Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Energy Savings for Occupancy-Based Control of VAV Systems

Jian Zhang Ph.D. and Guopeng Liu Ph.D, PE, LEED AP

Pacific Northwest National Laboratory

Presented at Building Energy Simulation Forum
Energy Trust of Oregon
Portland OR
Oct 21, 2015

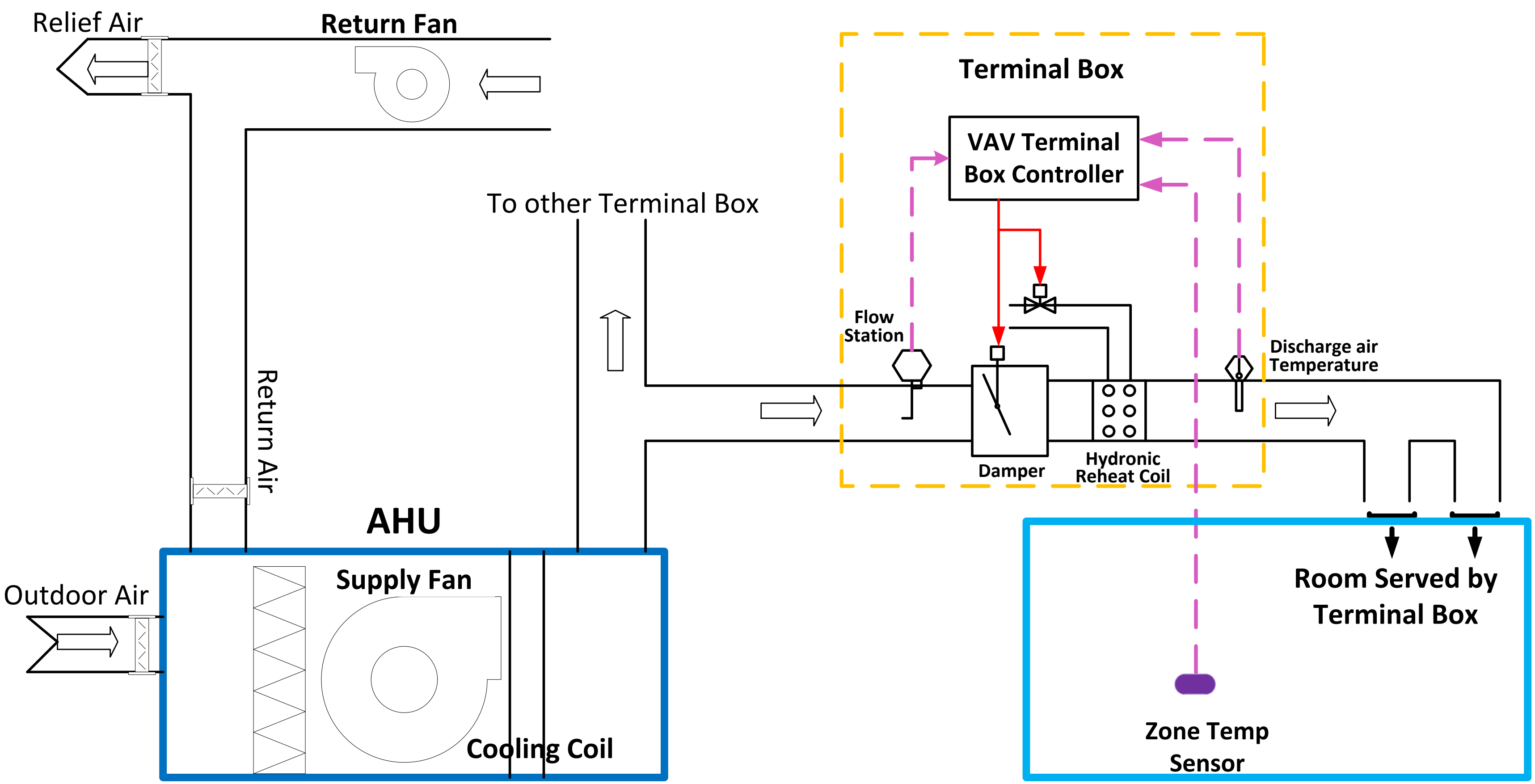
U.S. DEPARTMENT OF ENERGY

PNNL-SA-113934

Content

- Problem Statement
- Proposed Occupancy-Based Control
- Energy Saving Analysis
- Summary

VAV Systems


Relief Air
Return Fan
Terminal Box
VAV Terminal Box Controller
To other Terminal Box
Flow Station
Discharge air Temperature
Return Air
Damper
Hydronic Reheat Coil
AHU
Supply Fan
Outdoor Air
Cooling Coil
Room Served by Terminal Box
Zone Temp Sensor

VAV Systems – Typical Control

- Flow station controls the terminal box damper to maintain flow rate between minimum airflow set point (V_{min}) and maximum airflow set point (V_{max})

- Code requirements for V_{min}
  - 30% of V_{max}
  - 0.4 cfm/ft^2 of conditioned floor area, or
  - 300 cfm

- Common practice

Problem Statement – Same Ventilation?

- The minimum air flow setting for conference room normally is larger than the design maximum room occupancy ventilation requirement.
- **Are those rooms FULLY occupied ALL the time?**

Problem Statement – Same Ventilation?

- an

Problem Statement – Same Ventilation?

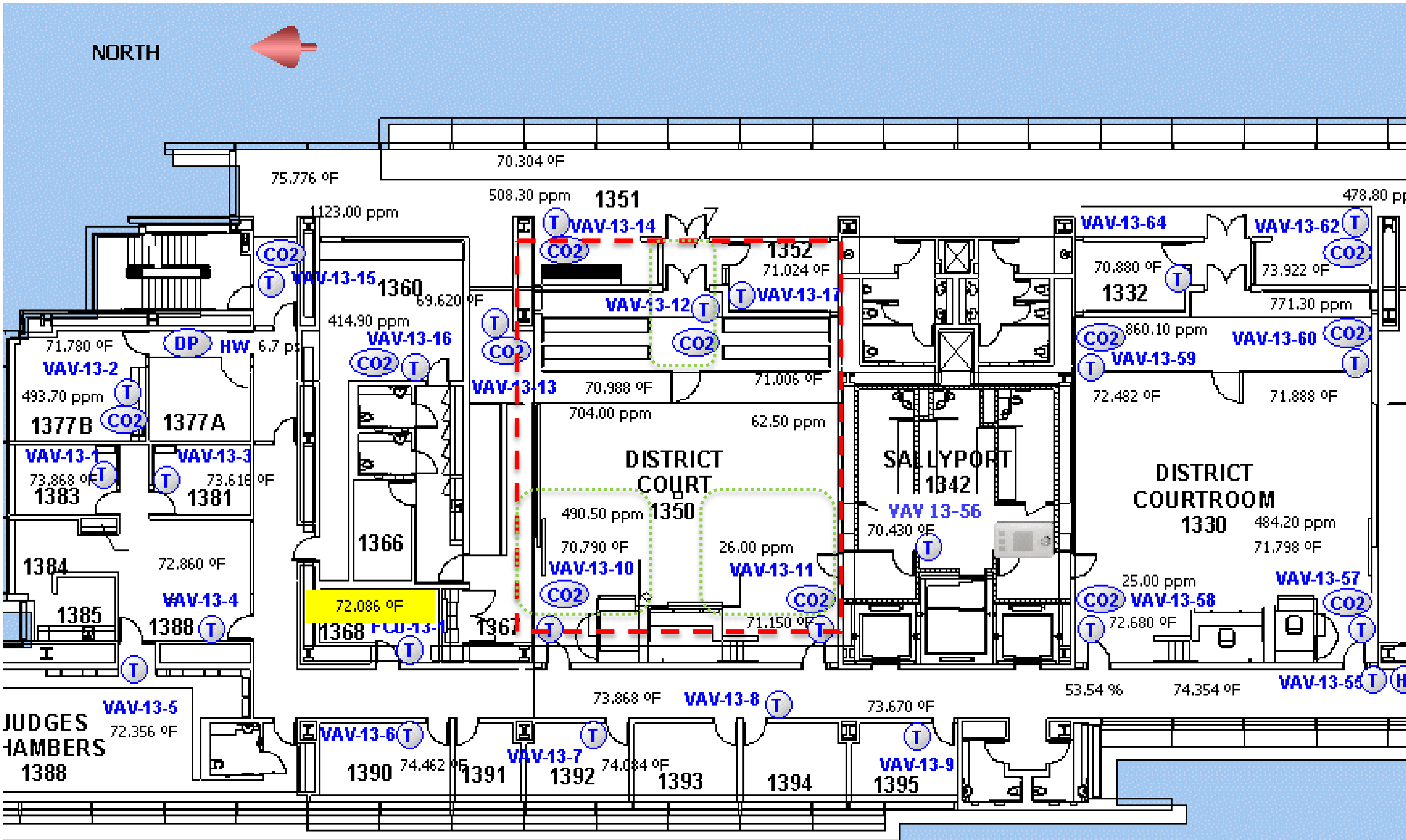
Problem Statement – Same Ventilation?

