

# **BUILDING PERFORMANCE MEASUREMENT PROTOCOLS and THEIR APPLICATION**

**Chilled Water Systems Workshop**

**ASHRAE Brazil**

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***Sao Paulo, Brazil***

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# Presentation Outline

- **Why we need protocols**
- **Characteristics of protocols**
- **Energy, Water, IEQ protocols at three levels of intensity**
- **Protocols applied to ASHRAE HQ building, pre- and post-renovation**
- **Questions?**

# The Challenge

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*We need a standardized, consistent set of measurement protocols to*

- **Substantiate claims of performance to establish credibility**
- **Facilitate appropriate, rigorous, and reliable benchmarking of measured performance**
- **Assure that improved energy efficiency does not degrade building services (IEQ)**

# Characteristics of Protocols

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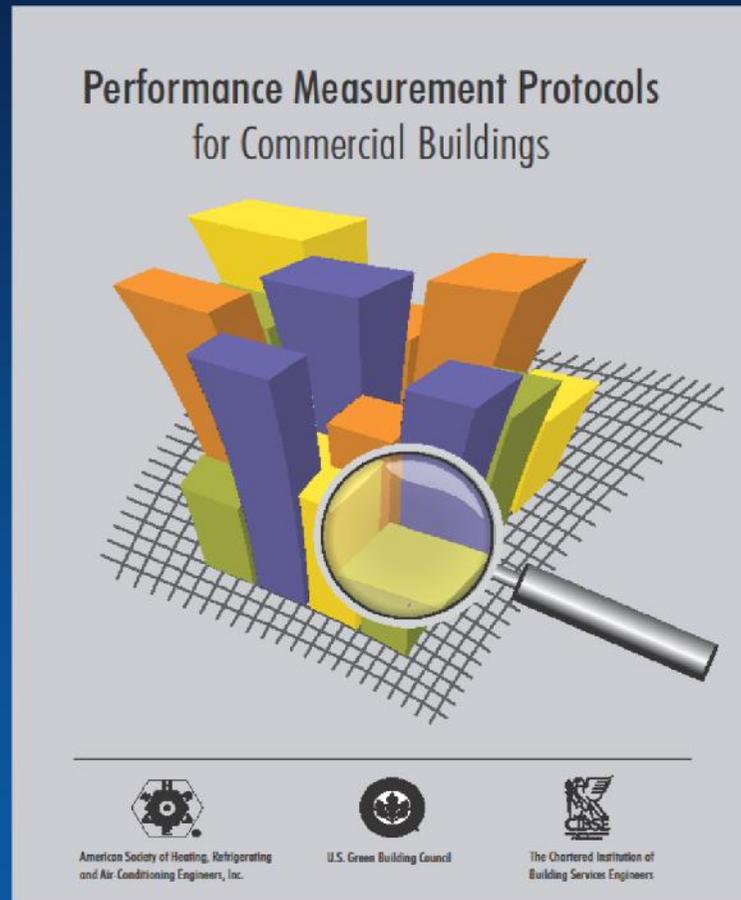
- Why is it measured? ***The objective***
- What is to be measured and how is it to be measured? ***The metric***
  - ✓ Instrumentation
  - ✓ Spatial resolution
  - ✓ Temporal resolution
- What are the appropriate benchmarks?



***Performance Evaluation/Benchmarking***

# ASHRAE/USGBC/CIBSE

## *Performance Measurement Protocols for Commercial Buildings*



Published as ASHRAE Special Publication in May 2010

# ASHRAE/USGBC/CIBSE

## *Performance Measurement Protocols for Commercial Buildings*

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### **Measurement Categories**

- Energy Use
- Potable Water Use
- IEQ Thermal Comfort
- IEQ Indoor Air Quality (IAQ)
- IEQ Lighting/Daylighting
- IEQ Acoustics

# ASHRAE/USGBC/CIBSE

## *Performance Measurement Protocols for Commercial Buildings*

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### **Levels of performance objectives**

- Basic (*indicative*)
- Intermediate (*diagnostic*)
- Advanced (*investigative*)

**Cost vs. accuracy / Instrumentation**

# INTERMEDIATE AND ADVANCED LEVEL PROTOCOLS

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- Objective is typically for more detailed evaluation (*typically disaggregated*) to identify how to improve performance
- Emphasis is on physical measurements rather than surveys
- Measurements at greater frequency and/or with greater spatial resolution

- Objectives
  - ✓ Characterize whole-building energy use and cost
  - ✓ Establish energy performance ranking
  - ✓ Estimate energy savings potentials
- Metrics
  - ✓ Catalog basic building characteristics
  - ✓ Annual whole-building energy use
  - ✓ Annual energy use and cost indices (per unit area)
- Benchmarks
  - ✓ Energy Star rating (by building type, climate zone)
  - ✓ Energy Performance of Buildings Directive rating

# Energy Use

## Basic Level 1

**TABLE 3-1** Total and Net Energy Use and Net Energy Cost

Energy Type	Source of Energy Data	Energy Use Numerical Value	Units	Conversion Multiplier to kBtu (kWh)	Energy, kBtu/yr (kWh/yr)	Energy Cost \$
1. Electricity – Purchased						
2. Natural Gas						
3. Steam						
4. Hot Water						
5. Chilled Water						
6. Oil # _____						
7. Propane						
8. Coal						
9. Thermal – On-site Renewable						
10. Other						
11. Electricity – On-site Generated						
12. Thermal or Electricity – Exported						
<b>Total energy<sup>1</sup></b> Sum of 1 to 11 minus 12					<b>A:</b>	
<b>Net Energy<sup>2</sup> –</b> Sum of 1 to 11 minus 9 and solar PV-generated kWh in 11					<b>B:</b>	<b>C:</b>

