Sustainable Residential Microgrid with Permaculture –

A Building Block in Sustainable Communities of the Future

Dr. Peter Mark Jansson, PE* and ***Dr. Victor E. Udo***

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** - Presenting*

Abstract

- Established initially as a research station by the Bucknell University Sustainable Energy Research Team (BUSERT), the microgrid was created to demonstrate off-grid operation of a residential home using the power systems of a PV Array and natural gas generator to supplement typical grid power. Over the past six years the microgrid site has evolved to demonstrate more climate friendly alternatives to energy storage and to demonstrate the benefits of permaculture and organic practices that can be applied to typical residential settings. The authors share the key elements of the systems employed at the site to decrease it's carbon footprint overtime and to capture carbon in the process. The technologies include: electric hybrid transportation, photovoltaic array, ultra-high efficiency natural gas heating, load management control via the microgrid Raspberry-Pi, pollinator gardens, perennial gardens, natural herb gardens and fruit and nut trees, organic compost supplementation and garbage/organics composting, rainwater capture, etc.

- During the past few years the site has experienced increases in the insect (particularly bees), amphibian and small mammal populations as the landscape has become increasingly organic in nature. From a technology standpoint the microgrid has operational capability to pull power from the grid, send excess generation to the grid or operate in an islanding mode (without need for the grid). Taken in combination this installation has the ability to operate to minimize costs or to minimize carbon for the homeowner. It represents one small site which now demonstrates multiple ways that homes can contribute to reducing carbon in the future (through reduction in use or sequestering onsite) as well as becoming more self-sufficient in terms of the production of local organic produce for the occupants and their neighborhood.

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The link to our paper of yesterday

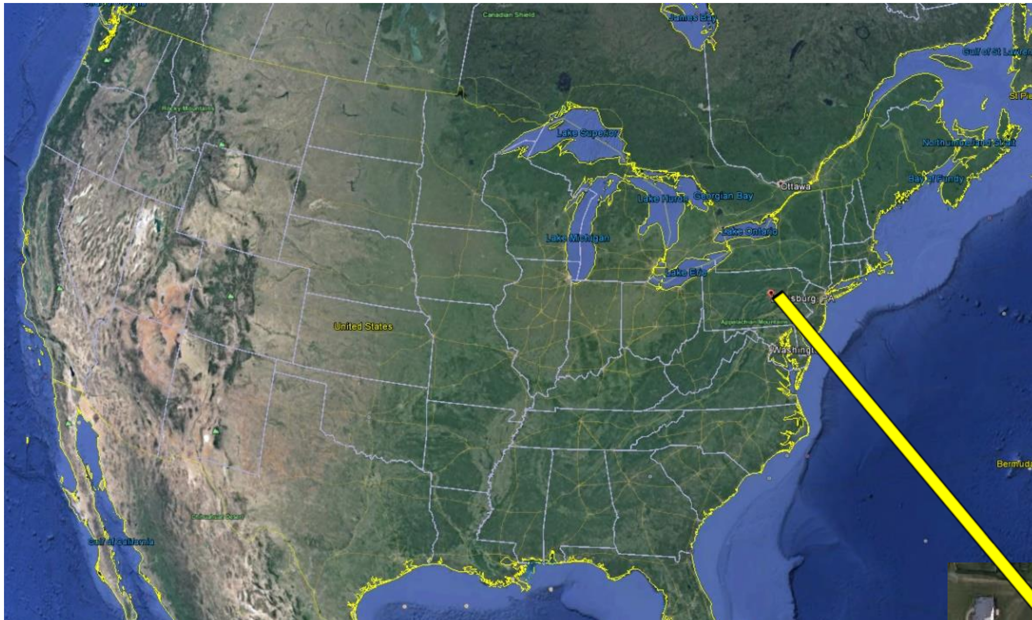
Making *all* of the 6Rs "real" at the local / community level?

We will revisit this at the end and see…

Aims of this research & talk

- Provide overview of tested technologies / techniques:
  - Electric/hybrid transportation, photovoltaic array, ultra-high efficiency natural gas heat, load management control technology, pollinator gardens, perennial gardens, herb gardens, fruit and nut trees, rain water capture, compost supplementing / creation, garbage and organics composting, 'biochar'/carbon sequestering, soil regeneration
- Provide overview of the design of residential microgrid and a permaculture system that reduces carbon and costs
- The creation and interconnection of these technical and natural systems at local level provides a competitive alternative to central grid power and industrial agriculture

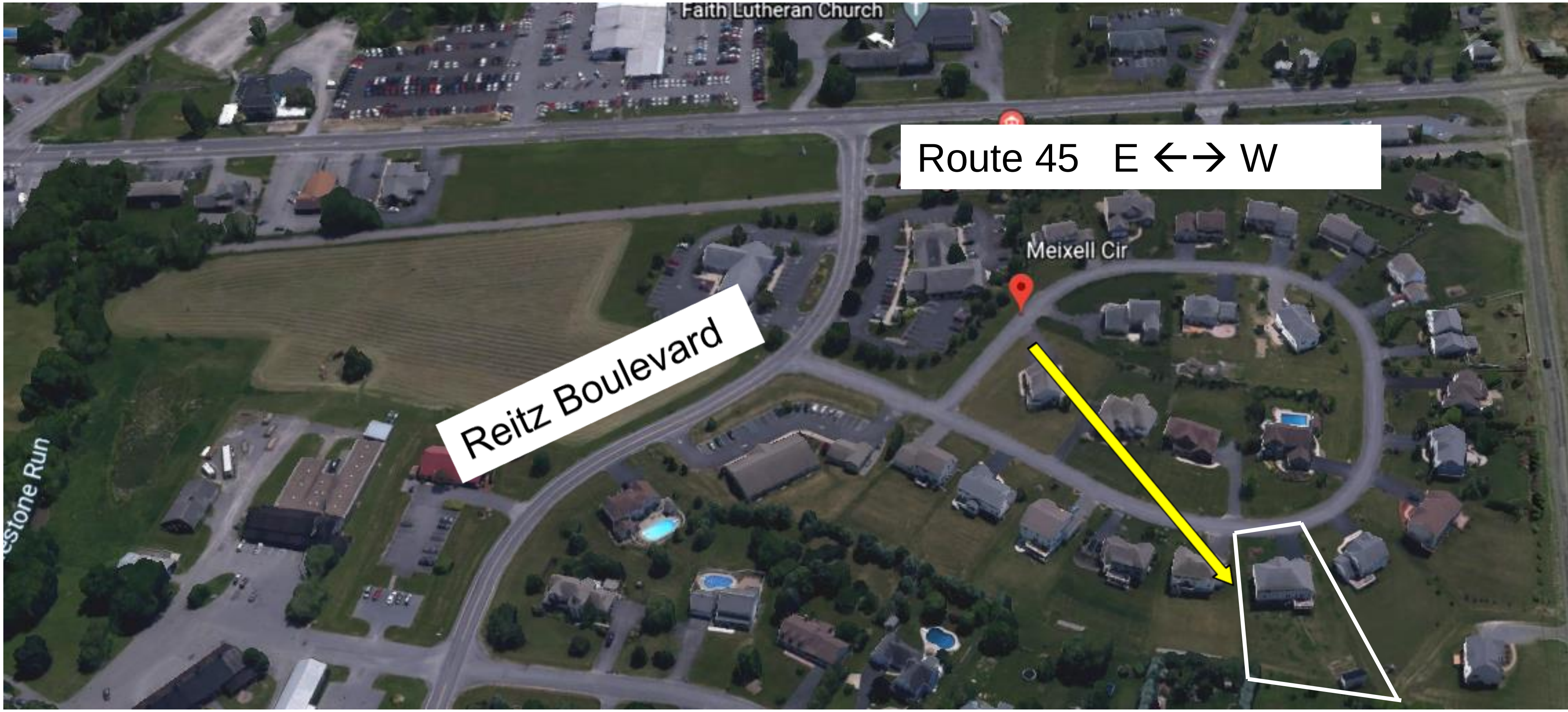
Bucknell Residential Microgrid Lewisburg, PA, USA



Where is this site?

