University of Toledo Transactive Energy Campus Project

Eclipse VOLTTRON^{TM} Platform Enables Successful Integration of Photovoltaic & Battery Energy Storage Systems on University Campus

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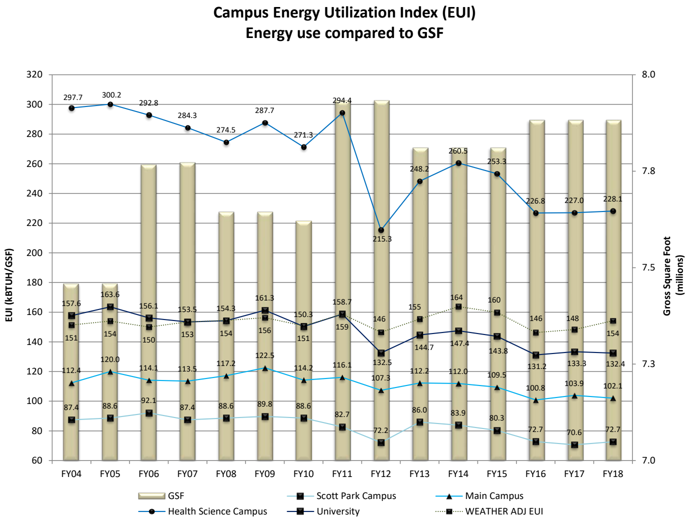
April 17, 2019



Campus Energy Utilization Index (EUI)
Energy use compared to GSF
EUI (kBTUH/GSF)
Gross Square Foot (millions)
FY04 FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12 FY13 FY14 FY15 FY16 FY17 FY18
297.7 300.2 292.8 284.3 274.5 287.7 271.3 294.4 215.3 248.2 260.5 253.3 226.8 227.0 228.1
157.6 163.6 156.1 153.5 154.3 161.3 150.3 158.7 132.5 144.7 147.4 143.8 131.2 133.3 132.4
151 154 150 153 154 156 151 159 146 155 164 160 146 148 154
112.4 120.0 114.1 113.5 117.2 122.5 114.2 116.1 107.3 112.2 112.0 109.5 100.8 103.9 102.1
87.4 88.6 92.1 87.4 88.6 89.8 88.6 82.7 72.2 86.0 83.9 80.3 72.7 70.6 72.7
GSF
Scott Park Campus
Main Campus
Health Science Campus
University
WEATHER ADJ EUI

Our Project

- Since January 2017
- Integrated photovoltaic and storage systems with the buildings on Scott Park Campus
- Testing control strategies for transactive energy.

Our team:

Dr. Michael Heben (P.I.) Professor of Physics

Dr. Raghav Khanna Professor of Electrical Engineering

Dr. Randy Ellingson Professor of Physics

David Raker Gradaute Researcher

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Michael Green Director, Energy Management

Robert Huntsman Plant Operations

Thank-you to our sponsors:

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U.S. DEPARTMENT OF ENERGY

Pacific Northwest NATIONAL LABORATORY

Why?

Campus Level

- Energy efficiency
- Cost management
- Occupant comfort
- Fault detection

Grid Level

- Grid integrity.
- Efficiency.
- Distributed energy resource integration.
- Reduce reserve requirements.

How?

The Smart Grid Enable communication & collaboration.

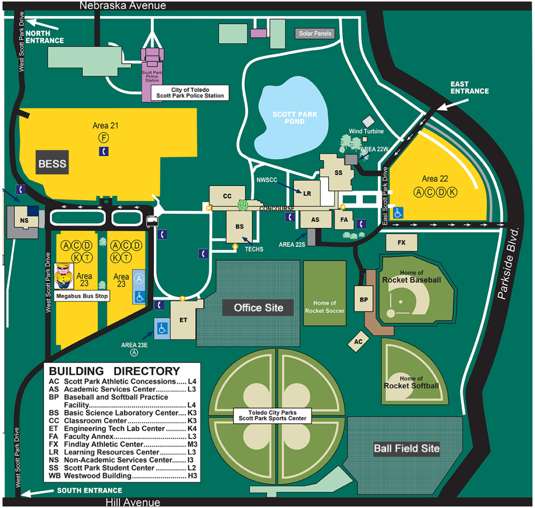
Demand Side Management Allow loads to contribute to stability.

Transactive Energy Use economic signals as a common metric.

Plant

The Scott Park Campus

- 8 buildings.
  - Constructed 1969.
  - Latest addition 1994.
- Photovoltaic generation.
  - 1 MW.
  - Constructed 2010.
- Battery Energy Storage System (BESS).
  - 130 kWh.
  - 125 kW.
  - Installed 2017.



Plant

Buildings

Summary of BAS

- Siemens Apogee System
  - Central top level control for all campuses.
  - 6 field panels on Scott Park campus.
  - 237 zone controllers on Scott Park campus.
- All electric equipment.
  - Mostly VAV with electric reheat.
  - 16 air handlers.
  - 1 campus-wide chiller plant.
  - Rated power of BAS loads: 4.6 MW
  - Average campus load: 730 kW

		LR	AS	CC	BS/AH	ET	NS	FA	SS	Total
Air Handler	Fan	78.5	3.7	29.8	26.1	18.6	7.5	14.9	48.5	227.6
	Preheat Coil	204.0	36.0	240.0	216.0	42.0	30.0		68.6	836.6
Roof Top Unit	Fan			1.7						1.7
	Heating Coil			46.0						46.0
Fan Coil	Fan	6.3						4.2	0.7	11.2
	Heating Coil	210.0			20.0			149.0	85.2	464.2
Chiller		0.0					634.6			634.6
Compressor		1.1		0.8		0.6	37.7			40.1
Cooling Tower Fan							29.8			29.8
Condenser Unit				24.1		0.8				24.8
Cold Diffuser					0.4	0.4				0.7
VAV Reheat Coils		901.5	319.5	409.5	294.0	386.0	49.5			2360.0
Exhaust Fan		2.6	0.4	0.6	8.6	6.8	2.0	0.1	5.7	26.9
Return Air Fan		41.0		14.9	11.2	7.5	5.6		9.7	89.9
Pump		7.5	0.6	3.4	3.5	1.6	231.7	3.0		251.3
Cabinet Heater		84.0	12.0	60.0	18.0	30.0	30.0			234.0
Unit Ventilator					70.5					70.5
Unit Heater		12.0		3.0	22.0	56.0	127.0	3.0	56.5	279.5
Baseboard		12.1	5.8	74.9	35.3	5.0	4.2		106.8	244.1
All		1560.5	378.0	908.6	725.7	555.2	1189.6	174.3	381.7	5873.5
						BAS Controlled Loads				4628.99

