ARPA-E Advanced Buildings Workshop

Breakout Group #2:

Simulation and Computation
(Chair: Michael Wetter, LBNL)

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.

What new challenges are posed on the simulation/computation of energy efficient buildings as compared to current buildings? [i.e. Physics, controls, user-behavior, real-time simulation, uncertainty, analysis support beyond time-domain simulation.]

- Need dynamic equipment models that tie into multi-physics system models
- Tie simulation tools into other toolchains (such as MATLAB) for analysis, optimization, code-generation etc.
- Support rapid prototyping to reduce time-to-market of new systems.
- Provide plug & play support, managed by a supervisory controller.
- Need multi-fidelity models that can be switched based on available data and process that model is used in.

- Need behavioral models for presence of users in buildings.
- Self-learning models with error bounds and convergence bounds, what is their range of applicability?
- Inverse models for operation.

Definite need for simulation of screw chillers, etc. But it has to be tied in with dynamic control. Europe has put in $45 million in this area. If we have a simulation platform, we can compare and contrast ways of doing things

Requirements:
- it has to be dynamic
- the models have to be accurate, if you are going to make an 8% improvement
- there are commercial tools, like in mathworks, it would be nice if you could be tied into these sorts of toolboxes. Things for rapid prototyping – how quickly can you tie it into a platform and run it?

Research to do new ways of testing things out. Need models to develop the strategies. But what do you need to compute from these models at the end of the day?

Some individuals are talking about modeling at the equipment level – how to optimize at the equipment piece level. We need dynamic models of the equipment?

There is no standard way of how to get the data into the models. What about uncertainty? Where does it come from? Uncertainty in the inputs.

One participant noted that he just looked at 9 chillers All AHUs were oscillating. There are fundamental faults that go on in buildings all the time. - That's an input problem, right? How many faults can you chase on that? Stuff degrades over time. You need continuous inputs, then.

What is required to simulate system level building performance and operation that is considered robust and scalable? What are the current limitations?

- Need standards for "test vectors" of non-nominal conditions (not only TMY3 weather data).
- Need science that deals with 10,000 sensors and parameters which are all uncertain.
  - Estimators that reduce number of installed sensors.
  - Model reduction
  - Tool for uncertainty characterisation.
  - Tool for uncertainty propagation
- Cost/benefit analysis of energy requirements by sensors vs. actual savings.
- Science & tools for verification of large scale hybrid systems.

Assume we give you all the data.

1. Modelling – "10,000 sensors in this building (at $100 a pop) and I look at 100 of them," said a large building operator.
776 parameters in the building
There is a problem with the numbers.
What we critically don't have is a way to deal with models with large numbers
What about model reduction? Get down to 15 numbers? Where is the mathematics?

Way more is needed.

Even if you had best models – if you wanted to look at how things could go wrong, imagine how you would look at this. A monte carlo type simulation is not feasible in the design stage. What types of tools allow you to accelerate?
Don't do simulation at every point?

What about the analogy of the Boeing Dreamliner 787? You decouple things and put sensors where it is important. But perhaps buildings are different, unique, small numbers of products. How much redundancy do we have in the design of the 787? What about complexity of coupling? You have an energy budget that changes over time based on the configuration of resources. Different regimes during the flight parts, etc.?

How do we integrate foundational science, systems modeling and optimization, building information to develop an organized and scalable model that could be used to design and operate a building efficiently?

- Need standards for expressing
  - Requirements
  - Data
  - Models
  - Performance

Need theory to move across multiple temporal and spatial scales (seconds to years, whole building to CFD)

We have a need for tools, which are not there. In autos, each field has its own simulator (powertrain, etc.) where they develop their own local models for local controls. Are you looking to use the same process? Would be great to use one simulator, which does parameter reduction, etc., etc.

