

# ORNL Flexible Research Platforms

Presented by: Joshua New

January 28, 2015

Empirical Validation of Whole-Building  
Energy Simulation Programs

Patrick Hughes

Ed Vineyard

Melissa Lapsa

PM: Joshua New

PIs – Piljae Im and Mahabir Bhandari (Model)

PI – Jibo Sanyal (Provenance)

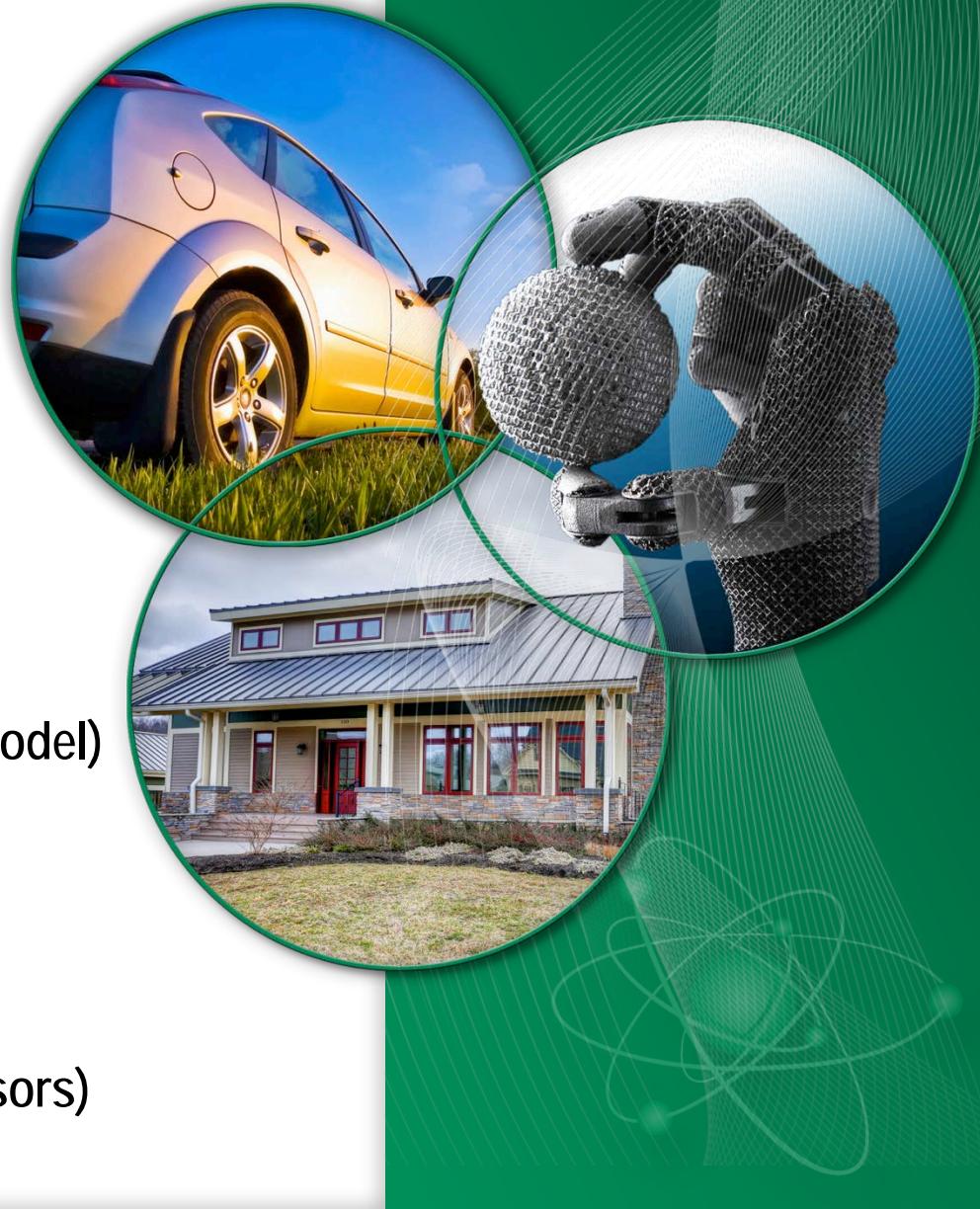
PI – Charles Castello (Sensor QA)

PI – Joshua New (Visual Analytics)

PI – Philip Boudreaux (Occupancy)

PIs – Tony Gehl and Chris Halford (Sensors)

PI – F&O (Installation)



# ORNL works with industry to accelerate delivery of solutions to market



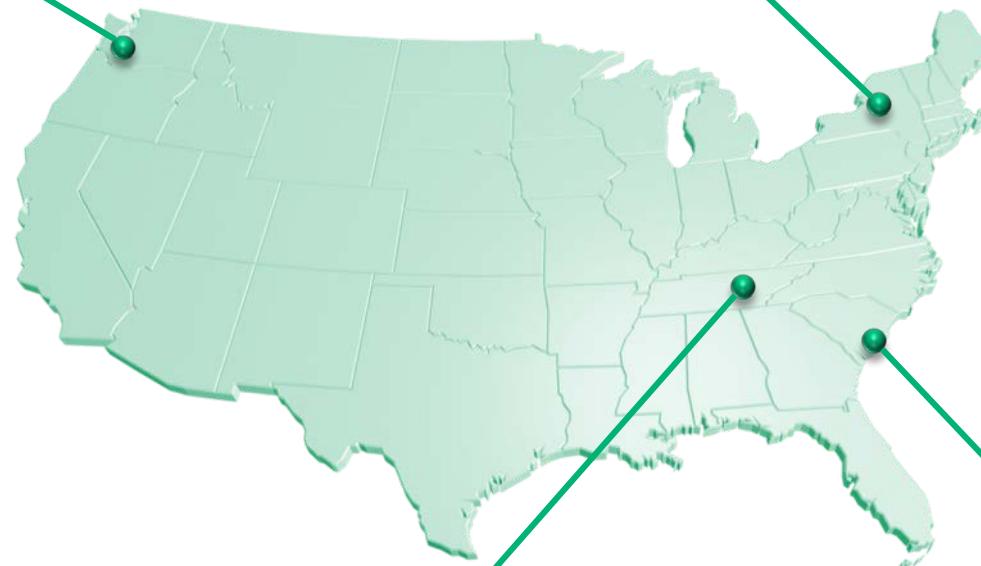
# Envelope research: Natural exposure facilities



Tacoma,  
Washington  
(cool/humid)



Syracuse,  
New York  
(cold/humid)



Oak Ridge,  
Tennessee  
(mixed/humid)



Charleston,  
South Carolina  
(hot/humid)

# Envelope research: Lab facilities



Heat flow through roof/attic assemblies



Heat flow through wall assemblies



Air/moisture flow through wall assemblies



Hygrothermal properties of materials

# Equipment research: Lab facilities

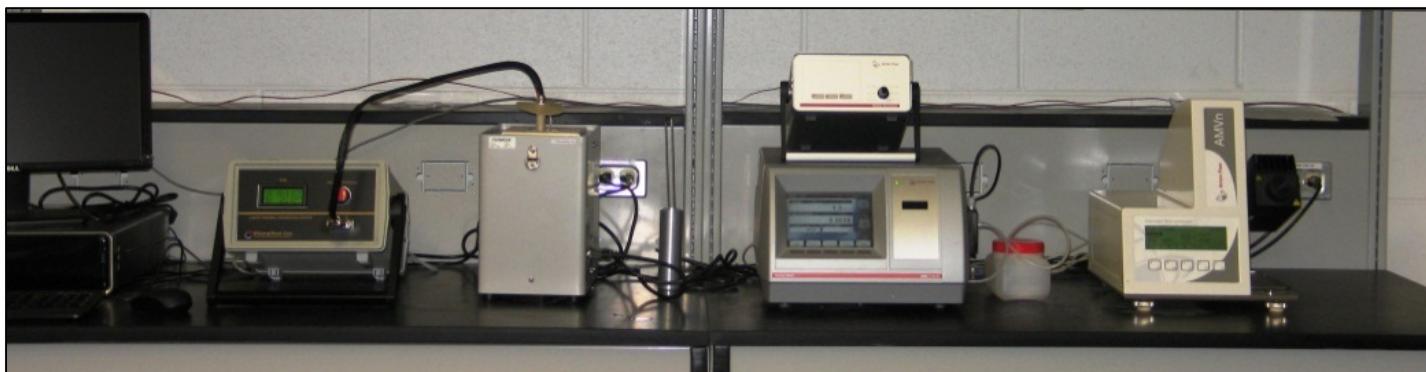
Environmental chambers



Compressor calorimeters



Heat exchanger R&D loops



Working fluid physical properties measurement

# FRP one-stop shop



Page Discussion

Read Edit View history

Search

Go

Search

## Projects:FRP

(Redirected from Projects FRP)

### Flexible Research Platforms

[edit]



### Software Tools

[edit]

Navigation

Main page  
Community portal  
Current events  
Recent changes  
Random page  
Help

Toolbox

## Project Data

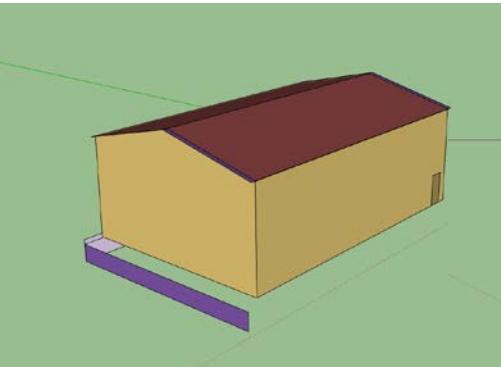
1. Master Directory - \\strider\FRP\_Readiness
2. Emulated Occupancy files - \\strider\FRP\_Readiness\Boudreaux
3. Sensor Data Quality Assurance - \\strider\FRP\_Readiness\Castello
  - Old test files, code, and installer -  
[https://www.dropbox.com/work/Data\\_Validation\\_Software/SensorDVC](https://www.dropbox.com/work/Data_Validation_Software/SensorDVC)
4. FRP Instrumentation (with pictures) - \\strider\FRP\_Readiness\ChrisTony
5. Server hardware and visualization - \\strider\FRP\_Readiness\New
6. Model files - \\strider\FRP\_Readiness\ImBhandari
7. Meeting Minutes - \\strider\FRP\_Readiness\Meetings
8. Publications - \\strider\FRP\_Readiness\Publications
9. Provenance and visualization - \\strider\FRP\_Readiness\Sanyal

Files may require permission to access, please contact newjr@ornl.gov to request access.

