AABC Commissioning Group

AIA Provider Number 50111116

Fault Detection & Diagnostics in Small & Large Commercial Buildings

AIA Course Number CXENERGY1527

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Green Valley Ranch Resort, Las Vegas, NV

April 30, 10:45 am – 11:45 am

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Course Description

This session will provide an overview of recent LBNL research on fault detection and diagnostics, monitoring-based commissioning, and associated tools. Key programs discussed will include 1) the Retrocommissioning Sensor Suitcase, a turnkey solution that can be used to automate and simplify the identification of efficiency opportunities in small commercial buildings, and 2) the development of a model-based real-time fault detection and diagnosis tool for central cooling plants.

Learning Objectives

At the end of the this course, participants will be able to:

1. Understand how to apply the findings of recent research by Lawrence Berkley National Laboratory (LBNL) to conduct fault detection and monitoring-based commissioning.

2. Learn how the Retrocommissioning Sensor Suitcase can be used to automate and simplify the identification of building faults and thereby enable retro-commissioning in small commercial buildings.

3. Learn how a model-based fault detection and diagnostic tool can be used to improve the performance of central cooling plants.

4. Learn about related tools and resources developed by LBNL to support building commissioning.

Outline

- Introduction
- Automated & Simplified FDD in Small Buildings
- Model-based Real-time FDD in Central Cooling Plants
- Other Resources

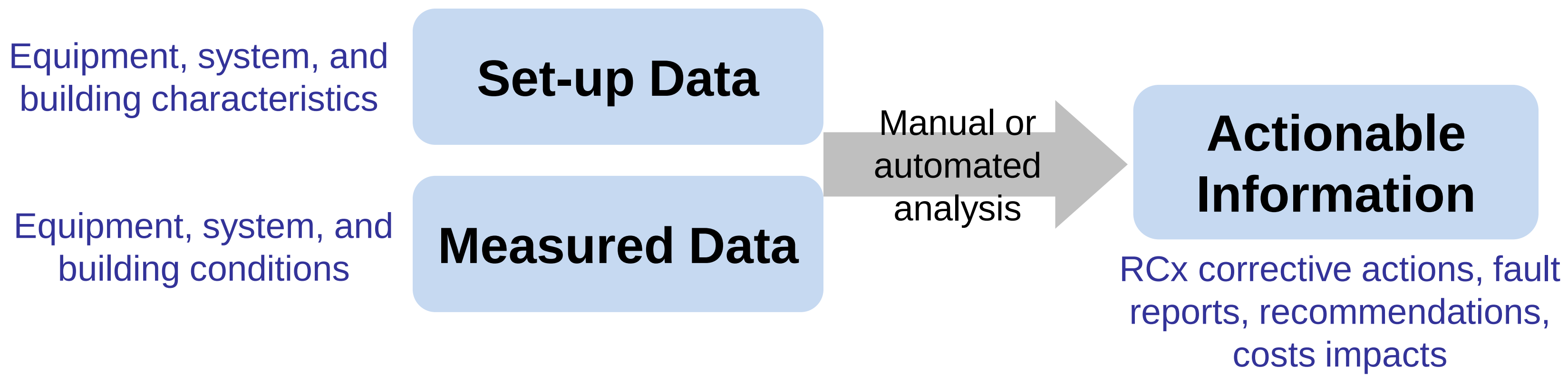
Introduction

- Commercial and industrial buildings use roughly 50% of the energy in the U.S.*
- Over $400 billion in total energy costs*
- Better Buildings Initiative to make buildings 20% more energy efficient by 2021*
- Over 20% of energy use can be saved by adjustments to building operation**

* Source: http://energy.gov/eere/better-buildings
**Source: TIAX LLC (2005), "Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential."

Fault Detection and Diagnosis (FDD)

Convert Data into Information



- Identify building operational problems
- Provide advice about how to address the problems
- Enable building managers to improve operation and increase energy efficiency

Application of FDD in Buildings

- Retro-commissioning (RCx): FDD gets building into shape
  - Diagnostic monitoring
  - Functional tests
  - Data from temporary sensors or data loggers

- Monitoring-based commissioning: FDD keeps building in shape
  - Real-time monitoring
  - Anomaly alarming
  - Data from existing meter infrastructure or building automation system

Automated & Simplified FDD in Small Buildings

Retrocommissioning Sensor Suitcase: A Turnkey Solution to Scale RCx to Small Buildings

Funded by DOE Building Technologies office, George Hernandez, A. Jiron

Why Are Small Buildings Important?

- Small commercial buildings (< 50,000 square feet)
- Cover 50% of U.S. commercial building stock*
- Consume 2.5 Quads annually*
- Substantial energy efficiency opportunity
- Currently receive little attention

*Source: U.S. Energy Information Administration (2006), “2003 Commercial Buildings Energy Consumption Survey”

Challenges of RCx in Small Buildings

- RCx: an effective means to achieve median savings of 16%
- Small commercial buildings
  - Do not typically have business economics that allow investing in energy improvement
  - Do not have 'in-house' staff with expertise in building systems, who can identify savings opportunities
- Solution: Enable RCx in small buildings by

Reducing transaction costs

Simplifying the process

Reducing required levels of expertise

Technology Value Proposition

- The innovation offered lies in **extensive streamlining of the RCx process** thereby
  - Innovations in sensor packaging, installation guidance, and nearly-fully automated identification of building performance improvement opportunities
  - Reducing labor costs through decreases in labor time and expertise required
  - Enabling penetration of the small buildings sector, where low energy expenditures place tight constraints on payback and human capital

- 50% reduction in labor time/costs
  - Guided, substantially automated sensor configuration and installation, in contrast to existing logger, which require expertise to deploy properly
  - Software and sensors eliminate need for walk-through, spot measures, and engineering expertise to interpret data

- Delivery of at least 10% average site energy savings - traditional RCx saves 16% on median