Plant

Photovoltaics

PV Statistics

- 13,373 First Solar FS-275 modules.
- CdTe thin-film technology.
- Rated Power:
  - DC: 1.1 MW
  - AC: 974 kW
- Average daily generation: 3.45 MWh

Plant

Battery Energy Storage System (BESS)

Parameter	Value
Total Energy Storage Capacity	130 kWh
Effective Capacity (10-90% SoC)	104 kWh
Max Charge/Discharge Capacity	125 kVA
Cell Capacity	41 Ah
Cells per Module	24 (2 strings of 12)
Module Strings in Parallel	18
Number of Lithium-Ion Cells	864
DC Voltage Range	712 - 864 VDC
Control System Interface	MESA Modbus
Ambient Operating Temperature	-20 to 65 °C

Table: BESS Specification

VOLTTRON™

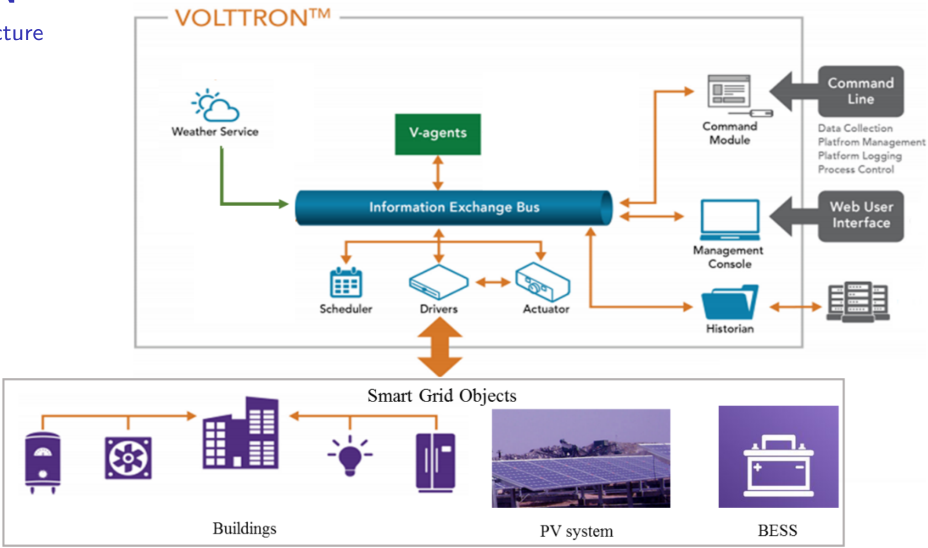
Devices | Data | Decisions

Eclipse VOLTTRON is a distributed sensing and controls platform developed by Pacific Northwest National Laboratory.

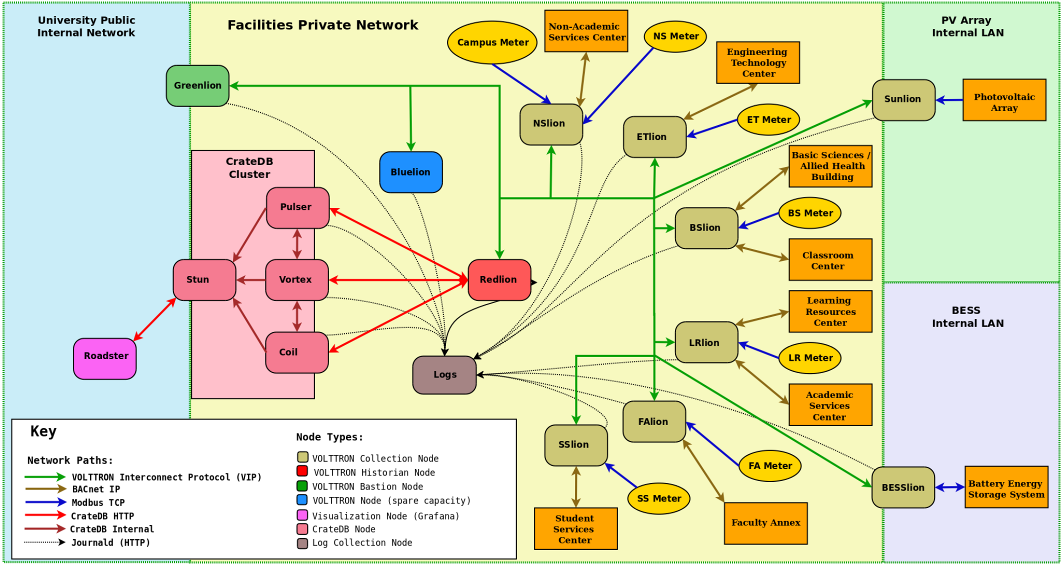
- Easily integrate equipment from many platforms.
- Secure connectivity between many instances.
- No need to change how independent equipment is operated.
- Run computationally expensive analytics & store large amounts of data without burdening the BAS.
- Integration with simulation frameworks.
- Test control strategies before they are incorporated in commercial BAS systems.

VOLTTRON

Platform Architecture



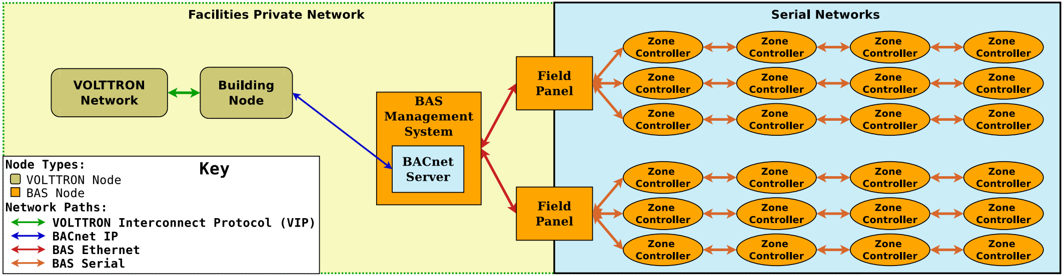
Scott Park VOLTTRON Network



Building Integration

BACnet Communication

- VOLTTRON contains tools for auto-discovery.
- Mapped points to BACnet with Siemens BACnet server (Not native BACnet).
- Used script to separate panels into logical devices.



