A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

BUILDING PERFORMANCE MEASUREMENT PROTOCOLS and THEIR APPLICATION

ASHRAE Triangle Chapter

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Raleigh, NC

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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

We need a standardized, consistent set of measurement protocols to

- Substantiate claims of performance so as to establish credibility
- Facilitate appropriate, rigorous, and reliable comparison of measured performance
- Provide feedback to designers and building operators

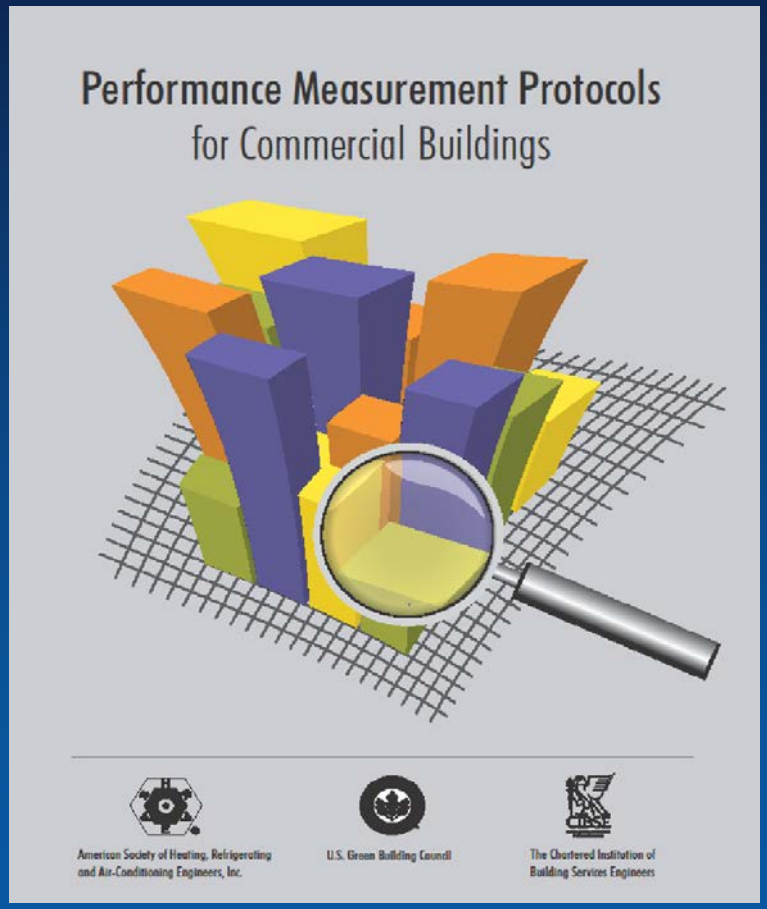
Characteristics of Protocols

- 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

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

Levels of performance objectives

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

Cost vs. accuracy / Instrumentation

INTERMEDIATE AND ADVANCED LEVEL PROTOCOLS

- 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

Energy Use

Basic Level 1

- 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						
Total energy[1] Sum of 1 to 11 minus 12					**A:**	
Net Energy[2] – Sum of 1 to 11 minus 9 and solar PV-generated kWh in 11					**B:**	**C:**

[1] The Total Energy is the sum of all energy used in the building, plus on-site generated electricity from renewable sources of 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.

[2] The Net Energy is the sum of the purchased energy minus sold or exported energy (thus accounting for both on-site generated energy

