DESCIPTION OF ELECTRIC ENERGY USE AND GENERATION FOR 12 SINGLE-FAMILY RESIDENCES IN SOUTHERN KENTUCKY

RESEARCH PROPOSAL

A proposal submitted in partial fulfillment of the requirements for the degree of Biosystems Engineering in the College of Engineering at the University of Kentucky

by:

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Abstract

Power demand patterns in the residential sector appear to be shifting as new building codes, renewable technologies, household electronics, and occupancy habits change how energy is both produced and consumed in the United States. In this study, we characterize current energy demand patterns on an hourly, daily, weekday vs. weekend, and seasonal basis in order to update previous end-use profiles, and to compare to past studies. This is accomplished by directly metering all circuits in 12 modern energy-efficient homes located in Emlyn, Kentucky. Each house in the study has similar building characteristics (building massing and orientation, insulation, fenestration, air infiltration, etc.), making it an ideal case-study for power demand variations due solely to occupancy demand patterns. Additionally, each house has 5 kW solar arrays situated on the roof, making it a great case study for the solar-grid interaction. The results of the study will define energy-demand profiles for all of the houses, develop end-use load shapes for Southern Kentucky, and create an energy consumption and production forecasting model for houses with solar using solar insolation and weather data, time of day, time of week, and season as predictor variables. This plethora of information will help to: inform the effectiveness of future residential time-of-use rate schedules for utilities in Southern Kentucky, define the impact of residential distributed solar generation on the grid, and ensure efficacy in state and federal government energy-efficiency initiatives by showing which end-uses in homes can be most effectively improved based on their energy use profiles.

Chapter One: Introduction

Electricity demand varies significantly in the residential sector depending on the time of day, week, and year, resulting in highly variable loads that must be managed by utilities and energy production facilities (Larson et al. 2014). Rates that take into account the fluctuations in electricity demand throughout the day, also known as time-of-use pricing (TOU), have been considered by utilities and government initiatives in order to minimize operational costs and fuel usage for utilities' associated with peak demand.

Each home in this study has 5 kW of solar generation capacity on the roof. Utilities have expressed concern about this type of distributed solar generation and how it may effect grid voltage stabilization, costs associated with net metering, and the utilities' ability to predict demand and generation to ensure grid reliability.

The focus of this research is to define daily, weekly, and yearly power demand variations for 12 homes in Southern Kentucky, and to determine if variations between the homes, which have similar building envelope characteristics, are observed. Additionally, the power demand profiles will be compared to previous studies (namely, Pratt et al. 1989 and Larson et al. 2014) to compare power usage patterns in Kentucky to that of the Pacific Northwest. The overall power usage patterns will be compared to Kentucky's end-use profiles that are often used in load forecasting for local utilities.

Background

Electricity is a fundamental component of our commercial, industrial, and residential infrastructure. To ensure electricity is available for all consumers, countless producers and utilities must work incessantly to predict how much instantaneous power is required. If less electricity is produce than is demanded from all of these energy consumers, there are inevitably undesirable brownouts or blackouts. For this reason, it’s important to understand how each energy sector uses electricity on a daily, weekly, and yearly basis.

Utilities often break electricity demand into three categories: baseload, intermediate load, and peak load. Baseload is the electricity usage that is always present. This typically consists of loads that are constantly on, such as heating and cooling systems. Intermediate loads refer to a slightly larger energy demand on top of the base load, typically found in the morning hours when everyone turns the lights on at work. Peak load is the largest load experienced throughout the day, and is typically found early in the evening, the exact time dependent on the location and season. These fluctuations in power demand provide a challenge for utilities across the United States. While the price of electricity remains constant all day for residential consumers, utilities must use more fuel during intermediate and peak demand, which requires a larger operational cost for the utilities. This leads to the commercial and industrial sectors largely subsidizing residential power consumption during peak demand. For this reason, many utilities are considering time-of-use (TOU) pricing systems for the residential sector in order to accommodate for higher electrical usage times. This has led to a demand for more electricity demand data from all energy consuming sectors.

The residential sector has the largest consumes 37.5% of all electricity consumption in 2015, making it the largest energy-consuming sector in the United States (U.S. Department of Energy, 2015). The residential sector also has large variations in electricity demand based on the location, season, time of day, and weekday vs. weekend periods. This has led to a growing interest in monitoring electricity usage to determine these trends, with utilities and government programs often funding research due to the high costs associated with metering programs.

The residential sector includes many different house typologies, including single-family detached and attached homes, apartment buildings, and mobile homes. Each of these typologies have different building envelope characteristics (insulation levels, fenestration elements, air infiltration, etc.). Furthermore, homes also have different appliance stocks, number of residents, and use different heating, ventilation, and air conditioning (HVAC) equipment. These variations in building characteristics and occupancy levels lead to large usage variations in each specific load source in homes. These large variations between each residence makes it very difficult for researchers to attribute specific behavioral tendencies or appliance stocks to energy-consumption patterns.

In our study, we have well defined and similar housing characteristics, which provides a unique opportunity to analyze energy variations among household appliances, lighting, and overall energy consumption between households based primarily on occupant behavior. The results of such study will be valuable for understanding potential TOU pricing programs, as they provide an insight into the cost savings associated with such programs. The results will be valuable for future government energy-efficiency programs, as they provide insight into the most intensive energy end-user, which can be targeted by the programs. Lastly, the results of this study are valuable for determining the effectiveness of the Department of Energy eQuest version 3.64 building monitoring program by comparing simulated residential performance to actual performance of the homes used in the study.

Literature Review

Residential end-use energy metering and monitoring largely began in the late 1980s with the End-Use Load and Consumer Assessment Program (ELCAP), a $30 million project conducted by Bonneville Power Administration between 1988 – 1992. Since then there have been countless studies related to residential end-use energy consumption, including over 40 studies within the last ten years (End Use Load Research Working Group, 2016). However, many of these studies have had large inconsistencies in their methodology, including: the metering techniques used (direct vs. indirect), sample size, building typology, location, climate, occupancy, and the overall time interval studied. These differences have ultimately led to differing results, a lack of protocol for future researchers, and potential inaccuracies in current building energy modeling programs.