Driver Configuration File

```
{
  "driver_type": "bacnet",
  "registry_config": "config://registry_configs/CC_F35A47ROOM2190.csv",
  "driver_config": {
    "device_address": "2:0x000000004601",
    "device_id": 7001
  }
}
```

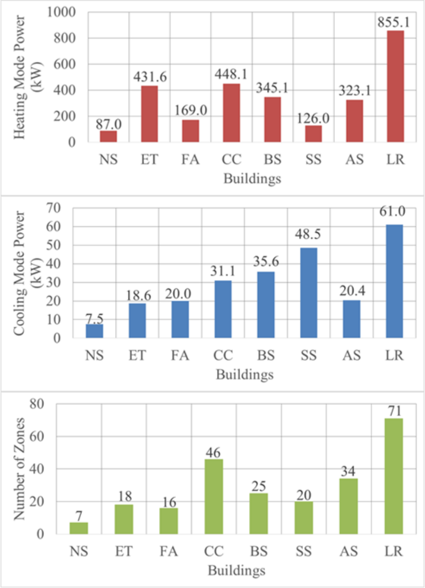
Registry Configuration File

	A	B	C	D	E	F	G	H	I	J
1	Reference Point Name	Volttron Point Name	Units	Unit Details	BACnet Object Type	Property	Writable	Index	Write Priority	Notes
2	CC F35A47 ROOM 2190:ROOM TEMP	ZoneTemperature	degreesFahrenheit		analogInput	presentValue	False	82	14	ROOM 2190
3	CC F35A47 ROOM 2190:AIR VOLUME	ZoneAirFlow	noUnits		analogInput	presentValue	False	83	14	ROOM 2190
4	CC F35A47 ROOM 2190:RM STPT DIAL	DialSetPoint	degreesFahrenheit		analogInput	presentValue	True	153	14	ROOM 2190
5	CC F35A47 ROOM 2190:FLOW COEFF	AirFlowCoefficient	noUnits	(default 0.599999964237)	analogOutput	presentValue	False	91	14	ROOM 2190
6	CC F35A47 ROOM 2190:DMPR COMD	ZoneDamperSignal	percent	(default 73.1999969482)	analogOutput	presentValue	False	92	14	ROOM 2190
7	CC F35A47 ROOM 2190:DMPR POS	ZoneDamperPosition	percent	(default 73.1999969482)	analogOutput	presentValue	False	93	14	ROOM 2190
8	CC F35A47 ROOM 2190:CTL TEMP	LoopTemperatureInput	degreesFahrenheit	(default 72.5)	analogOutput	presentValue	False	94	14	ROOM 2190
9	CC F35A47 ROOM 2190:CTL STPT	ZoneTemperatureSetPoint	degreesFahrenheit	(default 70.0)	analogOutput	presentValue	True	95	14	ROOM 2190
10	CC F35A47 ROOM 2190:DAY CLG STPT	ZoneCoolingTemperatureSetPoint	degreesFahrenheit	(default 74.0)	analogOutput	presentValue	True	375	14	ROOM 2190
11	CC F35A47 ROOM 2190:DAY HTG STPT	ZoneHeatingTemperatureSetPoint	degreesFahrenheit	(default 70.0)	analogOutput	presentValue	True	376	14	ROOM 2190
12	CC F35A47 ROOM 2190:NGT CLG STPT	UnoccupiedCoolingTemperatureSetPoint	degreesFahrenheit	(default 82.0)	analogOutput	presentValue	True	377	14	ROOM 2190
13	CC F35A47 ROOM 2190:NGT HTG STPT	UnoccupiedHeatingTemperatureSetPoint	degreesFahrenheit	(default 65.0)	analogOutput	presentValue	True	378	14	ROOM 2190
14	CC F35A47 ROOM 2190:RM STPT MIN	TemperatureSetPointLowLimit	degreesFahrenheit	(default 60.0)	analogOutput	presentValue	False	379	14	ROOM 2190
15	CC F35A47 ROOM 2190:RM STPT MAX	TemperatureSetPointHighLimit	degreesFahrenheit	(default 85.0)	analogOutput	presentValue	False	380	14	ROOM 2190
16	CC F35A47 ROOM 2190:OVRD TIME	UnoccupiedOverrideTimeout	hours	(default 0.0)	analogOutput	presentValue	False	381	14	ROOM 2190
17	CC F35A47 ROOM 2190:CLG FLOW MIN	MinimumZoneCoolingAirFlow	noUnits	(default 0.0)	analogOutput	presentValue	False	382	14	ROOM 2190
18	CC F35A47 ROOM 2190:CLG FLOW MAX	MaximumZoneCoolingAirFlow	noUnits	(default 1020.0)	analogOutput	presentValue	False	383	14	ROOM 2190
19	CC F35A47 ROOM 2190:HTG FLOW MIN	MinimumZoneHeatingAirFlow	noUnits	(default 500.0)	analogOutput	presentValue	False	384	14	ROOM 2190
20	CC F35A47 ROOM 2190:HTG FLOW MAX	MaximumZoneHeatingAirFlow	noUnits	(default 1020.0)	analogOutput	presentValue	False	385	14	ROOM 2190

Building Integration

Points

- 237 Zones:
  - VAVs w/ Electric Reheat: 152
  - Fan Powered VAVs: 48
  - Unpowered VAVs: 19
  - Fan coils: 4
  - Non-AHU connected zones: 14
- Poll rates:
  - BAS devices (8551 points): 1/min
  - 6 building meters (7 points each): 1/10s
  - 1 campus meter (7 points): 1/s
  - Aggregated total for all buildings: 9223 /min
  - Aggregated total w/ BESS & PV: 12546 points / min
- VOLTTRON does now support BACnet COV.



Building Integration

Controllability

- Per point configuration of writability & priority.
- Lower priority than operator override.
- Does not bypass BAS access settings.

