SRI/USEPA-GHG-QAP-34A
May, 2006

Addendum to Test and Quality Assurance Plan

ECR Technologies, Inc.
Earthlinked Ground-Source Heat Pump Water Heating System

Prepared by:

Greenhouse Gas Technology Center
Southern Research Institute

Under a Cooperative Agreement With
U.S. Environmental Protection Agency

SRI/USEPA-GHG-QAP-34A
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Greenhouse Gas Technology Center

A U.S. EPA Sponsored Environmental Technology Verification (ETV) Organization

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☒ indicates comments are integrated into Test Plan

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ECR Technologies, Inc.
Earthlinked Ground-Sourced Heat Pump
Water Heating System

This Test and Quality Assurance Plan has been reviewed and approved by the Greenhouse Gas Technology Center Project Manager, Quality Assurance Manager, and Center Co-Director, the U.S. EPA APPCD Project Officer, and the U.S. EPA APPCD Quality Assurance Manager.

___________________________ ___________
Richard Adamson Date
Center Co-Director/Project Manager
Greenhouse Gas Technology Center
Southern Research Institute

___________________________ ___________
David Kirchgessner Date
APPCD Project Officer
U.S. EPA

___________________________ ___________
William Chatterton Date
Quality Assurance Officer
Greenhouse Gas Technology Center
Southern Research Institute

___________________________ ___________
Robert Wright Date
APPCD Quality Assurance Manager
U.S. EPA

Test Plan Addendum Draft: 13 April 2006

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DISTRIBUTION LIST

U.S. EPA
David Kirchgessner
Robert Wright

SOUTHERN RESEARCH INSTITUTE
Richard Adamson
William Chatterton
Staci Haggis

ECR Technologies, Inc.
Hal Roberts
Joe Parsons

List of Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
Btu/h	British thermal units per hour
Btu/y	British thermal units per year
CoP	coefficient of performance
DQI	data quality indicator
DQO	data quality objective
DUT	device under test
ETV	Environmental Technology Verification
g/h	grams per hour
gal	gallon
gph	gallons per hour
kW	kilowatt
psia	pounds per square inch, absolute
psig	pounds per square inch, gauge
QA / QC	quality assurance / quality control
SUT	system under test
tpy	tons per year

1.0 INTRODUCTION

1.1. BACKGROUND

This document represents an addendum to the *Test and Quality Assurance Plan - ECR Technologies, Inc. Earthlinked Ground-Source Heat Pump Water Heating System* SRI/USEPA-GHG-QAP-34, Southern Research Institute, Greenhouse Gas Technology Center, May 2005 [1]. It incorporates the earlier document by reference and is not intended to act as a stand-alone plan.

In the course of performing the testing and analysis in accordance with the original plan it was determined that the installation was not representative of what could be considered a 'typical' retro-fit installation for the subject technology. Further it was determined that the data collected was inadequate to credibly and accurately reflect the performance of a 'typical' installation.

With that conclusion it was determined that :

1) the data collected during the short-term testing performed under the original plan is reflective of the performance of the 'device under test' (DUT);
2) the integration with the site, which constitutes the 'system under test' (SUT), should be modified to be more reflective of a typical retrofit installation; and
3) data generated during the long-term testing is invalid and testing should be repeated with suitably modified instrumentation arrangement to correspond to the new configuration.

This addendum documents the adjustments to the instrumentation and analysis corresponding to the new configuration.

One additional modification was made to the original test plan. After publication of the plan we received credible feedback from external stakeholders that a four-week test would be insufficient to provide an adequate measurement of the performance improvement. Consequently it was decided to extend the test to six weeks. That decision is carried forward and reflected in the addendum.

1.2. VERIFICATION PARAMETERS

Long-term monitoring will determine the SUT performance in normal daily use. Long-term primary verification parameters are:

- difference between SUT electrical power consumption with and without the EarthLinked system, kW
- estimated EarthLinked CO, CO_2, and NO_X emission changes as compared to the baseline electric water heater, grams per hour (g/h) or tons per year (tpy)
- estimated simple cost savings based on the price of electricity saved

Secondary parameters include the hot water utilization on site including parasitic thermal losses due to the re-circulating system, which will be separately measured. Primary parameters will be normalized to on-site hot water energy consumption. The operational Coefficient of Performance (CoP) for the DUT will also be reported. The operational CoP is the ratio of heat delivered to energy consumed by the DUT during actual operating conditions. This is distinct from the CoP measured under the controlled conditions of the short-term test..

