ARPA-E Advanced Buildings Workshop

Breakout Group #1:

Simulation and Computation
(Chair: Ron Judkoff, NREL)

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.]

- Can they be addressed with today's technologies?
  - Existing bldgs may be harder
    - Calibration of models is critical
    - Uncertainty in what the exact bldg envelope is
  - Models for new subsystems are lacking
    - Integrated systems models are lacking
    - Who is the user? Tools must be appropriate for them
    - Models don't include faults and degradation
    - Occupant behavior is not well-understood
    - Models must influence users' decisions
  - Missing computational approaches
  - Are we focusing on the highest impact bldg types?

- Current more challenging than new bldgs
- Physics and energy hog bldgs more difficult to model than efficient bldgs (solid bldgs vs.. empty cavities)
- Sim tools – calibrate existing bldgs to develop good starting points
- New bldg design – models for integrated systems lacking
- Need new models for innovative integrated systems and natural environment (i.e. low lift building – ac at night with lower lift vs. losses going in and out of storage)
- Users of tools – specialized experts vs. 2nd classes of users (i.e. architects) – tools and user interface need to be specialized to the user
- Simple tools in past with little horsepower vs. new advanced tools with lots of layers of fidelity and detail with different interfaces based on the user needs and aptitude
- Uncertainty as to what is in the current building – documentation is key to develop an effective mode tools – what is critical info for bldgs (i.e. existing) so that you can properly model bldg. vs. lots of assumptions
- Need more data – most current data is anecdotal
- Current tools don't model things like multiple (frequent) changes in temp setpoint – occupant behavior is not well understood (it can be modeled well but the data is not understood)
- Stochastic behavior of occupants – individuals mechanistic – multiple folks more like random noise – depends on the action, frequency, etc and the impact of the action – different actors will perform different actions – scenario modeling can help determine the impact of the various adjustments
- Must inform model user of the decision-making in the model – conceptual design vs. final design – 80% of design is done up front (in the beginning) – integration and interoperation of the models key – analytical hierarchy of models is key as the architect is usually the overseer of the bldg design
- Models vs.. computation – not the individual models and physics but the type of computations and the types of decisions to be made – approaches, processes, de3cision-making based on the modeling.

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

- Limitations
  - Lack of bldg performance data to influence user
  - Weather data is limited in temporal freq.
  - Spatial variation within bldgs can vary
    - Isothermal assumption is almost always wrong
  - Proper input of materials properties – esp. w/ age
  - Age changes in general…
  - Combination of short timescale and long timescales
  - Complex behavior is comp. intensive – need simplified models
  - Better calibration – we have an under-determined problem
- Envisioning the future
  - Data assimilation – heuristic models

- Limitation is lack of comparable information – lack of awareness on bldg performance data
- Model validation and disconnect between design and as-built – are models accurate based on modeling of either?
- Are people behavior and physics modeled correctly?
- Physics – multi-scale modeling – robustness and scalability. Weather data hourly – hard to model at finer resolution – must interpolate smaller timeframes
- Comfort level in different bldg areas – i.e. floor to floor variations with natural ventilation
- Isothermal modeling is current – worsens models with this assumption and natural ventilation
- Proper input is key to simulation/modeling
- Driving model input for climate data (floor by floor) – dry and wet bulb, solar radiation, wind direction and speed (generalized by speed increase and height) – wind speed can be a primary driver and varies based on heights, etc. – usual wind info is at 10 meters at airport)
- Computational challenges – logic within building to help operate bldg as well as for fault detection to operate bldgs
- Integration with grid
- Perfect bldg as built vs. after 5 yrs with leaks etc
- Cooling coil performance based on where sensors are positioned – chiller water temp for temp deltas inlet vs. outlet – controller always moves and we don't always have performance maps of equipment – hourly simulation assumes steady state and single output value – need short timescale data integrated with longer scale to model controls
- Are these computational problems? Based on accurate input data and prescribed models – modeling simulation for dynamics envelopes is not an issue – we have the horsepower – but operation can be modeled at lower fidelity to design a control system and different from a model
- Control system tied to closed loop feedback – integration problem is the key. Lots of bldgs have heating and cooling systems running at the same time to control the temps and this causes issues – some zones are too cold with AC and heat runs to make temp comfortable – this is a current and widespread issue
- Data simulation (like weather forecasting) should also be used in building modeling
- Operation of equipment in older bldgs is also not well understood
- Design of simulator should be linked to bldg run time – shadow vs. actuation and control – move from simulation only to actual feedback control to validate the simulation

