

# From the Building to the Grid: An Energy Revolution and Modeling Challenge

## Workshop Proceedings

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

**Technical Report**  
NREL/TP-6A00-56056  
January 2013

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NATIONAL RENEWABLE ENERGY LABORATORY

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# **1 Introduction**

Buildings are universal and shelter virtually every aspect of our lives—we work, live, learn, govern, heal, worship, and play in buildings. As a result, buildings have a significant impact on energy use and the environment. According to the U.S. Energy Information Agency, homes and commercial buildings use 71% of the electricity in the United States and this number will rise to 75% by 2025. Opportunities abound for reducing the enormous amount of energy consumed by buildings. NREL is at the forefront in developing advanced building technology and science to reduce the amount of energy consumed in our nation's buildings—our goal is to significantly improve the energy efficiency of buildings and to accelerate the use of renewable energy technologies within the next decade.

## **1.1 Workshop Motivation**

To address modeling and simulation challenges in integrating building energy management systems with those of the grid, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) in conjunction with the University College Dublin held two industry workshops entitled: From the Building to the Grid: An Energy Revolution and Modeling Challenge. The first workshop was held on May 1-2, 2012 on NREL's campus in Golden, Colorado. The second was held on June 6-7, 2012 at the University College Dublin, in Dublin, Ireland.

## **1.2 Workshop Objective**

The objective of these workshops was to engage the university and laboratory research communities to identify and define research directions for building energy management systems modeling and integration with the grid. Desired outcomes for the workshop were to 1) determine the value of integrating building energy management models with the grid and 2) generate and document a research agenda for advancing the development of new integrated models that link systems and models of buildings and grids.

## **1.3 Workshop Structure and Guiding Questions**

The structure of the workshop was mostly open forum discussion designed to encourage interaction among the group of participants. Workshop discussions were guided by the following four framing questions:

1. Is there value to integrating the existing models in building energy management systems with those of the grid?
  - a. If so, what are the particular research problems that these integrated models can tackle?
  - b. If there is not then how should these two modeling domains interact?
2. Is there a need to develop new models that span both domains?
  - a. If so, what are the particular research problems that these integrated models can tackle?
3. Does the ability to collect and process large amounts of performance data enable better models and create linkages between the actual systems and models of buildings and grids?
4. What is the role of hardware-in-the-loop testing?

The findings from each workshop are documented in this summary report.

## 2 NREL, Golden, Colorado (May 1-2, 2012)

The first *From the Building to the Grid: An Energy Revolution and Modeling Challenge* workshop was held on the NREL campus in Golden, Colorado on May 1-2, 2012.

### 2.1 Participants

Name	Affiliation
Amir Roth	DOE
Annabelle Pratt	Intel
Ben Kroposki	NREL
Bruce D'Amora	IBM
Connie Komomua	NREL
Duncan Callaway	UC Berkely
Greg Dobbs	GPIC/Penn State
Gregor Henze	CU Boulder
Jim McCally	Iowa State
Josh Hambrick	NREL
Kara Clark	NREL
Larry Brackney	NREL
Mark O'Malley	UC Dublin
Ralph Muehlesien	Argonne
Roger Dugan	EPRI
Sid Suryanarayanan	CSU
Sila Kiliccote	BNL
Zhi Zhou	Argonne

### 2.2 Agenda

#### From the Building to the Grid: An Energy Revolution and Modeling Challenge Workshop Agenda

May 1, 2012

**8:30-9:00** Welcome and Introductions

**9:00-10:00** Background

- Energy systems integration (O'Malley)
- ESIF (Kroposki)
- Discussion of workshop objectives

**10:30-12:00** Round Table discussion of workshop questions (Each person is given 5 minutes to discuss these questions)

- Is there value to integrating the existing models in building energy management systems with those of the grid?
  - If so, what are the particular research problems that these integrated models can tackle?
  - If there is not then how should these two modeling domains interact?
- Is there a need to develop new models that span both domains?
  - If so, what are the particular research problems that these integrated models can tackle?
- Does the ability to collect and process large amounts of performance data enable better models and create linkages between the actual systems and models of buildings and grids and what is the role of hardware-in-the-loop testing?

**1:00-3:00** Summarize morning discussion – come to consensus on issues.

Develop up to six research questions in ESI.

