ARPA-E Advanced Buildings Workshop

Breakout Group #1:

Systems Approach to
Fault Diagnostics and Controls
(Chair: Scott Bortoff, Mitsubishi Electric)

What are the building services and indoor environment that need to be provided in terms of space and time? That is, what are the baseline conditions?

- **Current state:**
  - Comfort
    - ASHRAE comfort zone and ventilation standards. May be a barriers to innovation in high performance buildings. By zone and usage, no of people and square footage. Base ventilation levels. Can be turned down during unoccupied times.
    - Noise / sound management.
    - Lighting (IES). Lumens, quality, glare.
    - Schedules (time of day, day of week, or sensed occupancy).
    - IEQ – CO_2 levels. Air changes / hour. Local building codes.
  - Safety and Security
    - Physical, fire safety.
  - Mission critical Services
    - Hospitals – O_2, etc.
  - Utilities
    - Power, water, communication, natural gas, steam, waste removal, food.
  - People transportation – elevators, etc.
  - Parking garages, recreational facilities, aesthetics, outdoor lighting
- **Desired state:**
  - Bringing up standby loads from hard of to a standby state.
  - **Dynamic Comfort Model**.
  - Managing the power resource. "Super Bowl" effect.
  - Understanding (measuring) VOC levels.
  - Lighting – dimming / daylight management.
  - **Feedback to modify behavior** - Behavioral cues. Increased awareness.
  - **A way to manage the building as its usage evolves over time**. E.g. wireless lighting.

- ASHRAE comfort zone and ventilation may be a barrier to innovation in high performance building standards by zone and usage (design days, # people, square footage, ventilation is proportionate to occupancy level and interior components – carpet) can be tuned down during low occupancy level
- Schedules - time of day/week, sensed occupancy level
- Need for dynamic comfort model
- Lighting – lumens, quality, glare, dimming and daylight management, security, outdoor lighting, aesthetics (white walls)
- Acoustics, noise control/sound management
- Ambient air quality (IEQ) CO_2 levels, air changes per hour, local building code
- Security, physical, fire safety
- Vampire loads – bring standby loads from hard off to standby state
- Power to building and loads – plug loads (super bowl loads), managing the power source,
- Waterline demand, hot and cold water
- Data communications
- VOC levels
- People movement – escalators ad elevators
- Occupancy behavior – queues, feedback, predicted movements and response (air handlers ion conference rooms before meetings)
- Building evolution management – usage over time, wireless lighting and thermostat
- Food management
- Waste removal
- Parking garages, recreational facilities
- Mission critical services (specialized like hospitals)
- Natural gas, fuel oil, steam – utility resources (dispatchable and nondispatchable), wind, solar,
- Leading categories: scale, response times, mission critical

How does one detect component and system level faults to improve the overall systems level efficiency? What is the most effective way of doing this? How could the building industry learn from other relevant industries?

- **Human feedback. Complaints.**
- Failure. (run to failure) Maint. Schedules.
- Human test and inspect.
- Measurements within nominal ranges.
- Specific sensor to detect a fault
- Statistical measure for an implied fault.
  - Compare the design intent with the actual.
  - Compare the past actual with the current (trending).
  - Comparison with peers
- Expert analysis of measured data.
- Use of simulation models driven by real time data.
- Inverse modeling – parameter estimation (and comparison to "ideal").
- **Stress tests. Proactive testing to determine faults. Automotive examples.**
- **Industries that do this well…**
  - Automotive –
    - OBD codes. Filter out false positives.
    - Algorithms to determine specific "top 80% faults"
    - Fault trees
    - Regulation drives technology (OBD, emission controls etc.)
  - Electronics industry. MTBF and warrantee. FMEAs. 6sigma practices.
  - Buildings industry – no accountability for systems issues. What is the value prop?
- Machine learning (and statistical learning methods). Always running during the life of the building. Be careful about learning "bad" behaviors / performance.

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- Human feedback/complaints, Human test/inspect
- Failure (run to failure)
- Statistical measures for an implied fault
  - Measurements within normal ranges and outside of normal range (sense to detect fault or implied fault by range) Compare design intent with actual
  - Compare the past actual with the current (trending)
  - Comparison with peers
- Specific sensor to detect a fault
- Finding anomalies in consumption, control, setting level
- Expert analysis of measured data
- Inverse modeling – parameter estimation (and comparison to ideal)
- Industries that do this well
  - Automotive – OBD codes, algorithms to determine specific top 80% faults, fault trees
  - Electronic industry – MTBF and warranty. FMEAs. 6Sigma practices.
- Machine learning (and statistical learning methods). Always running during the life of the building. Be careful about learning bad behaviors/performance
- Mechanisms to learn from other industries
- No accountability with buildings – go with cheapest bidder. Based on current business model. Incentive fills the vacuum. Building manager is not culturally in tune.
- IBM business model – sales to service – warranty with system integrator – services whole system (ecosystem of partners in building)
- No system integrator with buildings

How does one account for human intervention? Does one enable humans to correct faults or should this be automated? Does one disable humans from causing faults?