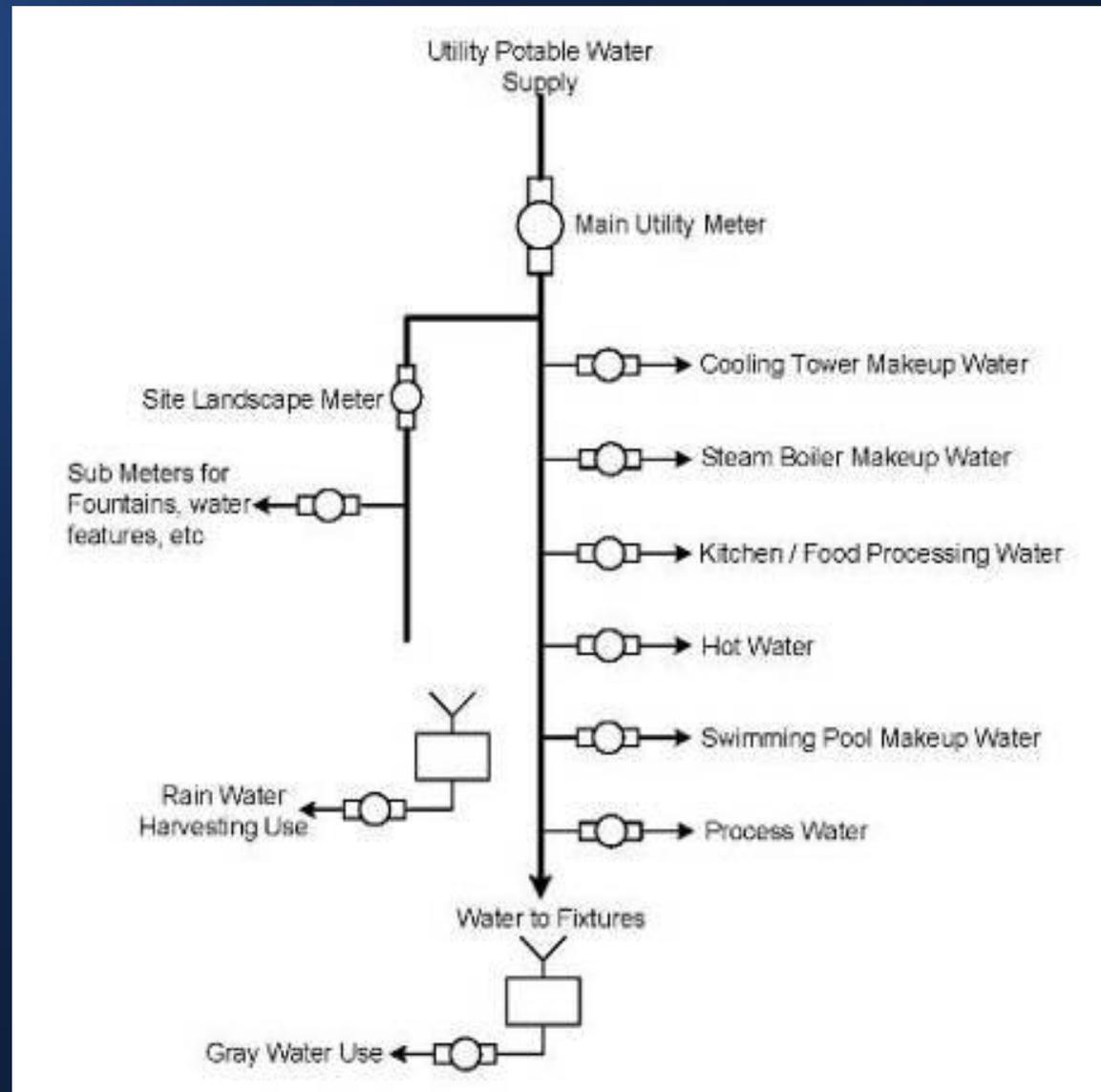
<sup>1</sup> The Total Energy is the sum of all energy used in the building, plus on-site generated electricity from renewable sources or from sources other than fuels covered in Items 2 through 8, minus exported energy. Under a net metering agreement, the electric utility meter may record the purchased energy minus the exported energy.

<sup>2</sup> The Net Energy is the sum of the purchased energy minus sold or exported energy (thus accounting for both on-site generated energy

- Objectives
  - ✓ Characterize whole-building water use and cost
  - ✓ Aggregate wastewater and non-wastewater uses
  - ✓ Identify water savings potentials
- Metrics
  - ✓ Monthly and annual water use and cost
  - ✓ Monthly and annual water use and cost indices (per unit area and occupant)
- Benchmarks
  - ✓ DOE/FEMP indices by building type
  - ✓ European indices by building type