1.3. ORGANIZATION

The GHG Center has overall verification planning and implementation responsibility. The GHG Center will coordinate all participants' activities; develop, monitor, and manage schedules; and ensure the acquisition and reporting of data consistent with the strategies in the test plan and this addendum.

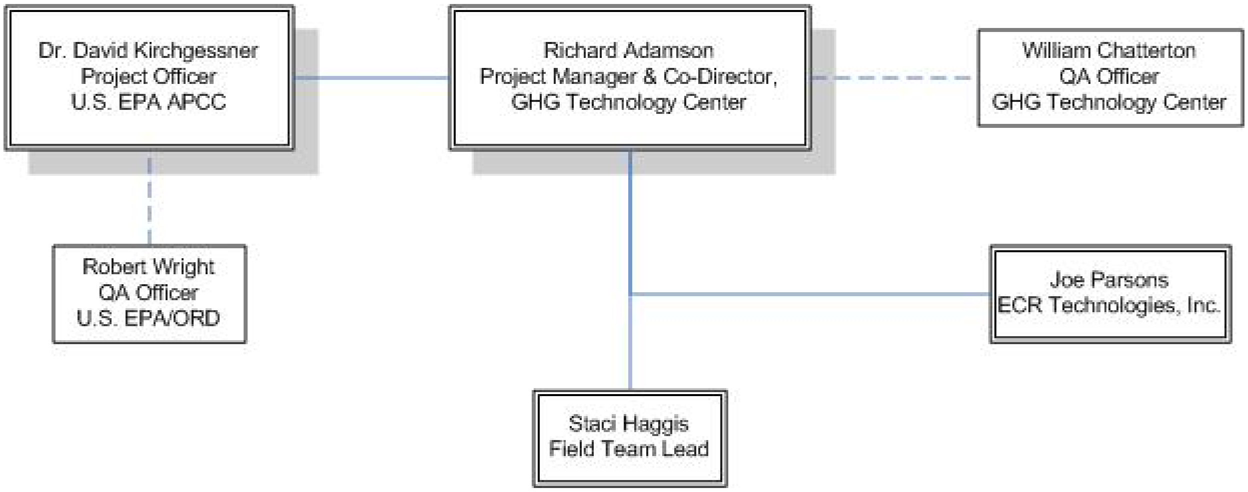

Figure A1-1. Project Organization Chart

The GHG Center Co-Director, Mr. Richard Adamson, will:

- allocate appropriate resources for the verification
- oversee GHG Center staff activities
- coordinate the addendum, report, and Verification Statement writing and review process
- oversee the field team leader's activities
- ensure collection, analysis, and reporting of high-quality data and achievement of all data quality objectives (DQO)s
- maintain communications with all test participants
- perform budgetary and scheduling review

Mr. Adamson will have authority to suspend testing for health and safety reasons or if the QA/QC goals presented in Section 3.0 are not being met.

Mr. Joe Parsons of ECR is the technology developer's primary point of contact. He or his designee will:

- review the addendum and report with respect to accuracy in the technology and system integration description
- coordinate ECR's installation of the EarthLinked system, plumbing, fittings, or other permanent equipment that will remain at the site
- coordinate weekly operations during the long-term monitoring period

Ms. Staci Haggis will serve as the field team leader and will supervise all field operations. She will assess data quality and will have the authority to repeat tests as deemed necessary to ensure achievement of data quality goals. She will:

- coordinate the installation of required plumbing fittings with ECR
- supervise and coordinate subcontractor activities
- arrange for installation and removal temporary power- and water-metering equipment
- collect interim test data for use in consultations with the project manager
- download data during the long term monitoring period
- perform other QA / QC procedures as described in Section 3.0

The field team leader will communicate test results to the project manager for review during the course of testing. The field team leader and project manager will collaborate on all major project decisions including the need for further test runs or corrective actions.