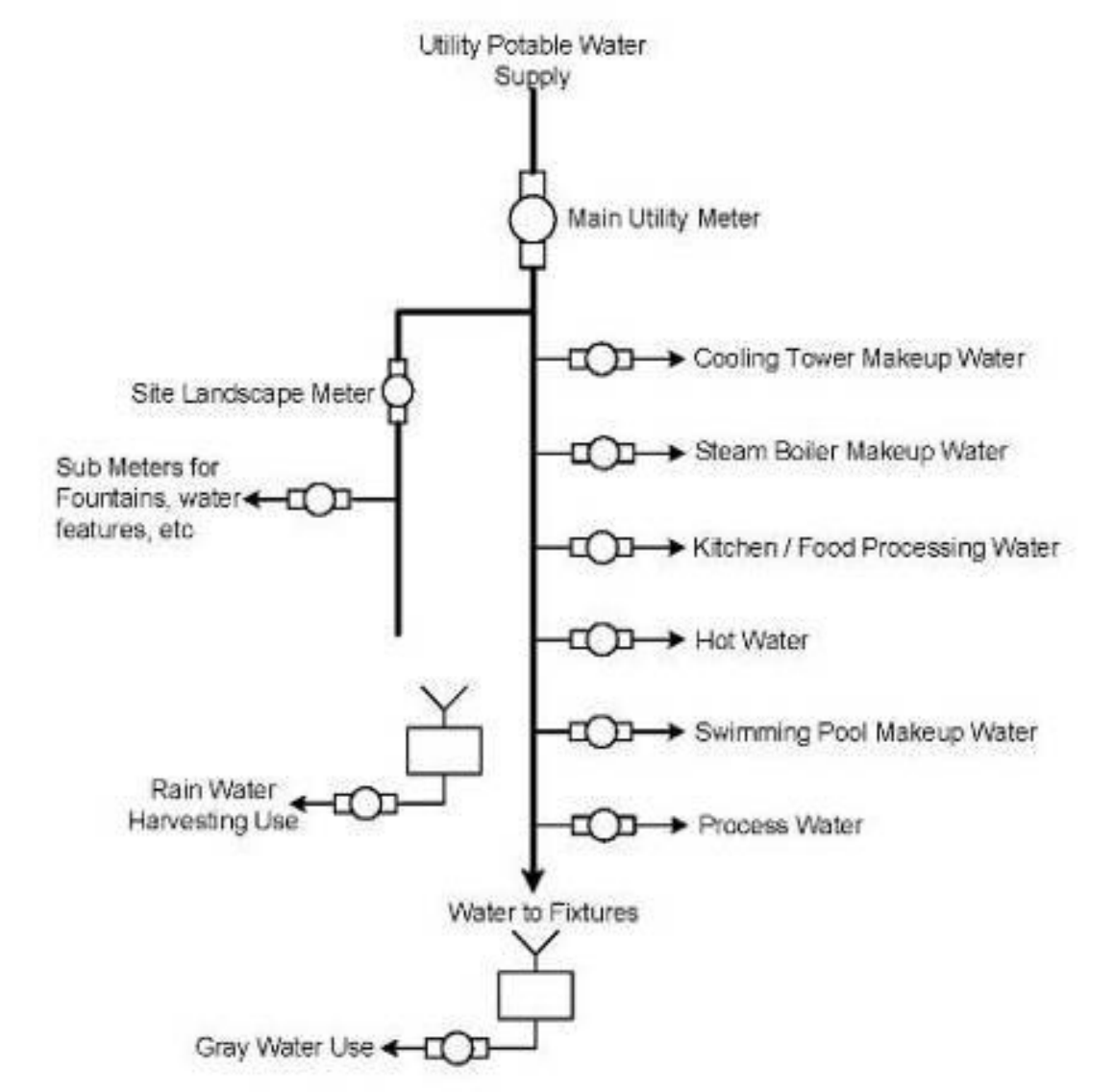
Water Use

Basic Level 1

- 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



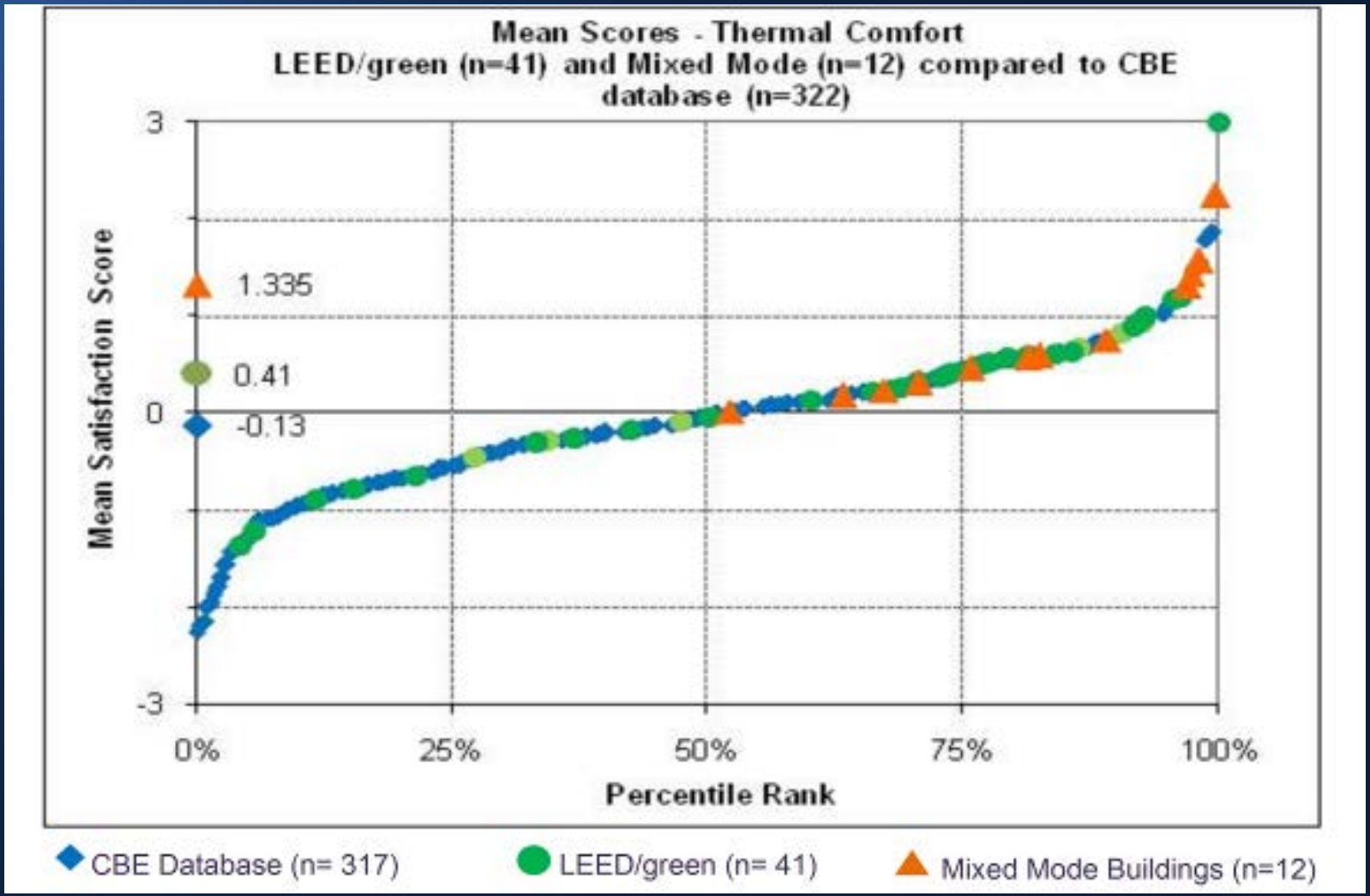
Thermal Comfort

Basic Level 1

- 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*

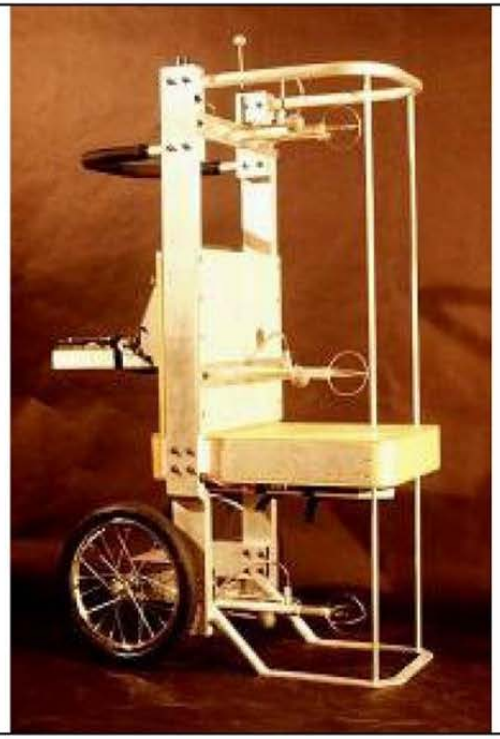


FIGURE 6-4

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

Indoor Air Quality *Basic Level 1*

- 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 (CO_2 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_2 measurement in representative spaces

Advanced

- Continuous measurement of CO_2, PM2.5, TVOC
- Contaminants of concern if suspected