**3:30-4:30** Development of hypothetical research program around the key issues

**4:30-5:30** Tour of RSF and ESIF

### **May 2, 2012**

**8:30-10:00** Summarize yesterday's meeting and discussion

- Develop specific actions that group can take on in the ESI area
- Arrange panel sessions at conference, influence research agencies, influence IEA working groups, collaborative papers or invited papers
- Understand how ESIF can play a significant role

**10:30-11:15** Summarize workshop (possible read out to select ESI TRP members)

**11:15** Conclude workshop

**11:15-noon** Optional RSF tour

The workshop agenda featured introductory presentations by Mark O'Malley, UCD, on energy systems integration and Ben Kroposki, NREL, on the Energy Systems Integration Facility at NREL. The presentations were followed by a group discussion on the workshop objectives.

### ***2.3 Workshop Objectives: Group Discussion***

At the beginning of the first day, participants were asked to share their expectations of the workshop. They expressed the following needs that focused around EVs, timescales, characterization of sources, and control strategies:

- Need enabling technology like real-time pricing
- Need Increased utility participation
- Need to figure out RTO modeling requirements
  - Control systems capable of responding to reliability events
  - On what time scale?
  - Operational, production costs, etc.
- Need modeling capabilities need to span from design and site plan to operations
- Need large scale simulation and testing capabilities

- Need frequency regulation and peak avoidance models for EV charging in residential vehicles
- Need to figure out the effect of new technologies (from a short term/long term viewpoint) on the distribution system
- Need transparencies in the data. Need to be able to show the effect of the technologies to make change to policy and rate design.
- Need to be able to analyze demand charges versus energy charges for better optimization.
- Need to be able to see into the level of the building model with a level of granularity not currently available.
- Need to education building energy managers
- Need models to look at aggregation of loads and characterizing loads, plus the controls that go with it.

The general consensus of the group was that it is better to simulate first; then build. The more that is known ahead of time the better. Know what these systems should look like and how they perform before buildings them. Work should be done up front, not after.

## **2.4 Workshop Questions: Roundtable Discussion**

Participants were then given 5 minutes each to comment from an industry perspective on the workshop questions. The following is a summary of participant comments grouped by industry focus.

### **Distribution Modeling and Simulation**

Building models are no use to electrical models. Need higher fidelity load models and can't get that from a building model. Zip models don't help understand "energy over time" – needed for a building / electrical modeling framework. The question then is: what type of interaction between building energy performance and electrical load models do we need? Trying to understand areas where you would need results from both.

- Conservation voltage reduction
- Grid-scale energy storage (not worked out yet or easy to model)
- AC/DC hybrid microgrids

The more we can take the two frameworks and work together, the better.

### **Transmission**

What is the variability of the load in aggregate? Chasing aggregate load is the focus, not one building or group of buildings.

Maybe something is needed in the middle, aggregated and individual loads. But, beware of creating an "unmanageable giant".

Utility load modeling is always a challenge, how will they manage integration pieces that come onto the grid?

- Making better use of transmission is important because of procedural and operational constraints we put on the system.

- Make the system more flexible in its ability to respond.

## **Buildings**

Particularly concerned about understand the end-uses in the building.

Big system models don't let us get into the individual variability in loads – basically, we look at loads in dis-aggregate:

- Building grid control issues
- Managing site renewables and storage

We need to make sure that solutions that start from building management to the grid connected model have the ability to reach HIL solution and the ability to swap hardware in and out to assess the characteristics of an optimal design solution.

We need to aggregate loads at some level, but not at the base. A possible new business entity: an aggregator between the two: buildings-to-grid.

From the aggregator level, the building model should know aggregator and the other buildings. What piece of the building model does the grid need to understand?

- Aggregator can provide load demand curve.
- Capability of building to be able to provide ancillary services; spinning reserves.
- Real time pricing information important to help demand response management.

## **Architectural Engineering**

Retail meters are artificial barriers. Benefits reside on timescales. Buildings can provide electricity by relying on forecasting strategies.

Buildings can provide ancillary services, spinning reserves. What impact does this have on reliability? If we allow them to participate in frequency regulation how do we regulate and verify?

Harnessing large amounts of data in some meaningful fashion -- what is the right model complexity?

Large commercial buildings into grid operations have to understand how one supervisory control has an affect – need to be able to go down into the lower levels. Loops are generally commissioned to begin with, how do we identify the appropriate model of the building based on set points at the level of an entire building?