Turnkey Solution, Components

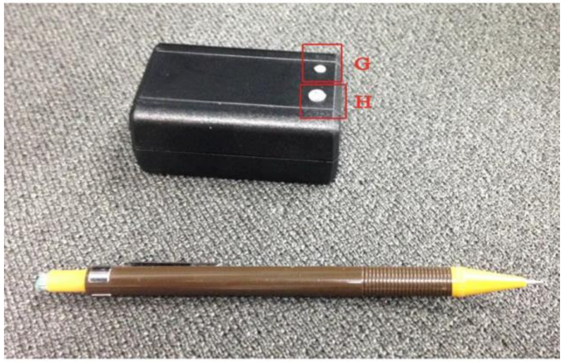
1. Easy-install **sensors** with on-board data storage
2. A **suitcase** provides a means of transport, storage capability and data transfer to a computer installed with analysis software
3. A **tablet** to configure sensors, provide installation guidance, and document installation info
4. Diagnostic **algorithms** to analyze sensor data and generate recommendations to improve operations and energy performance
5. **Software** with graphical user interfaces to collect, process, and analyze data, display recommendations and fault findings to user

3 Sensor types: light, temperature, and vibration

Turnkey Solution, Sensors & Suitcase

- Sixteen sensors
  - 2 RTU status (vibration), 14 others (light, room temperature, diffuser air temperature, outdoor air temperature, types can be set upon activation)

- Suitcase
  - Pre-wired sockets to “seat” and communicate with sensors
  - Data control module to communicate with handheld device via Bluetooth, launch sensors upon installation
  - Rechargeable battery



Sensor

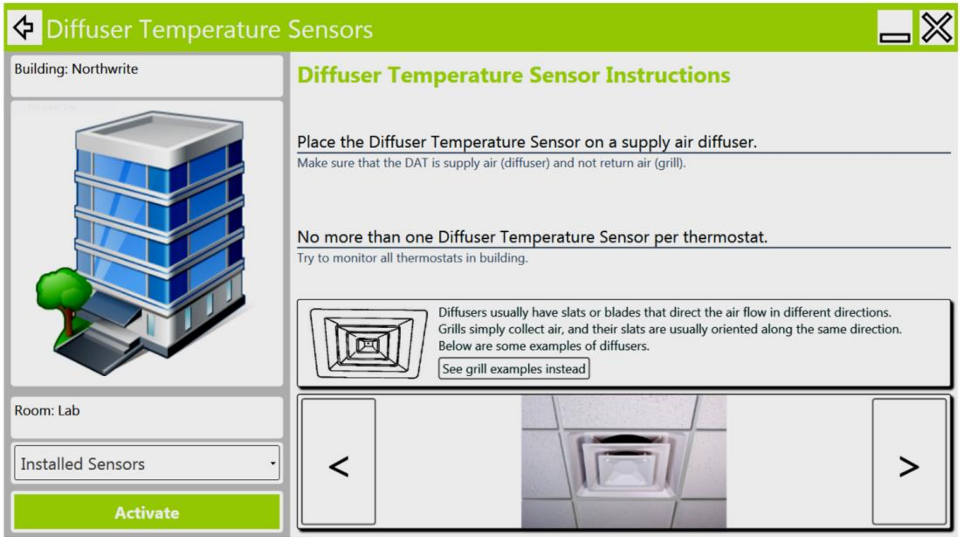
Suitcase

Turnkey Solution, Tablet

- Guide installation and retrieval of sensors
  - Entry of building information
  - Selection of a specific type of sensor
  - Entry of installation location (roof, outdoors, or a particular room)
  - Installer is provided simple instructions to guide the installation process

Bluetooth

Tablet

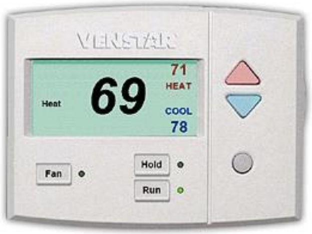


A sensor configuration screen from the tablet computer enabling configuration of a diffuser air temperature sensor.

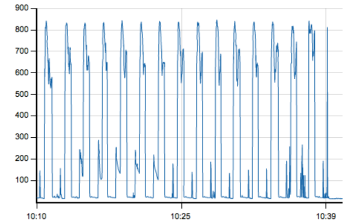
Turnkey Solution, Diagnostic Algorithms

- The 8 algorithms related to HVAC and lighting control and operation
- Identify most common, high-impact opportunities in small commercial buildings
- Rule-based algorithms, designed for the available sensor types
  - Light, temperature, RTU operating mode