Lighting Quality *Basic Level 1*

- 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

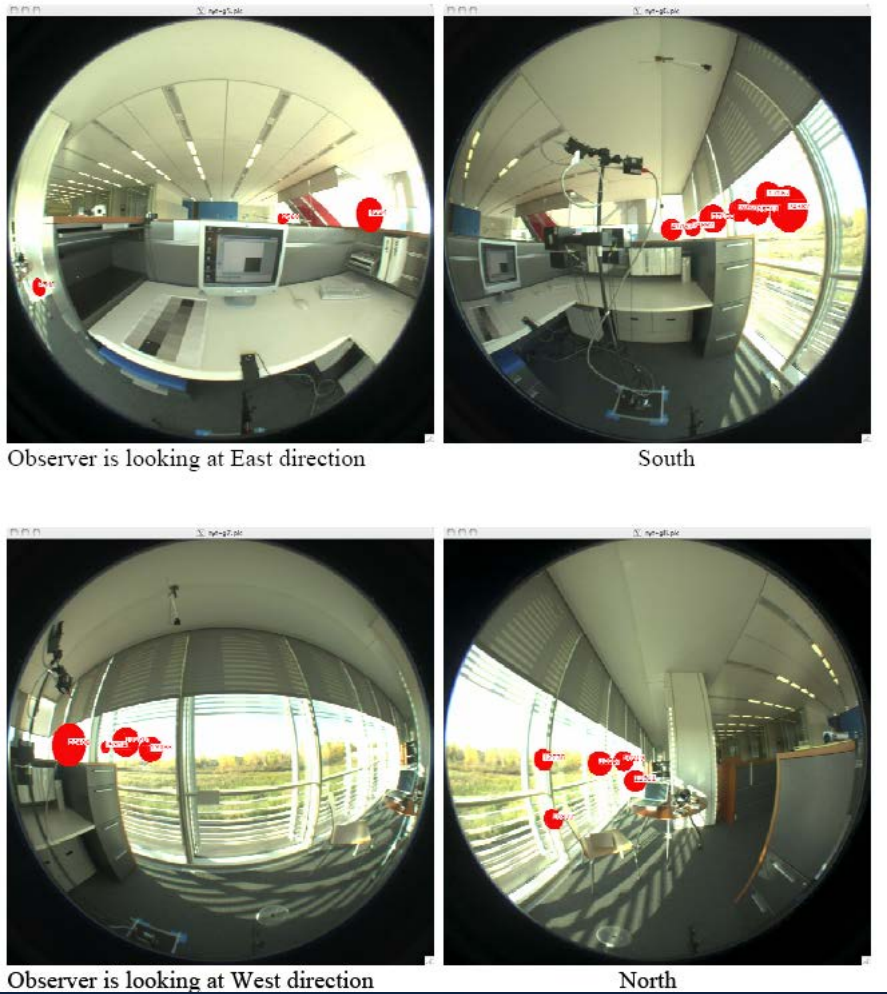
Lighting Quality

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	
Corridors	50 (5)	30 (3)	100 (10)	28	
Educational Spaces					
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	
Manufacturing					
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*