Direct metering involves monitoring of all circuits for data collection, while indirect metering typically uses a mixture of direct metering and energy modeling based on occupant and housing characteristics for data collection. Direct metering studies have historically been the most expensive metering technique, so most of the research prior to 2010 used indirect metering in order to reduce the cost by limiting the number of sensors required for each house, thus allowing researchers to increase the sample size of the studies. Most commonly this called for the use of the conditional demand analysis technique (CDA), which is a modeling strategy that uses direct metering and advanced modeling based on behavioral and building characteristics to predict end-use energy consumption. This technique was seen in Bartels & Fiebig 1996, Tiedemann 2007, Bartels & Fiebig 2000. Other modeling techniques have been attempted to improve the accuracy of energy modeling beyond the methodology of the CDA (Abreu et al. 2016, U.S. Energy Information Agency 2013, Kavousian et al. 2012, Rebman and Yu 2008, Carlson 2013), but ultimately the most accurate and conclusive models are obtained using direct end-use monitoring.

ELCAP has been the largest direct metering study to date. The project included over 250 single-family houses in the Pacific Northwest, and concluded: space conditioning loads are the largest use of electricity; heating load far exceeds that of cooling; all end uses show seasonal variation, size of end-use variations can be eclipsed by large seasonal space conditioning loads; annual energy consumption varies between households; end-use variability is strongly influenced by family size, size of residence, income level, occupant behavior, and other demographic variables; light and convenience loads increase the with number of occupants (Pratt et al. 1989).

However, results from several follow up studies indicate the energy usage patterns and overall energy usage have changed since the ELCAP study in 1989. The Residential Building Stock Assessment (RBSA) program directly monitored 100 households in the same region as ELCAP, and found the following key differences: water heating has declined; water heating has a different daily variation pattern; refrigeration loads are 40% of what ELCAP observed two decades before, and lighting varies seasonally (Larson et al. 2014). In fact, the Regional End Use Load Research Steering Committee and the Northwest Energy Efficiency Alliance (NEEA) recently noted that the ELCAP study overestimates water heating’s regional load by 300 MW when compared to the follow up study presented by RBSA program (End Use Load Research Working Group, 2016).

This would suggest that since the ELCAP studies were concluded, end-use consumption patterns have changed. This claim is further supported by the U.S. Energy Information Agencies' Residential Energy Consumption Survey (RECS) in 2009 which found that appliance loads have increased from 24% of a home's total load, to 34.6% of the total load, likely due to the increase in computer and television ownership. Results also indicate that space conditioning loads are no longer greater than 50% of the total household load, and that overall heating consumption has increased as a result home size increasing in the past decades (U.S. Energy Information Agency, 2013).

These changes in end-use consumption patterns directly affect today's building energy modeling programs. For instance, the Building America House Simulation Protocol uses the ELCAP study for all end-use hourly profiles, except for ceiling fans and MELs. This protocol is used to provide cost and performance assessments associated with retrofit improvements, energy-efficient construction and standard building practices by the U.S. Department of Energy building modeling programs such as DoE2 and EnergyPlus (Hendron & Engebrecht, 2010). By using outdated data, there exists the risk of building model inaccuracies.

These research discrepancies have led to a large demand for accurate direct end-use energy metering data. This demand will likely be an on-going requirement as behaviors and energy consumption patterns continue to change as a result of technological, cultural, and political changes.

Chapter Two: Objectives

The goal of this research is to establish and update end-use energy consumption profiles using direct energy metering for homes in Southern Kentucky with respect to the following load sources: total load, heating and cooling systems, water heating, miscellaneous electric loads (MELs), lighting, washer and dryer, and range loads. There are three main objectives associated with the study. The first objective is to define end-use load profiles for 12 homes in Emlyn, Kentucky. The hypotheses associated with this objective are: daily, weekday vs. weekend, and seasonal variation will be observed for each end-use. The second objective is to develop a solar generation and site-specific house load forecasting model using local solar insolation, weather, time of day, day of the week, and the date predictor variables. The hypothesis associated with the second objective is that local solar insolation data can be used to predict daily solar generation from the neighborhood's photovoltaics. The third and final objective is to compare the end-use load profiles with previous studies out of the Pacific Northwest (Larson et al. 2014), and to the overall residential load shapes used for electricity rate setting by the Public Service Commission (PSC) in Kentucky. Lastly, an exercise to determine the accuracy of eQuest version 3.64 will be conducted to determine the accuracy of the building model for residential purposes.

The results obtained from this study reflect the energy performance of modern energy-efficient and low cost residential dwellings in Southern Kentucky. Such results are valuable for determining the efficacy and cost effectiveness of efficient buildings practices for future low-income residences. Additionally, this knowledge is valuable for local utilities to better estimate peak load and determine if TOU pricing is a feasible pricing alternative for residential electricity rates. Lastly, this knowledge will be valuable for local utilities to better estimate peak load, government energy-efficient initiatives to determine the effectiveness of specific end-use incentives, and also to future studies into direct end-use metering. Data from this study is available upon request.

Chapter Three: Methodology

Housing Characteristics

Direct energy-metering will be conducted on 12 homes constructed from 2012 to 2016 in Emlyn, Kentucky, 40769 (figure 1). Each house in this study was built as a part of the Houseboat to Energy Efficient Residences (HBEER) project. For the HBEER project, the University of Kentucky College of Design, UK Center for Applied Energy Research, the Kentucky Highlands Investment Corporation, and the Kentucky Housing Corporation all collaborated to build energy-efficient and affordable houses in Southern Kentucky. Each house in the study was built by Southern Tier Housing, and contains similar building characteristics. This includes: insulation levels, fenestration elements, building materials, heating and cooling equipment, water heating equipment, range appliances, thermostat systems, lighting equipment, refrigeration and washing appliances, and massing and orientation. Additionally, all of the homes included in the study are in climate zone 4, with 4451 heating degree days (HDD), were built within 5 degrees of solar south, and are single-family homes.

