple-speed compressors, which can improve comfort and efficiency in areas where heating and cooling loads are quite different. An add-on feature is the capability to produce hot water.

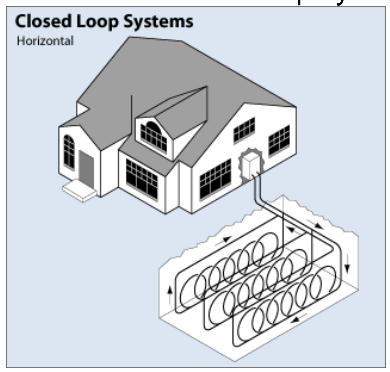
Geothermal energy systems can be open or closed-loop and can be installed in vertical wells or horizontal loops.

<u>Open-Loop Systems</u>
Open-loop systems draw groundwater from a conventional well for use as the heat source or heat sink. Groundwater is an excellent heat exchange medium for this technology, as it has a relatively constant temperature year-round. After it has passed through the heat pump, the water can be released into a stream, river, lake, pond, ditch, or drainage field using the open discharge method. Alternatively, the water can be discharged into a second well that returns it to the aquifer. The amount of water required by open-loop geothermal energy systems depends on the size of the system. According to Pioneer Electric Cooperative, approximately 3 gpm of water is needed per ton of system capacity. Therefore, a 3,000 ft^2, well-insulated home would typically require 8 to 15 gpm, with the average system using approximately 10 gpm. Open-loop systems are generally being phased out in favor of closed-loop systems.

<u>Closed-Loop Systems</u>
Closed-loop (or earth-coupled) systems circulate a water and antifreeze solution (typically ethylene or propylene glycol, which degrade into environmentally friendly compounds) to extract heat from the ground. They represent the great majority of the systems being installed.

- Horizontal loop systems are more cost-effective, where a sufficiently large lot size is available. Polyethylene (PE) pipes are installed in trenches that are 3 to 6 ft deep. The loop length depends on the configuration, soil type and system capacity, ranging from 250 to 1000 ft per ton.

Horizontal closed loop system



Source: US Department of Energy

- ○ Vertical loops are more practical where smaller site sizes are available and where soil disruption must be minimized. It is generally more expensive because vertical holes 150 to 450 ft deep must be bored into the ground to install the ground loops. A single loop with a U-bend at the bottom is inserted into each borehole before it is backfilled, generally with a special grouting. A horizontal pipe is connected to each vertical loop to transport the heat-transfer fluid to and from a heat pump. Less piping is required than for horizontal loops because the earth's temperature is more constant further below the surface.
- ○ Pond closed-loops can be most economical when the site is close to a body of water such as a shallow pond or lake. Fluid circulates under the water typically through PE piping in a closed system, without impacting the aquatic system. The pipes may be coiled to maximize the pipe surface-to-water contact.
- ○ Refrigerant loops, also called direct expansion (DX) systems, circulate refrigerant rather than water in soft copper tube closed loops. The loops are buried in the ground, and take advantage of the high thermal conductivity of copper to allow direct transfer of the heat between the ground and the refrigerant. These systems are potentially more energy-efficient than water loop systems, but require special care in application and design, as there is currently no standard method to size them. The copper loops are susceptible to corrosion in acidic soils. These systems are not as commonly used and represent a small proportion of existing installed systems.

Benefits

According to the California Energy Commission:

“Surveys taken by utilities have found that homeowners using geothermal heat pumps rate them highly when compared to conventional systems. Figures indicate that more than 95% of all geothermal system owners would recommend a similar system to their friends and family.”

Geothermal energy systems offer numerous benefits, some of which are listed below. Geothermal energy systems:

- ○ Can be more efficient than electric-resistance heating systems;
- ○ Are also typically more efficient than gas or oil-fired heating systems;
- ○ Are more efficient than air-source heat pumps because they draw heat from, or release heat to, the earth, which has moderate temperatures year round, rather than to the air;
- ○ Are less expensive to operate and maintain than other heating and cooling systems;
- ○ Are mechanically simple and outside parts are below ground and protected from the

weather;

- Save homeowners money in energy bills;
- Do not dry the air like most other heating systems;
- Produce energy that is clean and reliable; the U.S EPA estimates that 70% of the energy used in a geothermal energy system is renewable earth energy;
- Need no chimneys and have no open flame; and
- Produce no carbon monoxide and help reduce greenhouse gases.

Limitations and Other Considerations
Open-loop systems do not add pollutants to the environment but there is some concern that they may contribute to depletion of groundwater in regions of North America where groundwater supply is not abundant. Poor water quality is an issue that must be addressed in open-loop geothermal systems. Hardness, acidity, high iron content, particulates, minerals and organic matter in water sources can deposit in the heat exchanger, clog the pump, and make the system inoperable. Periodic cleaning is needed to remove the build-up.

In some jurisdictions, all or parts of the installation may be subject to local ordinances, codes, covenants or licensing requirements.

The ASTM E44 Committee on Solar, Geothermal and Other Alternative Energy Sources has developed standards for geothermal field development, utilization, and materials.

CSA standard C448.1-02 specifies requirements for PE pipe and fittings for geothermal systems that are in conflict with CSA standard B137.1. T the CSA technical committee is trying to address this conflict.

Both CSA and NSF International have programs to certify geothermal pipe for ground loop systems.

3.2. Energy Savings

The U.S. EPA estimates that geothermal energy systems can reduce energy bills by as much as 30 to 40% when compared to conventional air exchange heat pumps. They are included in the EPA's EnergyStar® program.

Typically, the investment in a geothermal energy system can be recouped in 6 to 12 years. However, the American Recovery and Reinvestment Act of 2009 offers a 30% tax credit for geothermal energy systems, reducing the payback period by 2 to 3 years.

Initial Cost
The initial cost of a geothermal energy system varies depending on local labor rates, lot geology and size, drilling conditions, type of system, equipment selected and local labor rates for installation. According to Toolbase.org, equipment costs can be 1.5 to 2 times more expensive for a geothermal system than an air source heat pump once the circulating pump, indoor tubing and water source heat pump are considered. This represents a $1,000 to $2,000 premium for the equipment necessary to run a 3-ton system.

The ground loop is generally the most expensive component of a geothermal system. Ground loop installation can cost between $1,000 and $3,000 per installed ton for a home. For either system, the cost of installed ducts is likely to be identical.

The total cost of a typical 3-ton system for a home varies between $8,000 and $15,000. Generally, a 3-ton geothermal system will cost $4000 to $11,000 more than an air source heat pump system. However, drilling can increase the total cost considerably, because the cost of drilling can run anywhere from $10,000 to $30,000 or more, depending on the terrain and other local factors.

Operational Cost

Geothermal energy systems offer a high-efficiency solution and low operating cost. According to the U.S. EPA, homeowners can save 30 to 70% on heating and 20 to 50% on cooling costs using geothermal energy systems compared to conventional systems.

A staff member at Ground Loop Inc., in Maryland, was interviewed and provided the following information for a residential system for a typical 4-bedroom, 2,200 ft^2 home:

- System capacity: 3 to 4 ton
- Capital cost: $30,000 to $40,000
- If a vertical loop is necessary, the system cost will increase by $7,000 (usually for smaller lots)
- Piping: Polyethylene
- Maintenance costs: Annual check-ups cost between $250 and $350. The supplier provides the service and the actual cost will depend on the distance from the company.
- Savings in energy: 40 to 70% of annual bill, or $358 to $1,475 annually.
- Tax credits: $500 per ton, per installation.

Calculations show that the average savings of electricity and natural gas, and consequently CO_2 equivalent greenhouse gases are significant. The following table shows the estimated energy savings, payback period, and associated CO_2 equivalent emissions reductions, assuming 50% reduction in the energy bill for a residential geothermal energy system with an installed cost of $15,000 and no rebates applied.

Residential System $15,000 Installed Cost	Annual Energy Savings, USD	Payback Period, years	CO_2 Emissions Reduction, tonnes
Florida	$900	16.7	2.8
Minnesota	$780	19.2	3.8
California	$870	17.2	3.6

The following table shows the estimated energy savings and payback period, assuming 40% reduction in total energy use for an office building.

Commercial System $100,000 Installed Cost	Annual Energy Savings, USD	Payback Period, years
Florida	$13,428	7.4
Minnesota	$10,055	9.9
California	$14,857	6.7

The CO_2 equivalent greenhouse gas emissions reduction for a 14,800 ft^2 reference office building is estimated to be 87 metric tonnes annually.

See the Energy and Water Savings Methodology subsection within the Introduction and Background section of the report for a description of methodology used and limitations of this simple payback analysis. Appendix B contains the data, calculations and data sources used for the energy savings analysis.

3.3. Materials Used (Piping, Tubing, Fittings)

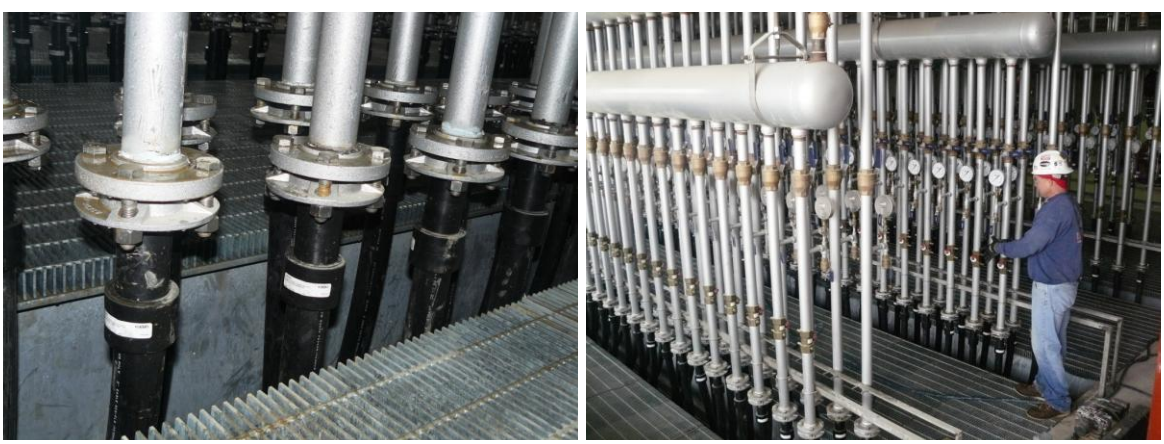
PE pipe is commonly used for geothermal energy systems loops, given its flexibility, resistance to chemical attack and corrosion, low cost and long service life. PE is also chosen because of it ease of joining using fusion welds, allowing for long runs underground without fittings.

PE pipe is used in almost all systems, with the exception of DX systems, where copper is the typical material given its greater conductivity. However, copper tube needs to be protected from galvanic corrosion, which may be achieved by running a small current through the tubes.

More recently, the use of PEX tubing is being promoted for geothermal applications based on its higher strength and durability. PP, CPVC, PVC and other plastic piping systems may also be used, depending on the specific application.

3.4. Operating Example(s) and Testimonials

Sherman Hospital, Elgin, Illinois
A new 645,000-ft^2 hospital is under construction, with a geothermal heating and cooling system with 150 miles of plastic pipe ground loops submerged in an adjacent 17-acre lake. The cost premium for implementing the system is expected to be $7,000,000, with projected annual savings on operating costs of $1,000,000 and a payback period of 5 to 6 years. The photographs below show the hospital's geothermal system manifold.



Source: Plastic Pipe and Fittings Association

Mandel Residence: 5-bedroom, 5-bath home in Bergen County, New Jersey
The owners expected to cut their gas and electric bill, which averaged about $1,000 a month, by slightly more than half and recoup the $60,000 cost of installing the new system within 10 to 12 years. The only drawback the owners noticed is the time it takes their home to warm. Because geothermal furnaces reach only about 120ºF - compared with 160ºF for an oil or gas furnace - there is more of a lag in bringing air up to desired temperature.

An installer posted the following comment: "*The payback period is 5 to 6 years with new federal incentives of 30% tax credit. Cuts heating & cooling bills up to 70%...*"

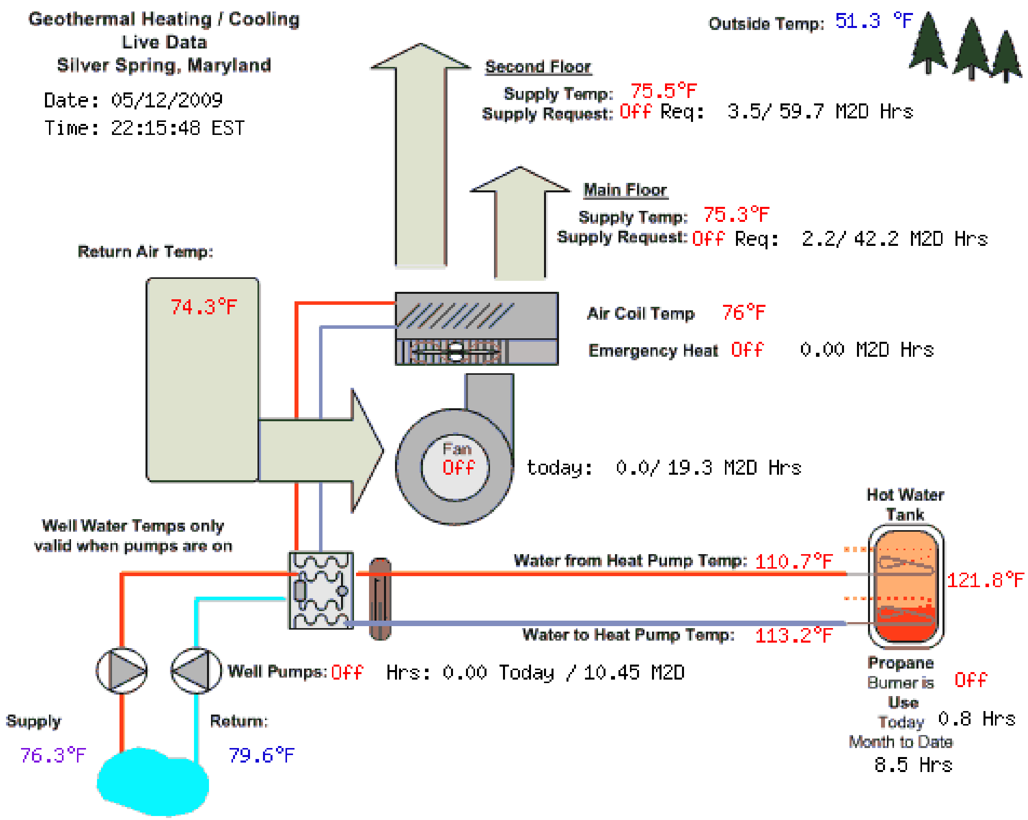
Fritz Residence: 2,900 ft^2 New Suburban House in Wellesley
A horizontal loop measuring 3,000 ft in length was buried in the backyard at a depth of 6 ft and a single forced air unit was installed in the basement to provide space heating, cooling, and hot water. The owners are enjoying great annual savings over the high-efficiency natural gas system that was the best alternative (they also have a reduced electrical bill from savings on air conditioning and hot water). The extra cost of installing the geothermal system will be quickly repaid. The geothermal system is also, of course, entirely non-polluting. They are also thrilled with the great comfort level geothermal energy provides. Even on the coldest days of last winter, the house was maintained at an even 70ºF during the day and 65ºF at night, as desired and there were no cold spots anywhere in the house. The Fritzes' experience demonstrates the applicability of the geothermal solution in a suburban environment.

30-year-old 2-Story House in Elmira, Ontario
The home was previously heated with a wood stove and an oil furnace, which was very loud during start-up, so the noise factor was a big issue. Even with the stove, it still cost $2,500 to heat the house and electric hot water costs amounted to $500 a year. A 1,000 ft loop was submerged in the pond behind the house, minimizing the amount of excavation and impact on the property and lowering cost. The geothermal system saves the owners $2,000 a year in heating and hot water costs, while also providing air conditioning and eliminated the hot and cold spots. The quiet operation of the forced air geothermal unit fixed the noise problem. Says Paul Schwindt: "We used to wake up in the middle of the night when the [oil] furnace would start up, now we never hear it [the geothermal system]."

Dobbens, Nineteenth-Century Farmhouse in Moorefield, Ontario
This 1,900 ft^2 farmhouse is 120 years old and has double-brick walls. Only the kitchen, bathroom, and one bedroom are insulated. The owners wanted a system that would cost them less than their fuel oil system, heat and cool their home more effectively, and would operate efficiently without any major renovations or upgrades. A horizontal loop measuring 3,600 ft in length was buried in the field beside the house. A forced air unit was installed in the basement along with a small amount of ductwork. A 40 gal preheat and a 60 gal water heater replaced the oil-heated water tank and oil furnace. The owners are saving approximately 65% annually on their heating bill, for a savings of $2,600 over the fuel oil system in the previous winter alone. With the additional savings on air conditioning and hot water bills, they can expect to get a full return on their investment in 8 years.

Freedman Residence, Silver Spring, Maryland
The owners have created a blog to track the progress of their home in Silver Spring, Maryland, and they state that:
"There are many reasons to go green: Save the planet, and reduce dependency of foreign goods. But to me it is all about dollars and cents.

Our investments in energy reduction includes Geothermal Heating & Cooling from Ground Loop Inc. Heating and Air Conditioning, BIBS insulation from Carroll Insulation, innovative heat storage and the use on-site resources are investments in our own future with a tremendous return on investment (ROI). No stock market investment will returns us the money that our reduced cost of operation in electrical and gas will provide us. If along the way we help save the planet for our children, that is good too."



Source: Dan & Patsy Freedman

Testimonials

The following owner testimonial was obtained from the Ground Loop Inc. website:

Earle and Donna Bailey wrote a letter to all of their neighbors to educate them about the benefits of geothermal energy systems:
"Dear Neighbor,
We just had a geothermal heat pump installed as were warned that our 15 year old heat pump needed to be replaced. Geothermal is more efficient than your traditional heat pump because it uses the constant moderate temperatures found below the earth's surface for heating and cooling rather than the air temperature that traditional heat pumps use. High efficiency geothermal systems use a small amount of energy to capture and move a large amount of energy. The U.S. Environmental Protection Agency recognizes geothermal systems as the most energy-efficient, environmentally friendly and cost-effective comfort systems available. It is environmental equivalent of planting 750 trees, or taking two cars off the road. It is so earth-friendly that the state and federal governments are offering incentives to offset the cost of installation. Please feel free to call, email, or stop by for more info."

3.5. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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CSA C448.2, Design and installation of earth energy systems for residential and other small buildings.

CSA C448.3, Design and installation of underground thermal energy storage systems for commercial and institutional buildings.

