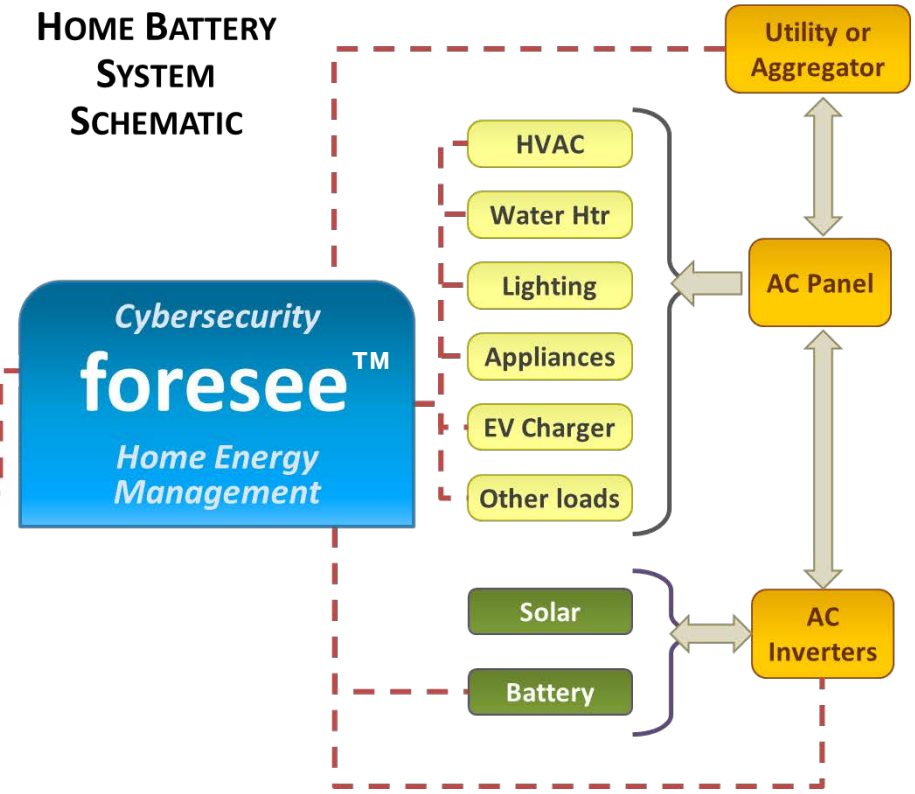
Home Battery System: Homeowner-Centric Automation for Cybersecure Energy Efficiency and Demand Response

2017 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: May, 2016
Planned end date: March, 2018

Key Milestones

1. Go/No Go: Demonstrate automated, self-learned control of simulated loads. Cybersecurity Risk Assessment approved. **09/20/2016 – Go Received**
2. Demonstrate improved efficiency, resource predictions, and laboratory readiness for use case demonstrations. 6/20/2017

Budget:

Total Project to Date: $2.4M thru FY17

- DOE: $500k
- Cost Share: $1,900k ($1M BPA, $900k Bosch)

Total Project: $3.1M

- DOE: $750k
- Cost Share: $2,400k ($1.25M BPA, $1.15M Bosch)

Key Partners:

- Bonneville Power Administration
- Robert Bosch, N.A.
- Colorado State University

Project Outcome:

Residential automation solution delivers "win-win" for homeowners, utilities, and energy service aggregators.

Increase residential energy efficiency (goal: 5% savings, or ~1 Quad) & demand response participation (goal: 2kW+ firm resource per home), by easing consumer adoption of integrated solutions, towards enabling >10% active devices to provide flexibility by 2035.

➔ **Targets goals in BTO/ET MYPP, DOE Grid Modernization MYPP, and BPA Innovation Roadmaps**