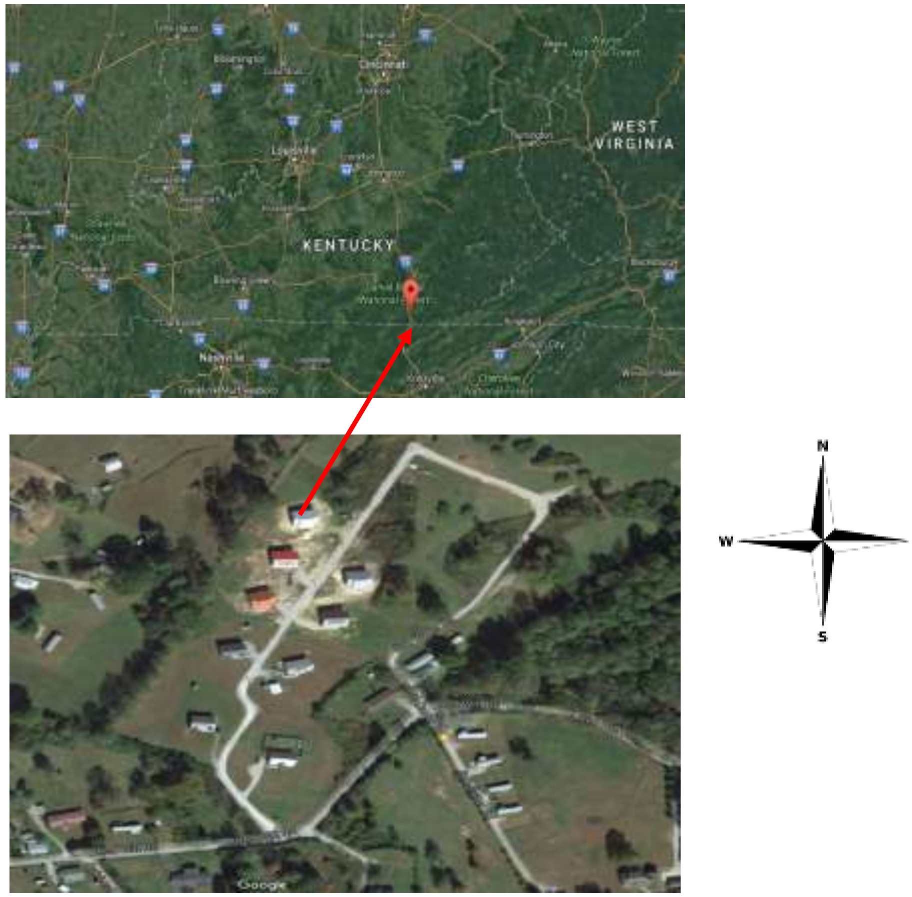

Figure 1: Location of houses used in the study (top photo), with 9 houses shown (bottom photo). No scale shown. *Source:* *google-maps*

The major difference between houses included in the study are that there are two different floor plans. One floor plan is a 3 bedrooms and 1 bath layout, with 1,232 ft^2, 10% glazing area, and an overall heat transfer value (UA) of 159 Btu/h°F. The second floor plan is a 3 bedroom 2 bath layout, with 1,584 ft2, 8% glazing area, and a UA value of 177 Btu/h°F. Other housing differences include the number of occupants, number of outlets available, and each family's individual electric end-uses appliances (space heaters, hair dryers, etc.). These end-uses that vary between houses will present themselves within the outlet loads, which will be referred to as miscellaneous electric loads (MELs), and will be monitored on a whole room basis. All of the outlet loads will be summed into the MEL grouping.

To ensure that the space conditioning load is as accurate as possible, thermostat set-point from each home will be collected. The loads that vary will present themselves within the outlet loads and other miscellaneous electric loads, which are monitored on a whole room basis.

Metering Technique

To monitor the hourly energy usage for each home, data will be collected using current transformers (CT), a type of current sensor that collects current flow readings from every circuit in each home in one minute intervals. Specifically, Accu-CT ACTL-0750 (Continental Control Systems) as well as Dent CTHSC-U/B (Dent Instruments) mini-split CTs will be used. Concurrently, voltage measurements will be taken with each current measurement, to allow for an overall power estimation on each circuit using the power law equation. The power will be determined using eGauge 3000 and eGauge 3010 power meters (eGauge). The eGauge controllers will read the supply L1 and L2 phase voltages (120 and -120 V, 240V between the two) and all of the current data from each CT sensor. This data then will be transmitted using TP-Link CPE210 Outdoor Units (TP-Link) using WiFi to a MultiConnect rCell Modem (Multitech), which allows the data to be transferred to individual URLs provided by the individual eGauge units for offsite data attainment. The power will then be normalized over the 15 minute intervals based on the data collected. Each power average includes the average of the previous 15 minutes prior to the recorded power value. See Appendix C for more information about the instrumentation used in the study.

Once hourly profiles are determined, daily, monthly, and yearly average profiles will be built in order to test for seasonal variations, weekday variations, and energy usage variations between occupants. This data will then be compiled using Excel, and analyzed using SAS statistical software (ANOVA). This data transmission process for the master house is demonstrated in figure 2.