The GHG Center QA officer, Mr. William Chatterton, will review this addendum. He will independently reconcile the measurement results with the data quality objectives as part of a planned audit of data quality. He will also review the verification test results, report, and conduct the audit of data quality described in Section 4.0. The QA officer will report all internal audit and corrective action results directly to the GHG Center Co-Director for inclusion in the report.

EPA's Office of Research and Development will provide oversight and QA support for this verification. The Air Pollution Prevention and Control Division project officer, Dr. David Kirchgessner, and QA manager, Mr. Robert Wright, will review and approve the test plan and report to ensure that they meet EPA QA goals and represent sound scientific principles. Dr. Kirchgessner will be responsible for obtaining final test plan and report approvals.

1.4. SCHEDULE

The tentative schedule of activities for the ECR EarthLinked ground source heat pump water heater verification test is:

Verification Test Plan Milestones	**Dates**
GHG Center internal draft development	27 March 2006 – 19 April 2006
ECR review	19 April 2006 - 26 April 2006
EPA review	26 April 2006 - 3 May 2006
Verification Testing and Analysis Milestones	
Long term testing	18 May 2006 – 9 July 2006
Verification Report Milestones	
GHG Center internal draft development	17 July 2006 – 4 August 2006
ECR review	7 August 2006 - 18 August 2006
Industry peer review and report revision	7 August 2006 - 18 August 2006
EPA review	21 August 2006 - 1 September 2006
Final report posted	15 September 2006

2.0 VERIFICATION APPROACH

This section describes the GHG Center's verification approach, the test design, data collection, and analytical methods. The addendum references the main Test and Quality Assurance Plan (TQAP) extensively and is not intended to be used as a stand-alone document.

2.1. TEST DESIGN

Long-term monitoring will begin with the Tank #1 and Tank #2 heating elements operating for one week while the EarthLinked system is disabled. The second week, ECR operators will set the controls so that the EarthLinked system provides Tank #1 and Tank #2 water heating service. All heating elements will be disabled. Test personnel will download the data by telephone and perform a brief quality review on a daily basis. This pattern will be repeated for at least six weeks.

Long-term monitoring results will allow assessment of:

- difference between SUT electrical power consumption with and without the EarthLinked system, kW
- estimated EarthLinked CO, CO_2, and NO_X emission changes as compared to the baseline electric water heater, g/h or tpy
- estimated simple cost savings based on the price of electricity saved
- on-site hot water usage and parasitic losses
- operational Coefficient of Performance (CoP) of the DUT

2.2. INSTRUMENTATION

Figure A2-1 shows the revised water piping schematic diagram and the proposed test instrument locations. Figure A2-2 depicts the electrical wiring schematic and the power meter locations.