- Glare evaluation at cardinal observer locations
- HDR photography

Acoustics Quality *Basic Level 1*

- 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

Acoustics Quality

Basic Level 1

Low-cost integrating sound level meter

Acoustics Quality *Intermediate and Advanced*

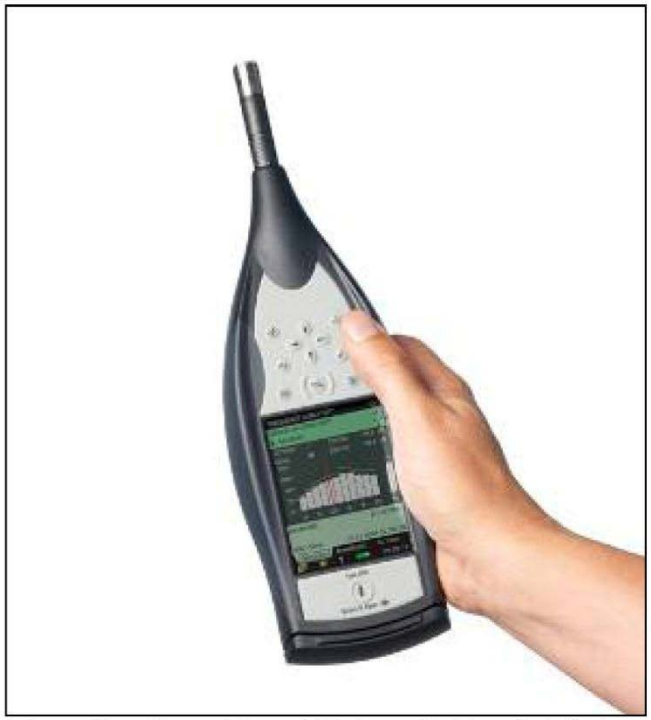


FIGURE 9-1 Integrating Sound Level Meter with Parallel Octave Band Filters
Source: Bruel & Kjaer Instruments
Reproduced by permission of Bruel & Kjaer Instruments

FIGURE 9-2 Measurement of Room Reverberation Time using Interrupted Sound Source and Sound Level Meter
Source: Bruel & Kjaer Instruments
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ASHRAE HQ BUILDING*ATLANTA, GEORGIA*Renovation Completed July 2008

