ARPA-E Advanced Buildings Workshop

Breakout Group #2:

Systems Approach to Fault Diagnostics and Controls (Chair: Srinivas Katipamula, PNNL)

Note: Additional raw reviewer notes are an attempt to capture the flow of the discussion that took place during the breakout sessions. Please pardon any errors in transcription or note-taking.

State-of-Art

- Low level SISO adaptive control work are currently deployed in buildings
- Fault Detection currently available not adopted by industry
- Interest in Monitoring and Automated Diagnostic
- Needs standard to measure the performance of the system
- Enlarge the scope, look at control of building envelope
- The are value propositions for FDD but not well sold to the market
  - Not sufficient incentives?
- Supervisory Control Design, human and control interaction

An organization like Johnson Controls has adaptive control (adjust gain and interval time to make it work) technology out there. There are 1.5 million adaptive controllers out there. We don't have problems with the controller. Single input - single output (SISO) is close to 100% of the controls approach.

We have fault detection technology that could be used today. It has been around since the 1990s. We have commercial real estate companies that are interested in fault detection issues.

Field test experience has shown that you can provide information for those who need to take action. But there are structural problems in who needs to make decisions vs. who is rewarded, etc.

"Self-correcting controls" that account for faults in components of the system is another development area. You aren't as reliant on people taking actions – some problems can be addressed automatically. There are probably applications in other fields that we could learn from, but they have different constraints (safety vs. operations and productivity).

8% of consumption is controlled by residential thermostats. Many of them put on fixed values. Perhaps there is a need to develop self-configuring controls to allow equipment to adapt and to compensate for all the mistakes made in the installation of controls. E.g., we don't use the outdoor air damper as an economizer.

State-of-Art

- MIMO nonlinear networked control
- Enterprise level ,asset management
- Control with Load forecasting
- Still using dampers for flow control
- “intelligent thermostat” with info on price of energy + space occupancy
- Not enough penalty for sub-optimality/undetected fault
- FDI for exergy loss based on few measurements
- Design intent driving control, operation and FDD

We currently can’t handle non-linear multiple input multiple output controls. One participant didn’t have the heat on in his apartment in NY because other people had theirs on.
Part of the problem is with the design of the interface. Like old VCRs.
Consider the “not too big house book.” Would you have something for each area? How would you organize this? Completely away from centralized model?
At the enterprise level – Walmart is defining some best practices. They do a lot of end-use metering, demand response with load forecasting.

We need to look at cost of distributing the plants. We still use dampers to control flow instead of variable fans. We have done some exploration of thermostats. Transactive control. Each thermostat has a tradeoff of price information and willingness to accept some discomfort. Devices work on some programming that is based on . . . something about the occupants. That is an interesting area.

Feedback between diagnostics and design is part of our problem.

Perhaps the penalty for sub-optimality is far too light? More resilience we build up, the more sub-optimality we tolerate. All head room designed is eliminated in operations.

Fault tolerant controller would also work?
Maybe if something fails the whole thing stops? [Analogy to the Toyota Production System]

Can environmental control inputs also serve as a fault detection? Have an indirect measure.

What is the proper divide between FD and controls? Is it getting blurry?
 - need to show the tradeoff of maintenance, monitoring, costs and analysis.
Reheat is a big problem. Maybe a sensor could diagnose that? Maybe not? How would you see what the system is doing? Can you use exergy as a parameter?

Biggest gain will likely be from proper design.

FDD and control are related at the point of design intent. Which becomes a dynamic representation of efficiency modes. It is a continuum of:
Design - design intent - control - and FDD operations

There is a bucket of unknown stuff. For expensive systems you generate fault trees. Gas turbine you run a fadec. Fault detection, isolation, etc. Don't see why research direction should be going in a different direction.

In buildings, there are a lot of constraints regarding capital and design costs. The exhaustive analysis in other fields may have barriers against that. You will have costs against that. We don't have simulation tools that embed FDD.

Let's call them closed, completely engineered systems. How about roads and cities? We don't get FD at design time. All the things you didn't cover need to be there, too.

It is a collection of highly engineered pieces, so let's embed into those pieces and sub-systems, how do you incentivize them to do so, and then how do you collect and piece it together to give a whole picture?

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?

