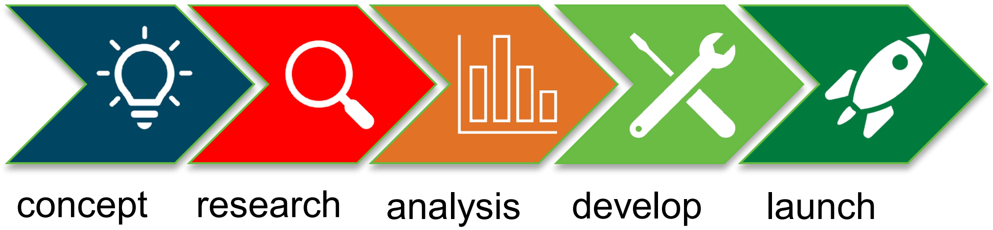
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Smart Building Start

Technology Commercialization Fund (TCF) Project



Target: buildings with centralized HVAC and multiple zones

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Project Summary

Timeline:

Start date: Jan 1, 2021
Planned end date: June 30, 2022

Key Milestones

1. Literature Review; 3/31/2021
2. Standalone algorithm; 6/30/2021
3. Distributed algorithm; 8/30/2021
4. Simulation Testing; 12/31/2021
5. VOLTTRON^{TM} implementation; 12/31/2021
6. Field Tests; 6/30/2022

Budget:

Total Project $ to Date:

- DOE: $104K (07/23/2021)
- Cost Share: $37K (06/30/2021)

Total Project:

- DOE: $250K
- Cost Share: $250K

Key Partners:

Pacific Northwest National Laboratory	*www.pnnl.gov*
verdicity	*www.verdicity.com*

Verdicity is a marketplace for open-source smart building solutions, to accelerate widespread adoption of a unifying data platform for commercial and multifamily residential real estate.

Project Outcome:

- Scalable and easily deployable algorithm that optimizes HVAC scheduling
- Documented results from rigorous simulation testing of algorithm
- Algorithm implemented in VOLTTRON^{TM} platform and field tested
- Algorithms fully documented and publicly disseminated for wide-scale industry adoption

Team

Pacific Northwest NATIONAL LABORATORY

Tim Salsbury

Austin Rogers

Karthikeya Devaprasad

Robert Lutes

- Research, math, proofs
- Algorithm development
- Coding
- Simulation testing
- VOLTTRON implementation

