THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	Ground-Source Heat Pump Water Heating System
APPLICATION:	Water Heating
TECHNOLOGY NAME:	EarthLinked® Water Heating System
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies

ETV works in partnership with recognized standards and testing organizations, stakeholder groups that consist of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates the performance of technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Greenhouse Gas Technology Center (GHG Center), one of six verification organizations under the ETV program, is operated by Southern Research Institute in cooperation with EPA's National Risk Management Research Laboratory. GHG Center stakeholders are particularly interested in building heating and cooling technologies, including technologies used primarily to heat domestic hot water, with the potential to improve efficiency and reduce concomitant GHG and criteria pollutant emissions.

The GHG Center collaborated with ECR Technologies, Inc. (ECR) to evaluate their EarthLinked Ground-Source Heat Pump Water Heating System's performance as installed in a commercial setting. The system incorporates a ground-sourced heat pump into a building's water heating system. ECR states that the

EarthLinked system may provide up to 70% reduction in power consumption when compared to electric water heating systems of equivalent capacity. This reduced energy consumption would also reduce emissions from the electric power system's generators or natural gas combustion in direct-fired systems. Broad utilization of such technologies could have a significant beneficial impact on GHG and pollutant emissions.

TECHNOLOGY DESCRIPTION

The following technology description is based on information provided by ECR and does not represent verified information. The EarthLinked system typically consists of two or more 50- or 100-foot copper refrigerant loops (earth loops) installed in the ground, a compressor, a heat exchanger, refrigerant liquid flow controls, and an active charge control. The earth loops can be installed in horizontal, vertical, or diagonal configurations. The EarthLinked system circulates non-ozone depleting refrigerant (R-407c) through the copper earth loops. The manufacturer claims that the system's direct heat transfer from the earth to the refrigerant is intended to improve heat transfer efficiency.

The liquid refrigerant absorbs heat from the ground, which is typically at a constant temperature year round (40-80 ºF, depending on location), and vaporizes. A compressor raises the refrigerant pressure and routes it to a heat exchanger. There, the vapor condenses and yields the latent heat of vaporization to domestic water passing through a heat exchanger and circulating back to the hot water tanks. Refrigerant is then returned to the earth loops via a patented refrigerant flow control device.

The EarthLinked system consumes power in the compressor and hot water circulation pump, and has no direct emissions. ECR states that typical EarthLinked heating systems will focus on commercial applications that require a minimum of 2,000 gallons per day such as restaurants and laundries.

The reader is encouraged to note that this is a heat pump water heater and performance results cannot be directly compared with those of conventional heating, ventilation, and air conditioning heat pumps.

The test plan defines the EarthLinked heat pump as the device under test (DUT). The DUT and its integration into the host facility are known as the system under test (SUT).

HOST FACILITY and INSTALLED SYSTEM DESCRIPTION

The Lake Towers Retirement Community, located in Sun City Center, Florida, served as the host facility. Tests occurred at the Sun Terrace, a one-story building with two residential wings for assisted living. Each wing has 15 rooms, each with a small vanity sink. Other domestic hot water (DHW) uses include two shower rooms, one bathtub, two utility closets, four nurses' stations, and a kitchen.

The system has four 100-ft copper earth loops installed at a depth of 100-ft and in a vertical configuration. The facility's DHW source consists of two 15 kilowatt (kW), 480 V electric water heaters operating in parallel. Each water heater has two electric elements controlled by a single theremostat. One element port in each heater was removed and is used for the heated water return from the DUT. As hot water at the site is used, cold city water enters the tanks. ECR claims that the EarthLinked system operates most efficiently when heating cold water. For this installation, the average return temperature to the heat pump was 94 ^{o}F. Table S-1 lists the specifications for the EarthLinked unit installed at the site.

Table S-1. EarthLinked Specifications

(Source: ECR Technologies, Inc.)