# Water Use

## *Intermediate and Advanced*



Energy Use

Potable Water Use

Thermal Comfort

Indoor Air Quality

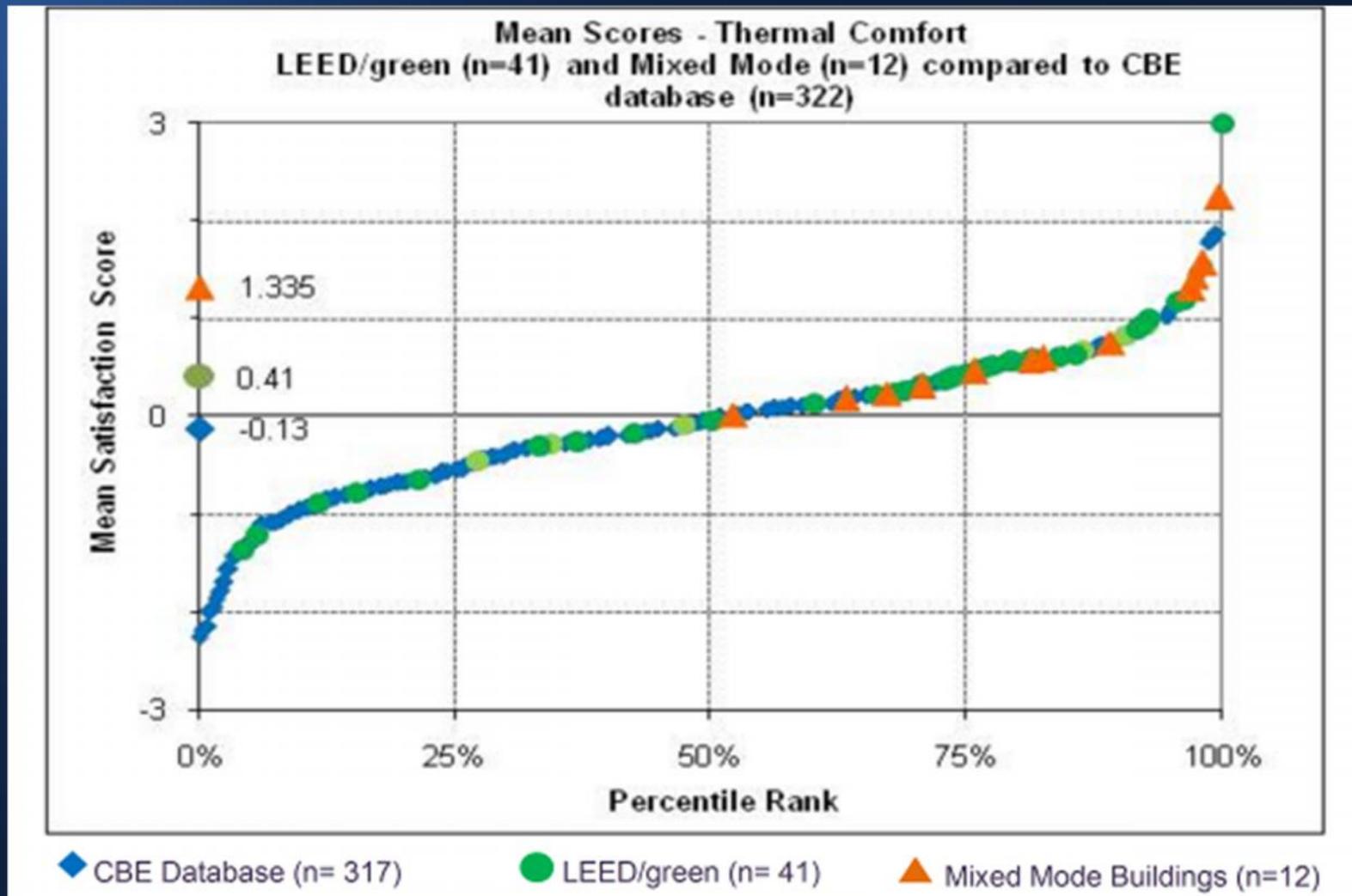
Lighting/Daylighting

Acoustics

- Objectives
  - ✓ Determine and rate occupant satisfaction
  - ✓ Identify thermal comfort problems
- Metrics
  - ✓ Evaluate complaint logs
  - ✓ Conduct occupant and operator surveys
  - ✓ Spot measure temperature, rh, MRT, airspeed  
(to determine causes of problems)
- Benchmarks
  - ✓ CBE or BUS survey databases
  - ✓ ASHRAE Standard 55

# Thermal Comfort

## Basic Level 1



# Thermal Comfort *Intermediate and Advanced*



**FIGURE 6-4**

a) Desktop Climate monitoring device. (left to right): shielded air temperature, rotatable hotwire anemometer, globe thermometer for MRT; humidity sensor internal.

b) Instrumented chair-like cart, measuring temperature, MRT, and velocity at three levels specified by ASHRAE Standard 55. Humidity is measured at mid-body, and plane radiant temperature measured at head level

c) SCATs instrumented cart; tethered sensors for measuring on desktop

- Objectives
  - ✓ Determine and rate occupant satisfaction
  - ✓ Observe condition of building and HVAC system
  - ✓ Evaluate compliance with ASHRAE Standard 62.1
- Metrics
  - ✓ Evaluate complaint logs, conduct occupant surveys
  - ✓ Determine if OA quality is poor (NAAQS)
  - ✓ If combustion sources, spot measure CO levels
  - ✓ Measure outside air flows (CO2 levels as indicator)
- Benchmarks
  - ✓ CBE or BUS survey databases
  - ✓ ASHRAE Standard 62.1 OA flows and distribution

# Indoor Air Quality *Intermediate and Advanced*

## ***Intermediate***

- Measure OA flow rate at each air OA intake
- One week continuous CO<sub>2</sub> measurement in representative spaces

## ***Advanced***

- Continuous measurement of CO<sub>2</sub>, PM2.5, TVOC
- Contaminants of concern if suspected

- Objectives
  - ✓ Determine and rate occupant satisfaction
  - ✓ Identify lighting quality problems
- Metrics
  - ✓ Conduct occupant and operator surveys
  - ✓ Evaluate lighting checklist to identify problems
  - ✓ Spot measurements of illuminance
- Benchmarks
  - ✓ CBE or BUS survey databases
  - ✓ IESNA and/or EN 12464 illuminance levels by space type

# Lighting Quality

## Basic Level 1

TABLE 3-7

Space/Task	IESNA		EN 12464		Additional Comments
	Horizontal or Task Plane Illuminance Lux (fc)	Vertical Illuminance Lux (fc)	Horizontal or Task Plane Illuminance Lux (fc)	UGR	
<b>Corridors</b>	50 (5)	30 (3)	100 (10)	28	
<b>Educational Spaces</b>					
Classrooms			300 (30) 500 (50) for adult education	19	
General (reading)					
VDT Screens	30 (3)	30 (3)			
#3 Pencil	500 (50)				
White boards		50 (5)			
Chalk boards		500 (50)			
8/10 point type	300 (30)				
Maps	500 (50)				
Lecture Hall			500 (50)	19	
<b>Manufacturing</b>					
Machining					Task plane may not be horizontal
Rough	300 (30)				
Medium	500 (50)				
Fine	3,000-10,000 (300-1,000)				
Assembly or Inspection					
Simple	300 (30)				
Difficult	1,000 (100)				
Exacting	3,000-10,000 (300-1,000)				

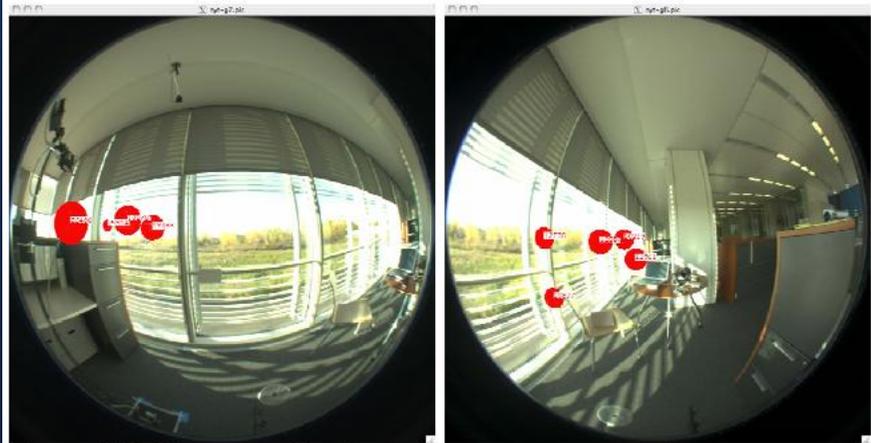
# Lighting Quality

## *Intermediate and Advanced*



Observer is looking at East direction

South



Observer is looking at West direction

North

- Glare evaluation at cardinal observer locations
- HDR photography

- Objectives
  - ✓ Characterize acoustic performance in occupied spaces
  - ✓ Determine and rate occupant satisfaction
- Metrics
  - ✓ Conduct occupant survey (identify annoying sounds)
  - ✓ Spot measurements of A-weighted sound pressure level [dB(A)] in representative spaces
- Benchmarks
  - ✓ CBE or BUS survey databases
  - ✓ ASHRAE design practice and ANSI standards for dB(A) by space type