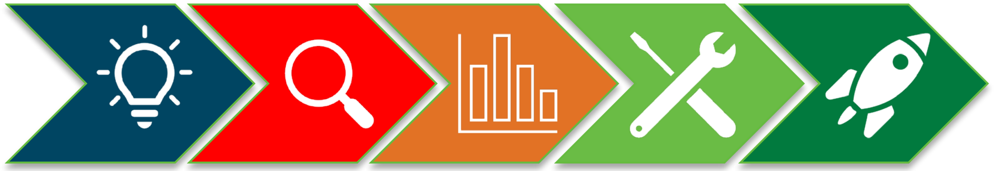
verdicity

Pete Scanlon

Rick Justis

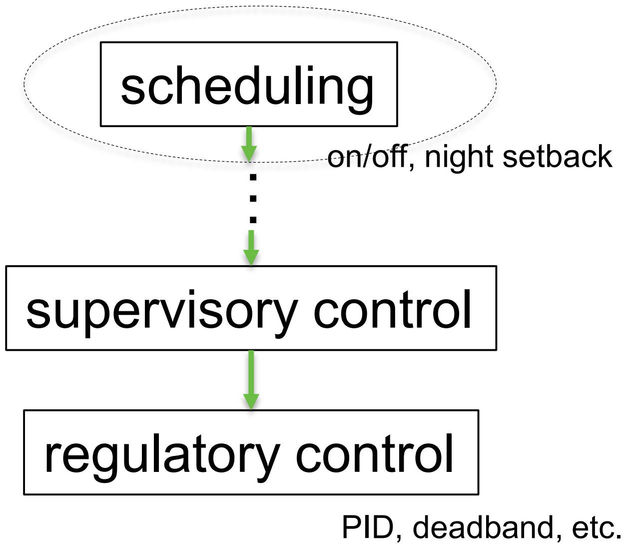
Andrew Rodgers

- User experience
- Product implementation
- Field testing
- Commercialization

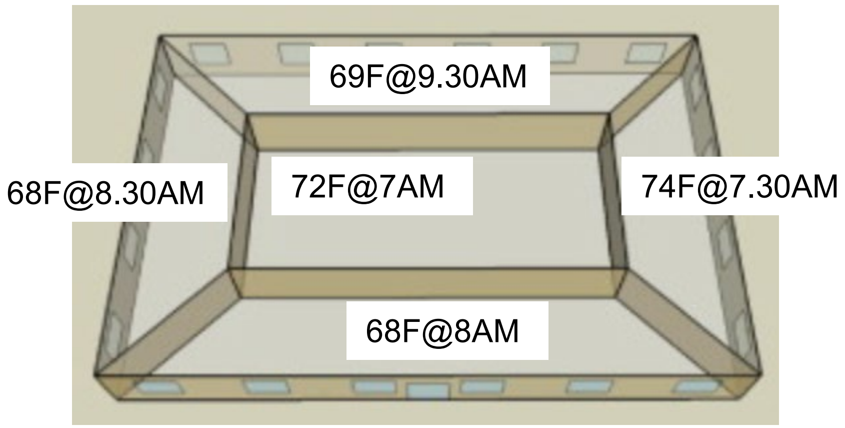


Challenge

- **Scheduling of HVAC equipment is critical but underdeveloped and often ad-hoc in buildings**
  - How can optimal schedules be determined?
- **Buildings often have many zones with different schedules and different responses**
  - How can different responses be predicted and coordinated?

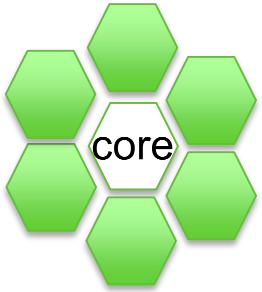


control layers

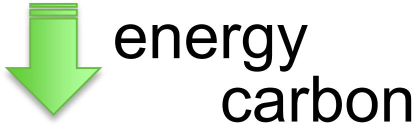


Challenge

- **Create a core optimization framework for HVAC system scheduling that:**
  – is simple, scalable, and easily deployable to different types of buildings
  – has self-learning capability to adapt to changing conditions
  – exceeds the performance and capability of the current state-of-the-art

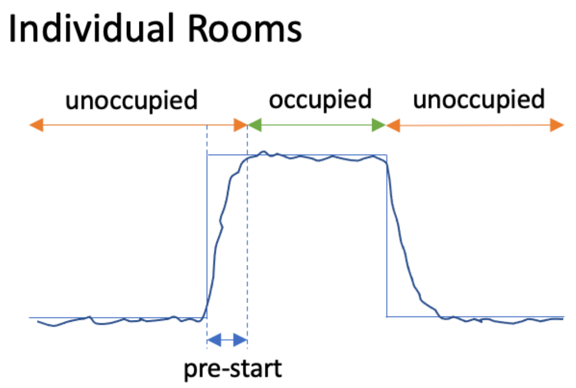


- **Contribute to energy efficiency and carbon reduction goals by:**
  – minimizing the energy used to achieve comfort requirements
  – enabling scheduling to be used as a grid service



Approach

- **Break the problem into TWO parts:**
  - (1) Individual zones
    - Learn the response of each individual zone so it can be predicted in the future