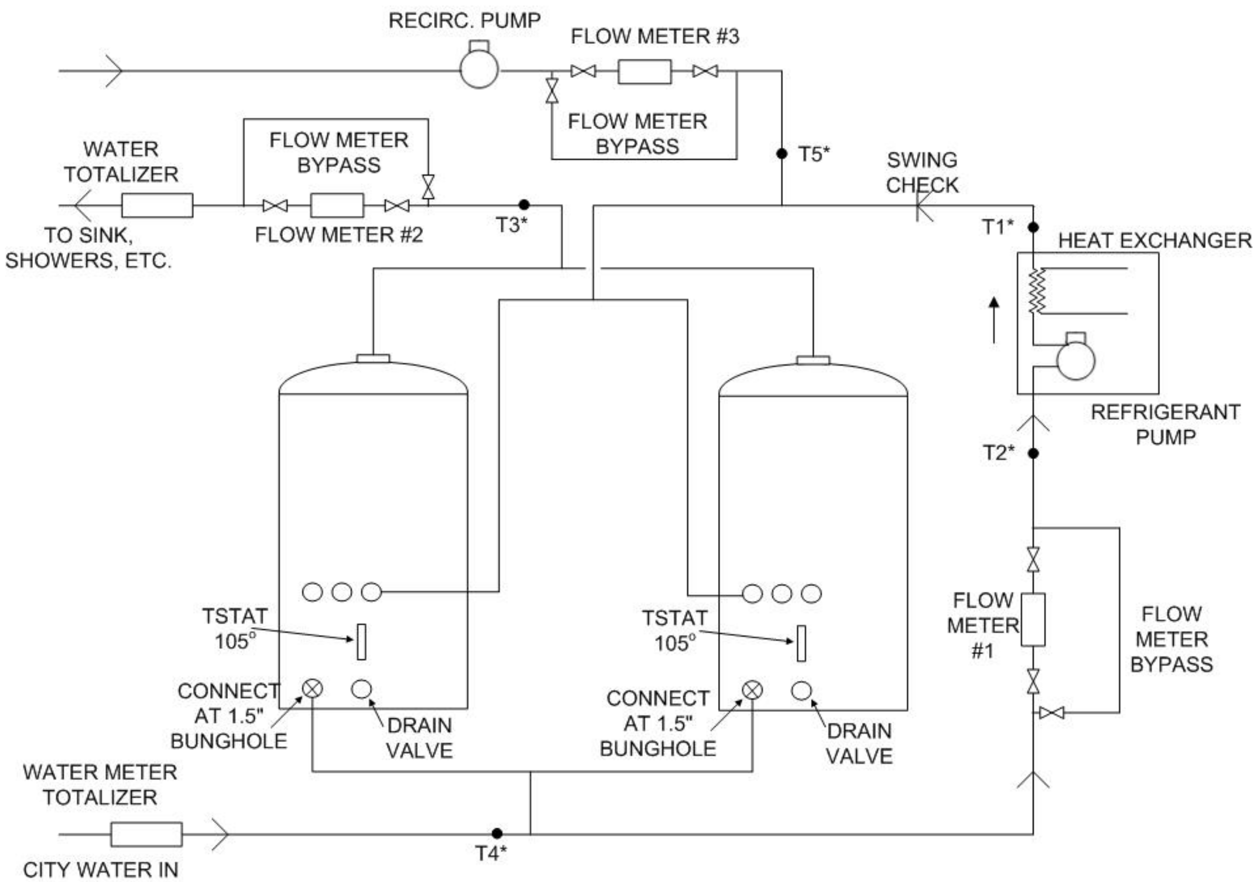

Figure A2-1. Plumbing Schematic and Sensor Locations

(Note that thermostat set-points may be lower in order to prevent exceeding specified hot water delivery temperatures.)