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4. HIGH-EFFICIENCY HOT WATER DISTRIBUTION SYSTEMS

4.1. Technology Overview

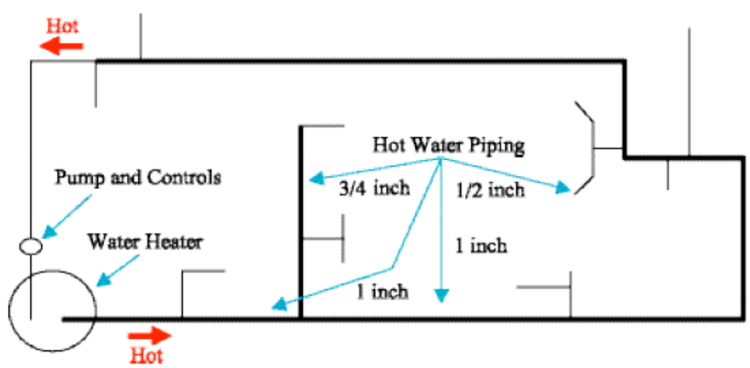
In many homes and buildings a significant amount of water, energy and time is wasted waiting for hot water to travel through pipes and arrive at the faucet, shower, appliance or device that uses and supplies hot water. A high-efficiency hot water distribution system minimizes the volume of water held in the piping and that must be purged prior to the hot water arriving at the point of use. Hot water remaining in the pipes after use then is left to cool and be expelled on the next use cycle as more wasted water. Efficiently designed hot water distribution systems reduce not only the wasted water but also the wasted energy used to heat it.

A high-efficiency hot water distribution system typically has:

- Piping that runs from the heater to the end fixture or appliance as short as possible and properly sized for the application (i.e., diameter as small as permitted by code);
- Energy-efficient water heaters (or boilers), located as close as possible to the end fixtures or appliances and properly sized for the application; and
- Insulated piping.

There are several options for achieving high-efficiency in hot water distribution systems.

<u>Structured Plumbing</u>
Structured Plumbing®, refers to a system in which a continuous loop of insulated CTS-3/4" or 1" PEX tubing (the trunk line) runs throughout the home from the water heater outlet and back to the water heater cold water inlet, and passes within 10 pipe-feet of each hot water fixture. Branch lines run from the trunk line to supply hot water to individual fixtures. Structured Plumbing is very effective when combined with a demand controlled hot water recirculation system. The following diagram illustrates a Structured Plumbing hot water system.



Source: Gary Klein

Recirculation systems are one alternative for achieving high-efficiency in hot water distribution systems, of which there are six different types:

- Continuous pumping;
- Demand-controlled pumping;
- Gravity (thermosiphon);
- Temperature-controlled pumping;

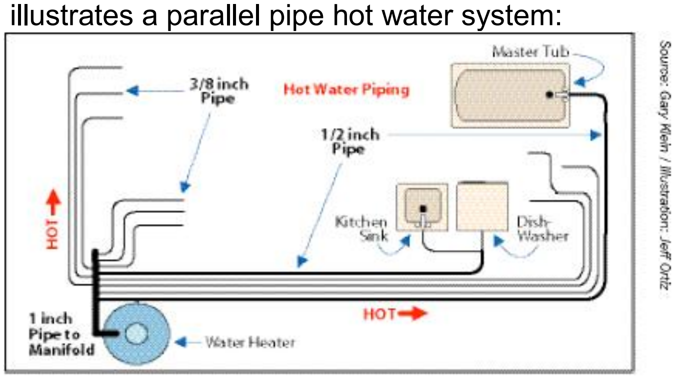
- ○ Time-controlled pumping; and
- ○ Time- and temperature-controlled pumping.

Demand-controlled pumping is the most energy efficient of the six types of recirculation systems listed above, and it is also the most energy-efficient hot water distribution system. The recirculation pump is user-activated by buttons, motion sensors or flow switches, and shuts off when the water temperature in the pipe reaches a preset limit. A study by Wendt, et. al. entitled *Evaluation of Residential Hot Water Distribution Systems by Numeric Simulation* show that demand-controlled recirculation pumps typically run as little as ten minutes a day while providing wait times similar to continuous recirculation systems (in which pumps run continuously), with the added benefit that water and energy waste is significantly reduced. Demand recirculation systems can be installed in both new construction and retrofit housing. They can cost several hundred dollars more than a conventional distribution system.

The least energy-efficient recirculation system is continuous recirculation. The energy requirements for running recirculation pumps, and more importantly the resultant significant piping heat loss when run twenty four hours a day make them economically unattractive.

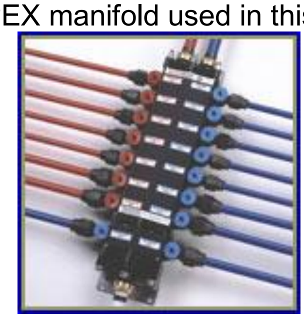
Another alternative to achieve high efficiency in a hot water distribution system is parallel pipe systems, also referred to as “home-run” systems, which use a central manifold to deliver water to individual fixtures or appliances through smaller diameter tubing. Because these smaller pipes hold less water volume and run directly from the manifold to the fixture, the wait times and water wasted during delivery are reduced, as is the energy wasted during cool down. However, energy and water savings for parallel pipe systems are sensitive to hot water usage patterns throughout the day and are most effective when most uses are non-clustered. These systems are typically less costly to install than conventional rigid copper pipe systems.

The following diagram illustrates a parallel pipe hot water system:



Source: Gary Klein. Klein, Gary. Hot-Water Distribution Systems – Part II.

The picture below shows a typical PEX manifold used in this type of system:



Source: Renovation Headquarters

All-plastic plumbing systems using remote manifolds or multi-port tees to supply groups of fixtures can offer additional significant advantages including reducing the number of fittings and connections, while providing flexible mounting options and not requiring access panels for maintenance. An added benefit of fewer fittings and connections is reduced pressure drop and turbulence in the supply lines.

Source: Uponor.

Benefits

High-efficiency hot water distribution systems offer numerous benefits, such as:

- Reduced energy and water utility bills for the home or building owner;
- Reduced wait times for the hot water to be delivered;
- a reduction in the volume of water wasted before the hot water reaches the fixture or appliance;
- A reduction in the amount of energy wasted when water sitting in the pipes cools down;
- A lower installed cost than conventional hot water distribution systems; and
- A Reduced burden on energy, water and wastewater utilities and associated treatment facilities.

Challenges

According to Gary Klein, an energy efficiency and renewable energy expert who currently helps administer the Public Interest Energy Research (PIER) Program at the California Energy Commission, most new home construction since 1970 has been in the south and western U.S., where basements are typically not constructed. Therefore, water heaters are generally located in the garage (resulting in longer pipe runs), pipes are often placed under the slab (creating greater heat loss) and, regardless of where they run pipes are rarely insulated.

Additionally, there are twice as many fixtures in the current median home as there were in 1970 and the distance to the farthest fixture has more than doubled. Therefore, trunk line diameter has increased from ½ inch to ¾ inch, and even up to 1 inch. As a result, the cross-sectional area of the pipe has increased by a factor of 2.25 to 4.0, with a corresponding increase in the volume and decrease in the velocity of water in the pipe.

All of these factors contribute to the fact that waiting times for hot water in new homes are longer than in older homes and hot water distribution systems are generally less efficient. The resulting water that is wasted requires energy to heat, energy to deliver (pump), and chemicals to treat, increasing the burden on both water and wastewater treatment facilities. There is also a great deal of mixing in the hot water lines running at low velocities, and as a result, wait times for hot water are extended even more.

Additional Considerations

The *Evaluation of Residential Hot Water Distribution Systems by Numeric Simulation* study evaluated the performance and economics of various domestic hot water distribution systems in California residences (i.e., potential energy savings and cost-benefit analyses). The study found that while the greatest opportunities for improved efficiency occurred in new construction, significant improvements could also be made in some existing distribution systems. The study recommended that policymakers:

- Remove barriers to the use of CPVC and PEX piping when appropriate quality and durability can be demonstrated.
- Consider ways to encourage the use of centrally located hot water heaters.
- Consider ways to encourage installation of demand recirculation and parallel pipe systems, when warranted.
- Educate builders and the public about the consequences of locating distribution systems below floor slabs and the benefits of alternative locations.
- Consider banning continuous recirculation systems.

The study also recommended that residential designers, builders, and plumbers:

- Install CPVC or PEX plastic piping in lieu of copper.
- Consolidate bathrooms and other hot water consuming activities in the same areas to take advantage of clustered patterns of hot water usage.
- Centralize the location of water heaters to minimize the length of piping between the fixtures and the water heater(s).
- Locate hot water distribution piping in the attic for single story homes without basements and interstitial space between floors for multi-storey homes.
- Avoid over-sizing hot water piping and use code-permitted minimums.
- Lay out systems with all hot water pipe runs as short as possible.
- Install demand recirculation systems in lieu of continuous recirculation systems if waiting time and water waste are an issue.

4.2. Energy and Water Savings

Energy and Water Conservation Estimates

The *Evaluation of Residential Hot Water Distribution Systems by Numeric Simulation* study shows, the construction costs, wait times, water and energy waste for a new 3-bedroom, 2-bathroom, 2,010 ft^2 home using a clustered hot water use pattern. The table below is adapted from tables in that study to show the type of system with the minimum and maximum value for each parameter listed.

Parameter	Minimum	Maximum
Construction cost, USD	Conventional system using CPVC pipe with a centrally located water heater	Continuous recirculation system using insulated copper pipe with the water heater in the attic
Typical wait time, seconds	Recirculation systems	Conventional system using copper pipe
Maximum wait time, seconds	Recirculation systems	Conventional system using copper pipe

Annual water waste, gal	Recirculation systems	Conventional system using copper pipe
Annual electricity waste, @$0.116 / kWh, USD	Demand recirculation systems	Continuous recirculation system using copper pipe
Annual gas waste @ $0.683 / therm, USD	Demand recirculation system using CPVC pipe	Continuous recirculation system using copper pipe

Source: Adapted from tables in Wendt et al.

A clustered use pattern occurs when individual draws are "clustered" together in the morning and evening as generally happens in a family that spends the middle of the day away from their home. The study assumed that for the first draw of the day (in the early morning) water in the piping system had reached ambient temperature. This pattern more closely predicts real world energy and water waste.

The study findings for a single family, 4-bedroom, 3-bath, 2-story, 2,810 ft^2 were similar, although the construction costs were between $1,038 and $3,170.

Parameter values for PEX parallel pipe systems with manifolds will typically fall between the minimum and maximum ranges indicated.

The following table shows the relative costs of operating conventional and high-efficiency hot water distribution systems.

	Water and Wastewater	Natural Gas	Electricity
Standard Distribution System			
Total annual cost for hot water including waste	$116	$250	$465
Annual cost associated with the wasted water	($36)	($84)	($156)
Annual cost associated with intended water use	$80	$166	$309
Additional Energy Costs to Operate Recirculation System			
Continuous pump (24 h per day, 5ºF temperature drop)		$366	$649
Thermosiphon (24 h per day, gravity, 5ºF temperature drop)		$336	$619
Timer-controlled pump (16 h per day, 5ºF temperature drop)		$244	$433
Temperature-controlled pump (12 h per day, 5ºF temperature drop)		$183	$325
Timer and temperature-controlled pump (8 h per day, 5ºF temperature drop)		$122	$216
Demand-controlled pump (10 min per day)		$15	$27
Additional Costs Associated with Residual Wasted Water			

	Water and Wastewater	Natural Gas	Electricity
Manifold systems (approximately 25% reduction)	$27	$63	$117
Heat Trace (approximately 90% reduction)	$4	$284	$284
All 6 recirculation alternatives (approximately 80% reduction)	$7	$17	$31
Notes: Water and wastewater costs at $0.05 per gallon, combined. Natural gas costs at $0.92 per therm. Electricity costs at $0.087 per kWh. Heat trace is only operated with electricity. The costs are the same whether the water heating fuel is natural gas or electricity.			

Source: Klein, Gary. Hot-Water Distribution Systems – Part III.

Estimated Cost Savings and Payback

The table below illustrates the consumption of energy associated with hot water use:

	Natural gas	Electricity
Gallons per day	60	
Gallons per year	21,900	
Energy into water	16,400,000 BTU	
Efficiency	0.6	0.9
Cost per unit	$0.92/therm	$0.087/kWh
Cost per year	$250	$465

Source: Klein, Gary. Hot-Water Distribution Systems – Part I.

Based on data from the California Urban Water Conservation Council for the San Francisco Bay Area (from Natural Resources Defense Council), the potential annual savings from using high-efficiency hot water distribution systems would equal the total annual water consumption of between 8,000 and 27,000 California homes.

The following table shows the estimated combined energy and water cost savings and payback period assuming a 10% reduction in the total energy and water bill for a typical residence. Payback is based on an estimated cost premium of $600 for design and installation of a higher efficiency hot water distribution system over a conventional hot water distribution system.

Residential System $600 cost premium	Annual Energy and Water Savings, USD	Payback Period, years	CO_2 Emissions Reduction, tonnes
Florida	$215	2.8	0.6
Minnesota	$200	3	0.8
California	$246	2.4	0.7

The following table shows the estimated combined energy and water cost savings and payback period assuming a 10% reduction in the total energy and water bill for a reference office building. Payback is based on an estimated cost premium of $2,000 for design and installation of a higher efficiency hot water distribution over a conventional hot water distribution system.

Commercial System $2,000 cost premium	Annual Combined Energy and Water Savings, USD	Payback Period, years
Florida	$7,000	0.3
Minnesota	$6,774	0.3
California	$9,718	0.2

The corresponding CO_2 equivalent greenhouse gas emissions reduction for a 14,800 ft^2 reference office building is estimated to be 20 tonnes annually.

Payback period estimates were based on combined annual energy and water savings.

See the Energy and Water Savings Methodology subsection within the Introduction and Background section of the report for a description of methodology used and limitations of this simple payback analysis. Appendix A and B contain the data, calculations and data sources used for the combined energy and water savings analysis.

4.3. Materials Used (Piping, Tubing, Fittings)

Several types of pipe and tubing are used for hot water distribution systems, namely PEX, CPVC, copper, PEX-AL-PEX, and more recently PE-AL-PE.

For a new home construction the estimated total materials cost can vary widely. For example, one manufacturer estimates that the cost of using PEX can vary between $1,000 and $3,000. The manufacturer noted that PEX tubing is substantially lighter than steel pipe, lighter than copper pipe and requires much less time for installation.

Usage of manifold or parallel piping hot water distribution systems may be limited in some jurisdictions such as the cities of Chicago and New York, as they have yet to adopt PEX tubing into their plumbing codes. However, PEX tubing has become the material of choice in most locations, especially those that experience problems with corrosion of copper tube. Local codes and water conditions must be carefully checked before specifying any material.

The *Evaluation of Residential Hot Water Distribution Systems by Numeric Simulation* study concluded that the use of CPVC piping or parallel pipe systems (PEX) and a centrally-located water heater resulted in lower construction costs compared to the typical copper trunk-and-branch system. However, retrofitting copper tubes still in serviceable condition in existing homes with PEX tubing is not economically feasible.

4.4. Operating Example(s)

Five residential hot water distribution operating examples are presented in the 2002 study conducted by Ally, M.R., and J.J. Tomlinson entitled *Water and Energy Savings using Demand Hot Water Recirculating Systems in Residential Homes: A Case Study of Five Homes in Palo Alto, California*.

4.5. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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http://www.allianceforwaterefficiency.org/Residential_Hot_Water_Distribution_System_Introduction.aspx.

5. RADIANT HEATING SYSTEMS

5.1. Technology Overview

Radiant heating technology is an efficient way to heat a space by applying heat underneath or within the floor, walls, ceilings, beams and panels of a building. The occupied space is heated by radiation (infrared radiation). In the case of floor heating, natural convective circulation of air also occurs as the heat rises from the floor.

There are three types of radiant floor heating systems: hydronic, electric and air. Although radiant heating systems are not limited to floor heating, this report focuses on hydronic (liquid-based) radiant floor heating systems, which are the most popular and cost-effective for heating-dominated climates.

There are three basic components to a hydronic radiant heating system: a heat source, distribution piping including a manifold and circulation pump, and controls (zoning valves and thermostats).

<u>Heat Source</u>
The heat source is usually a boiler or a water heater, but renewable energy sources such as solar and geothermal are increasingly being utilized.

<u>Distribution Piping</u>
The distribution system consists of a series of plastic or metal tubes or pipes laid in a pattern underneath the floor that typically carry hot water into specific rooms or "zones" and radiate the heat through the floor surface. The cooler water then returns to the heat source where it is reheated and recirculated in what is known as a "closed-loop system".

Photo courtesy of Plastic Pipe and Fittings Association

<u>Controls</u>
The system can be efficiently controlled with individual controls for domestic hot water, mixing, snowmelt, boiler staging and zone pumping, or with newer programmable multifunction controllers that offer less time-intensive installation and eliminate the need for multiple controls.

There are three types of installation systems - a slab-on-grad system, a thin slab system, and a dry or "plate" system.

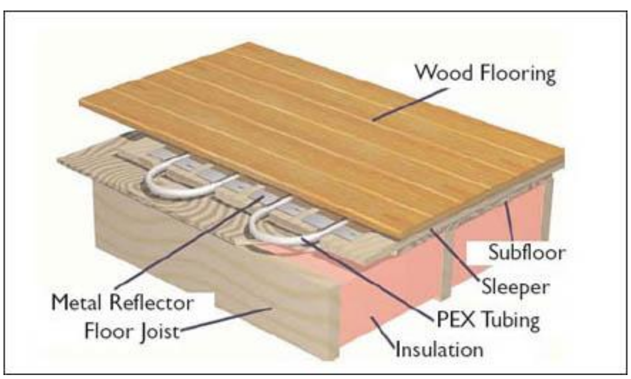
<u>Slab-on-grade</u>
Typically, plastic or composite tubing is attached to a wire mesh or clipped onto rigid Styrofoam insulation and concrete is poured over the tubing at ground level. Thick concrete slabs have high heat storage capacity and are ideal for storing heat from solar energy systems, which have a fluctuating heat output. The downside of thick slabs is their slow thermal response time, which makes strategies such as night or daytime setbacks difficult if not impossible. Maintaining a constant temperature is recommended in buildings with these heating systems.

<u>Thin slab system</u>
The tubing is fastened above the subfloor and covered with lightweight concrete or self-leveling gypsum cement underlayment. The floor ranges in thickness from 1.25 to 1.5 inches, however additional floor support may be necessary because of the added weight. Another variation has the tubing installed in between the subfloor and the finished floor, which raises the floor by about 0.5 inches. There are a variety of new underlayment panels that hold the tubing in place and incorporate aluminum transfer plates to improve heating performance.

<u>Dry or "plate" system</u>
The tubing is attached to the underside of the subfloor, also known as a below-deck or joist space dry system. In cold weather climates, the tubing should be attached with aluminum transfer plates and (the ceiling below?) well insulated for improved performance. Without the insulation, the heat will disperse into the basement. It is also possible to have an above-deck dry system, where heat transfer plates are supported by sleepers.

Plywood subfloors manufactured with tubing grooves and aluminum heat diffuser plates built into them are available, and it is claimed that this product can make a radiant floor system (for new construction) considerably less expensive to install and faster to react to room temperature changes. Such products also allow for the use of less tubing since the heat transfer of the floor is greatly improved over more traditional dry or wet floors.