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

Problem Statement – Common Issues

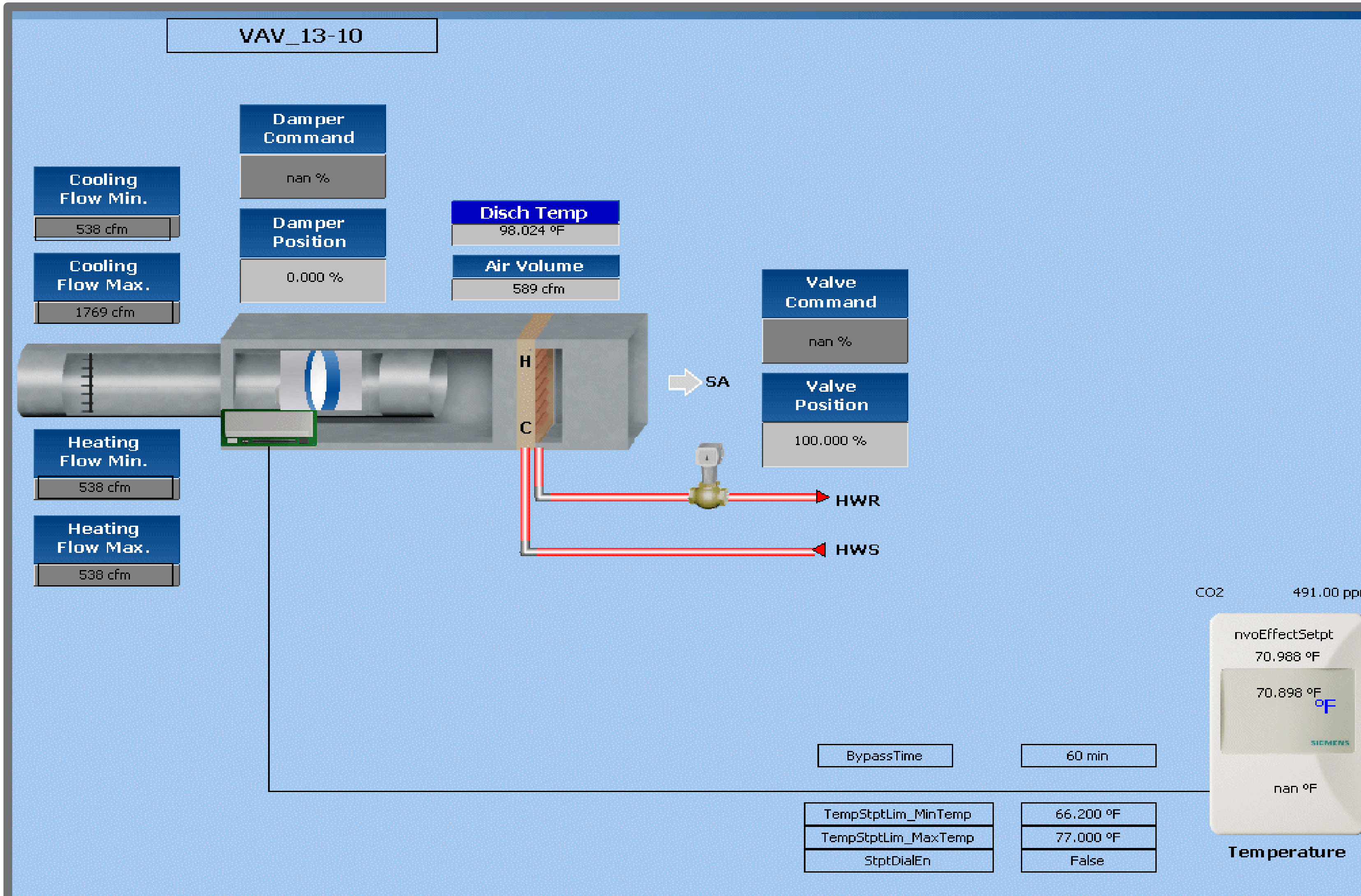
- Conference rooms designed for full occupancy
- Office space reconfiguration
- Overcooling and occupant discomfort
- Unnecessary reheat

Problem Statement – Challenges



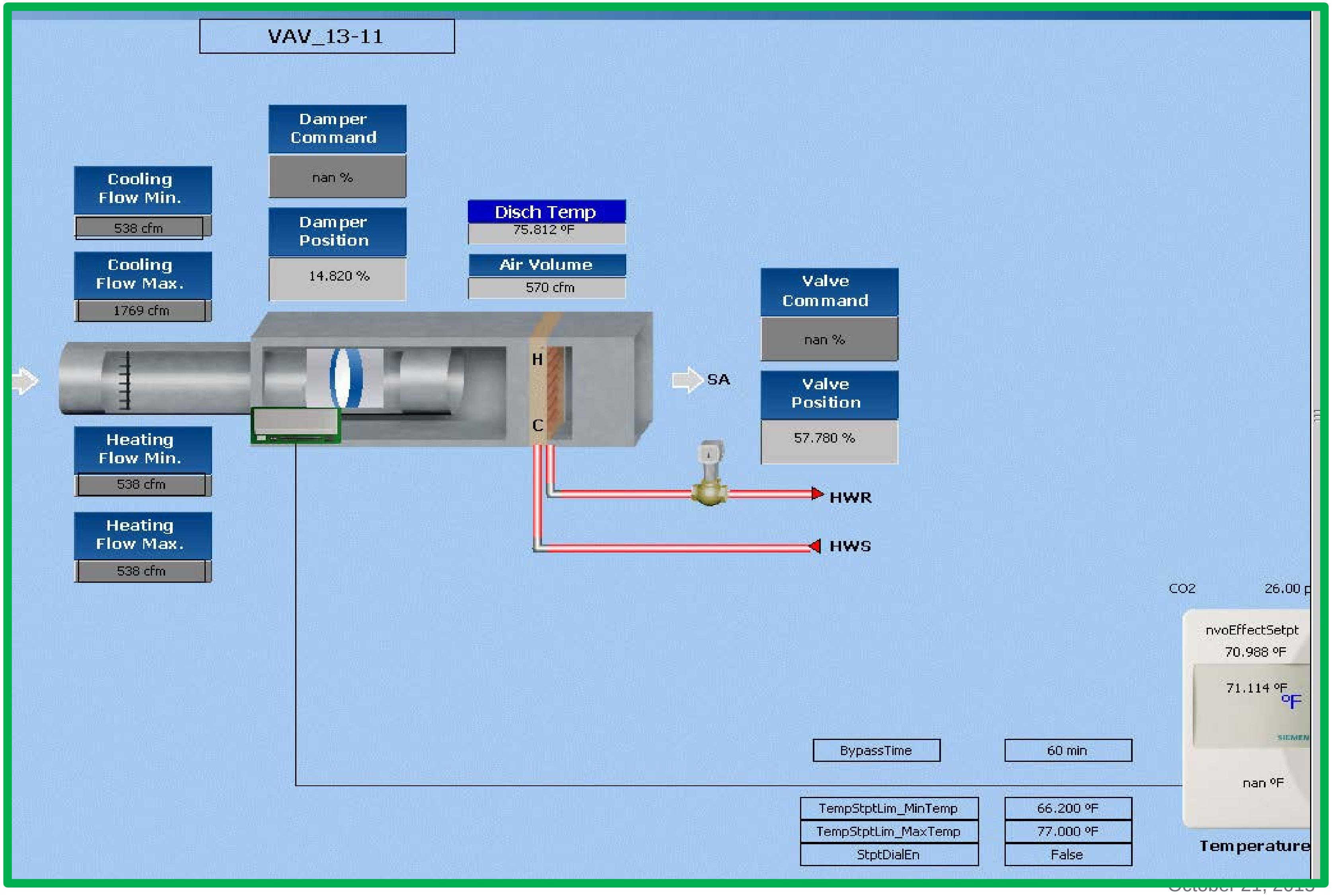
Problem Statement – Challenges

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



Problem Statement – Challenges

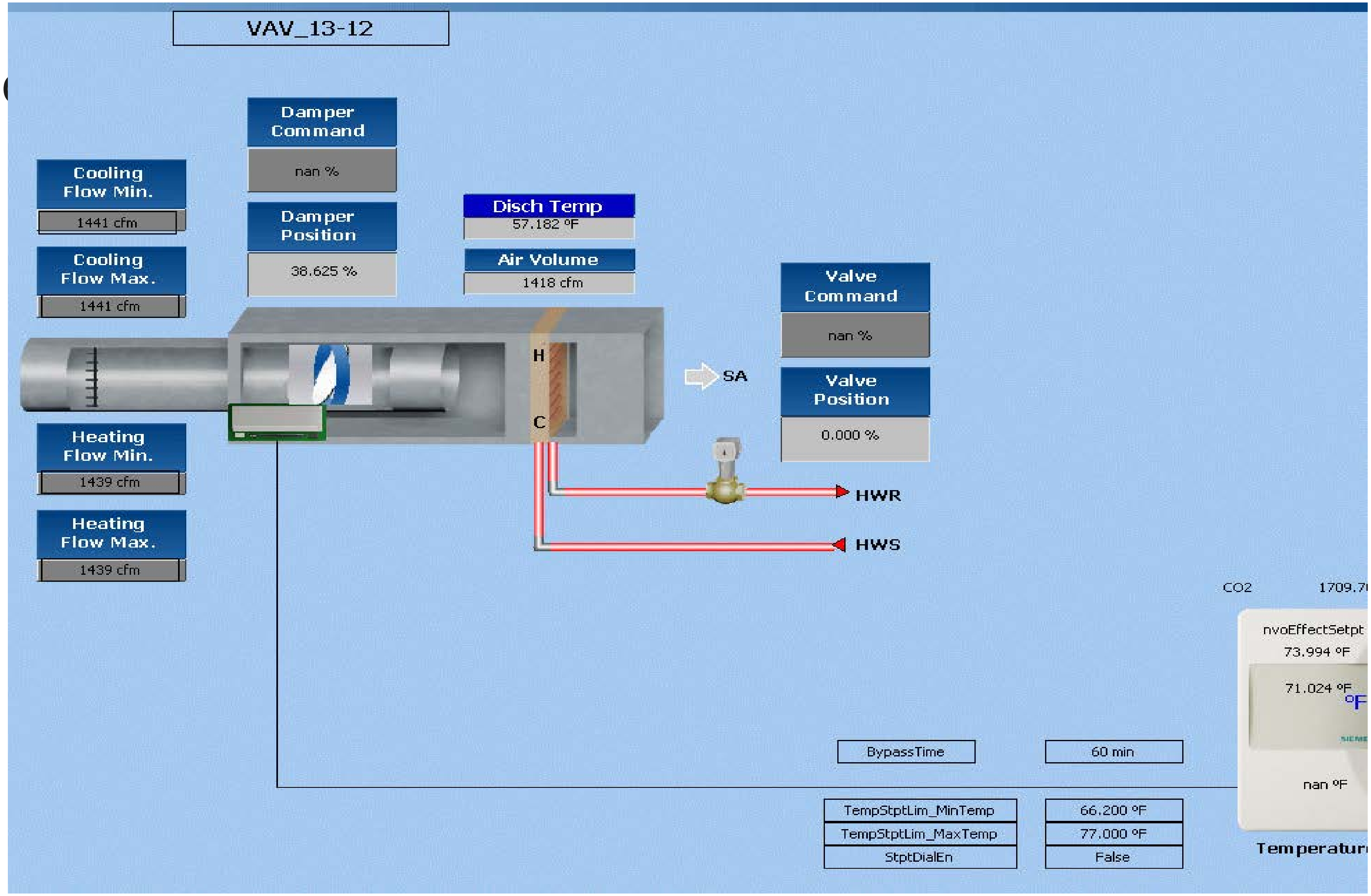
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