Setpoint deadbands,
over(under) heating/cooling



RTU short cycling, not economizing

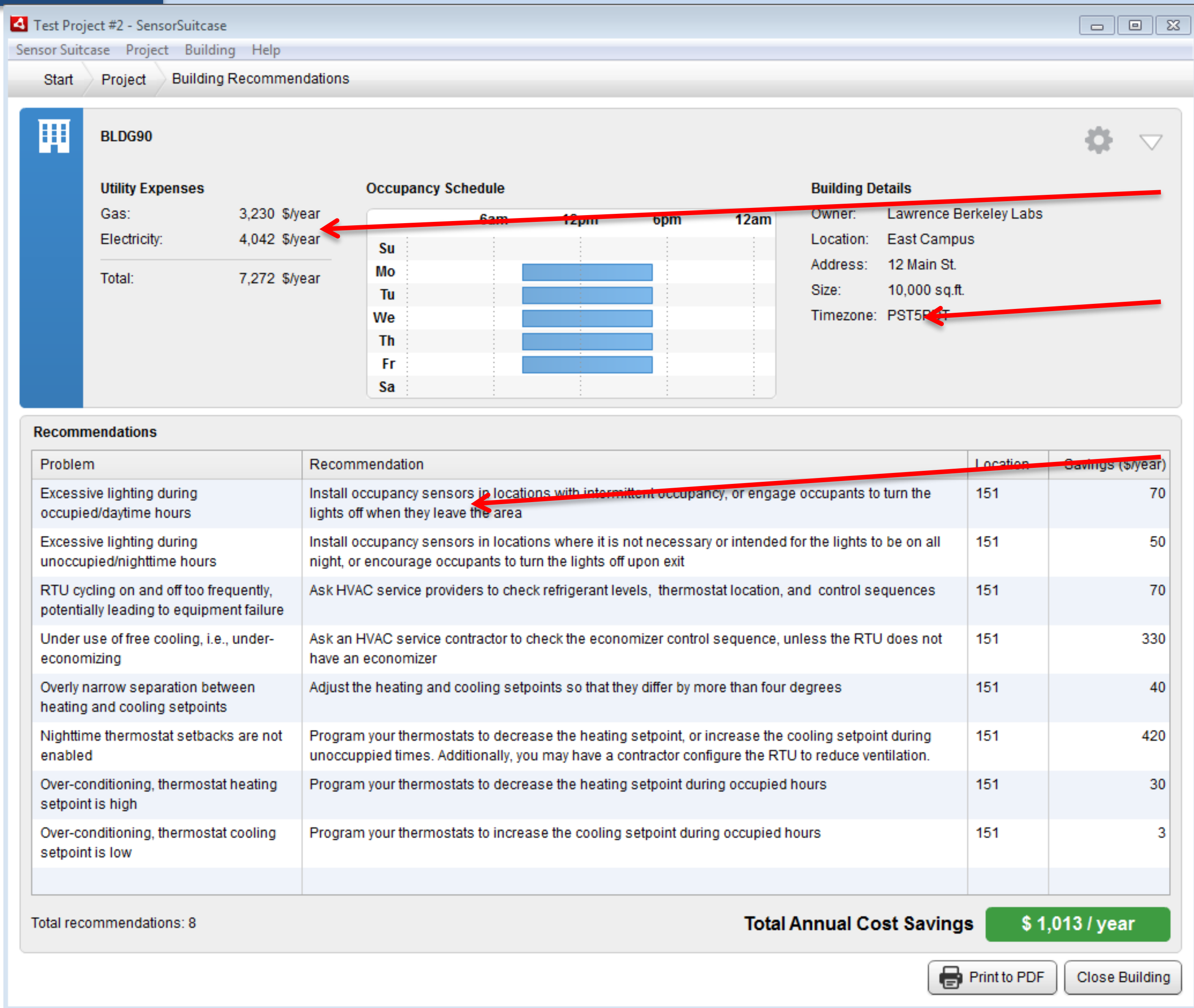


Scheduling, setbacks

Excessive daytime lighting

Excessive nighttime lighting

Turnkey Solution, Software Output



Problem	Recommendation	Location	Savings ($/year)
Excessive lighting during occupied/daytime hours	Install occupancy sensors in locations with intermittent occupancy, or engage occupants to turn the lights off when they leave the area	151	70
Excessive lighting during unoccupied/nighttime hours	Install occupancy sensors in locations where it is not necessary or intended for the lights to be on all night, or encourage occupants to turn the lights off upon exit	151	50
RTU cycling on and off too frequently, potentially leading to equipment failure	Ask HVAC service providers to check refrigerant levels, thermostat location, and control sequences	151	70
Under use of free cooling, i.e., under-economizing	Ask an HVAC service contractor to check the economizer control sequence, unless the RTU does not have an economizer	151	330
Overly narrow separation between heating and cooling setpoints	Adjust the heating and cooling setpoints so that they differ by more than four degrees	151	40
Nighttime thermostat setbacks are not enabled	Program your thermostats to decrease the heating setpoint, or increase the cooling setpoint during unoccuppied times. Additionally, you may have a contractor configure the RTU to reduce ventilation.	151	420
Over-conditioning, thermostat heating setpoint is high	Program your thermostats to decrease the heating setpoint during occupied hours	151	30
Over-conditioning, thermostat cooling setpoint is low	Program your thermostats to increase the cooling setpoint during occupied hours	151	3

Left: Software Output report summarizes

a) user-provided **Occupancy Schedule and Utility expenses**,

b) building details entered by the user and extracted from the sensor data

c) problems identified from the data, **actionable recommendations**, and estimated cost savings from implementing recommendations

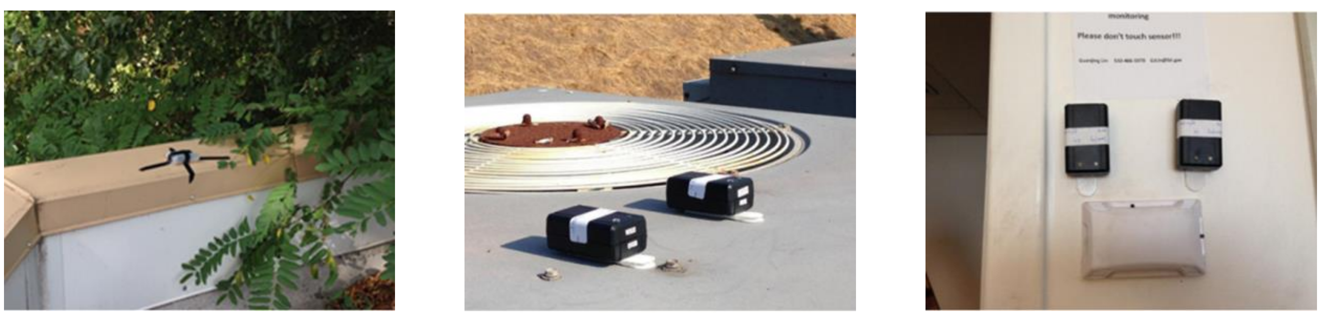
Field Testing Overview

3rd party industry testers - KW Engineering and Northwrite

- Activate and configure the sensors, install in two small buildings
  - 5,500 sf office, 2 RTUs/zones, multiple lighting zones monitored
  - 10,000 sf mixed office/warehouse, 3 RTUs/zones, multiple lighting zones monitored
- Acquire ~2 weeks of data
- Download data from sensors
- Run analysis software
- Partner feedback on usability, functionality, performance
- Additional laboratory evaluation of performance

Hardware Field Test Findings

- Users reported that hardware is well designed, and the tablet to configure of sensors is easy to use
- Sensors generated data sufficient for analysis and problem identification
- Refinement opportunities for next collaborative phases of development
  - Solar and weatherproofing for durability
  - Enhance or increase number of attachment mechanisms to accommodate a diversity of configurations

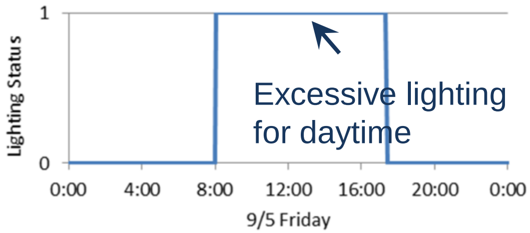


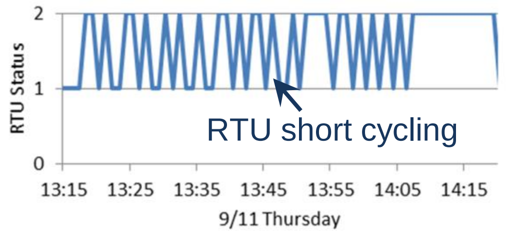
Photos of field testing

Software Field Test Findings

- Users reported that the software was easy to use, and the installation instructions were helpful
- Analysis outputs and recommendations “seemed reasonable” to users
- Refinement opportunities for next phase of development
  - Further vetting of diagnostic thresholds used in algorithms to identify problems
  - Further stakeholder feedback on necessity and value of utility cost information and associated savings estimates for each opportunity identified