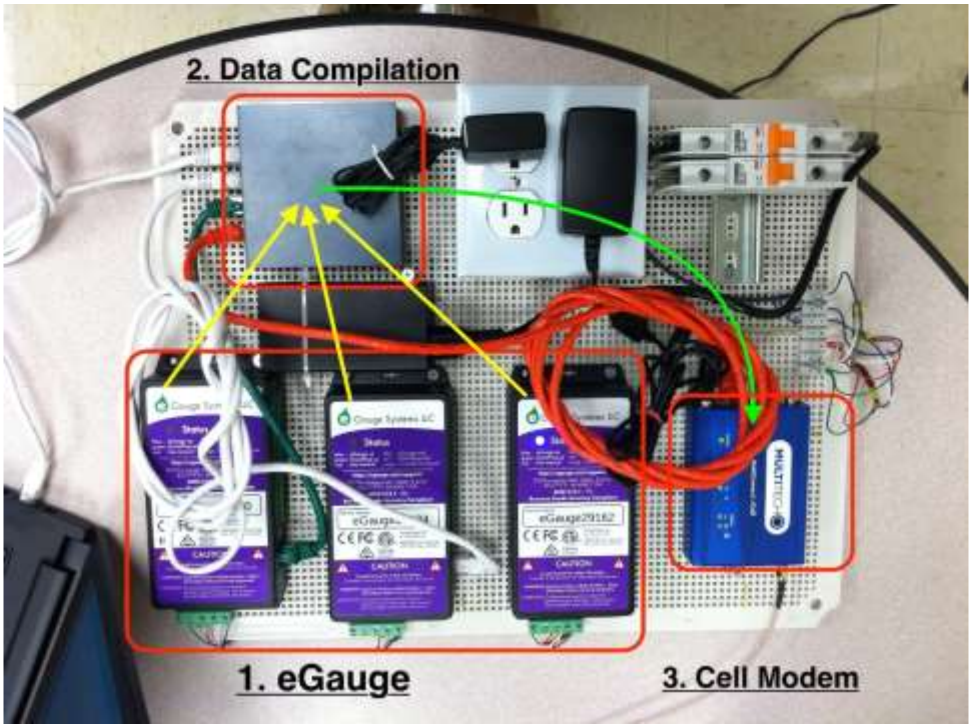

Figure 2: Overall perf board set-up for master house (with WiFi connection)

1. eGauge sensor – CT, L1, and L2 connections for current and voltage measurement. Each eGauge has a specific IP address / website URL for remote data access.

2. Data Bridge / Router – Ethernet connection to each eGauge, with Ethernet connection to WiFi TP-Link Antennas for communication between each house and to the cell modem in the master house.

3. Cell Modem – Only present in the master house, provides a connection to the internet for data transmission from site to University of Kentucky for online access.

<u>Data Validation</u>

The L1 and L2 energy usage will be compared to each home's overall metered end-use energy usage to determine the accuracy. Too, the sum of the L1 and L2 mains will be compared to all monitored circuits to ensure overall load accuracy. If these tests are within 2% accuracy, it is considered accurate and valid data.

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Appendix A - Budget

	Year 1	Year 2	Total
Total	**$161,637.32**	**$117,146.07**	**$278,783.39**
Direct	$115,455.23	$83,675.77	$199,131.00
Indirect	$46,182.09	$33,470.31	$79,652.40

ID#	Item	Units	Rate	Year 1	Year 2	Total
1	**Salary and Wages**			**$45,539.21**	**$46,275.38**	**$91,814.59**
1.1	Graduate Student Assistant	1.00	$16,000.00	16,000.00	16,000.00	32,000.00
1.2	Advisor: Dr. Donal Colliver (20%)	0.20	$122,696.04	24,539.21	25,275.38	49,814.59
1.3	Research Technician (15%)	1.00	$5,000.00	5,000.00	5,000.00	10,000.00
2	**Fringe Benefits**			**$11,438.28**	**$11,438.28**	**$22,876.56**
2.1	Graduate Student Assistant			-		-
2.1.1	Social Security	0.08	$16,000.00	1,224.00	1,224.00	2,448.00
2.1.2	Other Fringe	0.01	$16,000.00	192.00	192.00	384.00
2.1.3	Health Insurance	1.00	$2,500.00	2,500.00	2,500.00	5,000.00
2.2	Advisor: Dr. Donal Colliver			-	-	-
2.2.1	Social Security	0.02	$122,696.04	1,877.25	1,877.25	3,754.50
2.2.2	Other Fringe	0.01	$122,696.04	883.41	883.41	1,766.82
2.2.3	Health Insurance	0.20	$5,940.00	1,188.00	1,188.00	2,376.00
2.2.4	Retirement	0.02	$122,696.04	2,453.92	2,453.92	4,907.84
2.2.5	Life Insurance ($3/month)	2.40	$3.00	7.20	7.20	14.40
2.3	Research Technician			-	-	-
2.3.1	Social Security	0.02	$5,000.00	76.50	76.50	153.00
2.3.2	Other Fringe	0.01	$5,000.00	36.00	36.00	72.00
2.3.3	Health Insurance	0.20	$5,000.00	1,000.00	1,000.00	2,000.00
2.3.4	Retirement	0.1	$5,000.00	500.00	500.00	1,000.00
2.3.5	Life Insurance ($3/month)	2.40	$3.00	7.20	7.20	14.40
3	**Travel**			**$1,962.10**	**$1,962.10**	**$3,924.20**
3.1	ASABE Meeting (spokane)			-		-
3.1.1	Per Diem Rate	5.00	$99.00	495.00	495.00	990.00
3.1.2	Round Trip Flight	1.00	$742.00	742.00	742.00	1,484.00
3.1.3	Food	15.00	$10.00	150.00	150.00	300.00
3.2	5 Site Visits (Emlyn, KY)	1065.00	$0.54	575.10	575.10	1,150.20
4	**Equipment** **(see budget justification)**			**$32,276.00**	**$-**	**$32,276.00**
5	**Materials**			**$239.64**	**$-**	**$239.64**
5.1	Connecting Wires - estimate	12.00	$7.97	95.64	-	95.64
5.2	Perf board	12.00	$12.00	144.00	-	144.00
6	**Other Direct Costs**			**$24,000.00**	**$24,000.00**	**$48,000.00**
6.1	Publication Costs ($100/page)	20.00	$100.00	2,000.00	2,000.00	4,000.00
6.1.1	Tuition and fees	1.00	$22,000.00	22,000.00	22,000.00	44,000.00
7	**Indirect Costs**			**$46,182.09**	**$33,470.31**	**$79,652.40**
7.1	40%	0.40	$115,455.23	46,182.09	33,470.31	79,652.40

Budget Justification

1.0 Salary and Wages
- 1.1 Graduate student stipend award
- 1.2 20% of advisor's yearly salary ($122,696.04) with 3% increase budget escalation. (http://www.research.uky.edu/ospa/info.html)
- 1.3 Estimated research technician assistance.