The illustration below shows a typical radiant system detail.



Source: Uponor

Benefits

There are numerous benefits derived from radiant heating systems. In general, circulating water in pressurized pipes for heating and cooling use less energy than air circulation via ductwork. From an energy efficiency perspective, radiant heating systems:

- Use little electricity - a benefit for homes or businesses off the power grid or in areas with high electricity prices.
- Are more efficient than baseboard heating and usually more efficient than forced-air heating because no energy is lost through ducts.
- Use water that can be heated with a wide variety of sources, including standard gas or oil-fired boilers, wood-fired boilers, electric water heaters, geothermal or solar water heaters, or a combination of these sources.

In addition, radiant heating systems:

- Can be advantageous to people with allergies because of the lack of moving air (they do not blow dirt, dust and pet dander during the heating season).
- Make people feel more comfortable because when the floor is warm, their feet are also warm.
- Allow lower overall ambient air temperatures while maintaining overall thermal comfort of occupants, therefore saving money on energy bills.
- Make it easier to reach every corner of the house and take the chill out of spaces such as the kitchen, bathrooms and lower level floors.
- Do not dry the air and therefore do not dry out a person's breathing passages (dry breathing passages are more vulnerable to infections).
- Minimize the need for humidification of the air.
- Allow zoning different areas of the house for different temperatures, unlike forced-air central heating and air conditioning.
- Are child friendly and safer, since there are no hot surfaces for children to touch and no radiators for them to fall onto.
- Are concealed and make no sound.
- Are unobtrusive, as there are no radiators to interfere with furniture placement or interior design.

Traditional convective heating causes significant air stratification and heat loss to the ceiling, whereas radiant floor heating results in reverse stratification, which ultimately increases thermal comfort, by keeping heat closer to the occupied zone at floor level. Studies conducted by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) indicate that with radiant heating systems people can be comfortable at temperatures 6 to 8ºF lower than with forced-air and baseboard heating systems, as significant result.

Glass, particularly low-e glass, reflects long-wave radiance produced by residential radiant systems. This greenhouse effect serves to contain radiant energy within the heated building, reducing heat loss.

Air-infiltration heat loss is reduced with radiant heat. Air infiltration and exfiltration increase as the difference between inside and outside temperature (ΔT) becomes larger. With radiant systems, the temperature differential is less, thereby reducing air infiltration.

The average 65ºF radiant comfort temperature with 59ºF day/night setback should reduce building heat load by 25 to 35% over convective systems.

Limitations and Challenges
Radiant heating is less attractive if:

- the house is small to medium sized and very well insulated or uses advanced construction methods;
- the house design is not adjusted to the requirements of radiant heat; or
- a non-modulating or cast iron boiler is used as a heat source (in this case, the fuel costs will increase considerably compared to forced air heating).

The heat output of a radiant energy system is determined by pipe spacing, water temperature, flow rate and floor covering. The heat output must be calculated to meet the heat loss demands of the home, and water temperature for a properly designed system should not exceed 85ºF.

A house with radiant heating must be insulated under the slab to be efficient, as a heated floor can lose as much heat down as up. Improper or lack of insulation under a slab can cost much more than forced air heating.

Floor covering considerations:

- Ceramic tile is the most common and effective floor covering for radiant floor heating, as it conducts heat well from the floor and adds thermal storage because of its high heat capacity.
- Other floor coverings such as vinyl and linoleum sheet, carpeting or wood can also be used, but any covering that helps insulate the tubing from the room will decrease the efficiency of the system.
- If some rooms, but not all have a floor covering, those rooms should have separate tubing loops to allow more efficient heating of these spaces (e.g., water flowing under the covered floors needs to be hotter to compensate for the floor covering).
- Wood flooring should be laminated instead of solid wood to reduce the possibility of the wood shrinking and cracking from the drying effects of the heat.
- With radiant cooling systems, there is a potential for surface condensation in humid climates, making it necessary to add a mechanism to control moisture levels.

5.2. Energy Savings

According to Radiantec, energy experts have calculated that heating costs can be reduced by 25% with a radiant heating system. Other sources indicated that savings could be as high as 42%. In addition, it was noted that a building with thermo-active slabs may consume 60 to 70% less energy than an equivalent conventional building with a forced-air HVAC system.

Installed Cost
The cost of installing a hydronic radiant floor varies by location and also depends on the size of the home, the type of installation, the floor covering, remoteness of the site, cost of labor, number of zones, and other equipment such as controls and manifolds (plastic of brass). More expensive systems offer mostly more comfort features.

According to one PEX tubing manufacturer, the installed cost of PEX tubing is typically $1/ft, and it is the least expensive part of the radiant heating system. The installed cost of a radiant floor heating system is approximately $4.00 to $6.00/ft^2 for an average sized residential application.

There is still some debate on whether hydronic systems are more energy efficient than conventional forced-air systems. However, under certain circumstances radiant systems are a better choice (e.g., houses, commercial and industrial spaces with high ceilings or with large open spaces, where warm air would simply rise to the ceiling).

Heat source unit costs are as follows:

A Polaris water-heating unit will cost: $3,650 for a 34 gal, 100,000 BTU/h unit
$4,000 for a 50 gal, 130,000 BTU/h unit

The following tables, obtained from Radiantec's website, show typical cost ranges for radiant floor heating systems for residential and commercial buildings.

Residential					
Description		**Closed System**		**Open/direct System**	
		Low	**High**	**Low**	**High**
Labor allotment	40 h				
Joisted floor area	2,000 ft^2	$1,700	$3,000	$1,700	$3,000
Heating zones	2	$1,200	$1,450	$1,100	$1,250
Water heater		$3,000	$3,500	$3,000	$3,500
Total		**$5,900**	**$7,950**	**$5,800**	**$7,750**

Source: Radiantec

Industrial		
		Cost Estimate
Labor allotment	165 h	
Joisted floor area	2,000 ft^2	$10,000
Heating zones	10	$ 7,000
Water heater		$ 8,000
Total		**$25,000**

Source: Radiantec

Estimated Cost Savings and Payback

Typical materials costs for a 4-bedroom, 2,200 ft^2 home obtained from a company that provides materials, but does not install radiant heating systems are as follows:

- Slab and piping cost: approximately $4/$ft^2$
- High efficiency water heater: $2,000 to $4,500
- Operating cost: virtually none
- Maintenance: $200 to $400 annually (annual check for oxidation by plumber)
- Installation: cost depends on local labor rates. However, it is estimated that 3 hours of labor is required to install the PEX tubing.
- Economic payback: 4 to 7 years

Costs obtained from a company that installs radiant heating systems for residential applications are as follows:

- Boiler: up to $5,500
- Equipment, materials, and installation: $30,000 to $50,000

- Piping: PEX is preferred for its low cost, ease of installation and low time requirement for installation
- Economic payback: 5 to 7 years

The following table shows the estimated energy savings, payback period and associated CO_2 equivalent emissions reductions, assuming 25% reduction in the heating bill, for a residential radiant heating system with an installed cost of $7,000.

Residential System $7,000 Installed Cost	Annual Energy Savings, USD	Payback Period, years	CO_2 Emissions Reduction, tonnes
Florida	$450	15.6	1.4
Minnesota	$390	17.9	1.9
California	$435	16.1	1.8

The following table shows the estimated energy savings and payback period, assuming 25% reduction in the total building energy use, for a commercial radiant heating system with an installed cost of $25,000.

Commercial System $25,000 Installed Cost	Annual Energy Savings, USD	Payback Period, years
Florida	$8,393	3.0
Minnesota	$6,285	4.0
California	$9,285	2.7

The CO_2 equivalent greenhouse gas emissions reduction for a 14,800 ft^2 reference office building is estimated to be 55 metric tonnes per year.

See the Energy and Water Savings Methodology subsection within the Introduction and Background section of the report for a description of methodology used and limitations of this simple payback analysis. Appendix B contains the data, calculations and data sources used for the energy savings analysis.

5.3. Indoor Environmental Quality (IEQ) Impacts

People who have installed radiant heating systems have reported that switching from forced air or baseboard heating to radiant floor heating has greatly improved the quality of their indoor environment. One homeowner reported that their children’s asthma medication was reduced by half when they moved into a radiantly heated home.

Radiant heating systems do not have fans or blowers that produce drafts which circulate airborne allergens such as dust, dust mites, pollen, mould or pet hair and dander throughout the house.

Warm radiant floors can eliminate the need for carpeting, which is a breeding ground for dust mites that settle deep into the carpet fibers are not easily removed even with daily vacuuming. In addition, where carpeting is used the warmth of radiant floors and reduced moisture drives them to the surface of the carpet where they are more easily removed by vacuuming. In fact, Radiant Design Institute cites a European research project that showed that floor radiant heating reduces dust-mite population by at least 50%.

5.4. Materials Used (Piping, Tubing, Fittings)

The typical material used for radiant floor piping is PEX, because its flexibility makes installation easier, especially in smaller diameters. Some manufacturers offer composite PEX-AL-PEX and PE-AL-PE pipe and fittings for the distribution piping. Composite pipe is often used when the installation has to be done by one person since the pipe can be shaped without it recoiling back to its original shape.

Even when plastic tubing is used, copper tube will still generally be used close to the boiler.

In addition to PEX, CAN/CSA-B214-07 Installation code for hydronic heating systems specifies other types of pipe and tubing that can be used for radiant heating systems:

- Chlorinated polyvinyl chloride (CPVC) pipe and tubing
- Polypropylene (PP-R, random copolymer) pipe and tubing
- Metal/plastic composite pipe
- Steel pipe and copper tube

CSA B214 also specifies that:

- Galvanized steel pipe and fittings must never be used in hydronic heating systems; and
- The materials and equipment used in a closed hydronic heating system shall be selected to reduce the effects of corrosion created by oxygen entering the system. In particular, non-metallic tubing must incorporate an oxygen barrier because such tubing is normally permeable to oxygen.

The PEX tubing used for radiant heating systems typically comes with an oxygen diffusion barrier.

5.5. Operating Examples and Testimonials

<u>Armstrong Family Home in Lewiston, Idaho</u>
<u>Case</u>
The goal for this two-story, 7,400-ft^2, 23-room home in Lewiston was to be at least 75% more energy-efficient than homes built to the 1993 model energy code benchmark. Also, because of one family's member's health problems, the owners sought to minimize pollutants. More than 10,000 ft of NPS-1/2 NPS-3/4 NPS-1 tubing were used for in-floor, supply-and-return, and heat pump room piping. The operating costs are less than $5.00 per day during the winter.

<u>Testimonial</u>
"*We are extremely pleased with the operating costs, says Rebecca Armstrong of her new home's radiant floor heating and cooling system*."

<u>Automotive Dealership in Middleville, Michigan</u>
<u>Case</u>
98,000 ft^2, steel frame structure with a 6 in thick slab on grade for the service area and a 4.5 in thick slab on grade in the sales and showroom areas. Tubing was spaced 6 and 12 in on centers. The radiant floor heating system melts away snow and ice to keep the service area

floors warm and dry. Warmth is quickly recovered as automobiles enter and leave the service bays. Mobility is increased because the radiant floor heating provides short sleeve comfort for the mechanics. They perform their work more efficiently and sick days are down. The dealership is now heating nearly twice as much space with less energy.

Testimonial
"*After completing the addition and tearing down the wall separating the new and old service bays, the owner was astonished at the difference between the two areas. "The quality of the radiant floor heat was so apparent that mechanics working in the old section were constantly walking over to the addition. Even though it was now technically one space, it seemed like two separate rooms. The advantages of radiant floor heat are more than I could have ever imagined. The whole place is warm and comfortable and the price is respectable, too. And even though we've nearly doubled the size of the dealership, we're only using about 90% of our former energy requirement."*

Ballard Manor, a Retirement Home in the Seattle Metropolitan Area
Case
This 45,000 ft^2, 5-story, 65-unit retirement facility in Seattle had a floor construction of plywood decking with poured floor underlayment. NPS-3/8 tubing was spaced 6 and 12 in on centers. Heating the building costs an average of $500 per month during the cold Seattle winters, considerably less than the average heating costs for a building of similar size with a forced-air system, which can run several thousand dollars per month.

Testimonial
"I could instantly see it was quality tubing that would work reliably," the building designer says. "PEX tubing is durable, flexible and will continue to provide warmth and comfort to the residents of Ballard Manor for the duration of the building's existence."

5.6. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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6. SOLAR WATER HEATING SYSTEMS

6.1. Technology Overview

Solar domestic hot water systems are currently considered the most effective and viable way to harness energy from the sun for domestic hot water and radiant space heating applications. A solar water heating system consists of solar panels or collectors to collect energy from the sun (solar collector) and well-insulated storage tanks to store the hot water. This solar-preheated water is then supplied to the existing water heater. Solar preheated water is also being used for radiant heating applications.

Water heating uses a significant amount of energy and can account for 14% to 25% of the total energy consumed in a typical home, making solar water heaters a relatively cost-effective technology due to potential energy savings.

In most cases, a solar water heating system will harvest more energy than solar-electric photovoltaic (PV) panels at a substantially lower cost. Solar water systems are more than three times as efficient at producing energy from the sun as photovoltaic panels. The hot water from a solar system can be used for domestic hot water or space heating.

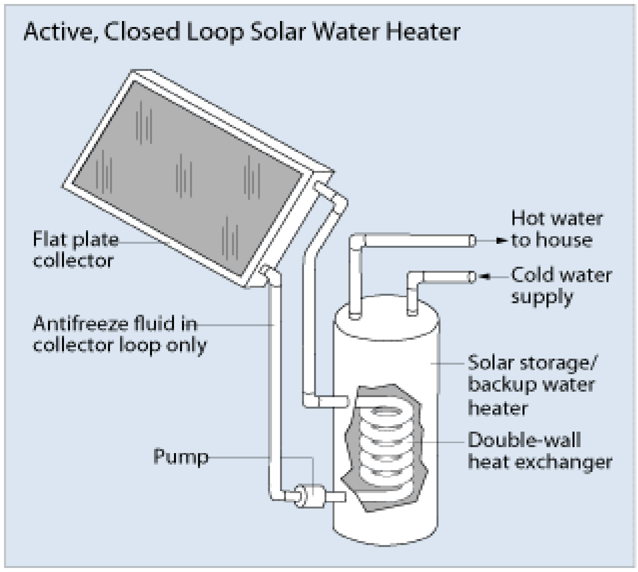
Commercial solar hot water systems are similar to those used for homes, except that the storage tank, heat exchanger and piping are larger and are proportional to the size of the solar collector array.

There are two types of solar water heating systems: *active*, which have circulating pumps and controls, and *passive*, without any pumps and controls.

There are two types of active solar water heating systems, as follows:

<u>Direct circulation systems</u>
Direct circulation systems (open loop) have pumps that circulate water through the collectors and into the building. They work well in climates where the temperature rarely falls below freezing.

<u>Indirect circulation systems</u>
Indirect circulation systems (closed loop) have pumps that circulate a heat-transfer fluid through the collectors and a heat exchanger. The fluid heats the water that then flows into the building. They are used in climates subject to freezing temperatures.

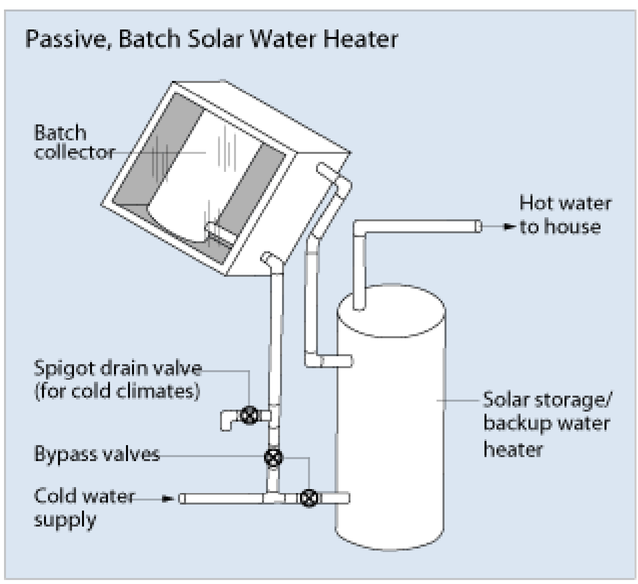


Source: U.S. Department of Energy. Energy Savers: Solar Water Heaters.

Passive solar water heating systems tend to be less expensive than active systems, but are usually not as efficient. However, passive systems can be more reliable and last longer. There are two basic types of passive systems, as follows:

<u>Integral collector-storage systems</u>

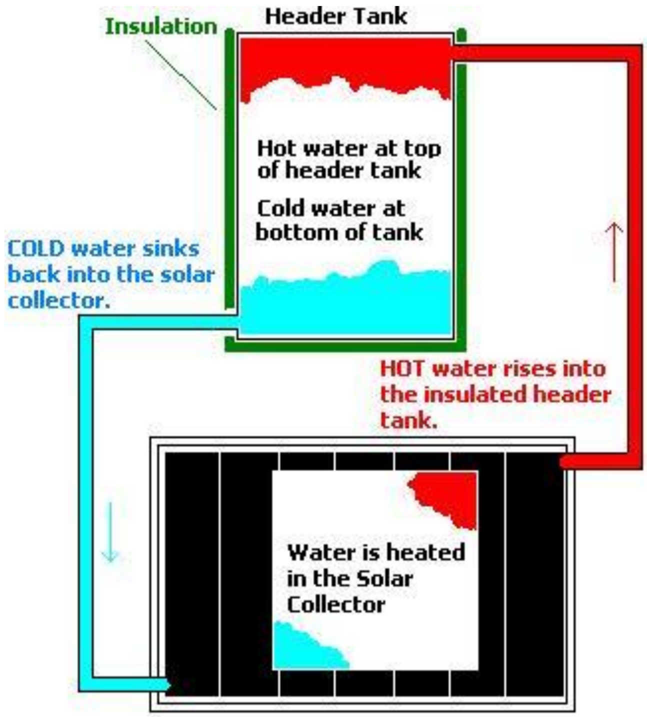
Integral collector-storage systems incorporate tanks or tubes in the collector, where cold water flows through and is preheated by the sun and then flows to a conventional backup water heater. These systems work best in climates where it rarely freezes, and are better where most hot water use occurs during the daytime.



Source: U.S. Department of Energy. Energy Savers: Solar Water Heaters.

<u>Thermosiphon systems</u>

In a thermosiphon system, water flows through the system when warm water rises as cooler water sinks. The collector must be installed below the storage tank so that warm water rises into the tank. Thermosiphon systems are reliable, but are usually more expensive than integral collector-storage passive systems. In addition, if the storage tank is located on the roof, careful attention must be paid to its structural design because of the significant weight of the storage tank. The illustration below shows how thermosiphon systems operate.