E	F	G	H	I	
BACnet Object Type	Property	Writable	Index	Write Priority	
analogInput	presentValue	False	82	14	RO
analogInput	presentValue	False	83	14	RO
analogInput	presentValue	True	153	14	RO
analogOutput	presentValue	False	91	14	RO
analogOutput	presentValue	False	92	14	RO
analogOutput	presentValue	False	93	14	RO
analogOutput	presentValue	False	94	14	RO
analogOutput	presentValue	True	95	14	RO
analogOutput	presentValue	True	375	14	RO
analogOutput	presentValue	True	376	14	RO
analogOutput	presentValue	True	377	14	RO
analogOutput	presentValue	True	378	14	RO
analogOutput	presentValue	False	379	14	RO
analogOutput	presentValue	False	380	14	RO
analogOutput	presentValue	False	381	14	RO
analogOutput	presentValue	False	382	14	RO
analogOutput	presentValue	False	383	14	RO
analogOutput	presentValue	False	384	14	RO
analogOutput	presentValue	False	385	14	RO

Building Integration

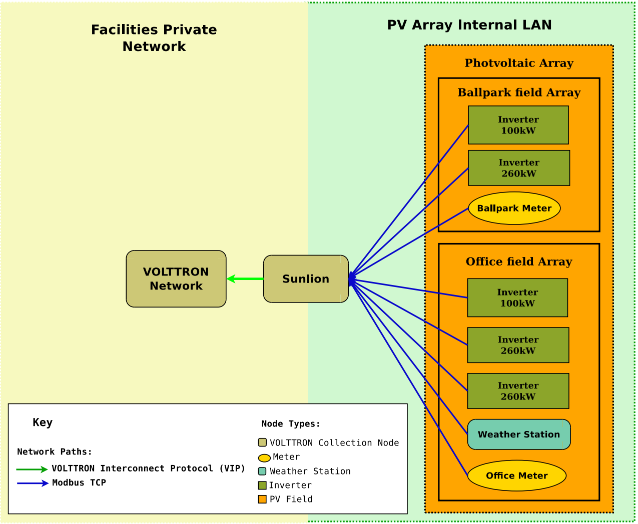
Reset & Heartbeat Mechanisms

In addition to protocol based priorities, VOLTTRON includes several features to ensure sane interactions with equipment:

- Reverts:
  - Drivers can revert points to original value.
  - We implemented panel-wide reset in BAS.
- Heartbeats:
  - Configurable heartbeat signals to monitor agent health.
- Overrides:
  - Per-device write overrides.
  - Global write override.

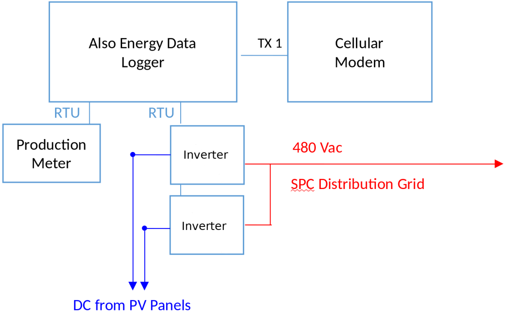
PV Integration

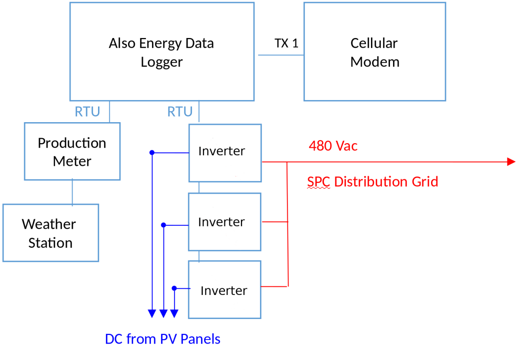
- Equipment on isolated network.
- Dedicated collection node.
- Modbus TCP to poll equipment.
  - Required manual configuration.
  - Required network changes.



PV Integration

Network Changes - Before

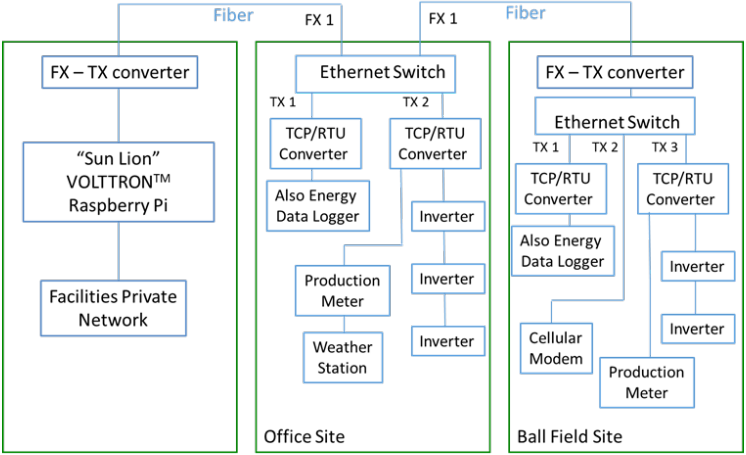




PV Integration

Network Changes - After

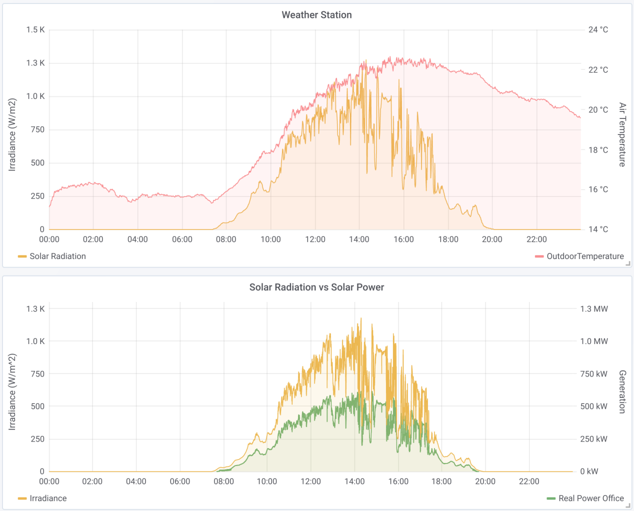
- Utilized existing dark fiber.
- Installed switches, Fx-Tx converters, Modbus RTU-TCP converters.
- Modbus-TCP to allow multiple access.
- SCADA provider retains independent access.