**Low-cost integrating sound level meter**

# Acoustics Quality *Intermediate and Advanced*



**FIGURE 9-1** Integrating Sound Level Meter with Parallel Octave Band Filters  
Source: Brüel & Kjær Instruments  
Reproduced by permission of Brüel & Kjær Instruments



**FIGURE 9-2** Measurement of Room Reverberation Time using Interrupted Sound Source and Sound Level Meter  
Source: Brüel & Kjær Instruments  
Reproduced by permission of Brüel & Kjær Instruments

# **ASHRAE HQ BUILDING**

## ***ATLANTA, GEORGIA***

### **Renovation Completed July 2008**



# Annual Energy Use and Cost

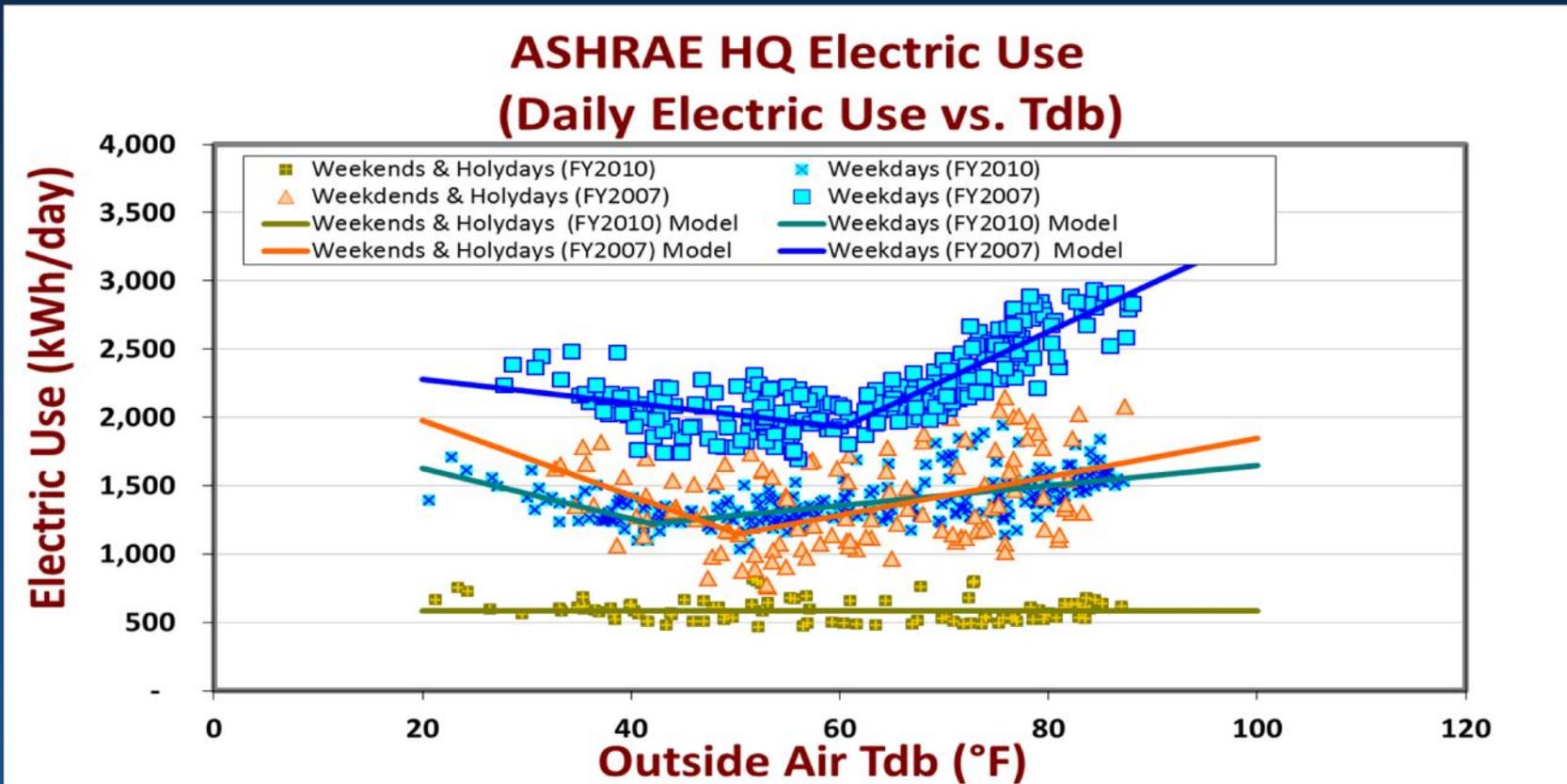
## Whole Building – All Electric

<b>12 Months Ending</b>	<b>Site EUI (kBtu/ft<sup>2</sup>-yr)</b>	<b>Source EUI (kBtu/ft<sup>2</sup>-yr)</b>	<b>Site ECI (\$/ft<sup>2</sup>-yr)</b>	<b>Energy Star Rating</b>
<b><i>Sept. 2006</i></b>	<b><i>77.1</i></b>	<b><i>257.6</i></b>		<b><i>44</i></b>
<b><i>Sept. 2010</i></b>	<b><i>40.7 (47% savings)</i></b>	<b><i>136.1</i></b>	<b><i>1.30</i></b>	<b><i>93</i></b>
<b><i>July 2014</i></b>	<b><i>37.2</i></b>	<b><i>116.9</i></b>	<b><i>1.38</i></b>	<b><i>89</i></b>