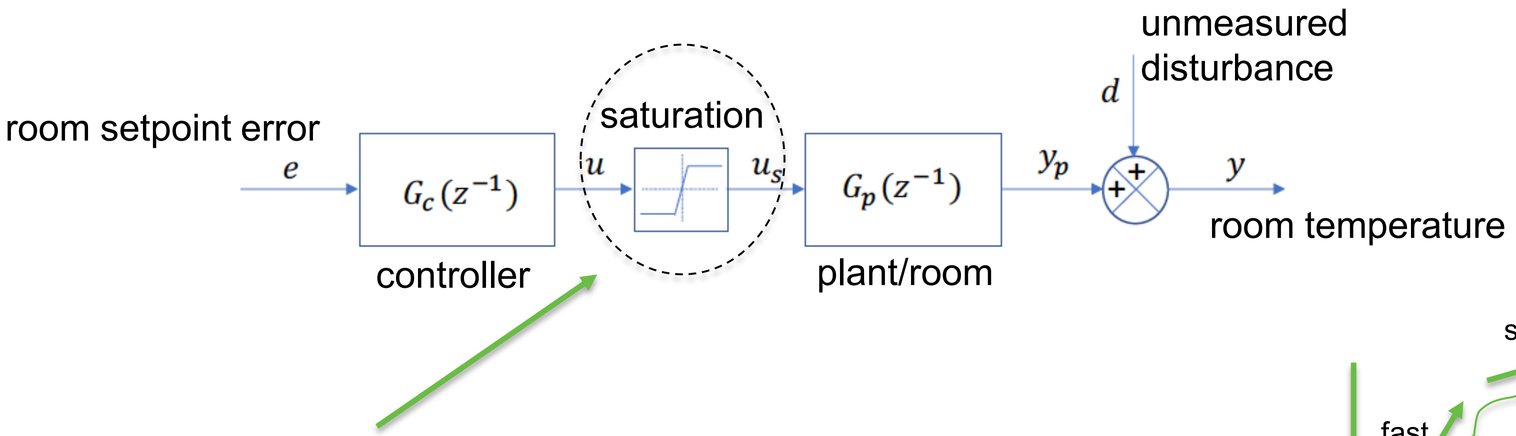


  - (2) Central system
    - Consolidate individual room information to optimize central system scheduling

$$\begin{array}{ll} \underset{t_s}{\text{minimize}} & f_0(t_s) \\ \text{subject to} & f_i(t_s) \leq b_i, \; i = 1, \ldots, m. \end{array}$$

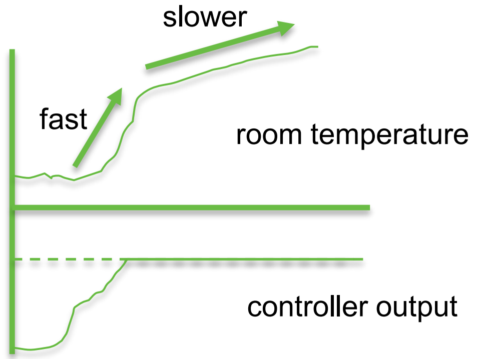
Approach: Individual Zones

- **Time series model of the room response that adapts over time**
  - Recursive least squares + forgetting
  - Controller and "plant" modeled separately



key innovation: model captures saturation

Saturation causes Nonlinear change in response time



Approach: Central System

- **Minimize run time (could also be cost) subject to constraints**
  – Consolidate room predictions of discomfort (setpoint error) and combine all rooms based on user specified priority to create building comfort measure

Room	1	2	3	4	5
Demand	0	0	1	1	0
Error @ occ.	3.2	2.4	3.6	1.2	4
Priority	0	1	1	1	2