Residential Cul de Sac – Meixell Circle
East Buffalo Twp, Union County

Bucknell Residential Microgrid Lewisburg, PA, USA



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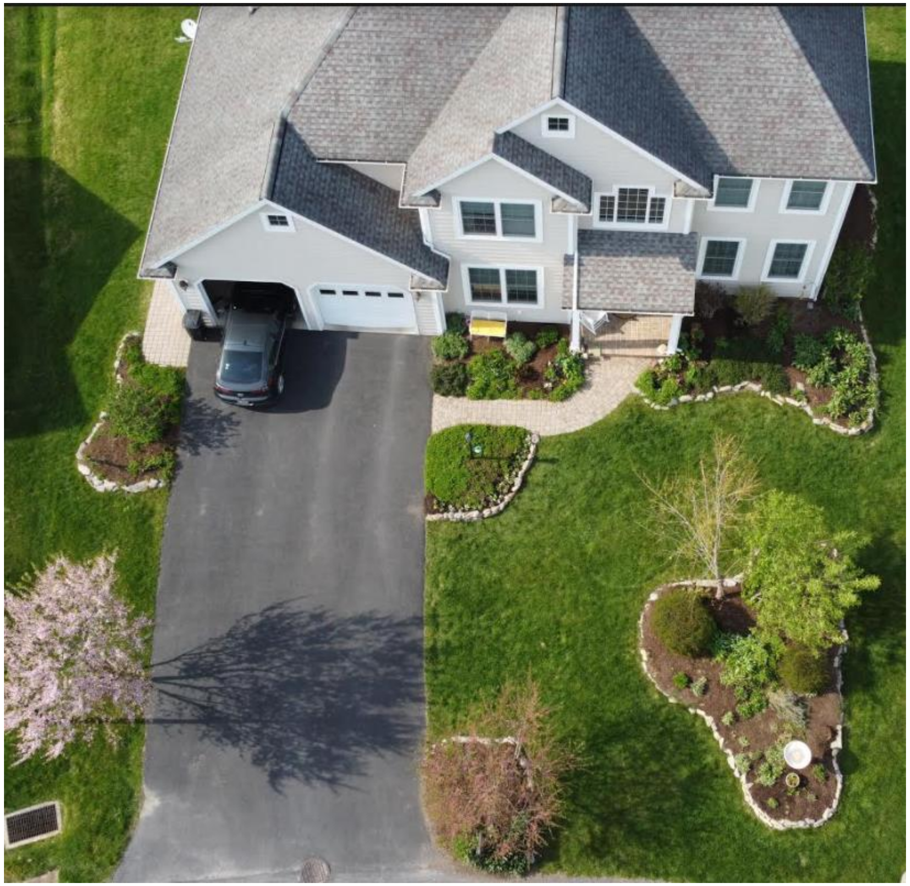
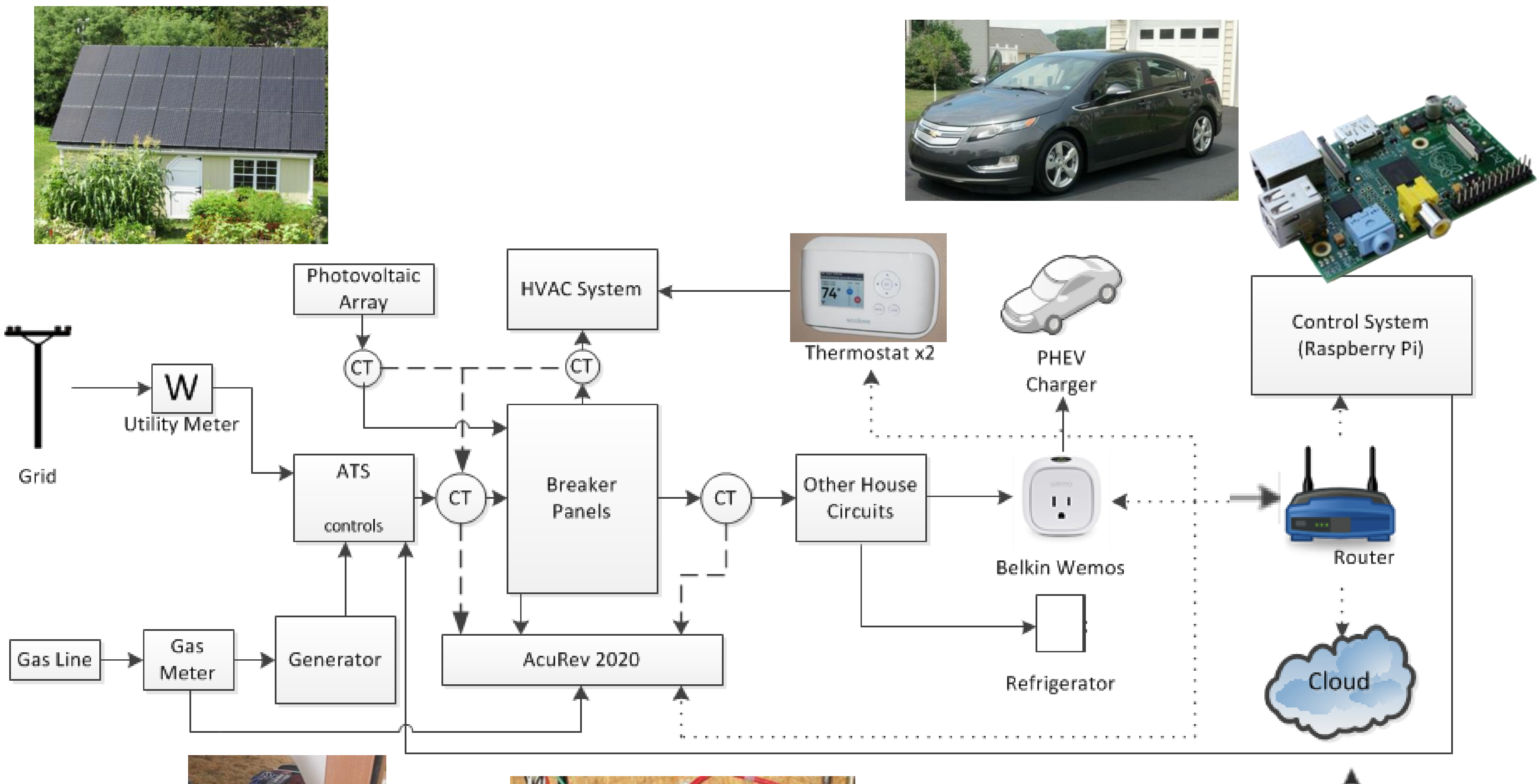


Bucknell's Residential Microgrid Prototype



Benefits of the BU Residential Microgrid

- Better response to variations from renewables (PV)
- Utility demand response and local load management
- Better energy security
- Financial feasibility
- Backup generation
- Load shaping
- Ideal utility customer
- Virtual energy storage

Residential Microgrid Test Site , Lewisburg, PA USA

Tech of the BU Residential Microgrid

- Renewable energy system (PV)
- Hybrid electric vehicle
- Load management
- Load metering
- End-Use control
- Onsite Generator
- Intelligent System Ops