# ENERGY

## *Intermediate Level 2*

# Daily-Average Energy Use Pre- and Post Renovation



**WATER**

***Basic Level 1***

# **Annual Water Use**

***Whole Building: Pre-  
and Post-Renovation***

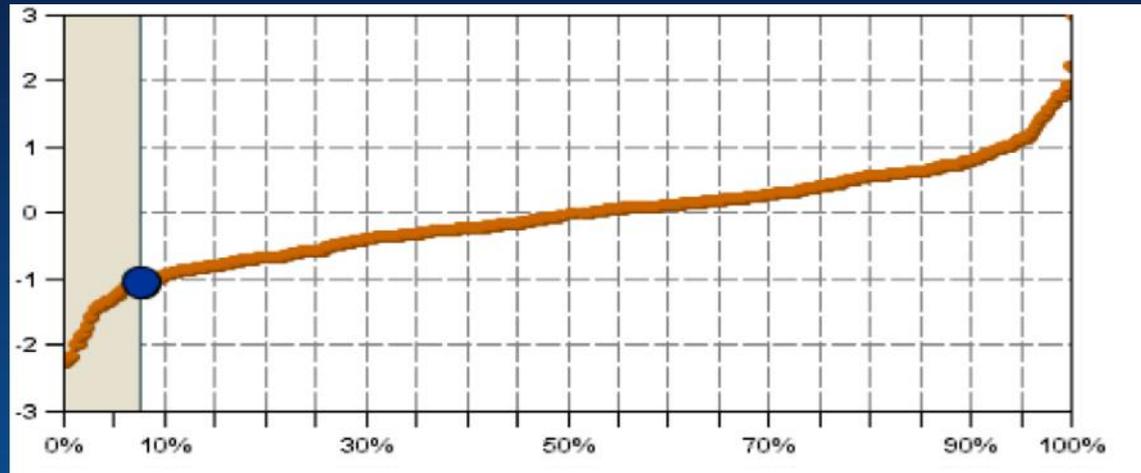
<b>Period Ending August 2007 (gal/person-day)</b>	<b>Period Ending October 2010 (gal/person-day)</b>	<b>Difference</b>
<b>15.1</b>	<b>5.0</b>	<b>67%</b>