PV Integration

Data Collection

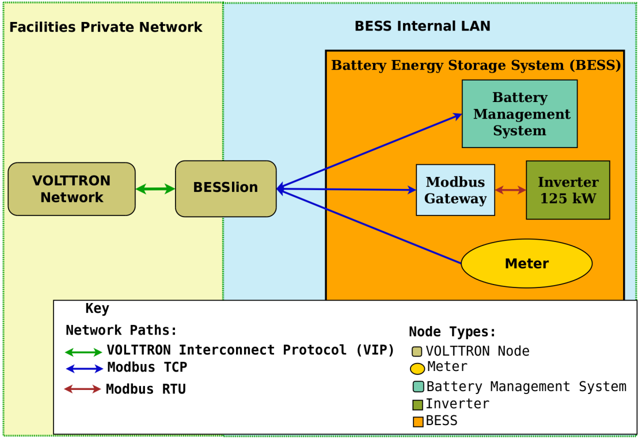
- One minute poll rate:
  - Inverters
  - Weather station
- One second poll rate:
  - Irradiance
  - Power



BESS Integration

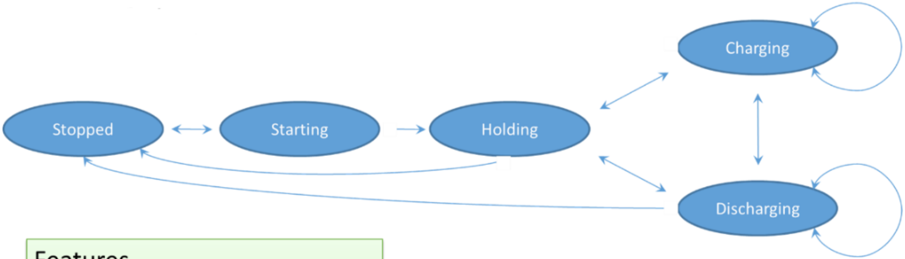
Network Setup

- Equipment on isolated local network.
- Dedicated collection & control node.
- Implemented controller as VOLTTRON agent.
- Vendor retains independent access.



BESS Integration

Controller Agent



Features

- Ensures clean state transitions
- Maintains consistent state
- Maintains heartbeat signal with inverter
- Automatic fault shutdown
- Automatic hold at SOC limits
- Automatic maximum current limitation
- Publishes state information to message bus
- Logs faults and warnings
- Extensible to additional equipment

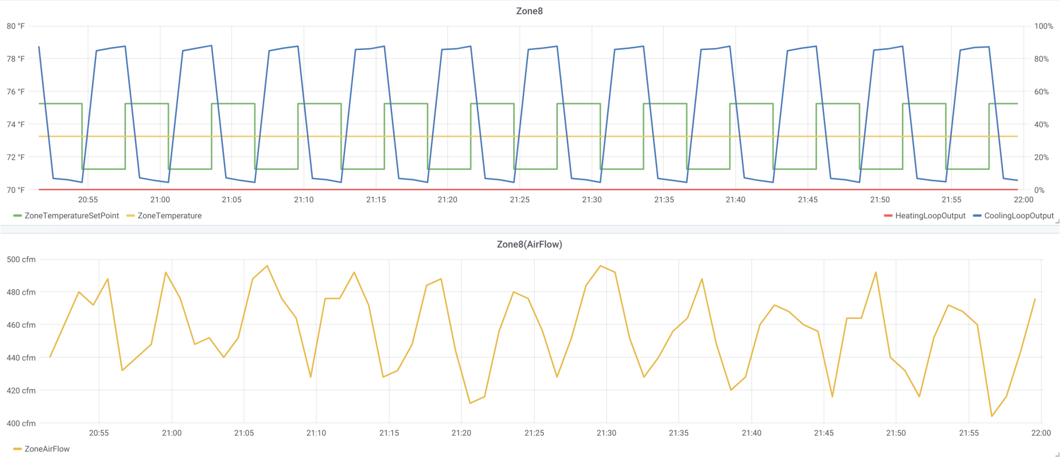
Exposed RPC Calls

- START()
- STOP()
- HOLD()
- CHARGE(command, pf=0)
- DISCHARGE(command, pf=0)
- RECOVER_SOC(command=None)
- GET_STATE()

https://github.com/VOLTTRON/volttron-GS

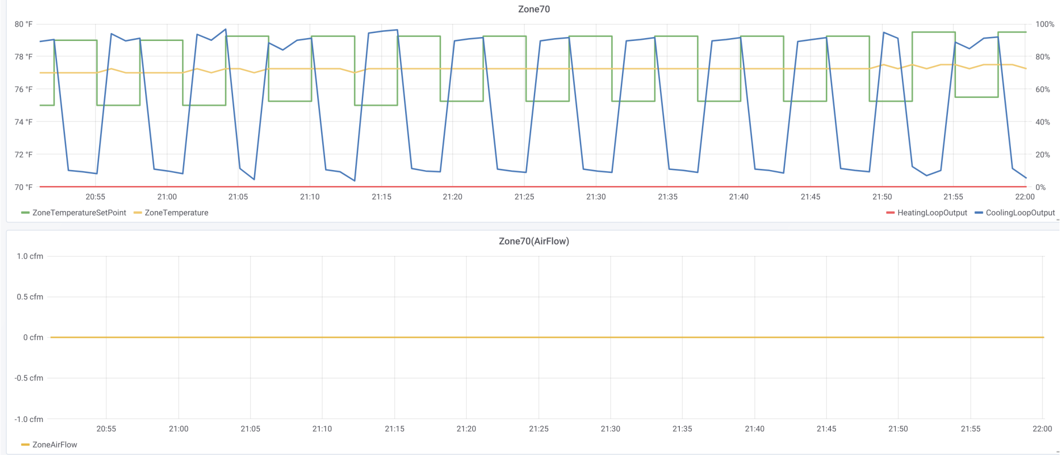
Fault Detection

Working Zone



Fault Detection

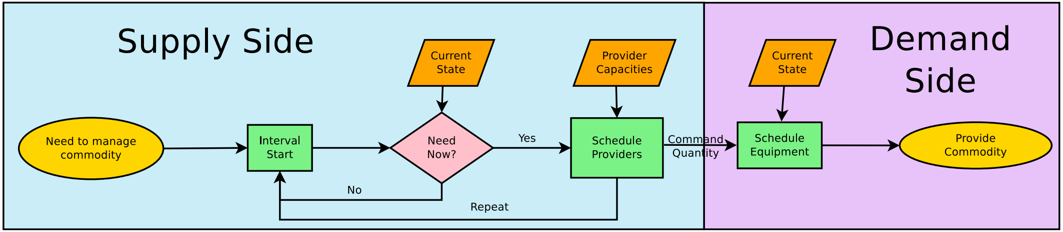
Failed Zone



Strategies for Demand-Side Management

Commanded Response

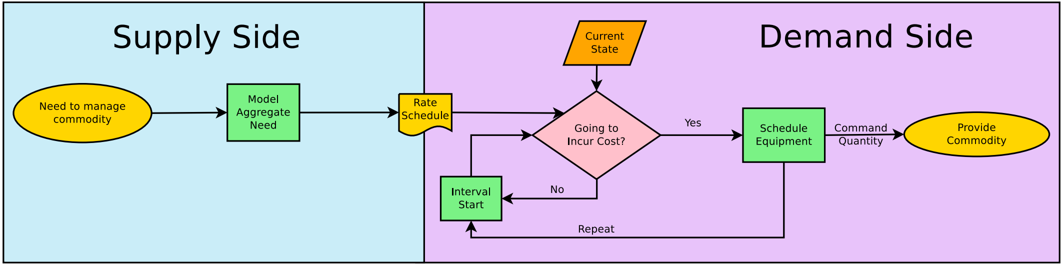
- Load adjusted in response to external signal.
- Signal may be a quantity or a curve.
- Signal sent to specific recipients.
- Excess reserve still required to manage missed targets.