Source: Renewable Energy UK

Benefits
Solar water heating systems offer numerous benefits, some of which are as follows:
- Can be used in any climate;
- Can last up to 50 years or more;
- Usually have very low operating costs;
- Maintenance needs are minimal, as there are no moving parts; and
- Can save money by reducing energy consumption.

Additional benefits associated with solar energy as a fuel source include:
- Free and unlimited supply, and does not require capital investment in transportation or distribution infrastructure;
- The production of no greenhouse gases or other harmful emissions;
- The protection of users from fuel shortages and price hikes;
- A reduction in pollution; and
- A reduced dependence on fossil fuels.

Limitations
Solar water heating systems have some limitations, such as almost always requiring a backup system (e.g., conventional storage water heater) for days with low solar radiation and times of increased demand. Initial costs are also a financial limitation of these systems.

The technical and economic feasibility of solar energy systems in general is limited by production scale-up, efficiency, materials availability, energy storage, and distribution challenges. However, significant research and development is underway to improve the efficiency and costs of capturing solar energy.

According to a source from Health Canada, health departments have expressed concerns with two-tank systems, where the solar water heater pre-heats water before it enters a conventional water heater, because pre-heated water is maintained at a temperature that is not high enough to eliminate bacterial growth and therefore could pose a serious health risk.

6.2. Energy Savings

The U.S. Department of Energy (DOE) cites that on average water heating bills drop 50% to 80% when a solar water heating system is installed.

Economic Analysis
Solar water heating systems usually cost more to purchase and install than conventional water heating systems. Buildings with high and consistent hot water needs year-round typically have the highest return on investment.

Data from Toolbase.org and from an expert interviewed indicates that, the installed cost of a solar water heating system for a single family home ranges between $2,000 and $15,000. The actual cost depends on several factors, including the size and nature of the solar system (e.g., supplemental or main), efficiency of the panels, and specific technology and installation configuration used. The U.S. DOE's *Energy Savers: Solar Water Heaters* resource provides guidance in estimating the annual operating costs and comparative analysis of different solar water heating systems.

In the long run, solar water heating systems usually save money in operating costs in terms of energy savings. Actual savings will depend on:

- The characteristics of the system being replaced;
- The amount of hot water used;
- Performance and efficiency of the solar system;
- Geographic location and solar resource;
- Available financing and incentives (e.g., tax credits and grants);
- The cost of conventional fuels replaced (natural gas, oil, and electricity); and
- The cost of the fuel used for the backup water heating system, where applicable.

The economics are more attractive when building new or refinancing, including tax credits or rebates. The American Recovery and Reinvestment Act of 2009 offers a 30% tax credit for "qualifying advanced energy projects", which include solar energy systems. This tax credit reduces the payback period significantly. The U.S. DOE maintains a database of state incentives for renewables and efficiency, available at http://www.dsireusa.org/.

Including the price of a solar water heating system in a 30-year mortgage usually adds between $13 and $20 per month. The federal income tax deduction for mortgage interest attributable to the solar system can reduce that amount by $3 to $5 per month. Therefore, if the fuel savings are more than $15 per month, the investment is immediately profitable.

One expert indicated that the payback period for a solar water heating system is between 9 and

15 years, although it could be as low as 4 years with government incentives.

EnerWorks Inc. reports that in a typical household, water heating accounts for up to 25% of the energy used and produces an average of 2 metric tonnes of green house gas emissions annually.

The following table shows the estimated energy savings, payback period, and associated CO_2 equivalent emissions reductions for a residential solar hot water system with an installed cost of $3,000, assuming 50% reduction in the water heating bill, equivalent to about 13% savings over the total energy bill.

Residential System $3,000 Installed Cost	Annual Energy Savings, USD	Payback Period, years	CO_2 Emissions Reduction, tonnes
Florida	$225	13.3	0.7
Minnesota	$195	15.4	1.0
California	$218	13.8	0.9

The following table the estimated energy savings and payback period, assuming 15% reduction in the total building energy use, for a commercial solar hot water system with an installed cost of $15,000.

Commercial System $15,000 Installed Cost	Annual Energy Savings, USD	Payback Period, years
Florida	$5,036	3.0
Minnesota	$3,771	4.0
California	$5,571	2.7

The CO_2 equivalent greenhouse gas emissions reduction for a 14,800 ft^2 reference office building is estimated to be 33 metric tonnes per year.

See the Energy and Water Savings Methodology subsection within the Introduction and Background section of the report for a description of methodology used and limitations of this simple payback analysis. Appendix B contains the data, calculations and data sources used for the energy savings analysis.

6.3. Materials Used (Piping, Tubing, Fittings)

The choice of piping material will depend on the solar system design, fluid composition, equipment configuration and local plumbing code requirements. Pipes transporting hot fluid from a solar collector to a storage tank must be able to withstand temperatures in excess of 212ºF. Most systems currently use copper pipe, but plastic materials such as PEX-AL-PEX are increasingly being considered for these applications.

Plastic pipe is suitable for use where the solar water heating (or preheating) system does not exceed the temperature limitations of the material, where it is protected with temperature and pressure relief valves and there is no risk of pump failure for pumped systems. Plastic is preferred where the composition of the water may adversely affect copper tubes. A short length of copper tube is often used as a transition between the heat source and the distribution piping.

Open-loop solar water heating systems use ABS piping. Other plastic piping materials that may be used in specific situations are CPVC, PE, PEX, PEX-AL-PEX, and PE-AL-PE.

6.4. Operating Example(s) and Testimonials

Drake Landing Solar Community, Okotoks, Alberta
The 52-home Drake Landing Solar Community was the first residential solar community in North America. It uses solar collectors in conjunction with seasonal storage to store the sun's energy during the summer and distribute heat to the homes in winter. A two-collector residential water heating system on each home provides domestic hot water, and the 800 commercial solar collectors capture 1.5 MW (5 MMBTU/hr) of thermal power on a typical summer day. The system is able to meet 90% of space-heating needs and up to 70% of domestic hot water needs for the subdivision. It results in annual greenhouse gas emissions reductions of 5 tonnes per home, for a total reduction of 260 tonnes from the community.

Source: EnerWorks Inc.

Davenport Residence, Central Wisconsin
The home is heated completely with renewable resources. The original solar hot water system consisted of three solar collectors on the roof, two pumps, two tanks (one with electric heating elements and one without), a heat exchanger, a controller, piping and other fittings. The cost of the solar water heating system was $14,000. The space heating portion of the system cost about $4,000 more than a conventional radiant floor system. Greenhouse gas emissions have been reduced by 14,369 lb of CO_2, 14.1 lb of NO_x, and 27.2 lb of SO_2 annually.

Testimonials
From a Wisconsin Focus on Energy case study:
The main benefit can be seen on the bottom line. The solar domestic hot water system is designed to provide 60 to 70% of the hot water needs at Quaker Housing, at virtually no cost. "Utilities are a significant part of our operating expenses," said [Judy] Olson. "The extremely low operating and maintenance costs make solar a viable energy option for multifamily housing, especially low-income."

Testimonials from Southern Solar, UK customers:
"Just to comment on how gobwhelmed we are at the effectiveness of the solar hot water thingy. We haven't had our oil fired heater on for nearly ten days now and yet have had scalding showers and baths nearly every day. We were away for two days and when we got back the hot water tank had cooked up so much that it was 61 ºC top and bottom. This enabled one hot shower and bath late last night and the same again first thing this morning. With a system this

effective every new home should have one as standard."
Mr Mooney, Blagdon, Somerset.

"We have been extremely pleased with our solar water heating system which has been running since January 2004 and has contributed greatly to the reduction in our gas consumption between March & October each year. Coming back home to a tank of free hot water after a few days away is such a bonus."
Mr Page, St Leaonards on Sea, Sussex.

6.5. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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7. WATER EFFICIENT IRRIGATION SYSTEMS

7.1. Technology Overview

Inefficient watering of lawns, gardens and landscaped areas contributes to water waste through runoff or evaporation, weak plant growth, fertilizer leaching, pest problems and weed growth, and can increase runoff of pesticides, insecticides and fertilizers into untreated areas.

Water efficient irrigation systems are designed to apply the correct amount of water required by a landscaped area, when and where required and with minimal wastage. They apply the water as closely as possible to the roots of the plant and with the largest droplet size possible. All of this reduces water loss due to evaporation or runoff. If properly used with a routine observation and maintenance plan and a schedule to manage how long and when to water, water usage for gardens can be reduced by up to 75% by choosing an irrigation system that is tailored to a specific garden, weather, soil and landscape conditions.

Proper use of irrigation systems typically requires:

- Running the irrigation system during the cooler morning hours to minimize water loss via evaporation.
- Applying the water at a rate and frequency at which it can be absorbed by the soil to minimize water run-off.
- Adjusting the frequency and duration of automatically controlled systems to match seasonal requirements.

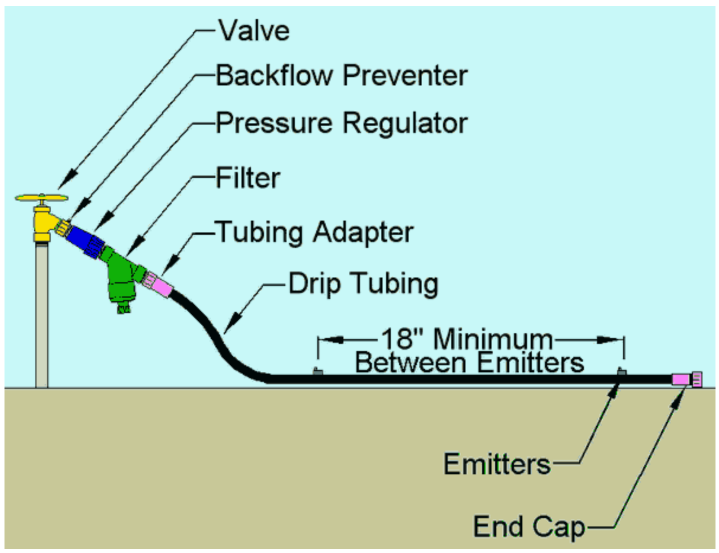
Drip irrigation - also termed as micro, low-flow, low-volume or trickle irrigation - is the preferred method for shrubs, flower and vegetable beds as it does not water the entire bed area uniformly, just the root zones of the selected plants. It is about 20% more water efficient than sprinklers, easy to install and reasonably inexpensive. Drip irrigation can be used above or under the ground surface, however sub-surface or under-mulch drip irrigation is the most efficient water-conservation method.

Drip irrigation systems include both drippers that deliver water to the garden as single drops, as well as shrubblers which release gentle streams of water up to a 40 inches (1m) radius. Both drippers and shrubblers reduce evaporation because they do not mist the water into the air, and the water soaks into the soil both horizontally and vertically.

Drippers (or drip emitters) can deliver water at 0.5, 1.0, or 2.0 gal/h (2, 4, or 8 L/h). Shrubblers can be adjusted to deliver exactly the right amount of water to each plant, up to 13 gal/h (50 L/h). Cleaning filters and flushing out the irrigation system lines is required generally twice a year.

Drippers are not suitable for lawns. The most efficient way of delivering water to lawn areas is to use pop-up heads that throw water, rather than spraying it.

Source: Antelco.



Source: Stryker.

All irrigation systems can be operated automatically from a timer or computerized control box. Rain sensors increase the efficiency of the systems because they will not automatically water when it is raining or has recently rained.

Benefits
Drip irrigation systems:

- Easily allow regulating the exact amount of water to a zone or plant by changing the emitter or flow rate.
- Easily allow installation of timers.
- Easily allow changing the layout if design or conditions change and as the landscape matures.
- Do not lose water through wind or sun evaporation, or from runoff.
- Make it easier to maintain evenly moist conditions and are better for the soil life and the growth, yield and health of the plants.
- Do not splash water on foliage, thus reducing salt burn and disease problems such as powdery mildew, leaf spot and fungus. The lack of splashing reduces the broadcasting of fungus and mould spores and prevents leaves from becoming muddied.
- Reduce runoff on sloped areas by controlling the flow-rate of water to proper absorption level. Vegetation planted for erosion control takes hold faster.
- Allow the use of pressure compensating emitters for even irrigation in uneven terrain.
- Allow water to slowly soak into the soil, maintaining better soil structure. Puddling water can

cause clay particles to stick together and compact the soil.

- Help prevent soil crusting.
- Help to minimize weeds by watering near the root zone of the plant, not the entire bed. The larger areas of soil in between the plants are dryer, preventing weed seed germination.

Water efficient irrigation systems benefit utility companies by reducing water use during the summer months, avoiding demand spikes that often force restrictions on water usage. Reduced water use also decreases energy necessary to treat and pump the water; and allows deferring or reducing capital investments in new infrastructure.

According to Colorado State University Extension, the build-up of salinity in soils is inevitable in arid and semi-arid climates. However, plastic mulches used with drip irrigation systems reduce salt concentration caused by evaporation. In addition, sub-surface drip irrigation pushes salts to the edge of the soil wetting front, reducing the harmful effects of salinity.

Other Considerations

The selection of perennial and annual plants, grasses, vines, trees and shrubs suited to the site and local climatic conditions is also an integral part of a water efficient irrigation system. Water efficient gardening is known as “xeriscaping”, which makes use of creative landscaping designs with low-water demand. Beyond plant selection and special landscaping features, grouping together plants with similar water needs (hydrozoning), soil amendments to improve water retention capability, and mulching are common xeriscaping practices.

EPA’s WaterSense program includes irrigation partners certified through WaterSense labeled programs for their expertise in water-efficient irrigation technology. These WaterSense irrigation experts help users reduce water consumption while maintaining healthy landscapes.

Limitations

Issues and drawbacks for drip irrigation systems:

- In buried systems, it is possible to accidentally damage smaller pipe with a spade or hoe.
- On a slope, pressure-compensating drippers are needed.
- Drip holes and emitters may become clogged and this may not be noticeable until it is too late and the plants wilt.
- Very long or wide garden beds with large numbers of plants in them may be expensive to maintain with drippers. A more cost-effective method is to use a porous pipe, buried under mulch, which drips water from tiny holes along the length of the pipe to deliver an even amount of water to the whole garden bed.

Considerations for increasing the efficiency of irrigation systems

<u>Location</u>

Properly located sprinklers reduce the amount of water sprayed onto paved surfaces. Sprinklers should be located between 4 and 6 in (10 and 15 cm) from the edge of sidewalks, curbs, or patios in lawn areas, or 12 in (30 cm) from the edge in shrub areas. These setbacks also reduce the potential for damage to the sprinkler heads caused by trimmers.

<u>Ease of relocation</u>

Emitters can be readily relocated in case of landscaping changes by using long and flexible plastic tubing.

Pressure regulating sprinkler heads

Sprinkler heads with built-in pressure regulators save water by reducing the water pressure at the sprinkler head nozzle. If too much water pressure is present, the sprinklers tend to create too much mist and give uneven coverage resulting in water waste. However, if there is no excess pressure, regulators may actually reduce the system's performance. Low head drainage can occur when the irrigation system is on a sloped area. After the system is turned off, the water in the pipes drains out through the lowest sprinkler heads or drippers. This water is wasted and often creates muddy areas around the sprinkler heads and the next time the irrigation system is run, the sprinklers and pipes are subjected to stress when the air is forced out. Pressure regulators or pressure compensating drippers help eliminate low-head drainage.

Controllers

Installing a smart controller will allow adjustment to the irrigation system operating times depending on the water needs of the plants.

Rain sensors

Installing a rain sensor turns off the automatic irrigation valves when rainfall is detected.

Filters

Installing a filter at the water source significantly reduces repair costs by reducing system breakdowns. Most valve and sprinkler malfunctions result from contaminants in the water supply, typically small grains of sand, pipe scale, or small fresh-water snails. A filter typically pays for itself within 5 years as will the cost of a filter. However, the cost of a single valve repair can be much greater than the cost of a filter.

Winterizing

If the irrigation system is located in an area where hard frosts occur, it must be properly winterized before the cold weather arrives.

Efficient sprinkler heads

Many new stream-rotor nozzle sprinklers are more water efficient than the older models because they achieve a greater spray radius while using less water. Generally this option is only cost effective for very old irrigation systems or if the system was poorly designed, otherwise there is usually only a marginal efficiency gain and switching nozzles is likely not cost effective.

Automated shut-off valves

These devices save water by automatically shutting it off when something in the irrigation system breaks. However, these devices do not save water during ordinary operation of the irrigation system. Automated shut-off devices are often used on irrigation systems where a break can cause serious damage (e.g., an irrigation system on a steep slope, where a break could cause massive erosion) or in locations where a break might go undetected for days, such as a vacation home or remote locations. The suitability of automatic shut-offs must be examined on a case-by-case basis because in many situations they are simply not cost effective.

7.2. Water Savings

On average, households use about 1/3 of their total water consumption for irrigating gardens and lawns. A conservative estimate of 30% reduction in potable water consumption for irrigation is readily achievable with efficient irrigation systems. Based on the estimated U.S. nationwide average annual household water consumption, this represents a savings of over 7,000 gal of water per year.

If gray water reuse and rainwater harvesting systems are installed to supply water-efficient irrigation systems, the combined reduction in potable water consumption and wastewater generation can be significant.

Economic Analysis
According to Travis Irrigation Plans & Supply the cost of an irrigation system varies widely depending on the type and number of components selected (controllers, sensors, etc.), labor rates and the region within the U.S. Costs may vary from $500 for sprinklers, valves, controller and backflow preventer for a small 3,000 ft^2 lot, to $1,500 to irrigate a 40,000 ft^2 lot. There are economies of scale for larger lots as they can utilize fewer part-circle sprinklers and more full-circle sprinklers (the cost is the same per sprinkler). In addition, there will be only one backflow preventer regardless of the number of sprinkler heads.

Maintenance cost is virtually zero and operational costs are about $20 per month. Yearly maintenance costs include re-adjusting the sprinkler heads and trouble-shooting. In cold climates the system has to be winterized and drained so the water in the system will not freeze and burst the pipes, and then be turned on again in the spring.

Water costs can be much higher if a sewer charge based on water use is added, and many municipalities allow sprinkler systems to have a separate meter (about $85+cost of installation).

For illustrative purposes, a simple analysis of economic payback for a residential and a commercial example of water-efficient irrigation systems resulting in a 30% reduction in the quantity of potable water used for outdoor irrigation only was completed based on water pricing in Florida, California and Minnesota:

	Installed Cost, USD	**Economic Payback Period, years**		
		Florida	**Minnesota**	**California**
Residential	$1,500	negative	negative	negative
Commercial	$3,600	1.6	1.3	0.8

A negative payback period indicates that annual operating and maintenance costs are higher than estimated annual savings achieved.

See the Energy and Water Savings Methodology subsection within the Introduction and Background section of the report for a description of methodology used and limitations of this simple payback analysis. Appendix A contains the data, calculations and data sources used for the water savings analysis.

7.3. Materials Used (Piping, Tubing, Fittings)

Most irrigation systems use flexible polyethylene PE or PVC piping because of its lower cost compared to other materials available, and ease of installation due to its light weight and flexibility. However, PVC, PEX, copper, aluminum and even steel pipe systems are used as well. The metal piping is primarily used for industrial and large commercial applications.

