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Monitoring of a zero energy house

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MONITORING OF A ZERO ENERGY HOUSE

by

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ABSTRACT

Monitoring of a Zero Energy House

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A comparative study is conducted to measure the actual performance of a Zero Energy House design. Ideally, a zero energy house produces as much energy as it consumes in a year's time. Two identically-sized houses (1610 ft^2), constructed side-by-side in southwest Las Vegas, Nevada, are equipped with a network of sensors that measure many aspects of energy usage in each home. One house serves as a baseline (standard comparison) house and was built using conventional construction techniques. The other house, the Zero Energy House, employs many energy saving features, solar power generation, and supplemental solar water heating. Both houses are utilized as model homes in an actual housing development, so it is reasonable to believe that both will experience similar and consistent usage. The data logged onsite are automatically collected throughout the day (in an almost real-time basis) and sent via telephone connection to the Center for Energy Research at UNLV for analysis. Results are posted on the web.

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NOMENCLATURE

BTU	British thermal unit
CFLs	Compact Fluorescent Lamps
DOE	Department of Energy
EER	Energy Efficiency Ratio
FSEC	Florida Solar Energy Center
FSL	Final Storage Label
ft^2	Square foot
ft^3	Cubic foot
^oF	Degrees Fahrenheit
hr	Hour
HVAC	Heating Ventilating Air Conditioning
kW	Kilowatt
kWh	Kilowatt-hour
m^2	Square meter
min	Minute
NAHB	National Association of Home Builders
NREL	National Renewable Energy Laboratory
NSWEP	Nevada Southwest Energy Partnership
OVE	Optimal Value Engineering
PV	Photovoltaic
RTDM	Real Time Data Monitoring
SEER	Seasonal Energy Efficiency Ratio
SIPS	Structurally Insulated Panels
SHGC	Solar Heat Gain Coefficient
SMUD	Sacramento Municipal Utility District
Tdb	Dry Bulb Temperature
UNLV	University of Nevada, Las Vegas
VT	Visual Transmittance
ZEH	Zero Energy Home

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CHAPTER 1

INTRODUCTION

The Department of Energy (DOE) estimates that buildings use 20% of the primary energy consumed in the United States each year [1]. Over the last few years, oil and natural gas rates have been increasing rapidly, which has generated an increased interest in alternative energy sources, and energy conservation technologies. Developing communities in the Southwestern United States like Las Vegas, which has been experiencing a boom in new home construction, are in a unique position to lead the way in integrating innovative energy conservation practices into new homes. The DOE Buildings Program conceived the Las Vegas Zero Energy House (ZEH) to serve as a model for what can be done when mainstream homes are designed with energy conservation in mind.

The goal of the Department of Energy's Zero Energy House initiative is to utilize the latest energy research in the design of new homes, and help builders create homes that produce as much energy as they use on a yearly basis. The DOE selected four teams to work with the National Renewable Energy Laboratory (NREL) to introduce the ZEH concept to the single-family, new home construction industry. The four teams are ConSol, the Davis Energy Group, NAHB Research Center and Steven Winter Associates.

As part of the Nevada Southwest Energy Partnership (NSWEP), The University of Nevada, Las Vegas received a project subcontract from NREL to develop and monitor the performance of two identically sized tract homes built side by side in the Las Vegas area. One house, built using conventional construction techniques, serves as a reference and is referred to as the Baseline House. The other is the Zero Energy House, which was designed to have an annual net energy usage of nearly zero.

The Zero Energy House generates electricity with a 4.8 kW photovoltaic array. The orientation of the ZEH roof was changed from east-west to north-south to provide the solar panels with adequate exposure to the sun. The house was built using high thermal mass walls, spectrally selective windows, an insulated foundation and additional attic insulation along with a radiant heat barrier in the attic. Heating is achieved by a hydronic fan coil. Hot water is supplied by an on demand tankless water heater and supplemented by a solar water heater. A highly efficient evaporative condenser supplies the air conditioning through ducts built into the conditioned space. The house utilizes compact fluorescent lighting, and all appliances are Energy Star.

The houses are located in a typical Las Vegas housing development and are open to the public as model homes. A network of sensors built into both houses allows the energy performance of each to be monitored in great detail. The data acquisition system located in each house can be accessed remotely via telephone connection. Data can be downloaded automatically to the Center for Energy Research at the University of Nevada, Las Vegas, analyzed and posted on the Internet.

Review of Related Literature

There have been quite a few Zero Energy Houses built in the past few years. The Florida Solar Energy Center (FSEC) has been the front-runner in this field since 1998 when they built the first Zero Energy House in Lakeland Florida. The study was organized in a similar way to this present study, where two identical houses were built, one served as a reference and the other was outfitted with energy saving features and photovoltaic energy generation to make it zero energy. The experiment allowed the investigators to draw conclusions on what technologies worked for the hot humid climate of Florida.

FSEC has since gone on to develop two more Zero Energy Houses: Florida Zero Energy Home 2 in New Smyrna, Florida, and California Zero Energy Home 1 in Livermore, California.

Florida ZEH 2, in New Smyrna, is a second generation ZEH that took the lessons learned from the Lakeland house and applied them to maximize the cost: benefit ratio of the various components [2]. The project utilized a duplex house, where unit 1 and unit 2 function as the zero energy and reference houses respectively. The power generation is done by a grid-connected PV system backed up by a small battery bank to power critical loads during times that utility service is not available [2].

Zero Energy Home 1, in Livermore, California, was built as an initial demonstration and proof of concept of ZEH technologies in California. It is the first zero energy house built by a commercial builder in Northern California. The house is meant to function as a test bed for HVAC technology developed under a California Energy Commission Public Interest Energy Research project [3]. The goal of this project is to refine the approach for integrating energy efficiency measures with PV and solar thermal systems by collecting performance data [3].

Located in Elk Grove California, the fastest growing city in the United States [4], Morrison Homes is offering the Sacramento area's first homes built under the Department of Energy's Zero Energy Homes initiative [5]. Five home plans are available with the ZEH package, and the houses range from 2,126 to 3,672 square feet [5]. Monitoring equipment was installed on a model home, and the Sacramento Municipal Utility District (SMUD) installed sensors to measure the solar insolation and PV panel temperatures.

The largest Zero Energy Home community in California is Clarum Homes Vista Montaña development in Watsonville, California. The development consists of 257 solar-powered single-family homes and town homes offered in ten different floor plans [6].

In Tucson's Armory Park Del Sol, all the homes are designed to use 50% less electricity than average Tucson area homes, and one was designed to be a Zero Energy Home [7]. The ZEH uses a 4.2 kW PV array with a solar water and space heating system to generate electricity and provide domestic hot water. Other features include solid masonry construction, reflective roof coating and radiant barrier roof decking. Engineers at the NAHB Research Center are monitoring the performance of this house.

Clarum Homes and ConSol are involved in a new Zero Energy Home project in Borrego Springs California. Four homes are being built, two with Dow T-mass walls, one utilizing structurally insulated panels (SIPS) and the other using 2x6 optimal value engineering (OVE) construction [8]. The houses, currently in development, are to be equipped with network of sensors to track their performance.

Careful monitoring of a Zero Energy House is necessary in order to draw conclusions about its performance. Campbell Scientific datalogging equipment is widely used by the partners of the Building America ZEH initiative, mainly because that is what researchers at FSEC used when they monitored the first ZEH project. The original set up was comprised of a Campbell Scientific CR10 datalogger supplemented by an AM 416 multiplexer and a SW8A pulse count board [9]. The FSEC systems in New Smyrna Florida and Livermore California are monitored in a similar way.

The new Borrego Springs ZEH project is using a Datataker system to collect its information. The Datataker 50/500/600 products are very similar to the Campbell Scientific CR10 products. They are good for use in stand-alone systems that are portable or in fixed locations. They allow flexible channel sampling and functions. Both have analog and digital channels and can be extended by the use of multiplexers [10].

Enetics dataloggers are being used by ConSol to monitor the end use of the power at the Elk Grove ZEH development. The system they put together is comprised of an Enetics 1203 AESG recorder, which measures the current of three Enetics Smart Current Transformers installed inside the main power panel. Two current transformers are installed on the main power legs from the utility and the third measures power produced by the PV system. The system is also connected to a telephone modem to allow data transmission. Enetics Master Station software provided with the datalogger interfaces between a central computer and the datalogger [8].

To display their data on the Internet, FSEC uses a program called WebGet, which retrieves text files from an HTTP protocol [11]. The user specifies the data they are interested in by selecting a location or ZEH. Then the user defines the time period they are interested in viewing data for. This is easily done through drop-down menus and is very intuitive. After the request is submitted, another screen appears that lets the user select any sensor that they are interested in seeing. One can then plot the sensor signals they are interested in, or download the data file.

This approach to data display requires users to be highly motivated and knowledgeable about the system. Comparing systems requires users to do all the work themselves, which is time consuming and discouraging for people with only a minor interest.

Building on the WebGet technology, the Steven Winter Associates (a partner in the Building America ZEH initiative) built a more user-friendly graphical interface to generate summary reports and plots of the ZEH built in western Massachusetts [12]. The home page has a tabulated data display showing information on electricity use, domestic hot water, heating oil and local weather conditions. The same page has a simplified WebGet menu, where the user only has to select the date range once and then choose what information they want to see. Available plots include electricity, hot water, environment and space heating. Plots pop up in a different window so the user does not have to always go back in their browser to generate a new plot. The Steven Winter Associates display is much simpler to use than the FSEC interface, but users still have to generate their own plots, and there are no real time data displays.

Fat Spaniel is a company that specializes in displaying energy data on the Internet. They provide a turnkey service where they manage all the data acquisition and display of their customers [13]. Their displays are very easy to understand due to their simple layouts and custom graphics. Through a proprietary PV2Web program, they display real time data as well as continuously archive new data. Included in their displays is: how much energy the house is using or generating and weather it is importing or exporting power. An animated gif graphically shows if power is being used or supplied by the house. A plot of the daily energy used is shown and updates automatically. Weekly, monthly, yearly and overall energy data are available as well. The systems also track the amount of greenhouse gases that have been avoided by the use of the renewable energy system. They also relate the energy savings to easily understandable terms like how many homes could run off the energy generated by the PV system for one day, and how many cups of coffee could have been made with all the generated energy. These displays appeal to casual users as well as those with more technical interests

Significance of this Study

Growing concerns over the United States dependence on imported oil and the environmental impact of burning fossil fuels have spurred a renewed interest in developing renewable energy resources and energy conservation.

Applying renewable energy technologies and energy conservation techniques in the residential sector would have a large impact on reducing overall energy use in this country. U.S. households rely primarily on three sources of energy: electricity, natural gas and fuel oil [14], electricity being used the most. Retail sales of electricity to U.S. households exceed sales of electricity to the commercial and industrial sectors [14] and residential buildings use 20% of the nations primary energy [1]. Having Zero Energy Homes (residential homes capable of supplying enough of their own energy over a year's worth of time to bring their net energy use to zero) would significantly reduce the demand for oil and natural gas, as well as ease the load on electric utilities; which in turn would reduce the amount of greenhouse gases emitted from power plants.

According to the United States Census Bureau, the ten fastest growing cities in the United States are located in California, Nevada, Florida, and Arizona [4]. These rapidly growing cities and relatively new communities are located on the outskirts of major cities like Sacramento, Los Angles, Phoenix, Miami, and Las Vegas. The Department of Energy's Building America program has initiated Zero Energy House programs in all these areas (as well as other locations) to address the national energy concerns. The goal of the DOE is to bring together researchers and builders to put into practice the latest energy conservation technology to reduce the residential energy usage and make Zero Energy Homes the standard for new home construction. Budding communities are an ideal place to begin since they have the opportunity to experiment and design new houses with energy conservation in mind from the start.

Before Zero Energy Houses enter the mainstream housing markets, it is important to test the designs and make sure they perform as planned. Regional conditions play a large role in the design of a zero energy house. The hot dry climate of Las Vegas, Nevada is greatly different than the hot humid climate of Lakeland, Florida. Therefore certain approaches to energy conservation that work in Las Vegas will not necessarily work in Lakeland.

The objective of this study is to monitor the actual performance of the Zero Energy House designed for the Las Vegas area. The performance aspects considered are electrical energy use, gas energy use, overall energy use, the efficiency of the photovoltaic system and the energy used by the two condensing units.

Also discussed are the construction differences between the two houses, the components and setup of the data acquisition system and how the results of the study are displayed in a nearly real time basis on the Internet.

CHAPTER 2

CONSTRUCTION AND DATA ACQUISITION

Construction Details

The ZEH is a modified version of the Baseline House. The Baseline house was built to the international residential code with Energy Star upgrades [15]. The houses share the same floor plan (only mirrored), and are nearly the same square footage (1,610 Baseline, 1,697 ZEH). The ZEH employs innovative technologies and construction techniques in order to significantly reduce its energy consumption relative to the Baseline House.

The most obvious change made to the ZEH was rotating the orientation of the roof from east-west to north-south. This change was necessary to provide the roof mounted solar energy components adequate exposure to the sun throughout the year. The roof was also built on a steeper slope to optimize the angle at which the sun strikes the solar components.

For the house to be zero-energy, it needs to produce energy as well as conserve it. For this, an array of 96 General Electric photovoltaic modules (GEPV-055-G) is installed on the roof capable of producing 4.8 kW AC of peak power (Figure 1). Two 2.5 kW Sunny Boy inverters convert the DC output from the panels to an AC output that can be used by the house and the utility grid.

The other solar component on the roof is a Sun Systems 40-gallon solar hot water heater, an integrated collector/storage unit. The unit is a tempered glass and copper tube collector with an area of 25 square feet. It is designed to supply hot water to the house operating at city water pressure. A tankless water heater provides back up hot water in times of increased demand and limited sunlight.

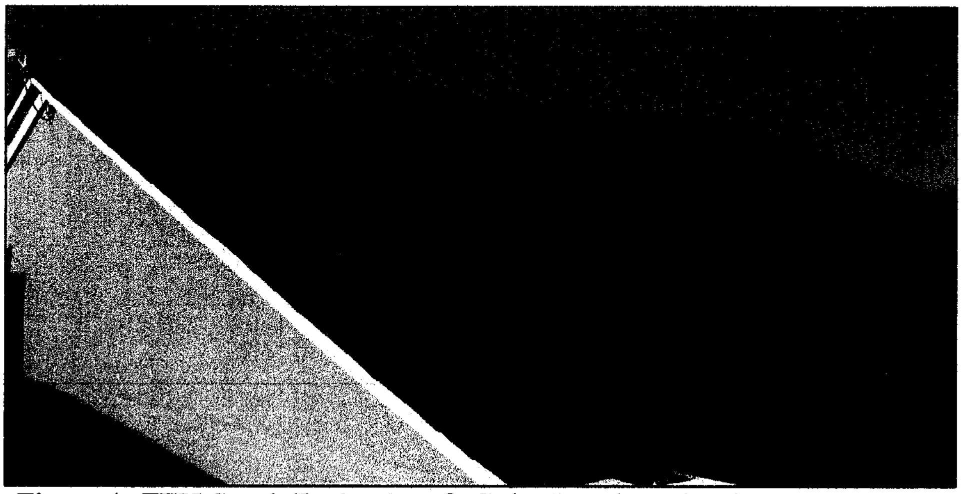

Figure 1. ZEH South Facing Roof. Solar Panels and Solar Water Heater

Rather than typical wood framed walls, the ZEH uses Dow Chemical Company's Styrofoam precast T-Mass walls (Figure 2). The Walls are made from a 4-inch layer of concrete on the interior; a 2-inch layer of concrete on the exterior and a 2-inch layer of Styrofoam extruded polystyrene board insulation in between. These high thermal mass walls are poured off site and shipped to the location where they were erected all in one day.

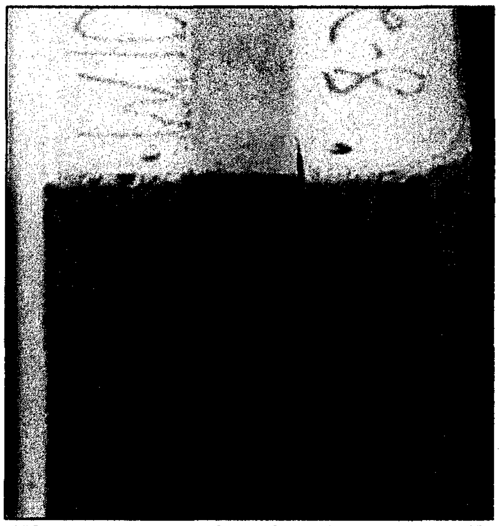

Figure 2. Dow Corning T-mass Wall

A study conducted at Oak Ridge National Laboratory [16] analyzed the experimental and theoretical dynamic thermal characteristics for complex massive wall configurations. A major finding of that work was that thermally massive wall systems function well in a hot dry climate like Phoenix. The high thermal mass of the walls and the configuration of the concrete and Styrofoam makes it so heat takes a long time to flow through the walls. It is this dynamic response that gives the walls an effective R-value exceeding R-30. The steady state R-value is considerably less than that.

The attics of the ZEH and the Baseline use a combination of netted and blown in cellulose insulation applied directly to the attic floor. The Baseline house has insulation up to R-29, where the ZEH has it to an R-value of R-38. Polar-Ply Radiant Barrier Sheeting is mounted on the plywood in the attic to reduce the amount of heat transferred from the roof to the attic floor. The barrier is a highly reflective sheet of aluminum foil that is installed with the reflective side facing the interior of the attic.

All houses in the Las Vegas area are required by code to use low emissivity (low E) windows. The windows in the ZEH exceed the codes since they are also spectrally selected to filter out infrared wavelengths. Table 1 summarizes the window characteristics of the Baseline house and the Zero Energy House.