# THERMAL COMFORT

*Basic Level 1*

## Occupant Survey Results

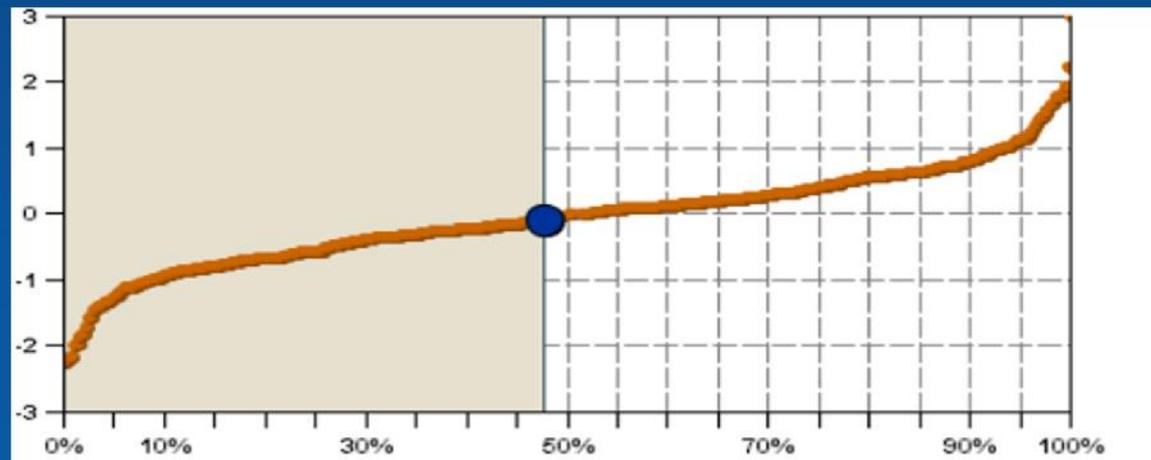
Pre-Renovation: 2005



*18% Satisfied*

Post-Renovation: 2010

*33% Satisfied*



**THERMAL COMFORT**    *Advanced Level 3*

# Temperature Gradients

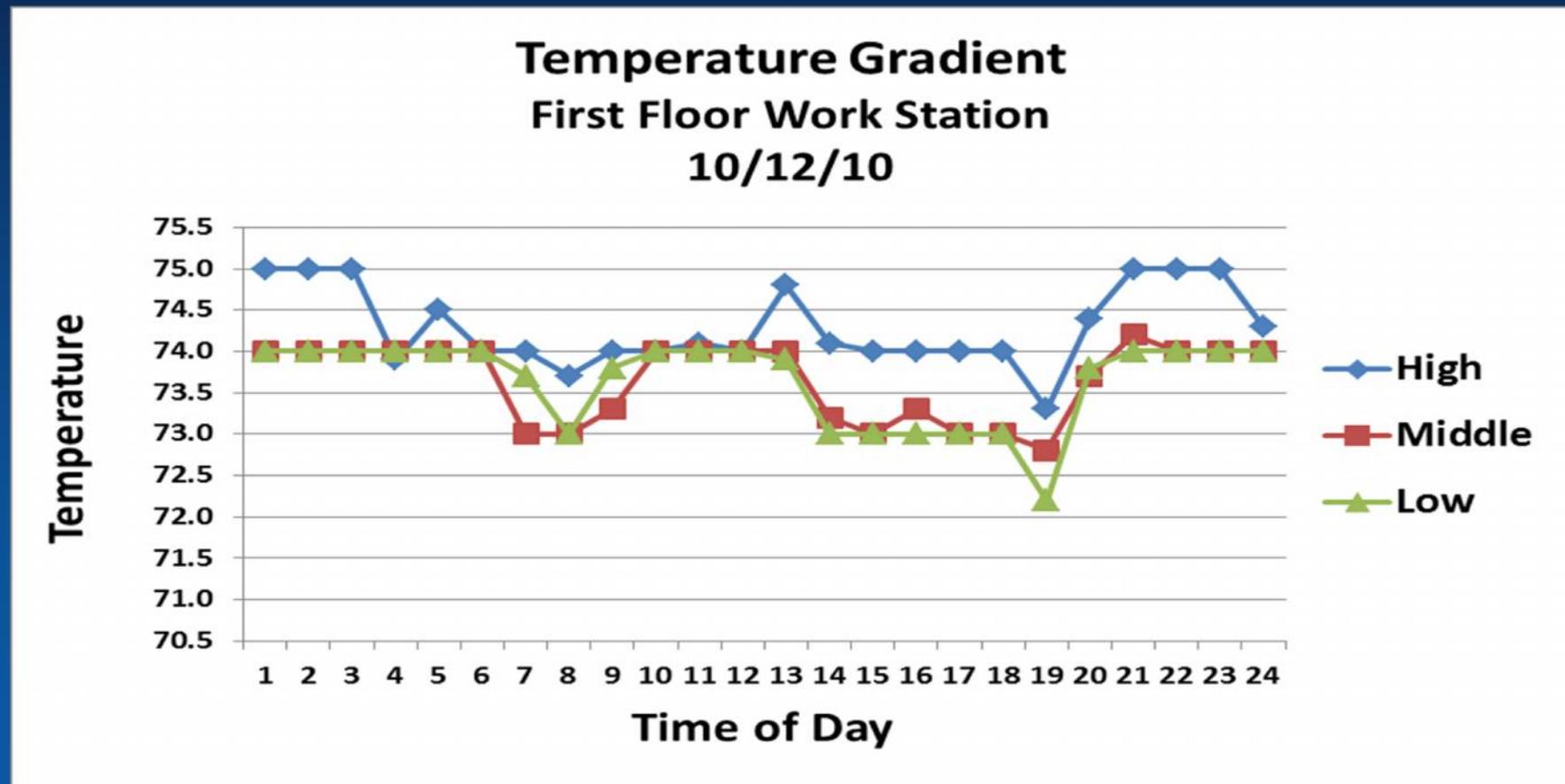
Head Height to Floor Level



# THERMAL COMFORT *Advanced Level 3*

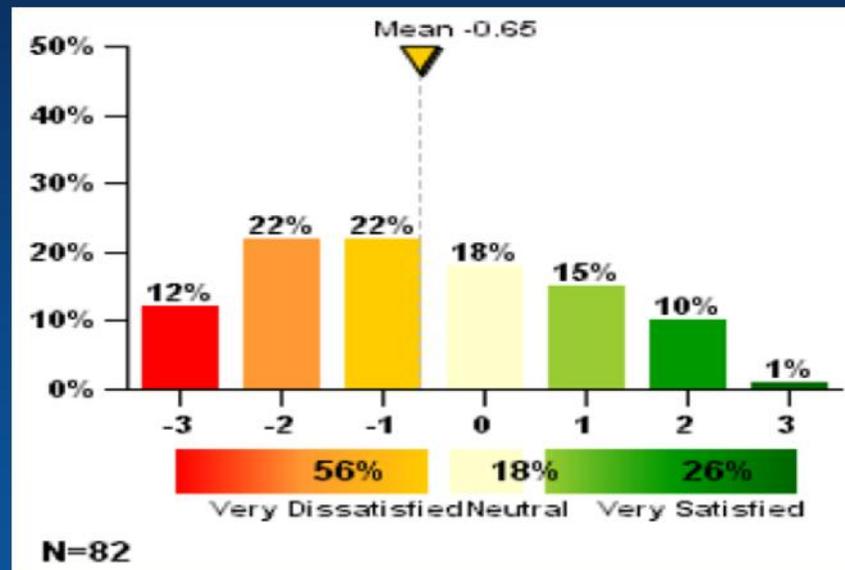
## Temperature Gradients

Head Height to Floor Level



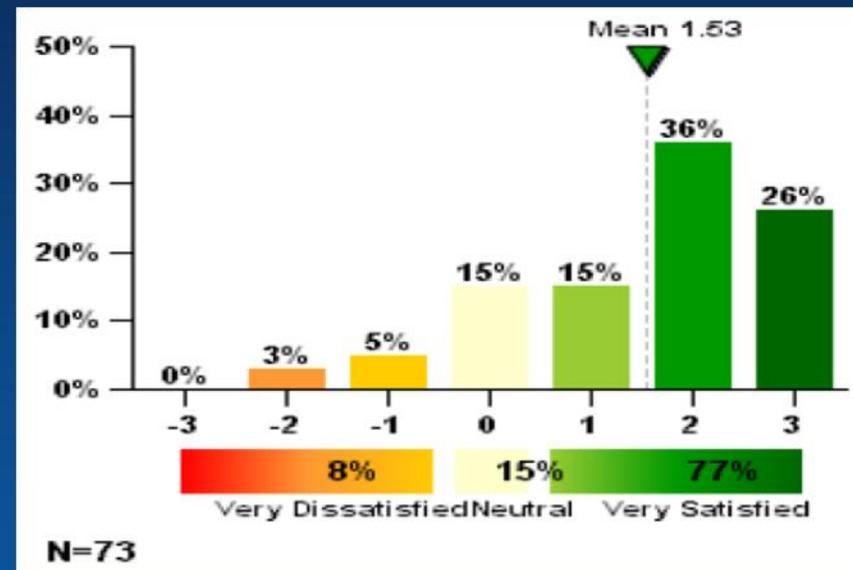
# INDOOR AIR QUALITY *Basic Level 1* Occupant Survey Results

Pre-Renovation: 2005



**26 % Satisfied**

Post-Renovation: 2010

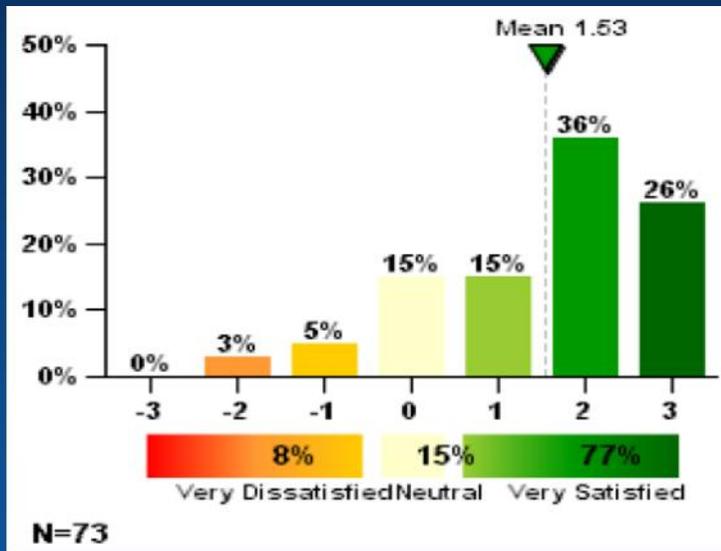


**77% Satisfied**

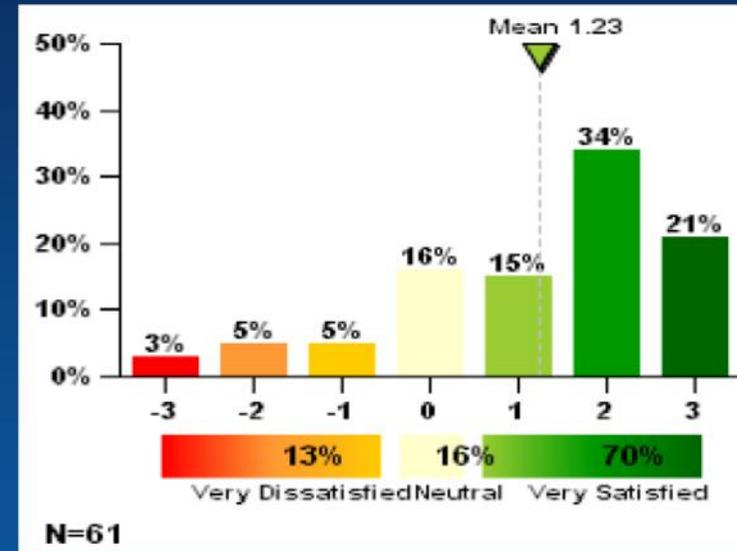
# INDOOR AIR QUALITY *Basic Level 1* Occupant Survey Results