Software results agree with trend data observation





Trends from sensors: (a) trend from a lighting status sensor (1=lighting on, 0=lighting off) on a weekday during the monitoring period, (b) Site B, example trend from a rooftop unit status sensor (0=off, 1= supply fan only on, and 2= compressors, condenser fans, and supply fan all on) during the monitoring period

Positive Early Market Feedback

McKinstry, NorthWrite, KW Engineering, Exergetics, and Greenpath Energy Solutions were each interviewed for Market feedback

Interest, Market Segmentation, Delivery

- Potential users confirmed value proposition of streamlining, simplicity, and ability to deliver services to small commercial

General Applicability

- Technology could serve wide set of building system types and regions
  - The algorithms and problems targeted have wide applicability
  - A few exceptions were noted: labs, low energy use buildings

Viability of price points

- Target range of $1,000-$1,500 seemed reasonable to all firms interviewed

Take Away

- Sensor Suitcase provides a turnkey hardware-software solution to uptake RCx of small commercial buildings by
  - Enabling lower-cost personnel without engineering expertise to identify energy-saving opportunities
  - Offering RCx providers the means to streamline existing processes and reduce costs, making it possible to expand their market to smaller buildings
  - Providing opportunities for new RCx providers to enter the market exclusively to small buildings

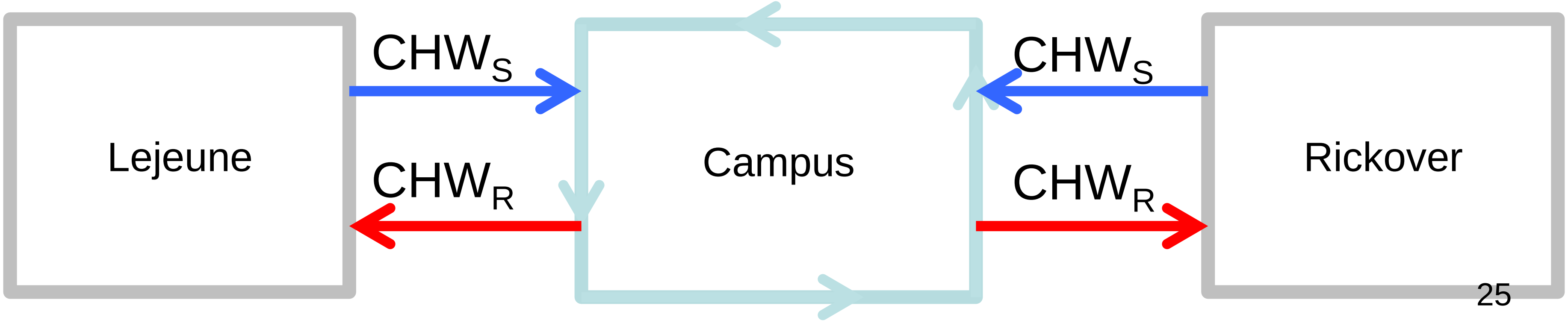
Model-based Real-time FDD in Central Cooling Plants

Robust On-line FDD Based on Calibrated Physical Models

Funded by US Department of Defense ESTCP program

Central Plants at a University

- Central cooling plant
- 2 locations
- 6 chillers
- Modern controls
- Expert operations staff
- Significant data collection and integration activities



FDD Software

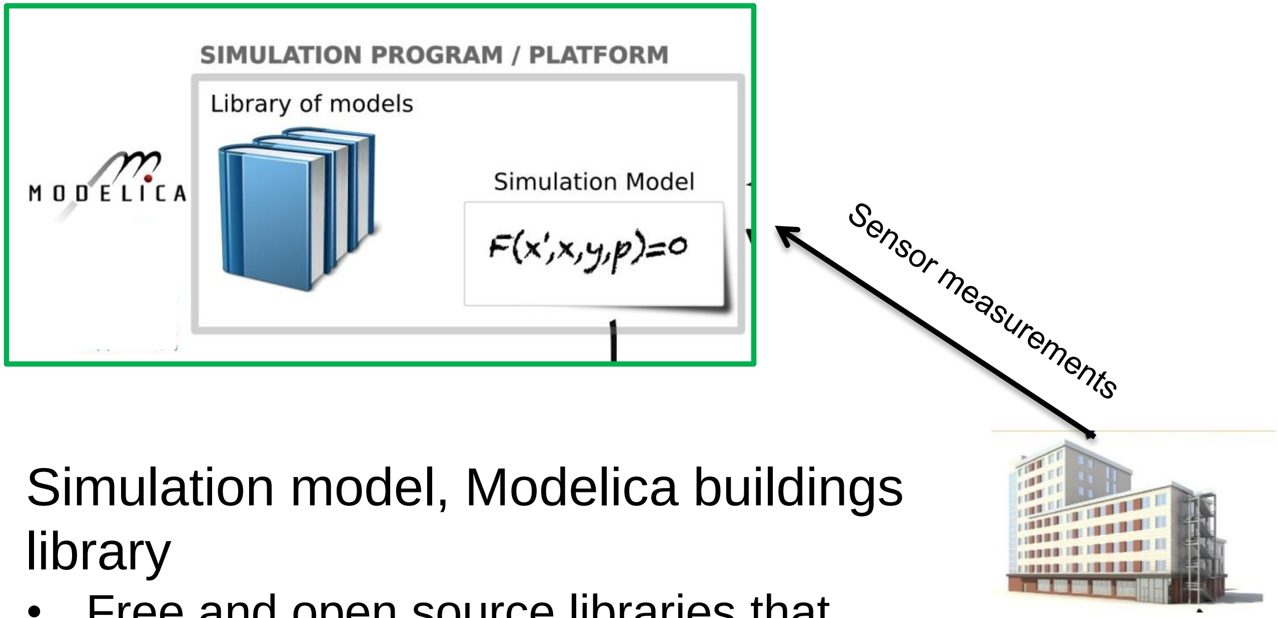
Goals: Save at least 10% in central plant energy use by providing an operational tool that