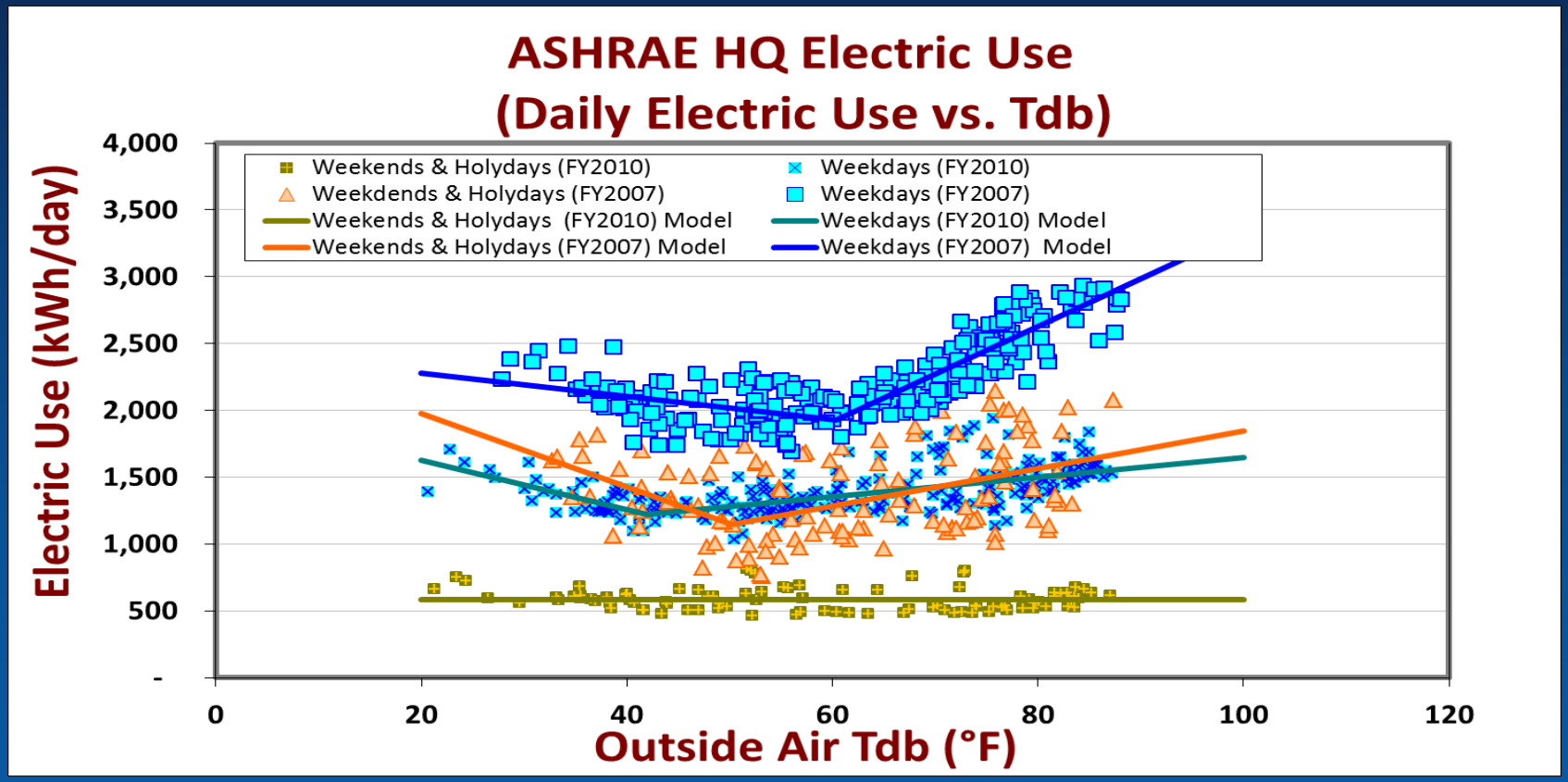
Annual Energy Use and Cost

Whole Building – All Electric

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

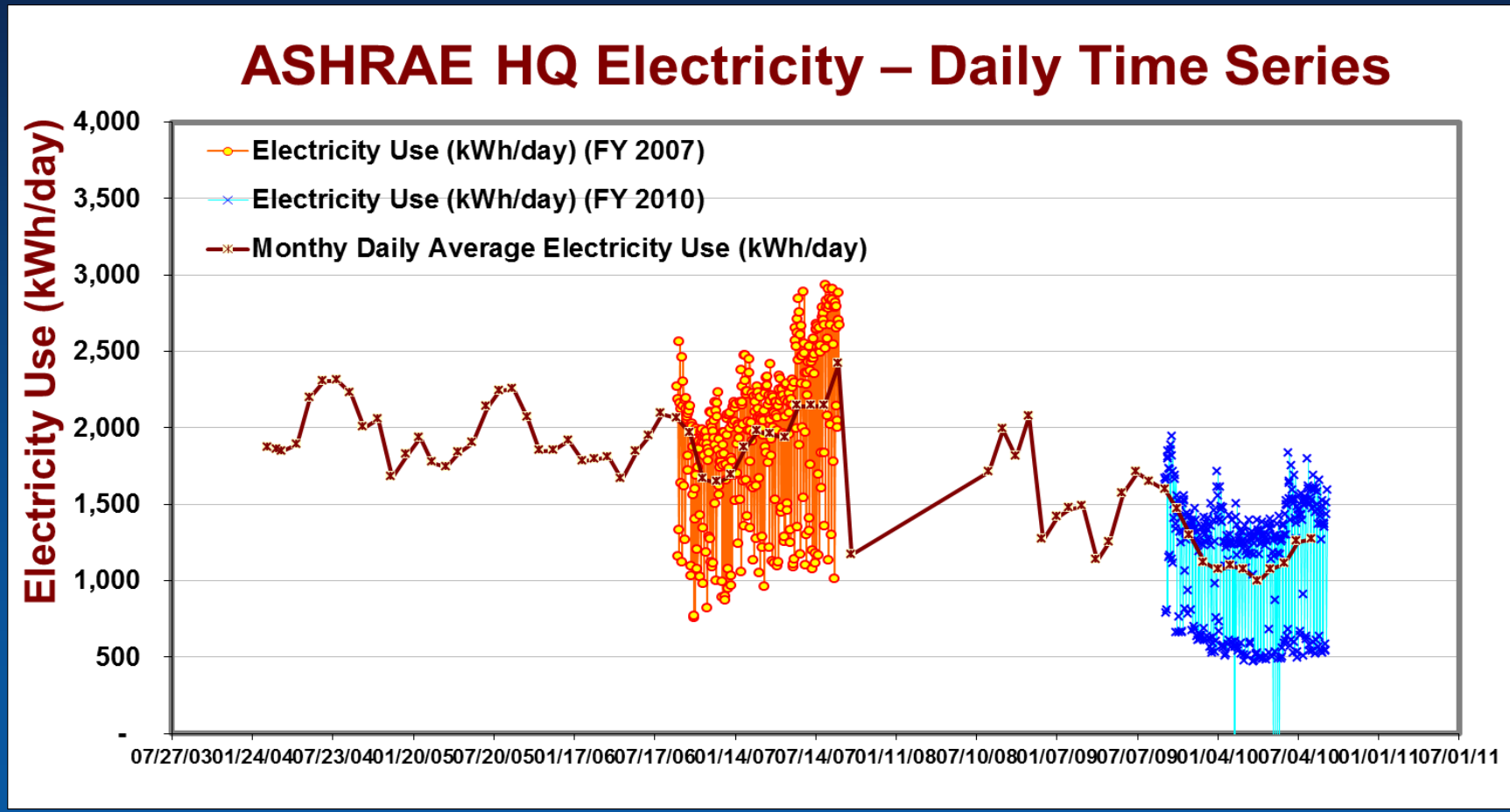
ENERGY *Intermediate Level*