Table 1 Window Characteristics of the Baseline and ZEH

	Baseline	ZEH
U-Value*	0.58	0.34
SHGC	0.35	0.21
VT	0.57	0.35

*Units: [Btu/hr-ft^2-^{o}F]

The air-conditioning system in the ZEH uses a Freus 3-ton evaporative condenser. The unit sprays water over the condensing coil as the fan blows air over the coils therefore utilizing the further cooling affect of evaporation. The Freus unit is rated by an energy efficiency ratio (EER) that compares the cooling power and power supplied to the unit at a dry bulb temperature of 95^{o}F. The Unit has an EER of 18 compared to a SEER 12 condenser in the Baseline House [17]. SEER is a ratio of the amount of cooling power achieved to the amount of power supplied to the unit over an entire season. Figure 3 shows a temperature performance comparison of the Freus evaporative condenser to a SEER 12 conventional air-cooled condenser [20].

All ducting in the ZEH is located within the conditioned space of the house. This eliminates transmission losses since any air that leaks through the ducts ultimately ends up in the conditioned space rather than being lost in the attic. The air conditioning and heating are single zone systems controlled by the thermostat temperature located centrally in the houses.

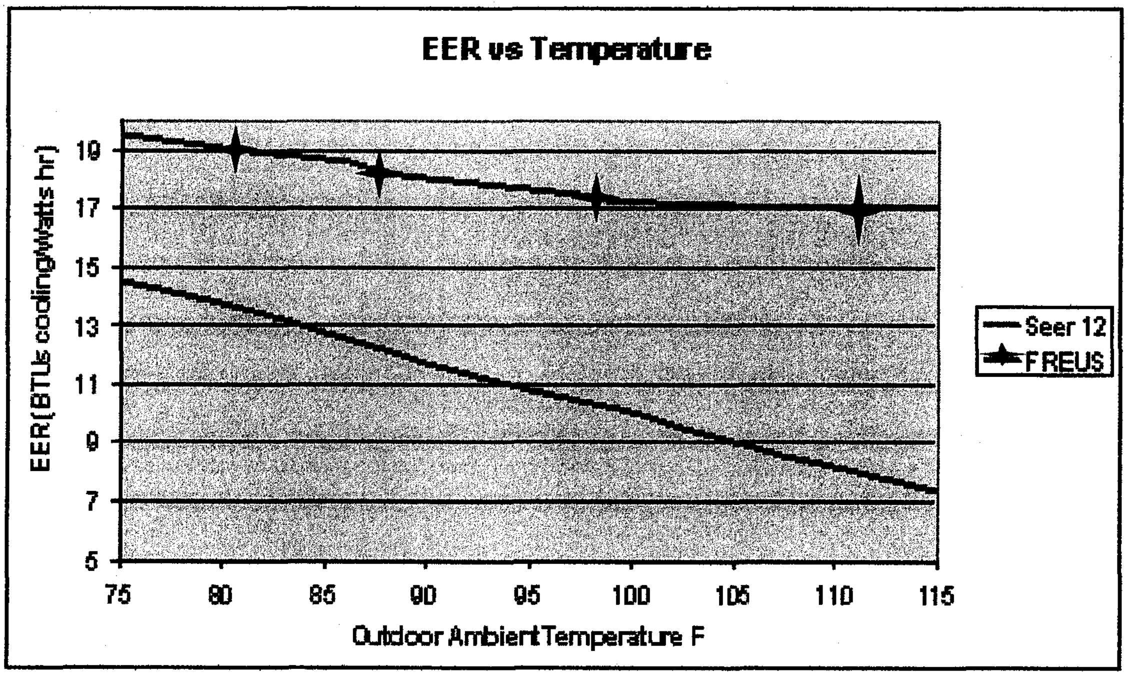

Figure 3. Performance rating of the Freus condenser compared to a SEER 12 conventional unit [15]

The ZEH uses a hydronic heating system rather than a typical residential gas furnace. A hot water coil in the air handler is connected to a Noritz tankless on demand natural gas water heater (Figure 4). The tankless water heater can also be used to supply domestic hot water in case the solar water heater cannot keep up with demand. Not having a hot water storage tank eliminates stand-by losses associated with traditional water heater configurations.

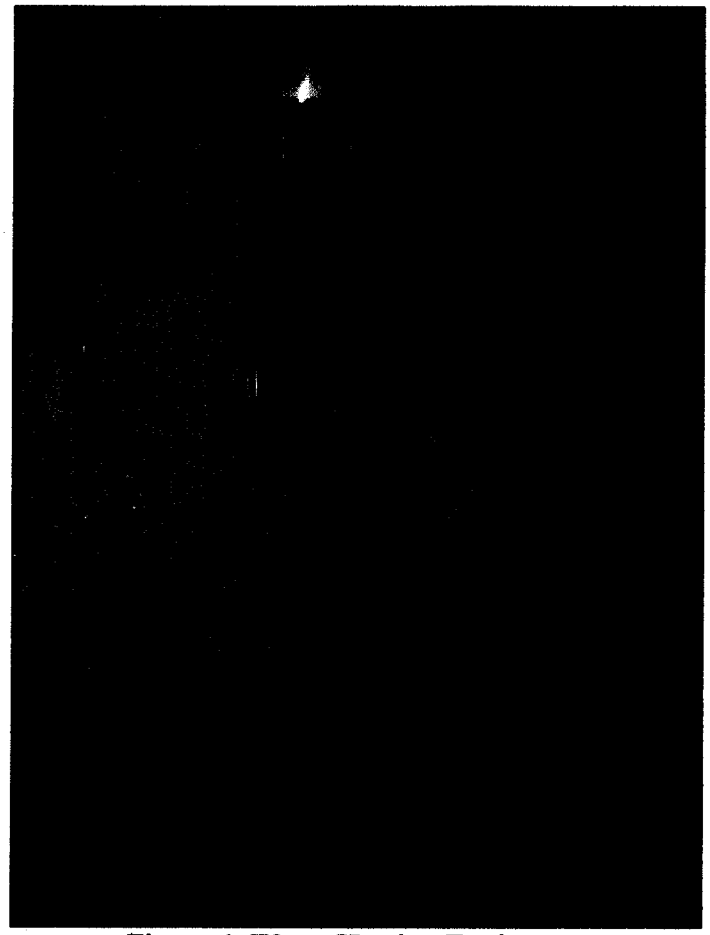

Figure 4. Water Heating Equipment

Lighting in the ZEH is accomplished by compact fluorescent lamps (CFLs). CFLs save energy in two ways: they use 70-75% less energy than incandescent counterparts, and they generate less heat than incandescent bulbs, which saves on cooling costs [15].

All appliances installed in both houses are Energy Star rated. Since the houses are used as model homes, appliances like the refrigerator and the dishwasher are never turned on.

Data Acquisition

A large amount of instrumentation was built into both homes at the time of construction. Wiring runs from all the sensors through the attics of both houses and into the data acquisition stations located in each garage. All the components of the data acquisition system used in the ZEH project come from Campbell Scientific. The datalogger is a CR10X measurement and control module that is connected to an AM 16/32 multiplexer and an SDM-SW8A pulse counter.

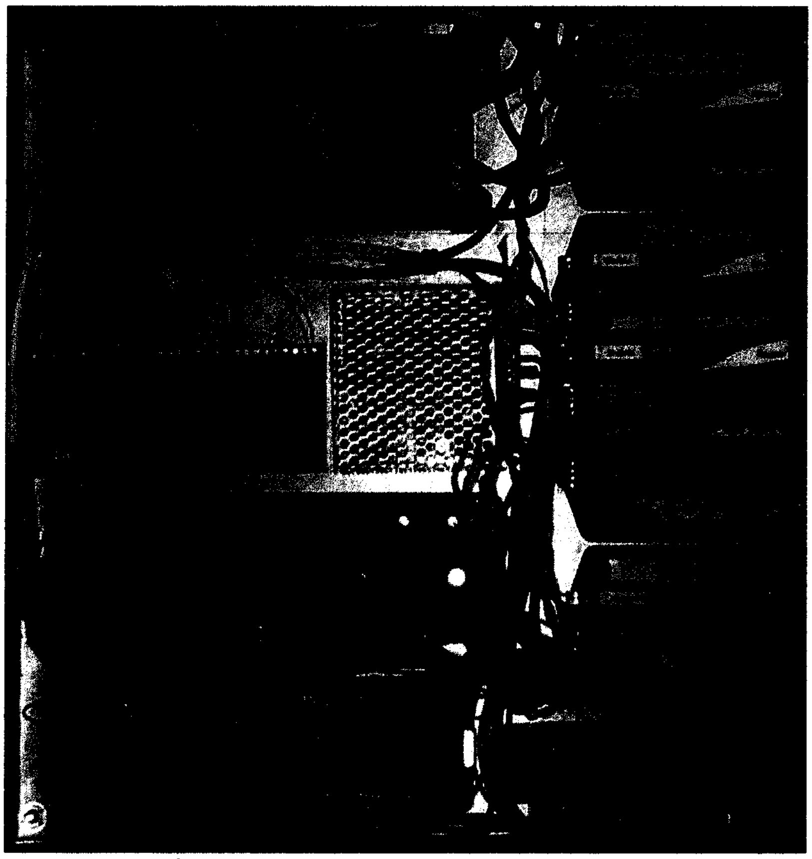

Figure 5. Data Acquisition Equipment

The datalogger is the hub of the acquisition system. Its primary function is to store and time stamp all the data collected by the system. It is also used to distribute power to the other peripheral components. The CR10X is powered by an external PS100 12 V power supply. The datalogger has inputs for analog, digital, and pulse signals. We are using the analog inputs to record heat flux signals as well as the local weather conditions from a weather station at the site. The other peripheral components record the majority of the signals.

A 9600-baud COM210 telephone modem connected to the CR10X via serial I/O port allows the data to be accessed remotely by computer and downloaded to the Center for Energy Research at UNLV for analysis.

An AM 16/32 Relay Multiplexer records the temperature signals at both houses. The Multiplexer increases the number of analog sensors that can be measured by the datalogger. Mechanical relays in the AM 16/32 connect each of the sensor channels in turn to a common output that is sent to the datalogger [21]. All the thermocouples used are single ended J-Type thermocouples, and all heat flux sensors are thin film heat flux sensors.

An SDM-SW8A switch closure input module handles pulse signals and power usage readings. The sensors that are connected to this module are the water and gas flow meters, as well as the power meters. In the Baseline House, this module records the power used by the entire house as well as the power used by the condenser and the fan coil unit. It records the whole house gas usage and the gas used by the fan coil only. It records the water used by the entire house as well as the amount used by the water heater. The module in the ZEH records energy generated by the photovoltaic panels, the amount of energy used by the condenser and the house, the amount of energy sent to the grid as well as the flow through the water heater, the solar water heater and the hydronic coil in the air handler.

Programming of the datalogger was initially done by engineers at Paragon Consulting Services. Copies of the programs that are currently in use are included in the appendices. The Baseline House program was revised two times: once to correct an error in the program where channels were labeled incorrectly, and again to change the collection interval from fifteen minutes to one minute. The ZEH program was only changed once to change the collection interval.

Changes were made to the programs through the Loggernet interface by clicking on the Edlog icon then opening up the current .CSI file. The current programs are ZEBASE03.CSI and ZEHOME01REVISION1.CSI for the Baseline House and the ZEH respectively. Once opened in Edlog, the programs can be altered and sent back to the datalogger to be put into operation. The FSL files label the data columns when the data is viewed in any Loggernet program.

Going through the sensor verification process, a number of changes were made from the original wiring diagram given to UNLV from Paragon. Updated wiring diagrams are provided in the appendices. Also in the appendix is the process for regaining communication to the ZEH dataloggers after a power outage at UNLV.

The Baseline House

Table 2 lists all the sensors that are used in the Baseline House and serves as a legend for the sensor map shown in Figure 6. Figure 6 is a floor plan of the Baseline

House and shows the locations of all the sensors used in the house. The house has a total of twenty-seven sensors.

J-Type thermocouples imbedded in the interior and exterior surfaces of the north, south, east and west walls give an indication of the temperature profile of the house walls. Heat flux is being measured on the interior surface of all four walls corresponding to the cardinal directions by Omega HS-4 thin film heat flux sensors.

Table 2 Baseline House Sensor Key

1	Interior wall thermocouples
2	Exterior wall thermocouples
3	Floor surface thermocouples
4	Low attic thermocouple
5	High attic thermocouple
6	Shortest run from AC thermocouple
7	Longest run from AC thermocouple
8	Thermostat thermocouple
9	Return air thermocouple
10	Water heater inlet thermocouple
11	Water heater outlet thermocouple
[1]	Wall mounted heat flux sensor
[2]	Low ceiling heat flux sensor
[3]	High ceiling heat flux sensor
1	AC power meter located at AC fan coil
1	Water heater flow meter
1	Water heater gas meter
2	Gas meter

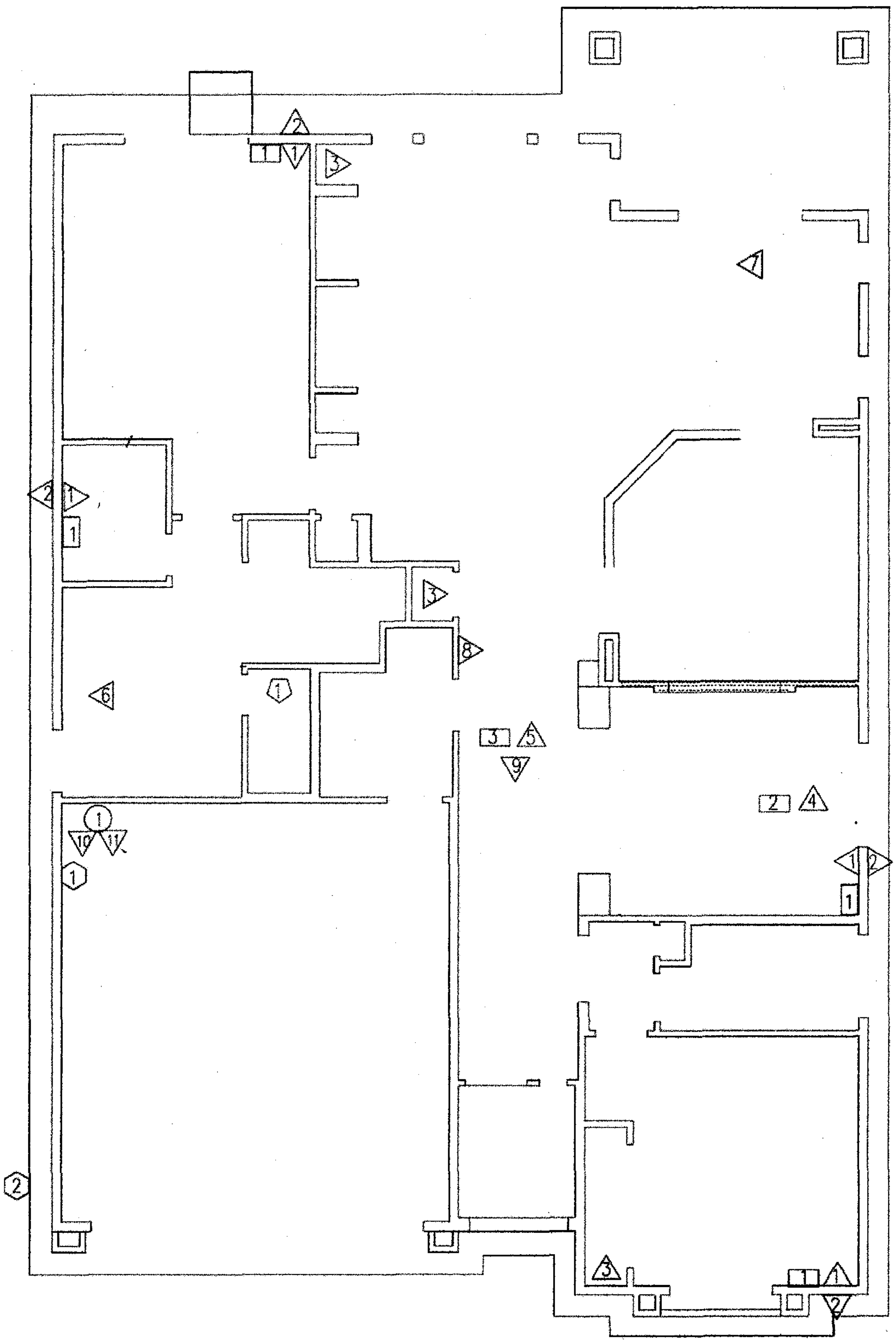

Figure 6. Baseline House Floor plan Sensor Map

The amount of heat that is transmitted through the ceiling is monitored in a way similar to that of the walls. Heat flux sensors are mounted to the ceiling in both the low attic and high attic. Thermocouples are placed on the underside of the roof in the attic directly above the flux sensors.

Sensing the return air temperature along with the temperatures at the long and short runs from the air handling unit makes it possible to evaluate the performance of the unit. The return air sensor as well as the long and short run sensors are placed in the ducts.

Heat transmission through the floor is also being monitored by thermocouples embedded in the floor at three locations. The first is by the fireplace, the second is in the pantry, and the third is in the bedroom closet on the northwest corner of the house. The overall house temperature is recorded by the thermostat which is located in a central area of the house.

The performance of the water heater is being recorded by an Omega FTB-4110A-P turbine water meter and thermocouples placed at its inlet and outlet.

The gas consumption of the house is being recorded by three gas meters: the first measures the total amount of gas used by the house (Riotronics pulsepoint meter), and the second measures the amount that the water heater uses, and the last one measures how much the air handler uses (both use E-MON 200CGFM meters).

Three CCS Wattnode energy meters are also employed to measure the total house consumption as well as the amount consumed by the air conditioning condenser and the fan coil blower.