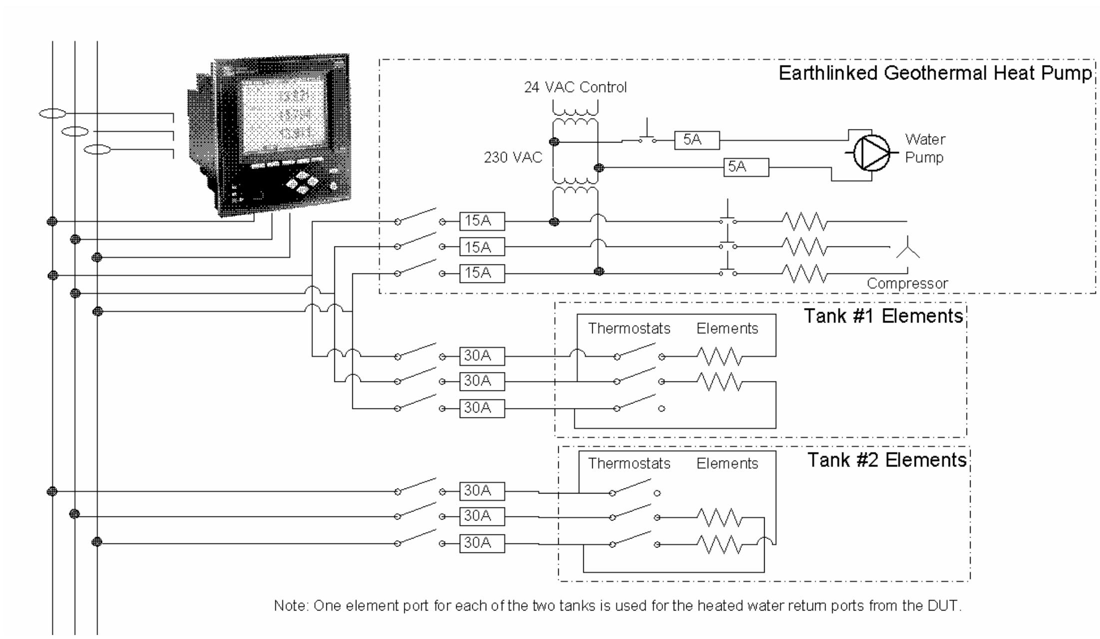

Figure A2-2. Electrical Schematic and Power Meter Locations

2.2.1. Heat Transfer Metering

Circulating flow rate through the Device Under Test (DUT), as measured by Flow Meter 1 on Figure A2.1, and the change in temperature across the DUT, measured at T1 and T2, provides a measure of the thermal energy delivered to the hot water tanks. Flow Meter 3 and the differential temperature between T3 and T5 provides a measure of the parasitic thermal energy lost in the recirculation loop. The difference between the flow measurement at Flow Meter 2 and Flow Meter 3 and the differential temperature measured across T4 and T3 provides a measure of the thermal energy delivered to the intended loads. That is, the total thermal energy delivered to the site less the parasitic losses. The ANSI / ASHRAE accuracy specification for flow rates is ± 1.0 %.

This verification will employ an Omega Model FTB-907 flow meter (Flow Meter #1) with a range of 6 to 93 gpm installed as shown in Figure A2-1. A data acquisition system will totalize and log the pulse output. Accuracy of this system will be ± 0.5 % of reading.

Flow Meter #2 will use an Omega Model FTB-905 meter with a range of 2.5 to 29 gpm. This point will have the most variable flow, with a minimum value of the flow due to the recirculation pump and a maximum of the sum of that and the total hot water usage on the site. Once more the accuracy is specified to be ± 0.5 % of measurement throughout this range.

Flow Meter #3 will use an Omega FTB-902 meter with a range of 0.75 to 5 gpm. This recirculation line flow is expected to be relatively constant in the range of 2.5 gpm. This meter is specified to provide ± 0.5 % of reading accuracy throughout its nominal operating range.

2.2.2. Temperature Measurements

This verification will employ Class A 4-wire platinum resistance temperature detectors (RTD) whose specified accuracy, including the data acquisition system, is ± 0.6 ^{o}F. This means that the combined accuracy for temperature difference will be ± 0.8 ^{o}F, based on the specifications. While this combined accuracy does not meet the method specifications for Type IV water heaters, it is sufficient for the QA / QC check. The GHG Center will perform pretest calibrations and it is likely that an RTD pair will be available whose combined accuracy is better than ± 0.8 ^{o}F. Also, analysts will account for and report the achieved accuracy and its potential effects on the results.

All temperature sensors throughout the test will be Class A 4-wire platinum RTD type.

Test personnel will install the RTDs on a strap-on configuration using high thermal conductivity compound and wrapping the sensors in at least 1 inch of insulation for a distance of a minimum of 10 inches to either side of the location. Sensors will be located on polished copper pipe at least 10 inches from nearby fittings that might compromise the thermal integrity of the measurements.

2.2.3. Mechanical Room Dry Bulb Temperature

The datalogger will record the test room dry bulb temperature from a single Class A 4-wire RTD located at head height. The ANSI / ASHRAE accuracy specification for air temperature is ± 1 ^{o}F. RTD specified accuracy will be ± 0.6 ^{o}F.

2.2.4. Power Consumption

The ANSI / ASHRAE accuracy specification for the power sensor (kW) is ± 1.0 %.

A Power Measurements ION 7500 or 7600 power meter will record real power consumption at a common point of power feed to the two tanks and to the DUT. Power meter accuracy is ± 0.15 %. Test personnel will install 0.3 % metering accuracy class current transformers (CTs) on each phase conductor. The combined kW accuracy will be ± 0.3 % of reading.

2.3. TEST PROCEDURES AND ANALYSIS

Revised Long term monitoring appears in Section 2.3.1. Note that nomenclature and equation symbols generally conform to those cited in ANSI / ASHRAE Standard 118.1 [2].