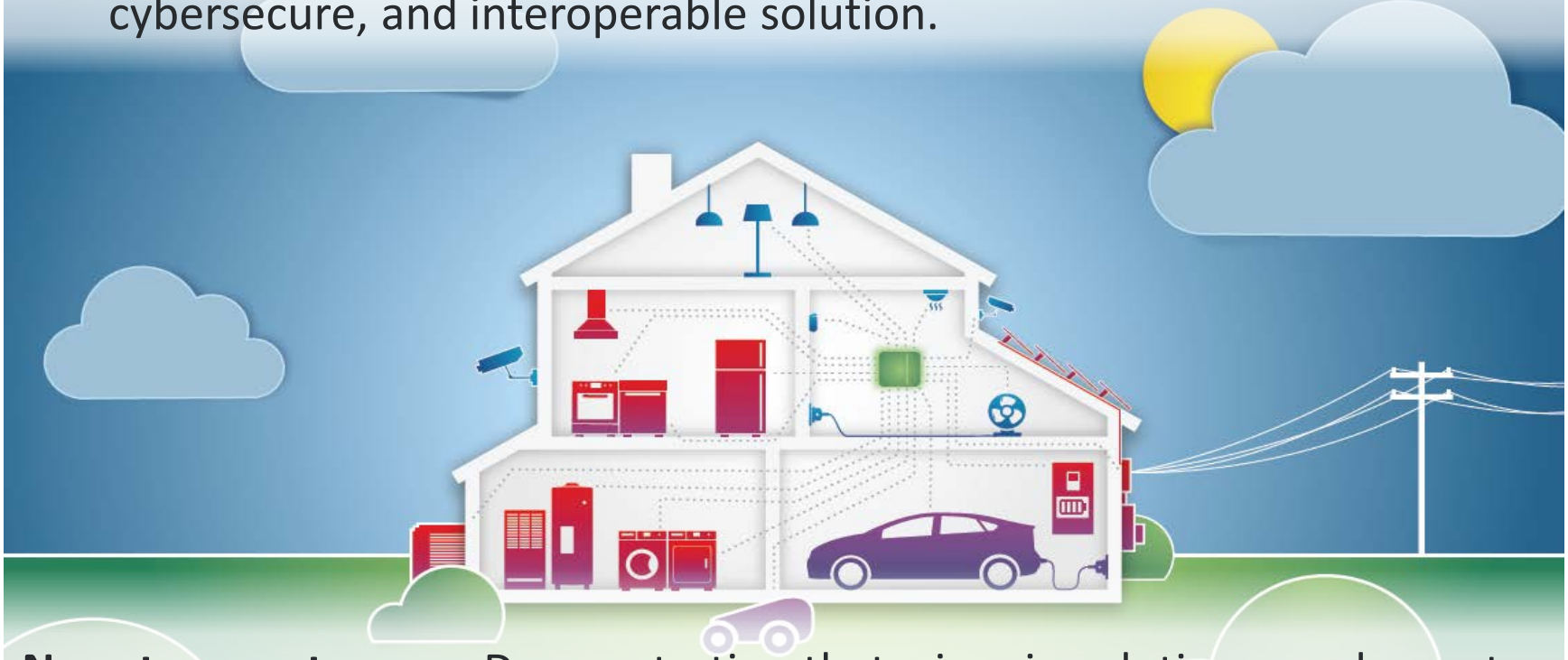
Purpose and Objectives

Problem Statement: Emerging residential technologies confuse homeowners with complexity and lack of interoperability. Integrated energy management is lacking among novel products. Demand Response appears to require homeowner discomfort, but homes drive utilities' peak demand.

	Target Market/Audience				
	Homeowners	**Leading Builders**	**Utilities**	**Grid Service Aggregators**	**Manufacturers**
Market Barriers (Today)	Confusion, frustration, high cost	Lack of proven, easy-to-integrate solutions. Utilities push back against rooftop PV	Limited residential DR participation via direct load management	No devices in homes to control, or high cost to retrofit	Connectivity features sell. Energy opportunities don't
Solution (Tomorrow)	Simple & secure automation acts on owner's behalf. Low costs, good comfort, highly sustainable	Smart, green homes increase profit margins, improve HERS scores and reduce sales time. Controls streamline PV permitting	Ample reliable DR resource available through aggregators. Flexible load responds to signals. More PV. Increased profit	Strong business opportunity & growing markets. Easier access to secure, firm resources.	Additional customer value from connected equipment increases sales & transforms appliance markets. PV & batteries take off

Purpose and Objectives

Impact of Project: Effectively meet homeowner comfort/budget and power-sector demand response needs with a low-cost, simple-to-use, cybersecure, and interoperable solution.