The Zero Energy House

Table 3 gives a list of all the sensors being used to monitor the Zero Energy House and serves as a legend to identify the sensors shown in Figure 7. Figure 7 is a sensor map that shows the locations of all the sensors located inside the house.

Many of the sensors in the ZEH are the same as the ones used in the Baseline House, so treatment here is only given to those sensors that differ from the Baseline House. The major differences between the two houses are the construction of the walls, the method of water heating, the method of space heating and the type of condenser used. Also, the ZEH has photovoltaic power generation and collects the local weather data.

Table 3 Zero Energy House Sensor Key

1	Interior wall thermocouples
2	Exterior wall thermocouples
3	Floor thermocouple 1/2" down
4	Floor thermocouple 4" down
5	Floor thermocouple 1' down
6	Floor thermocouple 3' down
7	Low attic thermocouple
8	High attic thermocouple
9	Shortest run from AC thermocouple
10	Longest run from AC thermocouple
11	Thermostat thermocouple
12	Return air thermocouple
13	Water heater inlet thermocouple
14	Water heater outlet thermocouple
15	Solar water heater inlet thermocouple
16	Solar water heater outlet thermocouple
17	Hydronic heating inlet thermocouple
18	Hydronic heating outlet thermocouple
19	High PV thermocouple

Table 3 Continued

△ 20	Low PV thermocouple
△ 21	Outside ground thermocouple
△ 22	AC condenser water thermocouple
| 1 |	Wall mounted heat flux sensor
| 2 |	Low ceiling heat flux sensor
| 3 |	High ceiling heat flux sensor
(1)	Water heater flow meter
(2)	Solar water heater flow meter
(3)	AC condenser water flow meter
(4)	Hydronic heater flow meter
⬡ 1	Water heater gas meter
⬡ 2	Whole house gas meter

To monitor how energy is transmitted through the floor of the ZEH, multiple thermocouples were embedded in the floor at depths of 0.5-inch, 4-inches, 1-foot and 3-feet. Since the foundation of the ZEH is wrapped with a two-foot layer of insulation, it was of interest to be able to see the temperature profile in the slab at greater detail.

The water heater in the ZEH is a Noritz tankless on-demand tankless gas water heater. When the house needs heat, the water heater sends hot water to a hydronic coil in the air-handling unit in the attic. The air passing through the coil heats up and provides warm air to the living space.

Figure 8 shows a schematic of the water supply system focused on the tankless hot water heater. The components of the water delivery system are the solar water heater, which is on the roof of the house, the hydronic heating system, which is in the attic, the tankless water heater and the Freus water-cooled condenser.

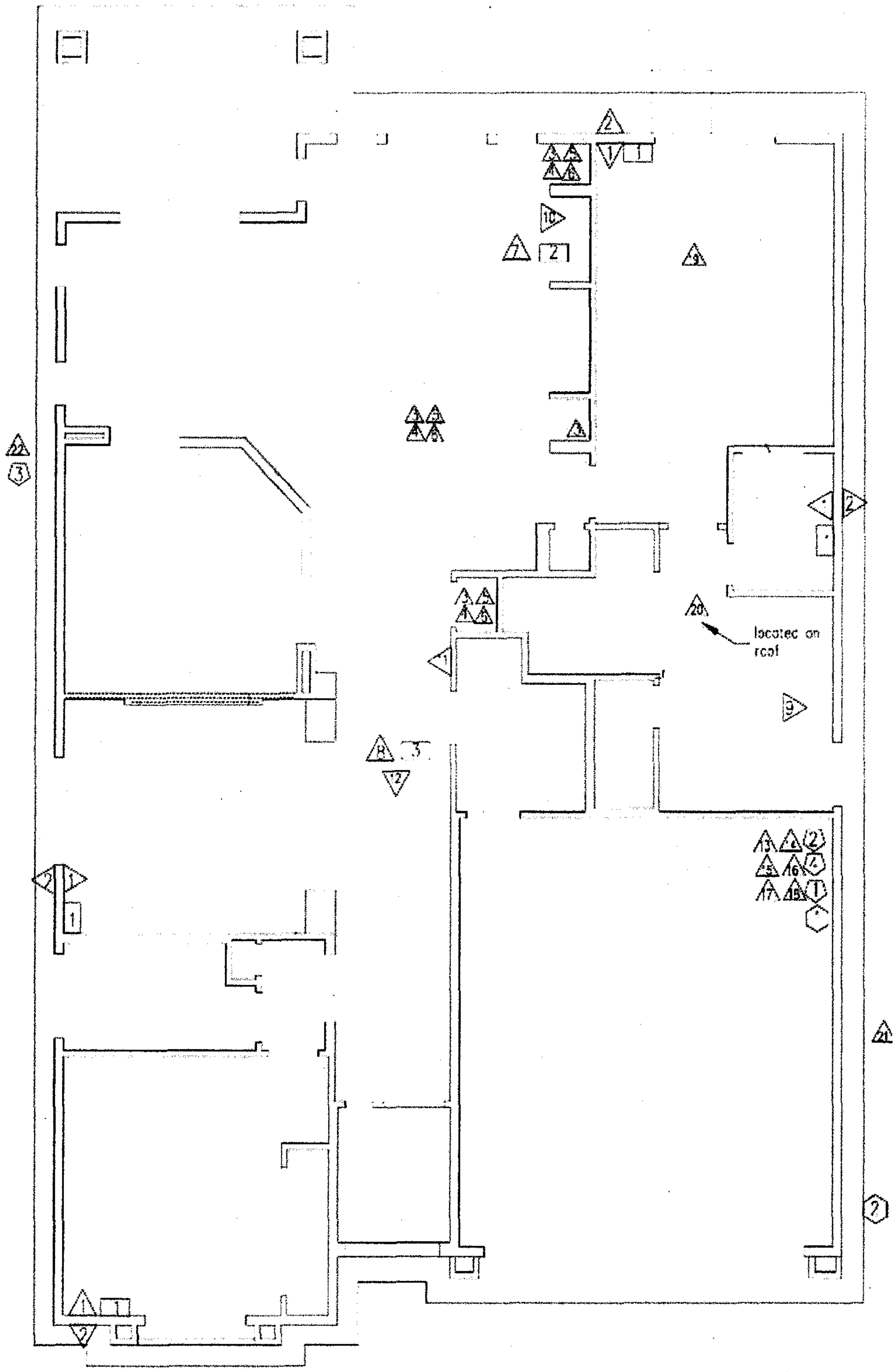

Figure 7. Zero Energy House Floor plan Sensor Map

A Seametrics SPX-038 Low Flow Water Meter measures the water used by the Freus unit.

An Omega FTB-4107A-P turbine water meter measures the water used by the solar water heater and the hydronic heating system. An Omega FTB-4110A-P turbine water meter measures the water used by the Tankless Water Heater. Since the tankless water heater uses gas, it also hooked up to an E-MON 200CFGM gas meter. Since there is no other major uses of water in the house (dishwashing, laundry, showers), a whole house water meter is not employed.

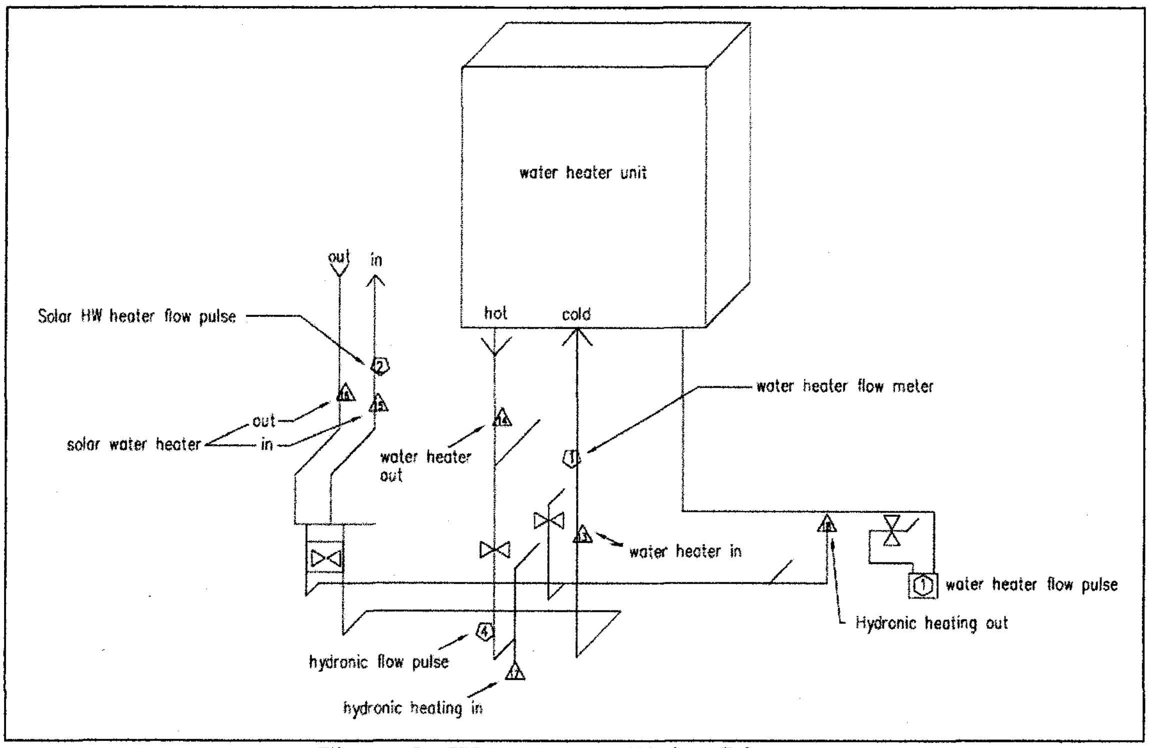

Figure 8. Water Heater Piping Diagram

Thermocouples are also placed at the inlets and outlets of the tankless water heater, the solar water heater, and the hydronic coil so their energy performance can be studied.

The performance of PV cells varies with temperature; therefore two thermocouples are mounted to the top and bottom surfaces of the PV array to measure the panel temperatures.

A weather station also mounted on the roof of the ZEH senses the local weather conditions at the site. A CSI 03001 Wind Sentry measures wind speed. The ambient temperature and relative humidity are recorded through a Vaisala HMP50 temperature and relative humidity probe with radiation shield. Solar radiation incident at an orientation coplanar to the PV panels is measured by a LI-COR LI200 Silicon pyranometer.

An extra Continental Control Systems WattNode energy meter was installed at the ZEH to record the amount of energy the house supplies to the grid at times when the PV is providing excess energy. A physical energy meter is installed on the outside of the house that records all the renewable energy generated by the PV system. Nevada Power also installed a net meter at the house that records separately, the amount of grid energy used by the house and the amount of energy the house supplied to the grid.

Meter Reading

There are many physical meters in place at the project site. These well-tuned accurate meters provide a way to verify the digitally collected data. The following describes how to read the different energy, gas and flow meters that are being employed at the ZEH project site since they are not all intuitive to understand.

Energy Meters

The renewable energy meter at the ZEH is a typical energy meter, but rather than measuring the amount of energy the house is consumes, it measures the amount of energy the PV array produces.

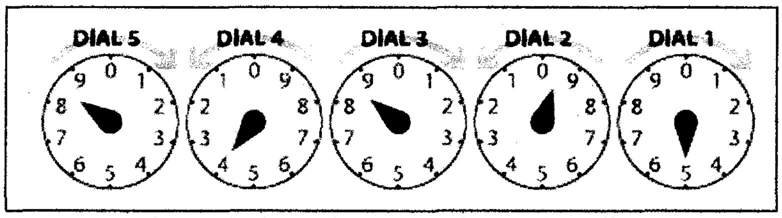

Figure 9. Sample Energy Meter Reading

Meters of this type have units of kilowatt-hours, and are read from left to right. Each dial is rotates opposite to the one adjacent to it. To read the meter, start at the far left and look where the pointer is. If the pointer is between two numbers, the smaller of the two values is taken. If it looks like the pointer is on a number, make sure the preceding dial is past the zero. A sample reading of an energy meter similar to ones used at the Baseline and ZEH is show above in Figure 9 [19]. The meter is reading a value of 83895 or 83,895 kWh.

Net Meter

The ZEH has another energy meter located right next to the renewable energy meter. This is a net energy meter, and it keeps track of how much energy the house has consumed from or supplied to the utility grid. This is the meter that governs how much Nevada Power charges for the electrical bill. Observing this meter for a minute or so, one will notice that the display cycles through four settings. Two of these are total energy readings, and two of them are average power readings. These modes are distinguished by a number code displayed on the far left of the window. The modes 5 and 15 show how much energy the house has consumed from and supplied to the grid respectively. Figure 10 below gives an example of the net meter reading in the "5-mode". This reading shows that the ZEH has consumed a total of 2,393 kWh of grid energy since the project began.

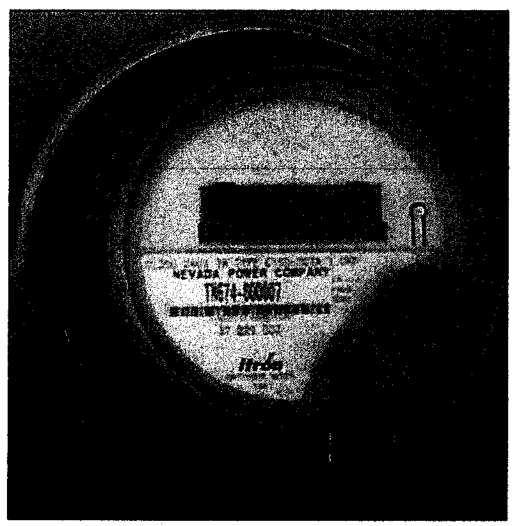

Figure 10. Net Meter Reading

Gas Meters

There are two types of gas meters being used at the project houses: typical gas meters supplied by the gas utility company, and smaller localized gas meters that are reading the use of specific equipment. The small meters are placed on the water heaters in both houses. We were fortunate to have the small gas meter installed on the water heater at the ZEH since the gas company made a mistake when they installed the main outside meter. The mistake stopped the dials on the meter from spinning, so for a majority of the winter months, that meter was not functioning and we had to rely on the water heater gas meter.

Utility Supplied Gas Meters

The outdoor meters supplied by the gas company are read from left to right, and have units of cubic feet. Figure 11 is an example reading from the ZEH.

Figure 11. ZEH Outdoor Gas Meter Example Reading

Like the energy meter, this meter also has a series of dials that turn in alternate directions. Notice the numbers on top of every dial; these are not necessarily the place numbers of the value given in the reading. Reading the meter like a power meter and applying the place number would indicate that 25,000 cubic feet of gas have been used. This is not the proper way to read the dial. The value above the dial represents the value you reach once the pointer has gone a full revolution from 0 all the way back to 0 again.

With this in mind, it is clear that the dial with 10,000 above it is really the thousands place, and the dial with the 1,000 above it is really the hundreds place. The true amount of gas used is 2,500 cubic feet.

Local Gas Meters

The local gas meters installed on this project are measuring the gas used by the water heaters in both houses. They are Emon 200CFGM gas meters and read 1 pulse per cubic foot [20]. Figure 12 shows a sample reading of the gas used by the ZEH water heater. The value is 34,898.1 ft^3.

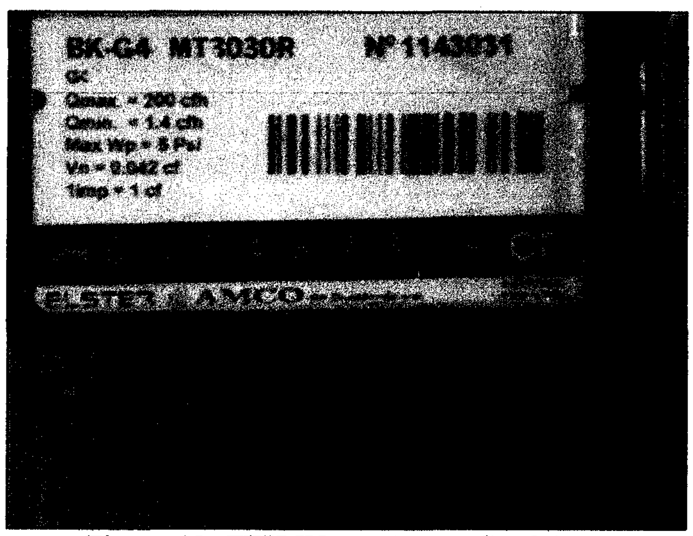

Figure 12. ZEH Water Heater Gas Meter

Flow Meters

An Omega FTB-4107A-P turbine measures the amount of water (in U.S. Gallons) flowing through the hydronic heating system and the solar water heater. Figure 13 shows what the meter looks like. The three digits that have black as the background represent the ones, tens and hundreds digits. The bigger of the two round dials is the decimal dial, and it has tick marks at every 0.05 gallons. The bigger tick mark is a whole decimal (i.e. 0.1, 0.2 0.3 etc.). The amount of water being displayed in the figure is 89,024.25 gallons.

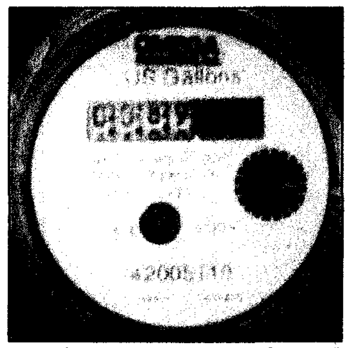

Figure 13. Solar Hot Water and Hydronic Heating Flow Meter Sample Reading

An Omega FTB-4110A-P turbine water meter measures the water used by the Tankless Water Heater. The meter, shown in Figure 14 below, can be used to demonstrate how the meter is read. The main display area represents digits from the hundreds to the millions of gallons. The three dials below the main panel are the tens, ones, and tenths digits respectively. The sample reading shown in the Figure is 106,229.4 gallons.