  – Solve optimization that allows trade-off between comfort and energy use/cost

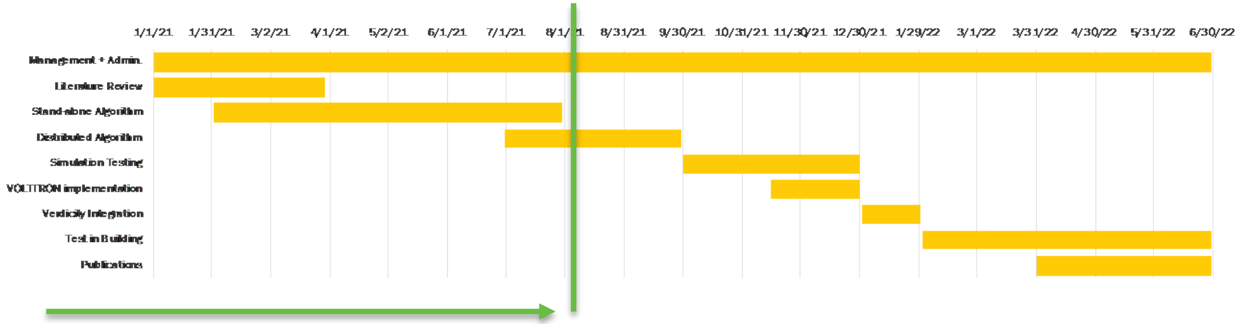
energy  comfort

$$\begin{aligned} \underset{t_s}{\text{minimize}} \quad & t_s \\ \text{subject to} \quad & \frac{1}{N_M}\sum_{i=1}^{N_M} |e_i(t_s)| \le c_{lim} \\ & e_i(t_s) \le c_{lim}, \; i = 1, \ldots, N_H. \end{aligned}$$

Impact

- **Energy use (and carbon) reduction**
  - Theoretical maximum energy savings of **33% during the start-up phase** with equivalent comfort compared to state of the art (representative zone)
- **Key differentiators from state-of-the-art**
  - Distributed approach that manages and coordinates multiple schedules
  - More accurate response prediction via control saturation modeling
  - Flexible framework for cost/energy optimization
  - Low configuration and set-up – self-learning and adaptive
  - Controllable trade-off between comfort and energy
- **Market potential**
  - Applicable to all types of buildings with multiple controllable zones
  - Flexible deployment options: cloud, BAS, smart thermostat, etc.

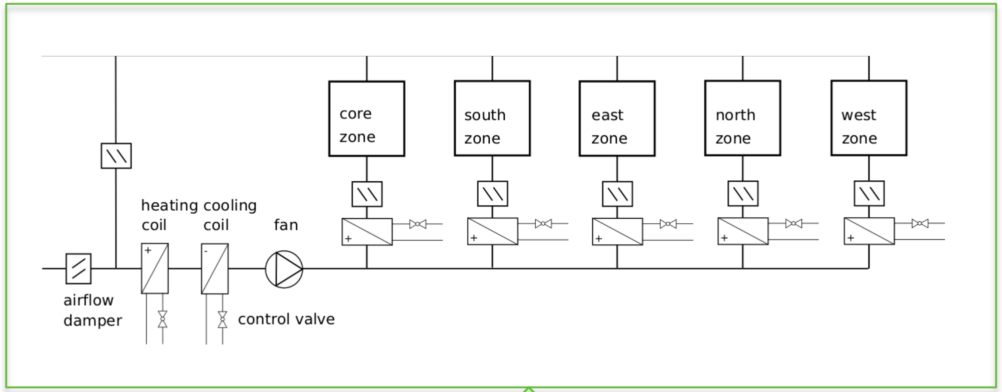
Progress: FY21

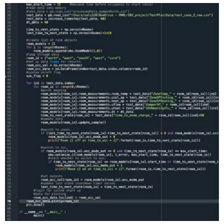


- Literature review done - to be incorporated in final report
- Algorithm formulated and documented
- Alpha version implemented in Python
- Testing using LBNL Modelica Buildings Library
  - DOE Commercial Building Benchmark, Medium Office
  - ASHRAE-2006 5-zones VAV with reheat
- Algorithm validated offline with data from simulation
- Active testing underway (ahead of schedule)
  - "product-ready" code in Python used in active testing
  - simulation is real building substitute