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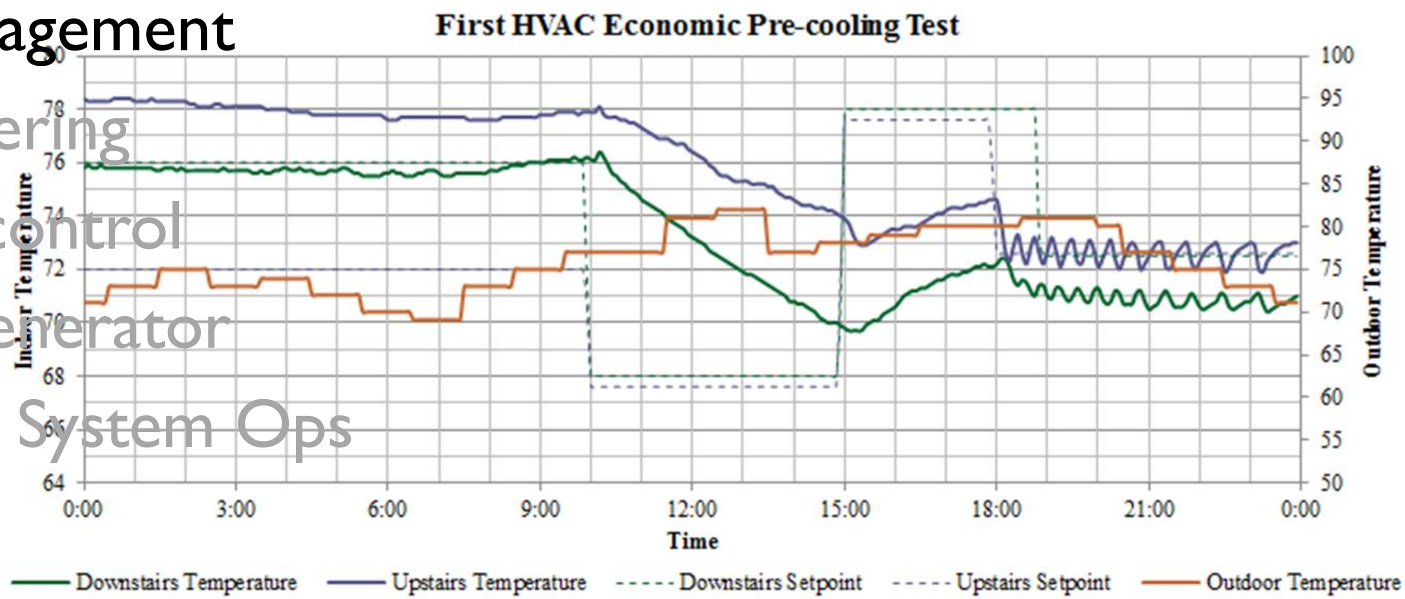

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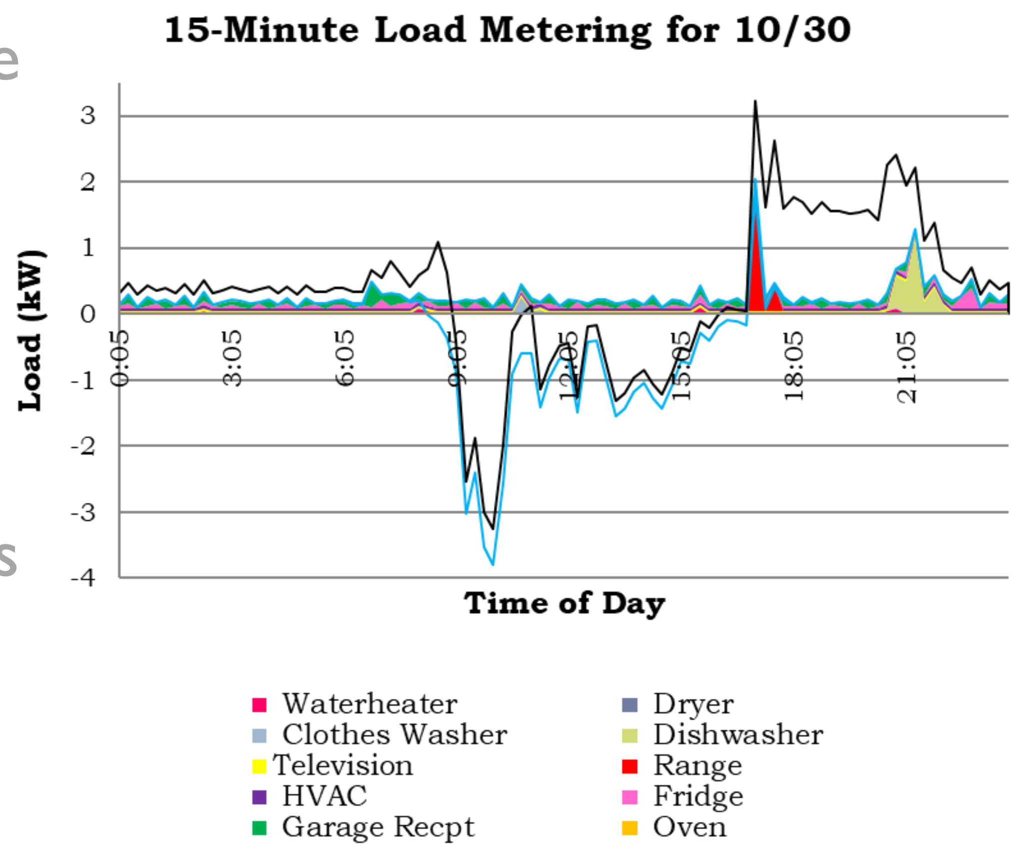

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- Belkin WEMO® Insight embedded voltage and current transformer and switch

Designed for residential indoor dry location use only
SYSTEM REQUIREMENTS
Wi-Fi® router
Android 4.0 or later
iOS v6 or higher
Max 120V~/16A/60Hz/1800W
Number of Power Outlets:1
Wi-Fi: 2.4Ghz 802.11n

Interior of WeMo® Switch

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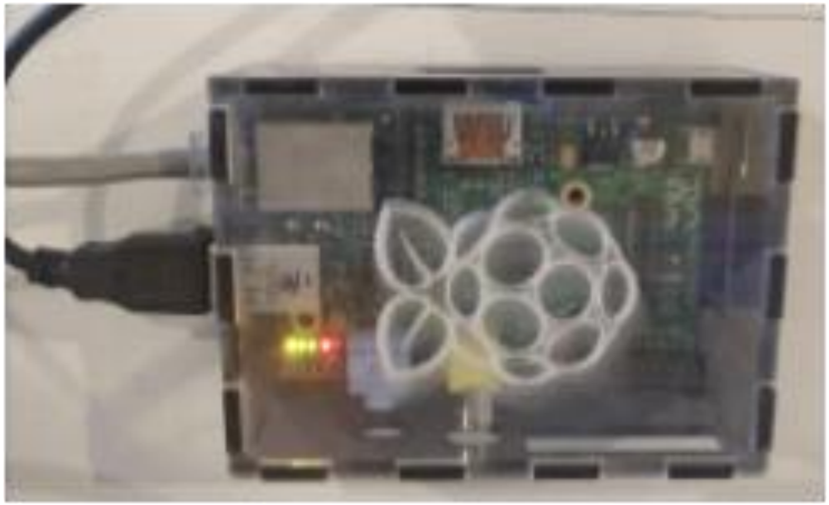

