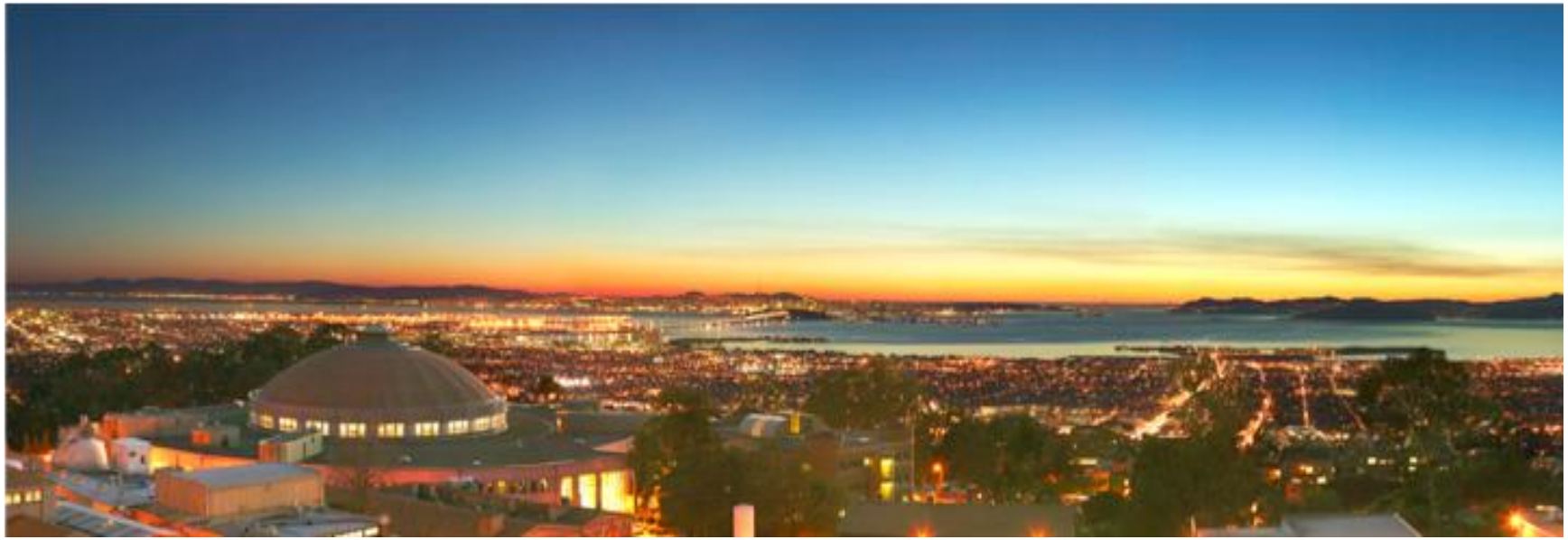


Building Modeling: EnergyPlus at Ames Research Center

Philip Haves

Lawrence Berkeley National Laboratory

phaves@lbl.gov

May 11, 2011

Lawrence Berkeley National Laboratory is operated for US DOE by the University of California

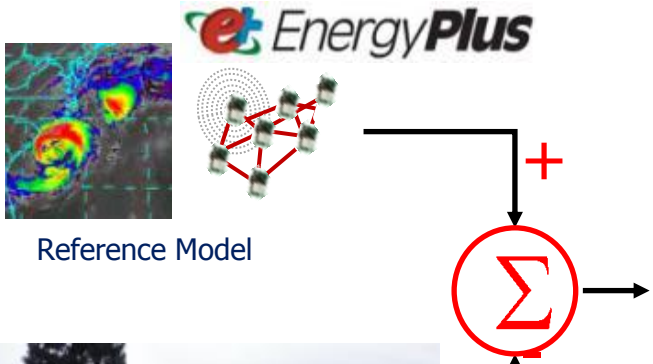
Presentation Outline

- Collaboration with NASA Ames
- EnergyPlus whole building energy simulation
- Building Controls Virtual Test Bed
- Predicting Actual Energy Performance
- Performance Monitoring at Sustainability Base
- EnergyPlus GUI

Ames/LBNL Partnership

- Sustainability Base – living lab
- DOE Commercial Building Partnership project
- BIM throughout the life-cycle
- Simulation-based performance monitoring
  - Real-Time EnergyPlus
  - Additional instrumentation
  - Database infrastructure

Compare measured and expected



Reference Model

Actual Building & Equipment Data

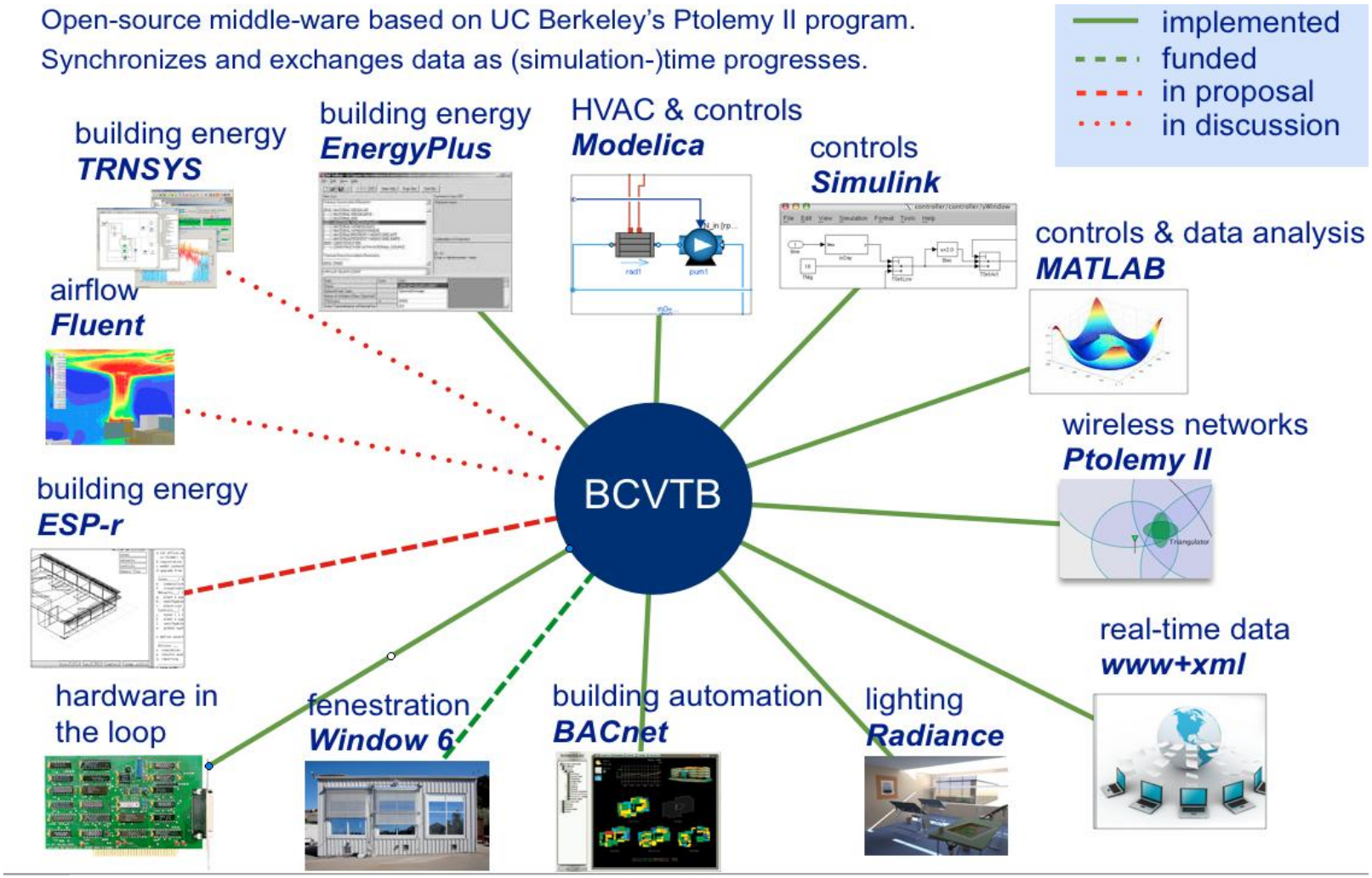
Simulation: Applications and Motivations

- Building Design
  - Comparison of design alternatives
  - Code compliance
  - Prediction of actual energy consumption
- Building Operations
  - Performance monitoring and fault detection
- Product Development
  - Identify price/performance targets
- Policy Development
  - Scenario analysis

EnergyPlus

- US DOE's flagship energy simulation tool
- Whole building, multi-zone
  - Envelope
  - Lighting and daylighting
  - HVAC
  - Comfort
  - Renewables
  - Water
- Continuous development
- Transparent
- Free
- Limited graphical user interfaces – geometry, not HVAC
- Multi-core processors