2.0 Fringe Benefits (http://www.research.uky.edu/ospa/info.html).
- 2.1 Graduate Student Assistant
  - 2.1.1 Social security 7.65%.
  - 2.1.2 Other fringe 1.2%.
  - 2.1.3 Health Insurance $2,500 for employees.
- 2.2 Advisor: Dr. Donald Colliver
  - 2.2.1 20% of time at 7.65% social security rate.
  - 2.2.2 20% of time at 3.6% other fringe rate.
  - 2.2.3 20% health insurance cost at $5,940 per year.
  - 2.2.4 20% life insurance rate for 12 months at $3 per month.
- 2.3 Research Technician
  - 2.3.1 20% of time at 7.65% social security rate.
  - 2.3.2 20% of time at 3.6% other fringe rate.
  - 2.3.3 20% health insurance cost at $5,940 per year.
  - 2.3.4 20% life insurance rate for 12 months at $3 per month.

3.0 Travel (google.com)
- 3.1 ASABE Meeting in Spokane, Washington
  - 3.1.1 $99 per night per diem rate for five nights (http://gsa.gov/portal/category/100120).
  - 3.1.2 Round trip flight as of Nov. 17,2016 for July 15 & July19 from Lexington, KY to Spokane, WA (google.com - travel).
  - 3.1.3 Food estimated at $10 per meal, three meals per day.
- 3.2 Five Site Visits per Year
  - 3.2.1 At a rate of $0.54 per mile, from Lexington, KY to Emlyn, KY (106.5 miles, one way). (Google.com/maps)

4.0 Equipment – *All equipment costs based on their purchase cost unless otherwise specified (see table below). All equipment assumed to be purchased the first year, and have no impact on the second year budget.*

ID#	Task	Units	Cost	Total Cost
4.1	Data Logging -12 houses			-
4.1.1	Webserver data logger	12.00	$349.00	4,188.00
4.1.2	Webserver data logger EG3010	24.00	$299.00	7,176.00
4.1.3	RS-485 to Ethernet converter BF-430	12.00	$85.00	1,020.00
4.1.4	12 V power supply	12.00	$10.00	120.00
4.1.5	TP Link Homeplug AV	12.00	$35.00	420.00
4.1.6	MeanWell 709 APV 12-12	12.00	$12.00	144.00
4.2	Communication - 12 houses			-
4.2.1	WiFi Access Point (TL-WA801ND)	12.00	$23.00	276.00
4.2.2	TP-Link-5-port switch (TL-SF1005D)	12.00	$10.00	120.00
4.2.3	Wireless Bridge (Edimax CV-7428NS)	12.00	$30.00	360.00
4.2.4	Super Power Supply 2 x 12 dBi 2.4 GHz 5GHz Dual Band WiFi RP-SMA Antennas	12.00	$13.00	156.00
4.3	Communication - Base House			-
4.3.1	Multitech cellular router - CR100MT	1.00	$325.00	325.00
4.3.2	TP-Link-TL-WR841HP 300MBPS High power rireless N Router	1.00	$57.00	57.00
4.3.3	AD14EX Amped Wireless High Power Outdoor (TP-Link TL-ANT2409A)	1.00	$58.00	58.00
4.4	Current and Voltage - 12 houses			-
4.4.1	Accu-CT Current Transformer	384.00	$45.00	17,280.00
4.4.2	Connector Tips (1/CT)	384.00	$1.50	576.00

4.1 Data Logging

4.1.1 Webserver data logger EG3000

4.1.2 Webserver data logger EG 3010

4.2 Communication – 12 houses

4.2.1 WiFi Access Point – (Amazon.com).

4.2.2 TP-Link-5-port switch – (Amazon.com).

4.3 Communication – Base House

4.4 Current and Voltage – 12 Houses

4.4.1 32 per house, 12 houses total, $45 each per Test Equipment Depot pricing.

4.4.2 $1.50 per CT, 384 total CT sensors.

5.0 Materials- *all materials purchased in first year.*

5.1 10 and 12 gauge wires – home-depot pricing $7.97/per house, 12 houses total.

5.2 Perf board – one per house, 12 houses total, at $12.00 per perf board.

6.0 Other Direct Costs

6.1 Publication costs based on $100/page, 20 pages total per report.

6.2 Tuition and fees estimated $22,000 per year.

7.0 Indirect Costs

7.1 40% of direct costs for Biosystems and Agricultural Engineering department at University of Kentucky. (https://www.research.uky.edu/ospa/info.html)

