TO MEASURE NOT MODEL:

Case Study – Purdue University Center for High Performance Design at the Ray W. Herrick Labs

Presented by: Kevin Krause, PE, LEED AP
Learning Objectives

1. Understand error margins in Energy Modeling and CFDs (Computational Fluid Dynamics)—and how they relate to both sustainable design and lab safety.

2. Understand Data Acquisition System Architectures—and the importance of ‘right tool for the job’ options/choices to be made early in a project.

3. Understand the keys to measurement, metering and baseline when predicting building systems performance.
Presenter

Kevin Krause, PE, LEED AP

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Purdue University
Center for High Performance Design at the Ray W. Herrick Labs
Living Laboratories
Psychrometric Chambers Laboratory
Power Laboratory
Air Quality Chamber
Thermal Systems Laboratory
High Bay Flex Laboratory
Perception Based Engineering Laboratory
An in situ HVAC research factory.

**Thermal Systems Laboratory**
- Raw idea
- Bench top
- Still very much “what if” stage

**Psychrometric Chambers Laboratory**
- Commercially viable
- Test in 7,000 ft³ chambers
- Precision energy balance is end goal

**Living Laboratories**
- Four 20-person office suites
- Highly reconfigurable
- Dedicated empirical baseline
- Quantifiable—primarily; qualitative—secondarily
Site: GeoExchange
Not Your Basic Bore Field

Informing geothermal model through measurement:

- Analysis of the numerical models
- Test Ground Coupled Heat Pump Experimentally
- Validate numerical models based on the test results
- Develop a robust validated model
Suite of Delta T’s & The Carnot Efficiency

$$\eta_{TH, \text{CARNOT}} = 1 - \frac{T_L}{T_H}$$

The Thermodynamicist’s Playground

- Variable Refrigerant systems
- GeoExchange systems
- Energy recovery chillers
- Absorption chillers
- Stirling engines
- Chilled beams, chilled sails
- Radiant heating and cooling panels
- Compressor test stands
- Gas fired boilers
- Heat pumps
Purdue Herrick: BTU/Delta T
Navigated Highway

GEO Exchange System (100% Water)

16 Bores @ 300' Depth

Thermal Systems Research

Heat Exchanger

Thermal Systems Process Cooling (100% Water)

Campus Chilled Water

CHS

CHR

Powertrain Process Cooling (30% Glycol)

Roof Top Dry Coolers

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Living Laboratories

Modular, flexible and reconfigurable – comparison and evaluation of design and control options

Concept:
Four open-plan, occupied, side-by-side office spaces with reconfigurable envelope, lighting, and HVAC/comfort delivery systems and controls. The facilities allow independent monitoring and environmental control with occupant-environment interaction.

Features:
• Two baseline labs. Two experimental labs: hydronic and air.
• Highly reconfigurable, modular construction
• Rigorously instrumented
• Dedicated baseline (aka “placebo” spaces)
• Ease of device and instrumentation accessibility and changeover.
Living Laboratories

Hydronic Lab

Measurement and Verification

<table>
<thead>
<tr>
<th>Envelope/Load</th>
<th>Experimental Data Collection</th>
<th>Baseline/Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall, roof and floor values</td>
<td>Uniform</td>
<td>Uniform</td>
</tr>
<tr>
<td>Solar load exposure</td>
<td>Uniform</td>
<td>Uniform</td>
</tr>
<tr>
<td>Plug loads</td>
<td>Uniform</td>
<td>Uniform</td>
</tr>
<tr>
<td>Occupant load</td>
<td>Uniform</td>
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</tbody>
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<table>
<thead>
<tr>
<th>System Under Test</th>
<th>Experimental</th>
<th>Experimental</th>
<th>Baseline</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double skin façade</td>
<td>Experimental</td>
<td>Experimental</td>
<td>Baseline</td>
<td>Baseline</td>
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<tr>
<td>HVAC—Thermal</td>
<td>Experimental</td>
<td>Experimental</td>
<td>Baseline</td>
<td>Baseline</td>
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<tr>
<td>HVAC—Humidity</td>
<td>Experimental</td>
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<td>Baseline</td>
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<tr>
<td>HVAC—Air Velocity</td>
<td>Experimental</td>
<td>Experimental</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>Lighting load/fixture type</td>
<td>Experimental</td>
<td>Experimental</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>Lighting controls</td>
<td>Experimental</td>
<td>Experimental</td>
<td>Baseline</td>
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</table>

Test Systems
- Chilled Rooms
- Radiant Floor
- Displacement Ventilation
- Double Façade Ventilation
- Daylighting and Control

Baseline Configurations
- Overhead VAV
- Raised Floor Distribution
- Double Façade Ventilation
- Daylighting and Control
Living Laboratories