Building Controls Virtual Test Bed

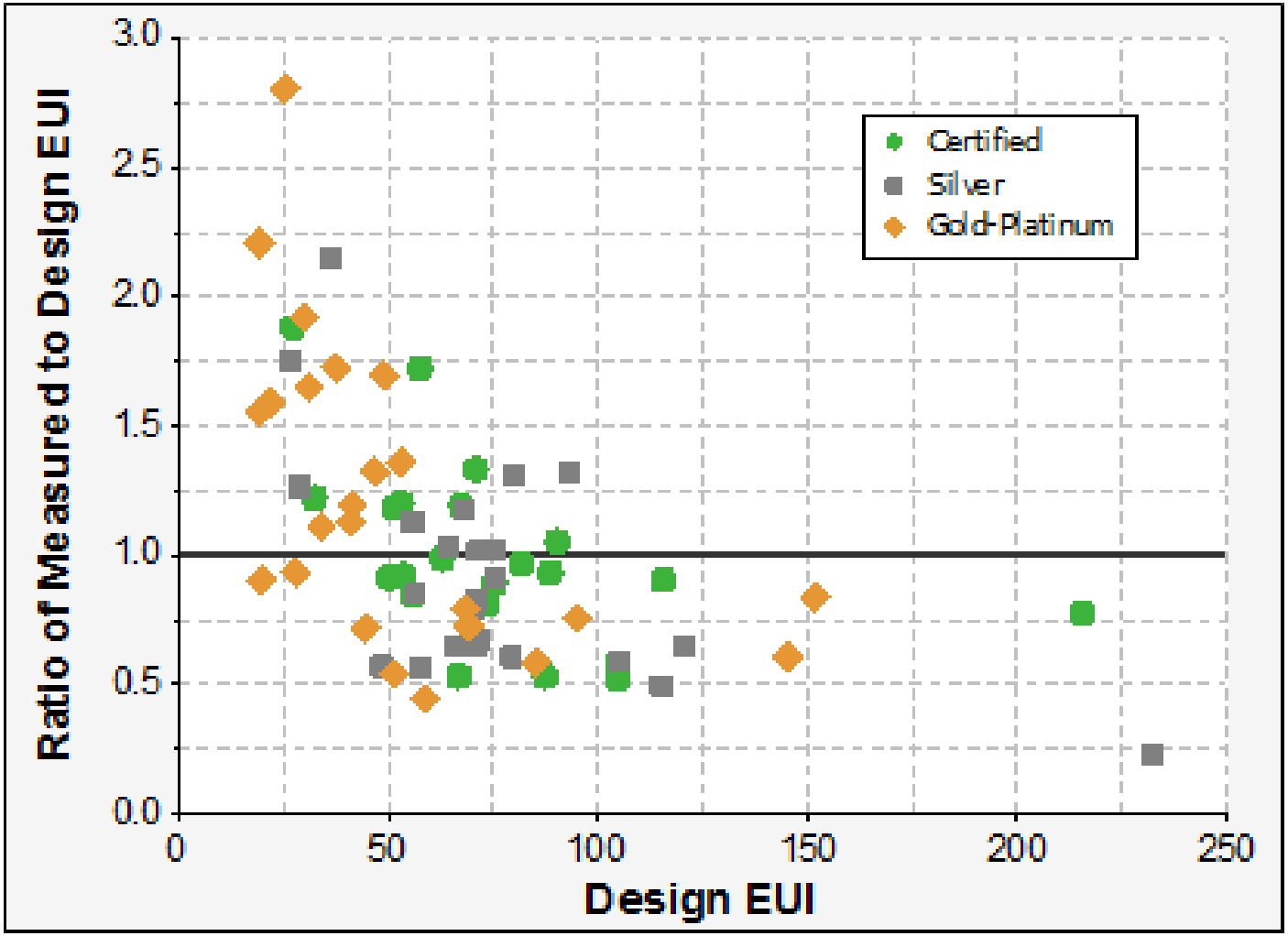


http://simulationresearch.lbl.gov/bcvtb

Modeling Innovative Designs

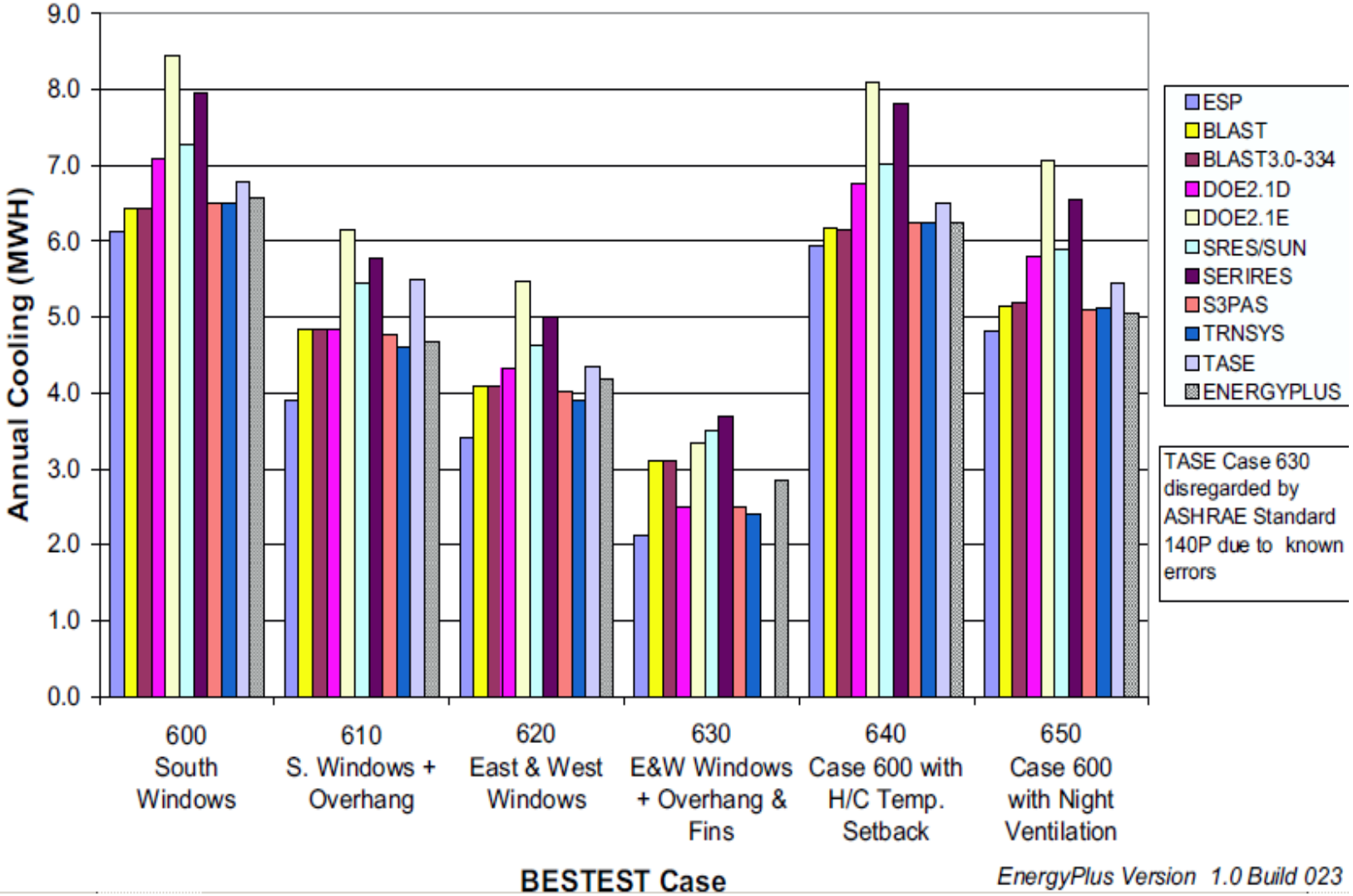
- Established Sustainable Systems – modeled in advanced whole building simulation tools:
  - Natural ventilation
  - High performance glazing
  - Active shading
  - High efficiency lighting
  - Daylight harvesting
  - Building integrated PV
  - Radiant cooling
  - Displacement ventilation
  - UFAD
  - Thermal storage
  - Heat recovery
  - Ground source heat pumps
- Innovative Systems - Modelica plug-in:
  - Existing components connected in novel ways
  - Novel components
  - Controls

Measured/Design Ratios Relative to Design EUI



Source: Frankel and Turner, NBI

Cross-Validation



Predicting Actual Energy Performance

- Design simulations don’t model real conditions
  - Occupancy schedules
  - Plug loads
  - Weather
- Real buildings often don’t perform as expected by their designers:
  - Faulty construction
  - Malfunctioning equipment
  - Incorrectly configured control systems
  - Inappropriate operating procedures

Vision: Accountability for Energy Performance

- Design simulation – dynamic representation of expected performance
- Commissioning: use design simulation for whole-building functional testing
  - Fix building, then reconcile model and measurements
  - Don't change model unless owner accepts construction/operation deficiencies (or model is wrong!)
- Operations: use 'as-commissioned' model as baseline for performance monitoring → fault detection
- *Challenges:*
  - How to enforce accountability in design-bid-build?
  - Improvements needed to simulation tools and procedures?