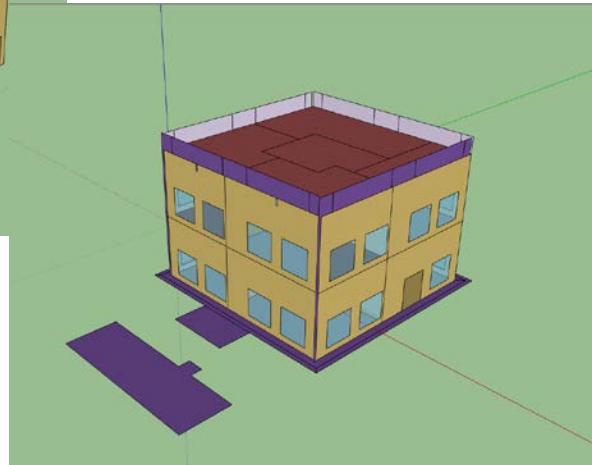
1. FRP Logbook - used to track changes to the FRPs
2. ProvDMS - provenance system for downloading FRP sensor data, tracking sensor use, uploading experiment files, creating dashboard visualizations, and exploring FRPs in 3D
  - Sensor status - 3-sigma hourly data for outlier detection and eventual notification
3. SensorDVC - sensor data validation and correction
  1. Windows installer - \\strider\FRP\_Readiness\Castello\setupSensorDVC.exe
  2. User manual - capabilities of the desktop application for sensor quality assurance and control
  3. SVN repo - source code and setupSensorDVC installer
  4. Developer manual - doxygen documentation of software code
  5. Dropbox - software design documents, test files, analysis, and application domains

# Reduce Uncertainties in Modeling

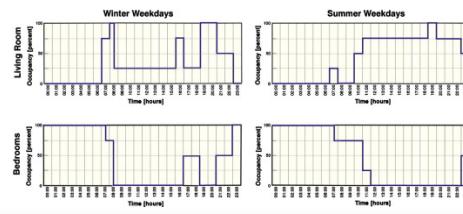
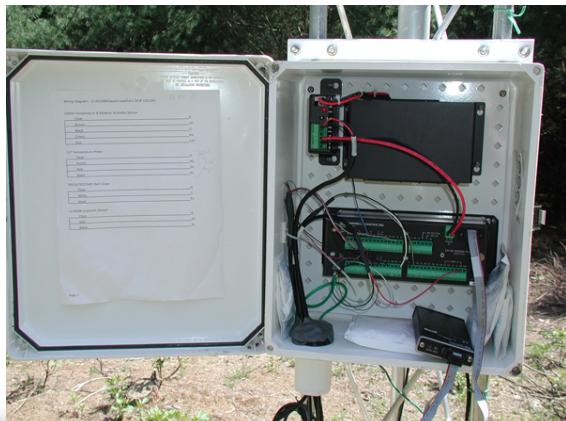
Temperature, RH, wind speed/direction, barometric pressure, precipitation  
Solar: direct normal, global horizontal, IR radiation from sky



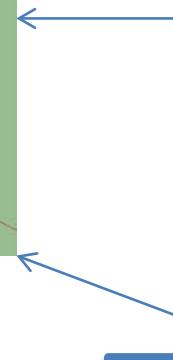
15min Data Measurements



Simulated Occupancy



Real weather file  
from the weather  
station



Active Foundation  
(adiabatic)



# Flexible Research Platform

- HVAC System Performance Measurement, Modeling, Calibration and Validation



**HVAC #3: Integrated GSHP**

→ Being Installed



**HVAC #2: VRF**



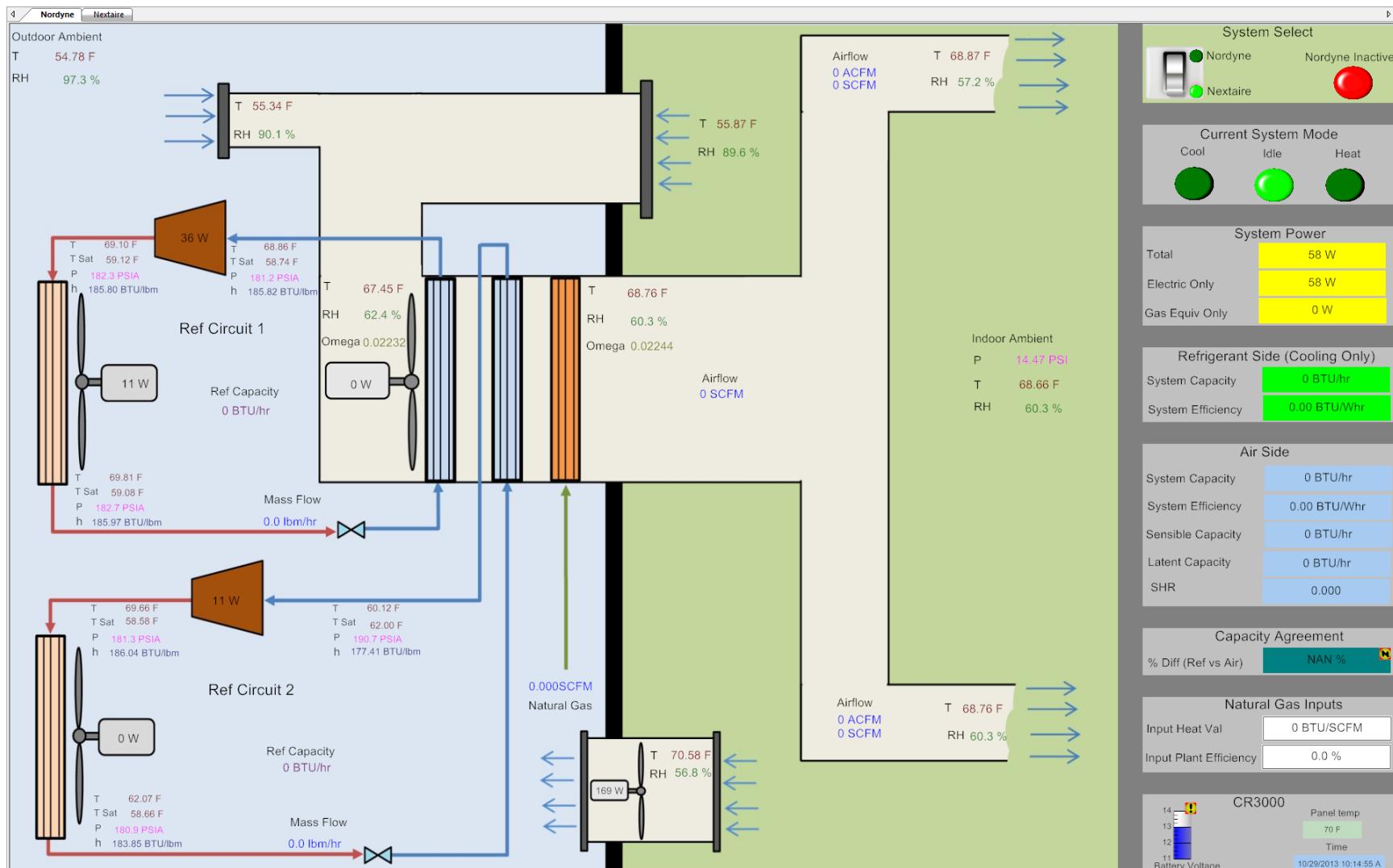
**Sensors & Data Acquisition**



# FRP1 DAQ Hardware

- 1 Master Cabinet
- 2 Peripheral Cabinets
- 128 Thermistor Channels
- 128 Single Ended Voltage Channels
- 50 Thermocouple Channels
- 32 Frequency input or 5V control Channels
- Integrated Refrigerant and Psychrometric Lookup Tables
- Linear Interpolation Routine To Calculate Thermodynamic Properties From Measured Quantities
- GUI For Real Time Data Picture and System Switch