- 2 ways to simulate – design (no data) and data driven (heuristic - self learning models) to make accurate notion of how controls work
- Existing bldg issue – need good model before we use as decision tool – need systematic processes to calibrate models and what measurements are required to feed model – underconstrained (or underdetermined) system
- Present state of art is lacking but there are good attempts with current dynamic system models but are mostly quasi-steady vs. actually dynamic with transient (HVAC is quasi-static but overall bldg is dynamic) – bldg thermal mass is modeled dynamically but evaluated over longer time periods)
- Model validation is issue solutions 3 ways– analytical; empirical; comparative (where do others diverge?)
- Overall tools vs. specific tools that work well but are not integrated in an overall model
- CFD, energy product, etc – when you work them in parallel they can provide different areas – which to believe?
- Integrate models at different levels (CFD, bldg multi-zones – Zonal model is not at fidelity of CFD) and extreme time scales (heat transfer to ground) vs. time scale of heat transfer to building (smaller time scale) as well as size scale (room vs. bldg) and large scale (bldg interaction of heat transfer and wind variation) – long timescale is ground heat xfer and small is controls
- Current codes are performance-based – qualifies tools to be used to measure compliance – capabilities in tools allows evaluation of design to meet codes (prescriptive – r values; and performance based with evaluation i.e. energy plus) e.g., no insulation but increase something somewhere else to meet performance requirement
- Answering questions is key – mode functionality in model adds complication – natural ventilation i.e., will air go into or out of windows depending on height in atrium?
- Early vs. late stage decision-making in design – architect wants quick and dirty tool for early stage decision-making
- Thermal mass is early stage evaluation but does not require each window placement (just height and size) – key questions in design stage
- Models to answer simple questions for a variety of users but must have good physics
- Model-based decision-making – stages of design need specific fidelity of models for specific answers – are models accepted in design clubs and used by the audience?
- Design process to structure how models are used
- Architecture views design as expression of design/art and are resistant to having design process

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?

- Integration is a challenge – CFD+Zonal models etc. etc.etc….
- Timescale is a challenge – e.g. ground heat transfer vs controls
- Size scale is a challenge
- Models must be able to answer simple questions for a variety of users – but must have good physics
- Use of models – certain models for certain stages of design – and good hand-off

See previous discussion notes – no additional discussion here – slide skipped.