What's the whole engineering bottleneck to making it work? Building model should inform the aggregate system model.

## **Building Management**

Building management in grid integration is important in order for buildings to respond more actively. Sending signals from the grid to buildings in intelligent feedback begs the questions:

- What level of details?

- What geographic scale makes sense to model?
- Time scales? Customer software development or existing?

## **Demand Response**

Emerging countries are currently developing ac/dc distributed centralized grids. In the sense of planning, simulation is important.

DR integration with grid and buildings side is not just about load, generation, storage....think about behind the meter in different time scales. Sensors will allow us the opportunities to calibrate some of the integrated models now that we have some data. Can we integrate simulation into our building operations to optimize building operations?

## **Analytics/Data**

Equally important as data collection is the analytics components. Massive amounts of data to be collected from many different buildings and the information can be reported back to building operators.

- *Simulating virtual power grid.* Combination of simulation and analytics try to predict how the real grid will behave over a period of time.
- *Extracting information from data.* Give it back to the buildings operators in a way building people can use it to optimize operations. New tools that model a different system – model renewables.

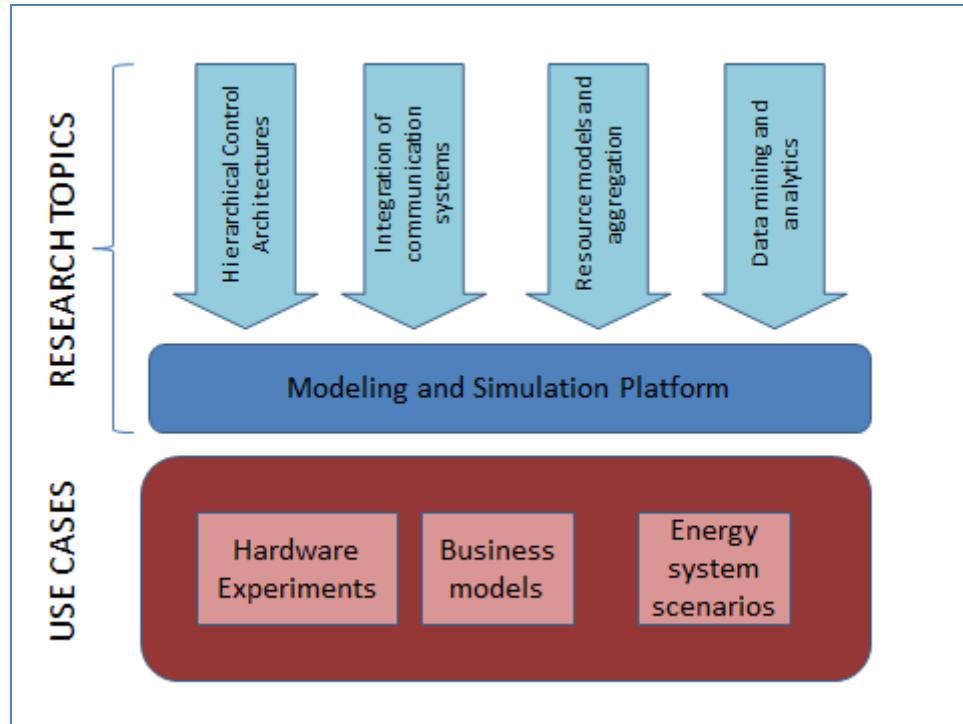
## 2.5 NREL Workshop Results

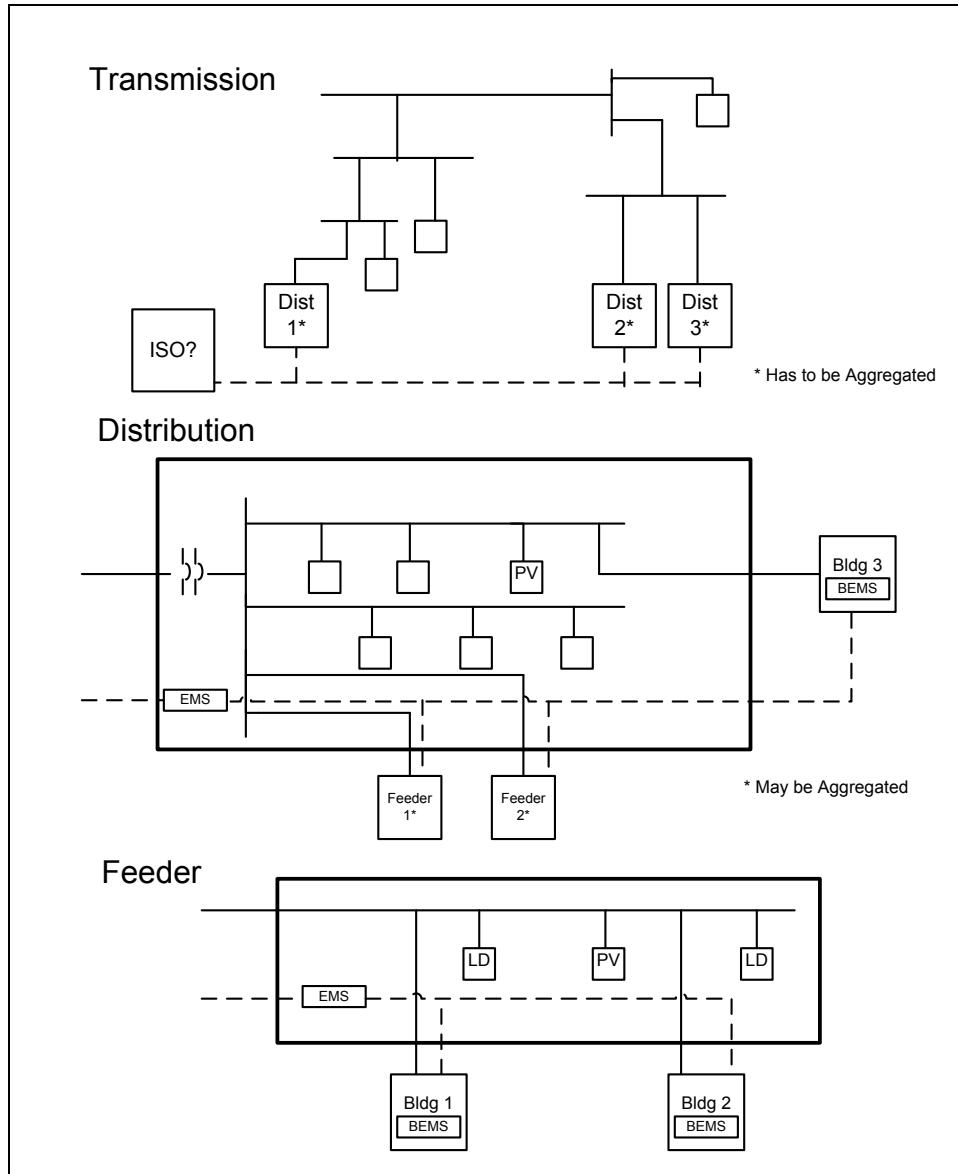
Key findings from two days of presentations, discussions, and participant reporting during the buildings integration workshop are summarized as follows:

1. Is there value to integrating the existing models in building energy management systems with those of the grid? **Yes.**
  - a. If so, what are the particular research problems that these integrated models can tackle? **See details below.**
  - b. If there is not then how should these two modeling domains interact? **N/A.**
2. Is there a need to develop new models that span both domains? **No need to create a “Super -all-encompassing” model, should create interactions between existing models, may need to develop features/models to fill gaps and better couple models.**