# FRP1 DAQ Hardware



Nordyne GUI Tab

# FRP1 Installed Sensors

- 25 Temp/RH Probes
- 12 Refrigerant Side Immersion Thermistors
- 12 Refrigerant Side Pressure Transducers
- 4 Refrigerant Mass Flow Sensors
- 2 Natural Gas Mass Flowmeters
- 2 Airflow Measurement Stations
- 9 HVAC Power Measurements (Wattnode and CTs)
- 16 General Building Power Measurements (Wattnode and CTs)

# FRP1 Sensors



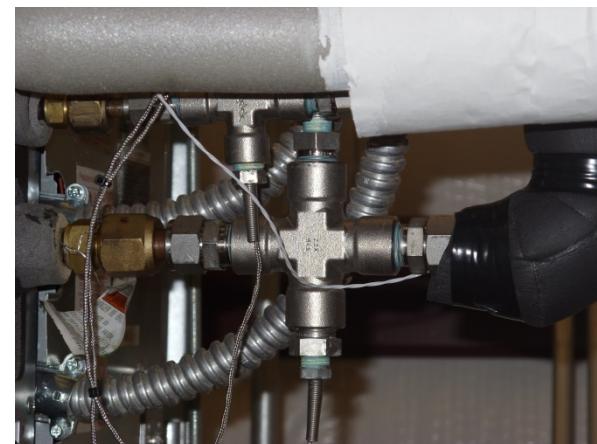
Refrigerant Mass Flow



Natural Gas Flow



Electrical Power



Refrigerant Temp and Press



Airflow



Air Temp And RH

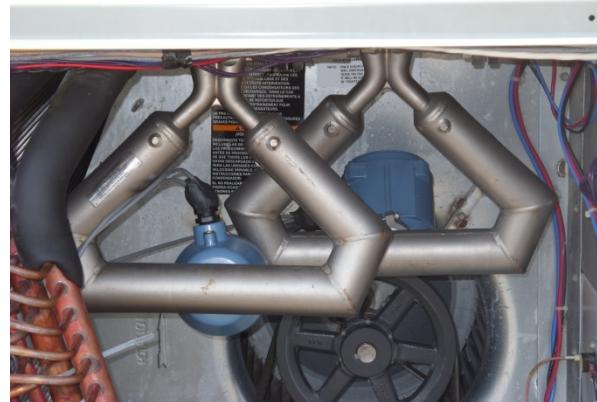
# FRP2 DAQ Hardware

- 1 Master Cabinet
- 4 Peripheral Cabinets
- 256 Thermistor Channels
- 256 Single Ended Voltage Channels
- 100 Thermocouple Channels
- 64 Frequency input or 5V control Channels

# FRP2 Installed Sensors

- 35 Temp/RH Probes
- 6 Refrigerant Side Immersion Thermistors
- 6 Refrigerant Side Pressure Transducers
- 2 Refrigerant Mass Flow Sensors
- 1 Natural Gas Mass Flowmeters
- 2 Airflow Measurement Stations
- 16 HVAC Power Measurements (Wattnode and CTs)
- 21 General Building Power Measurements (Wattnode and CTs)

# FRP2 Sensors



Refrigerant Mass Flow



Natural Gas Flow



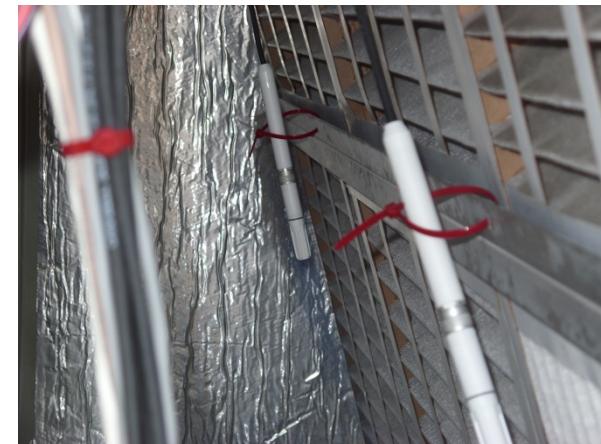
Electrical Power



Refrigerant Temp and Press



Airflow



Air Temp And RH

# FRP Occupancy Simulation

Philip Boudreaux

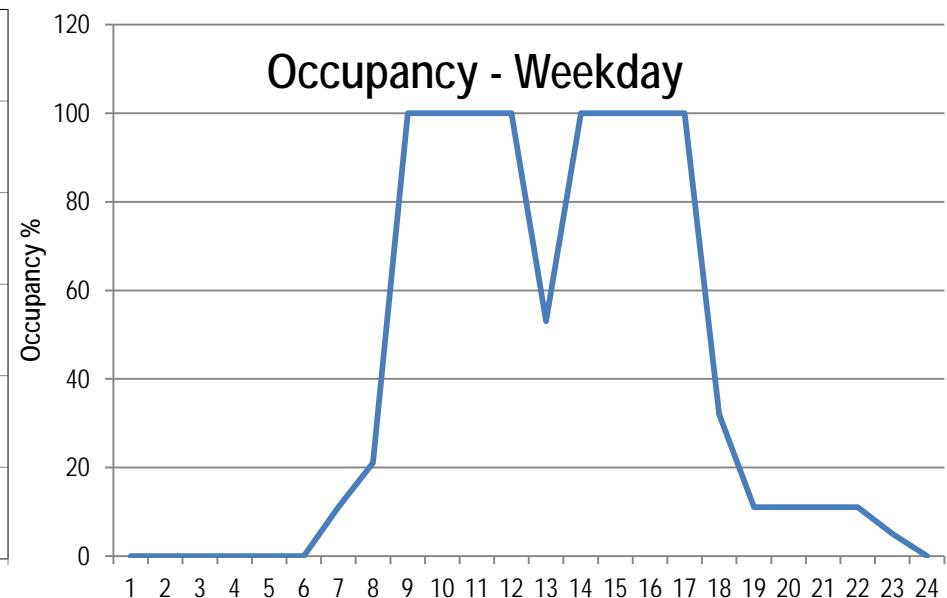
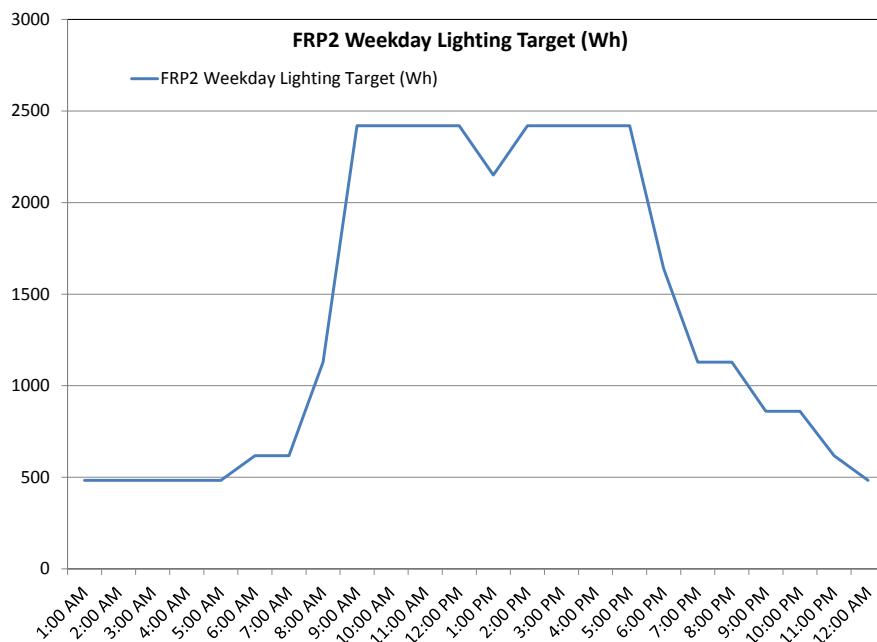
Tony Gehl



# Deliverable: Add latent, sensible, and lighting load to space according to occupancy schedule

- Various sources to define the schedules & power density

- ASHRAE 90.1-1989
- Huang et al. (1990) 481 PROTOTYPICAL COMMERCIAL BUILDINGS FOR 20 URBAN MARKET AREAS, LBL-29798
- Huang and Franconi (1999) COMMERCIAL HEATING AND COOLING LOADS COMPONENT ANALYSIS
- PNNL report (1990) ARCHITECT'S AND ENGINEER'S GUIDE TO ENERGY CONSERVATION IN EXISTING BUILDINGS: Volume 1 - Energy Use Assessment and Simulation Methods