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

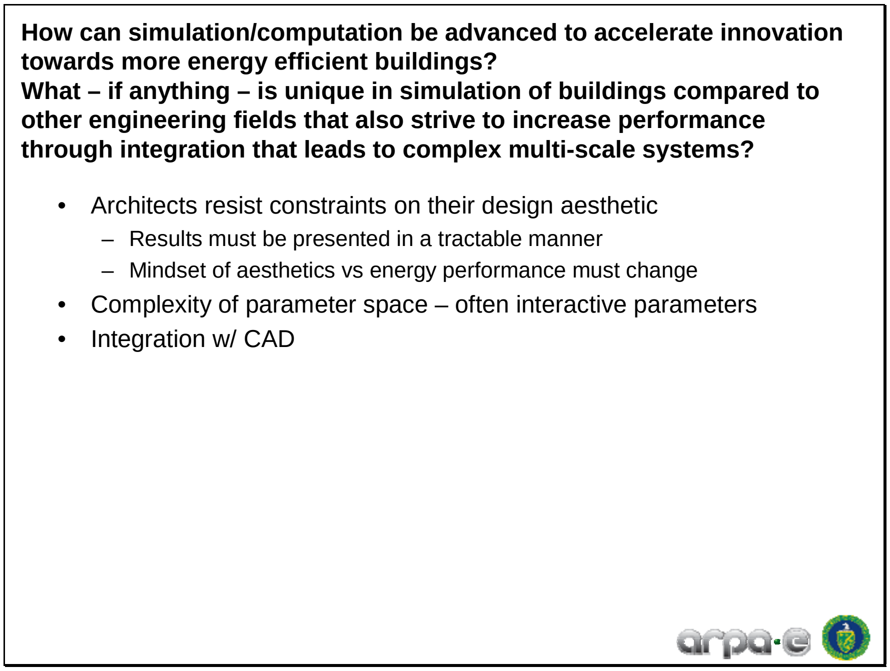
- See previous
- Quality of data is key – measurements aren’t precise, boundary conditions aren’t established
- Need to avoid data glut
- Optimize existing sensors and their location
- Hard to determine how much data density you need
- Experimental facilities and whole bldgs are important

- Real-time simulation requires high quality data – measured data must be accurate – indoor modeling of temp and velocity – data varies a lot depending on who makes the measurement – standards and practices
- Environmental variability will also affect – spatial and temporal variation lf measurement data
- Data does not always reflect boundary conditions
- Differences between measurements and modeling not always consistent
- Measurement dynamics is key issue – low flow in bldgs for low flow (hot wire anemometry) is at the level of measurement devices (issue for CFD)
- Lots of data is not always accurate data – lots of sensors vs. optimized position of sensors
- How to mine sensors for data – optimal sensor placement in structure to accurately represent the bldg – models can be used to help determine sensor placement (non-uniform zone is key)
- Temporal data capture is difficult to determine up front – density
- Sensors to support physics – what varies spatially and temporally to determine where to place sensors and how often to collect data to determine the physics of the structure to then inform where and how to collect data to inform model
- Whole building experimental test-beds in different geographic locations to determine how to collect data – depends on building type as well – building stock, inherent bldg performance (good or bad)
- I.e. what works well where – how does aesthetics track performance (Greek design vs.. Cape Cod) and how this might have changed more regularly)
- 2% of bldgs represent 95% of the commercial bldg footprint – large buildings – how do we build the simulation capabilities to target the largest proportion of buildings

Are the present algorithms sufficient or do we need to develop new algorithms?
What is the preferred data standard to collect inputs, generate outputs, transmit, and display information?

- Moisture issues are not well-captured
- Degradation of components and systems w/ time is not accounted for
- Air movement
- Ground coupling is a challenge
- High freq controls
- Coupling between models can be unstable
- Architecture tools (sketching tools) coupled to energy tools
- Focus needs to move to how data is interpreted by user
- SimBuilding (get a high score!)
- Optimization algorithms always need more help
  - Sensitivity analysis
  - Uncertainty analysis
- Coupling of electrical controls with thermo – tough!

- Moisture issues are not well captured
- System performance is not accounted for (maintenance and replacement)
- Air movement
- Ground coupling is a challenge
- High frequency controls – how to integrate one program output to the next program input – can compound errors (energy plus) and be unstable
- Multiple competitive approaches are key vs.. one solution
- Architecture tools (sketching tools) coupled to energy tools
- Visualization of Energy flows – user interface vs. underlying computational issue - depends on GUI – lots of work on analytics vs.. focus on how to represent data to user in an understandable way
- Feedback of energy tools – intuition can be informed and also be used as a learning tool to inform the architect as to the impact of their designs/changes
- Integrated engineering/architecture education
- Flexibility of tools – improvement of optimization algorithms (stochastic and mixed integer) – how to avoid local minima
- Coupling of electrical and thermal controls is very difficult
- Actuation authority and building dynamics (airflow and thermal inertia) - couple the two together to develop optimization approach – determine the most sensitive parameters and uncertainties to optimize the solution (vs.. nominal parameters that are tweaked) – determine where the variances stack up – what are the controlling parameters that you can change – these are how to control the system – uncertainty analysis is key