Plastic to metal connections can be made by using threaded transition joints, in which a plastic male thread is used to connect to metal female threads. However, plastic female threaded connectors are not recommended to be used with metal male connectors because of the potential for excessive hoop stress.

7.4. Operating Example(s)

Shoreline School District, Seattle, Washington
In 1992, the Shoreline School District was using 3,000,000 ft^3/yr of water. The Shoreline School District irrigates 16 sites scattered over approximately 15 mi^2 just north of Seattle. The suburban setting of the district's schools features extensive irrigated landscapes in addition to irrigated turf athletic and playfields. Together with Seattle Public Utilities, the school district developed a program to reduce the irrigation water centered on a weather-based control system. The project cost was $175,000, however it benefited from a $59,000 rebate. The water and wastewater savings were 20,000,000 gal/yr. As a result, the school district's cost for irrigation water dropped by approximately 50%, or $50,000 per year and the payback time for the project was less than 2 years.

Adobe Systems Corporate Headquarters, San Jose, California
The three high-rise office building towers and computer data center incorporated several green building energy and water efficiency features and earned a LEED platinum rating. Among the many benefits, the water used for landscape irrigation was reduced by 76% using a web-based weather station and a drip irrigation system for two of the office towers, at a cost of US $3,610. The payback period was 0.4 years, with annual savings of US $9001.

Nevada Study
A study performed by the Southern Nevada Water Authority completed in 2005 determined that landscapes with newly planted xeriphytic plants used 17.2 gal/ft^2/yr compared to 73.0 gal/ft^2/yr used for traditional turf grass landscapes. All test properties had in-ground irrigation systems that were metered and monitored. The study compared 499 properties of at least 500 ft^2 converted to xeric plantings using desert-adapted trees, shrubs, ornamental grasses and mulch with a canopy coverage of at least 50% at maturity with 253 residences that had traditional turf and plants averaging 2,462 ft^2 of landscaped area.

The annual water savings for the xeriscaped landscapes was 30% of the total household water use, or about 96,000 gal/yr for the average household. Homeowners with the xeriscaped landscape would realize a 70% savings on their water bill during the peak water use month of July.

Studies are proving that greater savings are obtained with irrigation controller adjustments (turning off irrigation systems after rainfall, change of seasons, etc.). In southern Nevada, 55.8 gal of drinking water are saved annually for every square foot of turf converted to a low water-use plant area.

Arizona Study
Southwest Trees and Turf reports on a study carried out in Phoenix, Arizona, comparing watering practices for two homeowners on the same street with similar front-lot size and similar xeriphytic plants. There was no measurable difference in plant appearance or fitness, although one homeowner used 218,000 gal more a year for the front lot (1.2 gal/ft^2/mo compared to 9.9 gal/ft^2/mo). The study highlights that user knowledge, awareness and expertise are an integral component of effective functioning of a low water-use irrigation system.

Saranac Hotel, Spokane, Washington
The renovation of downtown Spokane's century-old Saranac Hotel, which was completed in September 2007, included a green roof with recycling irrigation technology. The project, which also included solar and geothermal energy systems, obtained platinum certification in the USGBC (United States Green Building Council) LEED program.

The green roof included a rooftop garden planted with indigenous plants, a drip irrigation system, hardscapes (patio with 24-in square architectural concrete slabs), and 2 rooftop cisterns for collecting rainwater. Gray water collected in six 2,000-gal storage tanks in the basement contribute to the irrigation needs.

The irrigation system, if properly maintained and winterized, is expected to last for at least 20 years, and the piping should last indefinitely. About 3h of maintenance on the pumping system is required every week.

The irrigation system and drought tolerant plantings are projected to save 37,000 gal of water while the two rooftop rainwater cisterns are projected to save up to 38,000 gal of water annually. The building conserves another 55,000 gal of water annually by using the gray water system for irrigation and waterless urinals, for a total expected water savings of 130,000 gal/yr.

7.5. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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8. DECENTRALIZED (ONSITE) WASTEWATER TREATMENT SYSTEMS

8.1. Technology Overview

Decentralized or onsite wastewater treatment systems treat wastewater from individual or small groups of homes or buildings not connected to a centralized (municipal) sewerage system, and return treated wastewater back into the environment through the soil. These systems are constructed on or near the building site and are not part of the internal plumbing system.

Onsite wastewater treatment systems are primarily used for sewage treatment and disposal in low density communities and rural properties that lack ready access to municipal water and wastewater infrastructure. There may be a significant upfront savings by eliminating the need for a municipal sewer connection and reduced utility costs by avoiding charges for municipal sewage treatment. These savings can often pay for the cost of constructing and maintaining the system and also help to defer the need to upgrade existing centralized wastewater treatment facilities.

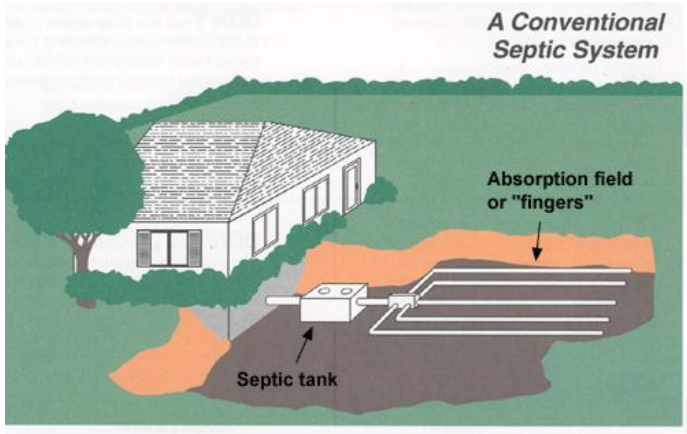
Conventional decentralized systems consist primarily of a septic tank for partial (primary) treatment and a soil adsorption field - also described as a subsurface wastewater infiltration system, soil treatment area, leach or drain field - for final treatment and dispersal.

The septic tank is the first step of the wastewater treatment process and allows for the separation of settled solids and floating material from the tank effluent so that solids do not plug the drain (soil adsorption) field. In addition, bacteria, which are naturally present in all septic systems, begin to digest the substances in the septic tank and transform them into liquids and gases. Final treatment and dispersal of the wastewater takes place in the soil adsorption field.

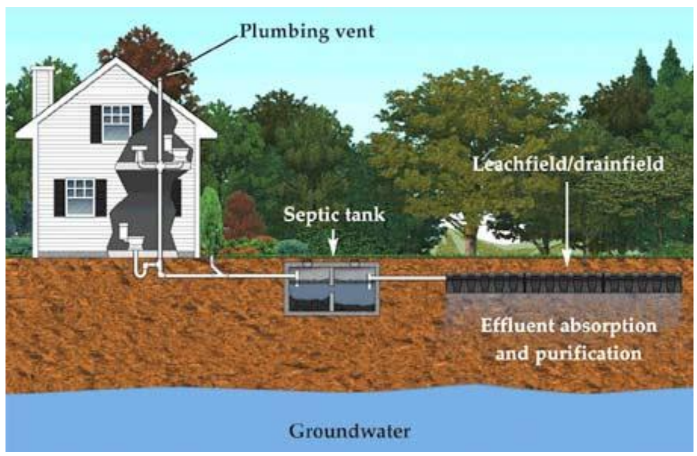
Subsurface wastewater infiltration systems are the most commonly used systems for the final treatment and dispersal of onsite wastewater. Infiltrative surfaces are located in permeable, unsaturated natural soil or imported fill material that allows wastewater to infiltrate and percolate through the underlying soil to the ground water. As the wastewater infiltrates and percolates through the soil, it is treated through a variety of physical, chemical and biochemical processes and reactions.

Typically, perforated DWV or sewer pipe, usually NPS-1¼ to NPS-2 PVC pipe, or plastic septic chambers (half-pipes) distribute the wastewater over the infiltration surface. A porous medium, usually gravel or crushed rock, is placed in the excavation below and around the distribution piping to spread the flow from the pipes across the trench. Other gravel-less or "aggregate-free" system components may be substituted.

A non-traditional system (usually referred to as secondary or tertiary treatment systems) will perform the same basic actions as the conventional septic system but uses advanced treatment and pumps when location, space, laws, regulations, soil type or quantity of wastewater being treated become a limiting factor. The advanced treatment system is installed downstream of the septic tank and upstream of the soil adsorption field. These systems use technologies that require greater frequency of operation and maintenance.



Source: Marion County Health Department, Northern Virginia Regional Commission



Source: Infiltrator Systems

Cluster, managed or small communal systems are decentralized wastewater systems serving more than one home, and in which the liquid effluent from the septic tank is conveyed to the treatment system through common collection lines called effluent sewers. Effluent sewers have several cost advantages over centralized "big pipe" sewers: (1) they are smaller in diameter, (2) they do not need to be installed as deep or laid on grade, and (3) they do not require manholes for access. There are two types of effluent sewers: gravity and pressure.

Following collection, there are a number of treatment and disposal system alternatives that can be used in cluster systems, depending primarily on the number of connections. Cluster systems are generally considered feasible for up to approximately 100 homes.

Beyond the obvious need for proper effluent characterization, design, siting and construction, effective ongoing management and maintenance is essential for proper system performance and to protect the environment and public health.

8.2. Life Safety and Environmental Impacts

Decentralized wastewater treatment and disposal systems help protect the environment (marine life and water quality), and most importantly human health. Onsite treatment and disposal can reduce the loading of waterborne pathogens and viruses in the wastewater, along with total suspended solids (TSS), biological oxygen demand (BOD), and total nitrogen, phosphorus and other chemicals that may be present in the effluent from a building.

In addition to protecting public health and the environment by disposing of onsite wastewater in a safe way, decentralized wastewater treatment systems:

- help eliminate illegal discharges ("straight pipes") into surface or open bodies of water;
- are an effective way for households in rural or remote areas to handle their wastewater in a safe, environmentally responsible manner;
- are a cost-effective way of dealing with wastewater where transportation of wastewater to treatment plants is not feasible;
- allow development of lands in low-density and rural communities; and

Clustered (managed) decentralized wastewater treatment systems present other benefits for public utilities, homeowners and developers.

<u>Public Utilities</u>
Decentralized wastewater systems:

- Are economical to install. An entire clustered system (including collection, treatment, and disposal) will often cost less than extending a municipal sewerage line, especially in low-density areas.
- Conserve the capacity of the central treatment facility, thus deferring or avoiding the need for capital expense of a plant expansion or upgrade.
- Are economical to operate and maintain. They require routine maintenance every few months and their performance can be monitored and controlled using remote telemetry. Two or three utility employees can maintain a cluster system serving hundreds of homes.
- Often allow utilities to acquire land for treatment facilities at minimum expense, as developers may deed over land for treatment in exchange for the benefits of a clustered decentralized wastewater system.

<u>Homeowners</u>

- Homes become available in areas where central sewers do not exist or conventional septic systems do not work.
- Individual homeowners are relieved of the responsibility for ongoing system maintenance.
- Monthly sewer rates are typically lower than with centralized sewerage systems because the costs of installing and maintaining the decentralized wastewater systems are lower.
- Better protection of groundwater resulting from managed treatment rather than reliance on individual responsibility for maintenance

<u>Developers</u>

- A prime residential location can be developed in a timely manner rather than waiting for a central sewage system to be extended.
- Development density can also be increased by as much as 20% because homes can be sited on smaller lots than onsite septic systems require.
- The presence of a publicly owned and operated decentralized wastewater treatment system is usually a selling point for homeowners.

Other Considerations
Most of the problems related to onsite wastewater systems stem from site limitations, poor management, or from older systems that are faulty or cracked. Malfunctioning systems can

discharge untreated or partially treated sewage that contaminates groundwater and surface waters. These problems can include:

- Systems that leak;
- Systems that are built on lands that cannot support the system;
- Improper siting, design, and construction; and
- Inadequate long-term and routine maintenance.

Some manufacturers use recycled plastic scrap for the production of wastewater treatment system components.

8.3. Costs

One manufacturer of tertiary treatment systems indicated that a fully installed system for a typical 4-bedroom house can cost between $14,000 and $18,000, including labor, septic tank, leaching beds and re-grading.

An installer indicated that a typical onsite wastewater system could cost between $5,000 and $25,000, depending on the soil type (e.g., systems installed in sandy, permeable soils are less expensive). In heavy clay areas, the cost is usually over $20,000.

A manufacturer of septic tanks that was also interviewed indicated that the cost of a septic system varies significantly depending on where in the U.S. the system will be installed. Soil conditions, regulatory requirements, and labor costs have significant impact on the system cost. For example, in Massachusetts, a septic system for a 2,500 ft^2 home can cost in excess of $30,000, whereas in a southern state (e.g., Mississippi, Alabama, or North Carolina) a similar system could cost as little as $5,000.

Other manufacturers and installers indicated that other system costs can be as follows:

- Installing/replacing a conventional septic system (including the tank) can cost from $2,000 to $5,000 in the Midwest, but can be anywhere from $4,000 to $12,000 or more in areas where materials and labor rates are higher.
- Enhanced, engineered, or alternative septic systems that use mounds, sand/peat filters, aerobic systems or constructed wetlands can cost from $10,000 to $20,000 or more, according to the Rhode Island Regional Water Quality Program. These alternative septic systems work better than the conventional approach for sites with high groundwater or slowly/rapidly percolating soil, or near potable water supplies, wetlands, coastal ponds or other water resources.
- A septic tank can cost from $500 to $1,800 depending on size (ranging from 300 to 1,000 gal) and type. Piping and other needed items add another $100 to $200 to the total cost of materials.
- Most jurisdictions require a building permit for installing or replacing a septic system, at a cost of $250 to $1,000 or more, depending on the location and the complexity of the project.
- Installing a septic system usually involves extensive digging and damage to the landscaping, resulting in a need for replacement turf and other plantings that can cost from $100 to $1,000 or more.
- Many jurisdictions require that decentralized wastewater systems be designed and installed by trained and licensed professionals. An engineered design can increase the cost of a system by as much as $2,000.

8.4. Materials Used (Piping, Tubing, Fittings)

A manufacturer of tertiary treatment systems that was interviewed indicated that their systems use only plastic pipe at a cost of approximately $200 for each system. They also indicated that conventional septic systems use more piping, as they require larger soil adsorption fields and therefore more pipe to distribute the effluent evenly. This information was confirmed in another interview with an installer. The cost of the piping in conventional systems is typically between $400 and $600.

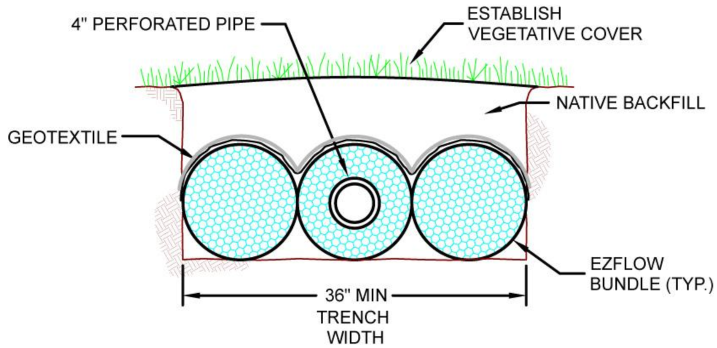
One installer of decentralized wastewater systems that was interviewed also indicated that:

- When primary treatment (e.g., a septic system) is the only treatment used, the soil adsorption field for a 3-bedroom house with 4 people (design flow of 500 gpd) in an area with “heavy clays” (i.e., dense, low-permeability soils) can be more than 5,000 ft^2 and 5 ft deep.
- If advanced treatment is used, the size of the adsorption field for the same household can be reduced significantly to approximately 200 ft^2 by 1 ft deep. However, the overall cost of the system will not change significantly: in one case the excavation and imported soil drive the cost, and in the other case the treatment technology drives the cost.
- The selection of the system (e.g., septic or advanced treatment) depends mostly on the size of the property (land available) but also on the preference of the user.
- Decentralized wastewater systems most commonly use PVC piping, and the cost of piping is not significant compared to the system cost, ranging between $200 to $500. A system typically requires 400 to 500 ft of pipe.

A manufacturer of septic tanks indicated that:

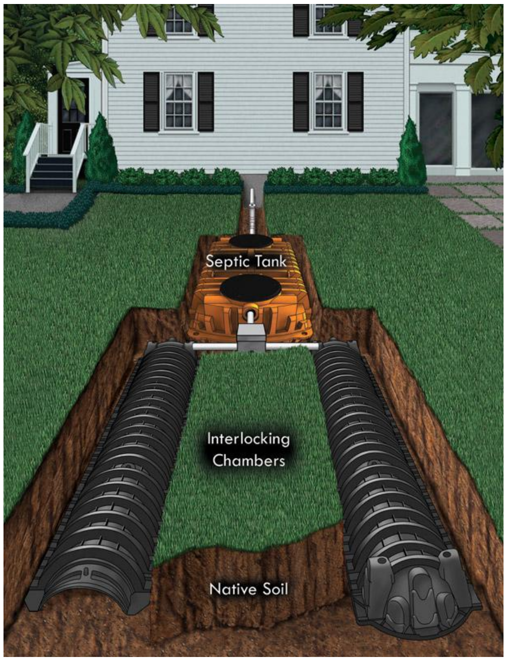
- Products are sometimes chosen depending on personal preferences of the installers, and in other instances the choice is driven by cost.
- Systems with pressure distribution can use in excess of 600 ft of NPS-1-½ plastic pipe perforated every 1 to 2 ft, whereas systems with gravity distribution will use less than 100 ft of pipe (only to the edge of the drain field).
- EZflow by Infiltrator Systems is a replacement for traditional stone and pipe drain fields using NPS-4 corrugated PE sewer pipe together with an engineered geo-synthetic aggregate. For this particular product, stone is the major competitor. The picture and diagram below illustrate such a system.

Source: Infiltrator Systems



Source: Infiltrator Systems

The diagram below illustrates a septic system with plastic chambers.



Source: Infiltrator Systems

The images below show two installations of All American Septic Systems.

Source: All American Septic Systems

Source: All American Septic Systems

8.5. Operating Example(s) and Testimonials

Operating Examples

Lake Shasta

Lake Shasta, which is part of the Shasta-Trinity National Recreation Area, is the largest reservoir in California. Before September 2006, houseboats and marinas were allowed to discharge gray water directly into the lake. However, as the number of visitors increased it became necessary to improve wastewater disposal practices to protect the environment and preserve water quality.

At the Jones Valley Resort in Redding, the wastewater system was designed to treat and dispose of up to 10,400 gpd. It includes 19,000 gal of septic tank capacity (a combination of existing and new concrete tanks) and 10,000 gal of surge capacity. Duplex pumps in a separate pump chamber send effluent to the disposal field via a 1,000 ft long, 2 in diameter force main. The disposal field incorporates 1,700 linear feet of PE chambers.