2Daily-Average Energy Use Pre- and Post Renovation



ENERGY *Intermediate Level*

2Daily-Average Energy Use Pre- and Post Renovation



WATER

Basic Level

*1*Annual Water Use

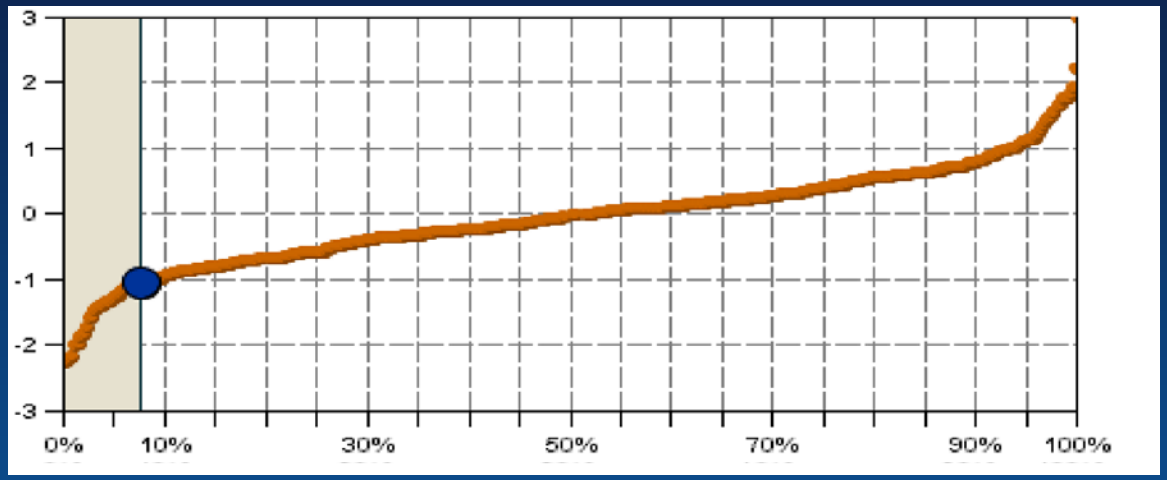
Whole Building: Pre- and Post-Renovation