Modelica Language

simulated building





SBS code

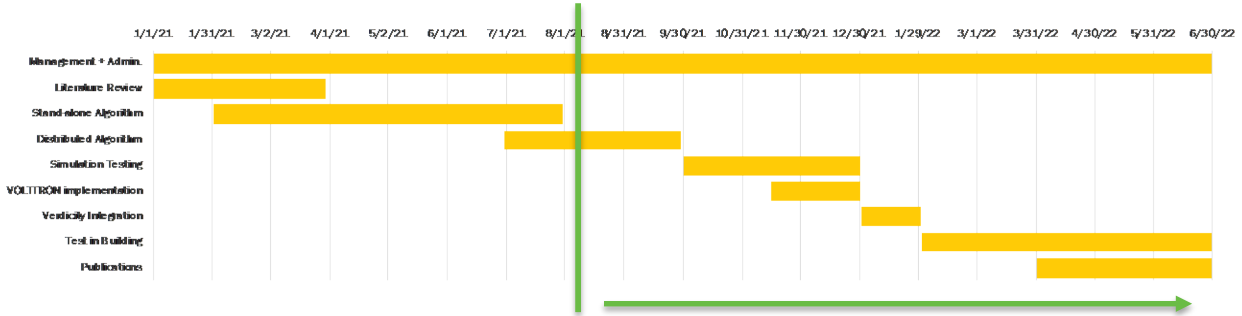
python™

Stakeholder Engagement

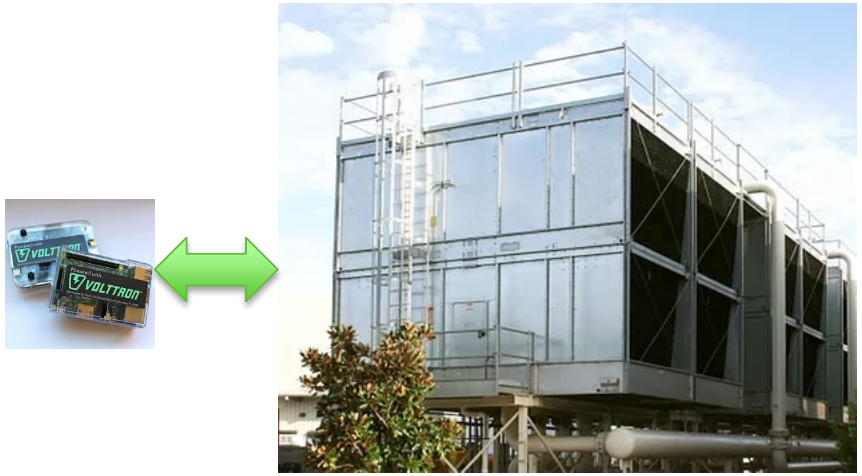
- **Real-world commercialization with project partner Verdicity**
  - The project team plans to offer SBS packages directly to Verdicity customers and channel partners.
  - Targeted stakeholders include: The City of Kansas City, MO, Akron Energy Services/City of Akron, OH, and between 1-10 public school systems across 6 states.

- **Accelerating market adoption of integrated smart controls/smart building/smart grid solutions**
  - Shared commitment to open, widely available technology, coupled with standards-based processes, languages and ontologies
  - Publish updates to the VOLTTRON™ platform code base to extend its usefulness to district energy and connected community deployments, to publicly available websites such as the Eclipse Foundation, DOE/PNNL's volttron.org, and GitHub.com.
  - Publish the research findings of the project, including supporting data, to freely available platforms and publications, or at conferences.

Remaining Project Work



- **Active simulation testing**
  – Quantify energy savings + comfort compared with traditional strategies
  – Debug edge cases
- **Implementation in VOLTTRON™ and code validation**
  – Python code clean up and streamline
- **Integration in Verdicity controls library**
  – Touchpoints and interfaces
- **Field testing**
  – Test data analysis
  – Document performance
  – Troubleshoot problems



Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: PNNL 250K over 18 months, uniform spend rate; Cost share 250K end weighted for field testing etc.
Variances: No/minor variances
Cost to Date: ~104K DOE; 78K Cost Share
Additional Funding: None

Budget History					
FY 2020 (past)		1/1/21 - FY 2021 (current)		FY 2022 – 6/30/22 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0	0	125K	78K	125K	172K

Project Plan and Schedule

Project Summary

- Start date 1/1/2021 planned completion 6/30/2022
- Project is slightly ahead of schedule

Smart Building Start			DURATION (days)
START DATE	END DATE	DESCRIPTION	
1/1/21	6/30/22	Management + Admin.	545
1/1/21	3/31/21	Literature Review	89
2/1/21	7/31/21	Stand-alone Algorithm	180
7/1/21	9/30/21	Distributed Algorithm	91
10/1/21	12/31/21	Simulation Testing	91
11/15/21	12/31/21	VOLTTRON implementation	46
1/1/22	1/31/22	Verdicity Integration	30
2/1/22	6/30/22	Test in Building	149
4/1/22	6/30/22	Publications	90