  - a. If so, what are the particular research problems that these integrated models can tackle? **See details below.**
3. Does the ability to collect and process large amounts of performance data enable better models and create linkages between the actual systems and models of buildings and grids? **There is a need to create linkages between data and models.**
4. What is the role of hardware-in-the-loop testing? **See details below.**

## Workshop Results

- A. Use cases
  - a. Business Models
  - b. Hardware experiments
  - c. Future energy systems scenarios
- B. Research topics
  - a. Modeling platforms and co-simulation
    1. Hierarchical models
    2. Communications systems models
  - b. Resource Models, aggregation issues
  - c. Data mining and analytics
- C. Actions Items





## A. Use cases

specific problems that the models and interfaces will solve

- Questions a use case can answer
  - What will these models and interfaces look like?
  - Who will use these models and interfaces and where?
  - What is the value proposition in each case?
  - What types of user interfaces are necessary?
  - What technologies (computing, communications) are needed
  - “performance specifications” – Use cases drive a requirement that the models must meet
    - E.g. reliability, availability, serviceability, latency

### a. (use cases) Business Models

- Example
  - Aggregators vs load serving entities interacting with TSO
- Questions
  - When does market saturate for a variety of services?
  - What's the value / incentive to various parties
  - Can grid-relevant models be required of buildings when they connect to the grid?
  - What are the enabling technologies?
- Things to consider
  - must understand business models when designing hierarchical frameworks
  - models need to be flexible as business models change

## b. (use case) Hardware experiments

- What is this for / why do this?
  - Data validation and calibration
  - Linking hardware to simulation environment in a “controlled manner”
  - Model based control and optimization
- Examples
  - Distribution system experiments
  - Device-level experiments
  - Transmission level?