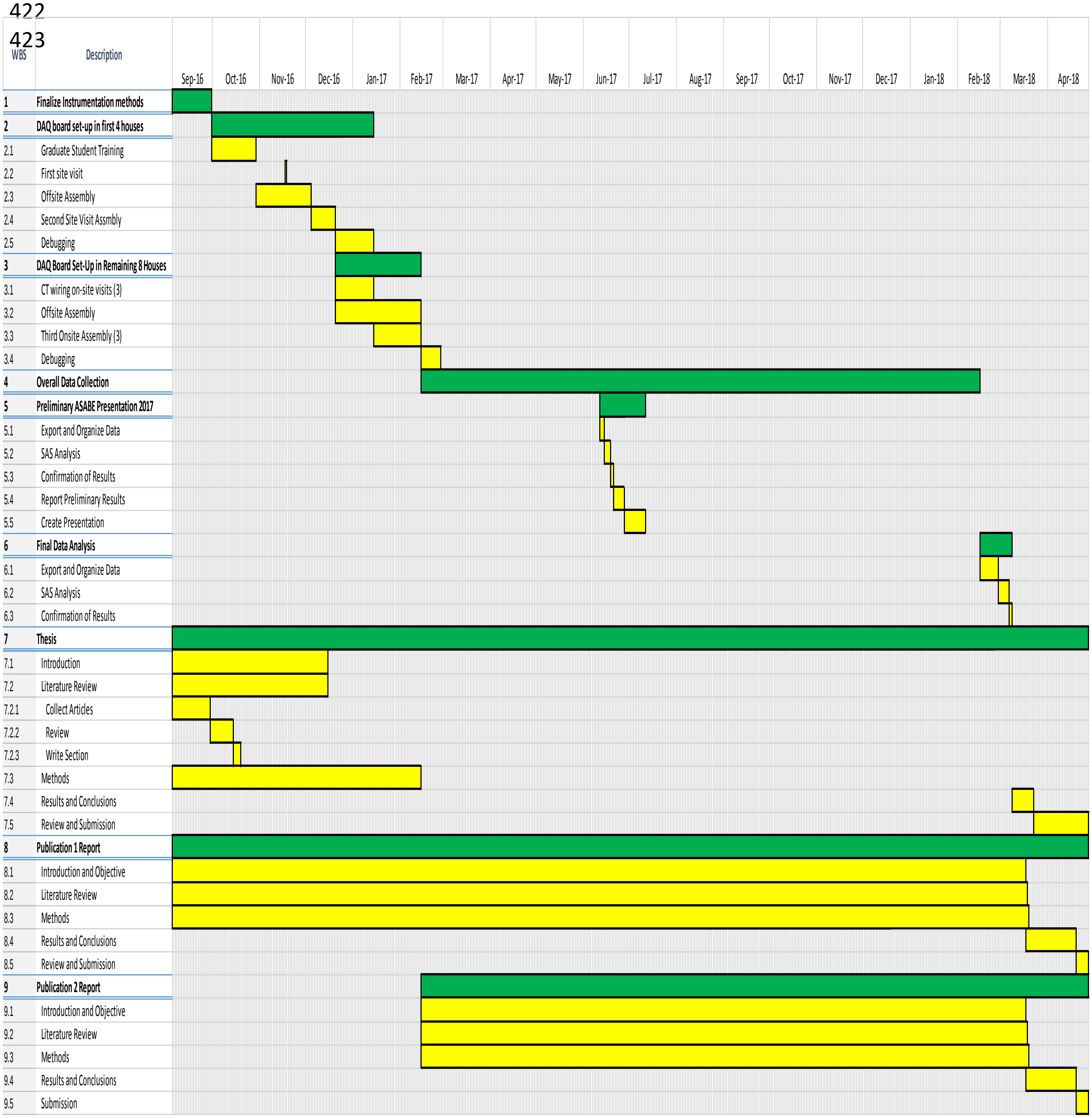
Appendix B – WBS and Gantt Chart

Work Breakdown Structure (WBS)

Note: key milestones are outlined as single integer values in the WBS column.

WBS	Description	Dependency	Resource	Effort Days	Start Date	Planned Completion
1	**Finalize Instrumentation methods**	**-**	**Grad Student/Advisor**	**26**	**9/5/2016**	**10/1/2016**
2	**DAQ board set-up in first 4 houses**	**-**	**Grad Student/Advisor**	**107**	**10/1/2016**	**1/15/2016**
2.1	Graduate Student Training	-	Grad Student/Advisor	29	10/1/2016	10/30/2016
2.2	First site visit	1	Grad Student/Advisor	1	11/18/2016	11/19/2016
2.3	Offsite Assembly	2.1	Grad Student/Advisor	46	10/30/2016	12/15/2016
2.4	Second Site Visit Assmbly	2.3	Grad Student/Advisor	6	12/15/2016	12/21/2016
2.5	Debugging	2.4	Grad Student/Advisor	25	12/21/2016	1/15/2017
3	**DAQ Board Set-Up in Remaining 8 Houses**	**-**	**Grad Student/Advisor**	**56**	**12/21/2016**	**2/15/2017**
3.1	CT wiring on-site visits (3)	2.4	Grad Student/Advisor	25	12/21/2016	1/15/2017
3.2	Offsite Assembly	2.4	Grad Student/Advisor	56	12/21/2016	2/15/2017
3.3	Third Onsite Assembly (3)	3.1	Grad Student/Advisor	31	1/15/2017	2/15/2017
3.4	Debugging	3.3	Grad Student/Advisor	13	2/15/2017	2/28/2017
4	**Overall Data Collection**	**3.3**	**Grad Student/Advisor**	**365**	**2/15/2017**	**2/15/2018**
5	**Preliminary ASABE Presentation 2017**	**-**	**Grad Student**	**28**	**6/12/2017**	**7/10/2017**
5.1	Export and Organize Data	3	Grad Student	3	6/12/2017	6/15/2017
5.2	SAS Analysis	5.1	Grad Student	1	6/15/2017	6/16/2017
5.3	Confirmation of Results	5.2	Grad Student	2	6/19/2017	6/21/2017
5.4	Report Preliminary Results	5.3	Grad Student	7	6/21/2017	6/28/2017
5.5	Create Presentation	5.4	Grad Student	12	6/28/2017	7/10/2017
6	**Final Data Analysis**	**4**	**Grad Student**	**22**	**2/15/2018**	**3/9/2018**
6.1	Export and Organize Data	4	Grad Student	13	2/15/2018	2/28/2018
6.2	SAS Analysis	6.1	Grad Student	7	2/28/2018	3/7/2018
6.3	Confirmation of Results	6.2	Grad Student	2	3/7/2018	3/9/2018
7	**Thesis**	**-**	**Grad Student**	**599**	**9/5/2016**	**4/27/2018**
7.1	Introduction	-	Grad Student	102	9/5/2016	12/16/2016
7.2	Literature Review	-	Grad Student	102	9/5/2016	12/16/2016
7.2.1	Collect Articles	-	Grad Student	25	9/5/2016	9/30/2016
7.2.2	Review	-	Grad Student	15	9/30/2016	10/15/2016
7.2.3	Write Section	-	Grad Student	5	10/15/2016	10/20/2016
7.3	Methods	-	Grad Student	163	9/5/2016	2/15/2017
7.4	Results and Conclusions	6	Grad Student/Advisor	14	3/9/2018	3/23/2018
7.5	Review and Submission	7.1 - 7.4	Grad Student	35	3/23/2018	4/27/2018
8	**Publication 1 Report**	**-**	**Grad Student**	**599**	**9/5/2016**	**4/27/2018**
8.1	Introduction and Objective	7.1	Grad Student	559	9/5/2016	3/18/2018
8.2	Literature Review	7.2	Grad Student	560	9/5/2016	3/19/2018
8.3	Methods	7.2.1	Grad Student	561	9/5/2016	3/20/2018
8.4	Results and Conclusions	6	#REF!	33	3/18/2018	4/20/2018
8.5	Review and Submission	8.1-8.4	#REF!	7	4/20/2018	4/27/2018
9	**Publication 2 Report**	**-**	**Grad Student**	**436**	**2/15/2017**	**4/27/2018**
9.1	Introduction and Objective	3.3	Grad Student	396	2/15/2017	3/18/2018
9.2	Literature Review	3.3	Grad Student	397	2/15/2017	3/19/2018
9.3	Methods	7.3	Grad Student	397	2/15/2017	3/19/2018
9.4	Results and Conclusions	4	Grad Student	33	3/18/2018	4/20/2018
9.5	Submission	9.1 - 9.4	Grad Student	7	4/20/2018	4/27/2018