# Deliverable: Add latent, sensible, and lighting load to space according to occupancy schedule

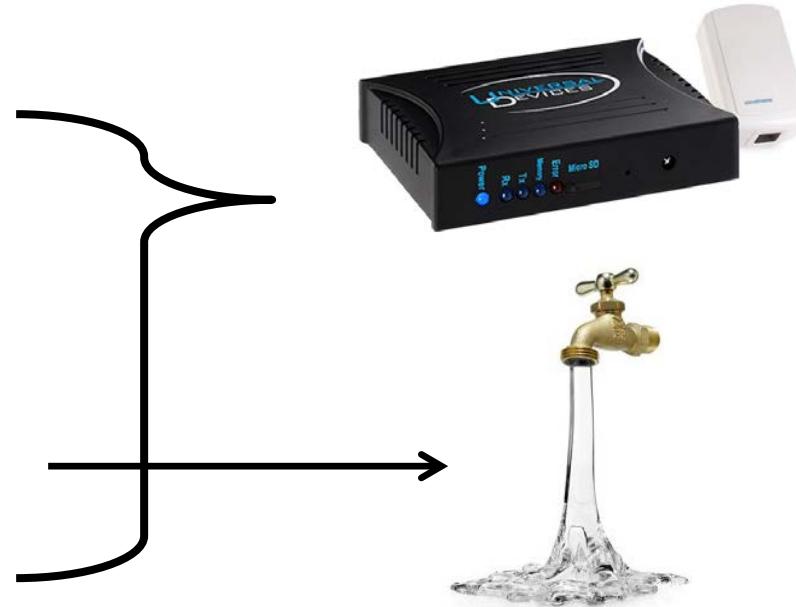
Sensible: from  
occupants  
and MELs



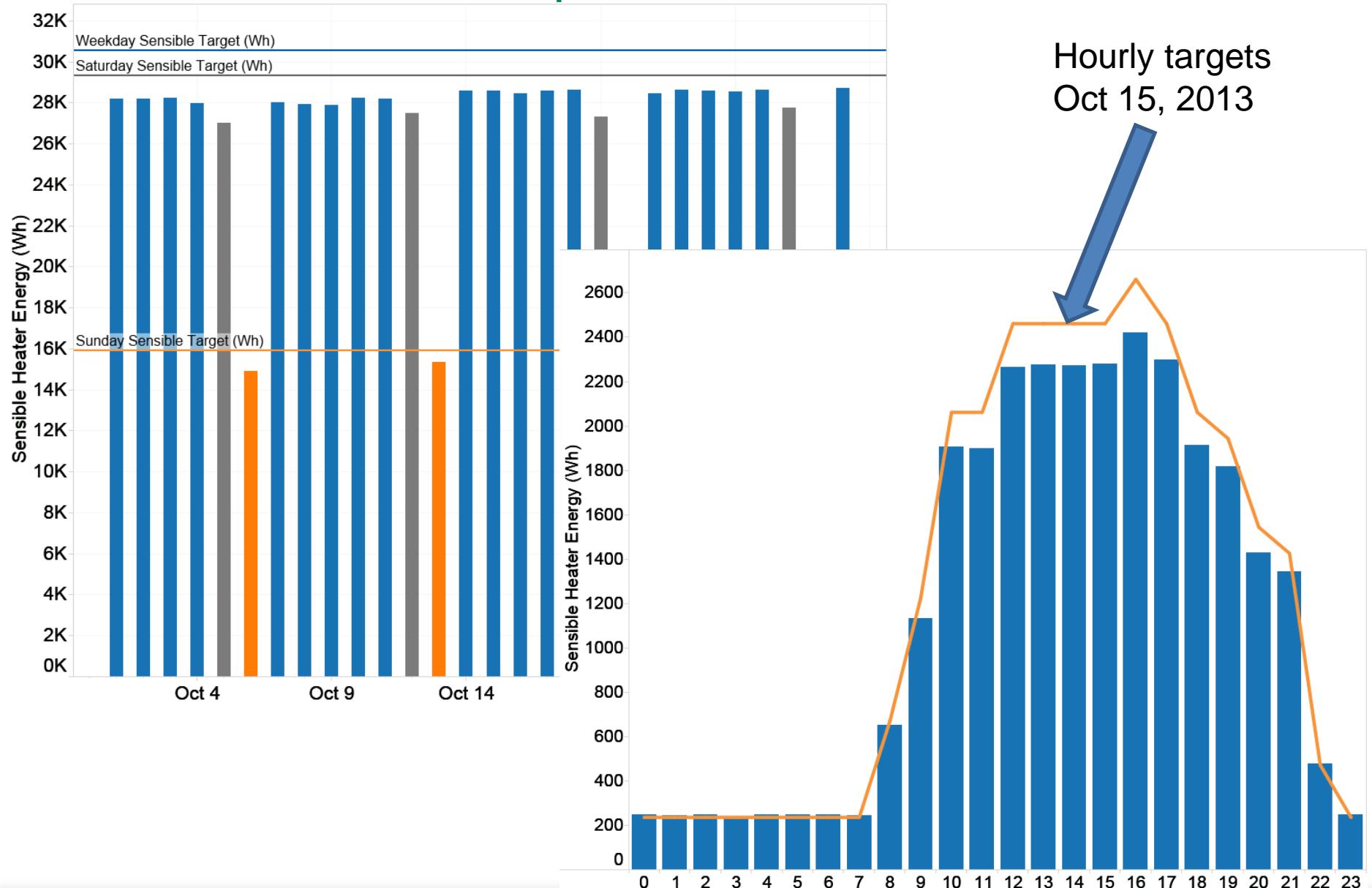
Latent: from  
occupants



Lighting

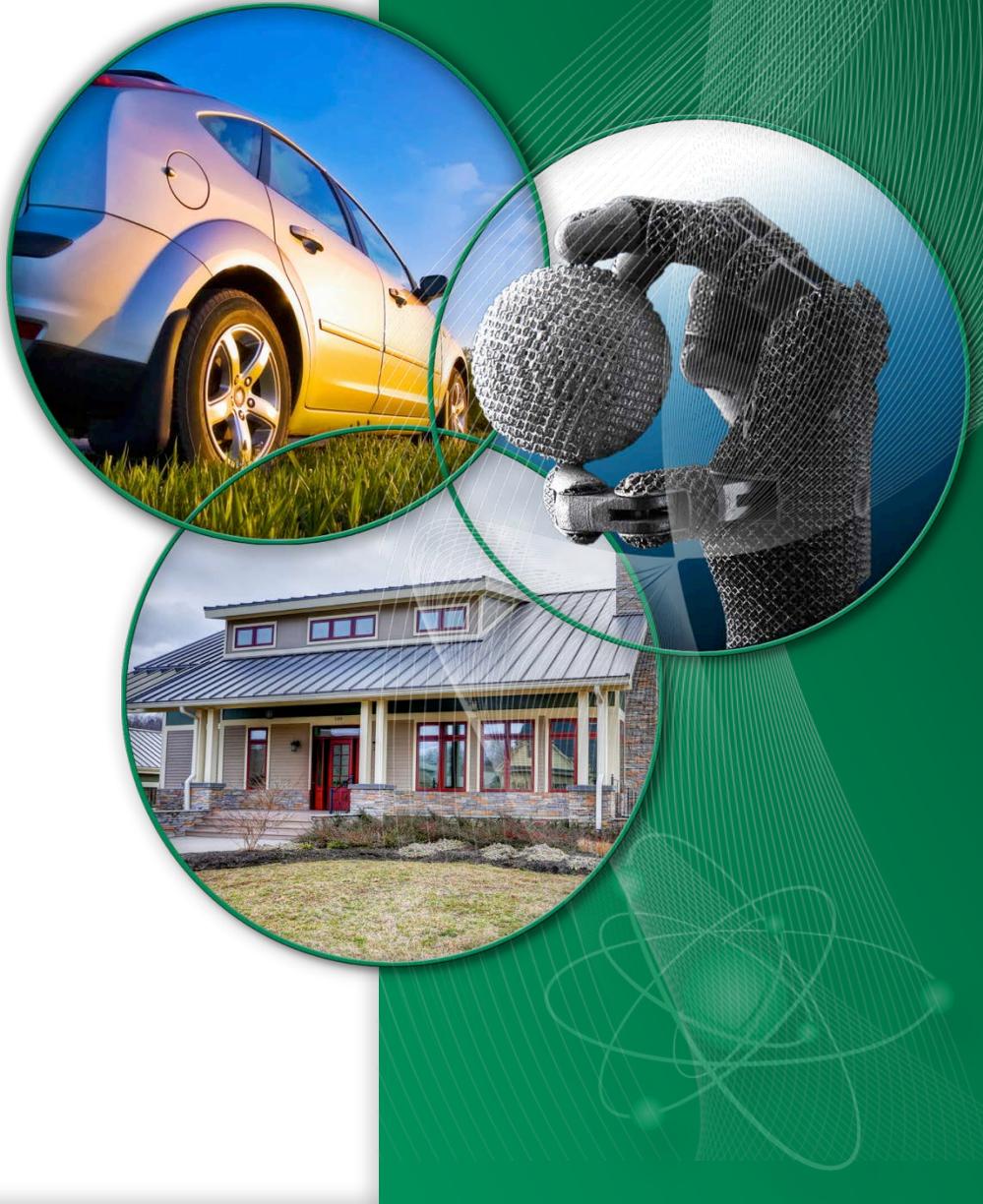


# Validation Example – FRP1 Sensible



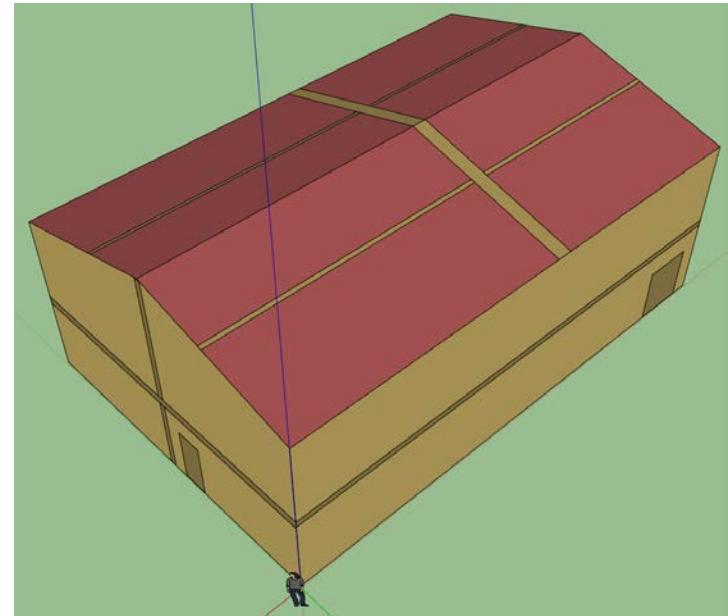
# FRP Energy Modeling for 1- and 2-Story Flexible Research Platforms