Consider the centralization challenge. Efficient central system not leading to efficient end use. Ask first what functions you are trying to achieve. Do simulation tools allow you to ask the right questions and explore options. Need a bigger separation between building physics and simulation of components. Trying to do them both together seems like it won't work.

As an analogy from the cellular industry, there is modeling to establish bandwidth of towers. Perhaps stochastic work on occupants could help you drive first order models. We don't understand how buildings are used. Need to have a tie with occupancy models. Maybe we could have more inverse models? Start with performance goals and work back.
Perhaps we could have a rich database to create insights into building operation as an alternative to simulations.

How do we use measurements to calibrate models in real-time?

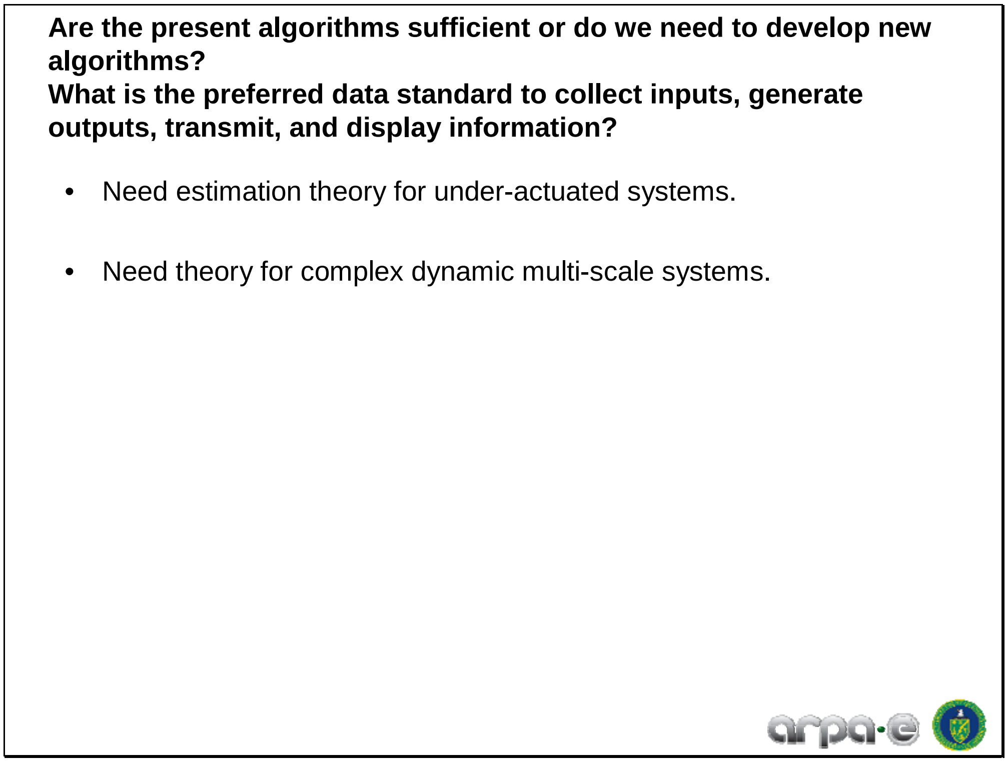
- Fundamental R&D is needed to understand what models are used during operation (physics-based, SVM, neural networks, others…)
- Determine what model is appropriate for real-time operation [controls, FDD, …]
- Grand challenge:
  - How to take models & data from design, apply it to operation, calibrate the model to actual building, use the model for operation.

At this point, the breakout group is engaged in 3 different discussions:
R&D discussion – building a piece or building system and how do we optimize that?
Design – a different cast of characters and time constraints. There will be some overlap with previous group.
Operations – driven by others. Ideally all linked, but were not sure. One giant model is probably not viable.

Need to get inputs to match up with what we can actually model
Measurement data, inverse model, then . . . If you don't understand what parameters matter, and we don't look at sensitivities, and we have no idea where things swing. You could do some simple things with right simulation engine.
Some have suggested there is an issue with engineers not liking natural ventilation. What would building look like? How do I deal with human comfort? We're not even near that from a controls perspective.