Model Number	HC-036-3A
Rated Performance	36,000 Btu
Rated Coefficient of Performance	3.7
Heating Capacity	60 gal/hr[a]
Width	24.375"
Depth	12.375"
Height	26.5"

[a] rated at 90 ^{o}F water temperature rise

A recirculation pump continuously cycles hot water from Tanks #1 and #2 through the building's DHW piping and back to the tanks. The circulation loop ensures the immediate availability of hot water at each tap throughout the facility. Thermal losses due to this loop can be substantial. For the purposes of this test, thermal losses due to the recirculation loop are considered as part of the total site load.

VERIFICATION DESCRIPTION

A series of short-term tests and a long-term monitoring period were conducted to determine the performance of the EarthLinked system as compared to the baseline electric resistance-type hot water heaters.

Short-term testing was conducted on May 26, 2005. Industry-accepted American National Standards Institute (ANSI) / American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Type V heat pump water heater test methods formed the basis for the short-term tests.

Short-term test verification parameters were:

- DUT water heating capacity while raising the lowest achievable city water temperature (likely to be approximately 72 ^{o}F in Florida in May) 20 ^{o}F or to whatever temperature can be achieved over a 60-minute period (whichever occurs first), British thermal units per hour (Btu/h)
- DUT water heating capacity while raising the water temperature from 110 to 130 ^{o}F or over a 60-minute period (whichever occurs first), Btu/h
- DUT coefficient of performance (COP) at the lower and elevated temperatures, dimensionless
- DUT standby heat loss rate, Btu/h, while operating with the EarthLinked system at 120 ± 5 ^{o}F

Long-term monitoring began on May 25, 2006 and continued through July 12, 2006. The goal of the long-term testing was to characterize the SUT performance in normal daily use. As such, the ANSI/ASHRAE test method was not valid for long-term testing. The ANSI/ASHRAE method is performed under controlled conditions over a specific temperature range and does not characterize in-use operations.

Long-term monitoring results allowed the assessment of:

- difference between SUT electrical power consumption with and without the EarthLinked system, kW

- hot water usage and parasitic losses, kW
- operational COP of the DUT, dimensionless
- estimated EarthLinked carbon dioxide (CO_2) and oxides of nitrogen (NO_X) emission changes as compared to the baseline electric water heater, lb/year
- estimated simple cost savings based on the price of electricity saved, $/year

Rationale for the experimental design, determination of verification parameters, detailed testing procedures, test log forms, and quality assurance/quality control (QA/QC) procedures can be found in the test and quality assurance plan titled *Test and Quality Assurance Plan – ECR Technologies, Inc. EarthLinked Ground-Source Heat Pump Water Heating System* (Southern Research Institute, 2005), and the addendum to the test plan, titled *Addendum to Test and Quality Assurance Plan - ECR Technologies, Inc. EarthLinked Ground-Source Heat Pump Water Heating System* (Southern Research Institute, 2006).

VERIFICATION OF PERFORMANCE

Results of the verification are representative of the EarthLinked system's performance as installed at the Lake Towers Retirement Community. Quality assurance (QA) oversight of the verification testing was provided following specifications in the ETV Quality Management Plan. This verification was supported by an audit of data quality (ADQ) conducted by the GHG Center QA manager. During the ADQ, the QA manager randomly selected data supporting each of the primary verification parameters and followed the data through the analysis and data processing system. The ADQ confirmed that no systematic errors were introduced during data handling and processing.

Short-Term Tests

Short-term tests first measured water heating capacity and COP. Water heating capacity assesses the heat pump's ability to generate hot water. COP is a dimensionless ratio of water heating energy output to input energy. The short-term tests consisted of three low temperature and three elevated temperature test runs, as per the ANSI/ASHRAE test method for Type V water heaters. The system was configured such that Tank #1 operated on the EarthLinked system and it was completely isolated from the facility's DHW. The results of the test runs are shown in Table S-2.