- Bridge the gaps separating today's energy monitoring and FDD tools
- Plays an active role in plant management routines and performance analyses
- Increase energy savings with FDD and optimization modules
- Enhance diagnostic power through physical models
- Quantifies the value of taking action

Approach, Model-based FDD

- Use physical models, i.e. a set of mathematical equations based on energy balances and heat transfer relations
- System behaviors calculated with measured inputs and model parameters
- How **should** the system be behaving VS how it **is** behaving?
- Strengths
  - Takes into account the physics of system behavior → accurate
  - Enable simulate dynamic and steady-state system behavior
- Weaknesses (lessened in the proposed FDD approach)
  - The modeling effort is high
  - A large number of measurement inputs means the noisy inputs may significant impact the results

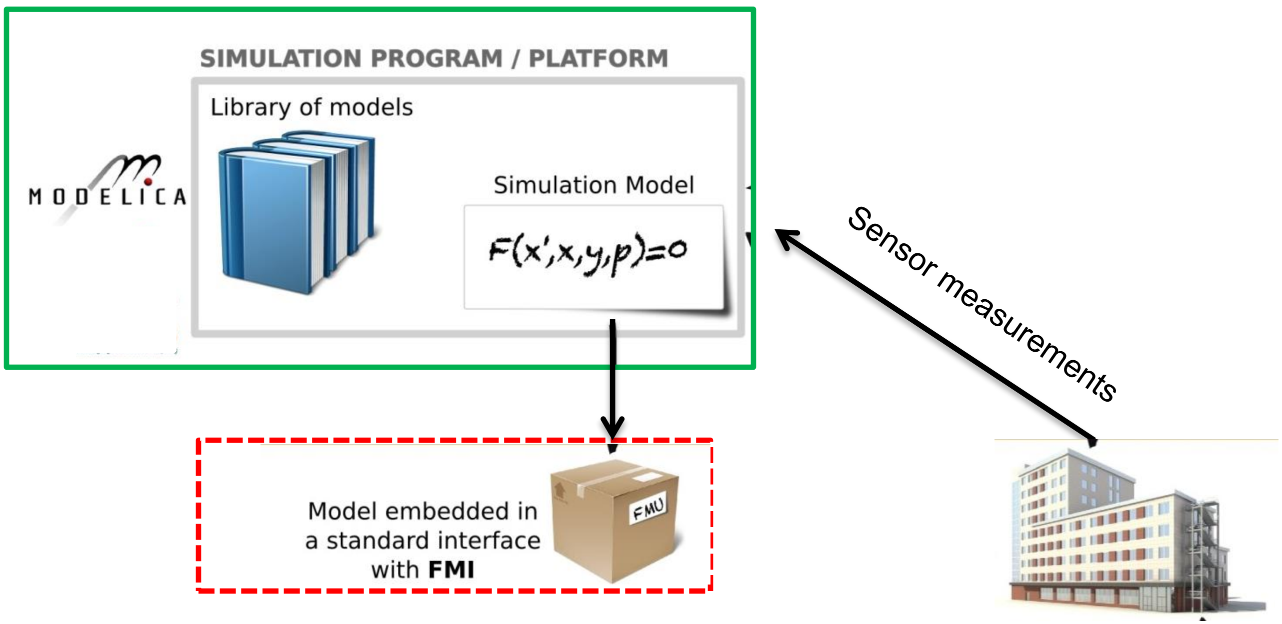
The Proposed Model-Based FDD Work Flow



Simulation model, Modelica buildings library

- Free and open source libraries that contain documented, tested and validated model for buildings and HVAC systems
- Reduce modeling effort
- Calibrated with sensor measurements