Overview of Residential Permaculture

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- ‘biochar’/carbo
- soil regenerati
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- perennial gardens
- herb gardens
- fruit and nut trees
- rain wat
- compost
- garbage
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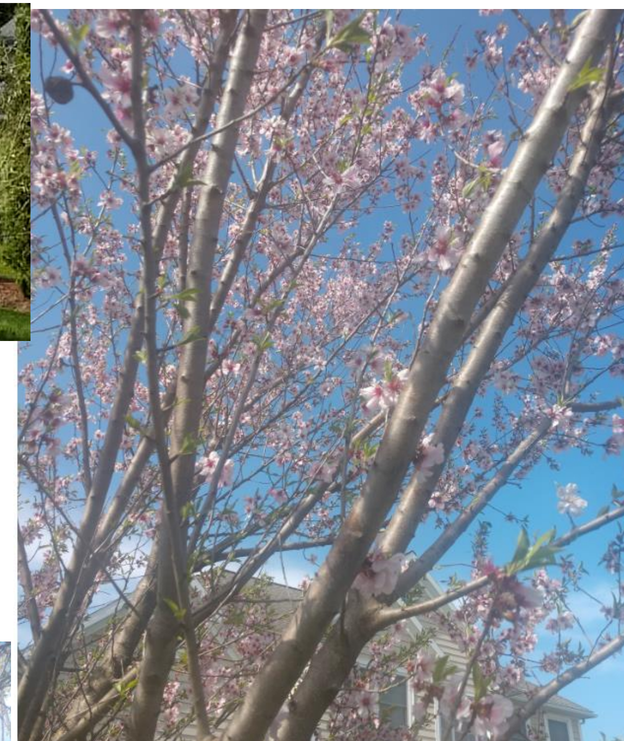

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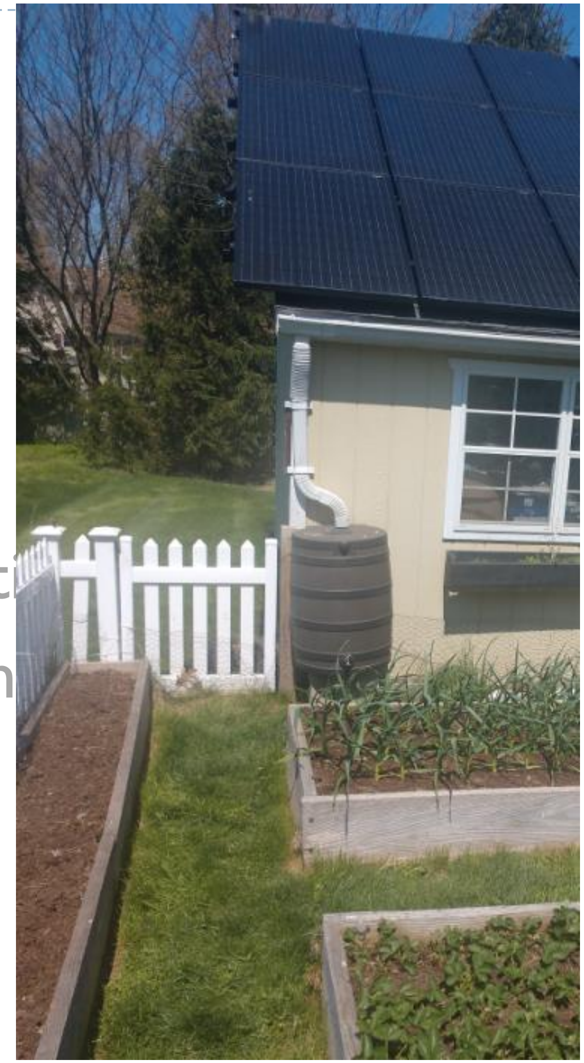

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Overview of Permaculture Plants

1) Peach
2) Apple
3) Cherries
4) Almond
5) Echinacea
6) Iris
7) Mint
8) Tomato
9) Choke Berry (Aronia berry)
10) Chamomile
11) Sage
12) Thyme
13) Basil
14) Strawberry
15) Brussel Sprouts
16) Lima Beans
17) Lettuces
18) Beet
19) Carrot
20) Spinach
21) Oregano
22) Marigold
23) Corn
24) Squash
25) Butternut squash
26) Rose Hips
27) Potatoes
28) Pepper
29) Kale
30) Sunflowers
31) Hollyhock
32) Chocolate Mint
33) Comfrey
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Significant Surpluses in Season

The link to our 6Rs paper of yesterday

No pesticides, No herbicides, feeding local soil bringing in rich supplements, return of numerous species in grass on property. Planting perennials, fruit trees, nut trees. Feeding birds

Residential Microgrid Control Platform Raspberry – Pi, Cloud connection, etc.

Natural communities are restored: the return of pollinators, amphibians, soil biota and small mammals. Increased diversity of annual and perennial species

Maximum use of recycled materials and all recyclable waste collected by local recycler or taken to Twp site.

Residential 6.12kW PV Array, Electric transportation, 18kW Natural gas gen, Ultra Hi-eff Natural gas Heating, On-site Organic Food production, etc.

Biochar production from all woody organic waste, cardboard balances composting of primarily greens, rain water capture/reuse in garden beds

Garbage and kitchen waste composting, use of paper/cardboard in composting systems

Behavioral Values

The Global/Local impact & value of the 6Rs

The Future of Sustainable Communities

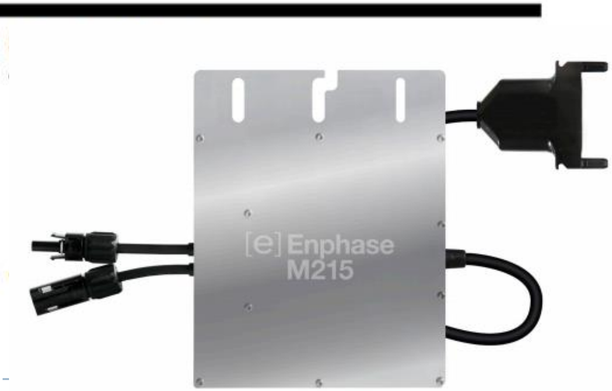
- Smart residential microgrid homes with permaculture gardens (pollinator, food, herb, etc.) and fruit/nut trees

Technical Detail ***SUPPORT*** Slides

- Slides which follow are details regarding the residential smart residential microgrid specifications, technologies as well as system capabilities and practical applications

Residential Microgrid Specifications

- Distributed Generation Sources (~ 23.4 kW)
  - Renewable:
    - Canadian Solar® 255-Watt Photovoltaic Modules (24) with
    - EnPhase® M215 DC-AC microinverters (24)
  - Fossil Fuel (Natural Gas):
    - 18kW Kohler® Back-up Generator Model 20RESA