## B. a. Research Topic: Modeling platforms, “interoperability” and co-simulation

- Idea: sandbox to join models together
  - Fully develop use cases in order to determine application of models
- Example solution:
  - functional mockup interface (FMI)
  - Linking single and multi-domain simulation models (e.g. Gridlab-D, SimScape)
- Things to work on
  - Provision of ancillary services with the full variety of options (e.g. combining power, building, communications simulation)
  - Detailed electricity models for buildings
  - Impact of grid conditions on energy conversion devices, operation of other loads
  - Impact of operation of loads on grid conditions
  - Needs of micro-grids vs bulk power
  - Incentives for sharing data and constructing models that don't have direct application in the domain of the “creator”

## B.a.1. Research Topic: Hierarchical control architectures

- Why do this?
  - Inform how we build modeling platforms
- Hierarchy examples
  - Business models (ISO → aggregator ...)
  - Supervisory vs lower level control
- Fundamental question:
  - How does the reliability of the system change with more hierarchies in the control system

## B.a.2 Research Topic: Integration of communications systems models with power and building models

- Use case
  - Grid communication to buildings – cognizant of impact of communications
- Why do we care?
  - Impact of delays, bit rate constraints, lost packets etc. on performance
  - Security and privacy
- What to do
  - Benchmarking reliability of demand side service to grid
  - Understand communications patterns - minimize network traffic and maximize efficiency

## B.b. Research Topic: Resource (anything behind meter) models and aggregation

- What is this for?
  - Planning – how much resource is available in the future, what are its capabilities
  - Operations – predicting how aggregations will respond to commands from system operator
  - Reducing requirements for metering infrastructure – is there a way to aggregate resources to reduce metering
- Approaches
  - Physically based aggregation models
  - Statistical models
- Modeling decisions
  - Resolution – spatial and temporal and electrical

## B.c. Research Topic: Data mining and analytics, situational awareness

- Why do this?
  - Calibration, benchmarking, performance monitoring (are buildings doing what they promised?)
  - Forecasting on all time horizons
  - Visualization and decision making
  - Resource Identification Verification – developing statistical models of resources based on real data

## **2.6 Next Steps: Action Items**

How can we spread the word? What types of materials are needed to proceed and who will develop them?

- Collect relevant materials (papers) on energy systems integration (ESI), data sources
- Clearly articulate story around ESI – develop material; develop use cases
- Create a framework for models
- Engage with utilities
- Arrange Super Sessions at conferences to discuss this topic (panel sessions are typically seen by more people)
- IEEE-Power & Energy Society, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) - Greg, Sila, Sid
- American Society of Mechanical Engineers (ASME), International Building Performance Simulation Association (IBPSA), IEEE-Conference on Decisions and Control, GridWeek, ConnectivityWeek - Sila
- Association of Energy Engineers (AEE), Association for Computing Machinery (ACM), e-Energy - Ben, Mark
- Special Issues on Journals (Power & Energy Society Transactions, IEEE Industry Applications Society Transactions, Energy and Buildings, Power & Energy, ASHRAE Journal, JEPS) Ben, Mark , Sid – sister articles in multiple magazines
- Task Force within larger existing group that may address these issues - Sid, Mark
- PhD Summer School – American Council for an Energy-Efficient Economy (ACEEE) Simurex 2012 (NREL host)
- Create a National Science Foundation (NSF) Center around the topic of energy systems integration.

## **2.7 NREL's Energy Systems Integration Facility**

It was determined by the group that the Energy Systems integration Facility at NREL can play a significant role in these efforts by:

- Physical manifestation of the ESI concepts and research
- Major contributor to the HIL testing
- Need for a DMS/EMS simulator that can demonstrate large scale deployments of new technologies
- Key: Need clear method to engage the use of ESIF.