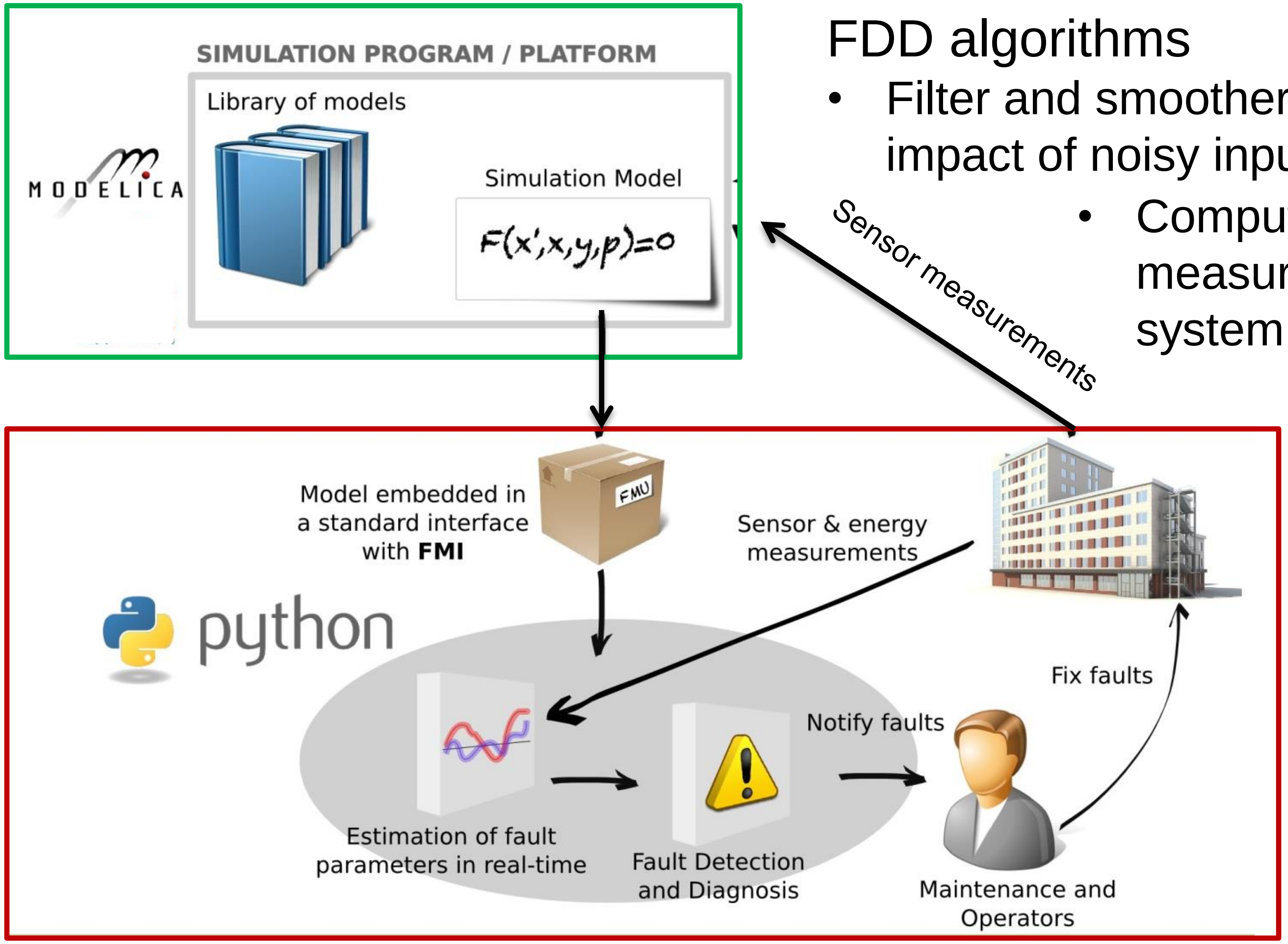
The Proposed Model-Based FDD Work Flow



Functional Mockup Interface (FMI)

- Export simulation models in a standardized way
- Help Model outputs import to FDD algorithms