Residential Microgrid Specifications

- Load Management and Control Opportunities
- Load Shedding:
  - EV Turn Off via WEMO (if connected): ~900 Watts
  - ECOBEE set thermostat up/down – TES):
    - HVAC Compressor Cycling / Off: Seasonal 1-2kW*
    - HVAC Fan – Cycling / Off: Seasonal up to 1 kW
  - Lighting Circuits: 500W – 2 kW
  - Other WEMO controlled loads (TBD)
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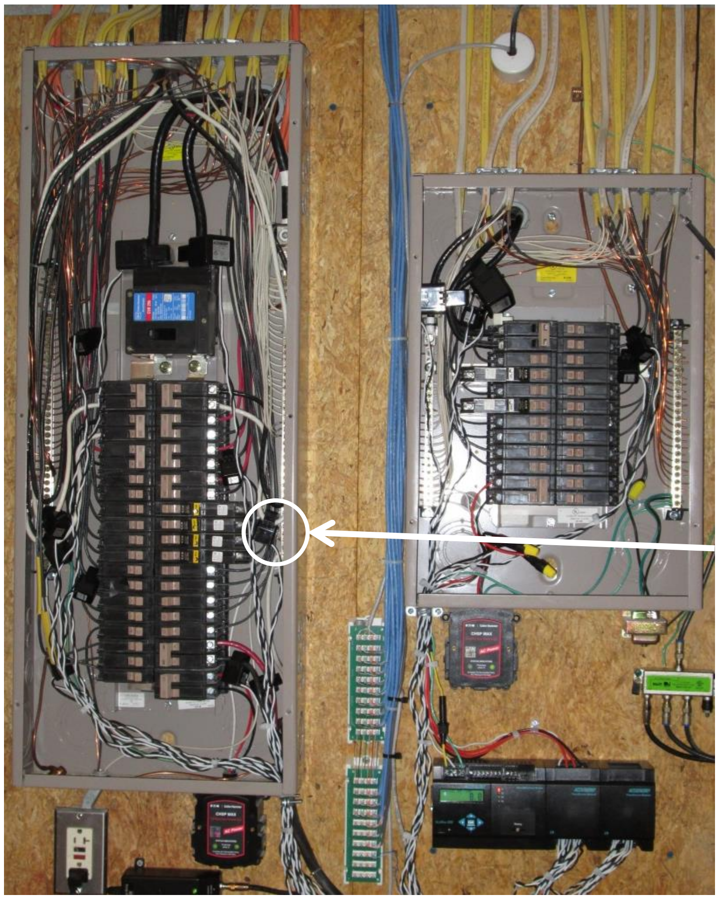
Circuit Panel Distinct Current Sensors

- Circuits Sensed via CTs



Installed AcuRev 2020 with CTs in Exposed Breaker Panels

AcuCT Hinged Series Split Core Current Transformers

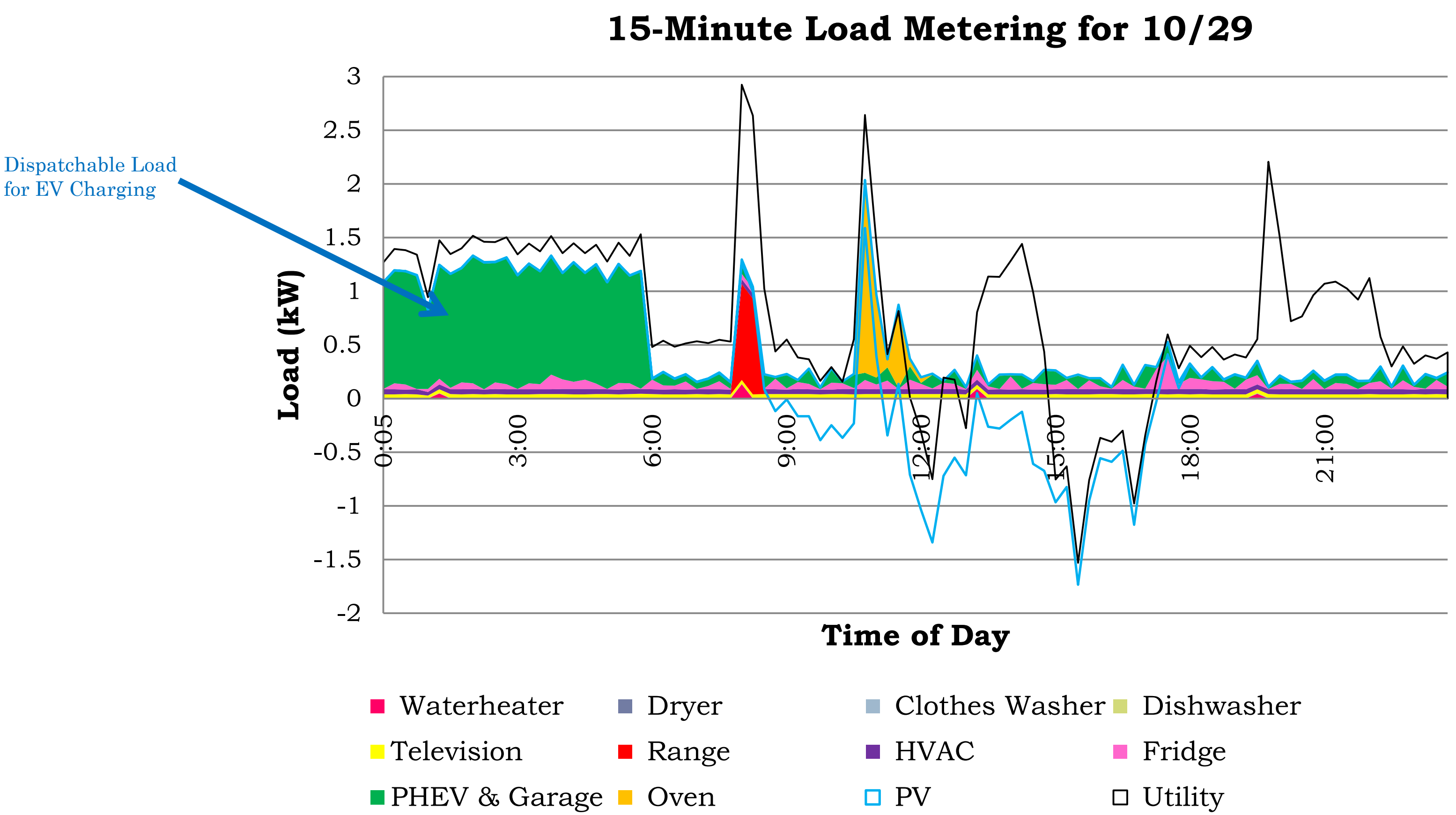
333mV Hinged Split Core AC Current Transformers

Compact & light-weight split core current transformer is designed for installation on branch circuits within the electrical panel

- Quick & simple install with hinged clip
- Safe mV secondary output
- 5A - 630A AC current input range
- 0.5% accuracy from 10-120% of rated current
- UL recognized