- Good and bad. Humans can make things worse or better.
  - Low level mundane stuff – automate
  - Higher level things – there are some things “self healings” that can be done in software (things like deltas).
  - Establish a hierarchy.
- Automation: People are disengaged from their own buildings. PIR sensors, thermostats that are not accessible. Made performance and consequences “invisible.” People get demotivated.
- “Plug and play” has consequences.
- People need to be empowered. Iphone app.
- Need for personal metrics. Dashboarding.
- Make performance visible (put the meters on the first floor).
- Chargebacks, submetering, tenant metering.
- Make performance visible relative to others.
- How to present information
  - What is important, what isn’t. Data overload. Smart alarm system.
  - Medicine is a field that could be learned from. “Medical mistakes”
  - Process industry (oil) has best practices. Shadowing, commissioning.

- The problem isn’t detecting problems – it is fixing it. We need different business model.

- People are now more disengaged from the system (automatic lights, covered thermostats)
- Lights – vacancy sensors – default is off and person turns lights on
- Buildings attempt to be smarter than the occupants – demotivate the stakeholder
- Devices installing inside machines – plug and play – works for PCs, but now people are very removed from buildings
- People need to be more responsible and empowered – need for personal metrics
- Dashboarding – feedback to save
- Make system performance visible (put meters on the first floor)
- Chargebacks, submetering, tenant metering
- Occupant degrees of freedom can be useful to people with advanced knowledge – how the information is presented can influence activity
- Garbage information is ignored (155 degree room due to faulty thermocouple is ignored as opposed to fixed) as opposed to foxed with data overload – most critical information needs to be displayed and acted upon
- Significant error messages tend to be ignored if they are not critical
- Medicine statistical learning theory and learning are good references to impart wisdom – triaging
- New Yorker article – positive outcomes based on prescribed actions
- Humans can make things both worse and better – physical issue needs person – controls can be addressed by machines
- How far can automation replace the human?
  - Issues are cost and ability – some things can’t be automated like changing hardware
- We care about deltas not absolutes – software can perform self healing until the system starts hunting
- Alerts to humans are relative to errors and priority – shadowing of the system to determine the impact – temporary fix to keep running (run to failure)
- Value of energy lost with machine out of range might not warrant a fix so run to failure
- The issue is not detection of issues but actually fixing the issue
- More money for more robustness might significantly reduce failure but it is hard to spend the money up front

How can we best leverage system level interaction to increase the overall efficiency?

- **Better metrics**. E.g. system level efficiency. E.g. window air conditioners can be more efficient than a central plant. E.g. turning down voltage on grid saves motor energy.
- **Benchmarks** to go with metrics.

- Storage and Schedule. Energy storage (load shifting). Dynamics.
- Exploit time – renewables are more available some times than other.
- Global set **points** and **dynamic optimization**.
- **Prediction**. (of disturbances, pre ventilation / cooling).
- **Exploit waste** (heat) in air and fluid streams at system levels. Exergy. Cogen.
- Interacting with the power grid: Most energy used by small buildings and residential. Smart meter, communicating thermostat, demand response, smart appliances. Simple, primitive but scale.
- DC directly from PV.
- **Human** in the loop. Towel in the hotel example. Changing people's behaviors is central.
- Policy: Carbon tax / cap n' trade. How those policy decisions will impact behavior.