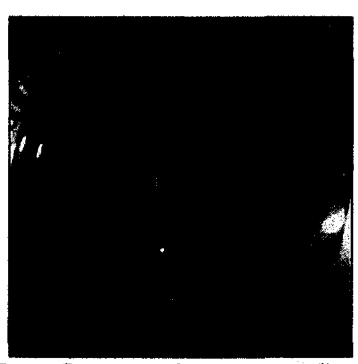

Figure 14. Water Heater Flow Meter Sample Reading

CHAPTER 3

DATA ANALYSIS

Electric Energy

Electric energy use is a major factor of the overall energy performance of the Zero Energy House. In most of the literature on ZEHs, a majority of the emphasis is placed on electrical energy usage, and how the PV system can run the power meter backwards. In terms of the electric energy usage, the Las Vegas ZEH has performed extremely well.

The ZEH has a grid-connected PV system and therefore does not store excess energy onsite. Rather it uses the utility grid as a battery; where it supplies its excess energy and where it can draw energy from during the night or at times of high demand. The net meter at the house records how much energy the house supplies to the grid, and how much energy it takes from the grid. Current transformers located on the main power supply line to the house are also logging these data.

The Baseline House on the other hand, having no supplemental power generation, is totally dependent on the utility grid to function. Figure 15 below contrasts the amount grid supplied energy consumed by both houses every month since monitoring began. It is apparent from the data that the ZEH consistently uses significantly less grid supplied electric energy than the Baseline House.

In the fall and winter, the ZEH uses more electricity from the grid than it does in the spring and early summer. This is due to shorter days during these months, translating into less operating time for the PV system. The increase in energy use during the winter is due to the heating load.

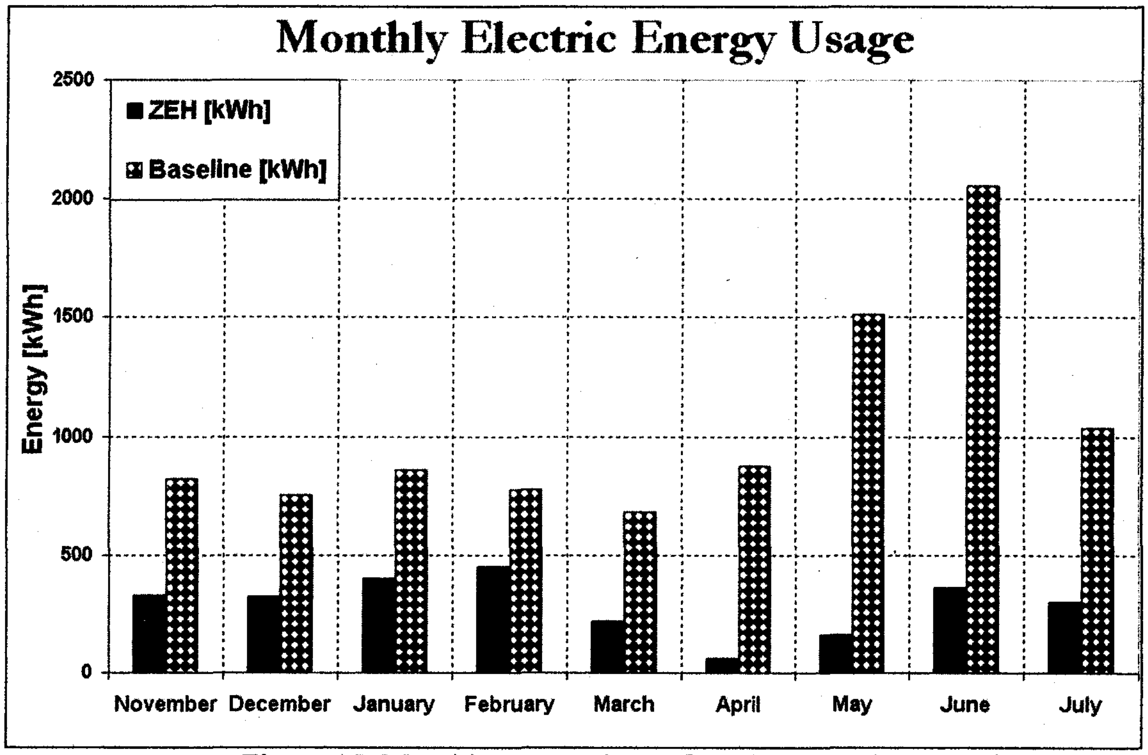

Figure 15. Monthly Comparison of Grid Energy Consumed

As the springtime begins and the heating season comes to an end, the energy used by the ZEH decreases. To date, the smallest grid energy drawn by the ZEH came in April. At this time, there was no significant heating or cooling loads, and the house generated over 800 kWh of PV energy.

Figure 16 below shows a breakdown of the total amount of energy generated by the PV system on the Zero Energy House.

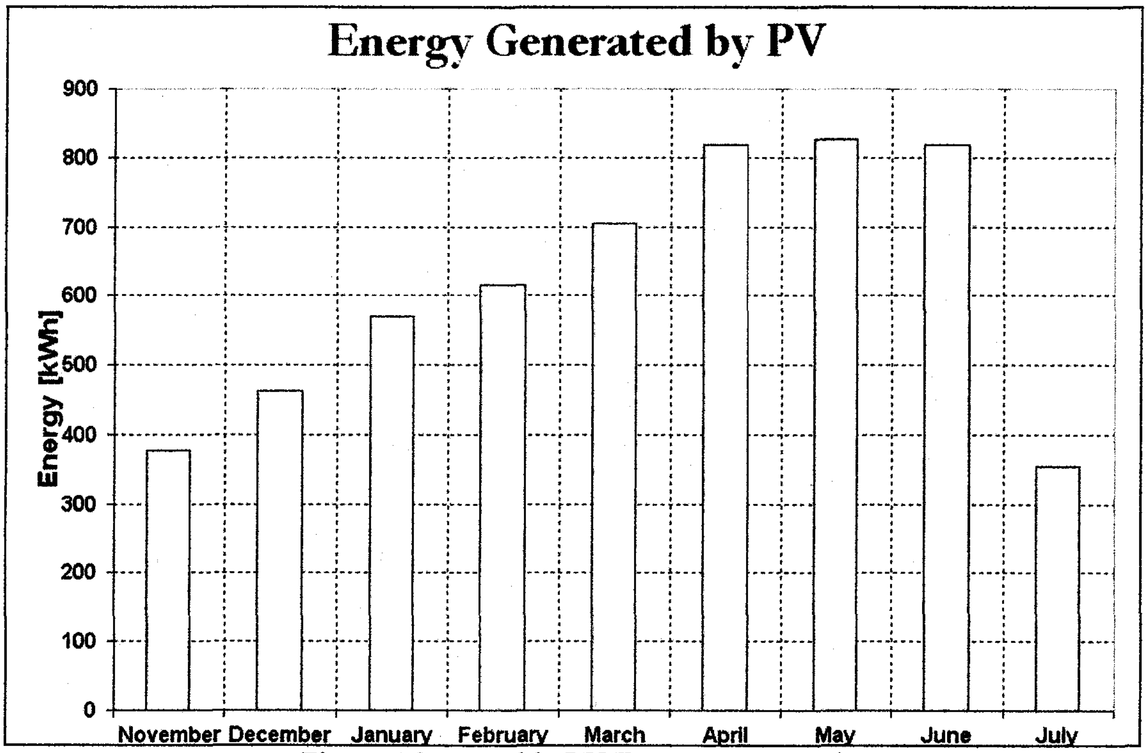

Figure 16. Monthly PV Energy Generated

There is a nearly linear increase in the amount of energy generated from November to April. The amount generated starts to level off at just over 800 kWh of energy in March, appears to reach a peak in May. The amount of energy produced in June dropped off to the amount that was produced in April, and if July production continues at its current pace, the PV array will not generate much more than 800 kWh.

Early on in the project, it was reasoned that the net electric energy used by the house could be obtained from subtracting the amount of energy generated by the PV system from the amount of energy used by the house. If the value was negative, the PV system produced more energy than the house used, and if it was positive, the house used more than it produced. While analyzing the data, it was determined that this procedure was slightly overestimating the amount of net energy used by the house since the house energy meter went to zero when the PV system began producing. An overestimation results since the lighting load of the house was not accounted for during the daylight hours. To remedy this, an additional current transformer was installed at the house at the end of April that directly measures the amount of energy being supplied from the house to the grid. Figure 17 below show the monthly net electric energy usage of both the ZEH and the Baseline House.

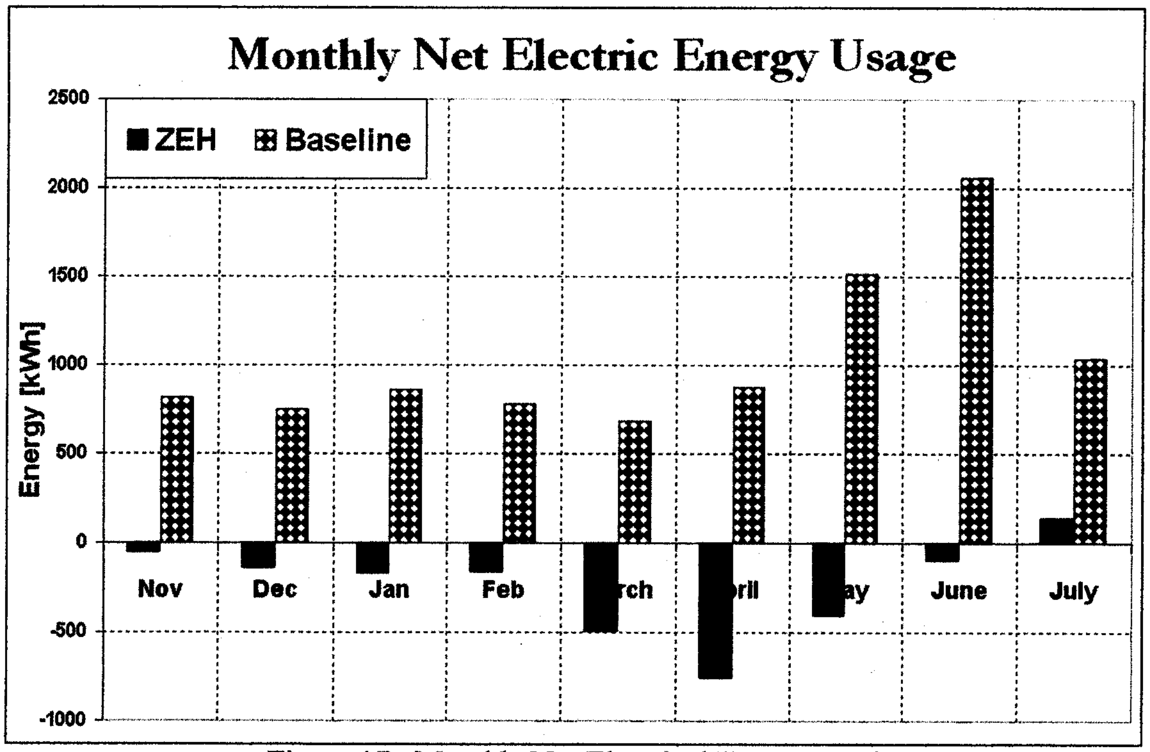

Figure 17. Monthly Net Electrical Energy Used

Negative values indicate that the ZEH produced more energy than it consumed that month. Throughout the heating season, the ZEH was consuming grid energy at its highest amounts, and producing energy at its smallest amounts resulting in a relatively small amount of excess energy produced. During the spring, the amount of grid energy consumed by the ZEH decreased while the amount of PV energy generated increased. The maximum amount of excess energy supplied by the house was 758kWh, and occurred in April. The beginning of summer shows an increase in the amount of grid energy used. This is due to increasing cooling loads corresponding with a leveling off of PV energy generation. July is observed to be the first month where net electrical energy use is positive. Table 4 shows the net amount of energy used by the ZEH for each month, and gives that the total usage to date. The ZEH has generated 2139.97 kWh over what it needed to power itself. This is a promising result that the house will be able make it to zero net usage over a year's time.

Table 4 Monthly Net Electric Energy Consumed by the ZEH

	[kWh]
November	-51.4
December	-142.7
January	-169.7
February	-165
March	-489
April	-758.1
May	-405.54
June	-96.67
July	138.14
Total	-2139.97

Gas Energy

Another important factor to consider in the energy balance of the Zero Energy House is how much gas it consumes. Figure 18 shows how many cubic feet of gas the ZEH and the Baseline House used each month

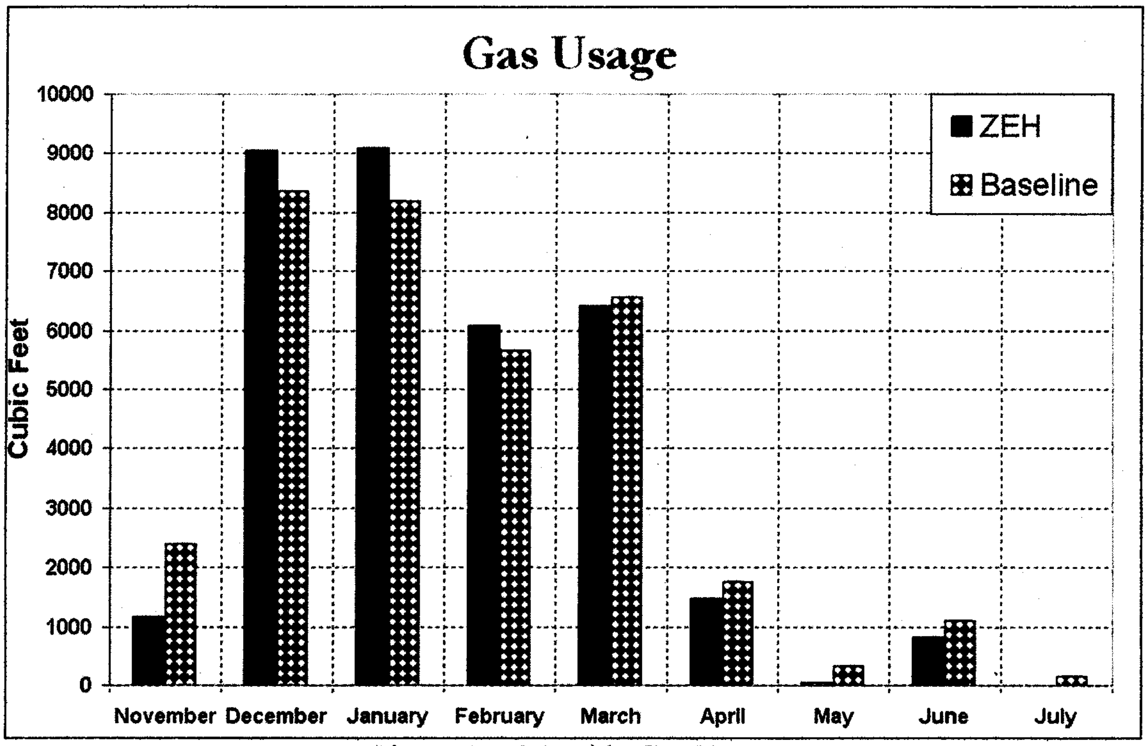

Figure 18. Monthly Gas Usage

During the winter months, the gas use of the ZEH exceeded that of the Baseline House. This came as surprise, and the cause was traced back to problem in the plumbing of the water system that made it so the hydronic heating system could not operate at its design set point.

To convert an amount of gas used in cubic feet to an energy value in kilowatt-hours, the following conversion was used:

$$\#kWh = (\#ft^3)\cdot\left(\frac{1000BTU}{ft^3}\right)\cdot\left(\frac{1kWh}{3412.14BTU}\right) \qquad \text{(Equation 1)}$$

Where 1000 BTU/ ft^3 is the heating value of natural gas. This is the heating value is used to arrive at the conclusion that 1 therm of natural gas (100 ft^3) is equivalent to 100,000 BTU. The real heating value of the gas supplied by the gas company varies by month and depends on the quality of the gas they have at the time. The monthly gas bill accounts for the quality of the gas through their billing factor, a number between 0-1, which usually is around 0.96. The following analysis represents an overestimation of the gas energy used since the ideal heating value is used. Copies of the monthly gas bills were requested, but did not arrive by the time of analysis. Table 5 shows the monthly gas used in cubic feet, and the corresponding energy use in kilowatt-hours.

Table 5 Gas Energy Used by the Baseline House and the ZEH

	ZEH		Baseline	
	Cubic Feet	[kWh]	Cubic Feet	[kWh]
November	1165	341.43	2408	705.72
December	9060	2655.23	8372	2453.59
January	9105	2668.41	8192	2400.84
February	6086	1783.63	5662	1659.37
March	6403	1876.53	6564	1923.72
April	1476	432.57	1762	516.39
May	44	12.90	334	97.89
June	824	241.49	1108	324.72
July	11	3.22	158	46.31

Combining the total gas energy used by the house with the net electric energy used by the house gives the total overall energy used. Figure 19 shows the total monthly overall energy used by both houses. Including the gas energy used changes the net energy usage picture drastically. Rather than only one month being net positive as was the case for the net electric energy, seven out of the nine months monitored are in the positive region indicating that the gas use in the house is far greater than was expected.