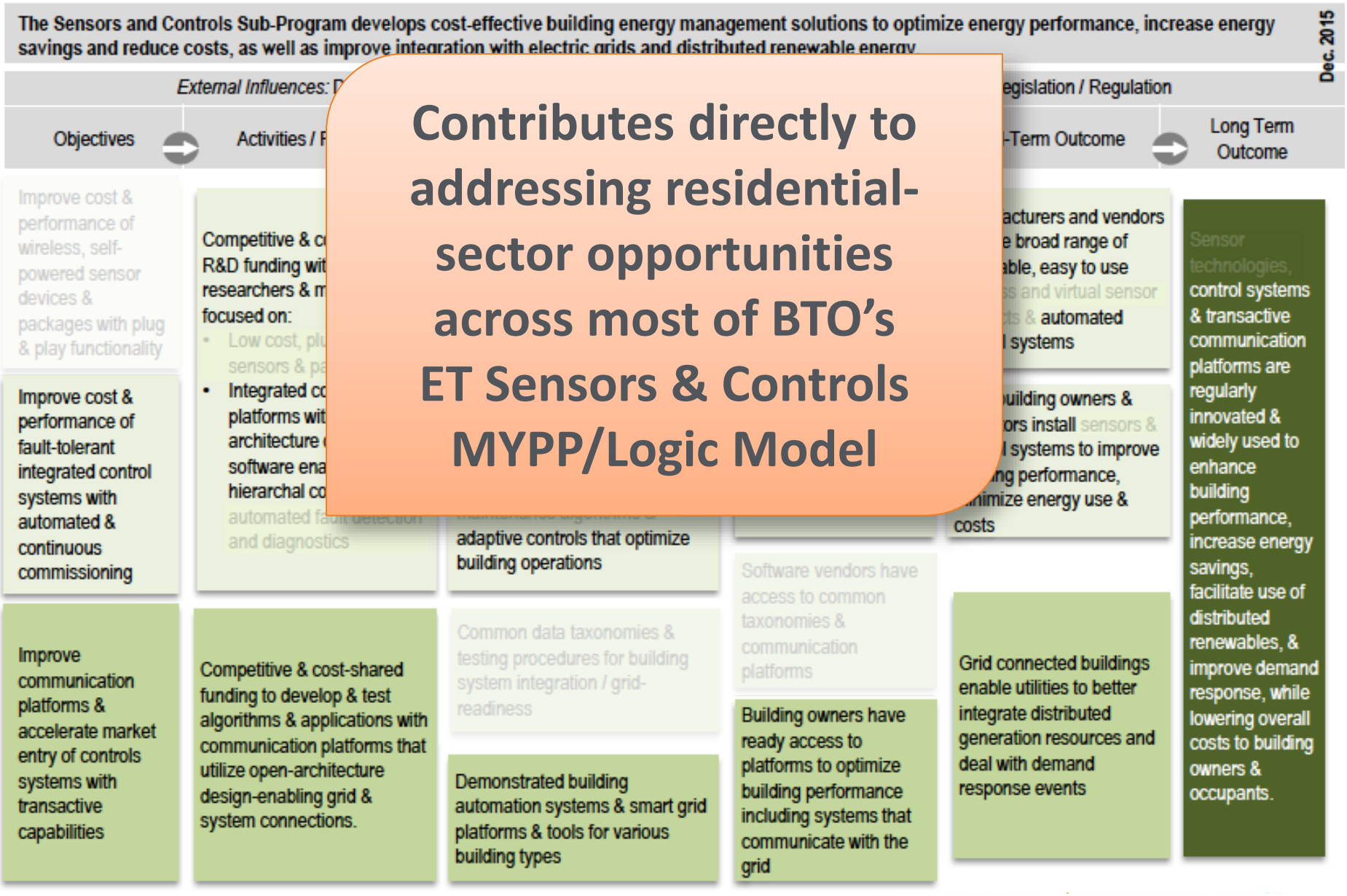
Near-term outcomes: Demonstration that win-win solutions can be cost-effective through emerging technological advancements

Intermediate outcomes: Connected equipment has increased value, speeding adoption of efficient tech and reducing net distributed resource costs

Long-term outcomes: No-pain demand response technology enables massive energy savings and increased infrastructure reliability

Graphic courtesy of Robert Bosch

Fit with ET Sensors & Controls Logic Model



Contributes directly to addressing residential-sector opportunities across most of BTO's ET Sensors & Controls MYPP/Logic Model