Sustainability Base

- 50,000 sq ft high-performance office building - ~210 occupants
- Construction complete May 2011
- LEED Platinum
- Overall potable water use is only 12% of a conventional building
- Expected to generate more electricity than needed, excess to Ames distribution system

Architecture

- Natural ventilation
- Daylighting:
  - large windows, narrow floor plates
  - skylights
- High performance glazing
- Exterior horizontal and vertical shades reduces glare and summer solar gain
- Well insulated PVC Cool Roof reduces cooling load
- Raised access floor allows user controllable fresh air distribution

Exoskeleton

Skylights & PVC Cool Roof

Raised Floor

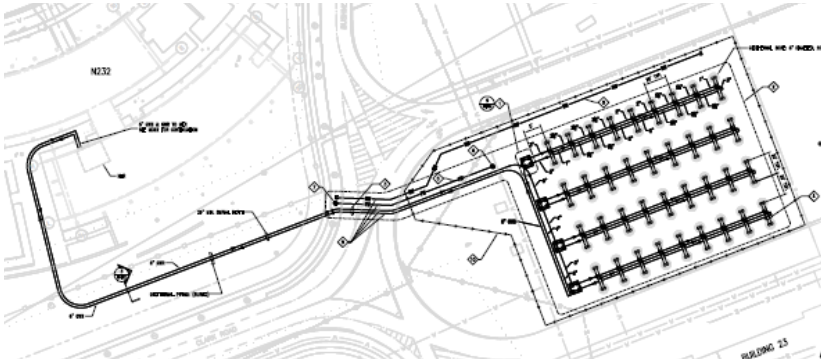
Mechanical

- Ground source heat pump system – no cooling towers
  - 106 well bores, 58 deg F ground temp year round
  - 4 heat pumps
  - Radiant cooling ceiling panels
  - Hot water radiant wall heating panels
- Air supply
  - Dedicated Outdoor Air System
  - Underfloor air supply distribution
  - Natural ventilation with automated windows to allow flushing during evening hours
  - Operable windows for occupant comfort

NXW 360 Water Furnace Reversible

Radiant Cooling Ceiling Panels

Automated (top) and Manual (bottom) Windows



Geothermal wells located in "parade grounds"

Prior Example of Whole Building Performance Monitoring and Fault Detection

- Proof-of-concept at Naval Station Great Lakes
- DOD ESTCP project with UTRC
- Real-time EnergyPlus connected to building control system
- Solarimeter and sub-metering installed
- Compare simulation and measurements:
  - Whole building electric and gas
  - Lighting
  - Plugs
  - Major HVAC:
    - Chillers
    - Large fans
- Significant differences
  - Calibrate the model?
  - Fix the building?

Instrumentation Requirements

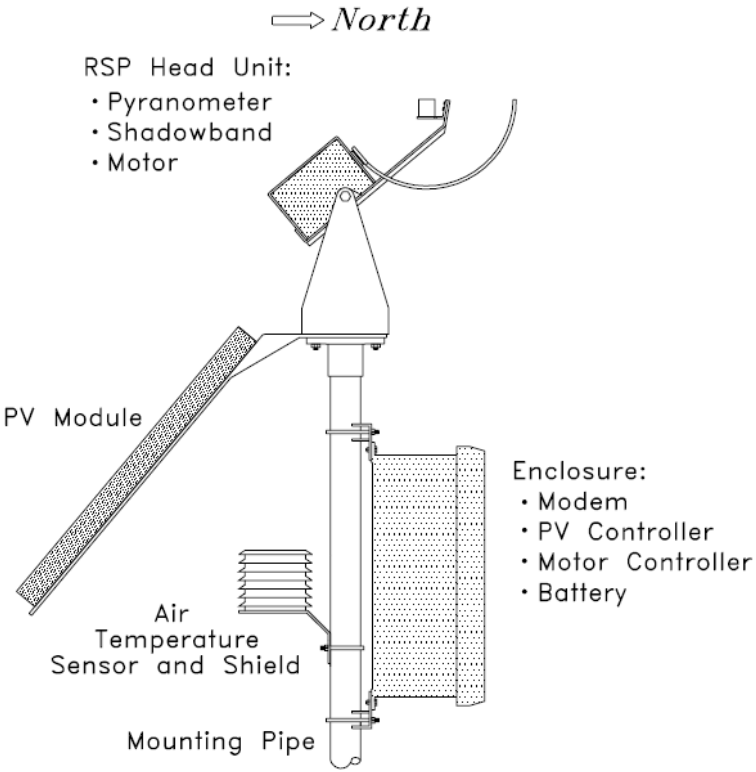
- Weather Station
- Submetering
- Thermal Energy Metering
- EMCS Measurements

Specifications Guide for Performance Monitoring Systems

http://cbs.lbl.gov/performance-monitoring/specifications

Weather Station

- High performance outside air dry bulb and RH sensor
  - Aspirated radiation shield
  - Stable measurement for RH> 90%
- Pyranometer
  - Total horizontal solar radiation, diffuse solar radiation and direct solar radiation
- Wind speed and direction
  - Ultrasonic sensor
  - No moving parts – more accurate at low speeds – natural ventilation