## **3 University College Dublin, Dublin, Ireland (June 6-7, 2012)**

The second *From the Building to the Grid: An Energy Revolution and Modeling Challenge* workshop was held on the University College Dublin campus in Dublin, Ireland on June 6-7, 2012.

### **3.1 Participants**

Name	Affiliation
Ian Pepper	Cylon Group
Henrik Madsen	DTU/RISO
Niamh O'Connell	DTU/RISO
Jonathan O'Sullivan	EirGrid
Jan von Appen	Fraunhofer-IWES
Einar Larsen	GE Energy
Dick Piwko	GE Energy
Stan Zachary	Herriot-Watt University
Michael Wurst	IBM - Smart Cities
Ben Kroposki	NREL
Stuart MacMillan	NREL
Erik Ela	NREL/ERC/UCD
Simos Oxizidis	UCD School of Mechanical & Materials Eng
Ray Foley	United Technologies Research Center
Stephen Duncan	University of Oxford
Roisin Duignan	ERC/UCD
Damian Flynn	ERC/UCD
Olivier Neu	ERC/UCD
Mark O'Malley	ERC/UCD
Fabiano Pallonetto	ERC/UCD
Jonathan Ruddy	ERC/UCD
Hassan Wajahat	ERC/UCD

### **3.2 Agenda**

#### **From the Building to the Grid: An Energy Revolution and Modeling Challenge Workshop Agenda**

June 6, 2012

**9:00-9:30** Welcome and Introductions

**9:30-10:30** Background

- Energy systems integration (O'Malley)
- ESIF (Kroposki)
- Discussion of workshop objectives

**11:00-12:30** Round Table discussion of workshop questions (Each person is given 5 minutes to discuss these questions)

- Is there value to integrating the existing models in building energy management systems with those of the grid?
  - If so, what are the particular research problems that these integrated models can tackle?
  - If there is not then how should these two modeling domains interact?
- Is there a need to develop new models that span both domains?
  - If so, what are the particular research problems that these integrated models can tackle?

- Does the ability to collect and process large amounts of performance data enable better models and create linkages between the actual systems and models of buildings and grids and what is the role of hardware-in-the-loop testing?

<b>1:30-3:30</b>	Summarize morning discussion – come to consensus on issues. Develop up to six research questions in ESI.
<b>4:00-5:00</b>	Development of hypothetical research program around the key issues
<b>7:00</b>	Dinner at The Orangerie Bar, Raddison Blu St. Helen's Hotel (Hosted by the ERC)

### **June 7, 2012**

<b>9:00-10:30</b>	Summarize yesterday's meeting and discussion <ul style="list-style-type: none"> <li>• Develop specific actions that group can take on in the ESI area</li> <li>• Arrange panel sessions at conference, influence research agencies, influence IEA working groups, collaborative papers or invited papers</li> <li>• Understand how ESIF can play a significant role</li> </ul>
<b>11:00-12:00</b>	Summarize workshop (possible read out to select ESI TRP members)
<b>12:30-1:00</b>	Discussion on differences/contracts/ similarities of two workshop outputs
<b>1:00</b>	Conclude workshop

The workshop agenda featured introductory presentations by Mark O'Malley, UCD, on energy systems integration and Ben Kroposki, NREL, on the Energy Systems Integration Facility at NREL. The presentations were followed by a group discussion on the workshop objectives.

### ***3.3 Workshop Objectives: Group Discussion***

At the beginning of the first day, participants were asked to share their expectations of the workshop. They expressed the following needs that focused around real-time pricing, time scale, building models vs. grid models, information collection, validation, and control strategies:

- Need tighter integration of grid, more automatic control
- Need to know how much information is needed (time scale, granularity?)
- Need to develop a stability model, ensuring closed loop control.
- Need to determine infrastructure required, time resolution, develop validated models
- Need modeling to understand what DR is, and modeling to integrate the grid and building models.
- Need everything to be automated, consumer should not be aware of flexibility
- Need to split demand into different categories – what needs RT control, what needs 24hr planning etc.

Several key questions came out of the discussion, which were then used to ensure important issues were addressed during the workshop:

1. How much do we need to model building level to see impact on grid level – to what detail level?  
Impact of (in) efficiency on flexibility available, what thermal storage available?