Problem Statement – Challenges

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

▶ (

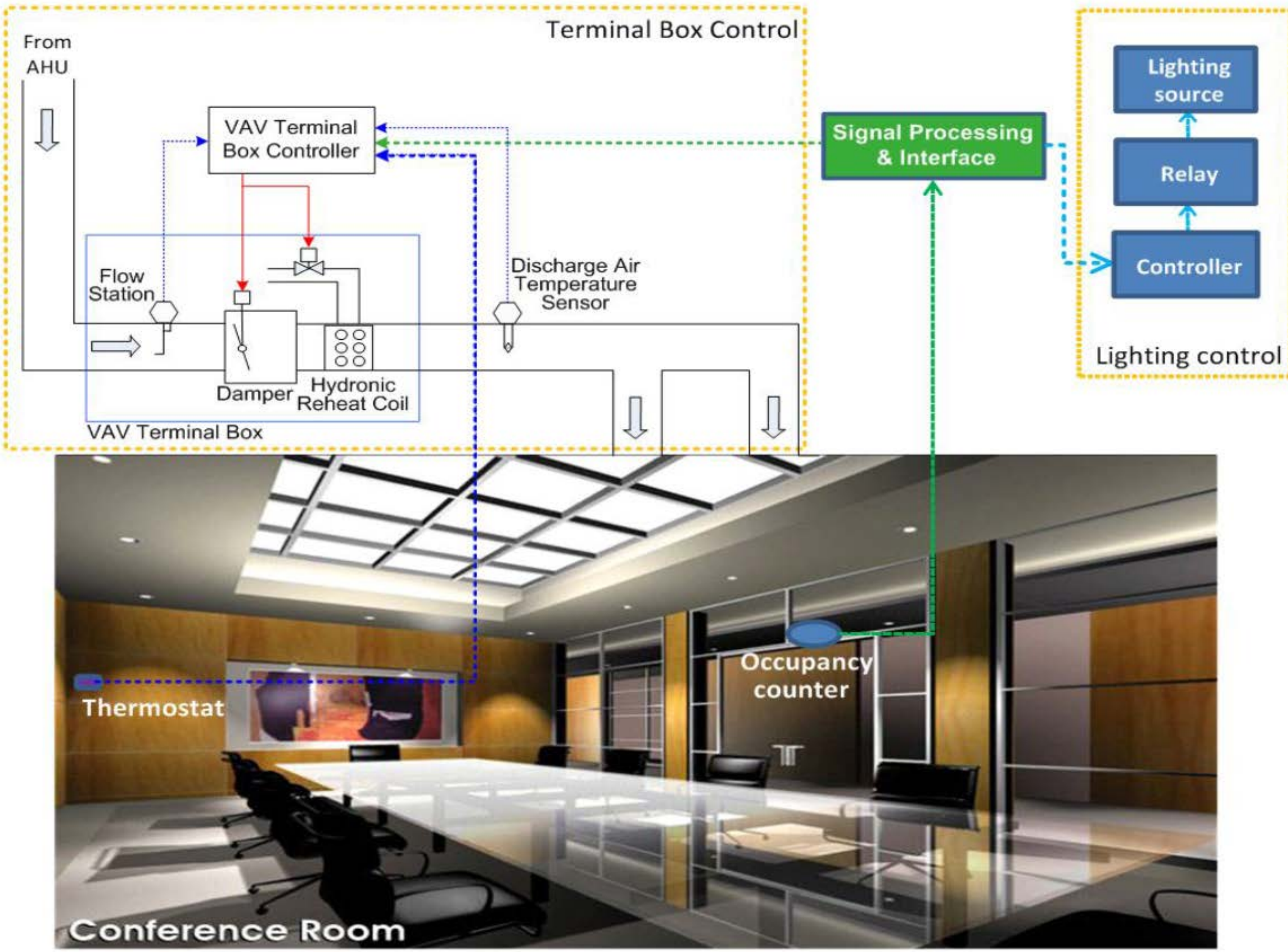


Problem Statement – Lighting

- Occupancy sensors commonly used today to control lighting in conference rooms, lunch rooms and other places of assembly have significant limitations:
  - Long delay times for turning lights off – generally 20 to 30 minutes
  - Lights turning off when occupants do not move frequently – delay times used to address this
  - Cannot identify locations of occupants in rooms
  - Are not suitable for other types of spaces, e.g., offices, rest rooms, and laboratories
- Enhanced occupancy sensors used to control HVAC terminal boxes could control the operation of lights also.

Proposed Occupancy-Based Control (OBC)

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



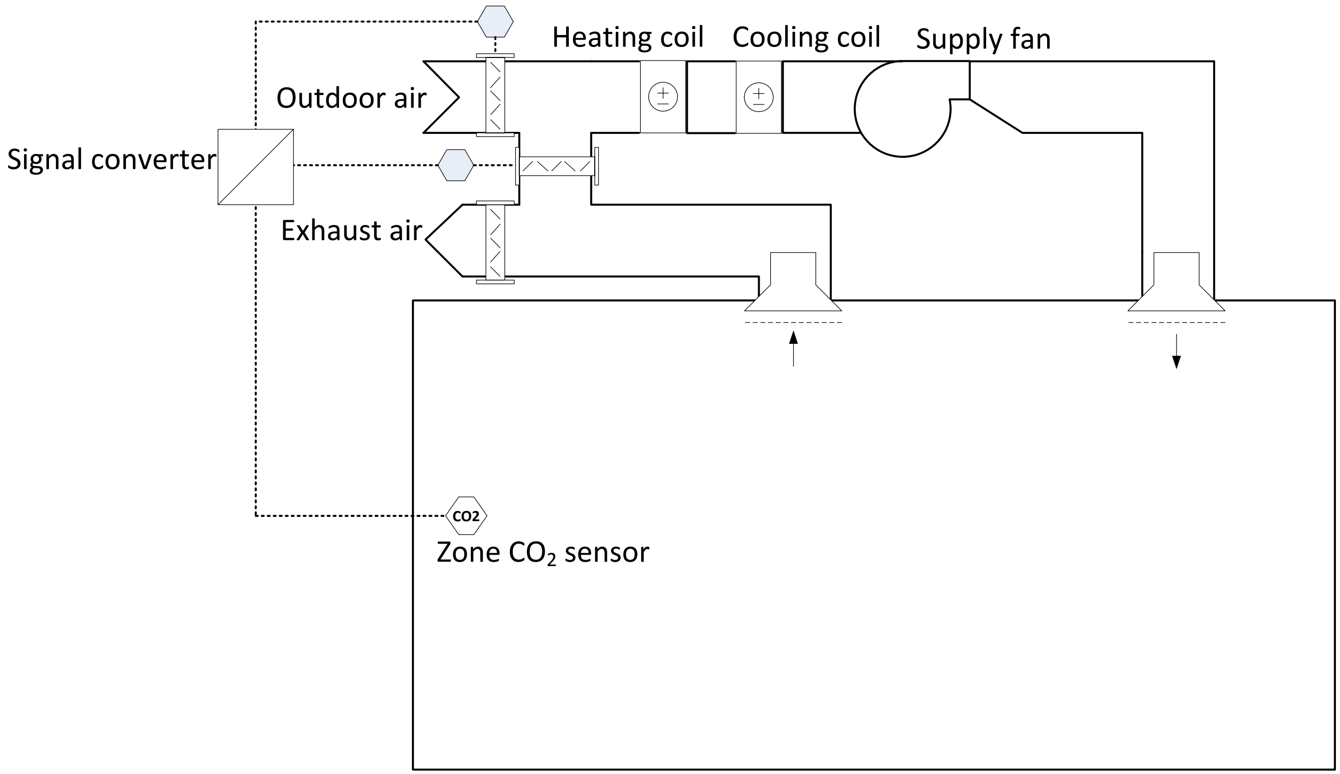
Proposed OBC

- Use monitored zone temperature and occupancy to determine terminal airflow rate
- Cooling mode: V_{min} is reset based on the actual occupancy and ventilation standard
- Heating mode: higher value of
  - V_{min} in cooling mode OR
  - airflow required to prevent air stratification and/or short-circuiting.
- No occupancy: V_{min} = *0 OR area component*

Proposed OBC

- Control actions when “unoccupied” status is detected - “Stand-by Mode”
  - Turn off lighting
  - Reduce minimum damper position
  - Setback thermostat setpoint
  - Reduce outdoor air intake (not included in this analysis)