Mahabir Bhandari  
Piljae Im



# FRP 1 : Initial E+ models

- Data preparation – Geometry, Thermal bridging
- Internal loads/schedules/Setpoints
- Infiltration – blower door test
- HVAC performance
  - Nordyne system : 2 stage RTU
  - NextAire : Engine Driven HP
- DesignBuilder/E+

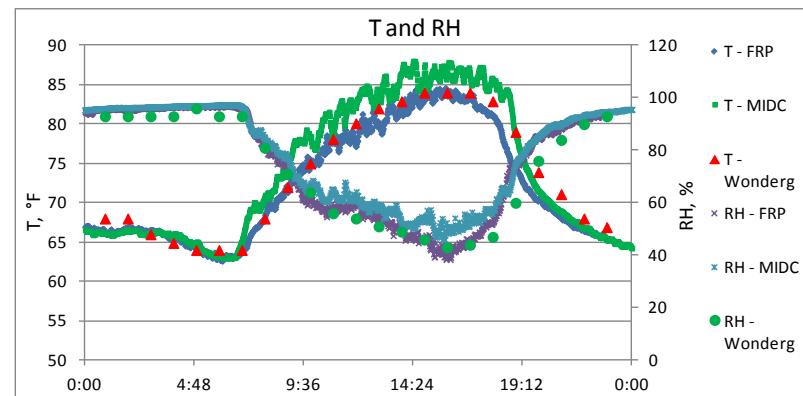
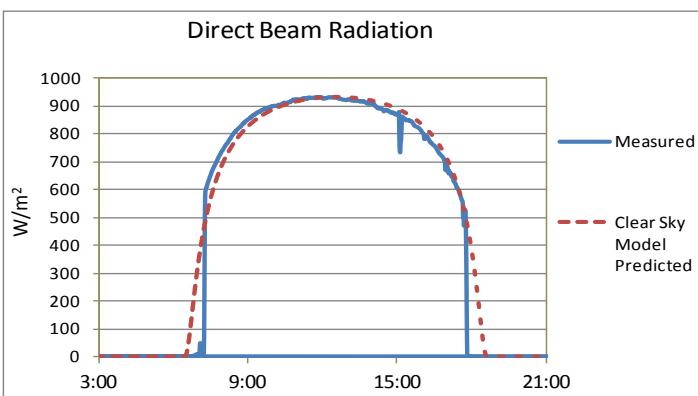


# Weather file for 2013 – weather data, QA, formatting from monthly template



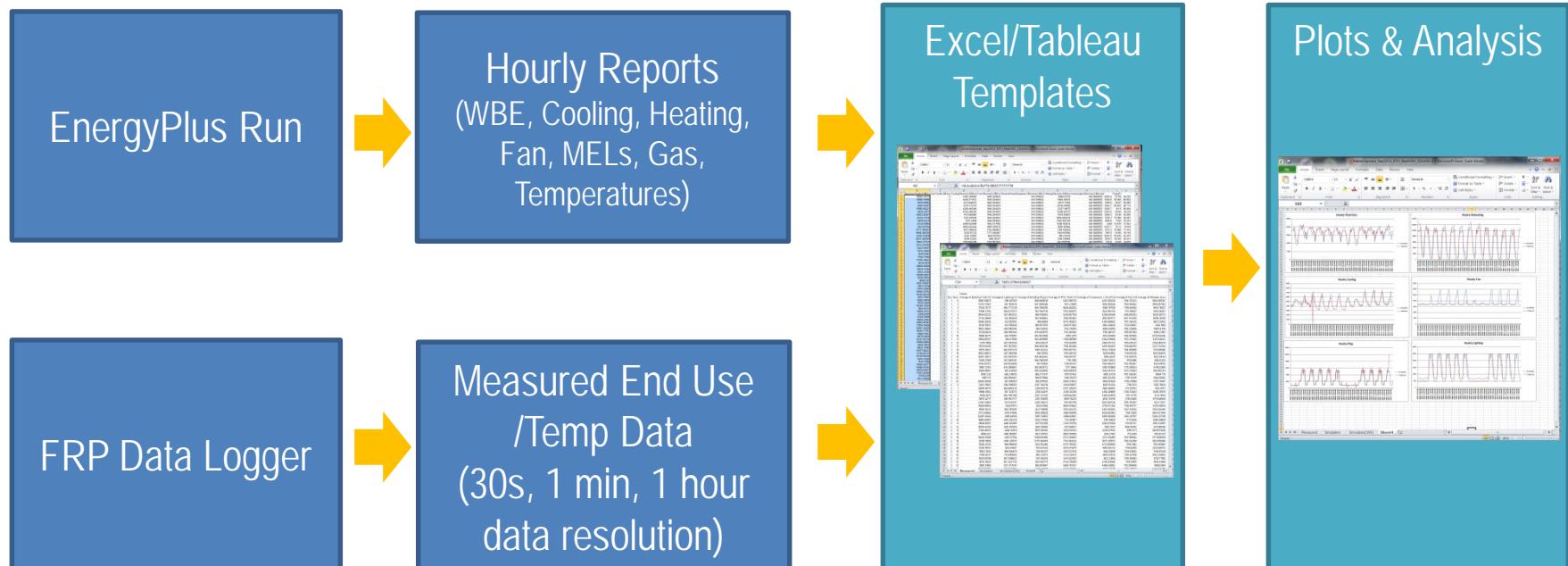
## Weather station

Temperature	Campbell Scientific	CS215
Relative humidity	Campbell Scientific	CS215
Wind speed/direction	Gill	WindSonic
Rainfall	Texas Electronics	TE525WS
<a href="#">Global Horizontal solar radiation</a>	LI-COR	LI-200X
Direct beam radiation	Eppley	NIP
IR radiation from sky	Eppley	PIR
Atmospheric pressure	Vaisala	CS106