Air Lab

Measurement and Verification

<table>
<thead>
<tr>
<th>Envelope/Load</th>
<th>Living Laboratory (Hydronic)</th>
<th>Living Laboratory (Air)</th>
<th>Living Laboratory (Baseline)</th>
<th>Living Laboratory (Baseline)</th>
</tr>
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| Double skin façade     | Experimental                | Experimental           | Baseline                     | Baseline                     |
| HVAC—Thermal           | Experimental                | Experimental           | Baseline                     | Baseline                     |
| HVAC—Humidity          | Experimental                | Experimental           | Baseline                     | Baseline                     |
| HVAC—Air Velocity      | Experimental                | Experimental           | Baseline                     | Baseline                     |
| Lighting load/fixture type | Experimental           | Experimental           | Baseline                     | Baseline                     |
| Lighting controls      | Experimental                | Experimental           | Baseline                     | Baseline                     |
Displacement Ventilation

1. Fresher Air
2. Personalized Cooling
3. Quiet
4. Energy Savings
5. Interior Design
Reconfigurable Double Skin Façade
Living Laboratory, Airside

(4) AHUs; 1 per Living Laboratory

(4) Measurement and Verification alcoves; (1) per Living Laboratory
Viability
Sustainability

Submitted for LEED Silver; received LEED Gold

Energy Efficiency
Approaching 50% annual reduction over ASHRAE 90.1

Water Efficiency
Blue is the new green
Data Acquisition System Architecture

**CONTROL POINT VOLUME**

- Typical R&D Lab/Office Building
- Typical Physical Sciences R&D Lab

- **BMS***
- **50% BMS**
- **50% R&D**

*Proprietary: Fire Alarm, Lighting, Security*
Controls: Languages Spoken

Andover Controls
ControlNet
HORNER AUTOMATION GROUP
ASHRAE
BACnet
AB
HART COMMUNICATION PROTOCOL
LonWorks
DeltaV
GE
FANUC
Bailey
Canbus
Fieldbus Foundation
Johnson Controls
Koyo
National Instruments
PROFIBUS
DeviceNet
MOORE
PROFIBUS
DeviceNet
Modbus
Yokogawa
Invensys
Wonderware
OMRON
Siemens
Foxboro
Modicon
Square D
Issues that Drive the Architecture

- Enterprise Network
- Integration
- Integration ROBUST/BULLETPROOF
- Regulation
- Automation
- High Sampling Rates
- 10Hz; 10,000 Hz
- ENERGY
- COST
- Legal/IP
- FDA
- Dexterity Given to Change
- Historian
- Fault Detection
- Safety
- Trend Logging
- High Accuracy
- High Repeatability
- IP/Control/Data Security
- Display
- Synchronization vs. Time Stamping
- Business/Process Network
- Creativity
- Creature Comfort
- Preventive Maintenance
- Software Maintenance
- Predictive WET BULB
- Maintenance/Staff
### SCADA and/or Network Level

- Business/Process Network
- Display
- Enterprise Network
- Historian

### BMS
- Cost
- Creature Comfort
- Energy Management
- Fault Detection
- Maintenance Staff
- Predictive Wet Bulb
- Preventive Maintenance
- Robust/Bulletproof
- Trend Logging

### PLC
- Integration
- Safety

### U.U.T.
- Automation
- Creativity
- Dexterity given to Change
- FDA
- High Accuracy/High Repeatability
- High Sampling Rates 10 Hz, 10,000 Hz
- IP/Control/Data Security
- Legal/IP
- Regulation
- Software Maintenance
- Synchronization vs Time Stamping
Purdue Network

[Diagram of Purdue Network with various systems and labels such as HVAC, Building Automation, etc.]
Air Quality Via CFD Modeling
Optics Lab – Baseline

Baseline Layout
Laser Table Microenvironment Velocity Streamlines
Air Quality Via CFD Modeling
Optics Lab – Option 1

Velocity Section Streamlines

- Central Return
- Perimeter Supply
Air Quality Via CFD Modeling
Optics Lab – Option 1

Velocity Profile Section

Velocity (fpm)

-75
-56.3
-37.5
-18.8
-0
Baseline Layout – Velocity Profile 9 Inches above Table

- Overhead Ceiling Supply Diffuser (Typ-2)
- Table Perimeter
- HEPA System Wall Return
Particle Image Velocimetry Measurement

In PIV measurement, the air is seeded with tracer particles for flow visualization. The particles are sufficiently small to be assumed to completely follow the flow dynamics.
Air Quality Via Empirical Measurement
Current Subject Environment Examples

Infectious disease air side transmission:
e.g., Ebola, Measles

Clean Rooms: Biological, Semi-Conductor, Nanofabrication

Aerospace: Thermal comfort, humidification, cabin pressurization, air filtration
Clean, Bright, Lines of Sight
“Research in Herrick’s new facilities will attack some of the most daunting and complex problems confronting the world, such as rising energy consumption and environmental pollution, climate change, public health, comfort and security, and issues associated with an aging population.”

- **Leah Jamieson**, The John A Edwardson Dean of Engineering/Ransburg Distinguished Professor of Electrical & Computer Engineering
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QUESTIONS