2.3.1. Long Term Monitoring Procedures and Analysis

During the long-term monitoring period, the power meter will monitor electricity consumption for both tanks and the DUT. System operators will alternate between DUT and resistive element heating on a weekly schedule for at least 6 weeks.

Analysts will report power consumption separately as overall mean real power consumption while operating from the EarthLinked system and from the heating elements. These measurements will then be normalized in terms of "Efficiency" or mean energy consumption over the period divided by mean thermal energy delivered to the site.

The improvement in efficiency will be calculated as an average improvement comparing the three weeks of operation using the DUT to three weeks of operation using the heating elements. Effective energy savings per month will be calculated using the measured site load data.

The re-circulation pump continuously circulates water through the hot water system and back to the heating tanks. This ensures a minimum delay at the tap whenever a resident calls for hot water. Depending on the flow rate and quality of insulation on the supply and return piping systems the thermal losses due to this circulation can be a substantial fraction of the total site load. Additional parasitic losses occur due to heat lost from storage tanks #1 and #2 and associated piping.

The instantaneous loss of thermal energy (parasitic loss rate Z_P, reported in kW) due to the recirculation loop (and excluding losses directly from the tanks) is:

$$Z_P = (T_5 - T_3) \times F_3 \times C_p \times \rho \qquad \text{Eqn.A2-1}$$

where:

$F_3 =$ water flow rate measured by Flow Meter #3;
$C_p =$ the heat capacity of water and is a function of temperature and pressure;
$\rho =$ the density of water, also a function of temperature and pressure.

Pressure is assumed to be similar to that measured previously. The above factors are not highly sensitive to water pressure, so small deviations will not have significant impact on the results of these calculations. The total rate of energy delivered to the site, Z_s, is equal to the sum of the rate of energy delivered to loads, Z_L such as showers and sinks, plus the rate of parasitic losses in the recirculation loop, Z_P

$$Z_L = (F_2 - F_3) \times (T_4 - T_3) \times C_p \times \rho \qquad \text{Eqn. A2-2}$$

And

$$Z_s = Z_L + Z_P \qquad \text{Eqn. A2-3}$$

The average system efficiency during any period is equal to the ratio of the average site load to the average system input power consumption expressed in common units.

$$\bar{\eta} = \frac{\overline{Z_s}}{\overline{Z_{kW}}} \times 100\% \qquad \text{Eqn. A2-4}$$

Thus, for the resistive elements case

$$\overline{\eta_{elements}} = \frac{\overline{Z_s}}{\overline{Z_{kW,elements}}} \times 100\% \qquad \text{Eqn. A2-5}$$

And for the DUT case

$$\overline{\eta_{Earthlinked}} = \frac{\overline{Z_s}}{\overline{Z_{kW,Earthlinked}}} \times 100\% \qquad \text{Eqn. A2-6}$$

The difference in efficiency between the DUT and the baseline resistive element heating is

$$\overline{\Delta\eta} = \overline{\eta_{Earthlinked}} - \overline{\eta_{elements}} \qquad \text{Eqn. A2-7}$$

Energy savings over a period may be calculated from the total energy consumption on site over a period of interest (for example, a month):

$$U_{savings}\big|_{month} = \int_{month} Z_s dt \times \overline{\Delta\eta} \qquad \text{Eqn. A2-8}$$

The rate of energy delivered to the SUT (into the hot water tanks) from the Earthlinked DUT is

$$Z_{DUT} = (T_1 - T_2) \times F_1 \times C_p \times \rho \qquad \text{Eqn. A2-9}$$

The average Coefficient of Performance of the DUT over the long term testing interval will be calculated as the ratio of the average energy delivered to the SUT and the average energy consumed by the DUT:

$$\overline{COP} = \frac{\overline{Z_{DUT}}}{\overline{\overline{Z_{kW,Earthlinked}}}} \qquad \text{Eqn. A2-10}$$

TQAP Appendix B provides the procedure for estimating emission reductions. The procedure correlates the estimated annual electricity savings in MWh with Florida and nationwide electric power system emission rates in lb/MWh. For this verification, analysts will assume that the EarthLinked system operates continuously throughout the year with the electric power savings as measured during the long-term monitoring period.