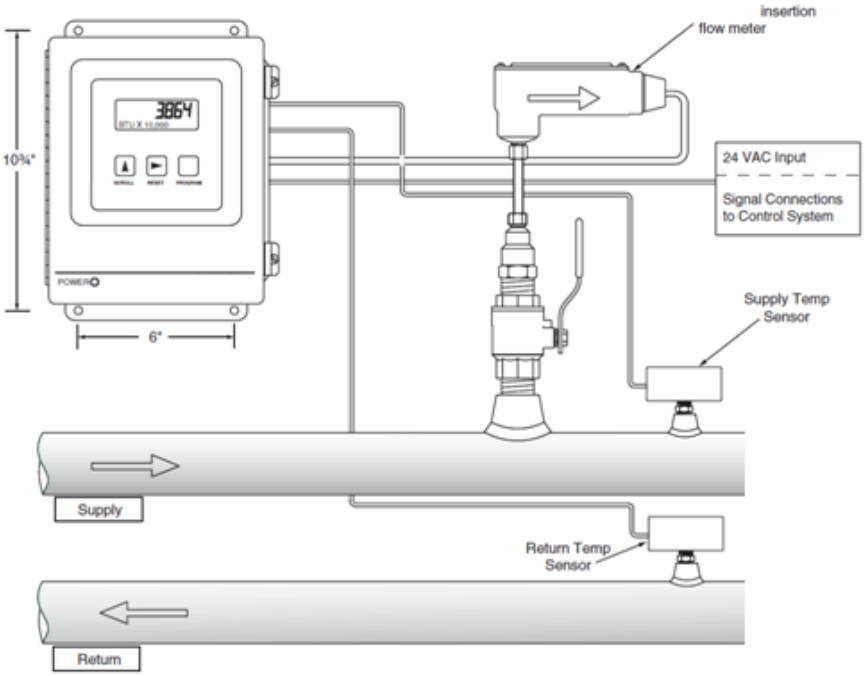
Submetering

- Lighting, equipments and chillers
  - isolated by several electric meters

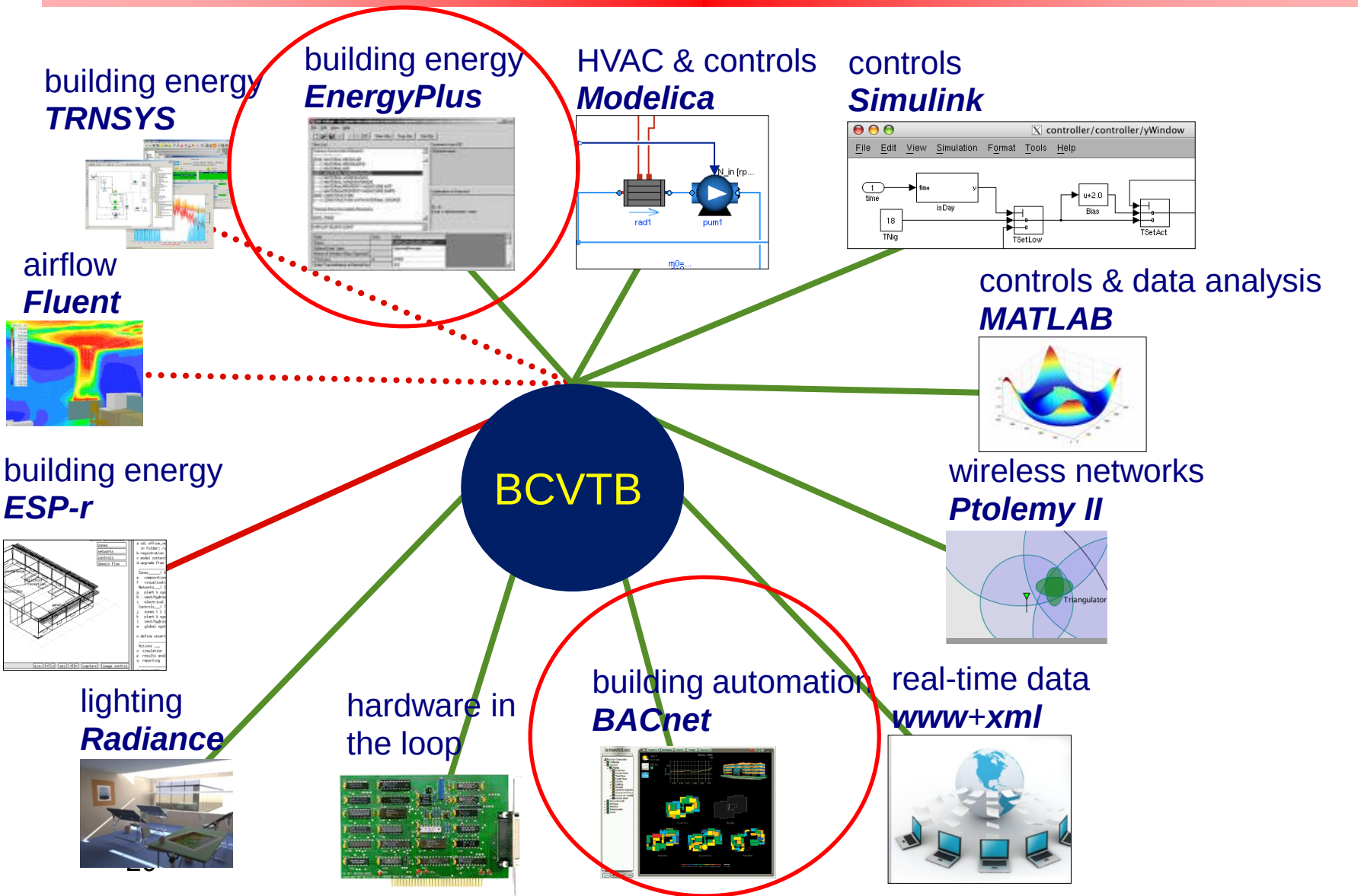
- Fans and Pumps, Miscellaneous
  - variable speed fans and pumps: VFD power outputs → EMCS
  - constant speed fans and pumps: one-time on-site measurement

Thermal Energy Measurement

- Total cooling energy consumption
  - BTU meter installed on secondary chilled water loop
- Total heating energy consumption
  - BTU meter installed on hot water side of the steam to water heat exchanger



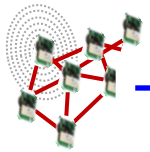
Connecting EnergyPlus to EMCS

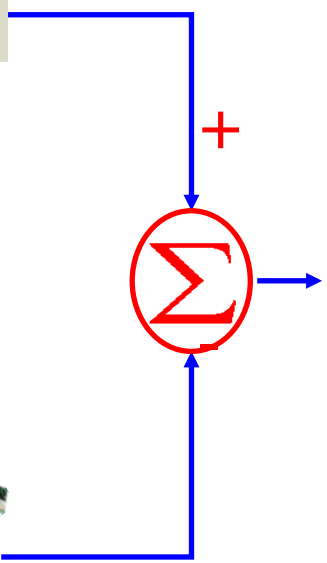


Fault Detection and Diagnosis

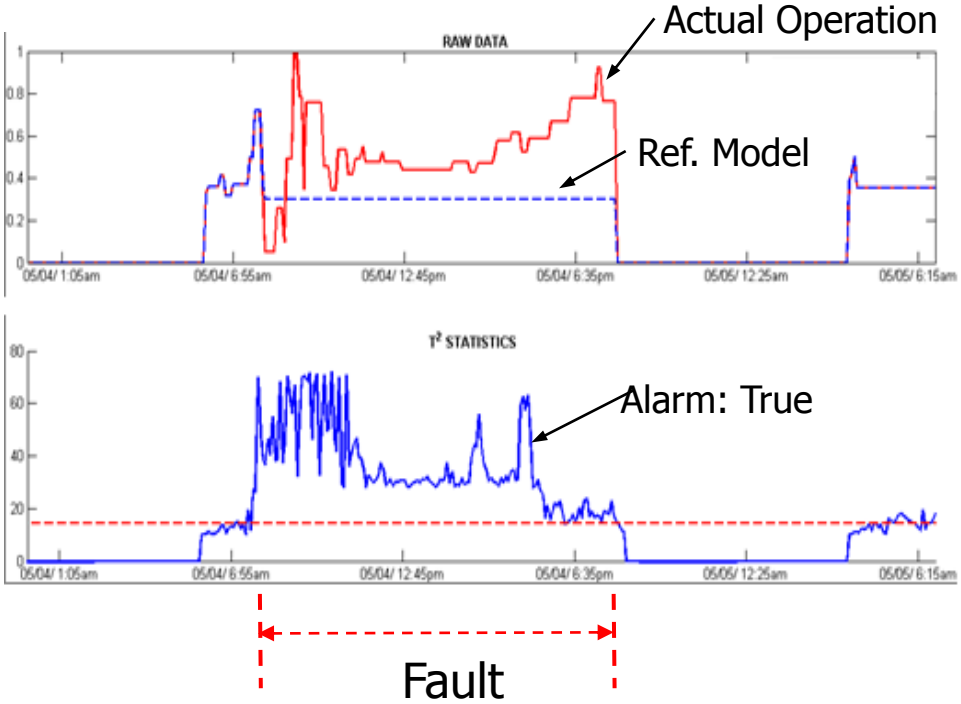
Reference Model (EnergyPlus)

Measured Data





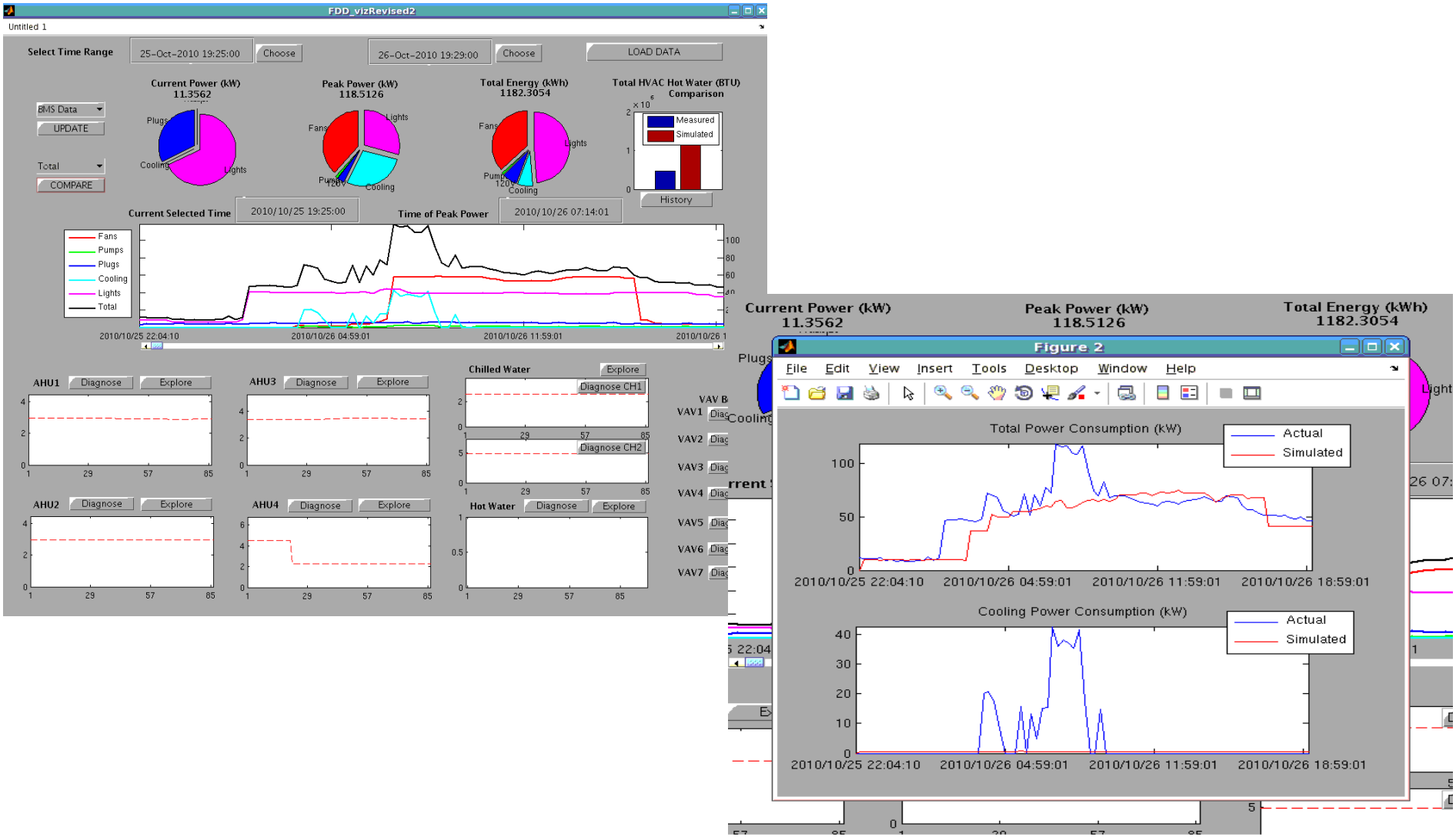
Building Performance Visualization & Diagnostics