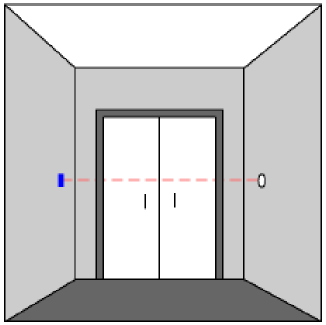
Proposed OBC – Different from DCV



Typical single zone CO2 based demand control ventilation (DCV)

Sensor Technology

- Common occupancy sensor (OS)
  - Occupancy presence
  - Motion sensing (infrared or ultrasonic)
  - Low cost
- Advanced occupancy sensor (OS)
  - Instantaneous head count
  - Commercially available but expensive ($1000~ per hardware unit)
  - Need further development for software



Project Status

Occupancy-Based Control

- Scoping Study
- OBC Control Strategies Development
- Development Plan Recommendations
- Impact Assessment (18% savings)
- Algorithm Development
- Occupancy Sensor Development
- Air Distribution Management Scoping Study

2010 2011 2012 2013 2014 2015

Fiscal Year

Objective of Energy Saving Analysis

Evaluate the savings from OBC of VAV and lighting using

Common occupancy sensors

Advanced occupancy sensors

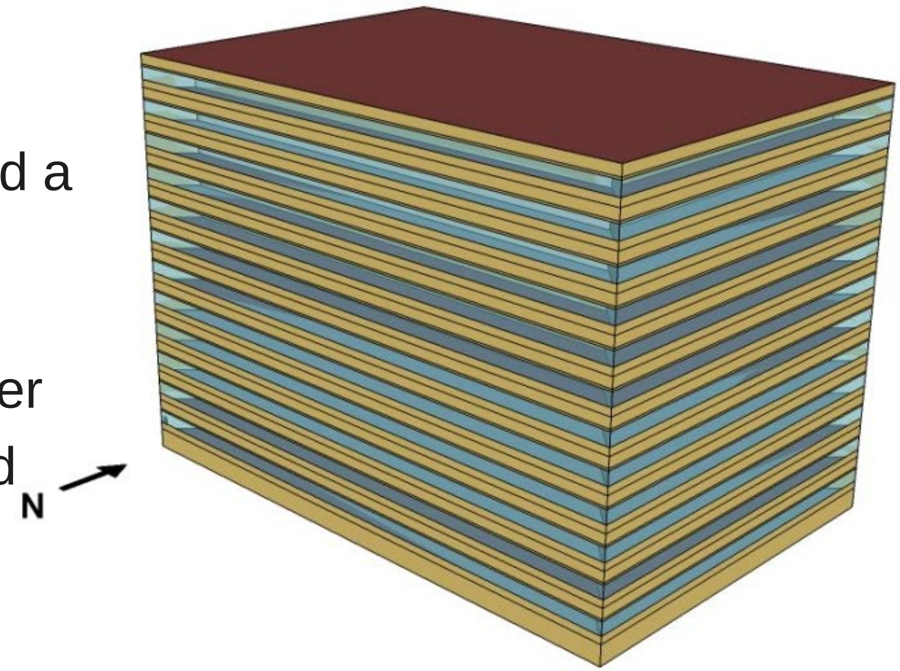
Baseline – Candidate Buildings

Building Type	Total Floor Space (Million Square Feet)	Fraction of Total Commercial Floor Space (%)	Total Annual Energy Consumption (Trillion Btu/y)	Post-1980 Buildings with VAV (% of Total Floor Space)	Pre-1980 Buildings with VAV (% of Total Floor Space)
Large Office	**4,354**	**6.1%**	**455**	**84**	**72**
Medium Office	3,647	5.1%	342	65	40
Small Office	4,207	5.9%	336	18	13
Warehouse	10,078	14.1%	456	22	12
Retail	4,317	6.0%	319	12	10
Schools (K-12)	7,265	10.1%	525	53	33
Colleges	1,421	2.0%	221	88	49
Hospitals/Impatient Health Care	1,905	2.7%	475	95	67
Food Sales	1,255	1.8%	251	17	10
Grocery Stores	715	1.0%	153	31	8
Restaurants/Cafeterias	1,062	1.5%	245	31	23
Fast Food	262	0.4%	118	12	40
Hotels and Motels	2,952	4.1%	288	42	23

Source: CBECS 2003

Baseline – Large Office

- 500,000 sf
- 12 floors (one VAV AHU per story) and a basement (CAV)
- 40% WWR
- Air-cooled chiller and natural gas boiler
- VAV terminal boxes with dampers and hot-water reheating coils
- Construction weighting factors for 15 climate zones

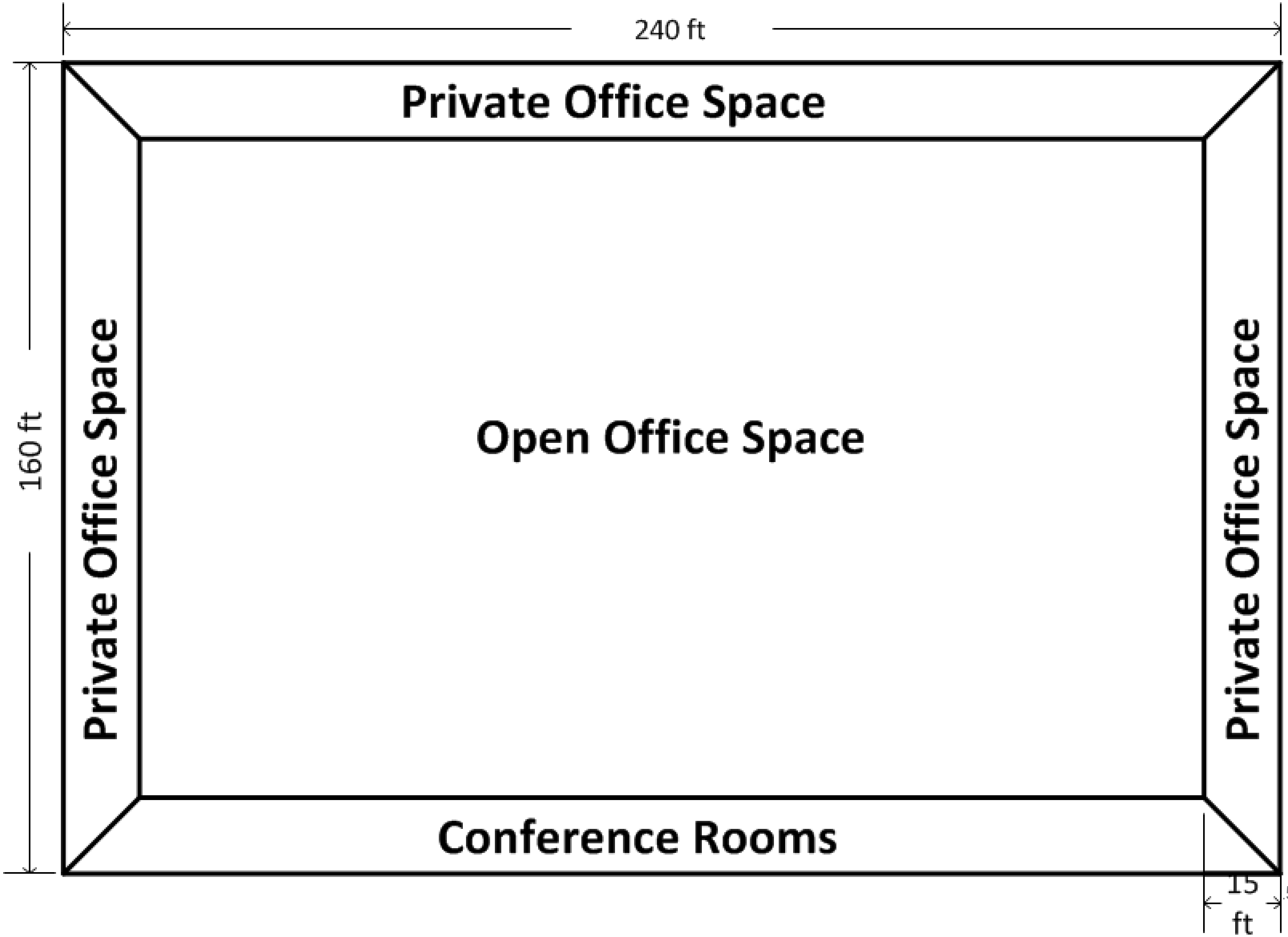


Source: DOE Commercial Prototype Building Models
https://www.energycodes.gov/commercial-prototype-building-models in EnergyPlus

Baseline - Changes to Large Office Prototype

- To capture OBC savings
  - Zone description
    - Specified space types (conference room, private office, and open office)
    - Occupancy density
    - Occupancy profile
    - Ventilation rate
- To represent 1980s construction
  - HVAC sizing
    - Increased sizing factors
    - Revised interior loads used for sizing
  - System OA calculation
    - Changed from 62.1’s multiple-zone calculation to sum of the zone ventilation