Table S-2. Water Heating Capacity and Coefficient of Performance for Short-Term Tests

	Low Temperature Tests[a]		Elevated Temperature Tests[b]	
	Water Heating Capacity (Btu/h)	COP	Water Heating Capacity (Btu/h)	COP
Run 1	35700 ± 1200	3.61 ± 0.12	32800 ± 1100	2.78 ± 0.10
Run 2	35000 ± 1200	3.57 ± 0.12	32300 ± 1100	2.63 ± 0.09
Run 3	34600 ± 1200	3.55 ± 0.12	31900 ± 1100	2.65 ± 0.09
Average	35100 ± 1300	3.58 ± 0.12	32300 ± 1100	2.69 ± 0.10

[a] For the low temperature tests, the average initial tank temperature was 82.1 ± 0.6 °F and the average final tank temperature was 102.3 ± 0.6 °F

[b] For the high temperature tests, the average initial tank temperature was 97.6 ± 0.6 °F and the average final tank temperature was 120.7 ± 0.6 °F

Standby heat loss, a measure of the heat loss rate for the water heater, was also calculated during the short-term testing. Three standby heat loss test runs were conducted with the system in the same configuration as for the water heating capacity and COP tests. That is, the heat loss includes the EarthLinked system, Tank #1, and the connecting pipes. As per the ANSI/ASHRAE test method and the test plan, data were collected for three complete heating and cooling cycles and were used to calculate average standby heat loss. The results of the test runs are shown in Table S-3.

Table S-3. Standby Heat Loss

	Heat Loss Rate (Btu/h)
Cycle 1	490 ± 90
Cycle 2	520 ± 90
Cycle 3	450 ± 90
Average	490 ± 90

Table S-3 shows that the average standby heat loss was calculated as 490 ± 90 Btu/h. The high heat loss indicates that piping in the system may not be adequately insulated.

Long-Term Monitoring

During the long-term monitoring period, the power meter monitored electricity consumption for both tanks and the DUT. System operators alternated between EarthLinked and resistive element heating on a weekly schedule. A weekly schedule was chosen because GHG Center personnel predicted that day-to-day variations in the data would likely follow a weekly pattern. All electric heating elements in both tanks were disabled when the system was under EarthLinked operation. The thermostats for Tanks #1 and #2 were set to 110 ^{o}F during both EarthLinked and resistive element operations. This set point was required by site management.

Analysts calculated power consumption separately as overall mean real power consumption while operating from the EarthLinked system and from the heating elements. These measurements were then normalized in terms of "efficiency" or mean energy consumption over the period divided by mean thermal energy delivered to the site. The change in normalized electrical power consumption (ΔZ_{kW}) was calculated by subtracting the mean normalized power consumption for the SUT during the three weeks of EarthLinked operations ($Z_{kW,EarthLinked}$) from the mean normalized power consumption for both tanks during the three weeks of resistive element heating ($Z_{kW,Elements}$). Table S-4 summarizes the results.

Table S-4. Electrical Power Consumption

$Z_{kW,EarthLinked}$ (kW)	$Z_{kW,Elements}$ (kW)	ΔZ_{kW} (kW)	% Difference
0.58 ± 0.03	2.33 ± 0.11	1.75 ± 0.11	75 ± 6%

At this site, the load was substantially below the recommended range for the equipment. Parasitic thermal losses from the recirculation loop represent 39 ± 8% of the total load.

The average system efficiency (η) is equal to the average rate of thermal energy delivered to the site loads divided by the average system input power consumption expressed in common units. The efficiency provides a measure of the energy delivered to site loads versus the total input energy. It characterizes the performance of the installation, rather than simply the performance of the DUT by itself. The improvement in efficiency was calculated as an average improvement comparing the three weeks of operation using the DUT ($\eta_{EarthLinked}$) to three weeks of operation using the heating elements ($\eta_{Elements}$). Table S-5 summarizes these values. The efficiency of the electric elements ($\eta_{Elements}$) was expected to be 1.00 and this result was achieved within the confidence limits.