- Better metrics – overall system efficiency is the big picture
- Individual air conditioners are more efficient than industrial building chillers
- Benchmarks
- Maximize efficiency vs. energy use
- Save 2% of nation's energy by better grid voltage management (motors are more efficient)– must look at system from end to end
- Energy storage (load shifting) with dynamic control can increase efficiency
- Dynamic load shifting to exploit renewable availability
- Charge storage when chiller lift is more favorable (night)
- Resource management vs. demand
- Determine gaps between system capability (efficiency) and building demand – global set-points and trade-offs with dynamic optimization – weather conditions, occupancy, prediction of disturbances (pre-ventilation and cooling)
- Radiation and reuse/exploitation of waste heat and gray water (air and fluid streams) – at system levels (Exergy, Cogen)
- Interaction with the Grid – smart metering, communicating thermostats, diagnostics, feedback or homes as well as large buildings – the solutions are scalable – demand response and modified usage profiles – simplicity of message and solution (don't turn on this when this is on) – simple and primitive but large scale
- DC directly from PV
- Human interface – what is the best messaging based on psychology – behavioral research and incentives (towel washing in hotels (80% of previous occupants did it – Princeton Study and Prius display of efficiency)
- Case studies with smoking and fundamental change to habits
- What are the key activities to effect in order to have the largest positive impact based on the design and delivery in a terminal environment – what factors do you allow the occupant to change and what knowledge do they require to take the right action?
- Policy – carbon cap and trade, how will these policies impact decisions?

Highest Impact Applications

- Applications with highest potential impact on ARPA-E mission areas:
  – Greenhouse gas emissions reductions; and/or
  – Improved efficiency of power generation and delivery
- Application A:
  – **Optimal and robust control algorithms**. Existing controls regulate. Tomorrow's controls must optimize system metrics robustly.
    - Robust control. Methodology, tools, technology. Codified procedures. Measures of performance of diagnostics/controls technology.
    - Diagnostics for CHP/BCHP systems. Complex systems.
  – **Smart grid**. Simple diagnostics leveraging diagnostics. Data mining. Small / medium residential building market.
  – **Open source platform** to empower a development / innovation community. Invest in the platform. Cuts across traditional building functions.
  – **"Green Worker" Productivity Kit.** IR Camera. Tools to help the maintenance worker / industry. Mass triage. Making the "green worker" more effective. The MRI for buildings.
  – Application of **6 sigma** type of process.
  – **Building information bus architecture**. Plug and play to address shortcomings in interoperability.
- Application B:
  – Why?
- Etc

- Japanese figured out process control to keep factories operating – how can we apply this to buildings (statistical process control – FMEA, issues, leading indictors, operational tracking of issues)?
- Robust control – current control is in unstable hunting mode
- Need controller/BMS to map system performance – need controls to stamp them out
- Measurable performance methodology, robustness, etc for the system
- How well can you hold a setpoint? Specific metrics – CHP and BCHP system metrics. Need robust building diagnostics to control loads that vary by installation and are able to perform robustly.
- Building information bus architecture that specifies level of interaction and communicates plug and play with other systems and grid
- Uniform operating platform with open architecture for wide implementation
- Failure minimization
- Design to address off-nominal conditions – design for robustness (like new cars)
- Diagnostics leveraging smart grid – from building level to community level
- Need for new control algorithms – now they reject disturbances – need to address these extremes
- Controls are error-based (feedback controls) and currently regulate – they need to move to system optimization
- Open source web-based architecture like an I-Phone environment that can control a complex system – invest in the platform and allow individual optimization to various systems (also allows for security management)
- Contractors will develop the specific algorithms by application.
- Integration of equipment/tools to help the maintenance worker (like current IR cameras and the ability to detect drafts, lack of insulation, etc.) IR sensor – germanium, FLIR in Boston, can be used in neighborhood settings (determine leaks home by home – mass triage) – technology to make the green worked more effective – jewel thief (technologies for Exergy to create jobs) – pick up inconsistencies and increase effectiveness (CyberAuditor) – home audits
- Scale of issue?

Required Performance/Cost for Significant Economic Adoption in Highest Mission Impact Applications

Application A:

- Performance Metrics?
- Cost Metrics?

Application B:

- Performance Metrics?
- Cost Metrics?

Etc

Key Technical Barriers

Technology #A:

- Barrier(s)
- Origin of technical barrier(s)
- Promising emerging approaches to overcome barriers

Technology #B:

- Barrier(s)
- Origin of technical barrier(s)
- Promising emerging approaches to overcome barriers

Etc

Funding Gaps and Path to Transition

- Most significant funding gaps in government/private sector?
- Optimal roles for ARPA-E vs DOE EERE in supporting Fault Diagnostics and Controls?
- Level of technology validation/demonstration required for successful hand-off of ARPA-E project to private sector (VC/corp R&D)/other funding entities?
- Necessary levels of funding for an ARPA-E advanced building technology project (~3 years)
  - Proof of concept: $??
  - Meaningful "bench" scale system prototype: $??
  - Meaningful small-scale demonstration project: $??