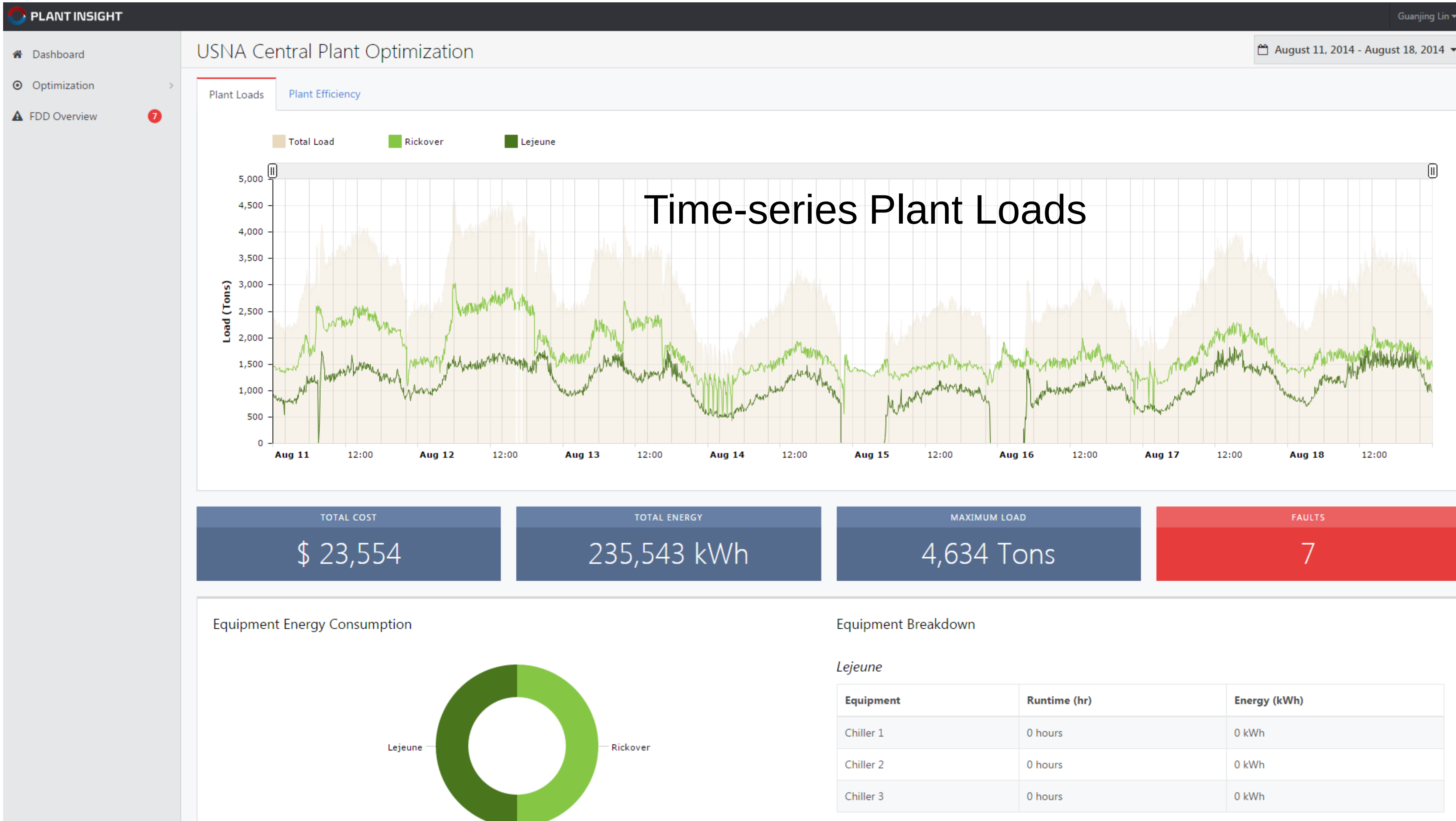
The Proposed Model-Based FDD Work Flow



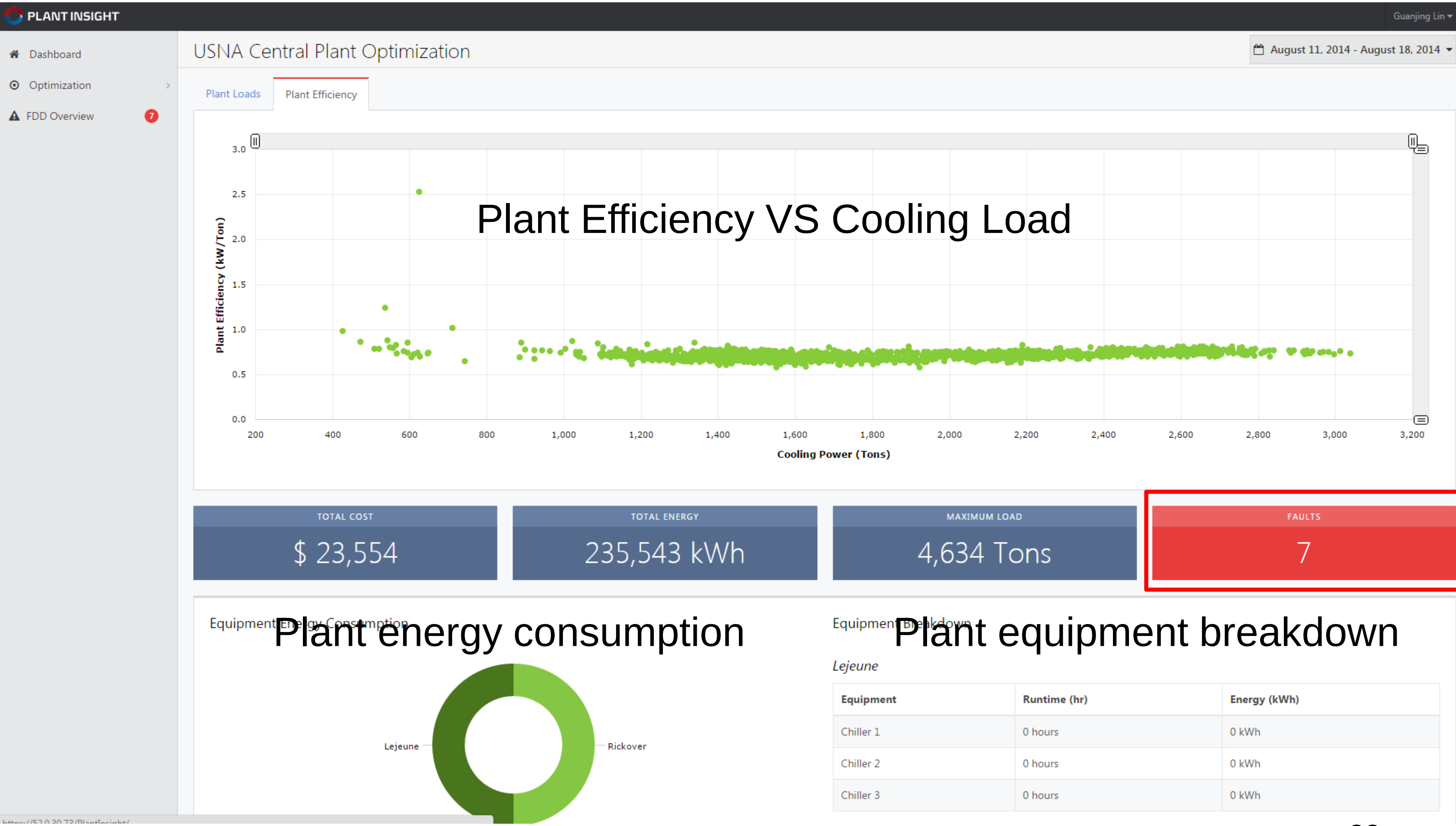
FDD algorithms

- Filter and smoother to reduce the impact of noisy inputs
  - Compute deviation between measured and expected system parameter
    - Provide the fault probability

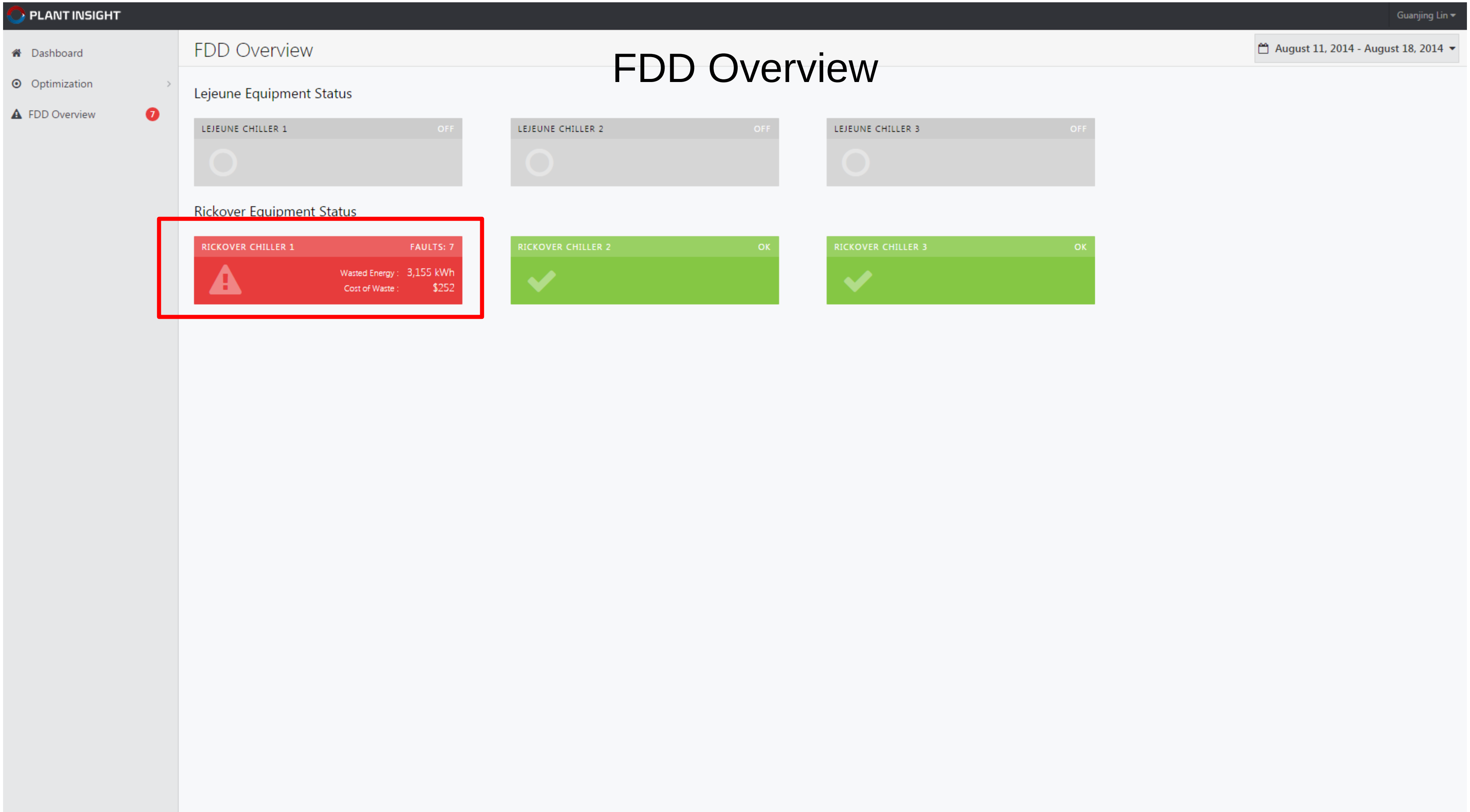
Application, Software Snapshot, Dashboard