The new drain field helped to reduce the cost for treatment and allowed compliance with the new regulations. The cost reduction was due to the elimination of septage hauling and increased capacity of the onsite systems to handle peak flows and future growth. Additional projects are currently in the planning process around Lake Shasta as a result of the success of these initial marina decentralized wastewater systems.

Testimonials

"It is with great pleasure that I write to you in support of the success we've had with the new Hoot septic system. As you are well aware, our story isn't unique, a beachside property with a conventional system undoubtedly designed for an area much larger than we were housing it on. The troubles were endless, with pump-outs, overflow and chronic mishaps. At one point, I sincerely thought that our problems might never be solved.

I cannot begin to tell you what a pleasure it was for us to deal with you in resolving these problems. You brought a solution based on environmentally sound engineering science that we can all feel good about. Not only can we Give-a-Hoot, Don't Pollute, we can also be assured that this alternative does the best job of all of the available options. We are also convinced that

in the very near future, given the clean water issues in the state of Florida, that this type of system will be mandatory, and we'll be ahead of the curve! We cannot thank you enough."
John and Barbara Saunders, Customer of All American Septic Systems

"When I use Infiltrator chambers I save time. Infiltrator installations are about 3 h faster than a stone field installation. I can pleasantly surprise the homeowners with a quick and thorough installation."
Jerry Coger, KBT construction, Wexford, MI

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Uniform Plumbing Code, Appendix K, Private Sewage Disposal Systems.

YouCanListForLess.com. Septics are private sewage disposal systems with these components. http://www.youcanlistforless.com/septicsystem.

9. RADON VENTING

9.1. Technology Overview

Radon is a "naturally occurring, colorless, tasteless, and odorless radioactive gas which is about eight times denser than air. It is formed by the radioactive decay of radium, and has a half-life of 3.82 days" (A Dictionary of Environment and Conservation).

Radon is normally trapped underground, but over time the gas escapes directly into the atmosphere and is usually rapidly dispersed. It can also dissolve in and contaminate groundwater and well water.

Radon gas can be released into buildings through cracks or holes in the foundation, potentially building up to dangerous concentrations if trapped in the indoor environment. The degree of ingress into buildings depends on the characteristics of foundation defects and soil characteristics.

The US EPA indicates that "the average radon concentration in the indoor air of U.S. homes is about 1.3 pCi/L (picoCuries per liter) and the average concentration of radon in outdoor air is 0.4 pCi/L." Localized concentrations in below grade areas or rooms in contact with soil can be significantly higher than the EPA action concentration of 4 pCi/L. Nearly 1 out of every 15 homes in the U.S. is estimated to have elevated radon concentrations. Although there is some controversy about the magnitude of associated health risks and "safe" levels, the U.S. EPA recommends installing a radon venting system when the radon concentration is 4 pCi/L or more.

Radon reduction methods vary in complexity and cost. The effectiveness depends on the characteristics of the foundation, the radon concentration, the routes of entry and the quality of the installation and installer expertise. A single method may be sufficient, but sometimes several methods must be combined to achieve acceptable results, especially if radon concentrations are high.

Designing radon mitigation systems for large commercial buildings or schools requires more extensive knowledge of HVAC operation and foundation components, pressure and airflow measurements and interpretation, fan sizing and other considerations than residential buildings.

The most commonly used methods for reducing radon concentration are:

<u>Active soil depressurization</u>
Active soil depressurization is when a vent pipe is installed through the basement floor slab or by connecting it to the foundation drain tiles through the sump. A crawlspace can be vented by from beneath a sealed polyethylene membrane installed over the soil. A continuously operated fan is connected to the vent pipe to reverse the air pressure difference between the house and soil, removing and reducing the concentration of radon at the foundation. This has been demonstrated to be the most effective and reliable radon reduction technique.
<u>Passive Soil Depressurization</u>
Passive soil depressurization relies on natural pressure differentials and air currents to draw radon up from the soil. This is generally not as effective at reducing radon levels.

<u>Heat Recovery Ventilator (HRV)</u>
A HRV can provide constant ventilation that can help reduce indoor radon concentrations,

especially when used to ventilate only the basement.

Systems that use continuously-run fans are more effective in reducing radon levels, however they will increase the electricity bill and result in some loss of heated or conditioned air.

Sealing cracks and other openings in the foundation limit ingress of radon and will also reduce the loss of conditioned air. However, sealing alone is not usually sufficient, as it can be difficult to locate all points of entry. Furthermore, as a building settles, new defects may appear that reverse any previous gains.

Radon vent exhaust outlets should be positioned above the highest eave of the building and as close to the roof ridge line as possible in order to prevent it from re-entering the building through doors and windows. In addition, the EPA states that the point of discharge must meet all of the following requirements:

- 10 ft or more above ground level;
- 10 ft or more from any window, door or other opening; and
- 10 ft or more from any opening into an adjacent building.

If chimneys, exhaust fans or HVAC equipment reduce indoor air pressure, there is a danger that higher amounts of radon can be sucked into the indoor environment. Conversely, maintaining a slightly positive pressure in the building can mitigate its ingress.

Radon mitigation can also minimize entry of moisture and other soil gases, reducing the potential for other indoor air quality problems.

Prospective home buyers who are not aware of the radon issue may perceive a problem with a home that has a fan-based radon mitigation system. Real estate agents report that this can have an adverse impact on the perceived market value of the house. This highlights the need to increase public awareness of this serious potential health threat and the options for mitigation.

9.2. Life Safety Impacts

Lung cancer is the only known effect on human health from exposure to radon in air. In fact, the World Health Organization reports that radon is estimated to be responsible for 3-14% of lung cancers worldwide, depending on average radon levels.

Venting reduces the concentration of radon in indoor air and therefore reduces the associated lung cancer risks. Considering the potential to reduce the incidents of lung cancer deaths every year in the U.S., the life safety benefits of installing a relatively inexpensive radon venting system can be significant.

According to the EPA, radon is:

- The number one cause of lung cancer among non-smokers.
- The second leading cause of lung cancer, after smoking.
- Responsible for approximately 20,000 lung cancer deaths in the U.S. every year, of which about 2,900 occur among people who have never smoked. (Exposure to 4 pCi/L of radon is the equivalent of getting 200 to 300 chest x-rays per year or smoking half a pack of cigarettes per day.)

The following table shows the cancer risk depending on radon concentration, illustrating that smokers face a significantly elevated risk of lung cancer due to the synergistic effects of radon and smoking.

Radon Concentration (pCi/L)	If 1,000 people who smoked were exposed to this concentration over a lifetime	If 1,000 people who never smoked were exposed to this concentration over a lifetime
20	About 260 people could get lung cancer	About 36 people could get lung cancer
10	About 150 people could get lung cancer	About 18 people could get lung cancer
8	About 120 people could get lung cancer	About 15 people could get lung cancer
4	About 62 people could get lung cancer	About 7 people could get lung cancer
2	About 32 people could get lung cancer	About 4 person could get lung cancer
1.3	About 20 people could get lung cancer	About 2 people could get lung cancer
0.4	About 3 people could get lung cancer	

Source: U.S. Environmental Protection Agency. A Citizen's Guide to Radon.

The Iowa Radon Lung Cancer Study funded by the National Institute of Environmental Health Sciences (NIEHS) was a 5-year large-scale epidemiology study initiated in 1993 in Iowa, which has the highest average radon concentrations in the U.S. The study participants were over a thousand women throughout Iowa who had lived in their current home for at least 20 years. Four hundred and thirteen of the participants had previously developed lung cancer and the remaining 614 participants were controls who did not have lung cancer. The study assessed residential radon exposure risk and concluded that cumulative radon exposure in the residential environment is significantly associated with lung cancer risk.

9.3. Installed Cost

According to EPA, the average house costs about $1,200 for a contractor to implement radon venting, although this can range from $800 to $2,500, depending on the size and other characteristics of the house and the reduction method used. The table below presents installation and operating costs for radon venting techniques.

Technique	Typical Radon Reduction	Typical Installation Cost	Typical Annual Operating Cost*	Comments
Soil depressurization	50 - 99%	$800 - $2,500	$50 - $200	Works best if air can move easily in material under slab.
Passive soil depressurization	30 - 70%	$550 - $2,250	There may be some energy	May be more effective in cold climates; not as effective as active

Technique	Typical Radon Reduction	Typical Installation Cost	Typical Annual Operating Cost*	Comments
			penalties	soil depressurization.
Drain tile suction	50 - 99%	$800 - $1,700	$50 - $200	Can work with either partial or complete drain tile loops.
Block wall suction	50 - 99%	$1,500 - $3,000	$100 - $400	Only in houses with hollow block walls; requires sealing of major openings.
Sump hole suction	50 - 99%	$800 - $2,500	$50 - $250	Works best if air moves easily to the sump under the slab.
Sub-membrane depressurization in a crawlspace	50 - 99%	$1,000 - $2,500	$50 - $250	Less heat loss than natural ventilation in cold winter climates.
Natural ventilation in a crawlspace	0 - 50%	none $200 - $500 if additional vents installed	There may be some energy penalties.	Costs variable
Sealing of radon entry routes	See Comments	$100 - $2,000	None	Normally only used with other techniques; proper materials & installation required
House (basement) pressurization	50 - 99%	$500 - $1,500	$150 - $500	Works best with tight basement isolated from outdoors & upper floors.
Natural ventilation	Variable/ Temporary	None $200 - $500 if additional vents installed	$100 - $700	Significant heated/cooled air loss; operating costs depend on utility rates & amount of ventilation.
Heat recovery ventilation (HRV)	25%-50% if used for full house; 25%-75% if used for the basement	$1,200 - $2,500	$75 - $500 for continuous operation	Limited use; effectiveness limited by radon concentration and the amount of ventilation air available for dilution by the HRV. Best applied to limited-space areas like basements.
Private well water systems: aeration	95 - 99%	$3,000 - $4,500	$50 - $150	Generally more efficient than GAC; requires annual cleaning to maintain effectiveness and to prevent contamination; requires venting radon to outdoors.
Private well water systems: granular activated carbon (GAC)	85 - 99%	$1,000 - $3,000	None	Less efficient for higher concentrations than aeration; use for moderate concentrations (around 5,000 pCi/L or less in water); radioactive radon by-products can build on carbon; may need radiation shield around tank & care in disposal.

* Includes electricity for running the fan and loss of conditioned air

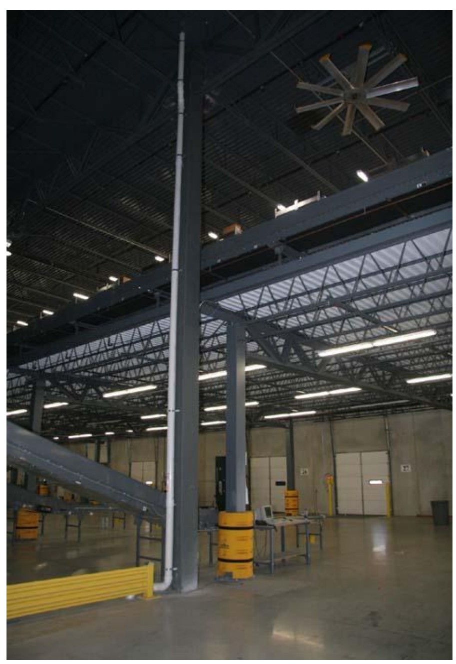
Source: U.S. Environmental Protection Agency. Consumer's Guide to Radon Reduction.

9.4. Materials Used (Piping, Tubing, Fittings)

Rigid DWV plastic (PVC or ABS) pipe is typically used for radon venting for its light weight, low cost and ease of installation. Active soil depressurization systems typically use PVC pipe to conduct the air outside of the building. The pictures below illustrate typical installations showing plastic pipe.

Source: Radon Safety LLC.

This WPB Enterprise installation shows the PVC pipe with the fan mounted on the roof. This system is depressurizing 60,000 ft² of a 1/2 million ft² warehouse.



Source: WPB Enterprise

9.5. Operating Example(s)

Ottawa Rockcliffe Park house (Walkinshaw)
Radon concentrations in the basement exceeded 4 pCi/L. The basement was finished with the Enclosure Conditioned Housing (ECHO) System which formed a ventilated and depressurized continuous subfloor and perimeter stud wall barrier to radon and any other soil gas entry. The system eliminates foundation water leakage. Its continuous, depressurized envelope cavity prevents soil and building material moisture, gases and mould spores from entering the living space. Its energy efficient, variable speed blower provides extra house ventilation when needed.

St. Lukes Hospital branch, Allentown, Pennsylvania
The WBP Enteprise radon mitigation system designed and installed in 2005 included increased outdoor air and a sub-slab depressurization system.

Testimonials
The following testimonials were from customers of Air-Pure Services:

We simply want to tell you how pleased we are with the radon mitigation system you recently installed in our new home in Canon City. Before you installed the radon mitigation system in our home, we had radon readings that were above 4.0 pCi/L and therefore potentially cancer-causing over time; after you installed the system, the radon readings in our home dropped to below 1.5 pCi/l, which as you know are safe readings.
Mary Ellen and Frank Lineaweaver
Canon City, CO

We want to thank Air-Pure Services for their fine service on the installation of the mitigation system and testing. We feel very comfortable with system in place and had reduced the radon level from 32.6 pCi/L to 1.3 pCi/L.
Doug & Carolyn Westlund - Pueblo West, CO

9.6. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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10. CENTRAL VACUUM SYSTEMS

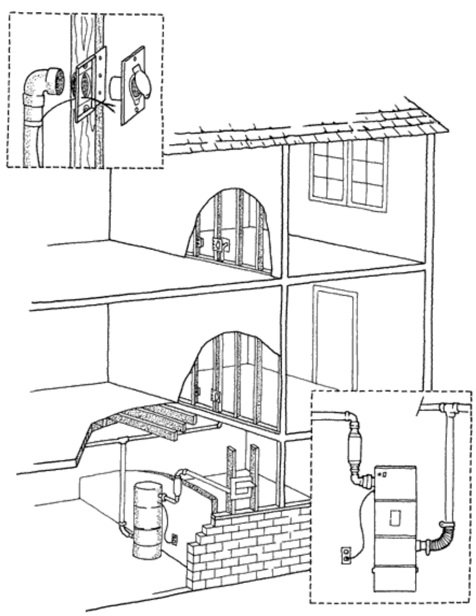
10.1. Technology Overview

Central vacuum systems can be installed in both new and existing homes and buildings. Commercial systems can be used in a variety of applications including restaurants, office buildings, hospitals, clinics, hotels, schools, showrooms, retail stores and more.

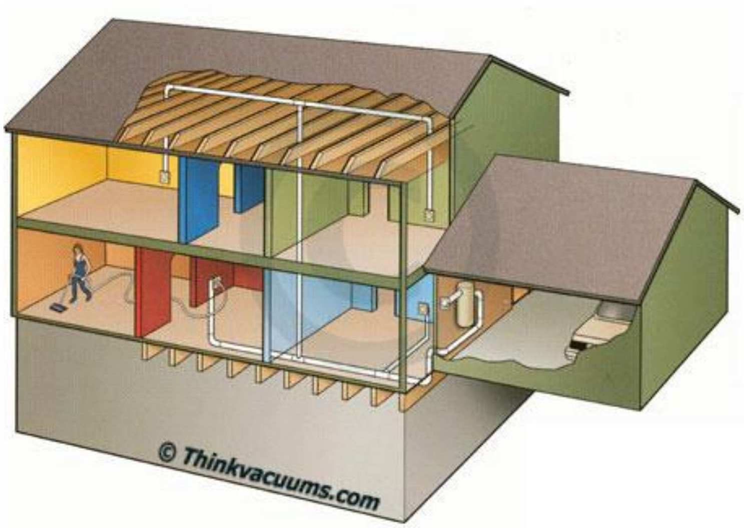
The main components of a central vacuum system are the air pump, power unit and dirt collection canister that are permanently installed in the garage or basement of a home or building. They are typically connected by concealed PVC piping interconnected to different rooms through the walls, floors or attic. Suction vents are located at various points throughout the building and low voltage wires run along the PVC pipes. Newer wireless systems are being developed that use acoustic or pressure sensing technology in place of wires. When the vacuum hose is inserted into a suction vent receptacle, the air pump turns on automatically and dirt, dust and debris are sucked through the hose and piping to the collection canister. The canister is typically large enough to only need emptying a few times a year.

As the motor (air pump) and collector are remote, most central vacuum systems are much more powerful than portable vacuums and the canisters have a much larger dirt storage capacity than portable units. Another benefit of these systems is a longer lifespan. Most important, however, is the improvement in indoor air quality by removing household allergens without blowing and re-circulating them throughout the indoor air as portable vacuums tend to do, especially if poorly maintained.

The diagrams below show typical installations of residential central vacuum systems, with the central unit in the garage or in the basement. The location and configuration of the components of the system (central unit, suction vents, connection to the PVC piping) are shown in detail. Commercial systems are similar, with more powerful motors and larger diameter piping.



Source: Don Vandervort's Hometips.com



Source: ThinkVacuums

Benefits

The main benefit of central vacuum system is that it provides cleaner indoor air by efficiently removing particles without releasing them back into the building, with the exhaust air vented outside of the living space or even outdoors. In addition, central vacuum systems:

- Can have two to five times more suction power than conventional portable vacuum cleaners;
- Typically produce less noise than conventional portable vacuum cleaners, improving indoor environmental quality (IEQ);
- Are usually located in a remote location; therefore the noise indoors is minimal;
- Have a larger dirt storage capacity, and therefore usually requires emptying only once or twice per year;
- Eliminate the need to drag a machine around the house, banging up walls and furniture in the process;
- Do not have to be carried up and down the stairs or potentially fall down the stairs if tugged while cleaning;
- Do not require disposable paper dust collection bags, reducing waste and ultimately helping to preserve forests;
- Last considerably longer than portable vacuum cleaners, conserving raw materials and ultimately reducing waste to landfills; and
- Are considered a home upgrade which may increase the value of the home.

Other Considerations

For a central vacuum system to be considered a truly green product from an IEQ standpoint, it should be piped to expel pollutants and allergens outside the building, and not in the garage. This requires a vent similar to a clothes drier vent and prevents the recirculation of harmful, microscopic allergens indoors.

An on/off switch at the unit allows it to be shut off completely, using zero standby energy. One such system has earned the Carpet and Rug Institute’s (CRI) Green Label for indoor air quality.

Central vacuum systems present opportunities for achieving green building rating points in the IEQ (improved air quality, reduced noise pollution) and materials recycling categories. For example, the National Association of Home Builders ANSI standard, National Green Building

Standard awards 5 points for central vacuum systems vented to the outside.

It should be noted that there are some highly efficient, light-weight, quiet portable vacuum cleaners which often have 5-10 year warranties, and light-weight carbon-fiber casing which are virtually indestructible and do not require replacement of vacuum bags. In lieu of central systems, these advanced technology vacuum systems (e.g. cyclonic systems) can be more cost-effective for the same application in some cases.