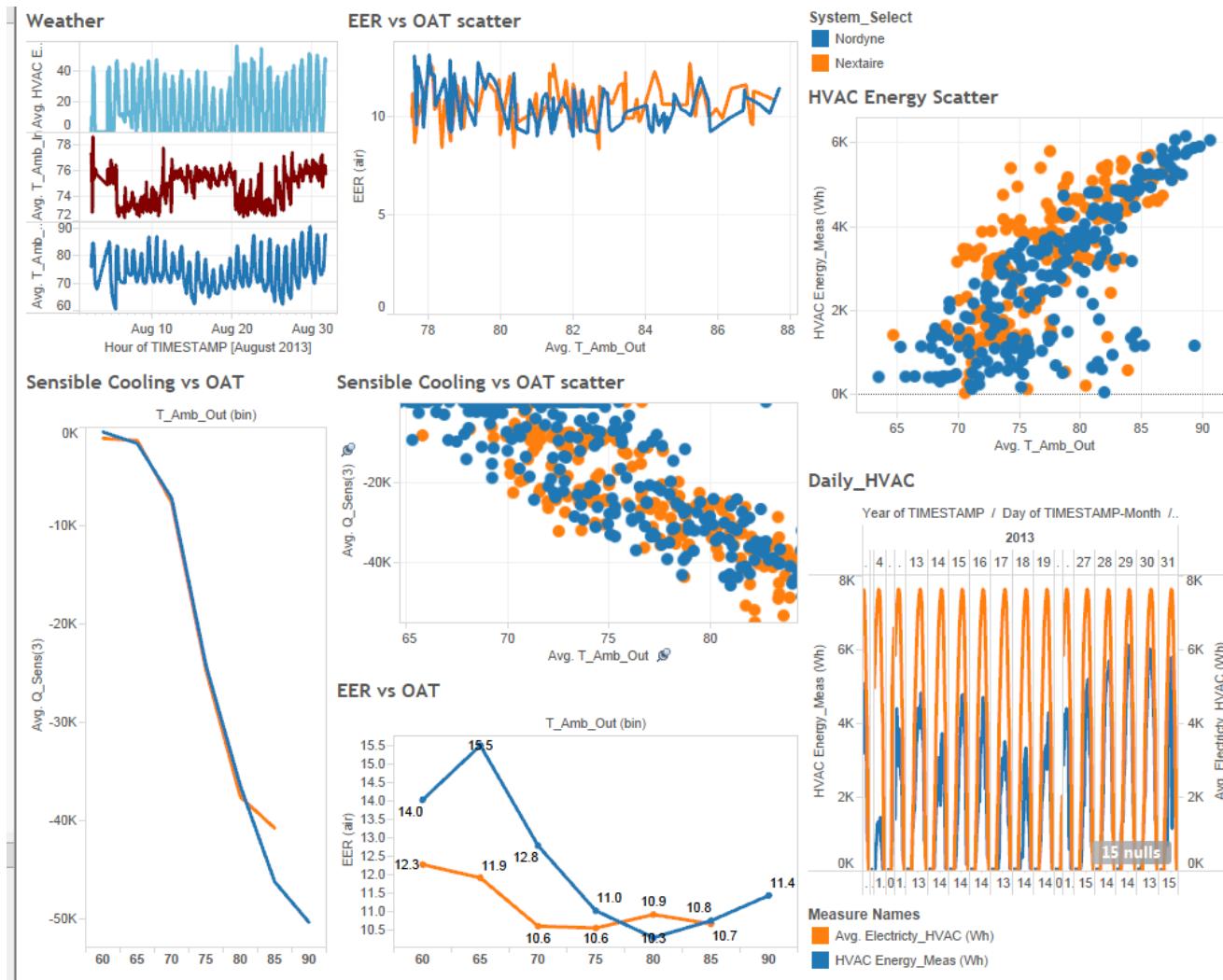


# Templates for Measured vs. Simulated Data

- Tableau
- Excel



# Tableau Template for 2 HVAC Systems (Screenshot)



# 2 Story FRP EnergyPlus Model

- Available models (as of 4/17/2014)

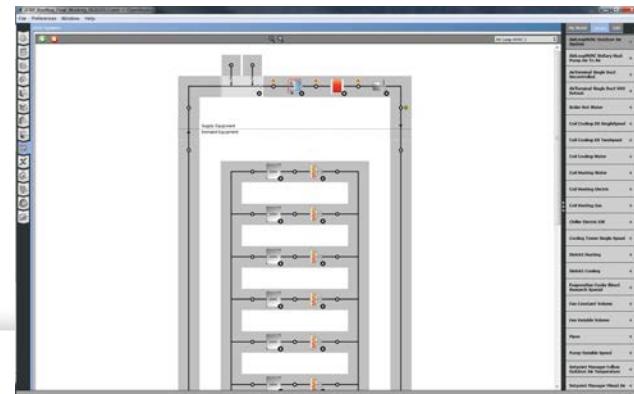
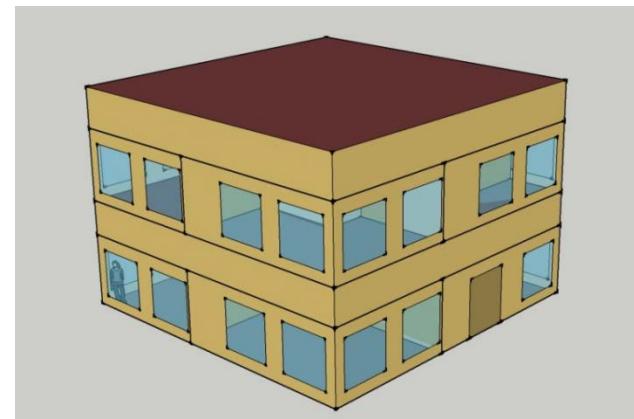
## 1. EPlus v.8.1

1. Building Envelope Model w/ Ideal System
2. w/ Packaged rooftop unit (Existing)
  - 12.5 ton VAV w/ Gas heating (Elec. reheat)
3. w/ VRF with DOAS system (Future)
  - 1 outdoor/10 indoor VRF units with 5 ton DOAS RTU
  - 1 outdoor/10 indoor VRF units without DOAS
  - 4 external and 1 internal thermal zone per floor

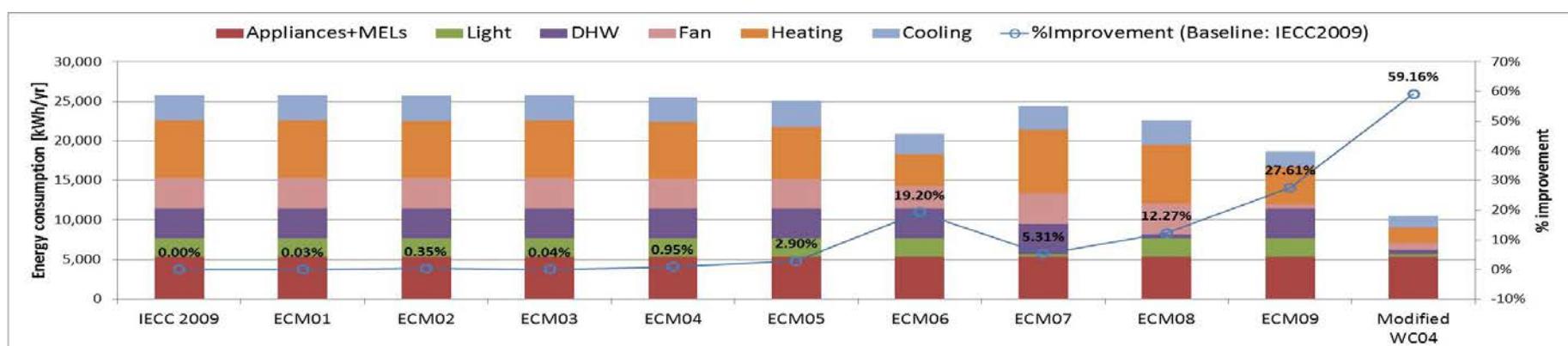
## 2. OpenStudio Model

- Weather files

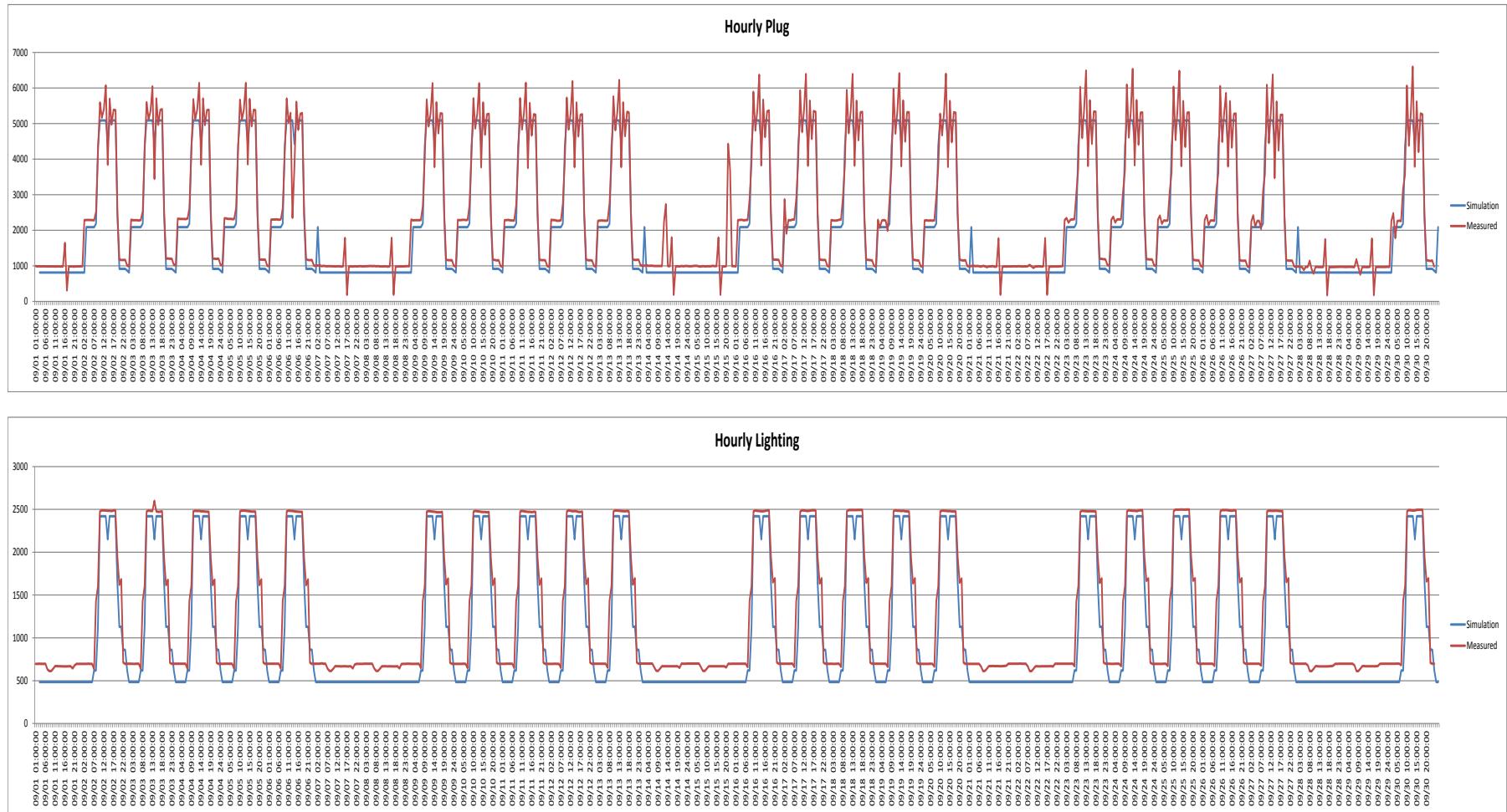
Actual weather files: 2011, 2012, & 2013



# Retrofit Pre-assessment



# Preliminary comparison: Measured vs. Simulated (September 2013)



# FRP Visual Analytics

Visual Analytics

Project Investigators:

Joshua New

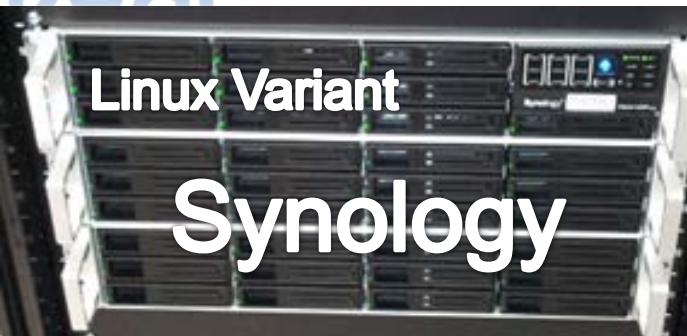
Jibo Sanyal

et al.