Application, Software Snapshot, Dashboard



Application, Software Snapshot, FDD



Application, Software Snapshot, FDD

Take Away

- A new quantitative model-based FDD tool applied in central cooling plants
  - Shows total system efficiency and equipment level fault
  - Takes into account the physics of system behavior with physical model
  - Provides deeper performance insights than data-driven statistical approach

Additional Tools and Resources to Support Building Commissioning

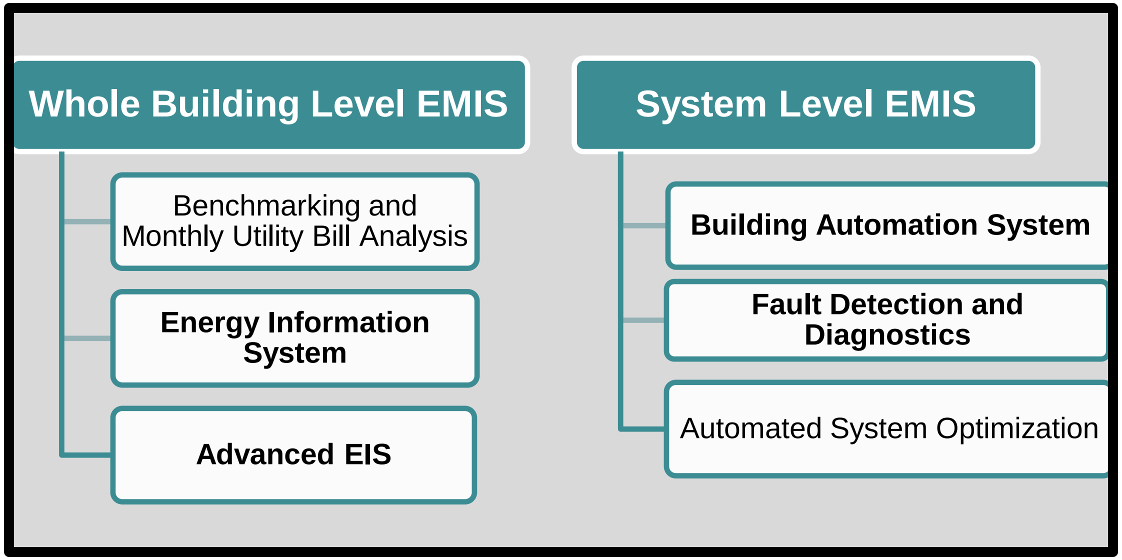
Adopt EMIS to Unlock Persistent Savings Benefits

Funded by DOE Building Technologies Office, Amy Jiron, A. Mitchell

Energy Management and Information Systems

- Energy management and information system (EMIS)
  - Emerging software tools to monitor and store building/system data and providing data analytics
  - Several types can be leveraged to building commissioning

EMIS Comprise a Family of Technologies

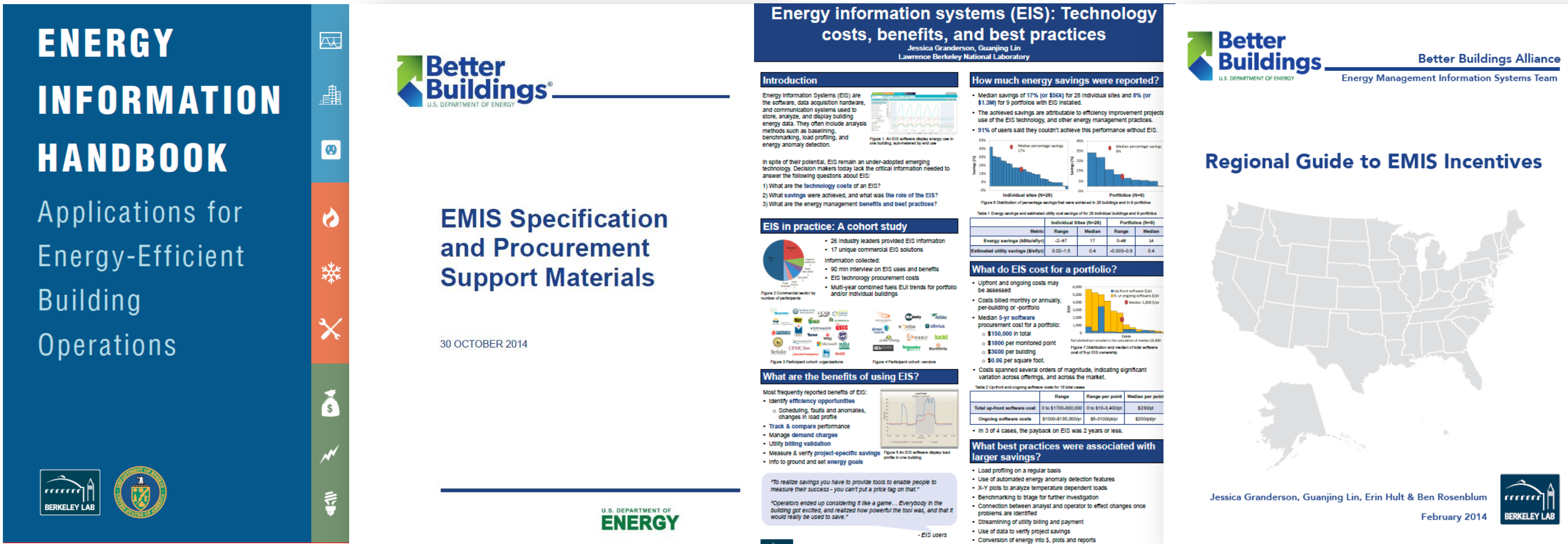


What Questions Are Being Asked?

- How do I distinguish one EMIS offering from another?
- What analysis capabilities does EMIS have?
- What are best practices in achieving persistent energy savings?
- What are the technology costs and benefits?
- How can the procurement and specification process be simplified?

See eis.lbl.gov for details on for details on prior and ongoing research that addresses these questions

Associated Resources Examples



Work with the US Department of Energy's Better Building Alliance (BBA) members addresses the common questions with the goal of increased adoption of these powerful emerging EMIS technologies

THANK YOU

This concludes The American Institute of Architects Continuing Education Systems Course

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