TQAP Appendix C provides the procedure for estimating simple cost savings based on the Florida and nationwide prices for retail electricity at “commercial” rates. Similar to emissions reductions, analysts will assume that the EarthLinked system operates continuously throughout the year with the 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 need not be considered for this verification.

3.0 DATA QUALITY

3.1. DATA QUALITY OBJECTIVE

Each test measurement contributes to the verification parameters according to the equations in Section 2.3.1. Each measurement is linked to accuracy specifications, or data quality indicator (DQI) goals which, if met, ensure achievement of the DQOs that are stated in the TQAP. The accuracy specifications quoted below, compounded through the applicable equations according to standard root-mean-square techniques, are the source of the DQOs. Reference [3] provides examples of compounded accuracy derivations.

The project manager will calculate and report the achieved DQO based on the actual instrument and measurement accuracies, as documented by specific instrument calibrations, manufacturer certifications, etc.

3.2. INSTRUMENT SPECIFICATIONS, CALIBRATIONS, AND QA/QC CHECKS

Table A3-1 lists the instruments to be used in this verification test, their expected operating ranges, and accuracies or DQI goals.

Table A3-1. Instrument and Accuracy Specifications

Measurement Variable	Expected Operating Range	Instrument Mfg., Model, Type	Instrument Range	Measurement Frequency	Accuracy Specification[a]	How Verified / Determined
Recirculation Flow (F3)	~3 gpm continuous	Omega FTB-902	0.75-5 gpm	Every 5 seconds, record 1-minute averages	± 0.5 %	NIST-traceable calibration within 2 years
Site flow (F2)	3-15 gpm variable	Omega FTB-905	2.5 – 29 gpm			
EarthLinked system water flow (F1)	~10 gpm continuous	Omega FTB-907 turbine	6 - 93 gpm			
All water system temperatures	50 - 140 °F	Omega Class A 4-wire Pt RTD	0 - 250 °F		± 0.6 °F	
Mechanical room temperature	60 - 90 °F					
Electric Power	0 - 15 kW	Power Measurements ION 7500	0 - 125 kW	Every second, record 1-minute averages	± 0.15 %	NIST-traceable calibration within 6 years; pretest crosscheck
Current trans-formers (for kW)	0 - 18 A	Flex-Core Model 191-151 metering class	0 - 150 A		± 0.3 %	Manufacturer's certificate

[a]Accuracy is % of reading unless stated as absolute units.

Table A3-2 summarizes QA / QC checks which the field team leader will perform before the long-term tests. These checks are intended only as field diagnostics. This is because, if the instruments function in the field as they did in the laboratory, it is reasonable to expect that calibration and accuracy specifications have not changed.

Table A3-2. QA / QC Checks

System or Parameter	QA / QC Check	When Performed	Expected or Allowable Result	Response
Flow meters	Zero check[a]	Immediately prior to run – use bypass	0 gpm	Troubleshoot and repair sensors
	Full flow check[a]	Immediately prior to run	9 - 12 gpm on F1 1-4 gpm on F3 F2 must be greater than F3	Consult with EarthLinked representative to confirm F1 flow
Resistive Element real power consumption	Voltage and current field reasonableness checks with Fluke 335 clamp meter	Prior to testing	Voltage within ± 2 % Current within ± 3 %	Troubleshoot and repair sensors
	Laboratory cross checks between power meters		kW readings within ± 1 % of each other	
Temperature sensors	Ambient cross check	Prior to installation	All within ± 1.5 °F of each other	
	Ice-bath checks	Pre-mobilization (lab)	Each pair within 0.5 F of each other	

[a]Procedure provided in Appendix A-2

4.0 REFERENCES

[1] *Test and Quality Assurance Plan - ECR Technologies, Inc. Earthlinked Ground-Source Heat Pump Water Heating System* SRI/USEPA-GHG-QAP-34, Southern Research Institute, Greenhouse Gas Technology Center, May 2005.