2. Do we want DR, what are the benefits, what time scale? At what level is control required / desired? Trade-off between level of accuracy and complexity of model, how much uncertainty can be taken out with feedback?
3. How can price be used to solve this problem, how can political issues be dealt with? How can user behavior be modeled? Psychology of user response to prices. Load coincidence issues.

### **3.4 Workshop Questions: Roundtable Discussion**

Participants were then given 5 minutes each to comment from an industry perspective on the workshop questions. The following is a summary of participant comments and discussions:

#### **Participant Comments**

- We first need to define what the model is *for*, what does the model have to support. What is the application in the real world? Who is the user, what are they trying to accomplish?
- The model needs to be a hierarchy for control, planning (one time stage feeds into another e.g. regulation to spinning to energy shifting)
- Different people have different specifications, which have the potential to conflict. There needs to be a control action to realize that specification and be able to predict the response.
- Time frame is essential, time scales of specification, effector and sensors need to be in line.

#### **What is the specification, who is the user?**

- Day ahead time scale is concerned primarily with hour to hour load shifting (energy management), contingency reserves look to 10 minute response, and regulation needs second to second response – more complex but not to be ruled out.
- How much data do I need, how much data do I want, how do I manage it?

#### **Microgrid Discussion:**

- Smart grids can be made economical through correct market design. How to determine the value of reliability – this will drive how markets are designed.
- In the US, security is main incentive for microgrids, not reliability, how much are you willing to pay for small amount of additional reliability?
- Cells will “grow” through aggregation of DERs that are gradually built up. Model levels are important.
- If we model a whole country, no need for detailed response, but need to know dynamic response. Sophisticated models are not required.
- Models should be optimized for control/forecasting.

**Key output:** There is no need for complicated building models if sole purpose is control. Simple representation is good; need to know how much you have and how fast it'll work. If objective is to solve grid issues, detailed models of building models are relatively unimportant. But if you're looking at what can go wrong with new functions, particularly those based on power electronics, you need more detailed models.

**Building energy management system people are building detailed models of energy optimization, should they also build detailed models of electrical behavior?**

- Building models may need to take voltage level of network into account (DP), currently they do not.
- Next generation thermostats and pumps build in detailed data recording to be fed into control functions.
- We need detailed model of residential area with high level of PV to determine level of buying from grid, selling to grid. No, we don't, these will smooth. This is more of a voltage issue. Some more detailed models could be used for grid analysis.
- System operator currently changes transformer/upgrades network in cases of excess DG, need to consider alternatives. Building management can help with this.
- The main question is: What are the main ways to use energy in a building, how can it be used as storage?
- Need to be able to avoid the increase of load coincidence where people are responding to the same price signal in the same manner for the same reason.
- Need some kind of connection between building and grid models to see impact at point of common connection.

**Key output:** Thermal storage of buildings is in the range of 5-8 hours. Need models at different time and spatial resolutions. Also, there are different requirements for models – thermal, electrical, behavior. All interact but different purposes.

**Is there value to integrating the existing models in Building energy management systems (BEMS) with the grid?**

There is a greater need to model LV network, different people will want different control levels, may do in house optimization, or remote optimization.

**What models exist in BEMS? Are they of any practical use?**

- EnergyPlus, ASHRAE models
- These are useful for design purposes, but not used in real time energy management.
- Objectives are typically to minimize energy use and to keep in budget. Cylon system gives information on consumption in all buildings, and allows optimization of consumption.
  - Statistical model, not physical.
  - 15 minute time resolution.
- Need to know maximum and minimum demand, time dynamics. From a system operator perspective, this is just additional storage. This is different as it's usually a customer. Need models to drive operational strategy, market strategy, policy strategy.
- Frequent readings are used to see model of building and to evaluate need for upgrades, and to use building as short term storage.

**Are we in danger of over engineering things? In the end, will the applications be very simple. Who will pay for it?**

It is advisable that we use complicated models as first step, then learn from these and develop scalable robust models. If your model is not accurate - may end up costing you money.

### **How much building energy is practically reducible?**

- Superquinn reduces cost by 28% using Cylon building management system.
- Energy consumption in BEMS managed building can be different to expected – e.g. too many sensors in Microsoft
- Internal building grid required to run diagnostics.
- Energy savings can come from simple customer awareness – this is a natural reduction. Building modeling is a large effort, but can be done through simplified models and learning from data.
- A lot of potential within interruptible loads alone (refrigeration, hot water). This is low hanging fruit – and has been exercised in US and France for generations. Even gas fired central heating has electrical circulation pump that has significant consumption which can be used for DR.
- DR will only take off on a domestic scale if society feels good about it.
- Simplified models should be used for grid models. Detailed models could be used to enhance efficiency of building.