Baseline - Changes to Zone Description



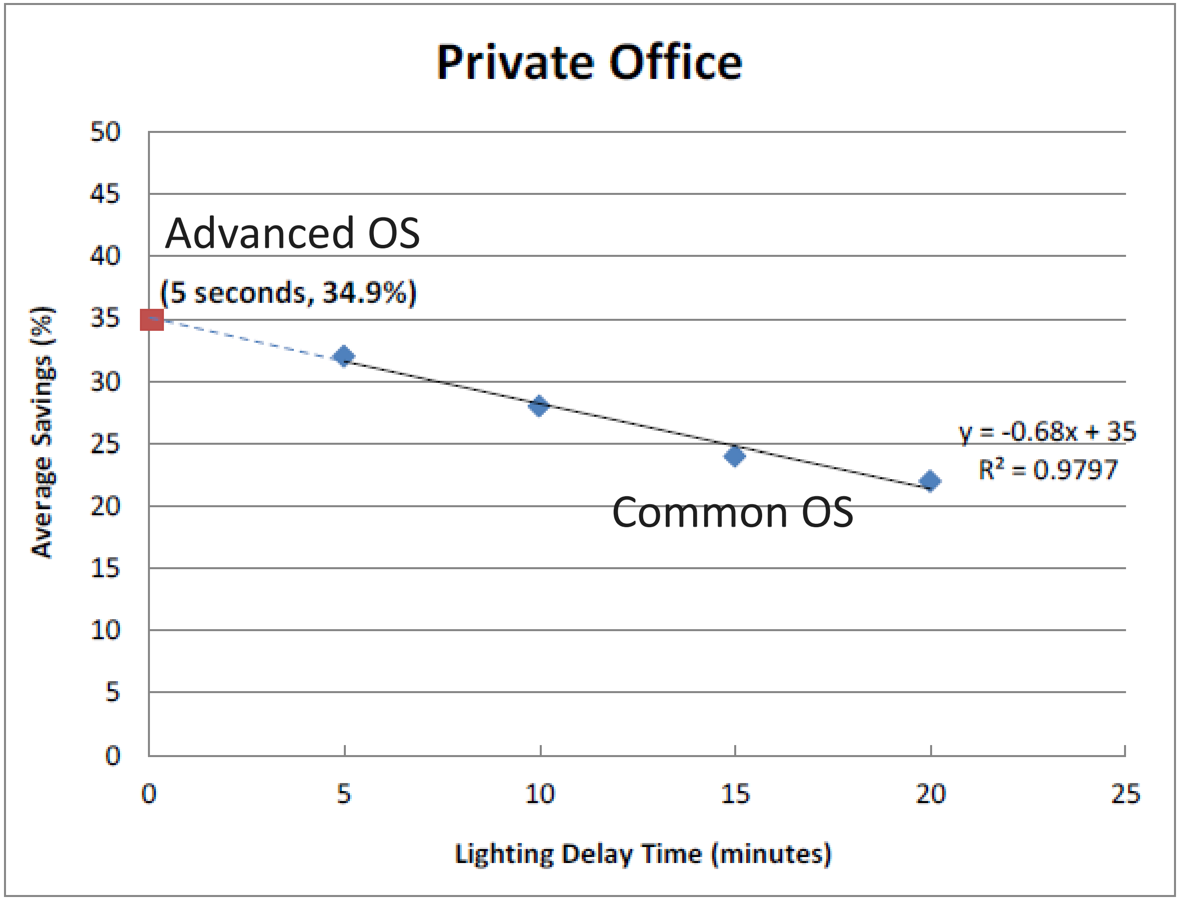
Modeled OBC for Lighting

Category	Controlled Zone	Baseline	Common OS	Advanced OS
Lighting	Private Office Conference Room	No OBC	Turn off after 15-minute	Turn off after 5-second
	Open Office	No OBC	No OBC	No OBC

$$LPD_{OBC} = LPD_{Baseline} \times (1 - \mathbf{\mathit{Fractional\ Savings}})$$

Modeled OBC for Lighting

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



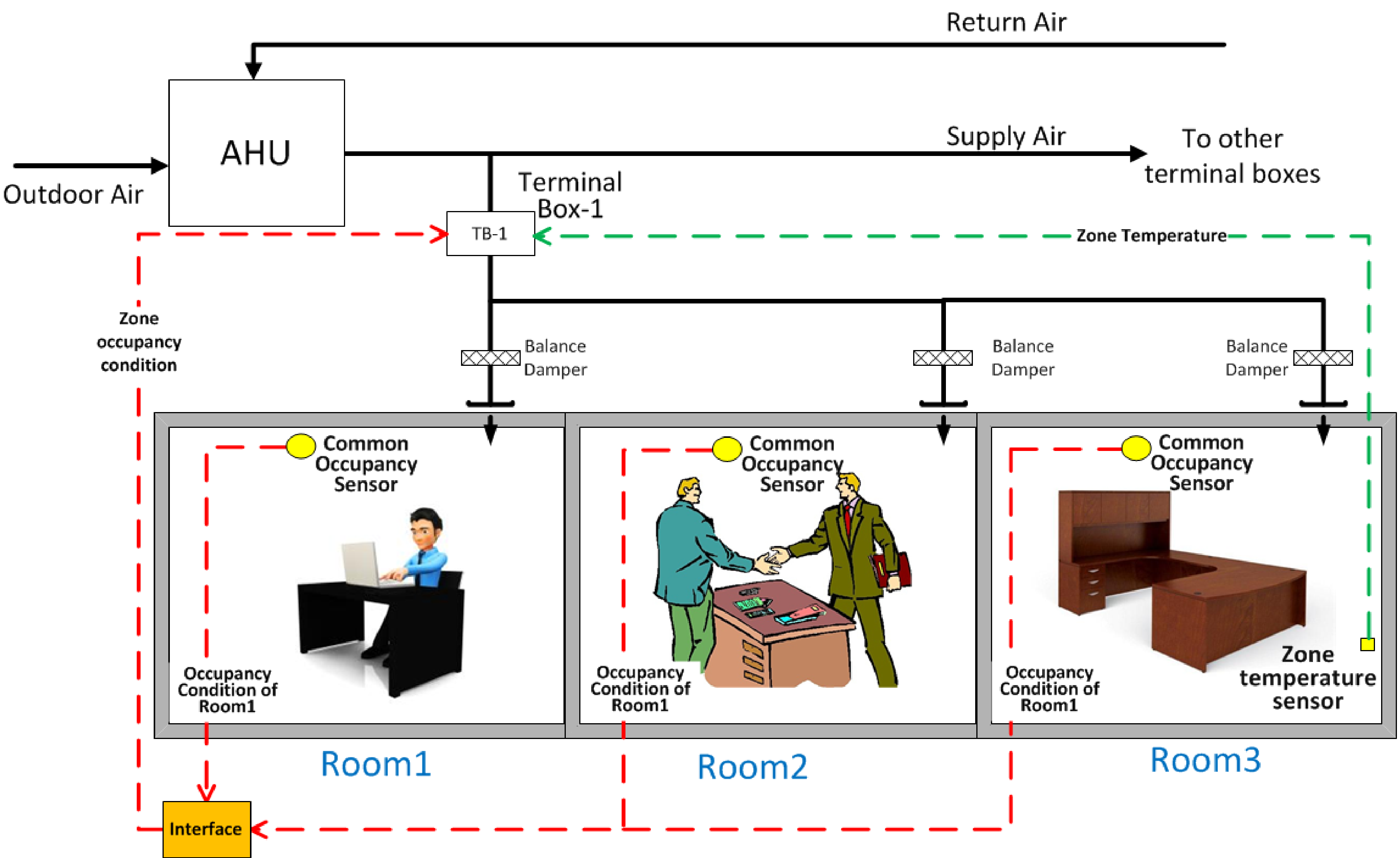
- Data in blue diamonds from Von Neida et al. (2000)
- Extrapolated to savings with delay time of 5 seconds

Modeled OBC for Minimum Air Flow

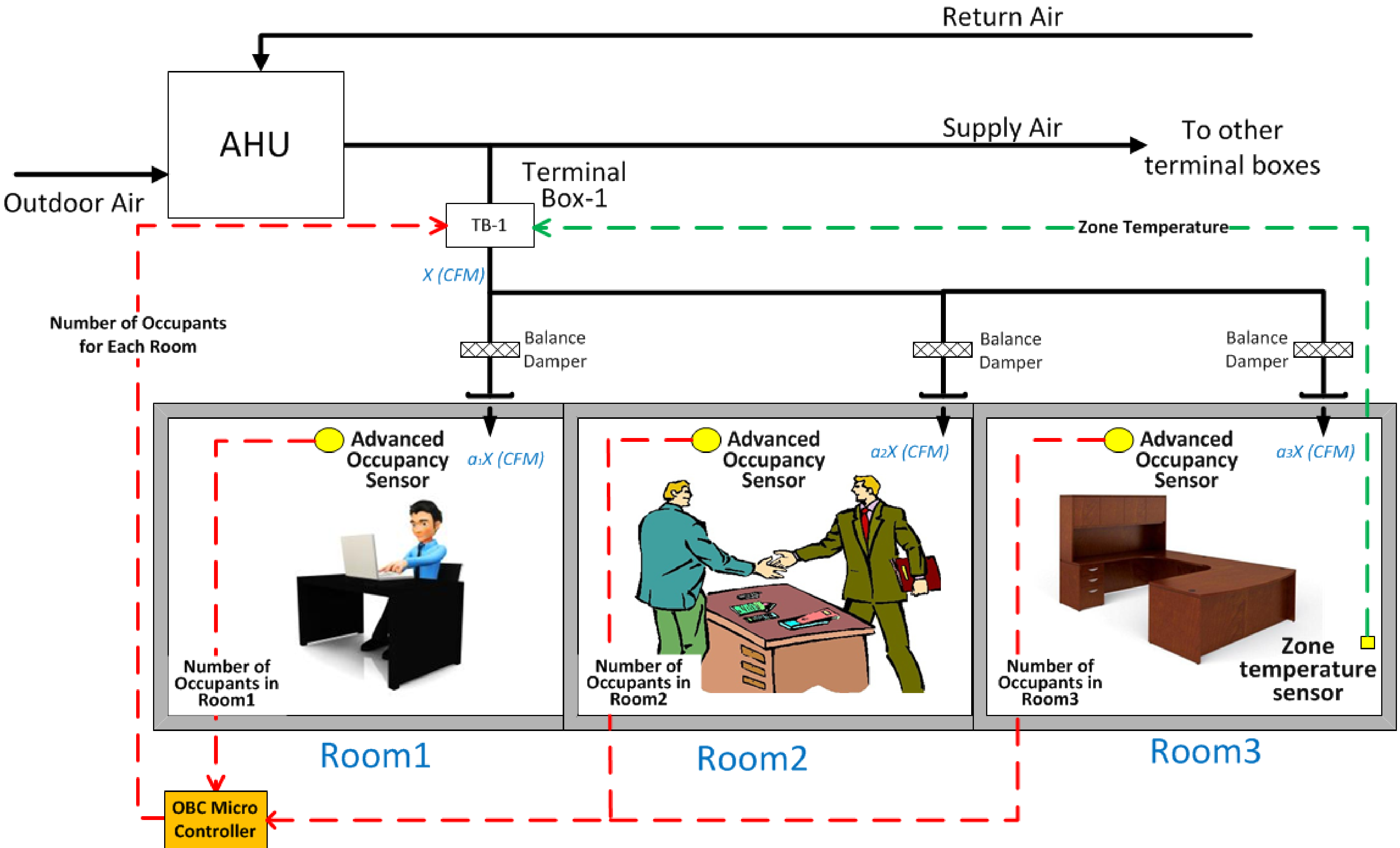
Category	Controlled Zone	Baseline	Common OS	Advanced OS
Terminal Box Minimum Air-flow	Private Office	30% (constant)	30% (occupied) 0 (unoccupied)	0 ~ 30% based on occupancy
	Open Office, Occupied	30% (constant)	30% (constant)	0 ~ 30% based on occupancy
	Conference Room	50% (constant)	50% (when occupied) 0 (when unoccupied)	0 ~ 50% based on occupancy