Strategies for Demand-Side Management

Incentive Response

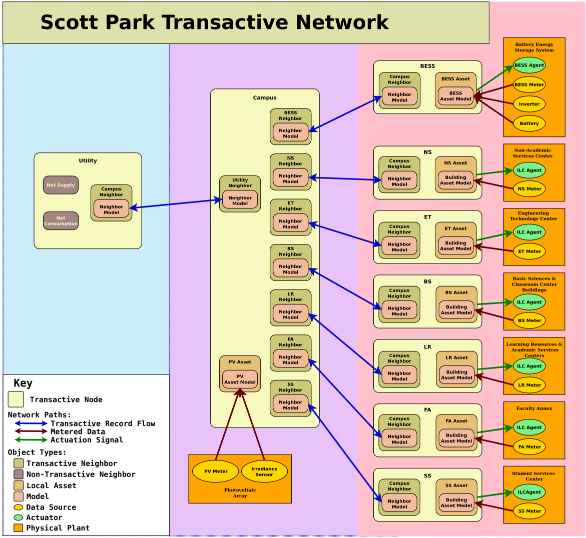
- External incentive built into tariff structure.
- Decision making is entirely local.
- Simplest example: metered energy.
- Widespread use of riders – e.g demand charges.



Strategies for Demand-Side Management

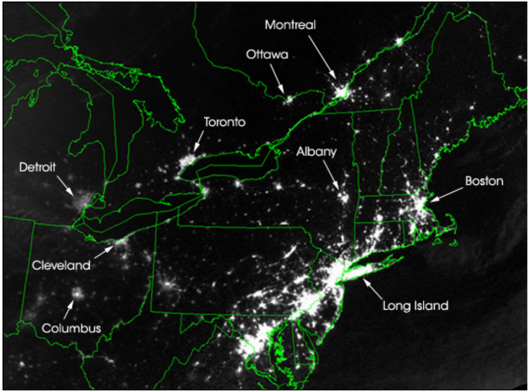
Transactive Energy

- Bi-directional signaling.
- Better efficiency than commanded response.
- Better coordination than incentive response.
- Does not require sharing internal data.
- Distributed or centralized markets.
- Dynamic price formation from changing conditions.

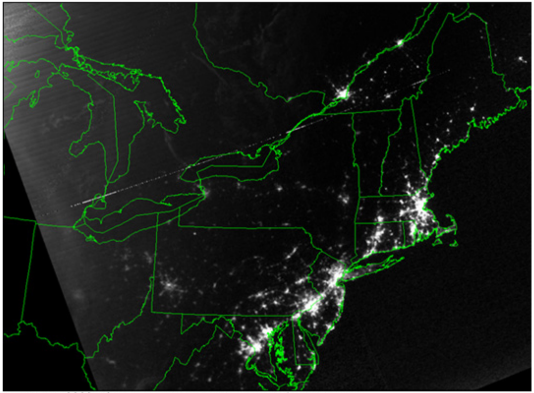


Use Case: Demand Peak Management

- Supply and demand must always be balanced.
- Periods of peak demand increase the risk of disruptions.
- Disruptions may be much longer lived than the period of peak demand.



August 14, 2003 • 9:29 p.m. EDT • About 20 hours before blackout

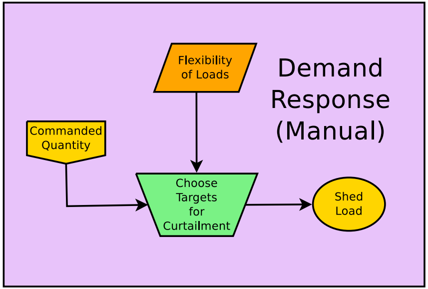


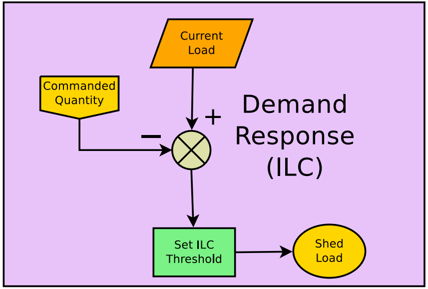
August 15, 2003 • 9:14 p.m. EDT • About 7 hours after blackout

Use Case: Demand Peak Management

Demand Response

- Reserve is actively managed by shedding load at prearranged quantities from large consumers.
- Existing programs of this type are widespread.
- Participation by UT has earned $300,000 in each of the last two years, with similar revenue expected this year.
  - This has been done with no effect on occupant comfort.
  - Currently, predetermined loads manually curtailed.