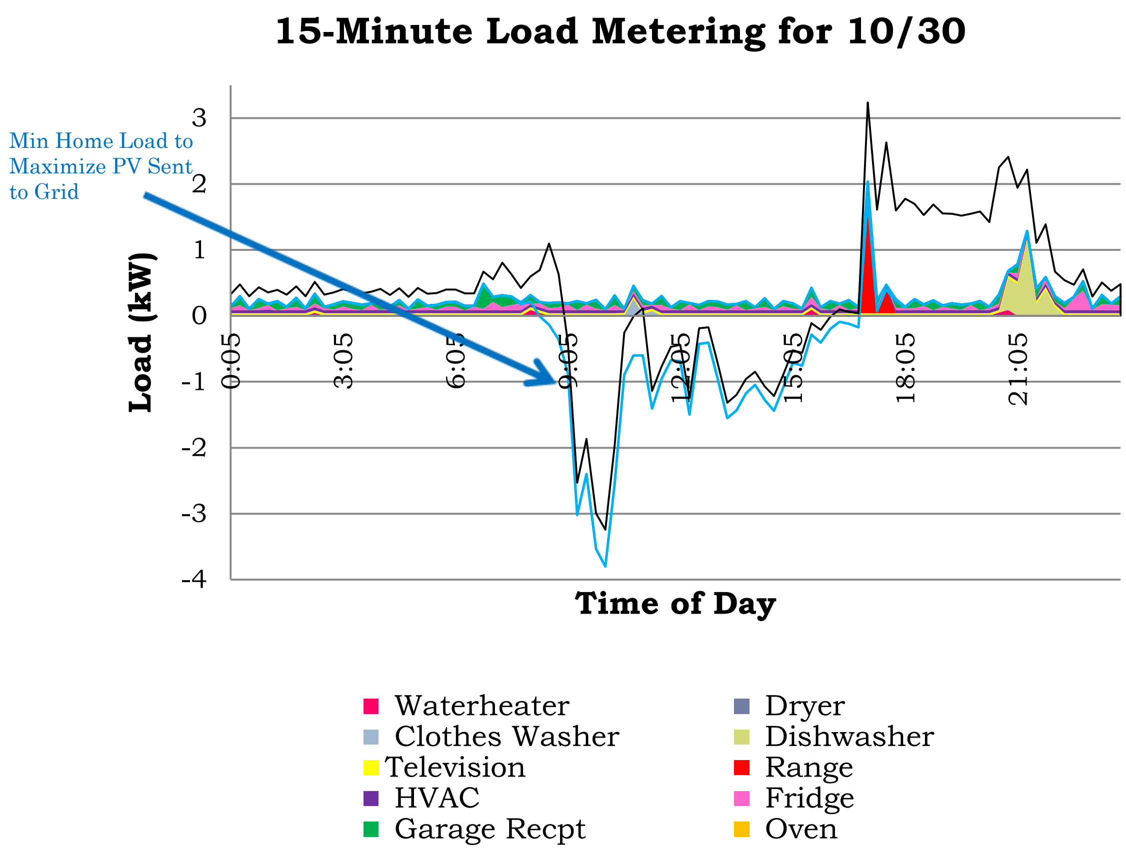
Channel	Circuit	Phase	Rating (A)
1	Main Panel Breaker	A	250
2	Secondary Panel Breaker	A	120
3	Generation Breaker	A	60
4	Main Panel Breaker	B	250
5	Secondary Panel Breaker	B	120
6	Generation Breaker	B	60
7	HVAC Aux & Blower	B	60
8	HVAC Aux	B	60
9	HVAC Compressor	B	60
10	Refrigerator	A	30
11	Water Heater	A	30
12	Range	A	30
13	Dryer	B	30
14	Clothes Washer	B	30
15	Dishwasher	B	30
16	Garage Receptacles	B	30
17	Entertainment System	B	30
18	Oven	B	60

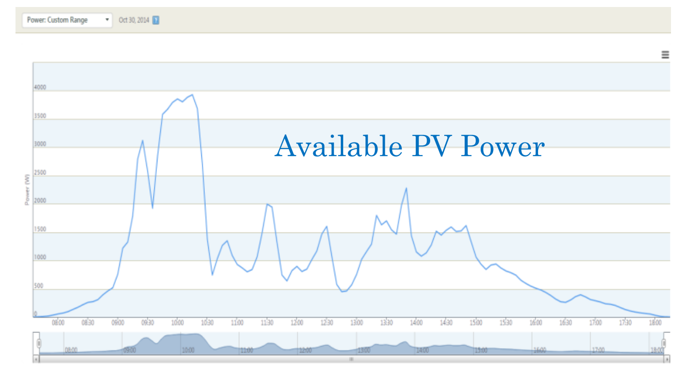
Load (Current) Sensor Data – EV Charge



Load Building Example

October day – Autumn 2014





Maximum Push of PV to Grid Example

Role of Control System

- Using Data from Multiple sources
  - PJM (regional RTO) locational marginal price signal
  - AccuRev® CT sensors for the residence and 120/240V circuits
  - Wemo® power sensing devices for individual end-use loads
  - Current site weather and local weather forecast
- Raspbery Pi Controller can decide to –
  - Store Thermal Energy – Preheat or Precool Home
  - Store Electrical Energy in Chevy Volt® EV
  - Maximize PV power placed on Grid (shedding internal loads)
  - Maximize use of PV power by home loads and EV
  - Island the microgrid from the Grid and operate in isolation and restore the Grid connection when economics are favorable

Installed Microgrid Instrumentation & Controls

Table 2: BOM of installed instrumentation

Part	Unit Cost	Quantity	Subtotal
AcuRev2020	$923	1	$923
250A or 120A CT	$39	4	$156
30A or 60A CT	$22	14	$308
Ecobee Smart-Si Thermostat	$136	2	$272
Belkin WeMo Insight	$56	6	$336
Modified Weather Station	$300	1	$300
Raspberry Pi & accessories	$60	1	$60
		Total	**$2,355**

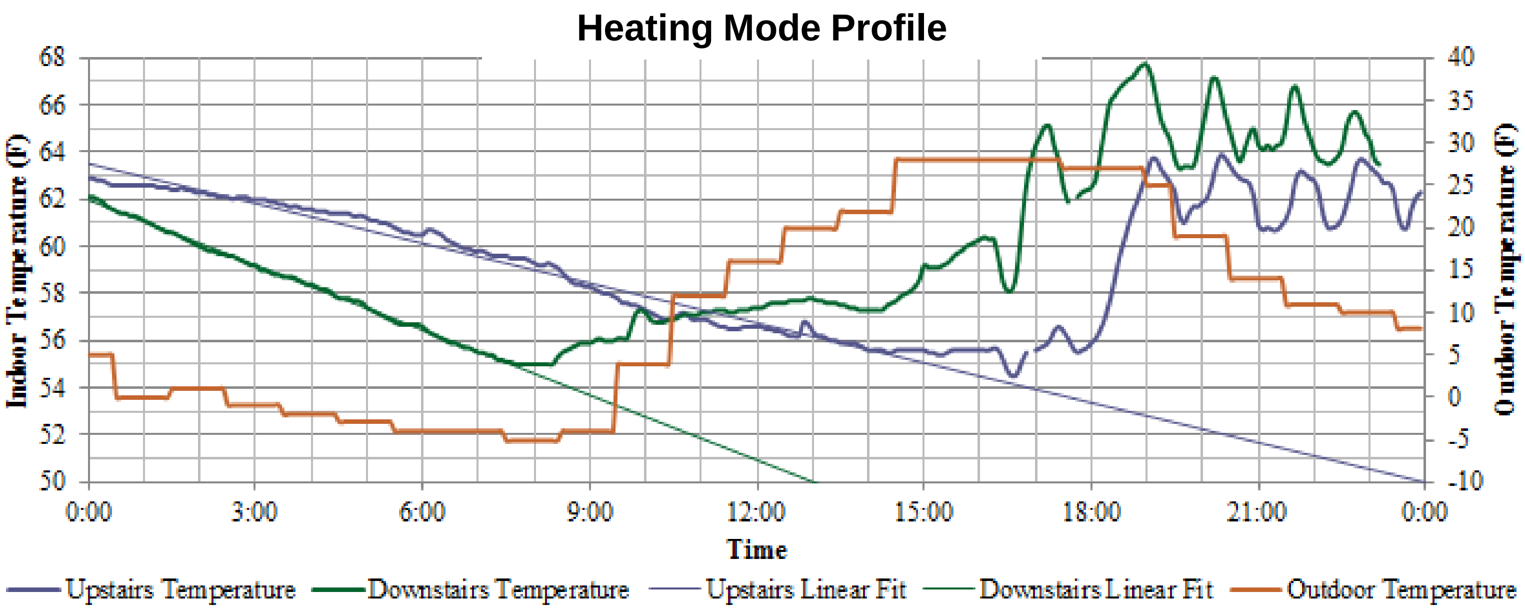
Sensors and Controls for Residential Microgrid → $668