Modeled OBC for Minimum Air Flow – Common OS

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

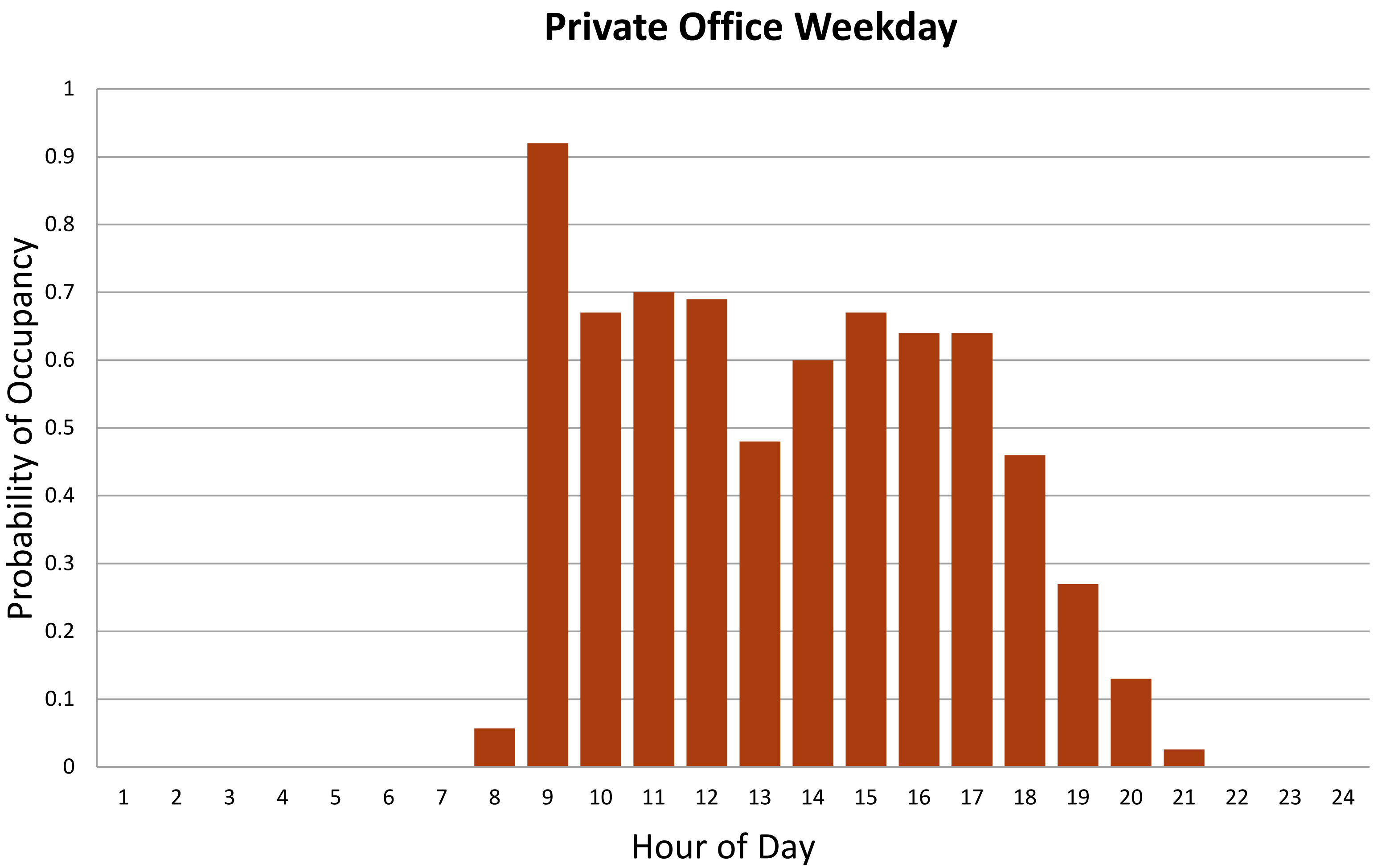


Modeled OBC for Minimum Air Flow – Advanced OS



Modeled OBC - Occupancy in Private Office

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*



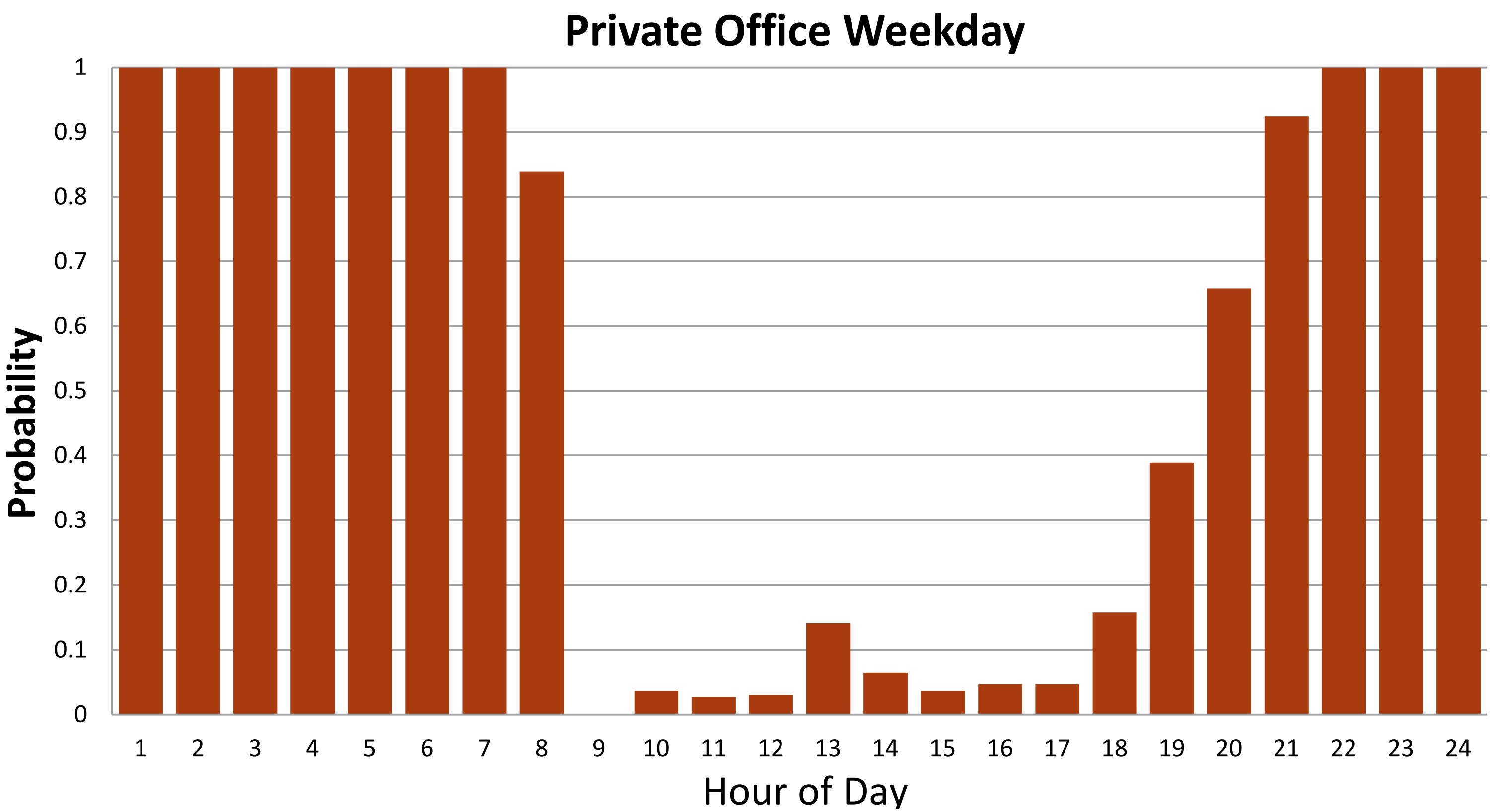
- Source: Wang et al. 2005

Modeled OBC - Occupancy in Private Office

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

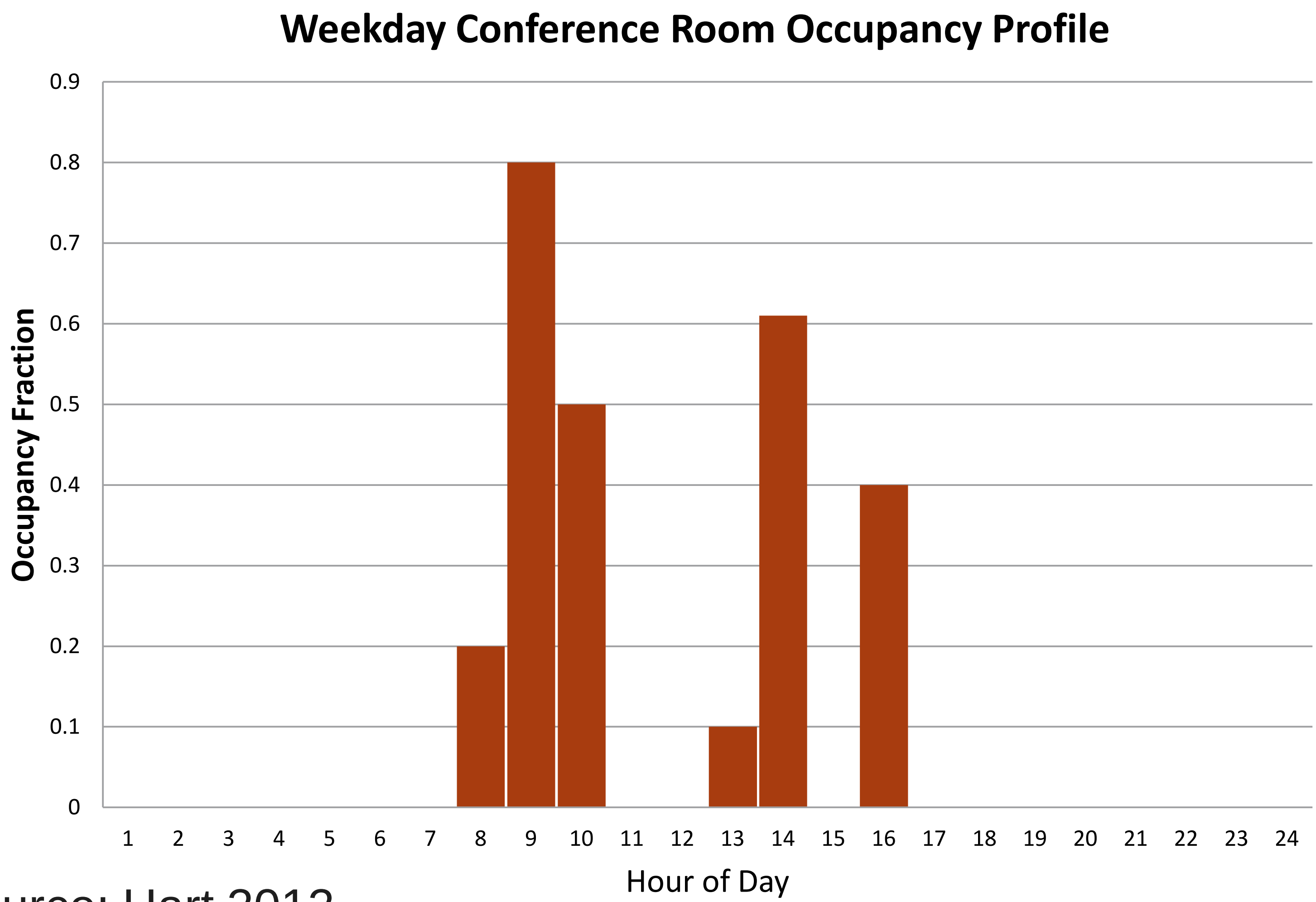
- Probability of a 3-private-office zone being all unoccupied

$$P_{3-office\ zone\ being\ unoccupied} = \left(1 - P_{individual\ office}\right)^3$$