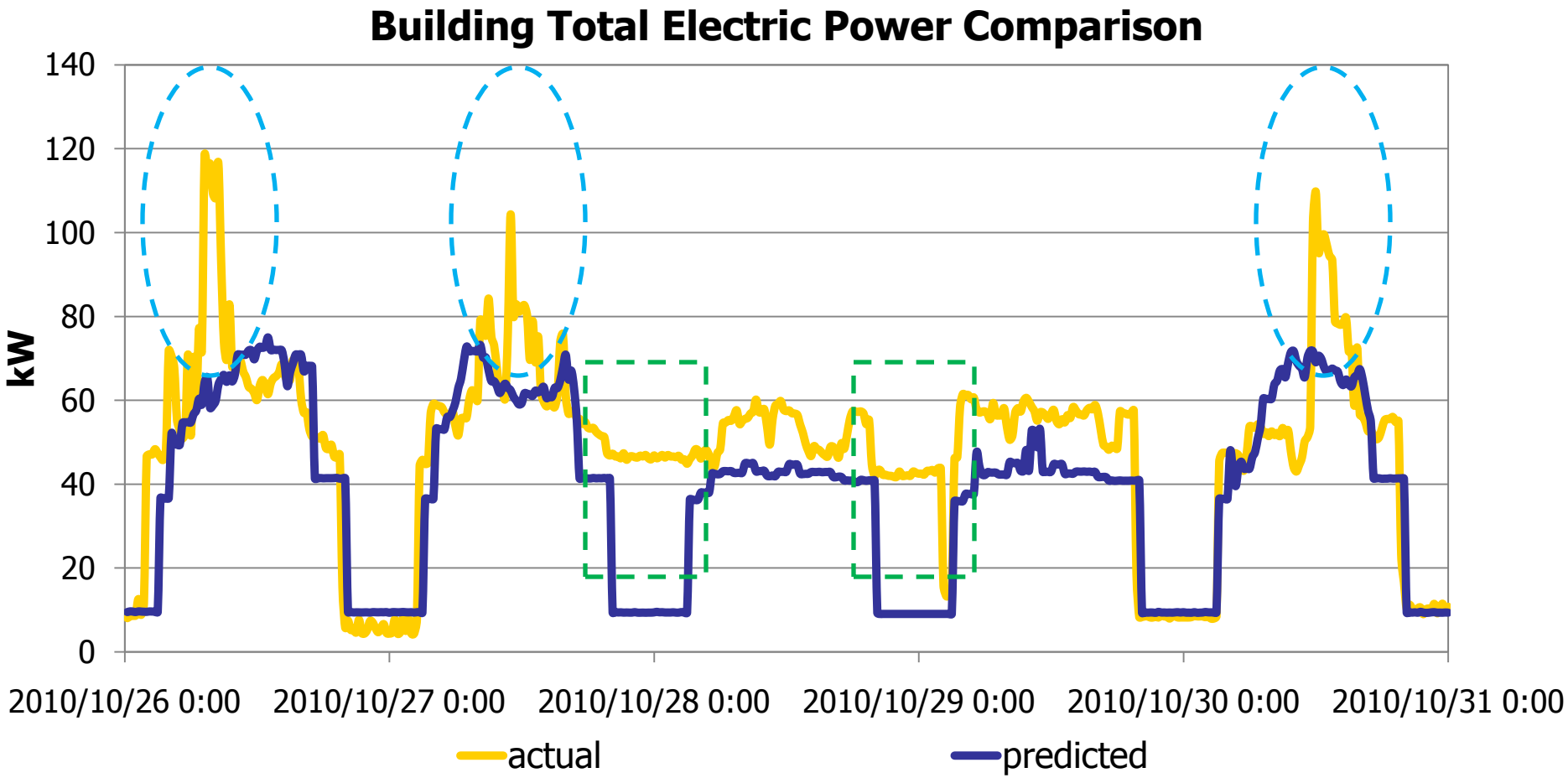
AHU non-economizer mode

Corrective Action?

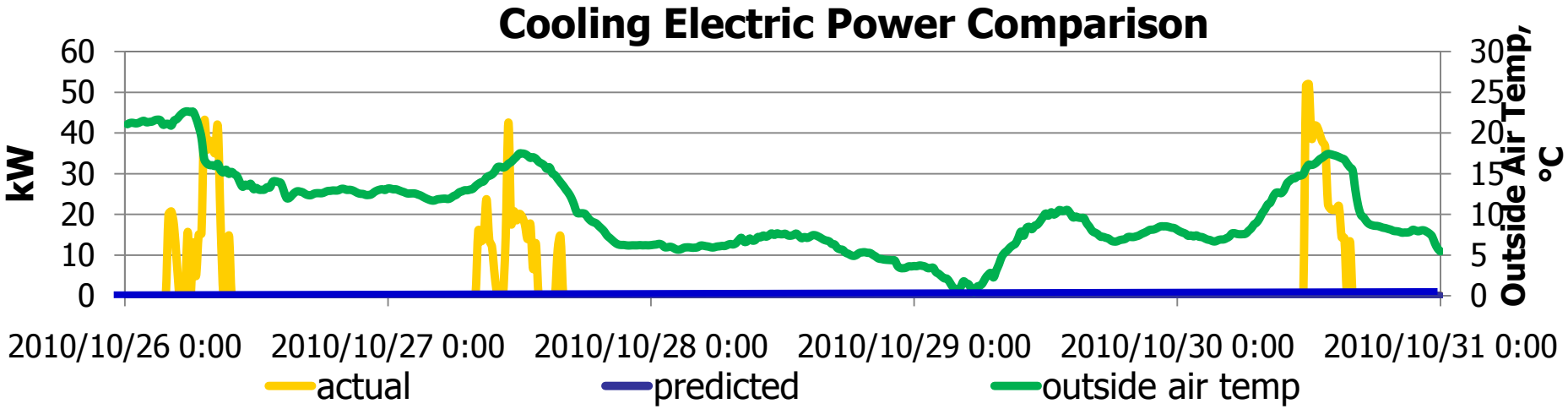
Results - I

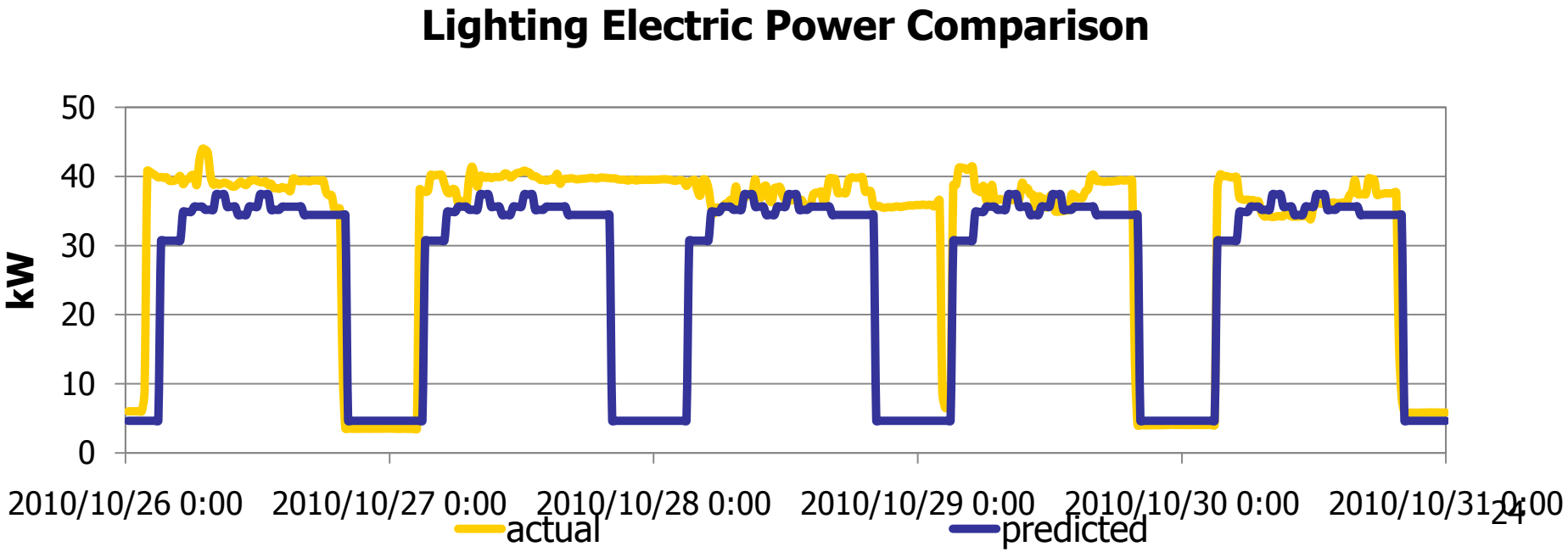

FDD_vizRevised2
Select Time Range
25-Oct-2010 19:25:00
Choose
26-Oct-2010 19:29:00
Choose
LOAD DATA
Current Power (kW)
11.3562
Peak Power (kW)
118.5126
Total Energy (kWh)
1182.3054
Total HVAC Hot Water (BTU) Comparison
Measured
Simulated
History
BMS Data
UPDATE
Total
COMPARE
Current Selected Time
2010/10/25 19:25:00
Time of Peak Power
2010/10/26 07:14:01
Fans
Pumps
Plugs
Cooling
Lights
Total
AHU1
AHU2
AHU3
AHU4
Diagnose
Explore
Chilled Water
Diagnose CH1
Diagnose CH2
Hot Water
VAV1
VAV2
VAV3
VAV4
VAV5
VAV6
VAV7
Figure 2
File
Edit
View
Insert
Tools
Desktop
Window
Help
Total Power Consumption (kW)
Actual
Simulated
2010/10/25 22:04:10
2010/10/26 04:59:01
2010/10/26 11:59:01
2010/10/26 18:59:01
Cooling Power Consumption (kW)