- In process control and aerospace FD is part of the design process, not the case in the Build. Ind.
- Research issues are different?
  - ~yes
  - Not: cost, lack of sensors, not simulation tools
    - But what is the message to Arpa-E?
  - Building as a collection of low eng. building
  - Functional life is 20/30 years? Do we want to drive buildings toward permanent systems? Instead of personalizable units.. What is the point of all this effort? Do it the IKEA way? A disposable building? But even if life is short we want it always optimal
- Open data model, interoperable platform fundamental for control and FDD

What about planned obsolescence? Why not throw it away. Don't expect all building components to last forever? Mechanical fails after 20, structure 70. Perhaps buildings should have a backplane with plug and play for physical systems as one possibility.

But what we are talking about is decline in performance after only 2 years.
Bridges with integrated sensors. We haven't talked about the role of materials.

What is most effective way to do FDD? We need some open standard data models.
What about a school of fish vs. the whale approach? When is that appropriate?

Some folks says the Prius is a game. Perhaps if people had more information, they would play the game with energy efficiency in the homes.
Trend-logging of existing systems is a problem, right? So data management itself is still a problem.

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?

- Human: Building Operator or Occupant
- Operator
  - How remove human from the loop?
  - Some fault will always require human intervention
  - Maintenance monitoring in buildings?
  - Facility manager paycheck function of the energy savings?
  - Disclose utility bills
- Occupants
  - Can generate fault by adjusting setpoints

Owner doesn't occupy in commercial buildings. Maintenance monitoring is so effective because the consequences are so dire. Simultaneous heating and cooling
What is the yield? Comfort? And energy as an input?

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

- Highly integrated system with thermal storage and variable
- Optimal/suboptimal hierarchical control
  - Make it scalable and low cost is a challenge
  - Reconfigurable
- Where are the boundaries?
  - HVAC?
  - The building?
  - The grid?
- Multiagent?
  - How do you address interoperability?
  - What about interaction with high level control?

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: Benchmark, take a arbitrary building, tools for easily assessing the possible improvement of efficiency?
- Application B: Modularly Eng. Building
- Application C: Global distributed optimization via network communication
  - Control that automatically adjust for degradation or faulty components
    - Sell-configuring controls
    - Intelligent devices which communicates
    - Learn form other field
- Application D: Open Source for a building?

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What would it mean for a building to be "waste-free"? Could we identify and differentiate the essential from the rest, and that difference is waste? What fraction is waste. Maybe we have 90% waste? Just focus on that one piece and separate the wheat from the chaff. What fraction of the overall spend is waste?

How do you define efficiency? Maybe some utility metric. Some lower bound to compare against the total. What should the energy usage be for this type of class of building. Best of breed comparisons? Maybe define it on an occupant basis and what s/he needs to be able to do? But how do you define that for personalized systems. That is a shooting for absolutes. Perhaps we would need to look at exergy use if we really care. Why are we using high quality energy for some of these applications like heating?

Can you quantify the waste within an order of magnitude? There are numbers. 10-30% is suggested, but don't know if we have had an updated study in the U.S. since 1975.

Consider that we don't outlaw VAV. Low energy has not been a design criteria.

"Recyclable buildings" buildings that are inherently designed for upgrades.

Engineered at system level from smart components.

All set points were independently controlled and networked. A pure software building like we have a software radio. Perhaps global optimization of setpoints in a destabilized fashion?

Improved optimization.   A broader set of objective functions.
Reprogrammable and reconfigurable hardware. Webcontrol

Open platform for controls of naturally convected buildings?

Components all independently act while knowing what others are doing. Need to develop and demonstrate that capability for distributed control with intelligent autonomous devices. Individuals working together for common purpose. Whether I have one control system or 100. Shouldn't have to say this sensor is controlled to this actuator.

How do we maximize the learning from one-building to another. What would be the appropriate analog to open source platform?
How do you capture what was learned in buildings? Building information modeling is almost there. Perhaps move to integrate these platforms.

Additional Comments:

We need to have a true value proposition. Not just thinking in terms of a narrow band of specifications. Maybe we need to look at the problem ahead, and not just the one behind. There is a value proposition for FD, but the market may not believe it. Field tests have found that you can provide information for those who need to take action. But there are structural problems in who needs to take decisions vs. who is rewarded, etc.