# Final Architecture STORAGE

ORNL WORLD



Research  
(Linux)  
Hadoop  
Stack



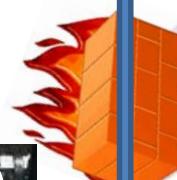
Maxlab-Linux  
Research/Development/Testing



## COMPUTE



RSC  
roofcalc.com (Win)



Same as Maxlab

Public/Deployment  
Server (Win)

Same as Maxlab-Linux

Public/Deployment  
Server (Linux)

# FRP Data Collection

Tony Gehl

Jibo Sanyal



# Data Path (MAXLAB Server):

CR3000 Dataloggers store data internally with battery backup.



LNDB software

LoggerNET software  
(Scheduled data collection)



ASCII file storage



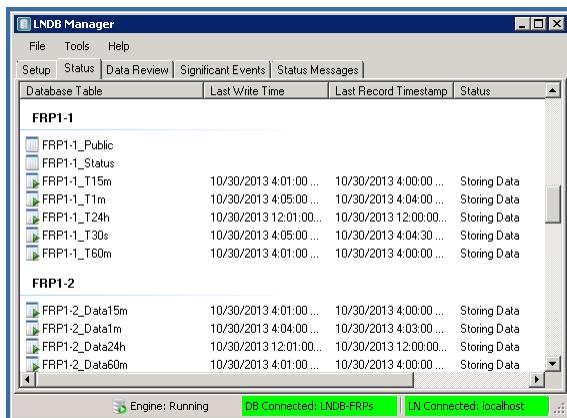
A	B	C	D	E	F	G	H	I	J	K	L	M
1	TOAS	FRP12	CR3000	2566 CR3000.55 CPU:FRP_	25506 FRP_1_HVAC							
2	TIMESTAMP	RECORD	Alt. Volt	Panel	Ter.T. Air(1)	T_Air(2)	T_Air(3)	T_Air(4)	T_Air(5)	T_Air(6)	T_Air(7)	T_Air(8)
3	TS	RN										
4												
5	10/2/2013 00:00:00	09471	13.01128	76.66607	72.30518	69.85013	69.81442	61.20003	64.8646	72.45664	72.42004	68.74824
6	10/2/2013 00:10:00	09472	13.01129	76.65947	72.30445	69.86203	69.83228	61.21047	64.8868	72.45659	72.37223	68.74343
7	10/1/2013 00:10:00	09473	13.00972	76.55277	72.25977	69.80235	69.83733	61.17610	65.01799	72.41471	72.32543	68.63007
8	10/1/2013 00:20:00	09474	13.00526	76.46413	71.07752	72.28974	69.81425	69.784	61.11665	64.94063	72.34975	72.33794
9	10/1/2013 00:20:30	09475	13.00526	76.43599	71.06362	72.17973	69.81425	69.76643	61.33315	64.95848	72.40875	72.36115
10	10/1/2013 00:30:00	09476	13.00526	76.43599	71.06362	72.17973	69.81425	69.76745	61.33315	64.95848	72.40875	68.70518
11	10/1/2013 00:30:30	09477	13.01025	76.43599	71.06362	72.17973	69.81425	69.76847	61.33465	64.95848	72.36115	68.70518
12	10/1/2013 00:40:00	09478	13.01025	76.43599	71.06362	72.17973	69.81425	69.76949	61.33569	64.95848	72.36115	68.70518
13	10/1/2013 00:40:30	09479	13.01025	76.43599	71.06362	72.17973	69.81425	69.77051	61.33575	64.95848	72.36115	68.70518
14	10/1/2013 00:50:00	09480	13.00958	76.40952	71.01742	69.77993	69.77397	61.14533	64.84673	72.35464	72.26734	68.72929
15	10/1/2013 00:50:30	09481	13.00982	76.19297	71.02338	72.19955	69.76208	69.76802	61.1612	64.81102	72.3209	72.26734
16	10/1/2013 00:56:00	09482	13.01183	76.92191	71.99427	72.22665	69.77491	69.75726	61.0067	64.84167	72.2504	68.77518
17	10/1/2013 00:56:30	09483	13.00987	76.38329	71.00947	71.1985	69.71241	69.7273	61.09081	64.88333	72.33757	72.26238



Database



Tape Backup



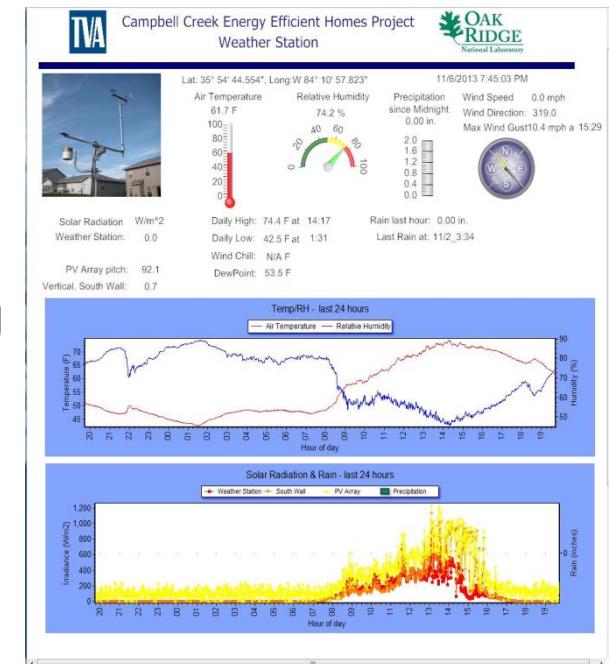
4020, Rm A103

# Real-Time Monitoring & Control (RTMC) Software, Professional

RTMC Pro is used to create and run graphical screens that provide real-time monitor and control capabilities. It can be used to design displays with graphical components including alarms, switches, status bars, charts, and gauges.

## Benefits and Features

- Large library of components: alarms, switches, charts, gauges, etc.
- Interactive components allows user to set datalogger values.
- Securely monitor and control your data from virtually anywhere by publishing your RTMC projects to your intranet or the Internet using the included Web Publisher and CSI Web Server
- View data from multiple LoggerNet servers, data files, LNDB databases, HTTP dataloggers, and virtual data sources.
- Send emails or execute code when alarms are triggered.
- Create reports.
- Use the extensive math and logic expression library to convert and/or combine your data for display.



# FRP Sensor Data Validation and Correction (SensorDVC)

Data Quality Assurance

Project Investigator: Charles Castello

HERE Intern: Jeffrey Rossiter

Project Manager: Joshua New



# What is our motivation?

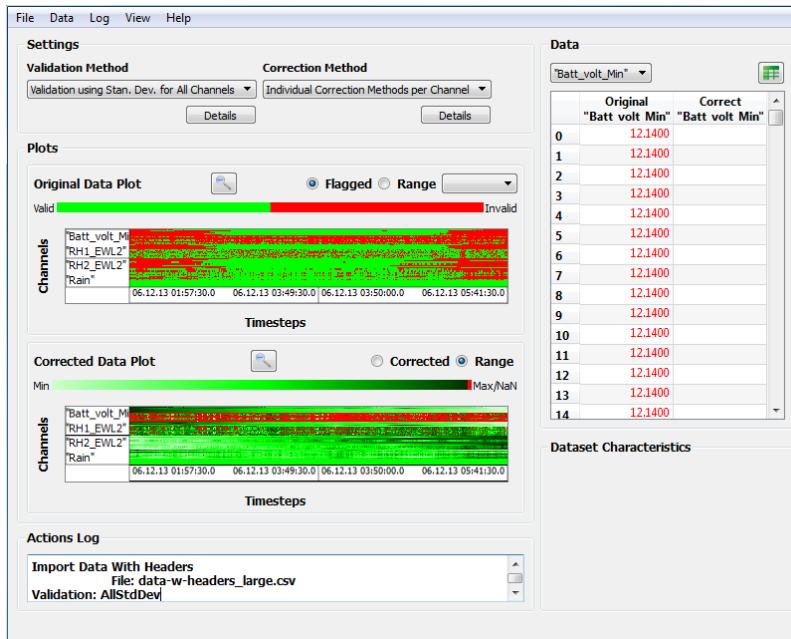
- A wide range of sensors are being used in our research to develop and characterize performance of buildings on a component, system, and whole-building level.
- Missing and corrupt sensor data can be an issue due to:
  - Sensor failure
  - Sensor fouling
  - Calibration error
  - Data logger failure