Modeled OBC - Conference Room Occupancy

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*



- Source: Hart 2012

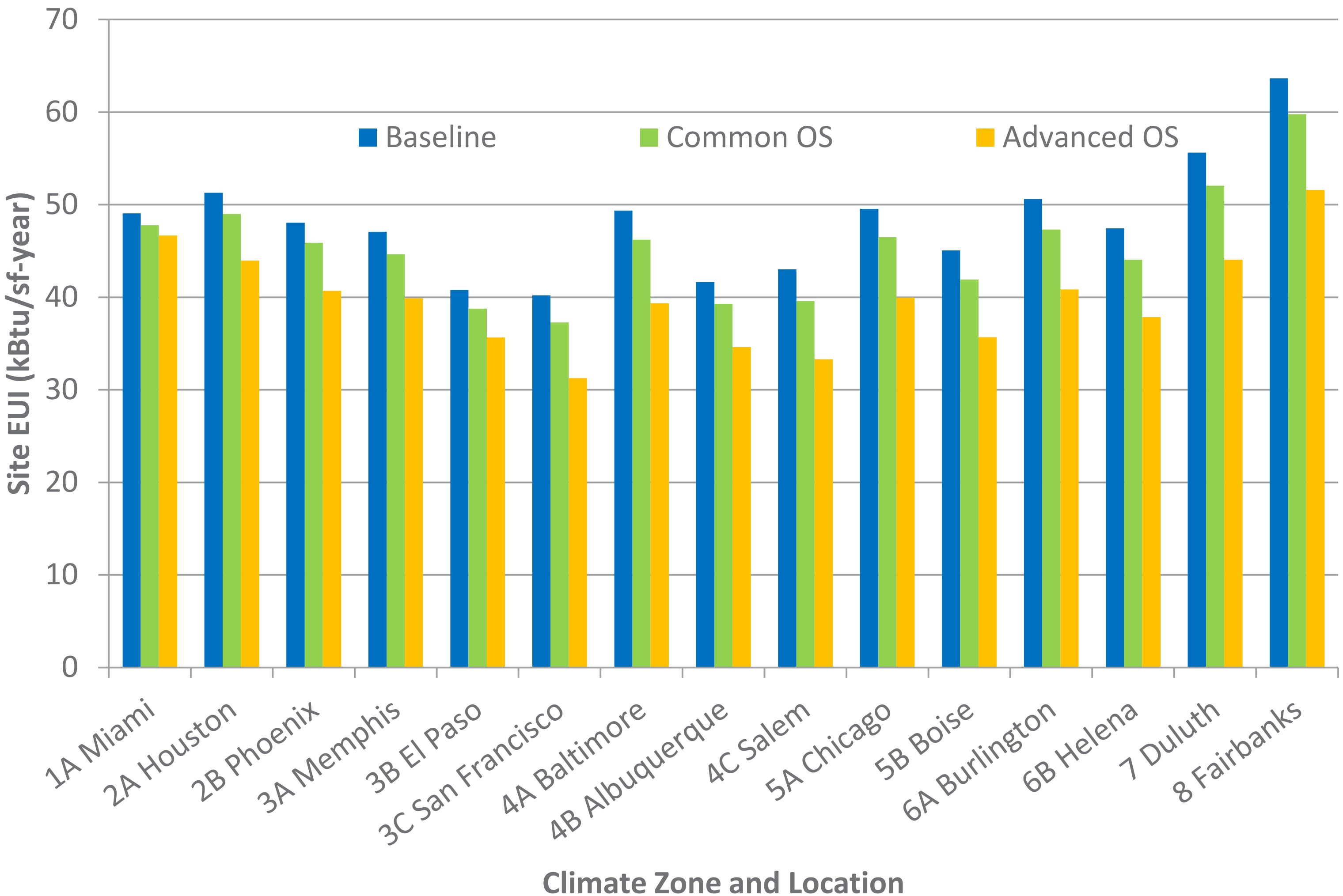
Modeled OBC for Thermostat Setpoints

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Category	Status	Base Case	Common OS	Advanced OS
Cooling Setpoint	Occupied	75°F	75°F	75°F
	Unoccupied	75°F (no setback)	**79°F (standby) Conference Rooms**	**79°F (standby) Conference RM and Private Offices***
Heating Setpoint	Occupied	70°F	70°F	70°F
	Unoccupied	70°F (no setback)	**66°F (standby) Conference Rooms**	**66°F (standby) Conference RM and Private Offices***