Approach

Key Issues currently being addressed:

a) Interoperability with a variety of connected appliances
b) Lack of existing whole-home automation products
c) Poor Internet-of-Things cybersecurity
d) Lack of prior research on complex homeowner decision processes
e) Lack of techno-economic opportunity assessment for home energy management and stationary battery storage.

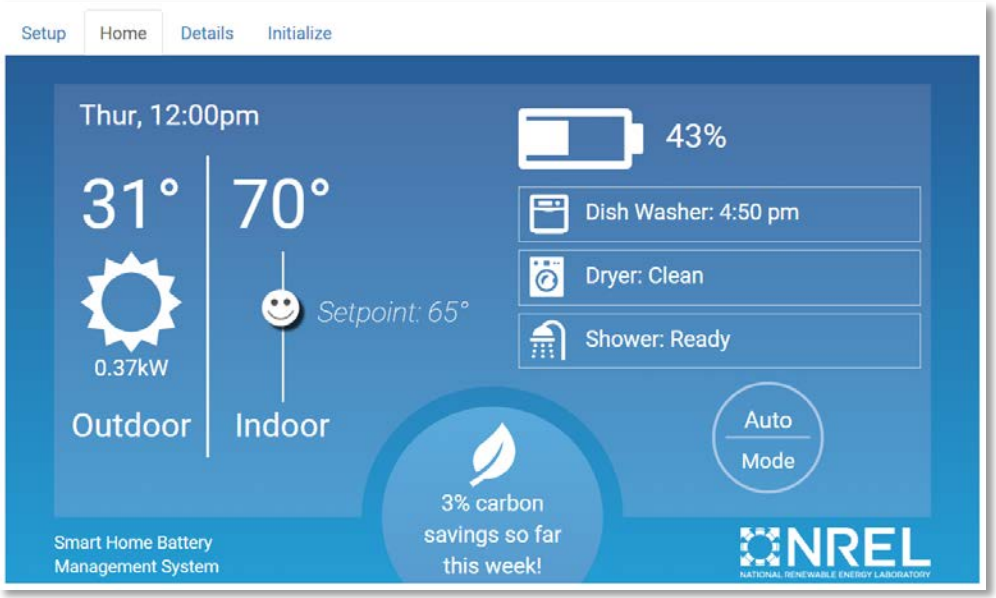
Distinctive Characteristics: Highly-predictive (72%+ at initialization) preference elicitation method identified, 12% uncertainty in resource availability at 12-hour look-ahead, and minimum 5% energy savings demonstrated in simulation