Post-Renovation: 2010

Post-Renovation: 2013



**77 % Satisfied**



**70% Satisfied**

# INDOOR AIR QUALITY *Basic Level 1*

## Ventilation Rate Measurement at OA Intake

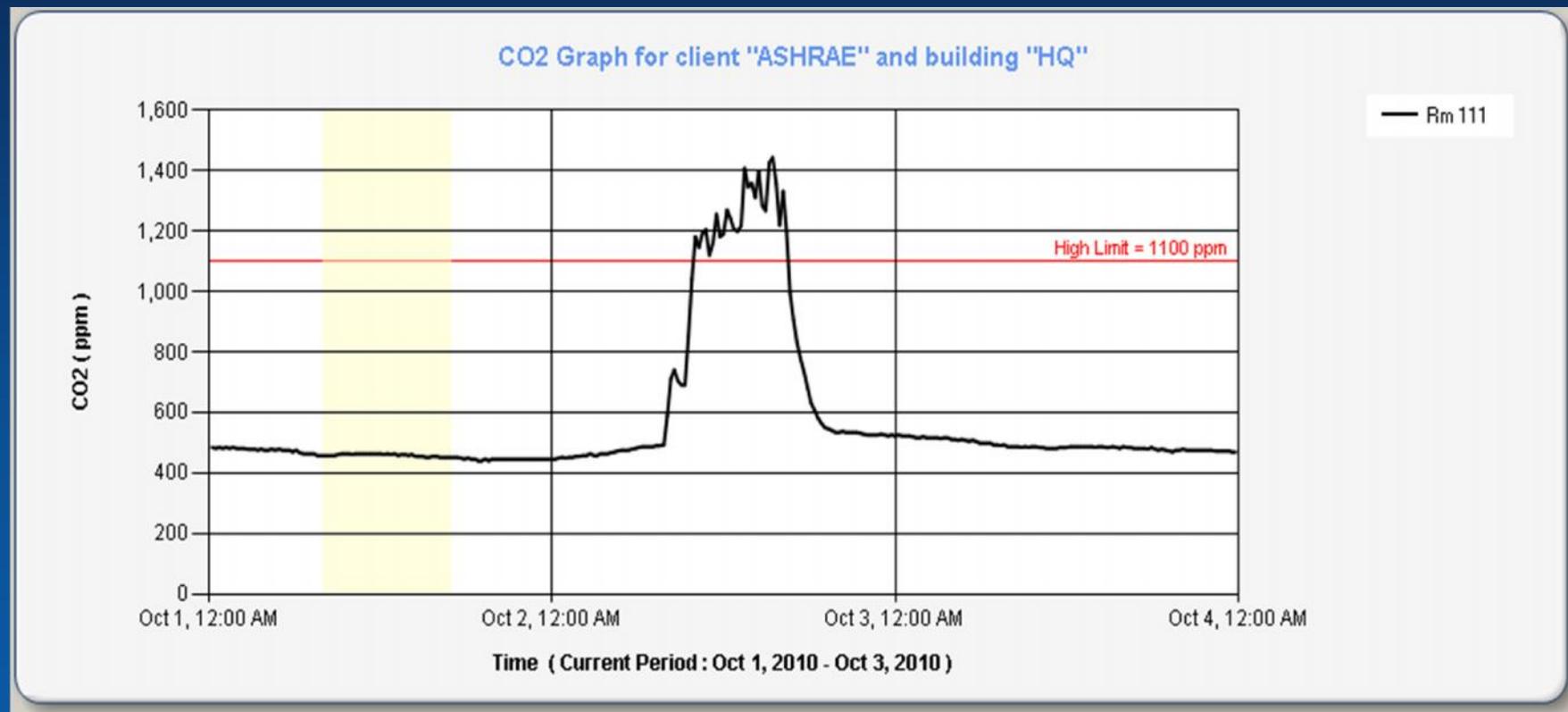
	Normal Occupancy	Maximum OA Flow
Measured OA (cfm)	<b>4328</b> <i>(43 cfm/person)</i>	<b>5862</b>
BAS indicated (cfm)	<b>3925</b>	<b>5938</b>
Difference	<b>9.3%</b>	<b>1.3%</b>



# INDOOR AIR QUALITY *Advanced Level 3*

## Continuous Measurement of CO<sub>2</sub>

### Education Center Conference Room



## LIGHTING

## *Basic Level 1*

# Illuminance Measurements in Representative Spaces

- Measurements in foot-candles
- IESNA Benchmarks
  - ✓ *Conference Room = 30*
  - ✓ *Private Office = 50*
  - ✓ *Open Office = 30*



# LIGHTING

## *Basic Level 1*

# Illuminance Measurements (fc) in Representative Spaces

Conf. Rooms	1 <sup>st</sup> Floor			2 <sup>nd</sup> Floor		
	Work Stn Exterior	Work Stn Interior	Enclosed Office	Work Stn Exterior	Work Stn Interior	Enclosed Office
<b>28-62</b>						
North	<b>23-32</b>	<b>16-28</b>	<b>37</b>	<b>37</b>	<b>34</b>	<b>50</b>
South	<b>50-73</b>	<b>28-45</b>	<b>109</b>	<b>41</b>	<b>21</b>	
East				<b>46</b>		<b>48</b>
West	<b>39</b>					