[2] *ANSI /ASHRAE Standard 118.1-2003: Method of Testing for Rating Commercial Gas, Electric, and Oil Service Water Heating Equipment*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. 2003

[3] *Distributed Generation and Combined Heat and Power Field Testing Protocol—Appendix G: Uncertainty Estimation*, Association of State Energy Research and Technology Transfer Institutions. 2004. Available from <http://www.dgdata.org/pdfs/field_protocol.pdf>.

Appendix A

Appendix A-1. Power Meter and RTD QA / QC Checks

Project ID: _______________ Location: ____

Power Meter Sensor Checks

Note: Acquire at least 3 separate readings for each phase. All ION voltage and current readings must be within 2 % or 3 %, respectively, of the corresponding DVM reading.

Power meter: Make: ____________ Model:_______________ Serial No: ________________

Date: ____________ Signature: ____

	Phase A			Phase B			Phase C		
	ION	**DVM**	**% diff**	**ION**	**DVM**	**% diff**	**ION**	**DVM**	**% diff**
Voltage									
Current									

RTD Ambient Crosschecks

Note: Allow RTDs to equilibrate in ambient conditions for at least ½ hour. All RTD readings must be within ± 1.5 ^{o}F of each other.

Date: ____________ Signature: ____

Ref.	RTD ID #	Description / location	^{o}F (at DAS)
1			
2			
3			
4			
5			
6			
7			
8			
9			
spare			

Appendix A-2. Flow Meter Checks and Water Heating Performance Crosscheck

Flow Meter Checks

Record at least 3 flow rates each while flow is bypassed around the meter and blocked through it and three with full flow through the meter and bypass blocked for each of the three meters.

Meter F1:

Zero flow should be ≤ 2.9 gpm. Full flow should be between 9 and 11 gpm.

Date: ___________ Signature: ____

Make: _________ Model: ______________Serial #: ____________________Mean K (pulses per gallon): ________________

$$Pulse/min = \frac{60(PulseCount)}{T_{elapsed}} \qquad gpm = \frac{Pulse/min}{K}$$

	$T_{elapsed}$, s	PulseCount	Pulse/min	gpm	OK ?
Zero flow					
Full Flow					

Meter F2:

Zero flow should be ≤ 2.9 gpm. Full flow should be between 2 and 20 gpm.

Date: ___________ Signature: ____

Make: _________ Model: ______________Serial #: ____________________Mean K (pulses per gallon): ________________

$$Pulse/min = \frac{60(PulseCount)}{T_{elapsed}} \qquad gpm = \frac{Pulse/min}{K}$$

	$T_{elapsed}$, s	PulseCount	Pulse/min	gpm	OK ?
Zero flow					
Full Flow					

Meter F3:

Zero flow should be ≤ .5 gpm. Full flow should be between 1 and 5 gpm. This meter has a 4-20 mA signal output.

Date: ___________ Signature: ____

Make: _________ Model: ______________Serial #: ____________________Mean K (pulses per gallon): ________________

	gpm	OK ?
Zero flow		
Full Flow		

Date: ____________ Signature: ____

Appendix A-3. SUT and Site Information

Date: ____________________ Signature: ____

SUT Data

Description: ____

Mfg: ____________________________ Model: ___________________ Serial No.: _________________

Temperature rise: __________ ^{o}F at _________ gph Nominal CoP: __________

Loop Data

Designer: ____________________________________ Installer: ________________________________

Tubing material: ____________ Dia: _____ Number of loops / bores: ___________________________

Loop length each: _____Total length: __________ Bore diameter: __________ Depth: _____________

Water table encountered? _________ Water table depth __________

Grouting method / material (describe): ____

Soil type / description (from driller's log): ____

Notes (Is installation representative? Problems encountered? Exceptions made?): ___________________

____

____

Site Data

Note: record number and type of hot water uses only.

Residence rooms: _____ Fixtures (describe): ____

Utility rooms: _________ Fixtures (describe): ____

Kitchens: ____________ Fixtures (describe): ____

Nurse Stations: ______ Fixtures (describe): ____

Baths / Spa: __________ Fixtures (describe): ____

Other: _______________ Fixtures (describe): ____

Daytime staff (function / number): ____

Nighttime staff (function / number): ____

Number of residents at start of tests: _________

Number of residents at end of long-term monitoring: __________