Can the building learn about what the people are doing? If you can anticipate what the people are going to do? Can you trash the entire controls system? Update and replace like you do interiors? How do you redesign and re-optimize.
Embedded intelligence is being implied. This is different from inverse model

Models need more than physical principles – need the actual controls sequences. One that can live with the building today.



Natural convection and ventilation, and occupants, we don't have the theory for non-linear convection – it's like weather prediction. And perhaps you still don't like your weathermen [their accuracy, that is]. There is no theory.

You can create some complex algorithms, but you need levels of those models and an understanding of the tradeoffs that come with that.
Improved algorithms and improved performance of existing algorithms. Can't wait hours for something to complete.

How can simulation/computation be advanced to accelerate innovation towards more energy efficient buildings?
What – if anything – is unique in simulation of buildings compared to other engineering fields that also strive to increase performance through integration that leads to complex multi-scale systems?

- Standards for expressing requirements, design data, measurement data and models are missing.
- Such a standard would facilitate collaborative R&D in the industry.

We have a lot of people in their own little worlds. People need to have a way to contribute to the broader whole. We have little islands. Can't do the whole problem. You could contribute to this by a commonly defined set of standards. Auto industry, for example, has some cross-cutting standards. Buildings are a step behind that. People talk about open systems. Whether we are there or not or can build open tools.

Why no consortia to define standards? Well, there are some – it is a bit of a push/pull problem. Need to comply with this interoperability data model is one requirement that the DoD or other user could do. There is a possibility to do this. But there is no Boeing in this industry to do this.

Thermal audit. California is now requiring energy audits. Europe, etc. It is happening slowly.

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: combined technology programs, aggressive large projects.
  - Why?
- Application B: how to fuse modeling & measurement to provide information [ctrl., fdd]. Models as “virtual sensors” to reduce sensing cost, how to deploy them into control systems?
  - Why?
- Hybrid model: stochastics, distributed temperatures, controls..

Cost of measurements is an issue. How do we use modeling combined with measurement to . . . what we are talking about is the inverse problem. How do we infer from what we can measure? I would use the word virtual sensor to bridge that gap to performance measures.
Essentially, you’ll never have enough data to do what you want. How can a smart model or tool fill in the gaps?

One participant developed low-cost RFID and is bullish that sensing will take off. MIT has lighting ballast that compensates [for occupancy rates]. What if you knew occupancy in rooms? What would be the impact of that? A hybrid model. Stochastics, controls, and thermal modeling. That will help us figure out if it is worth doing. Can you relax other rooms? Co2 sensors can measure that in terms of occupancy.

How do we integrate into a building control system, and make it scalable.
Models need to be smart so that they can learn and use fuzzy logic, etc.
Integrate thermal models and controls.

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

You can use 300 kwh/m2 – let's say we reduce that by 50% - that is a cost figure

Cost is tricky. Lifetime, capital, mature market costs. Also have to look at the benefits side. Better comfort, improved operations. Need to multiply the benefits with what is accepted in the marketplace.

Key Technical Barriers

Technology #A:

- Barrier(s): Lack of standards (data, models, communication, requirements). Lack of science for multi-scale system analysis of underacted systems.
- 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

Think about tool suites that allow you to explore a design space. Be able to do simulations at 10-100x faster and be able to make assessments of performance – you will get it right to +/- 20%

Electricity price signals can help drive decision on storage. Communication of anticipated loads is very valuable to the utilities. Utilities have a decoupling of incentives.

Funding Gaps and Path to Transition

- Most significant funding gaps in government/private sector?
- Optimal roles for ARPA-E vs DOE EERE in supporting Simulation and Computation?
- 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: $??

If you could instantly go from design model to actual operating model, that would be big.

Operators have inherited something which may or may not be true. The operator needs a calibrated model that works.