Table S-5. Average System Efficiency

$\eta_{EarthLinked}$	$\eta_{Elements}$	$\Delta\eta$
4.01 ± 0.07	1.005 ± 0.018	3.00 ± 0.07

The operational COP of the DUT was also calculated. Operational COP differs from the efficiency reported in Table S-5. COP looks at the performance of only the DUT and is commonly used to characterize heat pump technologies. The efficiency characterizes the performance of the whole system installation, not just the DUT. Operational COP was calculated as the rate of energy delivered by the DUT to the site ($Z_{kW, DUT}$) versus the rate of energy consumed by the DUT ($Z_{kW, EarthLinked}$) during actual operating conditions. This is distinct from the COP measured in the short-term tests. The short-term tests were performed under controlled conditions for a specific temperature range. This calculation of COP is performed during actual operating conditions. Table S-6 summarizes the results.

Table S-6. Operational Coefficient of Performance of the DUT

$Z_{kW,DUT}$ (kW)	$Z_{kW, EarthLinked}$ (kW)	COP
2.59 ± 0.19	0.58 ± 0.03	4.43 + 0.09, -0.3

The average COP of the DUT during the in-use monitoring was higher than the average COP observed in the short-term testing (refer to Table S-2). Calculation of COP for the short-term tests was conducted following the ANSI/ASHRAE tests for Type V heat pump water heaters. Analysts found that this procedure, however useful for comparison between different pieces of equipment of the same class under controlled circumstances, may not provide results that are directly representative of in-service operating conditions. Calculation of COP for the long-term tests was based on the ratio of thermal energy delivered by the device and the electrical energy consumed by the DUT.

The procedure used for estimating SUT emission reductions correlates the estimated annual electricity savings in megawatt-hours per year (MWh/year) with Florida and nationwide electric power system emission rates in pounds per megawatt-hour (lb/MWh). For this verification, analysts assumed that the EarthLinked system operates continuously throughout the year with electric power savings as measured during the long-term monitoring period (refer to Table S-4). Emission data from the EPA's "EGRID" database were used to estimate state and nationwide emission rates. Table S-7 summarizes the estimated yearly emission reductions.

Table S-7. Estimated Yearly Emissions Reductions

	Florida		Nationwide	
Pollutant	**CO_2**	**NOx**	**CO_2**	**NOx**
$ER_{EPS,i}$ (lb/MWh)	1420.42	3.36	1392.49	2.96
$MWh_{DUT,Ann}$ (MWh/year)	15 ± 1			
Emission Offset (lb/year)	21,700 ± 1,400	51 ± 3	21,300 ± 1,300	45 ± 3

The procedure for estimating SUT simple cost savings is based on the Florida and nationwide prices for retail electricity at "commercial" rates. Varying prices for retail electricity can be found in many resources. This methodology of estimating simple cost savings uses the prices found in the Energy Information Agency's *Table 5.6.A. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State*. Similar to emissions reductions, analysts assumed that the EarthLinked system operates continuously throughout the year with electric power savings as measured during the long-term monitoring period. The EarthLinked system does not use auxiliary fuel, nor is it intended as a power source, so their potential costs or revenues are not considered for this verification. Table S-8 summarizes the estimated yearly cost savings.

Table S-8. Estimated Yearly Cost Savings*

	Florida	Nationwide
$MWh_{DUT,Ann}$ (MWh/year)	15 ± 1	
RP_{elec} (cents/kWh)	9.88	9.2
Simple Cost Savings (dollars/year)	1,500 ± 100	1,410 ± 90

* Based on approximately 630 gallons per day average consumption on site. The intended load for this product is 2,000 gallons per day.

Details on the verification test design, measurement test procedures, and QA/QC procedures can be found in the test plan, titled *Test and Quality Assurance Plan – ECR Technologies, Inc. EarthLinked Ground-Source Heat Pump Water Heating System* (Southern Research Institute 2005), and the test plan addendum, titled *Addendum to Test and Quality Assurance Plan - ECR Technologies, Inc. EarthLinked Ground-Source Heat Pump Water Heating System* (Southern Research Institute 2006). Detailed results of the verification are presented in the final report, titled *Environmental Technology Verification Report for ECR Technologies, Inc. EarthLinked Ground-Source Heat Pump Water Heating System* (Southern Research Institute 2006). Both can be downloaded from the GHG Center's web-site (www.sri-rtp.com) or the ETV Program web-site (www.epa.gov/etv).

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