10.2. Indoor Environmental Quality (IEQ) Impacts

Outdoor air pollution can damage human health, however indoor air pollution can sometimes have even more detrimental health effects. EPA studies of human exposure to air pollutants indicate that indoor pollutant levels can be 2 to 5 times, and on occasion more than 100 times higher than outdoor levels. Indoor air pollutant levels are of particular concern because it is estimated that most people spend as much as 90% of their time indoors.

Over the past several decades, exposure to indoor air pollutants is believed to have increased due to a variety of factors, including the construction of more tightly sealed buildings, reduced ventilation rates to save energy, the use of synthetic building materials and furnishings and the use of chemically formulated personal care products, pesticides and household cleaners.

The decline in indoor air quality due to increased pollutants creates numerous negative health effects, most obviously asthma and allergies. Incidents of asthma have been rising steadily at about 6% per year for the last generation - roughly the time frame in which homes have been built more tightly. The World Health Organization, in its 1995 Global Initiative on Asthma, stated that asthma affects over 100 million people worldwide. The EPA estimates the annual cost of asthma at more than $6.2 billion.

Research shows removal of allergens from the home can greatly reduce the chance of developing asthma symptoms and the severity of those symptoms. The American Lung Association recommends central vacuum systems in houses where more than 70% of flooring is carpeted, and states: "Poor indoor air quality can cause or contribute to the development of chronic respiratory diseases such as asthma, and hypersensitivity and pneumonitis."

Furthermore, it has been reported in Annals of Allergy that:

Determination of the number of particles less than 0.5, 1, 2, 5, and 10 µm in the air before, during, and after cleaning of carpeting disclosed larger numbers of airborne particles while cleaning with portable vacuum cleaners than with central vacuum cleaners... Nearly all of these particles are small enough usually to be inhaled and deposited in the lower respiratory tract. Accordingly, they constitute a hazard for patients with asthma as well as those with allergic rhinitis.

Stanley Naguwa and Eric Gershwin, researchers at the University of California at Davis conducted a study to determine whether central vacuum systems can relieve allergy symptoms. The results were published in an article entitled "The Influence of a Central Vacuum System on Quality of Life in Patients with House Dust-Associated Allergic Rhinitis", which appeared in the Journal of Investigational Allergology and Clinical Immunology. The study found that, unlike conventional vacuums that can re-circulate dust, central vacuum systems remove 100% of contacted dust, mites, pollen, animal dander and other allergens, and are superior to conventional vacuum cleaners in providing relief from allergy symptoms.

10.3. Installed Cost

Our research indicated that:

- The base unit will typically cost between $500 to more than $1,200 including the hose and tools. The PVC piping, wall ports, and wiring could add another $300 to more than $750.
- In the U.S., most new houses are not roughed in for central vacuum systems, whereas in Canada the great majority of new houses are roughed in. The cost for the builder to rough-in a house is approximately $500 (labor and material, including cover plates only).
- In the U.S., retrofitting an existing house for a central vacuum system will cost between $3,000 and $3,500.

10.4. Materials Used (Piping, Tubing, Fittings)

The typical pipe and fittings used for central vacuum systems are PVC due to its light weight, durability and ease of cutting to specific lengths. The pipe is used to bring the vacuumed air and dust from the suction vents to the central power unit / dirt-collection canister.

Central vacuum manufacturers usually recommend central vacuum tubing for residential installations which are designed to fit directly with the fittings and inlets. However, PVC DWV plumbing pipe can be used with special PVC schedule 40 adaptors to connect to the central vacuum system fittings and inlets, where allowed by local building codes.

The dimensions (inside and outside diameters and wall thickness) of the typical vacuum 2-in PVC piping are not the same as the dimensions of 2-in Schedule-40 PVC DWV piping used for plumbing. Vacuum systems pipe is measured by its outside diameter, whereas Schedule-40 PVC DWV pipe is measured by its inside diameter. The wall thickness of vacuum systems pipe is approximately 1/16 in, whereas the wall thickness of NPS-2 PVC DWV pipe is greater than 1/8 in.

The higher wall thickness of DWV pipe make it more durable, but it can make the installation more expensive. However, when the installation requires that part of the piping run below grade (e.g., under a slab), that portion of the piping is done with DWV pipe and transition fittings are used to connect with the vacuum system piping.

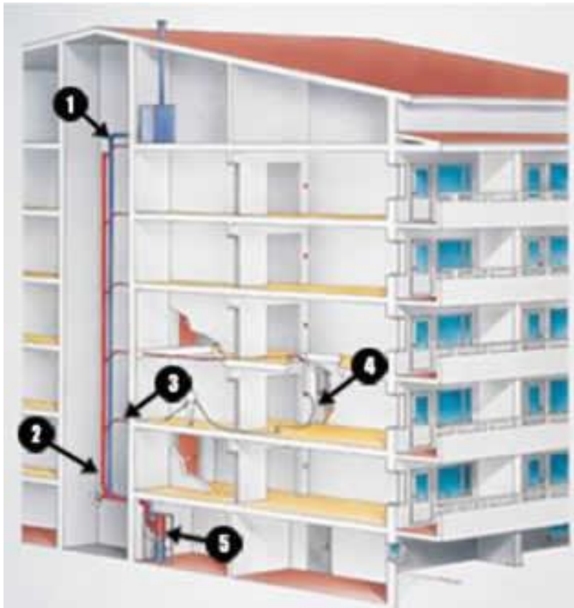
10.5. Operating Example(s)

<u>Hotel Gardenia in Italy</u>
Hotel Gardenia had an objective of deep cleaning 30 rooms in only one hour. After installing a Centec Systems unit, operating efficiency of 38% resulted from being able to achieve the same result as their previous conventional vacuums with less time and less people.

Fermanagh Office, Ireland

A Beam central vacuum system was installed in an office building in Fermanagh, Ireland. Up to 4 operators can simultaneously vacuum from any of the 150 inlets. The following elements were part of the central vacuum system (as illustrated in the diagram):

1. Exhaust that leads dirty air out of building
2. Vacuum suction main riser in the service duct
3. Distribution branch line installed in each raised floor or zone
4. Suction inlet
5. Power unit located in basement



Source: Beam Vacuums and Ventilation. Beam Vacuum Systems for Your Office.

Courtyard Marriott hotel in Galway, Ireland

A Beam central vacuum system with 105 inlets installed at the Courtyard Marriott hotel in Galway, Ireland delivered the following benefits:

- Up to 30% reduction in the annual housekeeping budget.
- Up to 52% improvement in indoor air quality.
- Vacuum cleaning permanently available where needed.
- Evacuates and ventilates odors from soiled carpets.
- Increase in life of carpets and upholstery.
- Eliminates noise at point of cleaning allowing carrying out housekeeping duties with minimum disturbance.
- Allows 8 operators to vacuum at any one time.

Testimonials

After vacuuming the carpets with my freestanding hypoallergenic vac, I vacuumed with the CV7700 Central *and went and checked the bag and was shocked how much more dirt the* CV7700 *pulled out after vacuuming with a freestanding.*
Pastor Gary
Hackensack, NJ

10.6. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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11. RESIDENTIAL FIRE SPRINKLER SYSTEMS

11.1. Technology Overview

Residential fire sprinklers are a newer technology gaining code acceptance and saving property and lives every year in single family homes, apartments and condominiums. In many cases, a fire sprinkler can contain the fire and possibly extinguish it in the time it takes for the fire department to arrive at the home with the deployment of only one or two sprinkler heads.

According to the National Fire Protection Association (NFPA), roughly 84% of all civilian fire deaths occur in homes. Alongside the obvious benefit of saving lives, a residential fire sprinkler system has also been proven to reduce property loss from heat, toxic emissions, smoke and fumes in the event of a fire.

Commercial sprinkler systems have been in use and required for many years in higher-risk office and industrial buildings, where their primary application has been protection of property. However, existing commercial systems are not appropriate for residential applications because residential water pressures are often too low to deliver the volumes required by commercial sprinkler heads. Lower ceiling heights made the spray patterns ineffective for homes.

Consequently, residential fast-response sprinkler heads are designed to react much more quickly than commercial heads to the presence of heat and work with typical residential water supply pressures. The hydraulic pattern produces broader spray patterns more suitable for homes. These designs became the basis of the NFPA 13D standard, *Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes*.

There are several types of residential fire sprinkler systems, which will depend on the pipe material used. . According to Lubrizol, in 2009 stand alone systems have accounted for over 90% of the market and may be installed using CPVC, copper or steel pipe. Multipurpose systems that use PEX, CPVC or copper pipe are usually combined with a cold-water plumbing system. An increasing number of multipurpose PEX sprinkler systems are looped rather than multiple-feeds to a single sprinkler head.

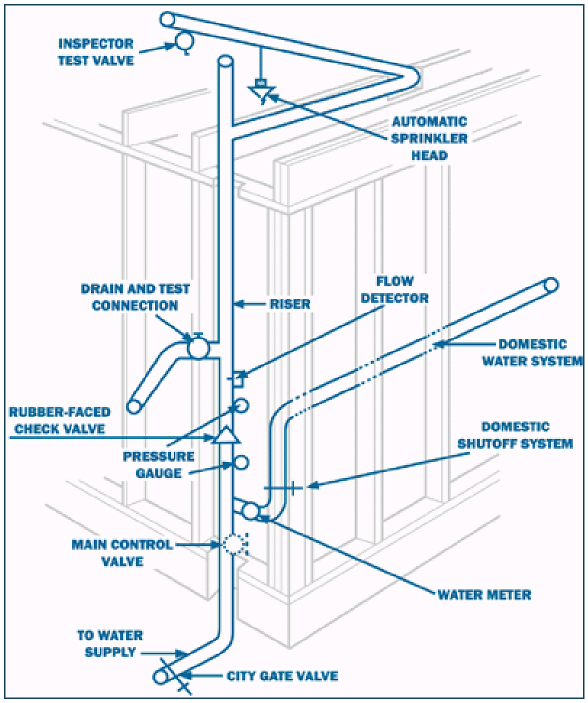
One of the advantages of a multipurpose system is that there is no need for backflow preventers or scheduled system testing and circulation of water. Approximately 30% of stand alone systems require a backflow preventer, and this depends on the requirements of the local code authorities. NFPA standards do not require backflow prevention.

In multipurpose systems the piping is run for the sprinkler system with branches for the plumbing fixtures. In other words, the sprinkler system serves the plumbing system, potentially resulting in a more economical installation. The pictures below illustrate a PEX network multipurpose network fire sprinkler system, PEX and CPVC looped multipurpose systems, and a CPVC stand alone system.

Source: Uponor.

Photos courtesy of Lubrizol

PEX tubing for fire sprinkler systems is used only in one and two-family dwellings because of its lower rated pressure (130 psi). Since CPVC fire sprinkler pipe has a pressure rating of 175 psi, it can be used in all residential applications (e.g., one and two-family dwellings, multi-family and high-rise buildings). The diagram below illustrates a typical piping riser diagram for a CPVC stand-alone system.



Source: U.S. Fire Administration.

In September 2008 the International Code Council (ICC) voted to mandate residential fire sprinkler systems in the 2009 International Residential Code. New homes and townhouses constructed under the 2009 IRC after January 1, 2011 will be required to include a residential fire sprinkler system where this code applies.

Benefits

Fire sprinklers can save lives and reduce water damage. On average fire hoses use more than 8.5 times the water that sprinklers do to contain a fire. As stated on the Home Fire Sprinkler Coalition website, the Scottsdale Report is a 15-year study of fire sprinkler effectiveness that found "a fire sprinkler uses, on average, 341 gal of water to control a fire. Firefighters, on average, use 2,935 gal", and that "reduced water damage is a major source of savings for homeowners." Additionally, much of the water used by firefighters becomes contaminated run-off.

Home Fire Sprinkler Coalition lists the following information:

- Residential fire sprinklers can contain and may even extinguish a fire in less time than it would take the fire department to arrive on the scene.
- Installing both smoke alarms and a fire sprinkler system reduces the risk of death in a home fire by 82%, relative to having neither.
- Only the sprinkler closest to the fire will activate, spraying water directly on the fire. Ninety percent of fires are contained by the operation of just one sprinkler.
- Fire sprinklers may help reduce insurance premiums.
- Residential fire sprinklers use only a fraction of the water used by fire department hoses (10 to 15 gpm compared to 250 gpm for fire hoses).
- Residential fire sprinkler systems are at least as reliable as home plumbing systems.
- Modern residential sprinklers are inconspicuous and can be mounted flush with walls or ceilings.
- For occupants who cannot readily "self-evacuate" in a fire, such as infants, young children,

elderly, the hard of hearing or deaf, fire sprinklers in the home are especially useful.
- They are also beneficial in cases where emergency services are distant from the residence.

Other Considerations
The sprinkler industry and groups concerned with fire prevention and control (e.g., the U.S. Fire Administration and the International Association of Fire Chiefs) have advocated having sprinklers mandated in new one and two-family homes.

In general, home builders associations in the U.S. and Canada – the National Association of Home Builders (NAHB) in the U.S., and the Canadian Home Builders Association (CHBA) in Canada - and organizations such as Habitat for Humanity and homeowners in general, have not embraced mandating residential fire sprinklers. This is primarily due to the following reasons:
- The risk of fire is considered to be relatively low in new homes in the U.S and Canada;
- The cost of residential fire sprinklers relative to those risks is very high, considering that every $1,000 increase in the price of an entry level new home means at least 6,000 potential first time buyers can no longer qualify for its mortgage;
- If people want to install fire sprinklers, it should be their choice; and
- Imposing the high costs of mandatory sprinklers through regulation cannot be justified on an economic or risk basis.

The NAHB provides the following additional information:
- Homeowners can check on the operation of smoke alarms without costly professional intervention.
- The fire sprinkler system valves must be checked periodically to verify the system is activated. If a backflow preventer is installed, an annual inspection is usually mandated by the local water purveyor.
- NFPA 13D advises that the sprinkler pipes in the antifreeze-type systems installed in colder climates be emptied and then refilled with an antifreeze solution every winter, and that monthly inspections and tests of all the water flow devices, pumps, air pressure and water level be performed.
- When the home relies on a well rather than a municipal water source, the costs of maintaining the necessary pumps and holding tanks must be factored in as well.
- In some cases the homeowner may receive a reduction in insurance premiums.

Additional points, from CHBA's position paper against mandating residential fire sprinklers:
- For houses in rural areas without regular fire services, sprinklers may be appropriate. However, these houses often pose the most serious difficulties for that technology, because of limited water pressure in wells.
- In some cases, it may be enough to make sure that smoke alarms are present and functioning.
- The fatality rate in houses without functioning smoke alarms is estimated to be 13 per 100,000 per year – very close to 10 times that of new housing. Installing two basic battery-operated smoke alarms in unprotected houses would cost about $40 to $80, and reduce fatalities by an estimated 7 lives per 100,000 houses per year. A more extensive system with four alarms might cost $80 to $160 and reduce annual fatalities by 8.5 lives per 100,000 per year. The smoke alarms have a very quick payback period.
- By comparison, spending more than $3,000 per new house for a fire sprinkler system might reduce fatalities by an estimated 0.78 lives per 100,000 per year – at a net cost to society of at least $38 million per life saved.

Several studies of residential sprinklers for new one and two-family homes (conducted among others by the Canada Mortgage and Housing Corporation, Canada's national housing agency) have concluded that the benefits of residential fire sprinklers may not justify the costs.

11.2. Life Safety Impacts

The U.S. Fire Administration reports that in the U.S. in 2007 there were:

- 414,000 residential fires
- 2,895 civilian fire deaths
- 14,000 civilian fire injuries
- $7.5 billion in property damage

Facts & figures reported by NFPA suggest that the risk of death decreases by about 82% when sprinklers are present along with smoke alarms in the home and that sprinklers reduce the average property loss by 71% per fire.

11.3. Installed Cost

The cost of a combined plumbing and fire protection system can be about 15% more than a stand-alone system. The Home Fire Sprinkler Coalition notes that nationally, on average home fire sprinkler systems add 1% to 2% of the total building cost in new construction. The average cost for installing a PEX tubing fire sprinkler systems in some markets is $2.50/ft^2, including the potable water plumbing. In competitive markets, the installation cost of a CPVC stand-alone system can be as low as $1.00/ft^2.

A poll of firms conducted by the Canadian Home Builders Association (CHBA) in early 2005 found that total cost estimates for a 2,000 ft^2 sprinkler coverage area including basement ranged between $3,000 and $4,000. Costs included the sprinkler system and associated piping (virtually always plastic), upgraded intake pipe, changes in other construction, schedule accommodation, etc.

Economies of scale apply, making systems for larger houses more expensive overall, but they will generally cost somewhat less per square foot. For renovation projects the costs can be much higher. In addition, there will be some costs for regular inspection and maintenance. In some municipalities, there may be extra charges to hook up to or increase municipal water supply size. In rural areas, sprinkler system costs could increase by $1,500 to $2,000 for a pump and tank system.

11.4. Estimated Cost Savings and Payback

The following table summarizes a comparative cost-benefit analysis for three types of houses in the U.S.

Summary of Baseline Benefit-Cost Analysis of a Multipurpose Network Residential Sprinkler System for the Colonial, Townhouse, and Ranch House.			
	Colonial	**Townhouse**	**Ranch**
Home information			
Area	3,338 ft2	2,275 ft2	1,171 ft2
Stories	3, with basement	3	Single
Benefits			
Fatalities Averted	$3,725.57	$3,725.57	$3,725.57
Injuries Averted	$224.74	$224.74	$224.74
Direct Uninsured Property Losses Averted	$79.64	$79.64	$79.64
Indirect Costs Averted	$15.93	$15.93	$15.93
Insurance Credit	$948.41	$948.41	$948.41
Benefit Subtotal	*$4,994.29*	*$4,994.29*	*$4,994.29*
Costs			
Installation (50% Mark-up)	$2,075.08	$1,895.17	$828.66
Costs Subtotal	*$2,075.08*	*$1,895.17*	*$828.66*
Net Present Value	**$2,919.20**	**$3,099.11**	**$4,165.62**

Source: Butry, Brown and Fuller, 2007.

11.5. Materials Used (Piping, Tubing, Fittings)

Residential sprinkler systems use potable cold-water water piping materials, most commonly CPVC, PEX and copper. Backflow protection is generally not required. The minimum tubing size permitted for a sprinkler system is NPS-3/4.

Copper tube (CTS)
Copper tube is allowed for fire sprinkler systems in NFPA 13D. Copper tube is durable, lightweight, and can withstand higher temperatures than plastic pipe when directly exposed to fire.

CPVC pipe
CPVC is the most commonly used piping for residential sprinkler systems due to its light weight, ability to withstand the pressure and heat, and due to its limited combustibility. The minimum size CPVC pipe permitted for a sprinkler system is NPS-3/4.

The CPVC pipe can be installed with a protective layer of gypsum wallboard or plywood. Lay-in ceiling tiles that are clipped in place may also be used.