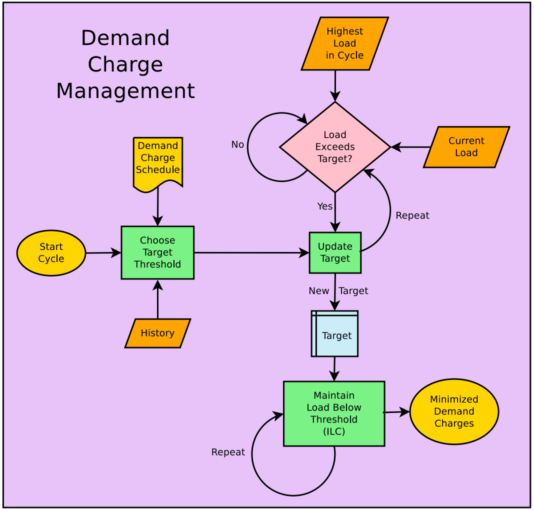




Use Case: Demand Peak Management

Demand Charges

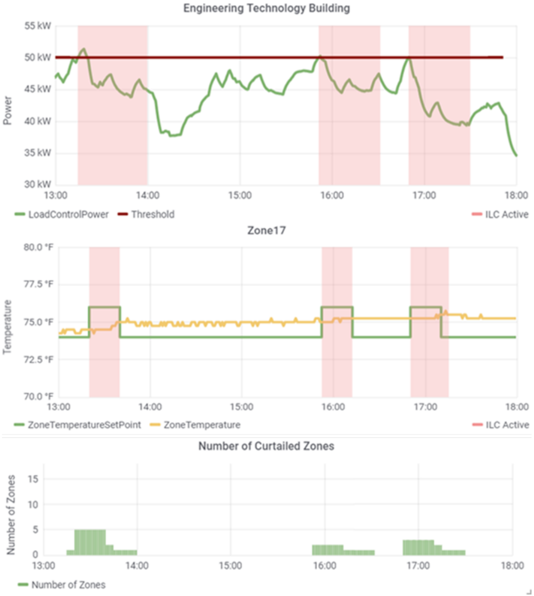
- Incentive is provided via demand charge mechanism.
- Threshold is stepped up over the course of demand charge period in step with maximum attained peak.
  - BESS can respond by discharging during times of high demand.
  - Buildings can respond by curtailing or time-shifting loads.



Use Case: Demand Peak Management

Intelligent Load Control (ILC)

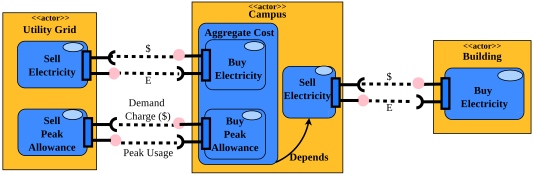
- Developed at PNNL.
- Deployed and tested on 8 buildings of Scott Park Campus.
- Uses an Analytic Hierarchy Process (AHP) to prioritize zones according to user defined criteria.
- Dynamic threshold targets allow use in capacity bidding, incentive response, and transactive applications.
- Bi-directional criteria allow proactive shifting of loads.
- Has been deployed commercially.

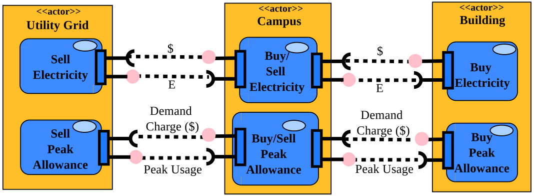


Use Case: Demand Peak Management

Transactive Plans

- Demand charges represented as the purchase of an allowance for peak power.
- Actors with most flexibility curtail at lower prices, relieving pressure on more inelastic nodes.
- Demand Charges can be aggregated into marginal price for next level or passed through in a secondary market.





Use Case: Variability Mitigation

Need

Grid Context

- Stability of the grid depends on balance.
- Generation must be kept on reserve to manage fluctuations.
- Computational cost of balancing increases dramatically with distributed generation.

Campus Context

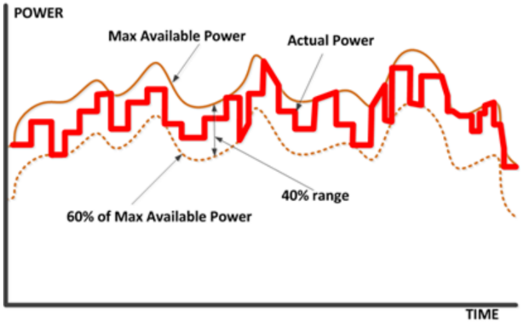
- Dips in PV may cause "demand spikes" despite flat load.
  - Local generation lowers probability of peaks, but the advantage may be lost to ill-timed clouds.
- Tariff structure may not support net-metering.

Sinister Fluffy Clouds of Evil

Use Case: PV Variability Mitigation

Inverter Control

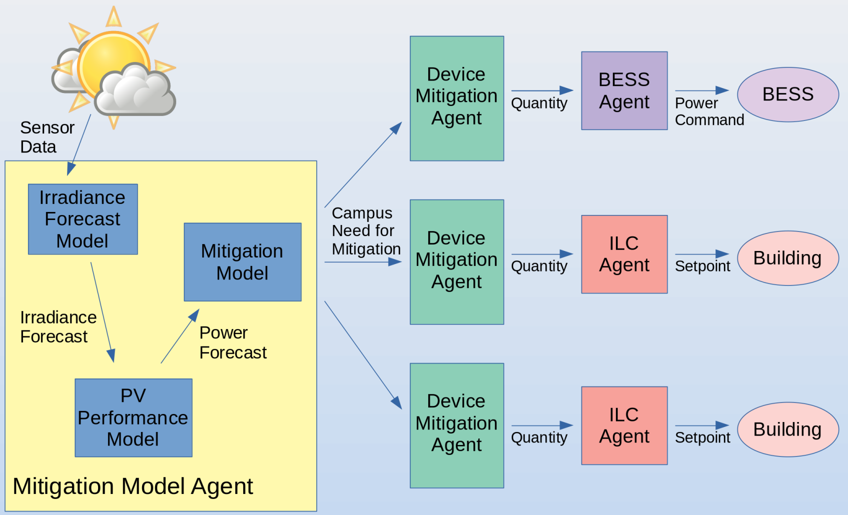
- Currently used technique for utility scale PV generation.
- PV inverters normally track the maximum power point (MPP) by balancing voltage and current.
- Moving off MPP changes power available to the network.
- Can be used to provide ancillary services such as voltage & frequency control.
- Non-optimal: Generated power is lost to heat.



[21] C. Loutan and V. Gevorgian, "Using renewables to operate a lowcarbon grid: Demonstration of advanced reliability services from a utility scale solar PV plant," Nat. Renewable Energy Lab., Golden, CO, USA. Dec. 2016. [Online]. Available: https://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf

Use Case: PV Variability Mitigation

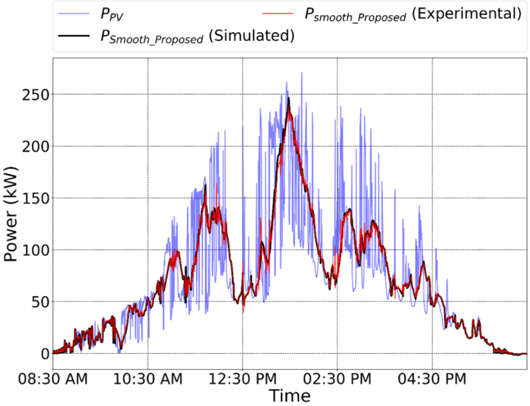
Incentive Response



Use Case: PV Variability Mitigation

Incentive Response: BESS Experiments

- BESS is used to counter dips & spikes in PV generation with respect to a moving average.
- Acts as a low pass filter controlled by the window size of the moving average.
  - Preferred frequency will depend on the incentive structure.
- Longer wavelength variations can be more easily managed by other means.