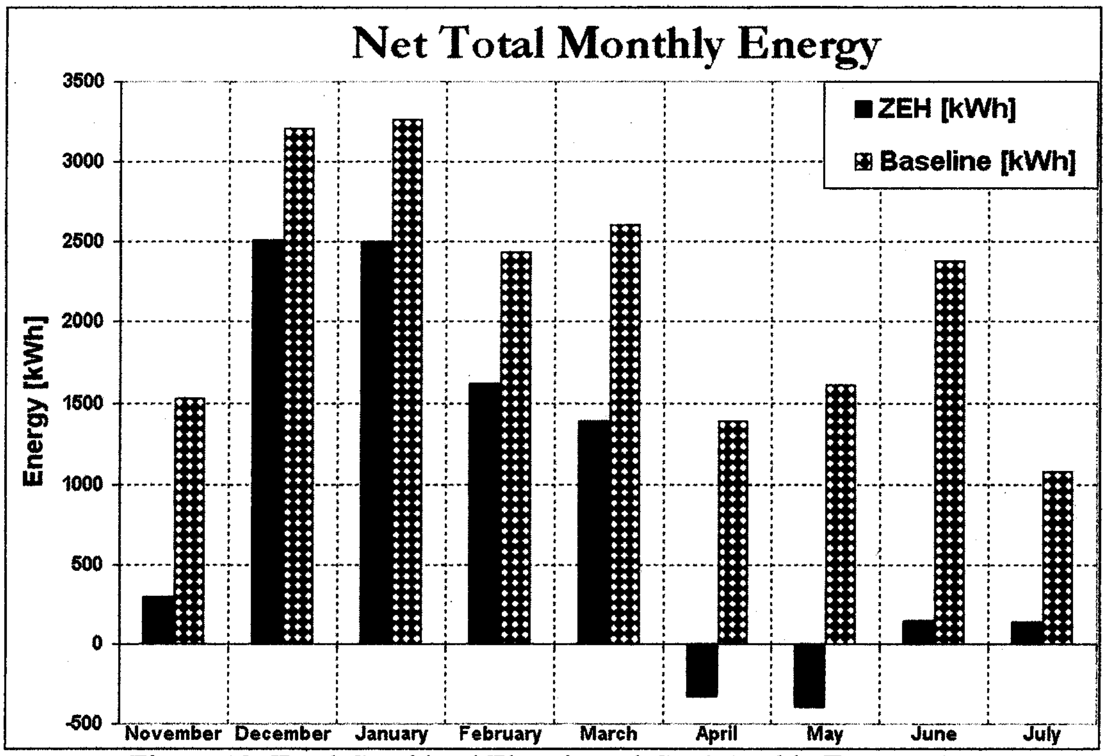

Figure 19. Total Combined Electric and Gas Monthly Energy Use

Adding up the total combined energy usage puts the ZEH at 7,734.08 kWh and the Baseline House at 19,504.12 kWh of energy used. Including the higher than expected gas usage, the ZEH is still using 60% less energy than the Baseline House during this nine-month period.

Peak Energy

Over the course of a year, the amount of power that a power utility is required to supply fluctuates with the amount that their users demand. In times of high demand, the utility has to work hard to maintain adequate supply. Utilities refer to these times as peak time. Here in Las Vegas, Nevada Power defines its peak season from June 1st to September 30th, and its peak hours from 1:00 pm to 7:00 pm. In areas that are experiencing rapid growth, utilities are concerned with their ability to keep up. Zero Energy Home developments are intriguing to them, since a ZEH can generate its own power during those peak times. So the ultimately more people are using power, but the utility will not have to expand as fast as it would if those houses were not zero energy.

So beginning June 1st, the amount of energy being used by both houses during the hours of 1:00 pm and 7:00 pm were recorded. This was accomplished using conditional expressions in Excel to filter this data from the larger set. Table 6 shows how much less peak energy the ZEH has used compared to the Baseline House. Overall the ZEH has used 85.48% less peak energy than the Baseline House.

Table 6 ZEH Percent Savings of Peak Energy Relative to the Baseline House

	[%]
June	88.25
July	79.51
Overall	85.48

Efficiency of the ZEH PV System

The output of the PV array depends on many factors that change frequently. The factors range from the relative location of the sun to the amount clouds in the sky to the temperature of the collector cells. It is common to report the performance of a PV array in terms of efficiency.

PV efficiency is found by taking a ratio of the PV power output to the power incident on the panels. The PV output power is calculated from the energy transducer signal that records the amount of energy generated by the PV system in kilowatt-hours.

The solar power incident on the panels is found by multiplying the area of all the solar cells (39.02 m^2) in the array by the pyranometer signal, which records incident solar radiation (insolation) in watts per meter squared.

The analysis began by finding the average efficiencies of the PV system for every month where data are available (Table 7). A simple Excel file was created that only requires the scaled PV data (already multiplied by the proper factor) and the corresponding raw pyranometer readings. Only times during the day, where the efficiency was not zero, contributed to the average efficiency calculation. Also filtered out of the efficiency computation were efficiency values that were over 20%, since it is so far above the realistic performance expectations of the modules. Values of higher than 20% were seen in the raw data, and this is due to sensitivity issues in the pyranometer. At night when no radiation is incident on the panels, the pyranometer reads negative values, and at twilight times, the pyranometer reads very low positive numbers. Since that signal is on the denominator of the efficiency ratio, efficiency values would get large. These non-sensical points were filtered out in Excel using conditional expressions.

Table 7 Average Monthly Efficiency of the ZEH PV System

	[%]
November	10
December	9.89
January	10.23
February	9.89
March	9.92
April	9.76
May	8.94
June	8.66
July*	8.73

*Data available for the part of the month only

Figure 20 shows a series of plots for a typical day in June. Figure 20(A) plots the temperature of the PV array against the efficiency. Figure 20(B) plots the efficiency against the ambient temperature, and the quality of the solar radiation on is demonstrated in Figure 20(C). Large variations in the insolation signal are due to cloud cover. When the insolation is disrupted, the effect is observed instantly in the PV output signal.

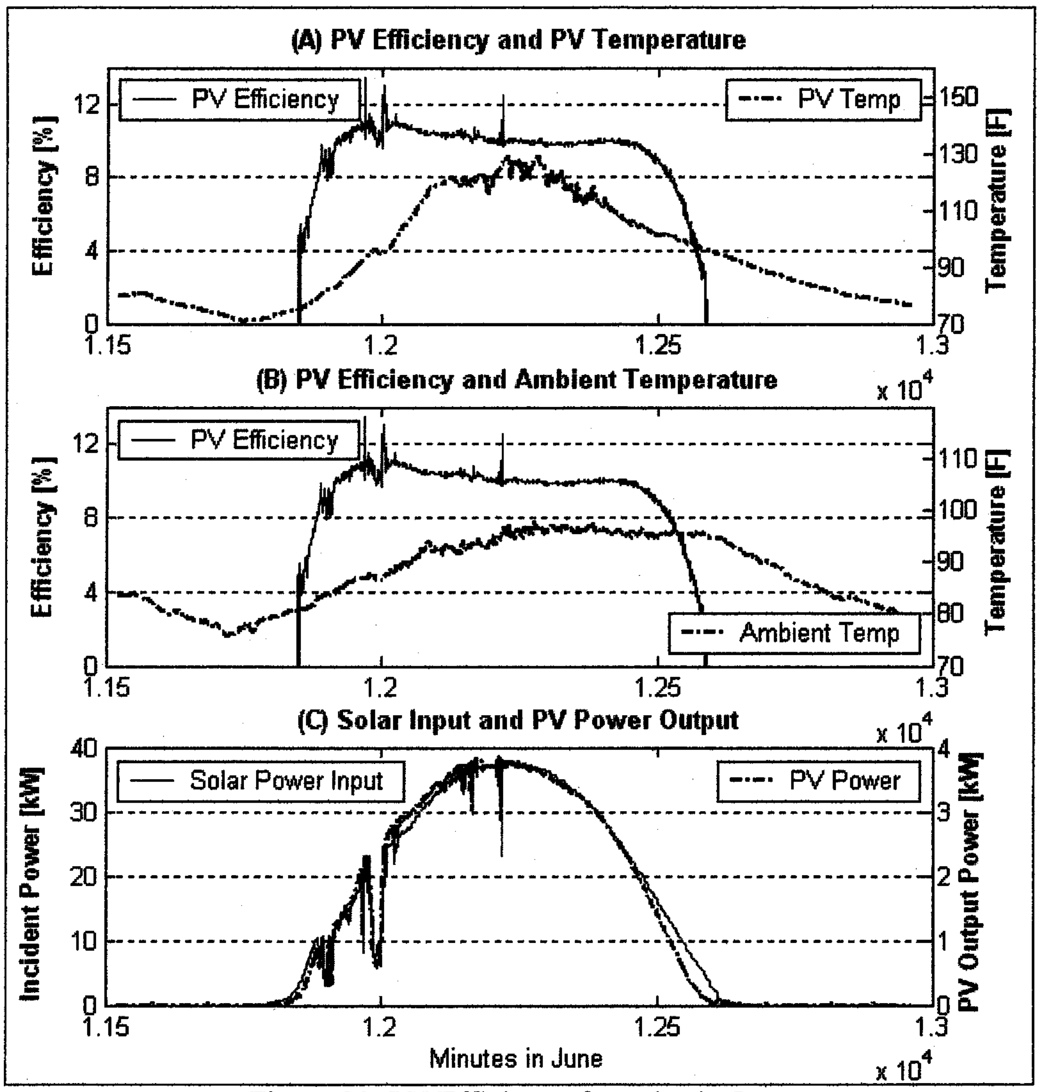

Figure 20. PV Efficiency for a day in June

In Figure 20(A), it can be seen that the efficiency of the PV array decreases with increasing array temperature. The PV array reaches a maximum power output of just under 4 kW. The system is rated at 4.8 kW peak. Figure 20(B) shows the efficiency plotted against the ambient temperature. Again, a noticeable decrease in efficiency is observed as the ambient temperature increases. Also, as the ambient temperature starts to level off just under 100°F, the efficiency also begins to level off. The PV array temperature peaks and begins to decrease at the same time as the inflection points occur on the efficiency plot.

The same analysis was done for the first week in December when the ambient temperatures ranged from 40°F to the low 70's (Figure 21).

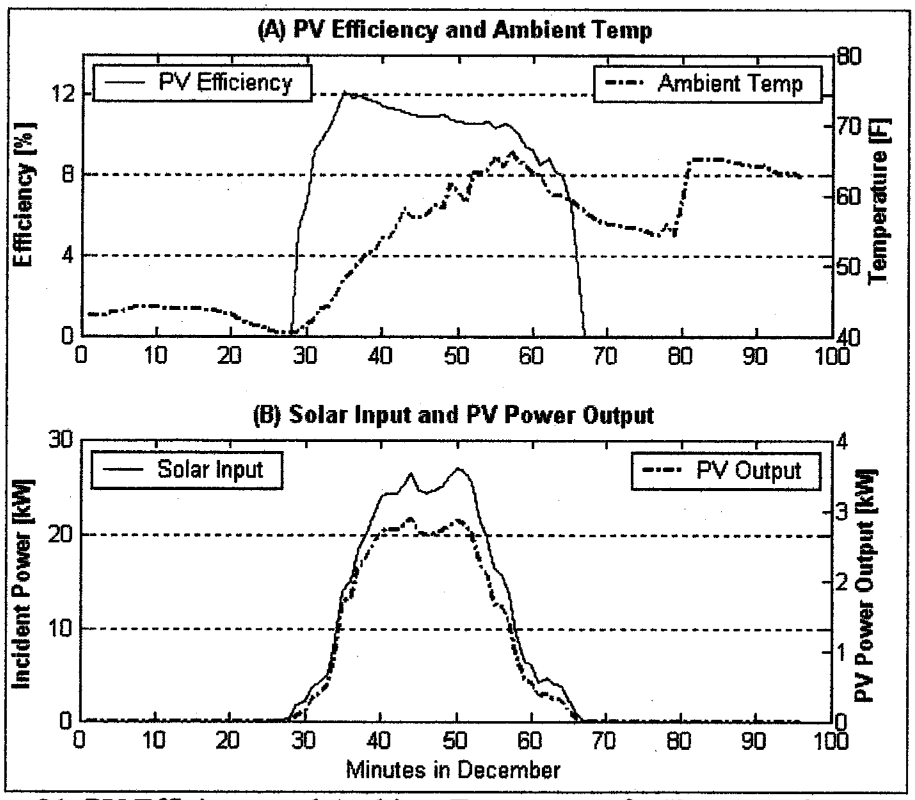

Figure 21. PV Efficiency and Ambient Temperature for Two Days in December

The efficiencies (10-12%) are slightly higher than they were in June, though the power output, around 3kW, is lower. Again the efficiency decreases with increased ambient temperature. Efficiencies determined are consistent with expected efficiencies of PV panels of this type.

A Matlab program was written to carry out the analysis. The raw monthly data file generated by Loggernet is the only required input. The program breaks the data file up into the individual sensor readings, applies any necessary conversion factor and stores the columns as useful array type variables with easy to understand names. The program can easily be expanded as further data reduction and analysis is required. A copy of the ZEH program is included in the appendices.

Condenser Energy Comparison

The most significant load that the houses experience is due to air conditioning. The ZEH uses a 3-ton Freus evaporative condenser, while the Baseline House uses a more conventional air-cooled condenser. Table 8 shows how much less energy the unit at the ZEH has used compared to the one at the Baseline.

Table 8 ZEH Condenser Percent Savings from the Baseline Condenser

	[%]
June	65.0
July	63.8
Overall	64.5

It is observed that the Freus unit has performed very well during the first couple of months of the cooling season. It used 65% less energy in June compared to the condenser in the Baseline House, and so far has used 63.8% less in July. Overall it has used a total of 64.5% less energy than the Baseline condenser. Water usage is a factor as well when considering evaporative condensers, and thus far, the condenser does use a lot of water, 2,395 gallons in nearly two months of operation.

CHAPTER 4

DATA DISPLAY

Posting Real-Time Data on the Internet.

The software being used to generate real-time data plots is called RTDM and is made by Campbell Scientific and integrates seamlessly with the other Campbell Scientific applications used throughout this project. RTDM stands for Real Time Data Monitoring. RTDM utilizes two modes in order to generate plots. The first is a design mode, where all the necessary plotting parameters are defined, and the second is the Runtime mode, which executes the programs and ultimately generates the plots and outputs them to the web directory where they can be displayed on the Internet.

RTDM Designer Mode

The RTDM Designer Mode is the starting place for creating a new 'form' or data display. A standard installation of the Campbell Scientific RTDM version 2 software places the program in the directory: C:\Programs\RTDM v2\RTDM v2 Designer. Once the program is running, a new form can be created by clicking on File | New Form. The form is given a default name of Form 1 within Project 1. The interface of the program (Figure 22) is very similar to that of many typical Windows applications.

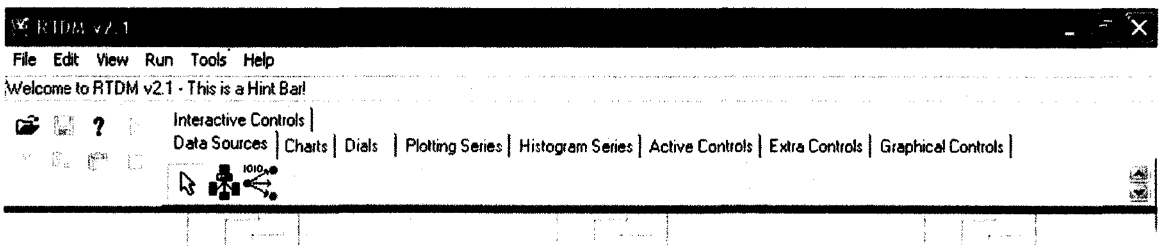

Figure 22. Graphical User Interface of the RTDM Software

A separate window, called the Object Inspector also opens when a new form is created. The Object Inspector is a valuable tool that makes changing object parameters and settings very simple.

The next step is to specify the type of chart to be displayed. The types of charts available are CSL charts, Table Displays, and Strip Charts (Strip Charts were mainly used on the ZEH Project). Selecting a chart type places a blank adjustable rectangle on the new form space. Within this rectangle is the area where the generated plot(s) will reside.

To easily display multiple charts in one project, a Graphical Control called a "CSL TabbedNoteBook" can be inserted into the project. This places all the different charts on their own clearly labeled tab as seen in Figure 23 below.

Once a plot type is selected, an input source must be defined. RTDM allows for two types of input sources: a Logger Source, or a File Source. A Logger Source retrieves data from a logger network using the LoggerNet application. A File Source retrieves data from the raw data file of a particular logger. RTDM only supports ASCII comma delimited files. File Sources were used exclusively to generate plots for the ZEH Project.

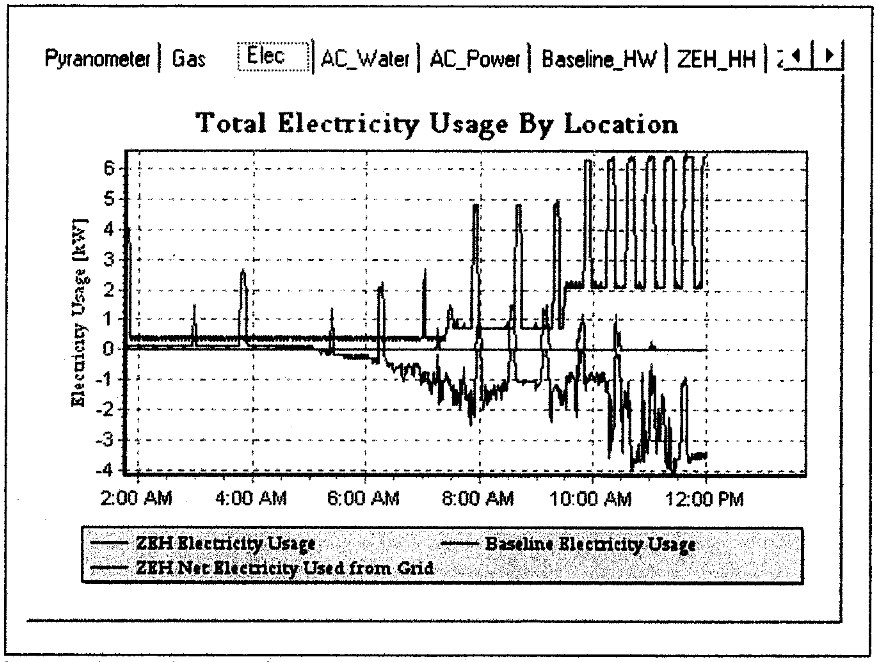

Figure 23. Multiple Charts Displayed with on a CSL TabbedNoteBook

To function properly, the File Source needs to be given the name of a data file, and an interval over which to check the data file for changes. It is possible to specify that the source file be read from where it previously left off, and how many bytes of data it is to read. The data files used in the ZEH Project are called Baseline.dat and ZEH_final_storage_1.dat. Also required are the corresponding Final Storage Label (FSL) files: ZEBASE03.fsl and ZEHOME01revision01.fsl respectively. FSL files hold the names of all the sensors that are being recorded by a datalogger. The interval at which the File Source checks the data file for updates is 120 seconds.