- Architects resist constraints on their design; however, computer can create many mode design solutions but may mask creativity
- Difficult to segment complexity of parameter space – often interactive parameters
- Depends on architect position as well as what consumers will expect – design differentiation vs.. requirements (car aerodynamic constraints vs.. art of bldg design) – light patterns vs.. airflow
- What simulations and conveyance methods are required to convey the info to the audience (architect interface in 3d/CGI integration with CAD for simulation) – perception is a key issue – bldg design for beauty vs.. for energy efficiency – need to integrate both in the mind of the designer/architect – trade space and design impact on functionality – optimization logic with result comparison
- Design impact on energy consumption is not tied to tools that quantify the impacts – packaging effects on efficiency as things are not additive – must consider as a system – not linked to architect decision-making

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:
  - Provide the right information, at the right time, in the right form, to the right person
    - Quantify the energy consequences of design – esp. early!
- Application B:
  - Why?
- Etc

8

- Provide right level of data/information in right form at right time in process to the right person
- Couple models to behavioral decision-making
- Ability to scientific design space design to quantify the energy consequences of design
- Architectural design needs to be influenced by the results of the energy analysis (is the architect receptive to the suggested changes?)
- Partner design with climate engineering to optimize/link design with energy performance
- Have architect interface with modeling tools
- Safety engineers should also be integrated (earthquake, fire, etc.) – fire and security is considered (occupation and pressure – regulatory driven to consider fire safety/smoke control in HVAC system – where do interactions occur and how can energy be coupled in to this analysis (when energy is usually considered as free and not considered in design – shift this interaction to architecture to move the consideration to earlier in process)
- Constructer involved earlier in process makes effort easier to complete – integrate design process from the beginning
- Owner must push integration as they are key to drive outcome
- Software engineering view – granularities along design process – open framework sponsored by DOE to allow plug-in of different modules (energy analyses) as perceived and necessary – software engineering framework dumbed down for beginning architectural stages but with open FWK you can add granularity downstream – Discussion on one model vs. multiple – would likely be too difficult to integrate to one model and not necessarily beneficial
- Simulation is enabling tech and only as beneficial as the insight gained by it
- As built vs.. as designed buildings – need to lower the disconnect between the two to improve the end efficiency of the structure – use energy savings and overall cost savings associated with this approach
- Cost of design of low energy buildings – stages of design and modeling granularity to work to drive down costs

- Maintenance and replacement should be a defined activity – health monitoring for maintenance – integrated building allows for this action and increases bldg performance ultimately lowering costs due to increased bldg efficiency – integrate models for design with models for performance
- Models used for design – increase percentage of use
- People can't design HP energy efficient bldgs (and operate them) without these tools – intended HP bldgs that don't actually make may have lacked good simulation or it might have been done incorrectly – get beyond check-box approach to efficient design
- Theoretical value for average HP building – cost trade-off for increase deficiency (cost performance basis)
- Best design integration at various points – theoretical at different points based on optimal designs – 5 year lifecycle costs (cost/performance curves and equivalent cash flow for theoretical designs) – longer ROI returns XXX over a 30 year mortgage but has mode upfront costs
- Simulation to influence design – we did not touch influencing the behavior of the user
- Choices of how to design based on monitoring tools

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

Application A:

- Lower the % disconnect between performance vs design
- Lower cost-to-design of high performance bldgs
- Integrate models for design w/ model for performance – drive down ops cost
- Increase the % of bldgs that use simulation in design
- Get beyond check-box approach to efficient design

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 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: $??