Progress and Accomplishments: User Preferences

- 3 method evaluated; 1,000 respondents each
- Follow-up survey, 250 each, to assess predictiveness

Method	Percent Correctly Predicted	Average Usability Score (scale of 1-7)	Average Completion Time (min)
AHP	49.0%	**2.48**	9.0
DCM	68.0%	2.57	5.7
SMARTER	**72.2%**	2.53	**5.5**

SMARTER selected as the method for **foresee**

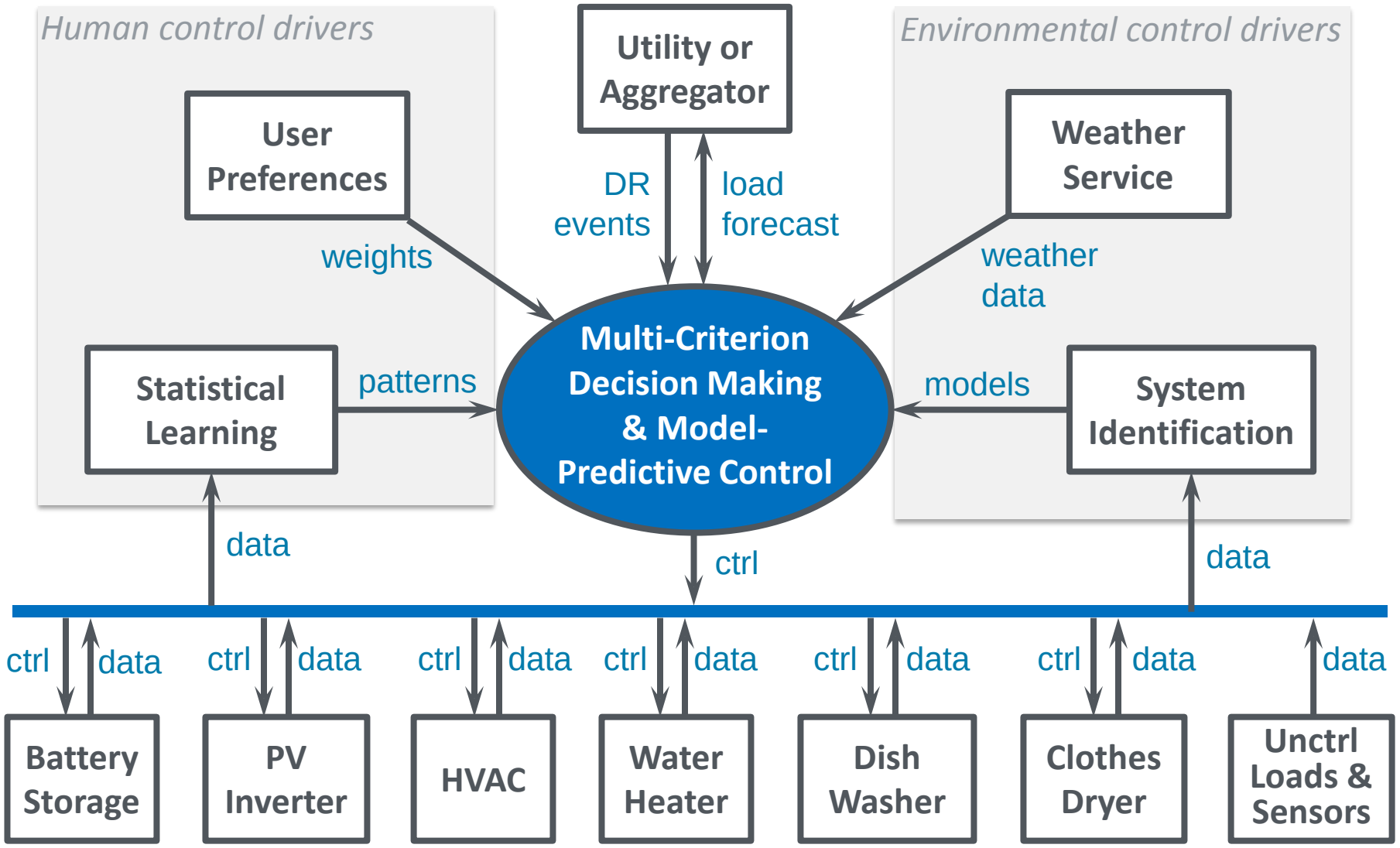


Money Dishes Shower Length Asym. Term

$$U_i = \beta_{i,m}M + \beta_{i,c}C + \beta_{i,d}D + \beta_{i,l}L + \beta_{i,sl}S_l + \beta_{i,t}A_t^2 + \beta_{i,tn}\, I_{A_t<0}A_t^2 + \epsilon_i$$

Source Energy Laundry Air Temperature Error

Progress and Accomplishments: Architecture



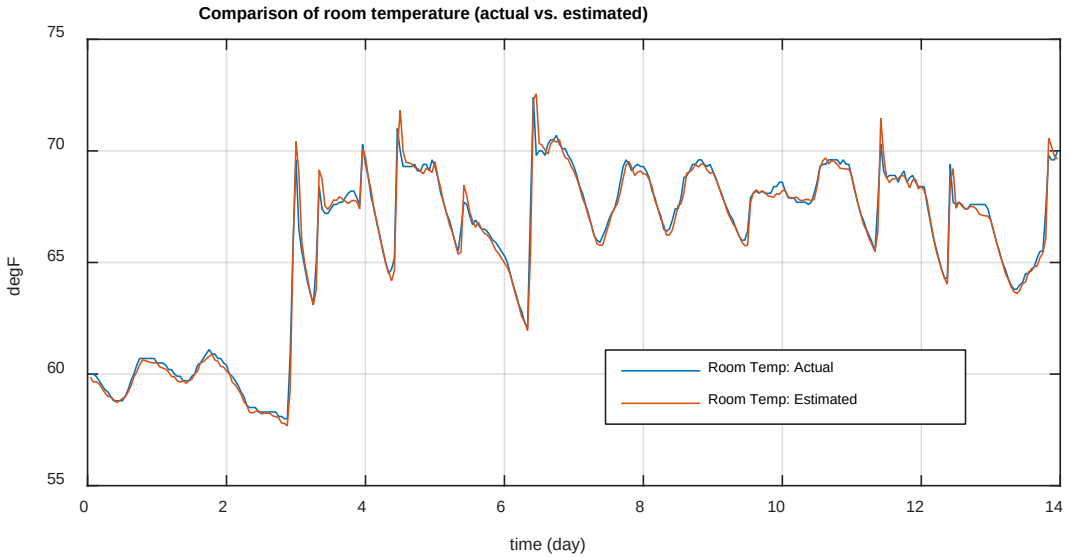
Progress and Accomplishments: Self-Learning System ID

RBSA House 14285
Seattle, WA

Heating: electric forced air furnace (22 kW)

Results:

- RMSE = 0.73°F
- R^2 = 0.95

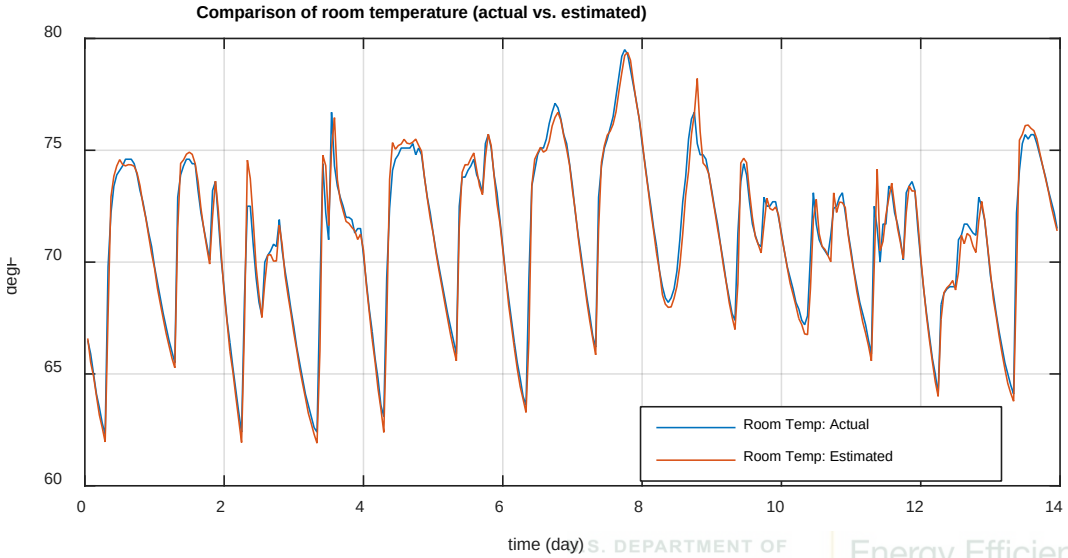


RBSA House 11775
Tenino, WA

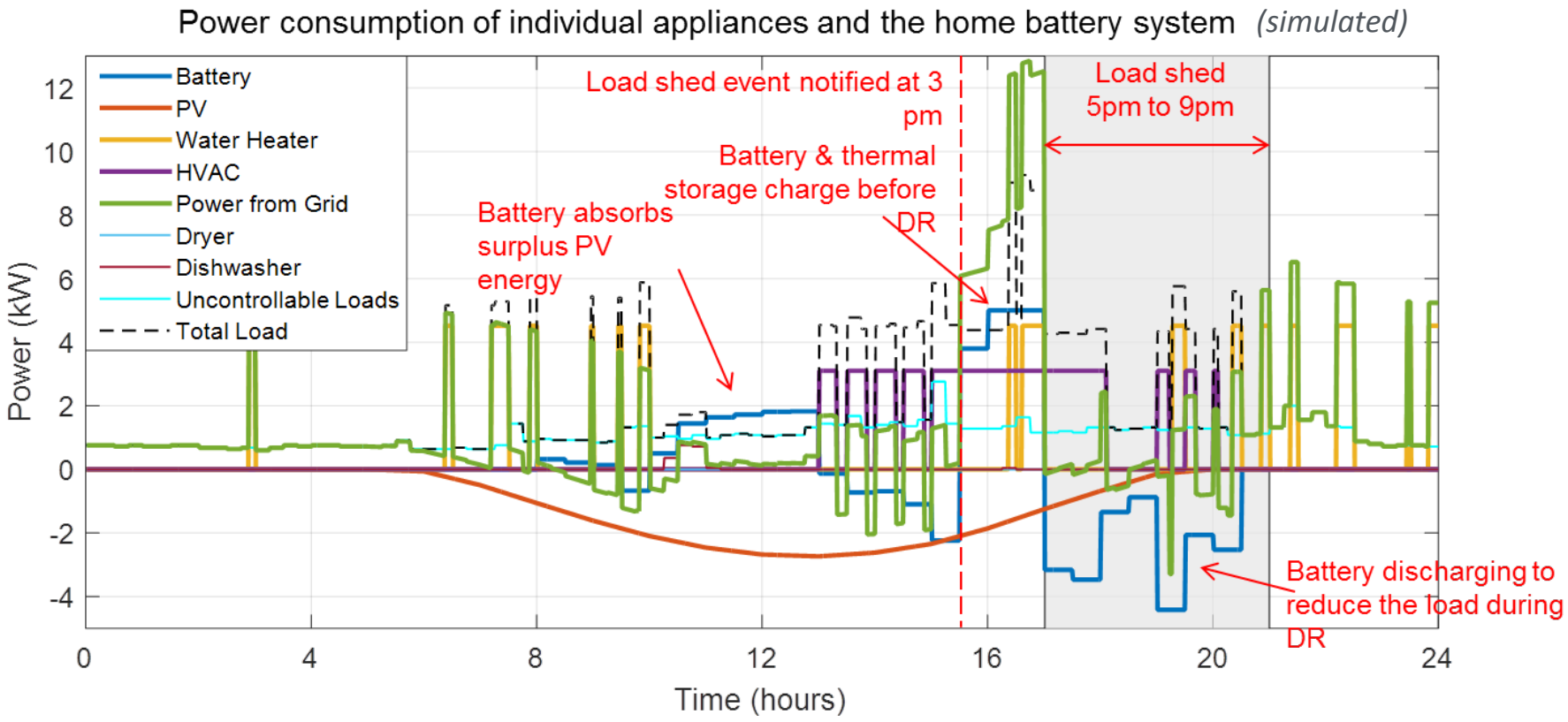
Cooling: heat pump

Results:

- RMSE = 0.37°F
- R^2 = 0.98



Progress and Accomplishments: Whole-Home Control



Current performance metrics: *(in Pacific Northwest homes studied)*

- Minimum energy savings, in any simulated home-day: 1.9kWh
- Maximum DR prediction error in simulated homes: 11%
- Average cost savings/home/day: $0.37 (or $130/yr)
- Average DR resource: 1.6 kW

Progress and Accomplishments: Cybersecurity

Progress and Accomplishments

Accomplishments: Successfully meeting all milestones and deliverables, on budget and on time after delayed start.