Results - II


Building Total Electric Power Comparison
kW
140
120
100
80
60
40
20
0
2010/10/26 0:00
2010/10/27 0:00
2010/10/28 0:00
2010/10/29 0:00
2010/10/30 0:00
2010/10/31 0:00
actual
predicted

Results - III


Cooling Electric Power Comparison
kW
60
50
40
30
20
10
0
30
25
20
15
10
5
0
Outside Air Temp, °C
2010/10/26 0:00
2010/10/27 0:00
2010/10/28 0:00
2010/10/29 0:00
2010/10/30 0:00
2010/10/31 0:00
actual
predicted
outside air temp


Lighting Electric Power Comparison
kW
50
40
30
20
10
0
2010/10/26 0:00
2010/10/27 0:00
2010/10/28 0:00
2010/10/29 0:00
2010/10/30 0:00
2010/10/31 0:00
actual
predicted

Conclusions of Performance Monitoring Pilot

- Developed and demonstrated proof-of-concept real-time whole building performance monitoring tool using EnergyPlus
- Real-time weather data required
- Submetering and thermal energy metering are important for model calibration and FDD
- Tools for modeling existing buildings
  - stereoscopic reconstruction of geometry
  - extend CEUS protocol
- Develop 'reconciliation' procedure

- Acknowledgements:
  - Xiufeng Pang, Prajesh Bhattacharia – LBNL
  - Zheng O'Neil, Madhusudana Shashanka, Trevor Bailey - UTRC

EnergyPlus GUI Project

Goals

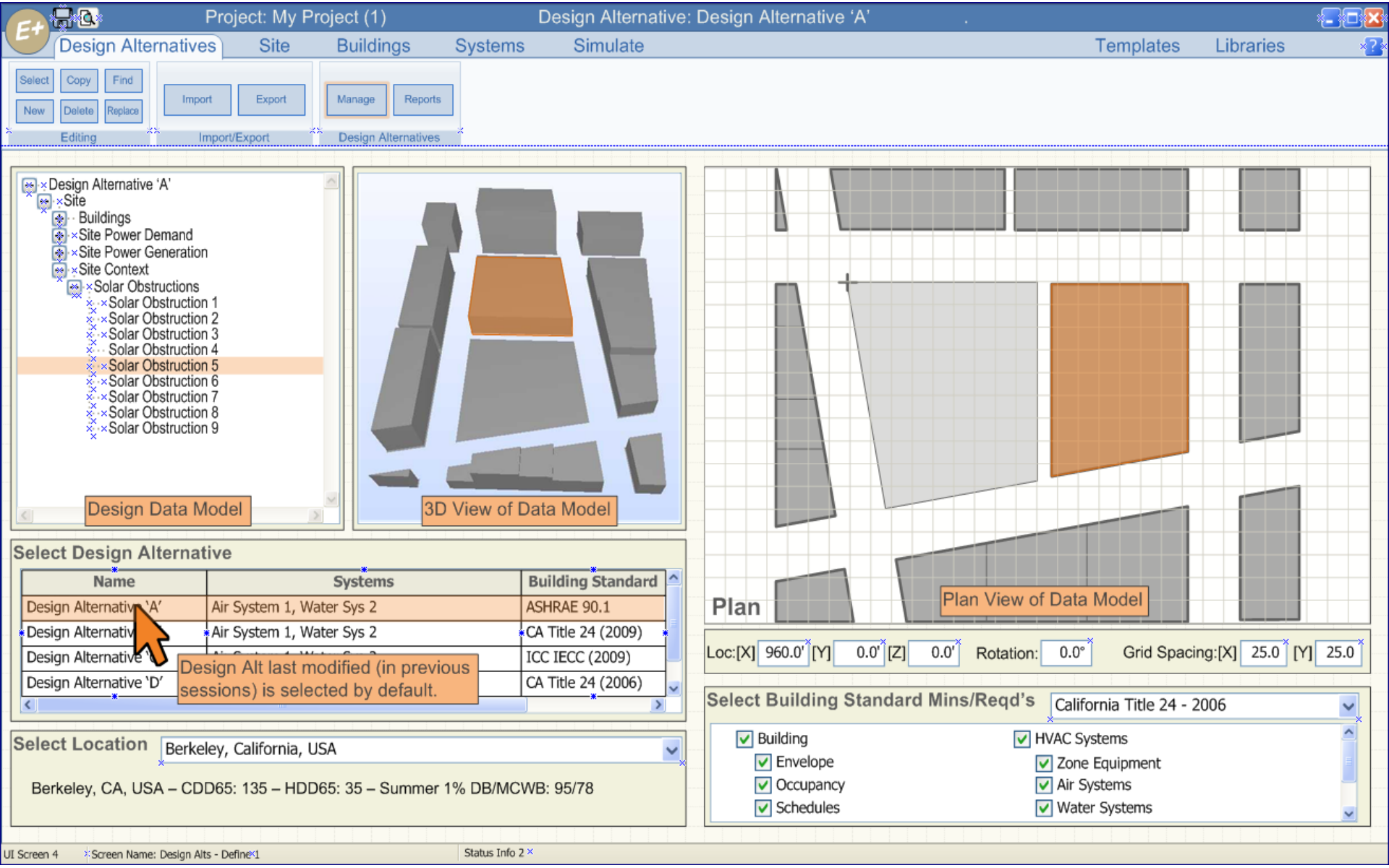
- Develop a free Graphical User Interface that enables EnergyPlus to be used more easily and effectively by building designers and other professionals

- Distribute as an "Open Platform" with well documented API's to facilitate collaborative development and derivative works

Project Overview

- Preparation Phase:
  - Definition of user requirements – workshops, office visits
  - Identification of the overall software architecture
- Software Development Phase:
  - Detailed functional specification
  - Coding
  - Internal and 3rd party testing
- Dissemination, Training, User Support and Code Maintenance Phase:
  - Identify business models for training and user support

Site


Project: My Project (1)
Design Alternative: Design Alternative 'A'
Design Alternatives
Site
Buildings
Systems
Simulate
Templates
Libraries
Select
Copy
Find
New
Delete
Replace
Editing
Import
Export
Import/Export
Manage
Reports
Design Alternatives
Design Alternative 'A'
Site
Buildings
Site Power Demand
Site Power Generation
Site Context
Solar Obstructions
Solar Obstruction 1
Solar Obstruction 2
Solar Obstruction 3
Solar Obstruction 4
Solar Obstruction 5
Solar Obstruction 6
Solar Obstruction 7
Solar Obstruction 8
Solar Obstruction 9
Design Data Model
3D View of Data Model
Plan
Plan View of Data Model
Loc:[X] 960.0' [Y] 0.0' [Z] 0.0'
Rotation: 0.0°
Grid Spacing:[X] 25.0 [Y] 25.0
Select Design Alternative
Name
Systems
Building Standard
Design Alternative 'A'
Air System 1, Water Sys 2
ASHRAE 90.1
Air System 1, Water Sys 2
CA Title 24 (2009)
ICC IECC (2009)
Design Alternative 'D'
CA Title 24 (2006)
Design Alt last modified (in previous sessions) is selected by default.
Select Location
Berkeley, California, USA
Berkeley, CA, USA – CDD65: 135 – HDD65: 35 – Summer 1% DB/MCWB: 95/78
Select Building Standard Mins/Reqd's
California Title 24 - 2006
Building
Envelope
Occupancy
Schedules
HVAC Systems
Zone Equipment
Air Systems
Water Systems
UI Screen 4
Screen Name: Design Alts - Define 1
Status Info 2

Import from BIM

Project: My Project (1) Design Alternative: My Design 'A'

Design Alternatives | Site | Buildings | Systems | Simulate | Templates | Libraries

Copy Selection | Delete Selection | Save as new Alternative | Import Design Data | Export Design Data