Gantt Chart


WBS
Description
Sep-16
Oct-16
Nov-16
Dec-16
Jan-17
Feb-17
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Sep-17
Oct-17
Nov-17
Dec-17
Jan-18
Feb-18
Mar-18
Apr-18
1 Finalize Instrumentation methods
2 DAQ board set-up in first 4 houses
2.1 Graduate Student Training
2.2 First site visit
2.3 Offsite Assembly
2.4 Second Site Visit Assmbly
2.5 Debugging
3 DAQ Board Set-Up in Remaining 8 Houses
3.1 CT wiring on-site visits (3)
3.2 Offsite Assembly
3.3 Third Onsite Assembly (3)
3.4 Debugging
4 Overall Data Collection
5 Preliminary ASABE Presentation 2017
5.1 Export and Organize Data
5.2 SAS Analysis
5.3 Confirmation of Results
5.4 Report Preliminary Results
5.5 Create Presentation
6 Final Data Analysis
6.1 Export and Organize Data
6.2 SAS Analysis
6.3 Confirmation of Results
7 Thesis
7.1 Introduction
7.2 Literature Review
7.2.1 Collect Articles
7.2.2 Review
7.2.3 Write Section
7.3 Methods
7.4 Results and Conclusions
7.5 Review and Submission
8 Publication 1 Report
8.1 Introduction and Objective
8.2 Literature Review
8.3 Methods
8.4 Results and Conclusions
8.5 Review and Submission
9 Publication 2 Report
9.1 Introduction and Objective
9.2 Literature Review
9.3 Methods
9.4 Results and Conclusions
9.5 Submission

Appendix C: Instrumentation

Power measurements are to be taken every minute, and energy calculations will be computed based on these power measurements for each hour, day, week, and month for the final analysis. Current measurement will be taken using Accu-CT current transformers on every circuit for each home (36 per house), which are tied to eGuage power meters that will take voltage measurements from the phase loads L1 and L2 (+120 and -120 V), which allow for the home's 120V/240V supply lines. Power will then be computed using equation 1.1. The power measurements will be calculated within the eGauge power meters (3 per house) and are compiled using TP-Link data transmission lines, which have Ethernet input and outputs. This data is transmitted for each home using the TP-Link Outdoor CPE 210 to the "master" house that has the MultiConnect rCell Modem which allows for the data to be transferred to an online server where it may be accessed by the research team. The eGauge system will be accessible online using eGauge's host website server, which stores the data for each eGauge power meter used in the study via a unique power-meter URL.