Under the Plot Definitions tab in the File Source Editor, it is possible to apply mathematical and conditional expressions to the plots of the raw data file. An example is shown in Figure 24 below. The signal COUNT_2_TOT is recording how much energy has been generated by the PV array at the ZEH in pulses. The signal is recorded by a 30-

amp current transformer (units of 1333.33 pulses/kilowatt-hour) and sampled by the datalogger every minute. It is referenced in the data array as \$45, similar to the way a spreadsheet program like Microsoft Excel references columns. Equation 2 is used to generate a plot of the power, in kilowatts, produced by the ZEH PV system.

$$Power[kW] = (\#Pulses) \cdot \left(\frac{1kWh}{1333.33Pulses}\right) \cdot \left(\frac{1}{\min}\right) \cdot \left(\frac{60\min}{hour}\right) \qquad \text{(Equation 2)}$$

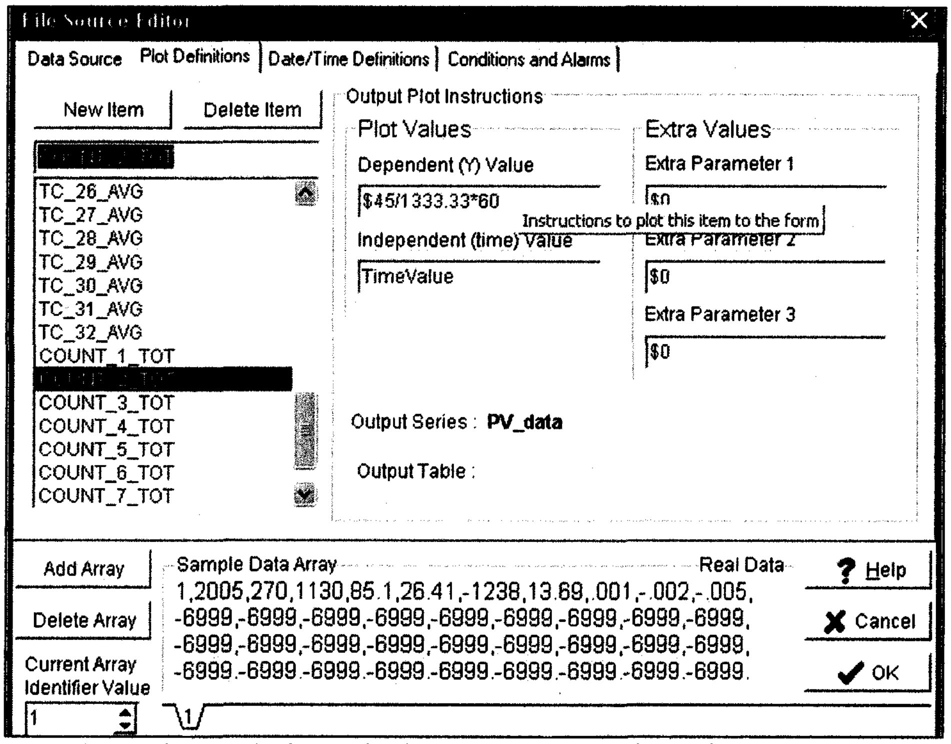

Figure 24. Applying Mathematical Expressions to Plots of Raw Data in RTDM

Now a plotting series must be designated. A number of different plotting series are available (i.e. Line Series, Bar Series or Point Series), but Line Series were used to represent the ZEH Project data. When a plotting series is selected, an icon appears on the graph that will be the series of data that will be plotted. Clicking on that icon allows one to select a specific signal under associated with a specific source file. With Line Series plots, it is assumed by the RTDM that time is the independent axis.

The plot is now fully defined, and all the objects associated with the plot can be named and formatted to the user's content. This is done using the Object Inspector window. Clicking on an object automatically makes that object current in the Object Inspector, and all the properties of that object can be changed in that window.

RTDM has the capability to automatically save JPEG (*.jpg), GIF (*.gif), Bitmap (*.bmp) or Portable Network Graphics (*.png) files created from portions of a form through its Snapshot feature.

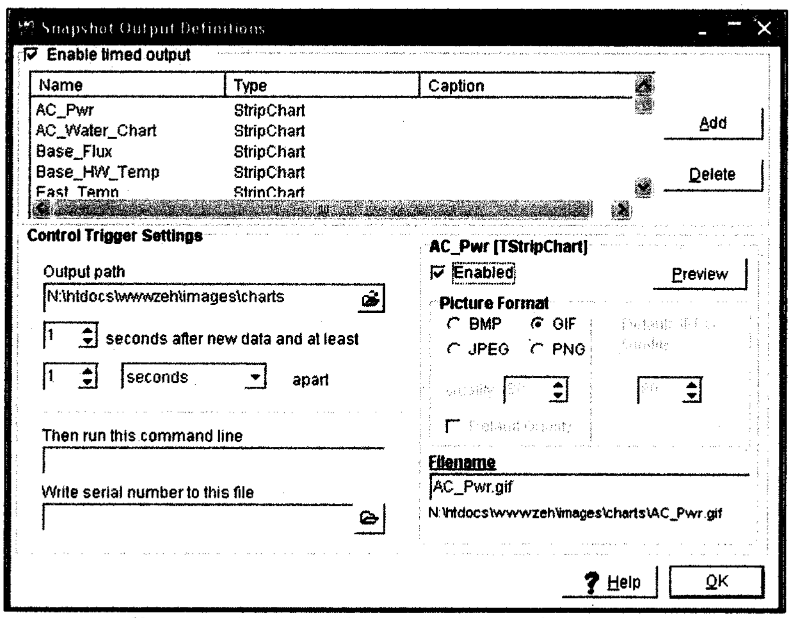

Figure 25. Snapshot Output Dialogue Box

This feature is found on the RTDM toolbar under Extra Controls. This is the feature that allows for the images on the ZEH Project website to update with current 'real-time' data. As new data becomes available, RTDM updates the graphs by reading the most recently added data. As the graphs change, Snapshot takes an updated picture of that chart and sends it to the ZEH web directory as an image file. Figure 25 above shows an example of the Snapshot dialogue box. It makes an image file called AC_Pwr.gif of the AC_Pwr StripChart one second after new data becomes available and then sends that file to the web directory N:\htdocs\wwwzeh\images\charts.

Zero Energy House Website

The University of Nevada, Las Vegas is part of the Nevada Southwest Energy Partnership. The National Renewable Energy Laboratory coordinates and supports many of the projects undertaken by NSWEP. To organize all the NSWEP related projects, NREL has adopted a bottom up approach for creating the greater NSWEP web site. In this method, individual project sites are developed first, and then an all-encompassing site that ties them together will be developed at a later time. Basic template files where provided by NREL when the project began so the site would have a style consistent with other NSWEP project sites.

The Zero Energy House Project website (www.zeh.unlv.edu) contains all the information about the project including times the house is open to visit, summaries of the energy saving features, project sponsors and "real time" data.

software is programmed to collect new data every hour from both the ZEH and Baseline House. The graphs generated by RTDM are formatted to display that data in a 12-hour window. The information is currently being displayed in a number of clearly labeled graphs. The pages automatically refresh every five minutes to ensure new data is displayed if a user in on a page during a collection time.

The data is being displayed under the 'Real Time Data' link on the side menu. Clicking on that takes you to a page where the site conditions (ambient temperature, relative humidity and incident solar radiation) are being displayed. The PV generation is plotted on a second y-axis on the same chart as the pyranometer readings since the two are inherently connected.

Along the top of this first page, a new tab menu (Figure 26) was created that organizes the other displays into various general categories, i.e. energy use, gas use, temperatures, heat fluxes and water systems.

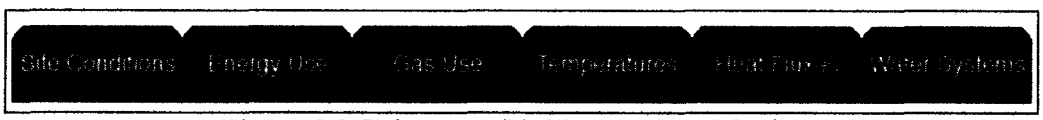

Figure 26. Tab Menu Linking to Data Displays

The Energy Use page consists of six graphs. The first is a comparison of the Total Net Electricity Usage of both the ZEH and the Baseline House for a 12-hour period. The next is the same plot extended over a 24-hour period. When the ZEH signal on this graph goes negative, that indicates that the house is producing more electricity than it is using. This plot updates automatically every hour.

The next three graphs are bar charts created in Microsoft Excel. They are monthly summaries of the grid energy used by both houses, the energy generated by the ZEH PV system and the net energy used by both houses. They are the same as Figures 15-17 in Chapter 3. Being monthly summaries, these plots are managed manually and updated a few times a month.

The fifth plot automatically updates every hour and it contrasts the amount of power being used by the air conditioners of each house.

The Gas Use page is only one graph that gives a monthly breakdown of the gas use at both houses. The graph is identical to Figure 18 in Chapter 3.

The Temperatures page compares the internal and external temperature readings of corresponding walls of the two houses.

The Heat Fluxes page has two plots that display the heat flux readings of all four walls for each house separately.

The Water Systems Page has four plots showing the Baseline hot water heater inlet and outlet temperature, the ZEH on demand water heater inlet and outlet temperatures, the Solar Water Heater inlet and outlet temperatures, and the Hydronic Heating coil inlet and outlet temperatures.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary and Conclusions

The ZEH project in Las Vegas is part of the Department of Energy's Building America ZEH initiative. As part of NSWEP, the University of Nevada, Las Vegas received funding through NREL to develop and monitor a Zero Energy House. Pinnacle Homes agreed to build the house a let monitoring take place for 18 months. They also devoted a house with conventional construction (the Baseling House) of the same basic floor plan for comparative evaluation. The goal of the project is to optimize the design of a ZEH in the Las Vegas area by monitoring and analysis.

Over the past nine months of monitoring, the ZEH has performed extremely well in regards to its electrical energy consumption. The house has produced over 2,000 kWh of excess electricity and used 85% less peak energy than the Baseline House. July is the first month thus far where the energy used by the house is greater than the amount being supplied by the PV. This trend is expected to follow through August and possibly into September. It is quite possible that the house will come close to achieving zero net electric energy consumption for this year. Most of the literature on zero energy houses seems to imply that net zero electrical energy is synonymous with zero energy.

When the amount of gas used in the house was converted to energy use and added to the electrical energy use, the house became a net consumer of energy. The ZEH employs a hydronic heating system, where hot water, heated by the on demand gas fired tankless water heater, is used to heat the house. The design of the water system called for the on demand water heater to supply 140°F water to the hydronic coil. Due to an oversight in the plumbing, the water heater could not be set that high because the domestic hot water supply and the hydronic supply were being drawn from the same line. Supplying domestic hot water at 140°F is dangerous so the set point on the water heater had to be set to a safer value of 110°F.

As a result, the hydronic coil was being supplied with 110°F water rather than its design 140°F water. This caused longer and less effective heating cycles which led to the larger than expected use of gas.

During the winter season, the valve closing off the solar water heater loop was left open; meaning cold water from the solar water heater tank was being supplied to the water heater. During cold nights, it is possible that the water being supplied to the water heater was colder than what normal city water would have been, which also would require an unnecessary amount of gas to be consumed to compensate.

The problem with the piping has been addressed by Pinnacle Homes. A mixing valve was added to the domestic hot water supply line and the water heater was raised to its set point. A check valve was placed in the solar water heater loop, and the plumbing was insulated. Figure 27 shows a before and after picture of the heating system. The photo on the right is highlighting the mixing valve that was installed which makes it possible to set the heater at the design set point.

These changes along with cutting off the solar loop should result in a reduction of the gas use next heating season.

Figure 27. Water Heater Plumbing: Before and After Missing Part Installation

This project does represent a triumph of collaboration and partnership; a lot of different people from government, academia and industry came together to make it happen. Transition from the design and construction phase to the monitoring and analysis phase of the project brought with it a change of personnel. A result of that transition was that the signal verification, a key component of the project, was slow to take place. Problems with sensors are inevitable when so many are used, but many problems experienced could have been easily avoided had a more rigorous and methodical sensor verification process taken place at the end of construction.

Sensor verification took place; the forms are included in the appendices. Uncertainties still remain in my mind about the validity of the heat flux signals. They exhibit a lot of noisy behavior. A student has designed a circuit to filter the noise, but it unclear what degree of accuracy in the signal this will bring.

Recommendations

Future developments of the project I recommend would be integrating the functionality of the WebGet software into the project website. This would make it possible for highly interested users to explore the project data on their own while keeping the site informative for more casual users.

It would also be beneficial to find a way to automate the monthly summary portions of our web displays. Currently updates are done manually every couple of weeks. The process is simple but time consuming. Having dynamic archiving similar to the daily, weekly, monthly and yearly displays on the Fat Spaniel systems would free up more time for data reduction and analysis.

APPENDIX

Datalogger Programs

Third Version of the Baseline Program:

```
;{CR10X}
; PROGRAM NAME: ZEBASE03.csi
; CREATED BY: Paragon Consulting Services 909-596-9626.
; APPLICATION: Designed for Pinnacle Homes Zero Energy Home Project, Baseline
Home Site.
; WIRING DIAGRAM FILENAME: "ZEH Wiring Schedule v2005 0912.xls"
; REVISION HISTORY:
; 9/12/05 - Version1 Created.2
; 4/31/06 - Version2 Created: Collection interval changed from 15 minutes to 1 minute.
; 4/07/06 - Version3 Incorporated South Wall Heat Flux for DIFF Channel 2.
;***********************************************************************
; MAIN CODE STARTS HERE
;***********************************************************************
*Table 1 Program
 01: 60        Execution Interval (seconds)
; READ HEAT FLUXES (Btu Hr/Ft2)
; South Wall
1:  Volt (Diff) (P2)
 1: 1       Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 2       DIFF Channel
 4: 1       Loc [ HF_2  ]
 5: 1.0      Mult
 6: 0.0      Offset
; East Wall
2:  Volt (Diff) (P2)
 1: 1       Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 3       DIFF Channel
 4: 2       Loc [ HF_3  ]
 5: 1.0      Mult
 6: 0.0      Offset ;
; West Wall
```

```
3:  Volt (Diff) (P2)
 1: 1        Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 4        DIFF Channel
 4: 3        Loc [ HF_4  ]
 5: 1.0      Mult
 6: 0.0      Offset
; Low Ceiling
4:  Volt (Diff) (P2)
 1: 1        Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 5        DIFF Channel
 4: 4        Loc [ HF_5  ]
 5: 1.0      Mult
 6: 0.0      Offset
; High Ceiling
5:  Volt (Diff) (P2)
 1: 1        Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 6        DIFF Channel
 4: 5        Loc [ HF_6  ]
 5: 1.0      Mult
 6: 0.0      Offset
; READ AM16/32 THERMOCOUPLES TYPE-J (Farenheit Degrees)
; Establish Reference Temperature for Thermocouple Measurements
6:  Internal Temperature (P17)
 1: 6        Loc [ RefTempC  ]
; Activate AM16/32
7:  Do (P86)
 1: 44       Set Port 4 High
; Start Reading Thermocouples, TC1 through TC32
8:  Beginning of Loop (P87)
 1: 0        Delay
 2: 19       Loop Count
9:  Do (P86)
 1: 75       Pulse Port 5
10:  Excitation with Delay (P22)
 1: 1        Ex Channel
 2: 1        Delay W/Ex (units = 0.01 sec)
 3: 100      Delay After Ex (units = 0.01 sec)
 4: 0000     mV Excitation
11:  Thermocouple Temp (DIFF) (P14)
 1: 1        Reps
 2: 2        7.5 mV Slow Range
 3: 1        DIFF Channel
```

```
 4: 4       Type J (Iron-Constantan)
 5: 6       Ref Temp (Deg. C) Loc [ RefTempC  ]
 6: 11    -- Loc [ TC_1  ]
 7: 1.8     Mult
 8: 32      Offset
12:  End (P95) ;
;Deactivate Multiplexer
13:  Do (P86)
 1: 54      Set Port 4 Low
; READ SDM-SW8A PULSE COUNT MODULE
14:  SDM-SW8A (P102)
 1: 7       Reps
 2: 0       SDM Address
 3: 2       Counts function
 4: 1       SDM-SW8A Starting Channel
 5: 30      Loc [ COUNT_1 ]
 6: 1.0     Mult
 7: 0.0     Offset
; READ WATER HEATER FLOW METER (PULSE COUNT)
15:  Pulse (P3)
 1: 1       Reps
 2: 2       Pulse Channel 2
 3: 2       Switch Closure, All Counts
 4: 37      Loc [ WTRHTFLOW ]
 5: 1.0     Mult
 6: 0.0     Offset
; *****LOGGING ONTO FINAL STORAGE MEMORY (1-MINUTE INTERVALS)
16:  If time is (P92)
 1: 0000    Minutes (Seconds --) into a
 2: 1       Interval (same units as above)
 3: 10      Set Output Flag High (Flag 0)
; ** Record Logger Software Revision Here As Array ID
17:  Set Active Storage Area (P80)^9724
 1: 1       Final Storage Area 1
 2: 1       Array ID
18:  Real Time (P77)^22575
 1: 1110    Year,Day,Hour/Minute (midnight = 0000)
; Store Averaged Values for CR10X Input Channels Data
; HF_2, HF_3, HF_4, HF_5, HF_6
19:  Average (P71)^4340
 1: 5       Reps
 2: 1       Loc [ HF_2  ]
; Store Averaged Values for AM16/32 Thermocouples
20:  Average (P71)^23202
 1: 19      Reps
```

```
 2: 11      Loc [ TC_1  ]
; Totalize Pulse Counts for SDM-SW8A Input Channels Data
21:  Totalize (P72)^6462
 1: 7       Reps
 2: 30      Loc [ COUNT_1  ]
; Totalize AC Condenser Water Flow Meter
22:  Totalize (P72)^1661
 1: 1       Reps
 2: 37      Loc [ WTRHTFLOW ]
*Table 2 Program
 02: 0.0000    Execution Interval (seconds)
*Table 3 Subroutines
End Program
```