Define Design Alternative | Import/Export Design Data

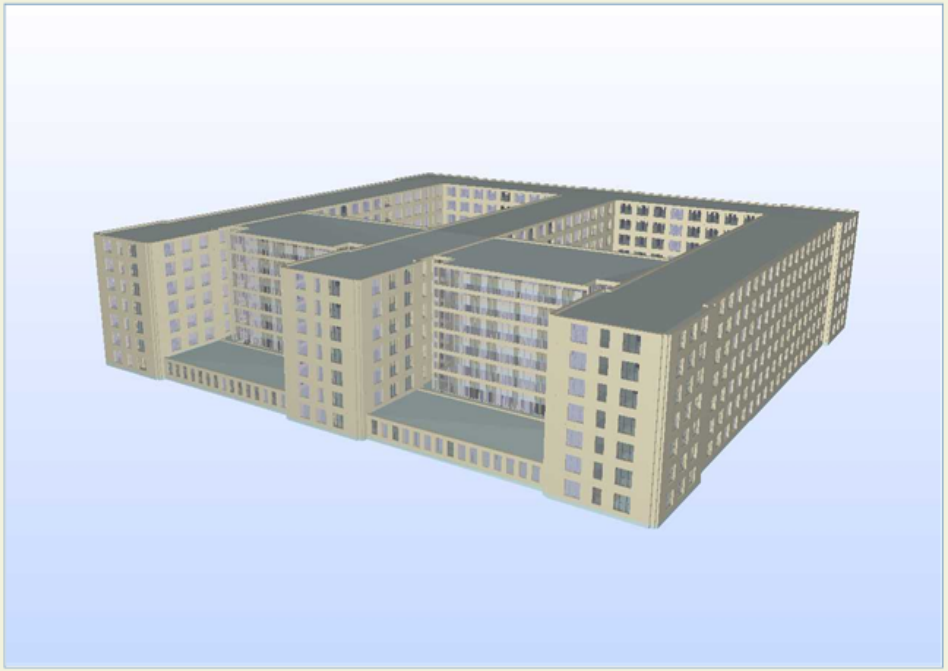
Locate File to Import

Browse | My_IFC_Project_A.ifc | Import Data

Select Data Types to be imported: Select All | Deselect All

- [x] Buildings
  - [x] Building Floors
  - [x] Walls
    - [x] Doors
    - [x] Windows
  - [x] Slabs
- [x] Material Assemblies
- [x] Zones
  - [x] Zone Equipment
  - [x] Schedules
- [x] Air Systems
  - [x] Schedules
- [ ] Water Systems
  - [ ] Schedules
- [x] Controls

3D View of Building Geometry



Data Validation

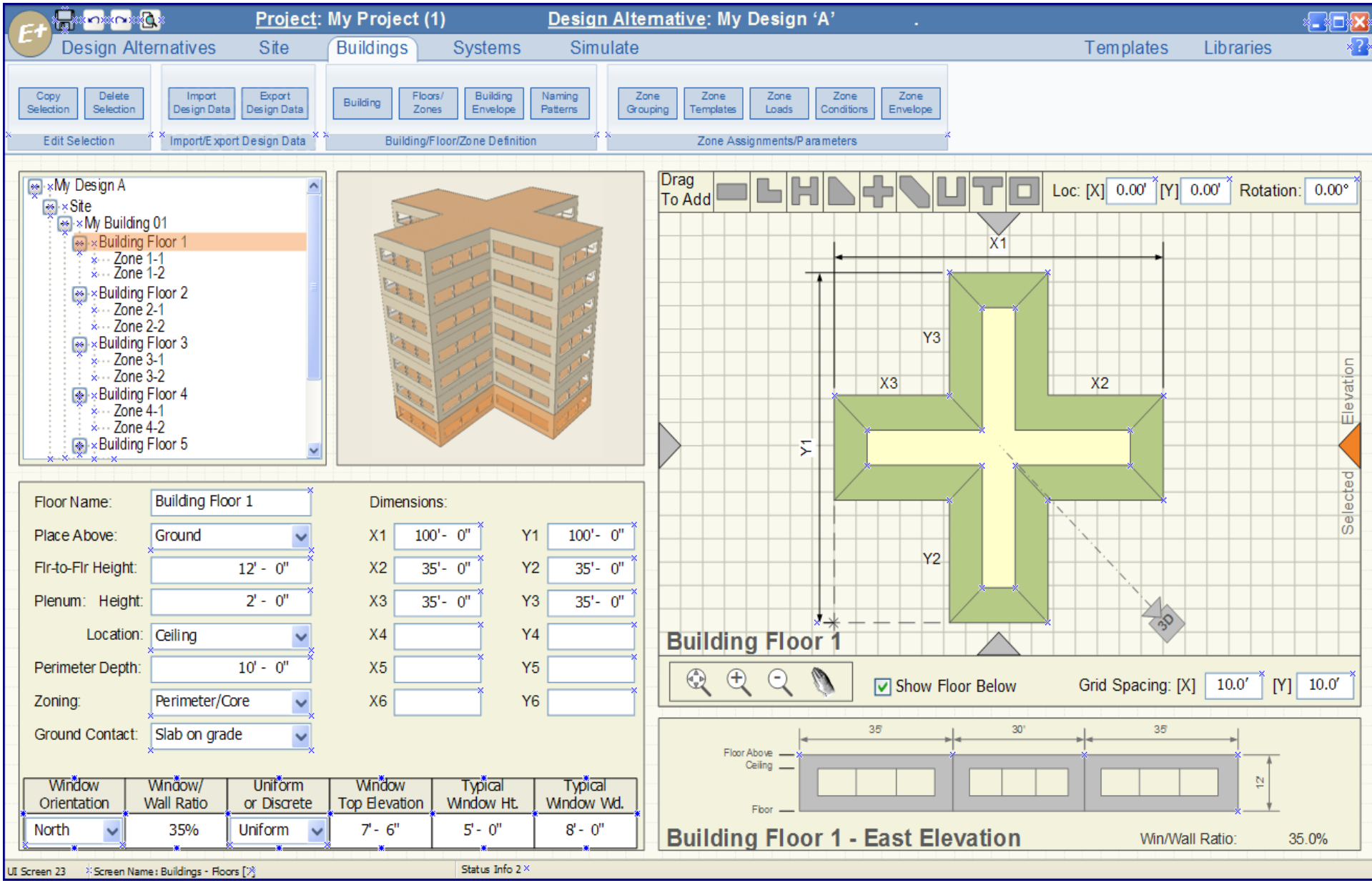
Data Type	Found in File	Validated	Invalid
Buildings	1	1	0
Building Floors	7	7	0
Zones	760	754	6
Walls	3114	3069	45
Doors	2047	2047	0
Windows	1736	1736	0
Slabs	29	28	1
Schedules	23	23	0
Zone Equipment	267	265	2
Air Systems	21	21	0
Water Systems	0	0	0
Controls	56	56	0

Summary Data

Avg. Area Per Floor:	580,000 sq ft	Total Win/Wall Ratio – North:	23%
Total Floor Area:	3,930,000 sq ft	Total Win/Wall Ratio – South:	20%
Total Win/Wall Ratio:	22%	Total Win/Wall Ratio – East:	22%
		Total Win/Wall Ratio – West:	22%

UI Screen 8 | Screen Name: Design Alts - Imp Data 4 [4] | Status Info 2

Internal Creation of Geometry



Zones – Internal Loads

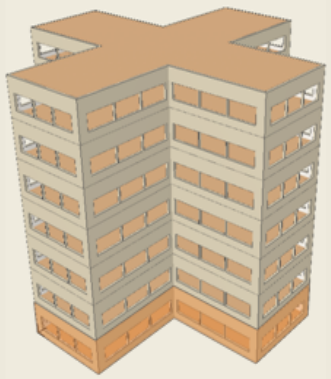
Project: My Project (1) Design Alternative: My Design 'A'

Design Alternatives | Site | Buildings | Systems | Simulate | Templates | Libraries

Copy Selection | Delete Selection | Import Design Data | Export Design Data | Building | Floors/Zones | Building Envelope | Naming Patterns | Zone Grouping | Zone Templates | Zone Loads | Zone Conditions | Zone Envelope

Edit Selection | Import/Export Design Data | Building/Floor/Zone Definition | Zone Assignments/Parameters

- My Design A
  - Site
    - My Building 01
      - Building Floor 1
        - Zone 1-1--Perimeter
        - Zone 1-2--Core
      - Building Floor 2
        - Zone 2-1--Perimeter
        - Zone 2-2--Core
      - Building Floor 3
        - Zone 3-1--Perimeter
        - Zone 3-2--Core
      - Building Floor 4
        - Zone 4-1--Perimeter
        - Zone 4-2--Core
      - Building Floor 5



New Group | Delete Group | Custom Edit Template Values

Zone Group List	Floor	Orientation	Zone Template	Internal Loads Template	Conditions Template
+ Zone Group - Perimeter			Zone Template 15A	Loads Template 12	Conditions Templt. 5
- Zone 1-1--Perimeter	1	North			
- Zone 2-1--Perimeter	2	South	Custom Values		
- Zone 3-1--Perimeter	3	East		Custom Values	
- Zone 4-1--Perimeter	4	West			
+ Zone Group - Core			Zone Template 14B	Loads Template 11	Conditions Templt 4
- Zone 1-2--Core	1	North			
- Zone 2-2--Core	2	South			Custom Values
- Zone 3-2--Core	3	East			
- Zone 4-2--Core	4	West			