'Virtual Storage' through Load Mgmt

- Energy storage is possible without conventional electrical storage asset (i.e., battery) by using the latent heat and thermal mass of the dwelling (sink and source)
- Analysis of real data in pre-heating or pre-cooling experiments suggests that multiple kWh can be stored in dwelling ahead of peak demand times allowing compressors to be turned off during the times of high cost and strain on the electric utility grid
- Control strategies allow for
  - 1) maximum push to grid of available resources (up to 5kW generation from PV),
  - 2) minimize/maximize domestic load presented to the Grid, or
  - 3) go completely offline in island mode (0kW load)

‘Thermal Storage’ can be observed

Thermal Storage



Upstairs slope: -0.92°F/hr

Downstairs slope: -0.56°F/hr

|Average slope|: 0.65°F/hr

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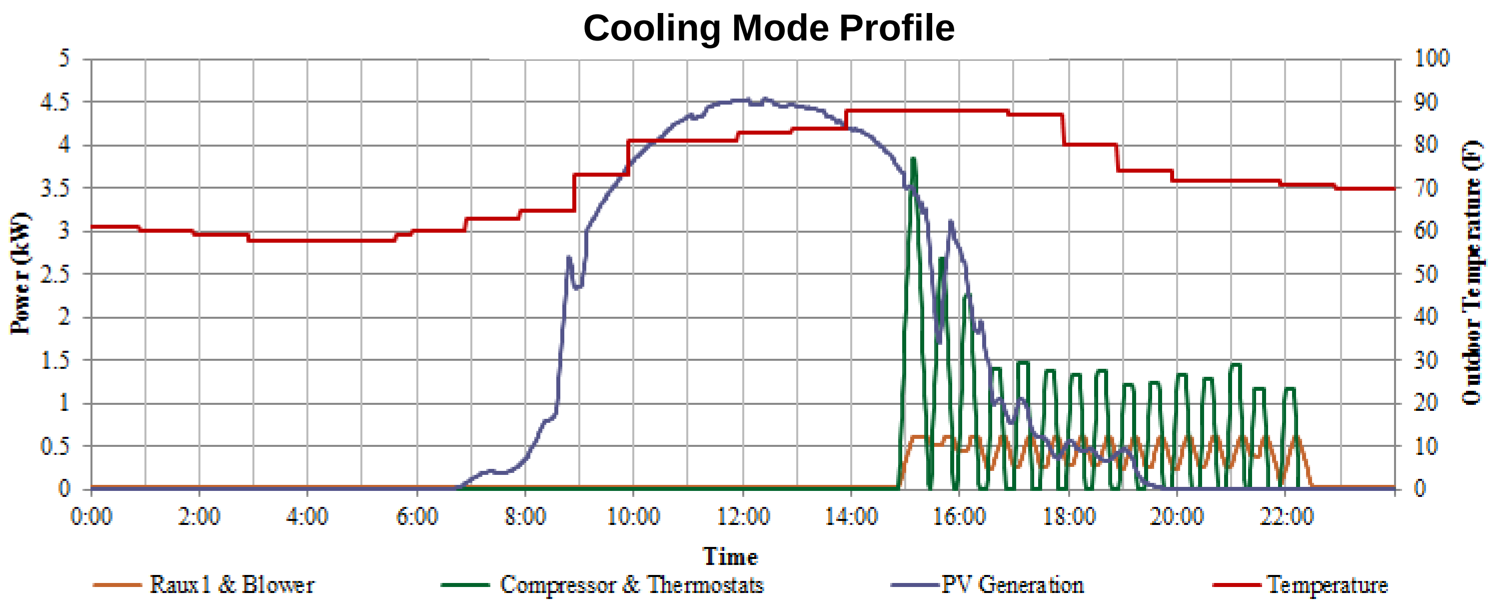
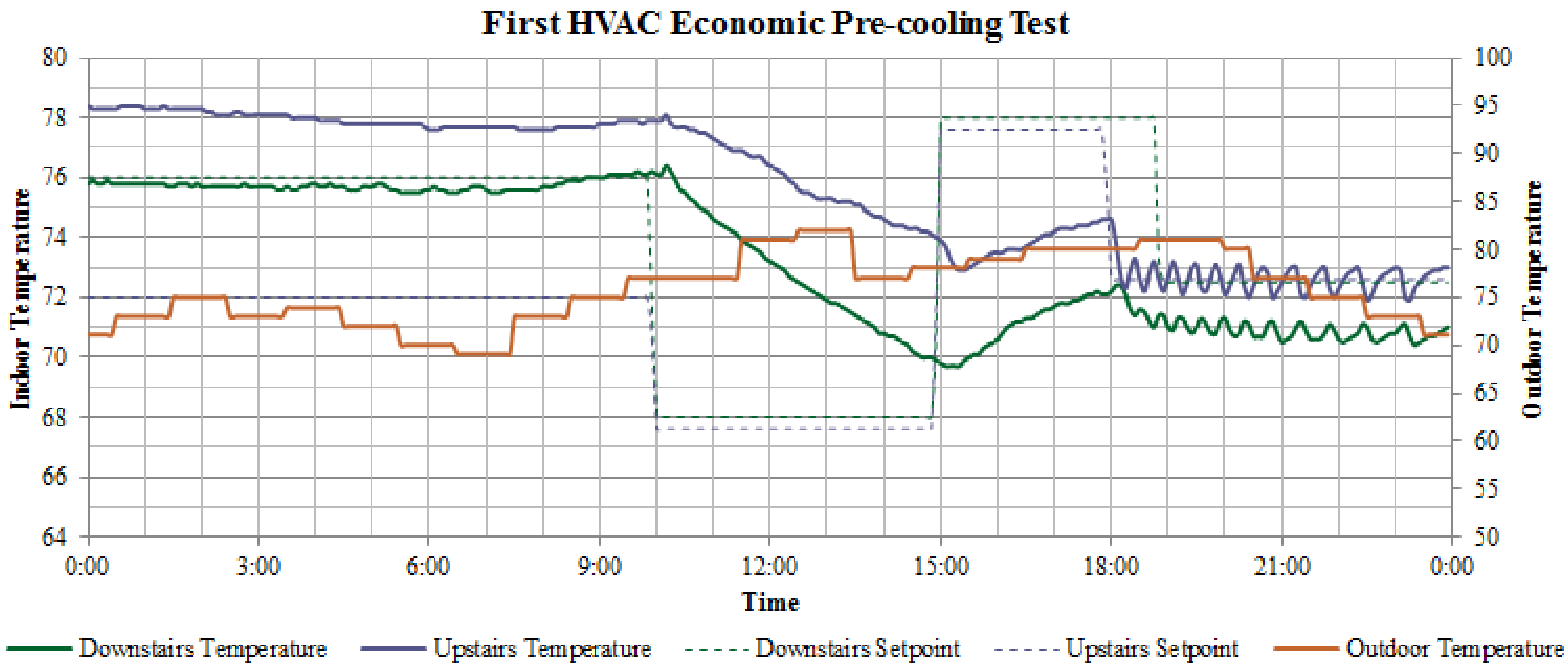
'Thermal Storage' – natural - night and day