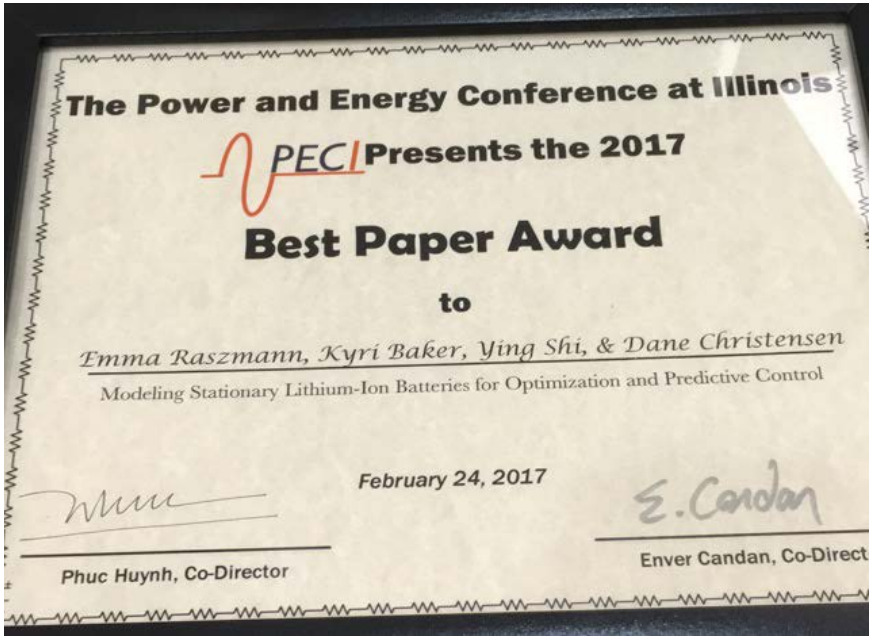
Passed Go/No Go milestone: Demonstrated prototype control platform, operating simulated homes with <20% error in look-ahead prediction of demand response resource, delivered with energy savings (at least 2kWh/home/day) and no negative comfort impacts

Market Impact: Pre-market innovative technology in development; no market impact to date.

1. Engaging with industry to disseminate technical lessons learned
2. Three publications; seven additional publications in preparation – disseminating lessons learned
3. Three commercialization opportunities being pursued

Awards/Recognition

- Bosch/ESCRYPT devoted DistribuTECH booth to highlight this collaborative project
- Copyright & Trademark approved by DOE, in support of future commercialization
- Continued strong support from Bonneville Power Administration (primary funder) and Robert Bosch (industry partner; substantial in-kind participation)



"The Bonneville Power Administration sees great potential in this Technology Innovation project with NREL in its ability to reduce energy use and peak demand through automated management of residential end loads. […] **The future of energy will rely on technologies which can help us manage grid issues […] without noticeable changes within the home while maintaining customer satisfaction**. This project is a great example of the creativity and success that BPA strives to support when funding Technology Innovation projects."

– Stephanie Vasquez, BPA

"Bosch is excited about its involvement in this highly innovative project with NREL and Bonneville Power Administration. One of the benefits to both residential homeowners and the power industry is the potential to **dramatically reduce peak demand energy usage while also lowering consumers' energy bills**. Technologies like those being developed for this project will play a valuable role in attaining a robust, low-cost, and resilient power system for the future. Bosch is dedicated to bringing energy-efficient products to market that are designed to improve quality of life."

– Scott Averitt, Robert Bosch North America

Project Integration and Collaboration

Project Integration: Tight collaboration with Bosch on co-development of the full cybersecure controller and connected home solution. Presentation and publication of results at industry conferences, journals. Engaging with other interested manufacturers for future collaborations.

Partners, Subcontractors, and Collaborators:

- **Bonneville Power Administration** – funder; Ryan Fedie & Kari Nordquist. Providing strategic and project direction. $1.25M participation, cash
- **Bosch/ESCRYPT** – partner; Scott Averitt. Developing cybersecurity layer, providing connected home appliances and battery, advising on controller hardware. $1.15M participation, in-kind
- **Colorado State University** – subcontractor; Sid Suryanarayanan & Pat Aloise-Young. Expertise in behavioral studies and multi-criterion decision making

BONNEVILLE POWER ADMINISTRATION

BOSCH

Colorado State University

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Project Integration and Collaboration

External Communications:

- D. Christensen, S. Isley, K. Baker, X. Jin, P. Aloise-Young, R. Kadavil, S. Suryanarayanan, "**Homeowner Preference Elicitation: A Multi-Method Comparison**," Proceedings of the 3rd ACM International Conference on Systems for Energy Efficient Build Environments (BuildSys 2016), Palo Alto, CA. Nov. 16-17, 2016.
- E. Raszmann, K. Baker, D. Christensen, and Y. Shi, "**Modeling Stationary Lithium-Ion Batteries for Optimization and Predictive Control**," Power and Energy Conference at Illinois (PECI). [Best Paper Award], 2017.
- X. Jin, K. Baker , S. Isley, and D. Christensen, "**User-Preference-Driven Multi-Objective Model Predictive Control of Residential Building Loads and Battery Storage for Demand Response**," in publication at 2017 American Controls Conference (Invited Paper)
- R. Kadavil, S.Suryanarayanan, P. Aloise-Young, S. Isley, and D. Christensen, "**An Application of the Analytic Hierarchy Process for Prioritizing User Preferences in the Design of a Home Energy Management System**," submitted to Applied Energy

➢ Six additional papers in development

Project Direction/Next Steps

Next Major Milestone Planned for 6/20/2017

The project team will demonstrate components of the Home Battery Solution to prove that the Home Battery System hardware/control system integration is **ready to proceed to laboratory performance and cybersecurity testing**.