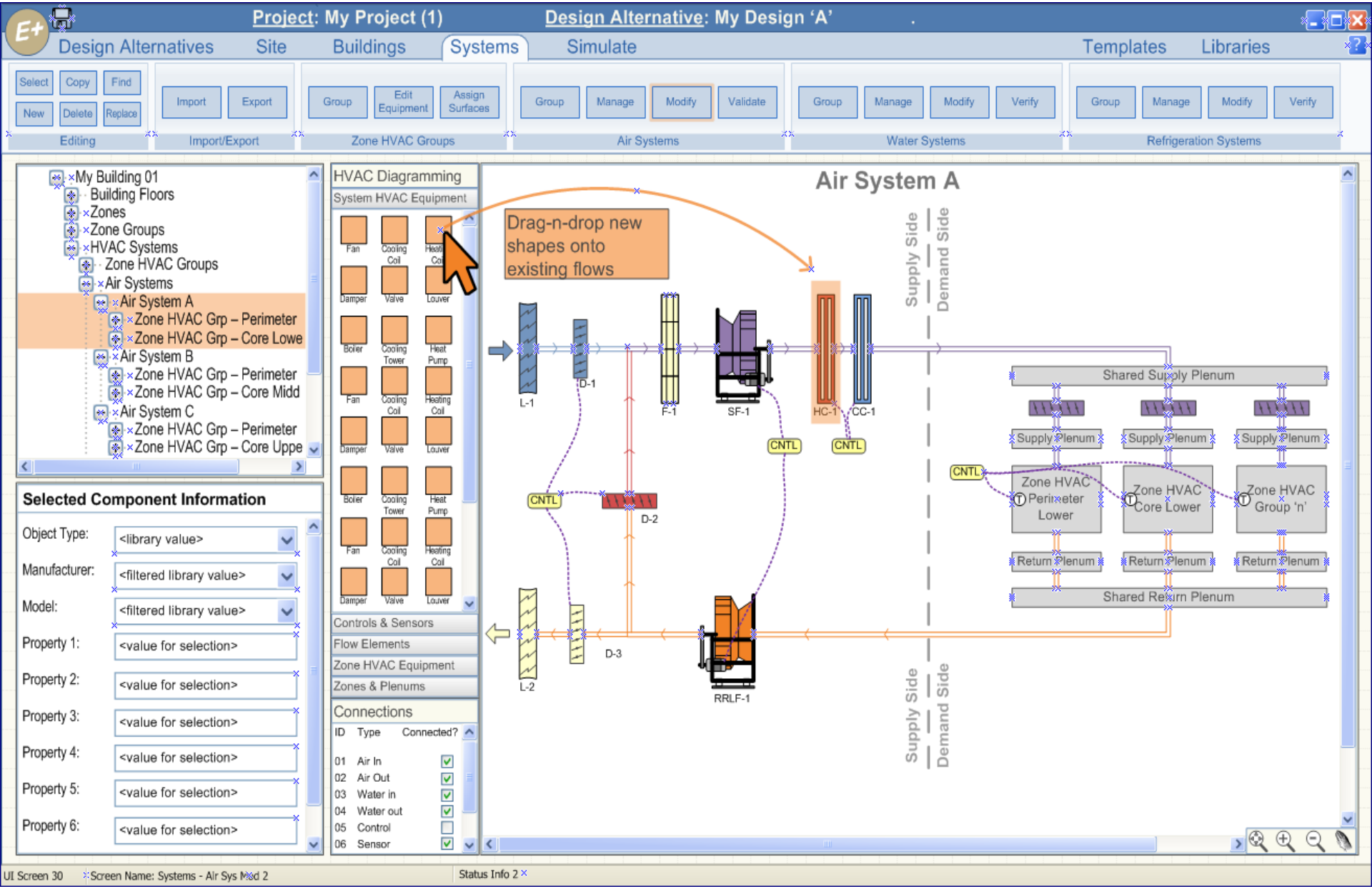
Edit Internal & Airflow Loads – Internal Loads Template 12

Peak Occupancy:	<value>	<units>	Infiltration:	<value>	<units>
Sensible Load:	<value>	<units>	Schedule:	<library value>	
Latent Load:	<value>	<units>	DHW Peak Use	<value>	<units>
Schedule:	<library value>		DHW Schedule:	<library value>	
Peak Electrical Load:	<value>	<units>			
% Sensible:	<value>				
% Load to Space:	<value>				
Schedule:	<library value>				
Peak Load to Group:	<value>	<units>			
& Load to Space:	<value>				
Schedule:	<library value>				
Daylighting Control:	<library value>				

	Sensor 1	Units	Sensor 1	Units	Sensor 1	Units
Sensor location						
Distance from nearest external wall						
Sensor height						
%Zone Affected						
Angle between occupant View and window surface						
Maximum glare index						

UI Screen 32 Screen Name: Zones - Edit Interna Loads [13-14] Status Info 2

HVAC Air Systems



Refrigeration Systems

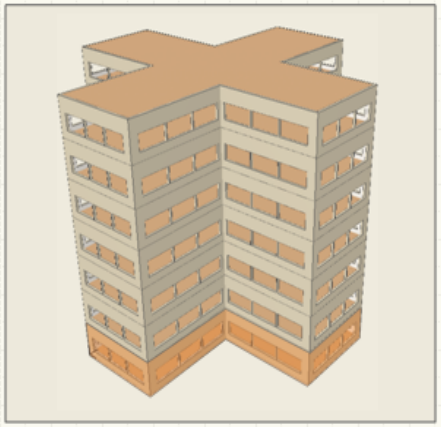
Project: My Project (1) Design Alternative: My Design 'A'

Design Alternatives | Site | Buildings | Systems | Simulate | Templates | Libraries

Copy Selection | Delete Selection | Import Design Data | Export Design Data | Equipment Groups | Edit Equipment | Assign Surfaces | Demand Group | Manage | Modify | Validate | Demand Group | Manage | Modify | Validate | Demand Group | Manage | Modify | Validate

Edit Selection | Import/Export Design Data | Zone HVAC Systems | Air Systems | Water Systems | Refrige Systems

- Building Floor 3
- Building Floor 4
- Building Floor 5
- Building Floor 6
- Zone Groups
- HVAC Systems
  - Zone HVAC Systems
  - Air Systems
  - Water Systems
- Refrigeration Systems
  - Refrigeration System F
    - Zone 1-1--Perimeter
    - Zone 1-2--Core
  - Compressor Rack System
    - Zone 1-1--Perimeter

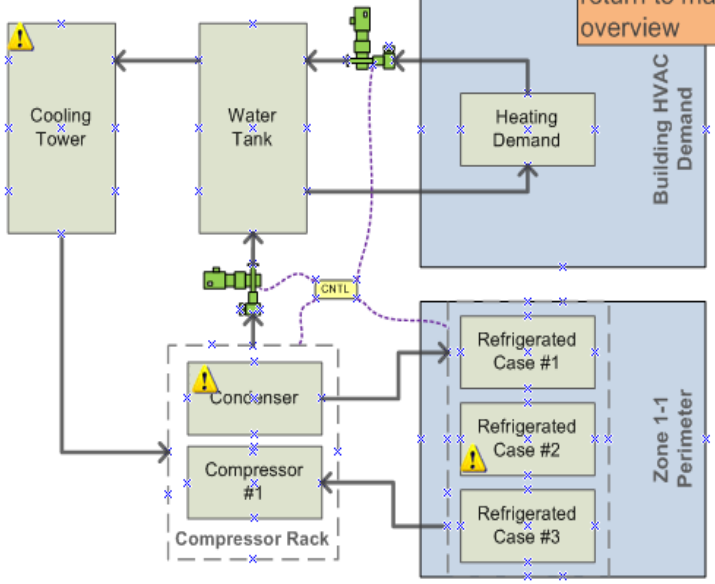


New Group | Delete Group | Custom Edit Template Values

Refrigeration System Group List	Floors	Orientation	Refrigeration Systems Template
+ Refrigeration System F			Unspecified
- Zone 1-1--Perimeter	1	Varies	
- Zone 1-2--Core	1	Interior	
+ Compressor Rack System G			Custom System Configuration
- Zone 1-1--Perimeter	1	Varies	

Manage Refrigeration Systen

Click on Manage to return to management overview



System Validation Issues

System Component	Issues to be Resolved
Component ID	Issue Description, advice for resolution ...
Component ID	Issue Description, advice for resolution ...
Component ID	Issue Description, advice for resolution ...
Component ID	Issue Description, advice for resolution ...
Component ID	Issue Description, advice for resolution ...
Component ID	Issue Description, advice for resolution ...

Issues are flagged by component in the overview and reported below. These issues should be resolved before this system is used in a simulation.

UI Screen 53 | Screen Name: Systems - Refrig Sys Validate 2 | Status Info 2

Output Visualization

Questions?