### **3.5 Workshop Results**

Key findings from two days of presentations, discussions, and participant reporting during the buildings integration workshop are summarized in the following set of slides:

## Major Issues

- Identify problem, user, timescales, spatial resolution
- Model to suit application – planning vs. operations
- Abilities of DR vs suitabilities
- System vs Local optimisation, or combination
- Load coincidence under market based operations
- Micro-grids require more detailed building models than macro, system level models
- DSO requires sophisticated models to analyse impact of larger customers
- Behavioural aspects – what will customers accept?
- Computational issues, data, complexity, degrees of freedom
- Increased uncertainty is a driver of models – potential evolution of models.
- Information exchange between buildings and systems
- Quality of data and communications for control and optimisation of demand

## Top Level Question

3

- Quantify the relationship between market and operational strategies and evolution of the grid with respect to load management
  - Building Needs and Capabilities
  - Grid Needs - Planning and operations
    - Years, Seasons, Days, Hourly (Sweet Spot)
    - minutes, seconds
  - Define the interface requirements between building and grid
    - System vs Local Optimisation, or combination thereof
  - Define the capability of the potential of
    - Existing technologies
    - Emerging technologies using existing infrastructure
    - Emerging technologies requiring additional infrastructurefor the provision of system services without impacting the utility of the end user

## Preliminary Analysis

4

- Relationship between renewables and building integration

### Systems Analysis

	High RES	Low RES
Many Active Buildings	Interfaced Models	Aggregate Building Models
Few Active Buildings	System Models for RES	Business As Usual

## High Level Research Topic Groups

5

- Preliminary Evaluation
- ICT
- Control
- Modeling Innovations
- Practical, Political and Policy

## Preliminary Evaluation

6

- High level evaluation of problems
  - To identify the most pertinent questions
- Quantify potential useful contribution of storage or DSM to balance on different time scales
  - Or a subset of the available options
- Is there a value in integration of local energy optimisation with system wide optimisation?
  - How do you implement it?
  - Who gets the value?
- What services can buildings supply to the grid, and in what order should they be supplied?
  - What does the grid need in order of priority?
  - Regulation, spinning reserves, time shifting of energy
- Quantify the opportunity of model innovation

## 7 ICT Questions

- What is the optimum/minimum sufficient level of communications/data required to achieve the application?
- What is the impact of shared network (IP) solutions for BEMS and its ability to respond to the grid?
- Data mining issue – extracting useful information from smart meter and sensor data.

## 8 Control Questions

- Will increased access to information and increased control lead to potential instabilities?
  - Example: Texas – price driven actions leading to 15 minute oscillations – Mack Grady (UT)
- What is the cost/benefit analysis of more detailed modelling or increased data optimisation vs. control (local vs. global)
- Use control theory to determine what level of accuracy/complexity from models and data is required to achieve a specified level of performance?
- Investigation of requirement for closed loop control of load and options for feedback.

## Modelling Innovations

9

- How to estimate/model responsiveness of the user, particularly how to adapt to changes in the responsiveness? (Context specific)
- Establish simplified operational models for heat dynamics of buildings on minute-hourly level.
  - Consider mixed time and spatial resolution issues, stiffness issues
- What is the value of real time monitoring of the load for power system dynamic models?
- Quantify the opportunity of value of improving systems' learning models. What is the point of zero marginal benefit?
- Automated model development
  - Statistical Approaches
  - Artificial intelligence approaches
- How to develop and validate simple, scalable load models for grid use
- Should joint forecasting be used for joint demand and wind/solar forecast?
  - What level of complexity/granularity?

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## Practical, Political and Policy

10

- What needs to be done to achieve/facilitate wide scale DSM
  - Modelling Issues

### **3.6 Next Steps: Action Items**

How can we spread the word? What types of materials are needed to proceed and who will develop them?

- Work on value proposition
- Get message out to audience – TSO/DSO, aggregators
- Collaborative research possibilities
- Sessions at PES
- Introduction of power systems work to control theorists
- IEA task 58
- Determination of value through regional analysis and customer collaboration.