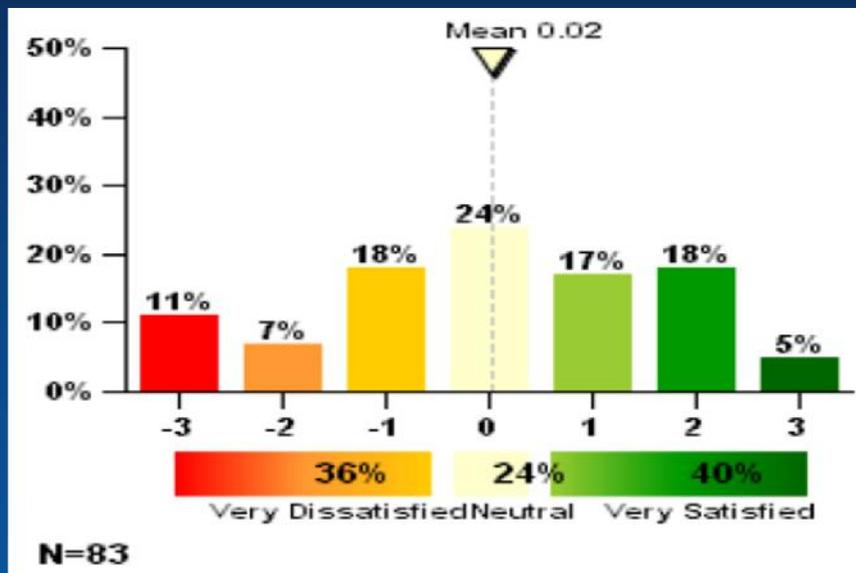
# ACOUSTICS

# Basic Level 1

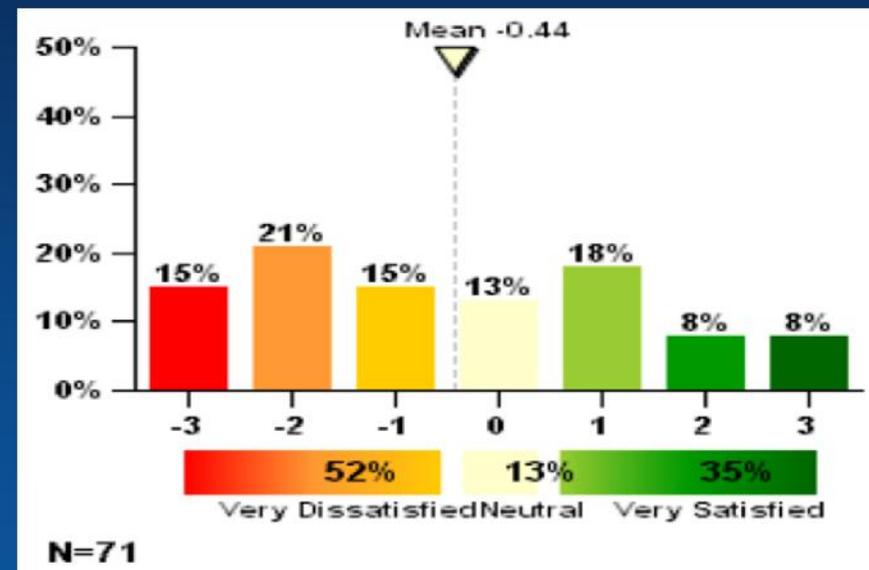
# Occupant Survey Results

Pre-Renovation: 2005

Post-Renovation: 2010



**40 % Satisfied**



**35% Satisfied**

# ACOUSTICS

# Basic Level 1

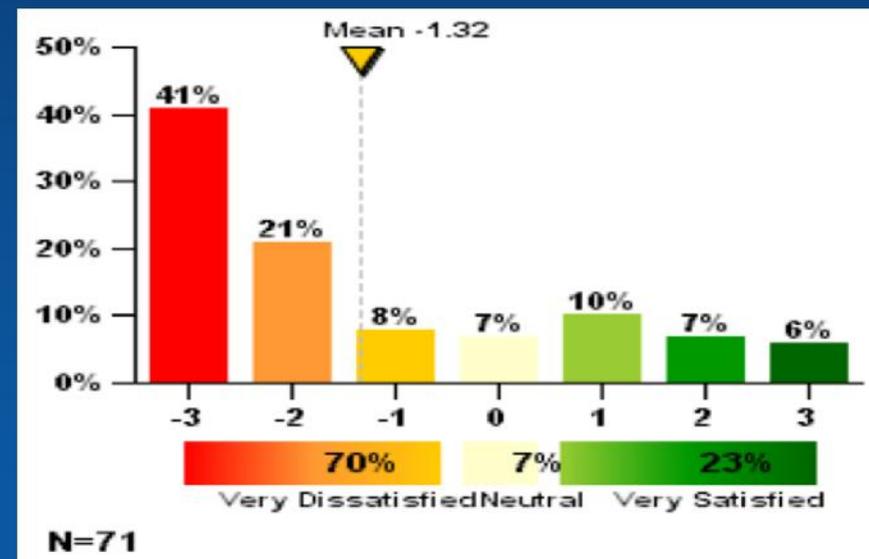
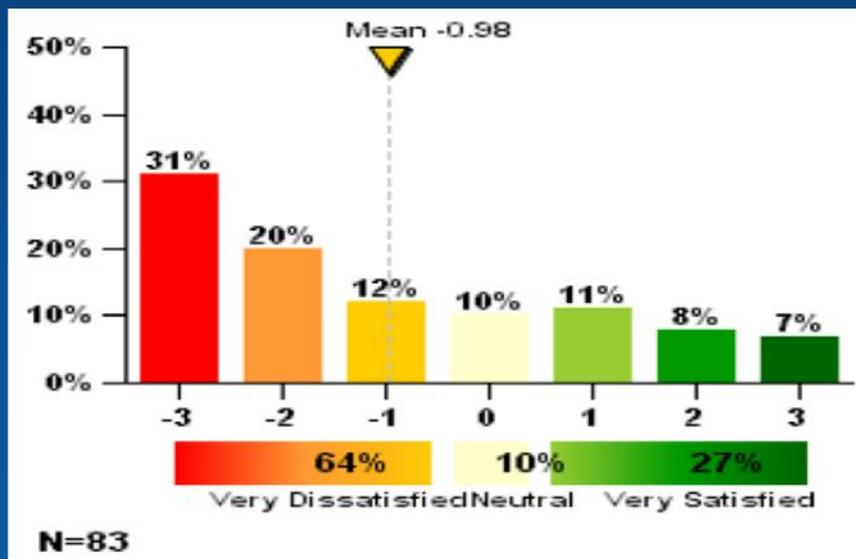
## Occupant Survey Results

### Diagnostic

How satisfied are you with sound privacy in your work space?

Pre-Renovation: 2005

Post-Renovation: 2010



# Research Update

## *ASHRAE Research Project 1702-RP*

- Application, testing, evaluation, verification of protocols
- Three university collaborative project
- Case studies to apply protocols to representative buildings
- 5 buildings in 3 climate zones
- Assess feasibility, usability, reliability, cost, staff time

# **QUESTIONS??**

**Bruce D. Hunn, Ph.D.**

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