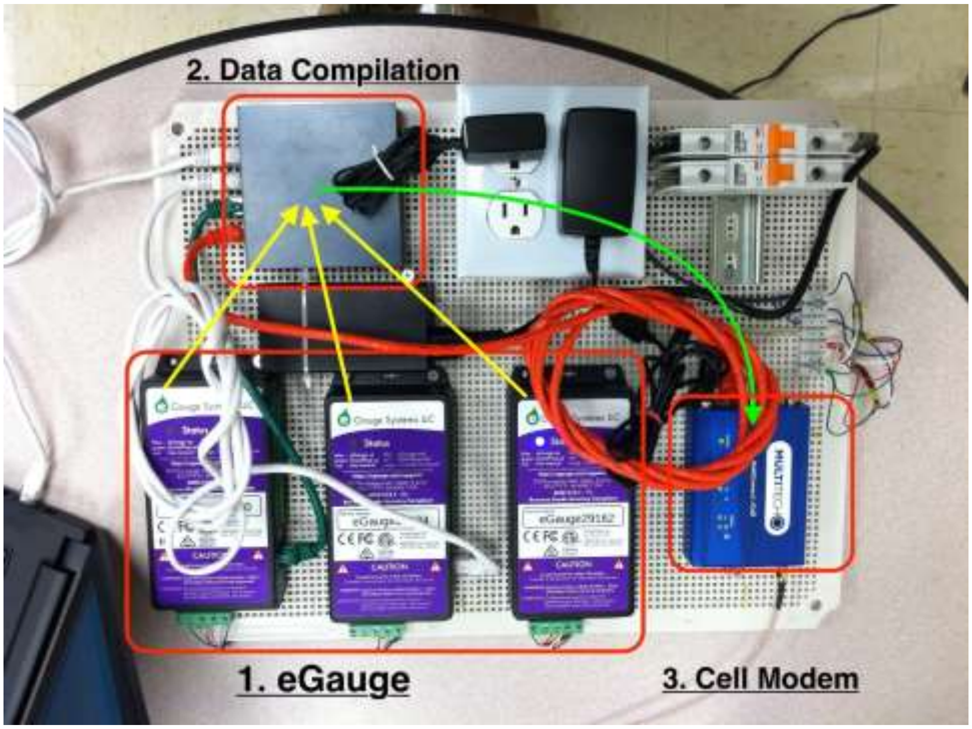


Figure 3: Overall perf board set-up for master house (with WiFi connection)

1. eGauge sensor – CT, L1, and L2 connections for current and voltage measurement. Each eGauge has a specific IP address / website URL for remote data access.

2. Data Bridge / Router – Ethernet connection to each eGauge, with Ethernet connection to WiFi TP-Link Antennas for communication between each house and to the cell modem in the master house.

3. Cell Modem – Only present in the master house, provides a connection to the internet for data transmission from site to University of Kentucky for online access.

Accu-CT

Current sensors used in the study are obtained from Continental Control Systems LLC. Each sensor used has an accuracy of +/- 0.59 Amps (A) within 1%-120% of rated primary current. For the mains within the home's a 100 A sensor will be attached, for the HVAC system 60-A sensors will be used, 50-A sensors for the range appliances, and for the rest of the loads 20-A and 30-A sensors will be attached. Output phase angle is rated for +/- 0.25 degrees for each sensor within 1%-120% of rated primary current.

Figure 4:Accu-CT current transformer, ACTL-0750

The output of the sensor is 333.33mVac at the current transformers rated current. This means that the output for the 20 A model can be described as:

$$Output\ Voltage\ (V) = \frac{Input\ Current\ (A)}{Rated\ Current\ (A)} * 0.333$$

Where current is the input from the circuit to the sensor and voltage is the output of the sensor across an internal resistor, which is read by the eGauge power meter. Equations can be found for the 20, 30, 50, 60, and 100 Amp sensors. All sensors come with a certificate of calibration provided.

eGauge Power Meter

eGauge 3010 sensors will be used for research's power meter. Three eGauge power meters will be allotted for each house. Each eGauge has 12 available differential inputs for the Accu-CT current sensors. Additionally, three house leads are available for each eGauge, though only L1 and L2 will be used for the +120V and -120V single phase leads. It assumed that the solar inverter produces a voltage of 120V, or the average voltage of both L1 and L2. A neutral terminal is also provided. L1 serves to power the device which uses approximately 2 W (7.5W max). L2 serves only as a voltage tap. L1 and L2 are both coupled to the neutral pin. Configuration of the power meter is done online through eGauge. Each input will be configured online using eGuage's website for accurate input voltage readings.

The eGauge sensors also have an Ethernet (LAN) connector insertion to provide hard wire Ethernet connection capabilities for the sensor. The LED on the eGauge will turn green when the Ethernet carrier signal is detected. This LED will turn yellow if it is operating at 100 Mbps and will turn off at 10Mbps.

eGauge time is maintained by synchronizing the public server NTP atomic-clock when connected to the public server. For our research, the eGauge sensors will not be connected at all times to a NTP server, thus the eGauge will rely on a batter-backed real-time clock. The battery is able to maintain proper time for one day. Once the battery is fully charged, time may be maintained for one week.

The eGauge database has the capability to store 1 year of 1 minute average data internally. The data that is collected will be transmitted wirelessly using TP-Link Wi-Fi connectors between houses.

Figure 5: eGauge Power Meters

TP-Link, Outdoor CPE210, Pharos

The TP-Link Outdoor CPE210 will transmit data collected from the eGauge systems between houses. The CPE has a range of 1000 feet, transmits data at 300 Mbps, and operates at 2.4 GHz and 9dBi (directional rating). For each home, data will be transmitted from a TP-Link data collection box to the TP-Link Outdoor CPE, which then will send the data to the home that has the MultiConnect rCell modem.

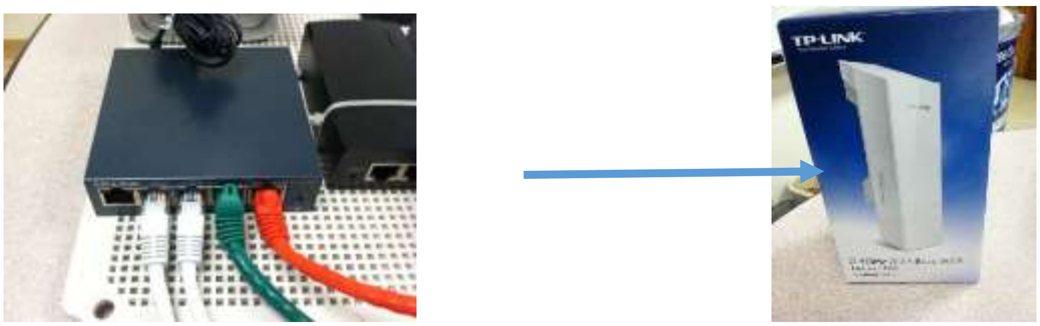


Figure 6: TP-Link Data Compilation and Transmission

Data collection box (left), data transmission unit (right)

MultiConnect rCell Modem

The MultiConnect® rCell 100 Series allows for the data to be transmitted using a wireless service provider. The device allows for Ethernet connection from the TP-Link device in the host house. The device operates at 2.5 GHz (20 MHz BW) and has a 54-65 Mbps max theoretical throughput.

Figure 7: MultiConnect rCell 100 Series Cellular Router