This milestone is passed when NREL:

a) Achieves **10% error in look-ahead predicted energy and resource availability in simple example cases**, and

b) The home battery system is **integrated with at least five connected appliances in NREL's ESIF Systems Performance Laboratory** with control capabilities which enable testing against realistic, complex use cases.

This progress milestone demonstrates the continued viability of the project's control methodology and substantial progress toward the ultimate goal of demonstrating 90% confidence in delivering demand response and energy efficiency under scenarios representative of real-world use cases (TRL 6+)




REFERENCE SLIDES

Project Budget

Budget History

FY 2016 (past – started May 2016)		FY 2017 (current)		FY 2018 (planned – ends March 2018)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$250k	$950k	$250k	$950k	$250k	$500k

Total Project: $3.1M

- DOE: $750k
- Cost Share: $2,400k ($1.25M BPA, $1.15M Bosch)

FY17 Spending, to date:

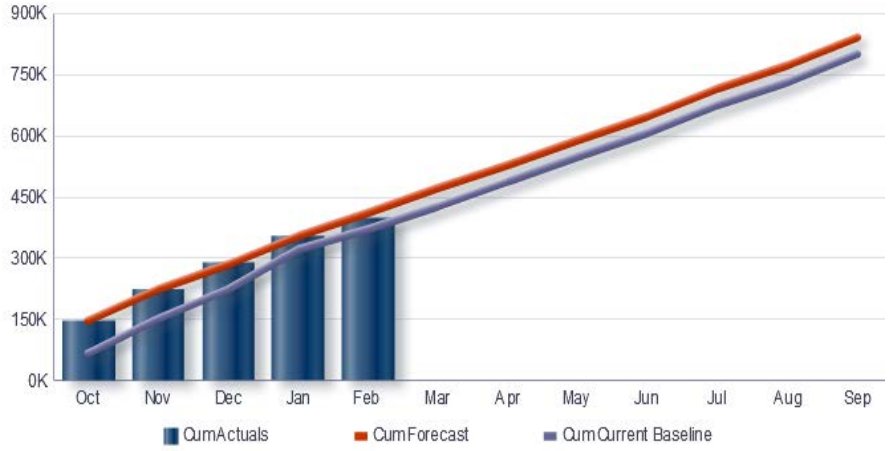
- DOE: $127k ($309k budget incl. carryover)
- Cost share: $272k BPA ($500k budget), $120k Bosch ($300k budget)

Apparent variance: Artificial

- High October accrual identified in November & being incrementally corrected over time (BPA funds)

Financial Summary: FY17 to date

Combined BPA and DOE funds



Spending & working according to plan.
57% of total budget spent.

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Project Plan and Schedule

Planned start date: 10/1/2015
Actual start date: 5/1/2016

- Delayed due to contracting
- Increased spending & met Year 1 Go/No Go Milestone on time

Project end date: 3/31/2018

Task	Task Name	FY16 1	FY16 2	FY16 3	FY16 4	FY17 1	FY17 2	FY17 3	FY17 4	FY18 1	FY18 2
1	**Control Platform**										
1.1	Control Architecture										
1.2	Data Model										
1.3	Equipment Drivers										
2	**User Preference**										
2.1	Input Methodology										
2.2	Preferences to Control Inputs										
2.3	Demo User Interface										
3	**Advanced Controls**										
3.1	Reduced-Order Equipment Models										
3.2	MPC for each equipment model										
3.3	Self-learning algorithms										
3.4	Supervisory MCDM										
4	**Hardware Development**										
4.1	Battery Selection & Integration										
4.2	Bosch Connected Appliances										
4.3	Demonstrate Integration in ESIF										
5	**Performance Test & Validation**										
5.1	Develop test use cases										
5.2	Install equipment in ESIF										
5.3	Scenario Tests										
5.4	Comfort Evaluation										
5.5	Final Demonstration										
6	**Cybersecurity (CIP)**										
6.1	Security Risk Analysis										
6.2	Security design and Specification										
6.3	Implement & deploy demo CIP										
6.4	Acceptance testing										
6.5	Penetration testing										
6.6	CIP certification										

Current Work

- Finalizing software on embedded platform
- Integrating equipment into laboratory
- Developing cybersecurity layer

Next major milestone: laboratory readiness demonstration 6/20/2017