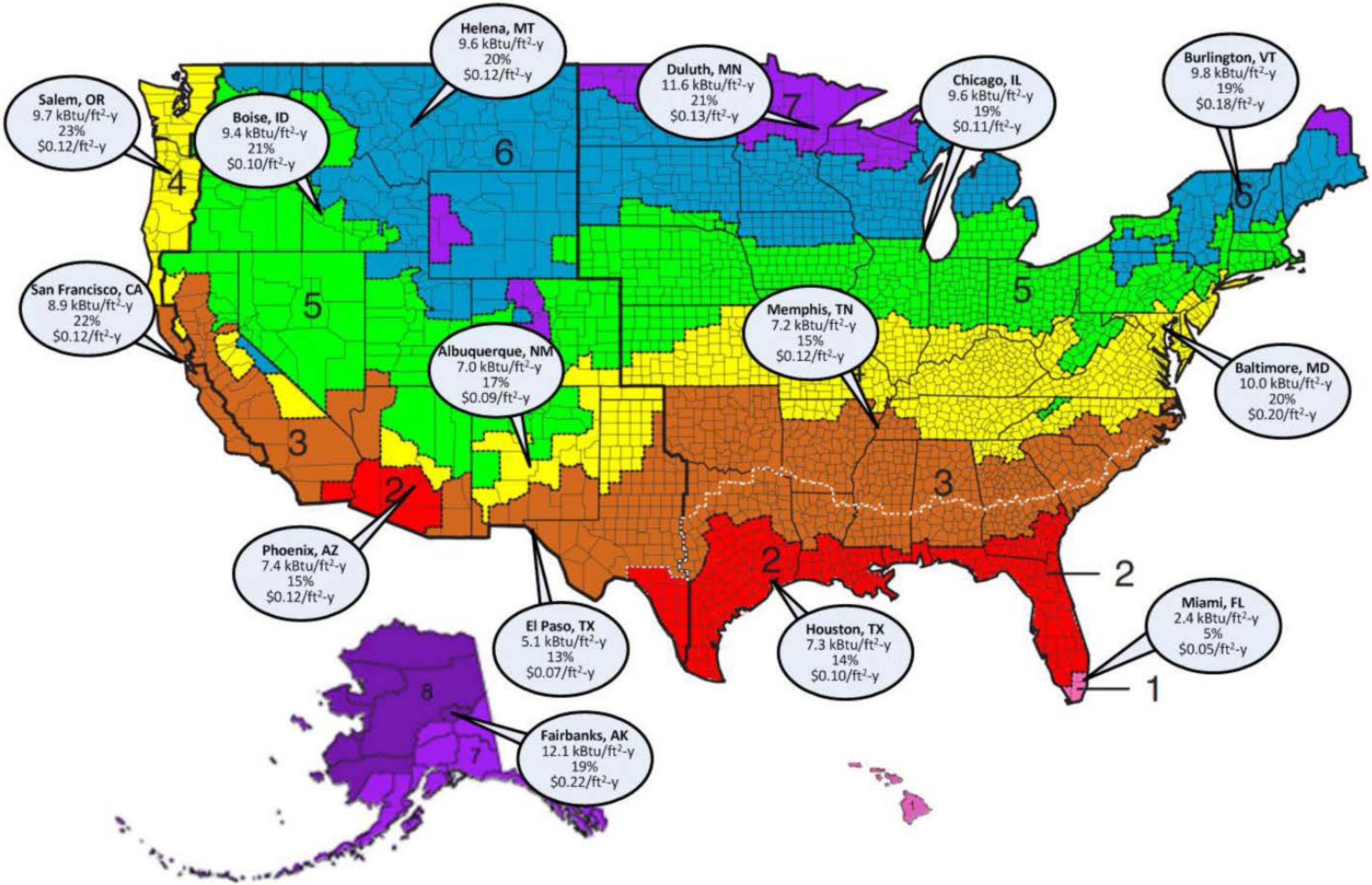
- Setback to standby mode only when the probability of the 3-office zone being all unoccupied is 50% or greater.

Results – Site EUI Comparison



Results – Energy Cost Savings

Results – Savings of Advanced OS



Results – Baseline vs Advanced OS for Lighting and HVAC

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

	National Weighted Average Site Energy Use (kBtu/sf-yr)						Energy Savings	
	Interior Lights	Cooling	Heating	Fans	Pumps	**Whole Building**	**kBtu/sf-yr**	**%**
Baseline	9.8	6.9	9.0	2.1	2.3	**47.8**	**-**	**-**
Common OS	9.2	6.5	7.4	1.9	2.2	**45.0**	**2.8**	**5.9%**
Advanced OS	8.9	5.9	3.0	1.5	2.2	**39.3**	**8.5**	**17.9%**

- Major Savings from reduction to reheat energy
- Significant improvement from OBC with common OS to advanced OS

Summary

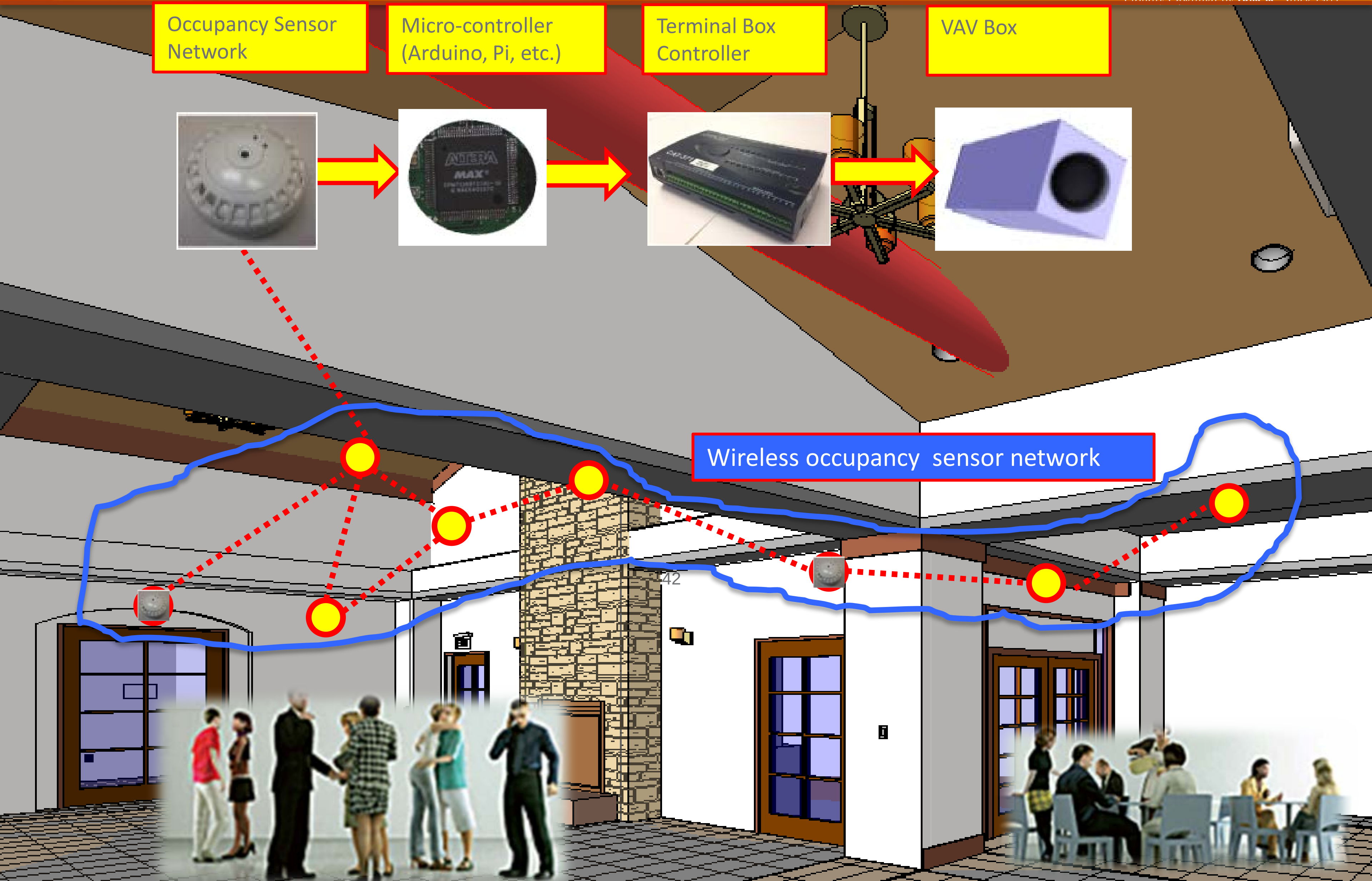
- Proposed OBC addresses issues of VAV systems with additional lighting saving benefits.
- Both common and advanced OS can be used
- Advanced OS are under development
  - Control strategies
  - Field testing
  - Cost barrier
- Simulation analysis of large office buildings retrofitted with OBC of
  - Lighting
  - Minimum airflow of VAV terminal boxes
  - Thermostat setpoint

Summary

- Both common and advanced OS yield significant savings, most from HVAC energy use.
- Advanced OS substantially increases savings comparing to common OS.
- Site energy savings of advanced OS could be 12 kBtu/ft^2-y (20% or $0.2/sf-yr) in the cold climate zones and national weighted average savings of 8.5 kBtu/ft^2-y (of 18%)
- Simulation models with OBC didn't result in significant increase in load not-met hours.
- OBC with advanced OS is a very promising technology.

References

- Zhang J, RG Lutes, G Liu, and MR Brambley. 2013. Energy Savings for Occupancy-Based Control (OBC) of Variable-Air-Volume (VAV) Systems. PNNL-22072, Pacific Northwest National Laboratory, Richland, WA.
- Liu G, AR Dasu, and J Zhang. 2012. Review of Literature on Terminal Box Control, Occupancy Sensing Technology and Multi-zone Demand Control Ventilation (DCV). PNNL-21281, Pacific Northwest National Laboratory, Richland, WA.
- DOE Commercial Prototype Building Models (16 prototypes in all US climates) https://www.energycodes.gov/commercial-prototype-building-models
- EIA. 2003. Commercial Building Energy Consumption Survey 2003. U.S. Department of Energy. Washington, DC. http://www.eia.doe.gov/emeu/cbecs/
- Wang, D., C.C. Federspiel, and F. Rubinstein. 2005. "Modeling occupancy in single person offices," Energy and Buildings 37(2):121–126.
- Hart, R. 2012. RE: Impact of Recent ASHRAE 62.1 Standard Committee Interpretations on 2013 Title 24 Code Ventilation Proposals. *California Energy Commission- Docket 12-BSTD-1*, February 2012, PECI, Inc., Portland, OR.


Occupancy Sensor Network
Micro-controller (Arduino, Pi, etc.)
Terminal Box Controller
VAV Box
Wireless occupancy sensor network

Acknowledgement

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

- Research funded by
  - U.S. Department of Energy

- PNNL project team
  - Michael Brambley
  - Guopeng Liu
  - Jian Zhang
  - Robert Lutes
  - Linda Sandahl

Thank you

Questions

j.zhang@pnnl.gov
guopeng.liu@pnnl.gov