Shiftable Load Potential



32kWh produced by PV array and 11kWh consumed by HVAC system

‘Virtual Storage’ – HVAC system control



3+ hours of ‘no load’ from compressor

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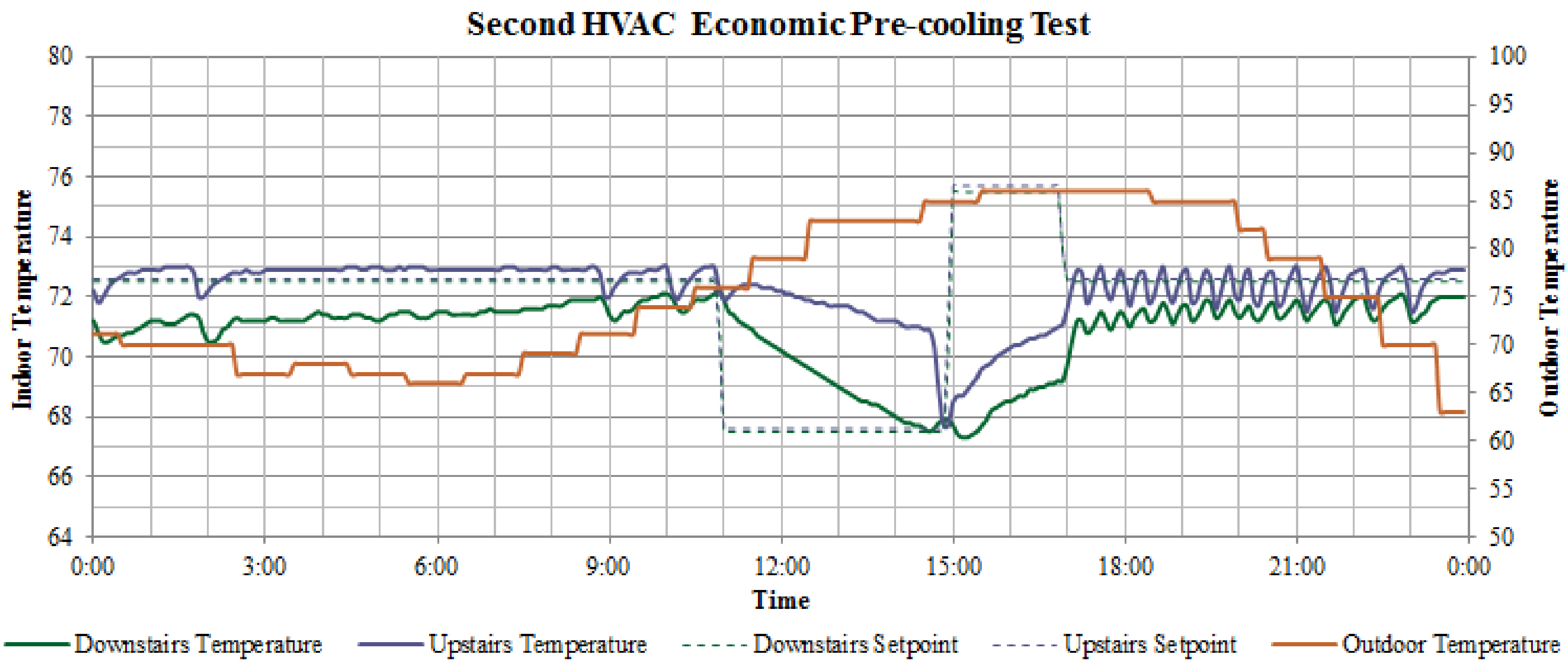
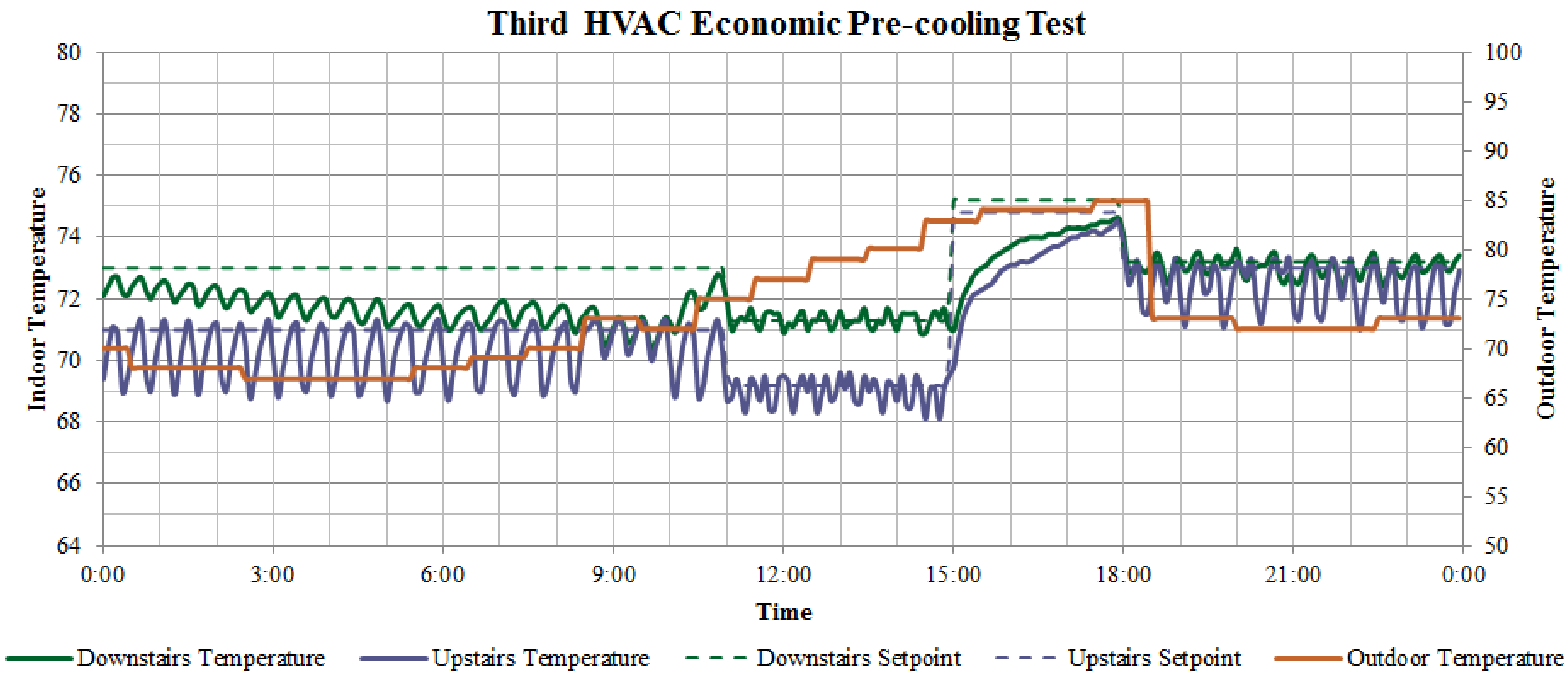
'Virtual Storage' – HVAC system control



2+ hours of 'no load' from compressor

'Virtual Storage' – HVAC system control



3+ hours of 'no load' from compressor

HVAC Load Shifting Results

Metric	Test 2	Test 3
Pre-cooling energy consumption	15.4 kWh	7.4 kWh
Pre-cooling average Load	3.85 kW	1.85 kW
Pre-cooling monetary cost	$0.73	$0.31
Non-load management energy consumption (Estimated)	8 kWh	7.92 kWh
Non-load management energy cost (Estimated, higher LMP)	$0.55	$0.73
Load management energy savings (Estimated)	6.8 kWh	5.6 kWh
Load management monetary savings	$0.27	$0.60

Total value estimated at $248/yr

- Estimated value at $88/yr based on LMP
- Additional value of $160/yr from Citizen's Electric

Conclusions

- Benefits of this technology far outweigh costs (<3 year pb)
- Many kWhs can be shifted through the day (<$100/kWh)
- Possibilities for this affordable residential microgrid as a storage alternative are just beginning to be realized
- Microgrids can help the Grid with instability issues it faces with renewables (PV and wind)
- Microgrids may represent the path forward in Grid modernization, improvement and control

Special Thanks to the Supporters of our Research:

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SUSTAINABLE ENERGY RESEARCH TEAM

comcast® xfinity™

TECH RESEARCH & DEVELOPMENT GRANTS