	A	B	C	D	E	F	G
1	TIMESTAMP	RECORD	Bat_Volt	Panel_Temp	T_Air(1)	T_Air(2)	T_Air(3)
19318	7/8/13 16:19:12	15052	12.97223	79.85068	57.62332	58.21236	66.72047
19319	7/8/13 16:19:42	15053	12.97289	79.85155	57.39069	57.94401	66.65437
19320	7/8/13 16:20:12	15054	12.96894	79.85155	57.21815	57.70008	66.62462
19321	7/8/13 16:20:42	15055	12.97158	79.85155	57.05751	57.51563	66.54727
19322	7/8/13 16:21:12	15056	12.97092	79.85233	56.94398	57.39021	66.48131
19323	7/8/13 16:32:00	15078	12.97217	79.80981	61.66223	61.97161	65.92816
19324	7/8/13 16:32:30	15079	12.97151	79.80981	61.75147	62.00731	65.98765
19325	7/8/13 16:33:00	15080	12.97152	79.80371	61.77525	62.03705	66.04713
19326	7/8/13 16:33:30	15081	12.97086	79.79678	61.79906	62.08464	65.95194
19327	7/8/13 16:34:00	15082	nan	79.79678	61.87045	62.21553	66.02928
19328	7/8/13 16:34:30	15083	12.97032	79.79619	61.90062	62.19215	66.08327
19329	7/8/13 16:35:00	15084	12.97164	79.78926	61.98987	62.30519	66.08922
19330	7/8/13 16:35:30	15085	12.96966	79.78926	62.05531	62.3528	7999
19331	7/8/13 16:36:00	15086	12.97362	79.78926	62.06126	62.37659	7999
19332	7/8/13 16:36:30	15087	12.97097	79.78311	62.13852	62.4836	7999
19333	7/8/13 16:37:00	15088	12.97097	79.78311	62.21586	62.5074	66.24381

# Typical Flow of SensorDVC

Import data (.csv file)

Validate data



Correct data

Output corrected data  
(.csv file)

Visualize data  
(spectrograms)

# Mockup of Senor Health Monitoring System (SensorHMS)

Oak Ridge National Laboratory's Sensor Health Monitoring System (SensorHMS)

**Import Data**    **Data Pull Rate**    **Alerts**    **Log**

**Sensors**

**Graph**

**Detail**

Min: 0  
Max: 275.1  
Avg: 91.2  
Std: 21.5  
Missing: 0  
Cal. Health: 71%  
Drift Health: 85%  
Comb. Health: 78%

**Data**

TIMESTAMP	A01_WH_bath
1/1/2011 0:15	0.75
1/1/2011 0:30	65.5
1/1/2011 0:45	142
1/1/2011 1:00	30.63
1/1/2011 1:15	74.88
1/1/2011 1:30	141.9
1/1/2011 1:45	2.375
1/1/2011 2:00	0.75
1/1/2011 2:15	0.625
1/1/2011 2:30	0.75
1/1/2011 2:45	141.4
1/1/2011 3:00	77.75
1/1/2011 3:15	0.75
1/1/2011 3:30	0.625
1/1/2011 3:45	132.3
1/1/2011 4:00	87.4
1/1/2011 4:15	18.25
1/1/2011 4:30	142.5
1/1/2011 4:45	59
1/1/2011 5:00	0.75
1/1/2011 5:15	27.75
1/1/2011 5:30	142.5
1/1/2011 5:45	49.75
1/1/2011 6:00	0.625
1/1/2011 6:15	0.75

# Prov DMS

Provenance Data  
Management System

Jibo Sanyal



# Provenance Data Management

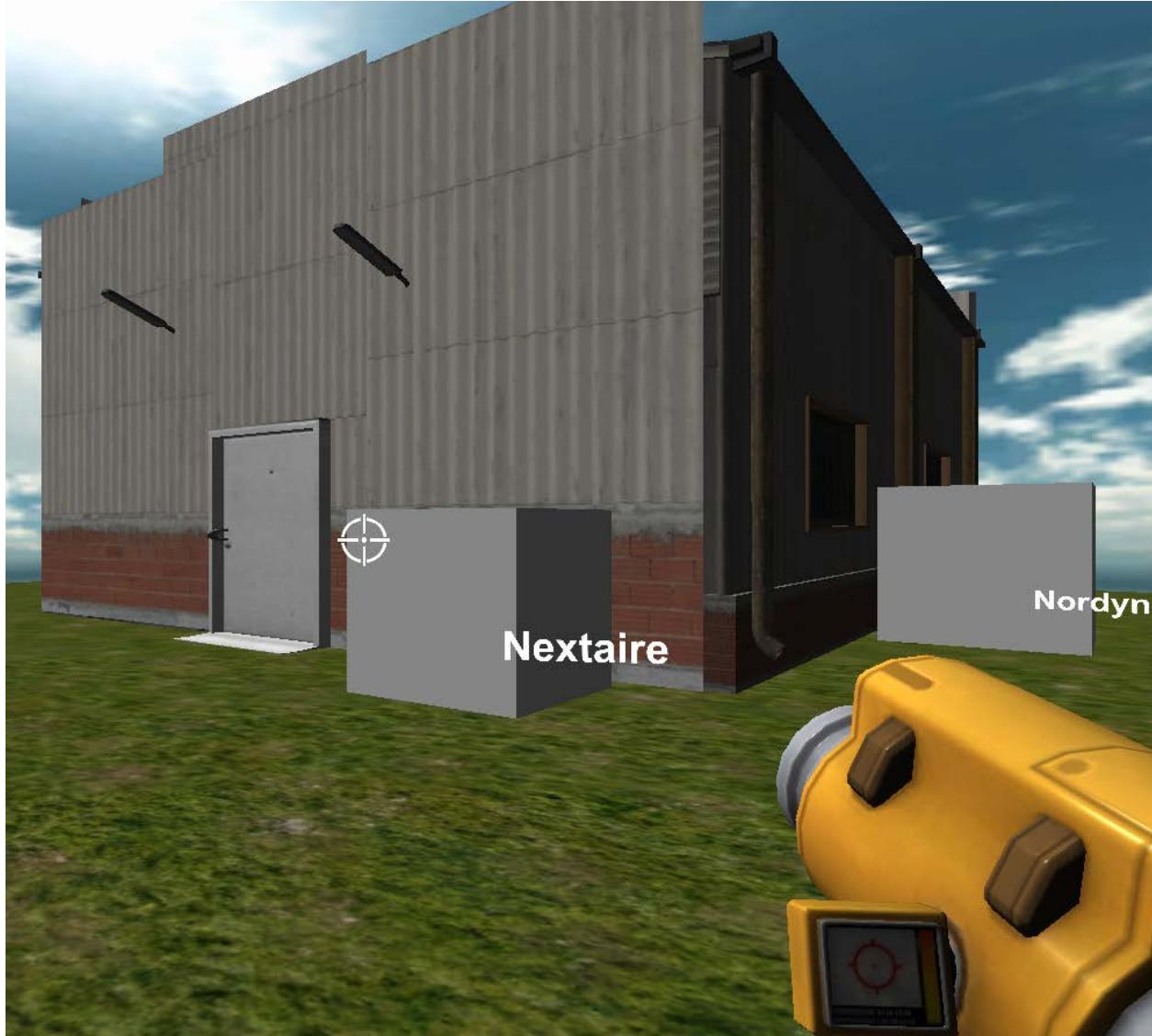
- Files are shared by email, network drives, USB sticks
- No history or lineage is maintained
- Derivative works often lose their ancestry
- Impediment to productivity



Provenance Data Management  
System for FRPs

# Provenance – sensor lineage

# Gamification of Building Data



## (DRAFT – Illustrative only)

Buildings  
Materials &  
Components

Systems, Controls, Tools & Energy Information for  
Buildings

Grid & EV  
Interactions  
with  
Buildings

BTRIC

Designated User Facility

Envelope  
Component  
Development &  
Testing

HVAC Sensors and  
Sequences, FDD

Whole Building  
Multi-zone HVAC  
Systems and  
Controls

Whole Building  
Mock Ups,  
Performance  
Testing

Whole Bldg Studies

Building Simulation

Envelope/  
Multi-zone HVAC

TBD

Comparative Studies

Tool Validation

Facades, Lighting,  
Zonal Systems/Perf

Operations to  
Grid Integration

TBD

Accelerated  
Emerging  
Technology Testing  
and Impacts  
Analysis

Zone Level Design &  
Performance of  
Integrated Systems

Integrated System  
and Component  
Controls  
Development &  
Testing

Linking Building  
Simulation &  
Energy Information  
to Operations &  
Performance

Grid & Distribution  
Equipment Testing

Renewables &  
Generation  
Integration

Energy Storage

FLEXLAB

ESIF



OAK RIDGE NATIONAL LABORATORY

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