Use Case: PV Variability Mitigation

Incentive Response: Building Participation

Buildings can act like batteries:

- Loads may be shifted to create virtual battery-like behavior.
- Curtailment $\iff$ discharging.
- Augmentation $\iff$ charging.

Augmentation of power consumption during an interval may be appropriate where loads can be time-shifted:

- Water heaters.
- Chillers
- Inside air temperature.

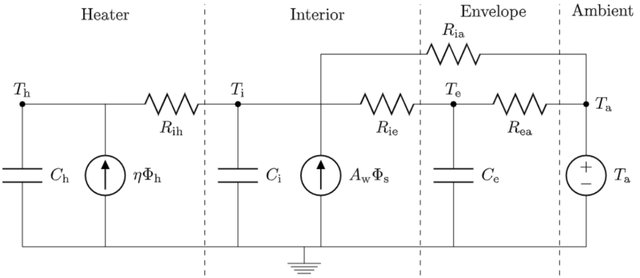


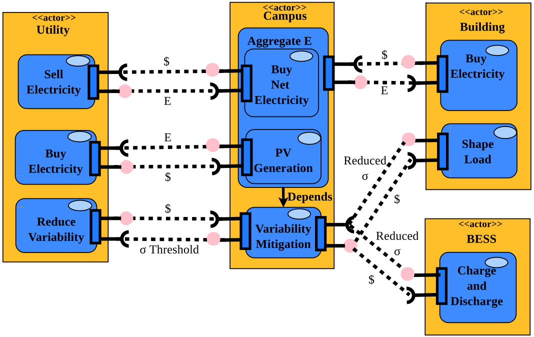
Fig. 1. RC-diagram for prediction model.

A. Thavlov and H. W. Bindner, "Utilization of Flexible Demand in a Virtual Power Plant Set-Up," in IEEE Transactions on Smart Grid, vol. 6, no. 2, pp. 640-647, March 2015. doi: 10.1109/TSG.2014.2363498

Use Case: PV Variability Mitigation

Transactive Plans

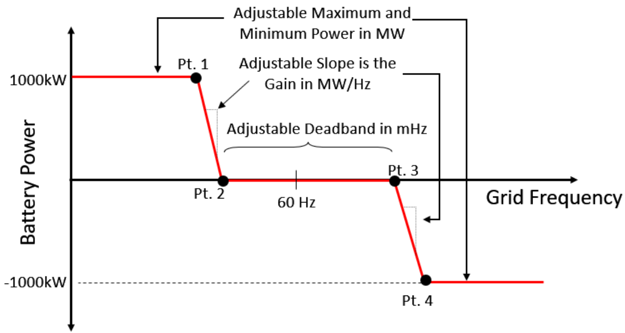
- Variability mitigation will be of increasing interest to utilities as distributed generation supplies more of our energy needs.
- Mitigation may be structured as as service or an incentive.
- Buildings & BESS respond according to supply curves for the commodity of variability mitigation.
- The same mechanism may be employed locally even without a market at the utility level.



Use Case: Ancillary Services

Need & Goals

- Generate revenue by participation in ancillary service markets.
- Regulation of grid parameters by controlling loads, generation, or storage.
  - Altering real or reactive power changes the frequency or voltage of the grid.
- We are researching the control & valuation aspects of providing these services with buildings & BESS.

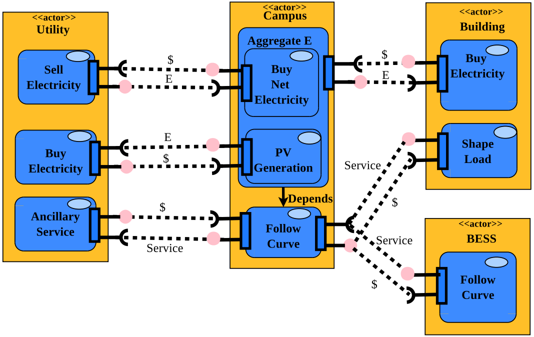


Stein, Karl & Tun, Moe & Matsuura, Marc & Rocheleau, Richard. (2018). Characterization of a Fast Battery Energy Storage System for Primary Frequency Response. Energies. 11. 3358. 10.3390/en11123358.

Use Case: Ancillary Services

Transactive Plans

- Market for provision of ancillary service.
- Campus bids on ability to conform to a curve.
- Buildings & BESS bid their own curves in the market.
    - BESS can directly follow curve with its inverter.
    - Buildings shape load to follow curve.

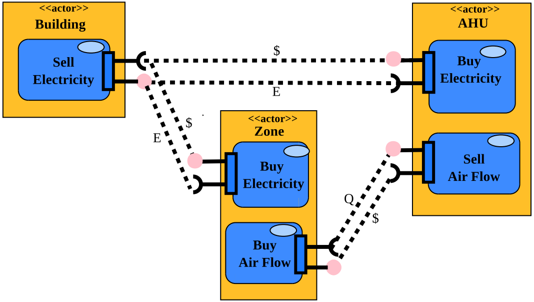


Use Case: Intra-Building Markets

Pseudo-Market Control

Create a sustainable & cost effective campus while improving comfort by allowing zones with greater flexibility to take the burden off those with less.

- Markets don't require literal exchange of consideration to operate so long as the participants treat the exchange as if it were real.
- Zones have varied & divergent flexibility with regard to energy use & comfort.

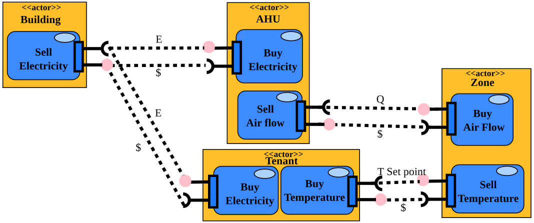


Use Case: Intra-Building Markets

Tenants

Tenants participate in intra-building markets by altering set-points or flexibility parameters at the zone level.

- Modify occupant behaviors by internalizing real costs of energy.
- Assign costs appropriately by department & division boundaries.
- Encourage more efficient scheduling of spaces.
- Create better focus on the task of energy management by rewarding those parties who can best optimize consumption.



Thank you

Questions

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