PEX tubing
PEX tubing is a newer material choice for these systems. PEX tubing should be installed to be protected from direct exposure to fire. PEX tubing is flexible and can be bent when installing the tubing, which can reduce the number of fittings required. This, in turn, can correspond to lower labor costs for installation. CTS-1/2 is permitted for PEX systems with sprinkler heads that have multiple tubing connections, which allow minimum flow requirements for the sprinkler to be met.

For homes that require winterization or are subject to severe cold temperatures, the NFPA recommends that fire sprinkler systems use glycerin as an antifreeze. Glycerin antifreeze with NSF Standard 61 certification should be used in accordance with manufacturers' recommendations.

11.6. Operating Example(s)

The following operating examples were obtained from the Uponor website:

Saddle Springs Estates home, Nashville, Tennessee
This 5,600ft2 home is about 3 miles away from the fire department, requiring 10 to 12 min for them to arrive in case of fire. In that time, there potential damage to the house would be considerable.

Tubing type: Wirsbo AQUAPEX
Tubing length: 6,500 ft of ½ inch tubing for fire protection
2,100 ft of ½ inch to 1¼ inch tubing for cold-water distribution
Fittings: ProPEX

Town home in Durango, CO
This is one of seven attached three-level, 1,600-ft^2, townhome that caught fire from flames from an overheated van in the garage. Two of the home's fire sprinklers in the garage had activated, largely responsible for limiting the damage to the garage. Other than the garage itself and some light smoke damage to the upper two floors of the home, the seven attached units in the building escaped the blaze unscathed.

Tubing type: Wirsbo AQUAPEX
Tubing length: 1,300 ft of ½ inch tubing per unit for fire protection and cold-water distribution
Fittings: ProPEX

Residence in North Las Vegas, Nevada
This is a 1,200-ft2, single family home wood frame home built by RCR Companies

Tubing type: ½ inch Wirsbo AQUAPEX
Tubing length: 1,600 ft
Number of heads: 19

Townhome complex in Weston, Connecticut

1,200 ft²/unit (28 units total) wood-frame townhome built by Bartlett Construction Company.

Tubing type: ½ inch Wirsbo AQUAPEX to sprinkler heads and plumbing
1 inch Wirsbo AQUAPEX to manifold
Tubing length: 1,000 ft per unit, plus 200 ft for domestic hot water
Number of manifolds: One 10-port manifold in kitchen ceiling
Number of heads: 12 to 14 per unit
Installation method: Homerun
Length of installation: 2 days with 2 plumbers and 1 apprentice to complete 28 units with plumbing and fire protection

Testimonials
"New homeowners worry about aesthetics when they design their homes. Modern residential sprinklers are inconspicuous and the system is user friendly. When homeowners do the dishes, wash their car or get a drink of water, they have peace of mind knowing their home's fire protection system is working properly. This is a true lifesaver."
Tom Walls, field superintendent for RCR Companies
Las Vegas, NV

"I know I made the right decision to install the fire protection system in the Primrose units. We sold out the whole project — and have not experienced any problems. The first thing that comes to mind is simple — one system, one contractor, no problems. These are all crucial to ensuring a cost effective, high-quality system for builders and homeowners alike."
Kevin Bartlett, owner of Bartlett Construction Company
Weston, CT

For Hazelton, installing a BlazeMaster fire sprinkler system strengthened his commitment to promote home fire safety and prevention to Good Morning America and HouseCalls viewers. And as a homeowner, the peace of mind that fire sprinkler protection provides to him is invaluable. "My worst fear is being cut off from my daughter in a night fire and not being able to go to her aid," he said. "I know from a great deal of experience that sprinklers will suppress and usually put out a fire before it becomes life threatening. This is why I have it, and I would absolutely recommend fire protection systems to other homeowners."

11.7. Source Materials

Source materials used for this technology chapter are referenced in-text in abbreviated form, and in full in this section.

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Viking Group Inc. Viking Fire Sprinklers - Residential www.vikinggroupinc.com

CONCLUSIONS

The study shows that for those situations where plastic is preferred over non-plastic components for the green building technologies discussed in this report, the primary advantages cited generally included:

- Material flexibility and lighter weight, enabling greater design flexibility, ease of installation and lower installation time and cost;
- Durability and strength combined with chemical, weather and corrosion resistance and biological inertness, leading to effective performance and long service life in the field;
- Ease of color coding and marking to clearly distinguish between safe acceptable uses and applications;
- Cost-effective in terms of manufacturing, transportation and ease of installation;
- Recyclability and recycled content improves end-of-life impacts;
- Growing acceptance of a range of newer plastic product types by authorities having jurisdiction, based on an extensive testing and acceptance framework in accordance with established consensus standards, third-party certification, and referencing in building codes and regulations.
- Plastic piping products designed to deliver potable water are certified to meet the requirements of ANSI/NSF Standard 61 for drinking water health effects.

Energy and water savings achieved in homes and buildings from implementing individual or combinations of green building technologies were estimated by comparing the reduced consumption values with a hypothetical baseline scenario that uses conventional building technologies. The actual consumption and savings potential for a given building will be highly dependent on many interrelated factors, including:

- Building type and size;
- Site conditions, landscaping needs and constraints;
- Use and occupancy;
- HVAC systems;
- Number and types of plumbing fixtures;
- Irrigation needs for landscaping;
- Fuel types replaced;
- Renewable sources of energy;
- Energy and water pricing and rate structures;
- Labor rates for installation;
- Local codes and regulations;
- For existing buildings, the age of the building is an important factor.

Given the pricing of electricity, natural gas and water, current at the time of this review, several technologies do not currently have a reasonable payback period based on a simple economic payback analysis, especially for residential applications. Larger, commercial scale systems generally offer a more reasonable return on investment.

It should be noted that applicable incentives and rebates offered by public agencies or utilities can significantly reduce the initial investment and shorten the payback period. This benefit varies by location and was not taken into account in the simple economic analysis presented. In addition, if the impact of avoided wastewater and energy costs are added to onsite water and energy savings, the overall economic benefits would be even more readily apparent.

Simple economic payback analysis does not account for the possibility of higher rates for energy (including possible carbon taxation) and municipal potable water and wastewater services. Pricing water to better reflect its real cost stimulates conservation efforts and utilization of substitute sources. Savings beyond the payback period can add significantly to the overall investment return over the life cycle of a project. It is important to note that the underlying cost data will typically vary between markets nationally with fluctuations in commodity or raw material prices and over time as technological innovations are brought to bear.

For all of these reasons, a more comprehensive cost-benefit analysis using life cycle costing is recommended in order to assess the true economic feasibility and payback period for implementing these technologies individually and in combination with other technologies. Key inputs to life cycle cost analysis include:

- Costs for purchase, acquisition, construction and installation
- Resource costs (fuel, water, wastewater, materials)
- Operation, maintenance, repair and replacement
- Reuse, resale, salvage or disposal Costs
- Financing rates and amounts
- Total lifespan of the project or service life of the technology

Other factors that also impact the overall costs and benefits are not readily quantifiable, such as impact on occupant health and comfort, improved indoor air quality, productivity, lower noise pollution.

Commercial and institutional facilities consume the most significant proportion of the total water supply, but relatively little information is available for reliable benchmarking of water usage and water efficiency characteristics of these sectors. A key reason is the dissimilarity between various facilities and their specific uses and consumption volumes. Detailed case studies across a range of building types and uses would provide useful information to characterize potential water efficiency improvements and associated economic benefits, as is currently the case for energy performance measurements.

RECOMMENDED NEXT STEPS

In support of PPFA's sustainability policy, recommended next steps for the plastic pipe industry are to:

Further characterize the environmental impacts and benefits of green building technologies that incorporate plastic pipe, tubing and fittings by conducting life cycle assessment of the plastic components utilized. The LCA studies would build on the life cycle inventory (LCI) study recently conducted by Franklin Associates, comparing CPVC, PEX and copper piping. The LCA would report the environmental impacts of the full life cycle of the products from extraction of the resources, manufacturing, transportation, installation onsite, the use phase, and finally, demolition and disposal at the end of the life of the building, taking into account recycling and reuse of products and materials and handling and management of waste. All of the materials, energy and water flows into and emissions to air, water and land resulting from the building's full life cycle would be identified and quantified.

The results of these LCA studies can be used to:

a. Encourage the selection of these components and adoption of these technologies by green building design teams and manufacturers of the systems. It may help to develop comparative LCA with alternative materials for this purpose.
b. Comparative LCA studies with alternative materials can play an important role in overcoming negative perceptions of plastic in these applications. Previous LCA studies conducted by USGBC and others have shown that plastic pipe is a better alternative for certain applications.
c. Enhance the eligibility of building projects for credits in the materials and resources categories by integrating LCA results in tools such as the Athena EcoCalculator being used by the leading green building rating systems;
d. Enable the industry to better identify and improve on manufacturing, transportation and installation efficiencies, end-of-life impacts, thereby contributing meaningfully to overall sustainability of resources and access to resources;
e. Enable the industry to plan for opportunities and risks related to environmental product declaration programs, carbon management programs and regulatory schemes.

2. Conduct a more comprehensive economic analysis for the identified technologies using life cycle costing tools. This will help to address the limitations of simple payback analysis and provide more reliable economic indicators expressed in terms of net present value and discounted cash flow analysis over the service life of the technology.

3. Develop and publicize comprehensive case studies demonstrating the use of plastic pipe, tubing and fittings in a greater variety of green building installations, quantifying the associated environmental, health and life safety benefits achieved and illustrating how site, installation and configuration constraints were overcome.

APPENDIX A: WATER SAVINGS ANALYSIS

Table A1 - Residential Water Savings Example

Residential (Average Household)				**Nationwide Average**		
				(gal)	**($)**	
Baseline annual water consumption				73,000	$504	
Water-saving Technology	**Installation and capital cost ($)**	**Operating costs per month, ($)**	**Estimated water savings (%)**	**Annual Water Savings (gal)**	**Annual Water Savings ($)**	**Economic payback (years)**
Gray water reuse (savings of 40% of total water consumption)	$4,000	$48	40%	29,200	$202	-10.9
Rainwater harvesting (savings of 50% of total water consumption)	$5,000	$20	50%	36,500	$252	416.7
Water-efficient Irrigation (savings of 30% of total outdoor water consumption)	$1,500	$20	10%	7,293	$50	-7.9
Efficient Hot water distribution (savings of 10% of total water consumption)	$600	$0	10%	7,300	$50	11.9

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Residential (Average Household)	Miami-Dade, Florida			Minneapolis, Minnesota			California		
	(gal)	**($)**		**(gal)**	**($)**		**(gal)**	**($)**	
Baseline annual water consumption	85,410	$351		60,000	$443		169,443	$720	
Water-saving Technology	**Annual Water Savings (gal)**	**Annual Water Savings ($)**	**Economic payback (years)**	**Annual Water Savings (gal)**	**Annual Water Savings ($)**	**Economic payback (years)**	**Annual Water Savings (gal)**	**Annual Water Savings ($)**	**Economic payback (years)**
Gray water reuse (savings of 40% of total water consumption)	34,164	$141	-9.3	24,000	$177	-10.2	67,777	$288	-14.2
Rainwater harvesting (savings of 50% of total water consumption)	42,705	$176	-77.8	30,000	$221	-268.7	84,721	$360	41.7
Water-efficient Irrigation (savings of 30% of total outdoor water consumption)	8,532	$35	-7.3	5,994	$44	-7.7	16,927	$72	-8.9
Efficient Hot water distribution (savings of 10% of total water consumption)	8,541	$35	17.1	6,000	$44	13.6	16,944	$72	8.3

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Table A1 - Commercial Building Water Savings Example

Office Building				**Miami-Dade, Florida**			**Minneapolis, Minnesota**		
				(gal)	**($)**		**(gal)**	**($)**	
Baseline annual water consumption				5,363,675	$36,426		6,570,000	$42,600	
Water-saving Technology	**Installation and capital cost ($)**	**Operating costs per month, ($)**	**Estimated water savings (%)**	**Annual Water Savings (gal)**	**Annual Water Savings ($)**	**Economic payback (years)**	**Annual Water Savings (gal)**	**Annual Water Savings ($)**	**Economic payback (years)**
Gray water reuse (savings of 40% of total water consumption)	$50,000	$48	40%	2,145,470	$14,571	3.6	2,628,000	$17,040	3.0
Rainwater harvesting (savings of 50% of total water consumption)	$20,000	$95	50%	2,681,838	$18,213	1.2	3,285,000	$21,300	1.0
Water-efficient Irrigation (savings of 30% of total outdoor water consumption)	$3,600	$120	10%	535,831	$3,639	1.6	656,343	$4,256	1.3
Efficient Hot water distribution (savings of 10% of total water consumption)	$1,000	$0	10%	536,368	$3,643	0.3	657,000	$4,260	0.2

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Office Building				**San Diego, California**		
				(gal)	**($)**	
Baseline annual water consumption				6,570,000	$60,042	
Water-saving Technology	**Installation and capital cost ($)**	**Operating costs per month, ($)**	**Estimated water savings (%)**	**Annual Water Savings (gal)**	**Annual Water Savings ($)**	**Economic payback (years)**
Gray water reuse (savings of 40% of total water consumption)	$50,000	$48	40%	2,628,000	$24,017	2.1
Rainwater harvesting (savings of 50% of total water consumption)	$20,000	$95	50%	3,285,000	$30,021	0.7
Water-efficient Irrigation (savings of 30% of total outdoor water consumption)	$3,600	$120	10%	656,343	$5,998	0.8
Efficient Hot water distribution (savings of 10% of total water consumption)	$1,000	$0	10%	657,000	$6,004	0.2

APPENDIX B: ENERGY SAVINGS ANALYSIS

Table B1: Residential Household Energy Savings Example

Household Energy Consumption, 2005	**2000**	**ft2 floor space**		
Baseline		Florida	Minnesota	California
Energy consumption	kBtu per ft2	32.1	44.1	41.7
Energy expenditures	$ per ft2	$0.9	$0.8	$0.9
Total energy consumption	kBtu	64,200	88,200	83,400
Annual energy expenses	$	$1,800	$1,560	$1,740
Electricity (% of total consumption)	41%			
Natural Gas (% of total consumption)	59%			
Assumption: All non-electricity fuel use from natural gas				

CO2e conversion factors		
1 kWh	3413	Btu
100 ft3 of NG = 1 therm = 103000 Btu	103000	Btu
1 tonne CO2	1392.757	kWh
1 tonne CO2	200	therm

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Florida Average Household	**Installed Cost ($)**	**Total Energy Savings (%)**	**Energy Savings (kBtu)**	**Energy Savings ($)**	**Simple Payback Period (Years)**	**Electricity Savings (kWh)**	**Natural Gas Savings (therm)**	**Total CO2 equiv. GHG emissions reduced (tonnes)**
Baseline		0%						
Geothermal	$15,000	50%	32,100	$900	16.7	3,856	5.2	2.8
Efficient Hot Water Distribution	$600	10%	6,420	$180	3.3	771	1.0	0.6
Radiant Heating	$7,000	25%	16,050	$450	15.6	1,928	2.6	1.4
Solar Hot Water	$3,000	13%	8,025	$225	13.3	964	1.3	0.7

Minnesota Average Household	**Installed Cost ($)**	**Total Energy Savings (%)**	**Energy Savings (kBtu)**	**Energy Savings ($)**	**Simple Payback Period (Years)**	**Electricity Savings (kWh)**	**Natural Gas Savings (therm)**	**Total CO2 equiv. GHG emissions reduced (tonnes)**
Baseline		0%						
Geothermal	$15,000	50%	44,100	$780	19.2	5,298	4.5	3.8
Efficient Hot Water Distribution	$600	10%	8,820	$156	3.8	1,060	0.9	0.8
Radiant Heating	$7,000	25%	22,050	$390	17.9	2,649	2.2	1.9
Solar Hot Water	$3,000	13%	11,025	$195	15.4	1,324	1.1	1.0

California Average Household	**Installed Cost ($)**	**Total Energy Savings (%)**	**Energy Savings (kBtu)**	**Energy Savings ($)**	**Simple Payback Period (Years)**	**Electricity Savings (kWh)**	**Natural Gas Savings (therm)**	**Total CO2 equiv. GHG emissions reduced (tonnes)**
Baseline		0%						
Geothermal	$15,000	50%	41,700	$870	17.2	5,009	5.0	3.6
Efficient Hot Water Distribution	$600	10%	8,340	$174	3.4	1,002	1.0	0.7
Radiant Heating	$7,000	25%	20,850	$435	16.1	2,505	2.5	1.8
Solar Hot Water	$3,000	13%	10,425	$218	13.8	1,252	1.2	0.9

Table B2: Commercial Office Building Energy Savings Example

Baseline annual energy intensity (office building)		95	kBtu/ft2		
Electricity Consumption (66% of total)		62.7	kBtu/ft2	18.37	kWh/ft2
Natural gas and other fuels (34% of total)		32.3	kBtu/ft2	0.31	therms/ft2
Floor space for office building (nationwide median)		14800	ft2		
Assumption: All non-electricity fuel use from natural gas					

Commercial Office Building 14,800 ft2 floor space	Installed Cost	Total Energy Use	Total Energy Savings	Electricity Use	Electricity Savings	Natural Gas Use	Natural Gas Savings	Total CO2e GHG emissions reduced
	$	**kBtu**	**%**	**kWh**	**kWh**	**therm**	**therm**	**tonnes**
Baseline		1,406,000	0%	271,890		4,641		
Geothermal	$100,000	843,600	40%	163,134	108,756	2,785	1,856	87
Efficient Hot Water Distribution	$2,000	1,265,400	10%	244,701	27,189	4,177	464	22
Radiant Heating	$25,000	1,054,500	25%	203,917	67,972	3,481	1,160	55
Solar Hot Water	$15,000	1,195,100	15%	231,106	40,783	3,945	696	33

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	Florida				Minnesota			
Commercial Office Building 14,800 ft2 floorspace	**Electricity Savings**	**Natural Gas Savings**	**Total Annual Energy Savings**	**Payback Period**	**Electricity Savings**	**Natural Gas Savings**	**Total Annual Energy Savings**	**Payback Period**
	$	**$**	**$**	**years**	**$**	**$**	**$**	**years**
Baseline								
Geothermal	$10,712	$2,716	$13,428	7.4	$8,102	$1,953	$10,055	9.9
Efficient Hot Water Distribution	$2,678	$679	$3,357	0.6	$2,026	$488	$2,514	0.8
Radiant Heating	$6,695	$1,698	$8,393	3.0	$5,064	$1,221	$6,285	4.0
Solar Hot Water	$4,017	$1,019	$5,036	3.0	$3,038	$732	$3,771	4.0

	California			
Commercial Office Building 14,800 ft2 floorspace	**Electricity Savings**	**Natural Gas Savings**	**Total Annual Energy Savings**	**Simple Payback Period**
	$	**$**	**$**	**years**
Baseline				
Geothermal	$12,681	$2,176	$14,857	6.7
Efficient Hot Water Distribution	$3,170	$544	$3,714	0.5
Radiant Heating	$7,926	$1,360	$9,285	2.7
Solar Hot Water	$4,755	$816	$5,571	2.7

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