Second Variation of the ZEH Program

```
;{CR10X}
; PROGRAM NAME: ZEHOME01revision1.csi
; CREATED BY:  Paragon Consulting Services 909-596-9626.
; APPLICATION:  Designed for Pinnacle Homes Zero Energy Home Project.
; WIRING DIAGRAM FILENAME:  "ZEH Wiring Schedule v2005 0912.xls"
; REVISION HISTORY:
; 9/12/05 - Version1 Created.
; 3/31/06 - Version2 Created: average data over 1-minute interval rather than 15-min
;*************************************************************************
; MAIN CODE STARTS HERE
;*************************************************************************
*Table 1 Program
 01: 60      Execution Interval (seconds)
; READ AMBIENT TEMPERATURE (Fahrenheit Degrees)
1:  Volt (SE) (P1)
 1: 1       Reps
 2: 5       2500 mV Slow Range
 3: 11       SE Channel
 4: 1       Loc [ AmbT_F ]
 5: 0.18     Mult
 6: -40      Offset
; READ RELATIVE HUMIDITY (Percentage)
2:  Volt (SE) (P1)
 1: 1       Reps
 2: 5       2500 mV Slow Range
 3: 12       SE Channel
 4: 2       Loc [ RH_P  ]
 5: 0.1      Mult
 6: 0.0      Offset
```

```
; Limit Relative Humidity to 100%
3:  If (X<=>F) (P89)
 1: 2       X Loc [ RH_P  ]
 2: 3       >=
 3: 100      F
 4: 30      Then Do
4:  Z=F (P30)
 1: 100      F
 2: 0       Exponent of 10
 3: 2       Z Loc [ RH_P  ]
5:  End (P95)
; READ PYRANOMETER (Watts/m2)
6:  Volt (Diff) (P2)
 1: 1       Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 2       DIFF Channel
 4: 3       Loc [ SI_Wm2  ]
 5: 200      Mult
 6: 0.0      Offset
; READ Wind Speed (MPH)
7:  Pulse (P3)
 1: 1       Reps
 2: 1       Pulse Channel 1
 3: 21       Low Level AC, Output Hz
 4: 4       Loc [ WS_mph   ]
 5: 1.677    Mult
 6: 0.4      Offset
; READ HEAT FLUXES (Btu Hr/Ft2)
; South Wall
8:  Volt (Diff) (P2)
 1: 1       Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 3       DIFF Channel
 4: 5       Loc [ HF_3  ]
 5: 1.0      Mult
 6: 0.0      Offset
; West Wall
9:  Volt (Diff) (P2)
 1: 1       Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 4       DIFF Channel
 4: 6       Loc [ HF_4  ]
 5: 1.0      Mult
 6: 0.0      Offset ;
; High Ceiling
```

```
10:  Volt (Diff) (P2)
 1: 1        Reps
 2: 23       25 mV 60 Hz Rejection Range
 3: 5        DIFF Channel
 4: 7        Loc [ HF_5  ]
 5: 1.0      Mult
 6: 0.0      Offset
; READ AM16/32 THERMOCOUPLES TYPE-J (Farenheit Degrees)
; Establish Reference Temperature for Thermocouple Measurements
11:  Internal Temperature (P17)
 1: 8        Loc [ RefTempC  ]
; Activate AM16/32
12:  Do (P86)
 1: 44       Set Port 4 High
; Start Reading Thermocouples, TC1 through TC32
13:  Beginning of Loop (P87)
 1: 0        Delay
 2: 32       Loop Count
14:  Do (P86)
 1: 75       Pulse Port 5
15:  Excitation with Delay (P22)
 1: 1        Ex Channel
 2: 1        Delay W/Ex (units = 0.01 sec)
 3: 100      Delay After Ex (units = 0.01 sec)
 4: 0000     mV Excitation
16:  Thermocouple Temp (DIFF) (P14)
 1: 1        Reps
 2: 2        7.5 mV Slow Range
 3: 1        DIFF Channel
 4: 4        Type J (Iron-Constantan)
 5: 8        Ref Temp (Deg. C) Loc [ RefTempC  ]
 6: 9      -- Loc [ TC_1  ]
 7: 1.8      Mult
 8: 32       Offset
17:  End (P95) ;
;Deactivate Multiplexer
18:  Do (P86)
 1: 54       Set Port 4 Low
; READ SDM-SW8A PULSE COUNT MODULE
19:  SDM-SW8A (P102)
 1: 8        Reps
 2: 0        SDM Address
 3: 2        Counts function
 4: 1        SDM-SW8A Starting Channel
 5: 41       Loc [ COUNT_1  ]
```

```
 6: 1.0     Mult
 7: 0.0     Offset
; READ AC CONDENSER WATER FLOW METER (PULSE COUNT)
20: Pulse (P3)
 1: 1       Reps
 2: 2       Pulse Channel 2
 3: 2       Switch Closure, All Counts
 4: 49      Loc [ ACWTRFLOW ]
 5: 1.0     Mult
 6: 0.0     Offset
; *****LOGGING ONTO FINAL STORAGE MEMORY (1-MINUTE INTERVALS)
21: If time is (P92)
 1: 0000    Minutes (Seconds --) into a
 2: 1       Interval (same units as above)
 3: 10      Set Output Flag High (Flag 0)
; ** Record Logger Software Revision Here As Array ID
22: Set Active Storage Area (P80)^16135
 1: 1       Final Storage Area 1
 2: 1       Array ID
23: Real Time (P77)^5257
 1: 1110    Year,Day,Hour/Minute (midnight = 0000)
; Store Averaged Values for CR10X Input Channels Data
; AmbT_F, RH_P, SI_Wm2, WS_mph, HF_3, HF_4, HF_5
24: Average (P71)^15753
 1: 7       Reps
 2: 1       Loc [ AmbT_F   ]
; Store Averaged Values for AM16/32 Thermocouples
25: Average (P71)^1351
 1: 32      Reps
 2: 9       Loc [ TC_1  ]
; Totalize Pulse Counts for SDM-SW8A Input Channels Data
26: Totalize (P72)^24846
 1: 8       Reps
 2: 41      Loc [ COUNT_1 ]
; Totalize AC Condenser Water Flow Meter
27: Totalize (P72)^25203
 1: 1       Reps
 2: 49      Loc [ ACWTRFLOW ]
*Table 2 Program
 02: 0.0000    Execution Interval (seconds)
*Table 3 Subroutines
End Program
```

Updated ZEH Data Acquisition Wiring Diagrams

CR10X Datalogger

	G	G	
#56 Pyranometer (clear)	G	G	
AM16/32 (COM:ODD H)	1H	4H	#41 W Wall Heat Flux (+)
AM16/32 (COM:ODD L)	1L	4L	#41 W Wall Heat Flux (-)
	AG	AG	
#56 Pyranometer (red)	2H	5H	#43 High Ceiling Heat Flux (+)
#56 Pyranometer (black)	2L	5L	#43 High Ceiling Heat Flux (-)
#56 Pyranometer (white)	AG	AG	
#39 S Wall Heat Flux (+)	3H	6H	#57 Amb Temp & RH Probe (black)
#39 S Wall Heat Flux (-)	3L	6L	#57 Amb Temp & RH Probe (brown)
	AG	AG	
	E1	E3	
	AG	AG	
	E2	G	#57 Amb Temp & RH Probe (green)
#55 Wind Speed (Clear)	G	G	#57 Amb Temp & RH Probe (clear)
#55 Wind Speed (Black)	P1	5V	
#55 Wind Speed (White)	G	5V	
#48 AC Condenser Water Flow Meter (Pulse Out)	P2	G	
#48 AC Condenser Water Flow Meter (-)	G	SW 12V	
	C8	SW 12V	
	C7	G	
	C6		
AM16/32 (CLK)	C5		
AM16/32 (RES)	C4		
SDM-SW8A (C3)	C3		
SDM-SW8A (C2)	C2		
SDM-SW8A (C1 IN)	C1		
SDM-SW8A (GND)	G		
#48 AC Condenser Water Flow Meter (12V Supply Power)	12V		
#57 Amb Temp & RH Probe (red)	12V		

		AM16/32 Analog Multiplexer (Type J Thermocouples)			
#20 Floor Living Room 3' Below Slab TC (red)	16L	SET8	SET16	32L	#37 AC Condenser Water Temperature TC (red)
#20 Floor Living Room 3' Below Slab TC (white)	16H			32H	#37 AC Condenser Water Temperature TC (white)
#19 Floor Living Room 1' Below Slab TC (red)	15L			31L	#36 Outside Ground Temperature TC (red)
#19 Floor Living Room 1' Below Slab TC (white)	15H			31H	#36 Outside Ground Temperature TC (white)
	SHIELD			SHIELD	
#18 Floor Living Room 4" Deep TC (red)	14L	SET7	SET15	30L	#35 Hydronic Heating Output TC (red)
#18 Floor Living Room 4" Deep TC (white)	14H			30H	#35 Hydronic Heating Output TC (white)
#17 Floor Living Room 1/2" Deep TC (red)	13L			29L	#34 Hydronic Heating Input TC (red)
#17 Floor Living Room 1/2" Deep TC (white)	13H			29H	#34 Hydronic Heating Input TC (white)
#12 Floor S Wall 3' Below Slab TC (red)	12L	SET6	SET14	28L	#33 Solar Hot Water Heater Output TC (red)
#12 Floor S Wall 3' Below Slab TC (white)	12H			28H	#33 Solar Hot Water Heater Output TC (white)
#11 Floor S Wall 1' Below Slab TC (red)	11L			27L	#32 Solar Hot Water Heater Input TC (red)
#11 Floor S Wall 1' Below Slab TC (white)	11H			27H	#32 Solar Hot Water Heater Input TC (white)
	SHIELD			SHIELD	
#10 Floor S Wall 4" Deep TC (red)	10L	SET5	SET13	26L	#31 PV Low TC (red)
#10 Floor S Wall 4" Deep TC (white)	10H			26H	#31 PV Low TC (white)
#9 Floor S Wall 1/2" Deep TC (red)	9L			25L	#30 PV High TC (red)
#9 Floor S Wall 1/2" Deep TC (white)	9H			25H	#30 PV High TC (white)
#8 W Exterior Wall TC (red)	8L	SET4	SET12	24L	#29 Water Heater Output TC (red)
#8 W Exterior Wall TC (white)	8H			24H	#29 Water Heater Output TC (white)
#7 E Interior Wall TC (red)	7L			23L	#28 Water Heater Input TC (red)
#7 E Interior Wall TC (white)	7H			23H	#28 Water Heater input TC (white)
	SHIELD			SHIELD	
#6 S Exterior Wall TC (red)	6L	SET3	SET11	22L	#27 Return Air Temperature TC (red)
#6 S Exterior Wall TC (white)	6H			22H	#27 Return Air Temperature TC (white)
#5 N Exterior Wall TC (red)	5L			21L	#26 Air Temperature By Thermostat TC (red)
#5 N Exterior Wall TC (white)	5H			21H	#26 Air Temperature By Thermostat TC (white)
	COM:EVEN L			COM:ODD L	**CR10X (1L)**
	SHIELD			SHIELD	**CR10X (G)**
	COM:EVEN H			COM:ODD H	**CR10X (1H)**
#4 W Interior Wall TC (red)	4L	SET2	SET10	20L	#25 Long Run from AC TC (red)
#4 W Interior Wall TC (white)	4H			20H	#25 Long Run from AC TC (white)
#3 E Exterior Wall TC (red)	3L			19L	#24 Short Run from AC TC (red)
#3 E Exterior Wall TC (white)	3H			19H	#24 Short Run from AC TC (white)
	SHIELD			SHIELD	
#2 S Interior Wall TC (red)	2L	SET1	SET9	18L	#23 High Attic TC (red)
#2 S Interior Wall TC (white)	2H			18H	#23 High Attic TC (white)
#1 N Interior Wall TC (red)	1L			17L	#21 S Exterior Wall (red)
#1 N Interior Wall TC (white)	1H			17H	#21 S Exterior Wall (white)
				12V	**Power Supply 12V**
				GND	**Power Supply GND**
				RES	**CR10X (C4)**
				CLK	**CR10X (C5)**

AM16/32 Mode = "2 x 32"

Means, changed from original set up

Formerly 17 H/L Floor Closet By FP 1/2" Deep TC

	SDM-SW8A Pulse Input Module	
Power Supply (12V)	12V	
CR10X (G)	GND	
CR10X (C3)	C3	
CR10X (C2)	C2	
CR10X (C1)	C1 IN	
SDM-SW8A (C1 IN)	C1 OUT	
#44 Kwh Meter AC Condenser (-)	GND	
	5V	SPST Mode
#44 Kwh Meter AC Condenser (+)	IN 1	
#45 Kwh Meter PV Generation (-)	GND	
	5V	SPST Mode
#45 Kwh Meter PV Generation (+)	IN 2	
#46 Kwh Reverse Main (-)	GND	
	5V	SPST Mode
#46 Kwh Reverse Main (+)	IN 3	
#47 Kwh Meter Whole House (-)	GND	
	5V	SPST Mode
#47 Kwh Meter Whole House (+)	IN 4	
#49 Solar Water Heater Flow Meter (-)	GND	
	5V	SPST Mode
#49 Solar Water Heater Flow Meter (+)	IN 5	
#50 Water Heater Flow Meter (-)	GND	
	5V	SPST Mode
#50 Water Heater Flow Meter (+)	IN 6	
#51 Hydronic Heater Flow Meter (-)	GND	
	5V	SPST Mode
#51 Hydronic Heater Flow Meter (+)	IN 7	
#53 Water Heater Gas Meter (-)	GND	
	5V	SPST Mode
#53 Water Heater Gas Meter (+)	IN 8	

Formerly signal IN 3 Kwh Meter FAU Blower
Means, changed from original set up

Updated Baseline Data Acquisition Wiring Diagrams

CR10X Datalogger

	G	G	
	G	G	
AM16/32 (COM:ODD H)	1H	4H	#23 W Wall Heat Flux (+)
AM16/32 (COM:ODD L)	1L	4L	#23 W Wall Heat Flux (-)
	AG	AG	
#21 S Wall Heat Flux (+)	2H	5H	#24 Low Ceiling Heat Flux (+)
#21 S Wall Heat Flux (-)	2L	5L	#24 Low Ceiling Heat Flux (-)
	AG	AG	
#22 E Wall Heat Flux (+)	3H	6H	#25 High Ceiling Heat Flux (+)
#22 E Wall Heat Flux (-)	3L	6L	#25 High Ceiling Heat Flux (-)
	AG	AG	
	E1	E3	
	AG	AG	
	E2	G	
	G	G	
	P1	5V	
	G	5V	
#30 Water Heater Flow Meter (Pulse Out)	P2	G	
#30 Water Heater Flow Meter (-)	G	SW 12V	
	C8	SW 12V	
	C7	G	
	C6		
AM16/32 (CLK)	C5		
AM16/32 (RES)	C4		
SDM-SW8A (C3)	C3		
SDM-SW8A (C2)	C2		
SDM-SW8A (C1 IN)	C1		
SDM-SW8A (GND)	G		
#30 Water Heater Flow Meter (12V Supply Power)	12V		
	12V		

	AM16/32 Analog Multiplexer (Type J Thermocouples)				
#16 Air Temperature By Thermostat TC (red)	16L			32L	
#16 Air Temperature By Thermostat TC (white)	16H	SET8	SET16	32H	
#15 Long Run AC TC (red)	15L			31L	
#15 Long Run AC TC (white)	15H			31H	
	SHIELD			SHIELD	
#14 Short Run AC TC (red)	14L			30L	
#14 Short Run AC TC (white)	14H	SET7	SET15	30H	
#13 High Attic Temperature (red)	13L			29L	
#13 High Attic Temperature (white)	13H			29H	
#12 Low Attic Temperature (red)	12L			28L	
#12 Low Attic Temperature (white)	12H	SET6	SET14	28H	
#11 Floor by Fireplace TC (red)	11L			27L	
#11 Floor by Fireplace TC (white)	11H			27H	
	SHIELD			SHIELD	
#10 Floor Pantry TC (red)	10L			26L	
#10 Floor Pantry TC (white)	10H	SET5	SET13	26H	
#9 Floor Bedroom Closet TC (red)	9L			25L	
#9 Floor Bedroom Closet TC (white)	9H			25H	
#8 W Exterior Wall TC (red)	8L			24L	
#8 W Exterior Wall TC (white)	8H	SET4	SET12	24H	
#7 E Exterior Wall TC (red)	7L			23L	
#7 E Exterior Wall TC (white)	7H			23H	
	SHIELD			SHIELD	
#6 S Exterior Wall TC (red)	6L			22L	
#6 S Exterior Wall TC (white)	6H	SET3	SET11	22H	
#5 N Exterior Wall TC (red)	5L			21L	
#5 N Exterior Wall TC (white)	5H			21H	
	COM:EVEN L			COM:ODD L	CR10X (1L)
	SHIELD			SHIELD	CR10X (G)
	COM:EVEN H			COM:ODD H	CR10X (1H)
#4 W Interior Wall TC (red)	4L			20L	
#4 W Interior Wall TC (white)	4H	SET2	SET10	20H	
#3 E Interior Wall TC (red)	3L			19L	#19 Water Heater Output TC (red)
#3 E Interior Wall TC (white)	3H			19H	#19 Water Heater Output TC (white)
	SHIELD			SHIELD	
#2 S Interior Wall TC (red)	2L			18L	#18 Water Heater Input TC (red)
#2 S Interior Wall TC (white)	2H	SET1	SET9	18H	#18 Water Heater Input TC (white)
#1 N Interior Wall TC (red)	1L			17L	#17 Return Air Temperature TC (red)
#1 N Interior Wall TC (white)	1H			17H	#17 Return Air Temperature TC (white)
				12V	Power Supply 12V
				GND	Power Supply GND
				RES	CR10X (C4)
				CLK	CR10X (C5)
	AM16/32 Mode = "2 x 32"				

	SDM-SW8A Pulse Input Module	
Power Supply (12V)	12V	
CR10X (G)	GND	
CR10X (C3)	C3	
CR10X (C2)	C2	
CR10X (C1)	C1 IN	
SDM-SW8A (C1 IN)	C1 OUT	
#26 Kwh Meter AC Condenser (-)	GND	
	5V	SPST Mode
#26 Kwh Meter AC Condenser (+)	IN 1	
#27 Kwh Meter FAU Blower (-)	GND	
	5V	SPST Mode
#27 Kwh Meter FAU Blower (+)	IN 2	
#28 Kwh Meter Whole House (-)	GND	
	5V	SPST Mode
#28 Kwh Meter Whole House (+)	IN 3	
#29 Water Meter Whole House (-)	GND	
#29 Water Meter Whole House (+5V)	5V	SPDT Mode
#29 Water Meter Whole House (Pulse Out)	IN 4	
#31 Water Heater Gas Meter (-)	GND	
	5V	SPST Mode
#31 Water Heater Gas Meter (+)	IN 5	
#32 Gas Meter FAU (-)	GND	
	5V	SPST Mode
#32 Gas Meter FAU (+)	IN 6	
#33 Gas Meter Whole House (-)	GND	
	5V	SPST Mode
#33 Gas Meter Whole House (+)	IN 7	
	GND	
	5V	SPST Mode
	IN 8	

```
%Data Analysis Program for ZEH DATA
%---------------------------------------------------------------------------
%                   Signals from the Raw Data File
%---------------------------------------------------------------------------
%                       Conversion Factors
%Heat Flux Sensors [Omega HFS-4]
%Raw signal is in milli-volts, and the Omega Calibration Report gives factor
%in micro-volts per Watts/m^2
hf_factor=1000/1.81;
%Current Transformers [Pulses per kilowatt-hour] (Continental Control
%Systems Calibration Report)
%15 amp Fan Coil Wattnodes
fc_factor=1/2666.67;
%30 amp AC Condensers and PV Wattnodes
ac_pv_factor=1/1333.33;
%100 amp Whole House Wattnodes
house_factor=1/400;
%AC Condenser Water Flow Factor
condenser_flow_factor=.0007;
%Hours in Months:
%---------------------------------------------------------------------------
%                     Site Conditions
%Ambient Temperature [F]
TambF=ZEH_JUN_data(:,5);
%Ambient Temperature [C]
TambC=5/9*(TambF-32);
%Relative Humitidy [%]
RelHum=ZEH_JUN_data(:,6);
%Pyranometer Reading [W/m^2]
insolation=ZEH_JUN_data(:,7);
%Wind Speed
Windspd=ZEH_JUN_data(:,8);
%PV Array Area [m^2] [GEPV-055-G spec sheet] ZEH has 96 panels
%Using the Area of the cells:(35 in^2)
%(.2258m^2/cell)(18 cells/module)(96modules/Array)
pv_area=0.02258*(18*96);
%---------------------------------------------------------------------------
%                  Heat Flux Sensors [W/m^2]
%South Wall
hf_sw=ZEH_JUN_data(:, 9)*hf_factor;
%West Wall
hf_ww=ZEH_JUN_data(:, 10)*hf_factor;
%High Ceiling
```

```
hf_hc=ZEH_JUN_data(:, 11)*hf_factor;
%-----------------------------------------------------------------------
%                    Wall Thermocouples [F]
%North Interior Wall
n_int=ZEH_JUN_data(:, 12);
%South Interior Wall
s_int=ZEH_JUN_data(:, 13);
%East Interior Wall
e_int=ZEH_JUN_data(:, 18);
%West Interior Wall
w_int=ZEH_JUN_data(:, 15);
%North Exterior Wall
n_ext=ZEH_JUN_data(:, 16);
%South Exterior Wall
s_ext=ZEH_JUN_data(:, 28);
%East Exterior Wall
e_ext=ZEH_JUN_data(:, 14);
%West Exterior Wall
w_ext=ZEH_JUN_data(:, 19);
%-----------------------------------------------------------------------
%                    Floor Thermocouples [F]
%       SOUTH FLOOR
%South Floor 1/2 inch Down [Label as #1]
sfloor1=ZEH_JUN_data(:, 20);
%South Floor 4 inch Down [Lable as #2]
sfloor2=ZEH_JUN_data(:, 21);
%South Floor 1 foot Down [Lable as #3]
sfloor3=ZEH_JUN_data(:, 22);
%South Floor 3 feet Down [Lable as #4]
sfloor4=ZEH_JUN_data(:, 23);
%      LIVING ROOM
%Living Room 1/2 inch Down [Label as #1]
lr_floor1=ZEH_JUN_data(:, 24);
%South Floor 4 inch Down [Lable as #2]
lr_floor2=ZEH_JUN_data(:, 25);
%South Floor 1 foot Down [Lable as #3]
lr_floor3=ZEH_JUN_data(:, 26);
%South Floor 3 feet Down [Lable as #4]
lr_floor4=ZEH_JUN_data(:, 27);
%      CLOSET
%Closet 1/2 inch Down
closet_tc=ZEH_JUN_data(:,28);
%-----------------------------------------------------------------------
%               Air Delivery System Temperatures [F]
%High Attic Temperature
```

```
hi_attic_temp=ZEH_JUN_data(:,29);
%AC Short Run
ac_short=ZEH_JUN_data(:,30);
%AC Long Run
ac_long=ZEH_JUN_data(:,31);
%Thermostat Temperature
Tstat=ZEH_JUN_data(:,32);
%Return Air Temperature
RA_temp=ZEH_JUN_data(:,33);
%-------------------------------------------------------------------------
%                Water System Temperatures [K]
%Water Heater Input Temperature
wh_in=5/9*(ZEH_JUN_data(:,34)-32)+273.15;
%Water Heater Output Temperature
wh_out=5/9*(ZEH_JUN_data(:,35)-32)+273.15;
%Solar Water Heater Input
solar_wh_in=5/9*(ZEH_JUN_data(:,38)-32)+273.15;
%Solar Water Heater Output
solar_wh_out=5/9*(ZEH_JUN_data(:,39)-32)+273.15;
%Hydronic Heater Input
hydronic_in=5/9*(ZEH_JUN_data(:,40)-32)+273.15;
%Hydronic Heater Output
hydronic_out=5/9*(ZEH_JUN_data(:,41)-32)+273.15;
%-------------------------------------------------------------------------
%                    PV Temperatures [F]
%PV High
PV_hi_Temp=ZEH_JUN_data(:,36);
%PV Low
PV_low_Temp=ZEH_JUN_data(:,37);
%-------------------------------------------------------------------------
%                  Outside Ground Temperature [F]
%Ground Temperature
ground_temp=ZEH_JUN_data(:,42);
%-------------------------------------------------------------------------
%                  AC Condenser Temperature [F]
%AC Condenser Temperature
cond_temp=ZEH_JUN_data(:,43);
%-------------------------------------------------------------------------
%                    Energy Sensors [kWh]
%AC Condenser Energy
cond_energy=ZEH_JUN_data(:,44)*ac_pv_factor;
%PV Energy Generated
PV_gen=ZEH_JUN_data(:,45)*ac_pv_factor;
%Fan Coil Usage
fc_energy=ZEH_JUN_data(:,46)*fc_factor;
```

```
%Whole House Energy Usage
house_energy=ZEH_JUN_data(:,47)*house_factor;
%------------------------------------------------------------------------
%                          Flow Sensors [m^3/s]
%Solar Hot Water Flow [gpm -> m^3/s]
solar_flow=ZEH_JUN_data(:,48)*(1/60)*(1/264.17);
%On Demand Water Heater Flow [gpm -> m^3/s]
wh_flow=ZEH_JUN_data(:,49)*(1/60)*(1/264.17);
%Hydronic Coil Flow [gpm -> m^3/s]
hydronic_flow=ZEH_JUN_data(:,50)*(1/60)*(1/264.17);
%Whole House Gas Usage
house_gas=ZEH_JUN_data(:,51);
%AC Condenser Flow
cond_flow=ZEH_JUN_data(:,52)*condenser_flow_factor;
%------------------------------------------------------------------------
x=1:38101;
for i=1:38101
  %--------------Energy Flow Through Water Components [kWh]-------------
  %Density [kg/m^3] Table A-3 Cengel and Boles
  rho=997;
  %Specific Heat [kJ/kg K]
  cp=4.18;
  %Heat Flow through the Tankless Water Heater
  Qwh(i) =    rho*cp* wh_flow(i)*(wh_out(i) - wh_in(i));
  %Heat Flow through the Solar Water Heater
  Qsolar(i) = rho*cp* wh_flow(i)*(solar_wh_in(i) - solar_wh_out(i));
  %Heat Flow throught the Hydronic Heater
  Qhydronic(i)= rho*cp* wh_flow(i)*(hydronic_in(i) - hydronic_out(i));
    %----------PV Efficiency [Array Output / Incident Wattage]-------------
  %Avoid Division by Zero
  if PV_gen(i)<=.00225
    PV_efficiency(i)=0;
  elseif insolation(i)<=0
    PV_efficiency(i)=0;
  Else
%Minute Data: PV Efficiency [%] PV_gen has units of kWh/min. So 60*1000 to get W.
%15 Min Data: PV Efficiency [%] PV_gen has units of kWh/15 min. So 4*1000 to get W
  PV_efficiency(i)= PV_gen(i)*4*1000/(pv_area*insolation(i))*100;
  end
  %----------------------------End PV Efficiency-------------------------
end
```

The data analysis program for the Baseline House is structured the same way, only it had fewer sensors, therefore the variables defined from the input file were given different numbers and names.

Signal Verification Sheets

ZEH

Lable	Sensor Description	OK	Method of Verification
	Year	x	inspection
	Day of Year	x	inspection
	Time	x	inspection
Tabm	Ambient Temp	x	Verified with an external instrument
RH	Relative Humidity	x	Giving readings consistent with reported values
SI	Pyranometer	x	Giving readings consistent with expected values
WS	Wind Speed	x	Phisically stoppen the vein and spun it
HF-3	S wall Heat Flux		
HF-4	W wall Heat Flux		
HF-5	High Ceilling Heat Flux		
TC-1	N int wall	x	Verified with an external instrument
TC-2	S int wall	x	Verified with an external instrument
TC-7	E int wall	x	Verified with an external instrument
TC-4	W int wall	x	Verified with an external instrument
TC-5	N ext wall	x	Verified with an external instrument
TC-6	S ext wall		Problem in the CR10X module (signals average)
TC-3	E ext wall	x	Verified with an external instrument
TC-8	W ext wall	x	Verified with an external instrument
TC-9	S Floor 1/2 in	x	Verified with an external instrument
TC-10	S Floor 4in	x	Consistent with previous signal
TC-11	S Floor 1 ft	x	Consistent with previous signal
TC-12	S Floor 3 ft	x	Consistent with previous signal
TC-13	Living Room 1/2 in	x	Verified with an external instrument
TC-14	Living Room 4 in	x	Consistent with previous signal
TC-15	Living Room 1 ft	x	Consistent with previous signal
TC-16	Living Room 3 ft	x	Consistent with previous signal
TC-17	S ext wall	x	Verified with an external instrument
TC-18	High Attic Temp	x	Verified with an external instrument
TC-19	AC Short Run	x	Verified with an external instrument
TC-20	AC Long Run	x	Verified with an external instrument
TC-21	Thermostat	x	Verified with an external instrument
TC-22	RA Temp	x	Verified with an external instrument
TC-23	Water Heater Input	x	Verified with an external instrument
TC-24	Water Heater Output	x	Verified with an external instrument
TC-25	PV High	x	Verified with an external instrument
TC-26	PV Low	x	Verified with an external instrument
TC-27	Solar Water Heater In	x	Verified with an external instrument
TC-28	Solar Water Heater Out	x	Verified with an external instrument
TC-29	Hydronic In	x	Consistent with expected values
TC-30	Hydronic Out	x	Verified with an external instrument
TC-31	Outside Ground Temp	x	Not plugged in
TC-32	AC Condenser Temp	x	Verified with an external instrument
CT-1	AC Cond kWh Pulse	x	Agrees with cycling of the unit and house power readings
CT-2	PV Generation kWh Pulse	x	Verified with onsite PV meter
CT-3	Energy Supplied to Grid	x	Agrees with net meter
CT-4	Whole House kWh Pulse	x	Agrees with net meter
CT-5	Solar HW Flow Pulse	x	Verified with onsite meter
CT-6	Water Heater Flow Pulse	x	Verified with onsite meter
CT-7	Hydronic Flow Pulse	x	Verified with onsite meter
CT-8	WH Gas Meter Pulse	x	Verified with onsite meter
	AC Cond Water Flow Pulse	x	Consistent with expected values

Baseline

Lable	Sensor Description	OK	Method of Verification
	Year	x	inspection
	Day of Year	x	inspection
	Time	x	inspection
HF-2	S wall Heat Flux		Uncertain how to verify
HF-3	E wall Heat Flux		Uncertain how to verify
HF-4	W wall Heat Flux		Uncertain how to verify
HF-5	Low Ceiling Heat Flux		Uncertain how to verify
HF-6	High Ceiling Heat Flux		Uncertain how to verify
TC-1	N int wall	x	Verified with an external instrument
TC-2	S int wall	x	Verified with an external instrument
TC-3	E int wall	x	Verified with an external instrument
TC-4	W int wall	x	Verified with an external instrument
TC-5	N ext wall	x	Verified with an external instrument
TC-6	S ext wall	x	Verified with an external instrument
TC-7	E ext wall	x	Verified with an external instrument
TC-8	W ext wall	x	Verified with an external instrument
TC-9	Bedroom Closet Floor	x	Giving reasonable readings
TC-10	Pantry Floor	x	Giving reasonable readings
TC-11	Fireplace Floor	x	Giving reasonable readings
TC-12	Low Attic Temp	x	Verified with an external instrument
TC-13	Hight Attic Temp	x	Verified with an external instrument
TC-14	AC Short Run	x	Verified with an external instrument
TC-15	AC Long Run	x	Verified with an external instrument
TC-16	Thermostat	x	Verified with an external instrument
TC-17	RA Temp	x	Verified with an external instrument
TC-18	Water Heater In	x	Giving reasonable readings
TC-19	Water Heater Out	x	Verified with an external instrument
CT-1	AC Condenser kWh Pulse	x	Agrees with cycling of the unit and house power readings
CT-2	FC Blower kWh Pulse		No meter to compare with
CT-3	Whole House kWh Pulse	x	Agrees with onsite meter
CT-4	House Water Pulse	x	Agrees with usage
CT-5	WH Gas Meter Pulse	x	Agrees with onsite meter
CT-6	FAU Gas Meter Pulse		No meter to compare with
CT-7	House Gas Pulse	x	Agrees with onsite meter when multiplied by 2
HTWTFLO	Hot Water Flow	x	Agrees with onsite meter

Datalogger Communication Settings

When power is lost in the lab at UNLV, communications to the datalogger are difficult to establish. Usually it is required to go through the new datalogger set up process.

First: Test the modem on the computer by using a hyperterminal connection. Do this by going to Start / Programs / Accessories / Communications / Hyperterminal. Give the terminal a name and hit okay, then dial a number that you know is ringing (Cell phone, Lab Phone)

If that works: Try another hyperterminal connection to one of the dataloggers at the site. ZEH phone number: 82695459. Baseline phone number: 86144675. The '8' is necessary to dial out of the UNLV system. Once this is complete, try making a connection through Loggernet.

If a Loggernet connection still does not work go through a Loggernet EZSetUp.
If the Stored data has been erased, these are the settings to enter:

Datalogger information:
Datalogger Name: Baseline or ZEH
Datalogger Type: CR10X
Phone Modem Connection:
Phone Modem: <default modem>
COM Port: COM 3
Phone Number: 8-614-4675 Baseline, 8-269-5459 ZEH
Datalogger Settings: (Same for both loggers)
Baud Rate: 9600
Security Code: 0
Extra Response Time: 10s
Max Time Online: 0d0h0s
Collection Schedule: (Same for both loggers)
Base Date: Use Current Date
Normal Schedule: 0d 1h 0m 0s (automatically downloads every hour)
Primary Retry Schedule: 0d 0h 2m 0s
Primary Retry Count: 3
Secondary Retry Schedule: 1d 0h 0m 0s

The system has only lost power twice, and these were the steps taken to regain communication. Only do one logger at a time. When one comes back online, the other one does also.

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