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

THERMAL COMFORT *Basic Level*

*1*Occupant Survey Results

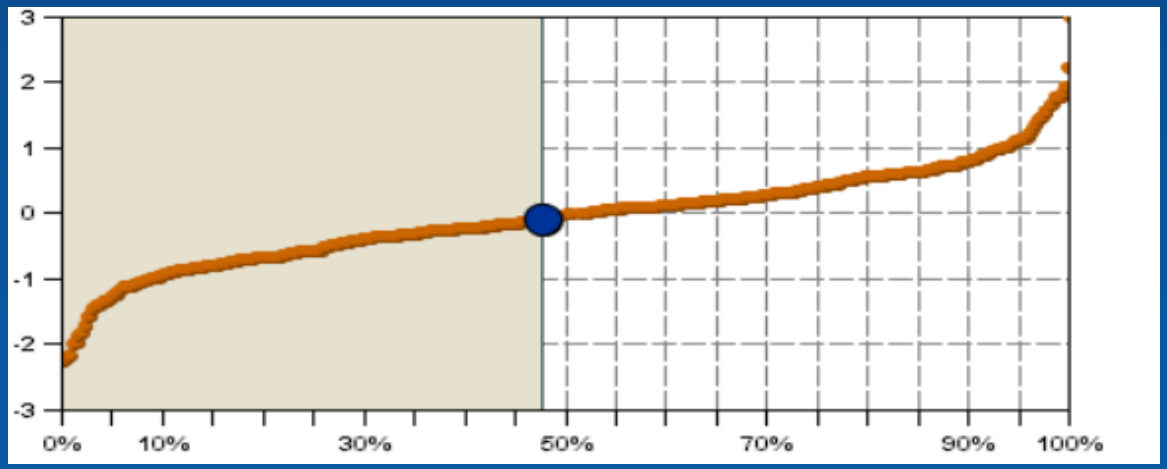
Pre-Renovation: 2005



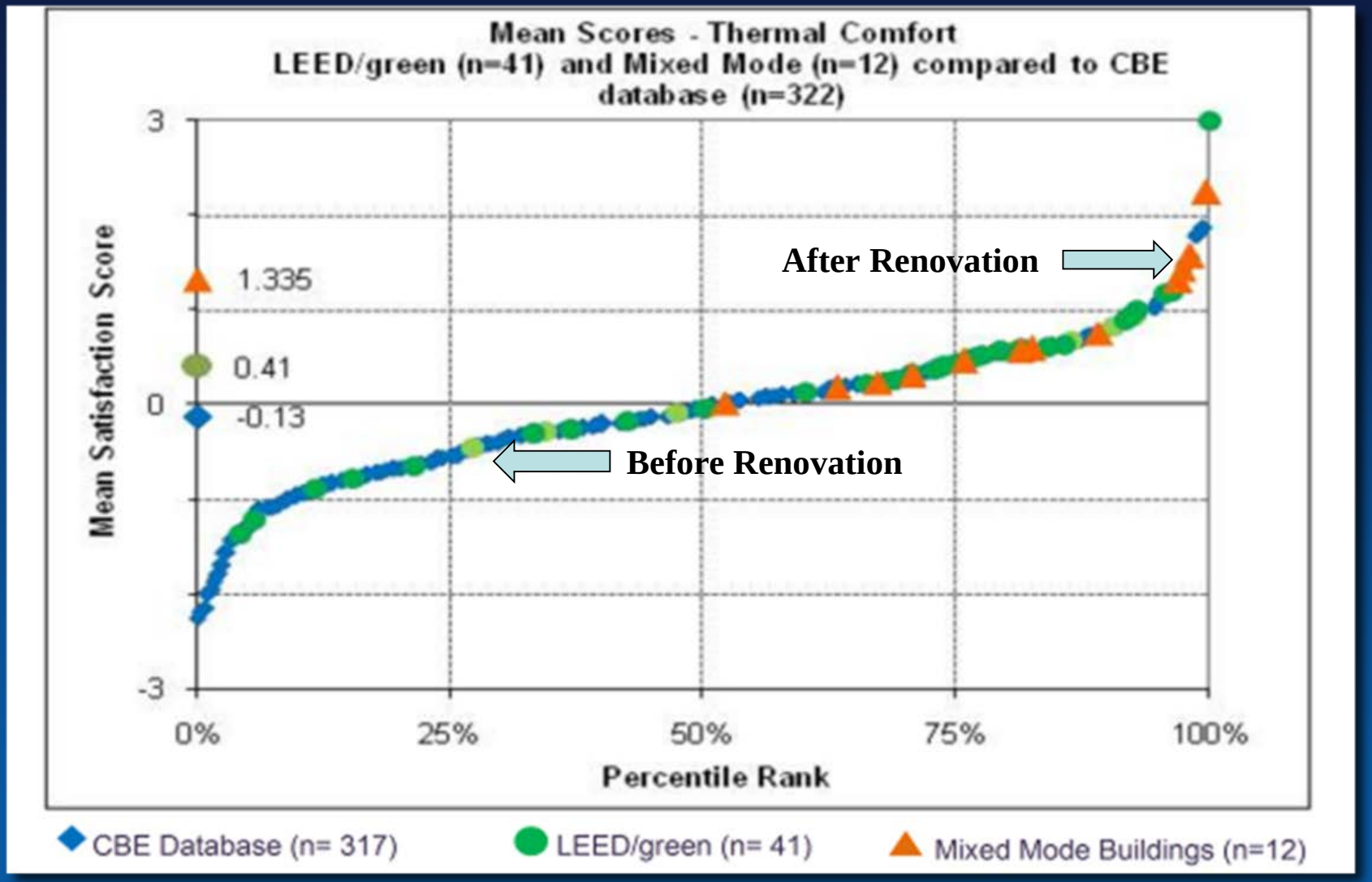
18% Satisfied

Post-Renovation: 2010

33% Satisfied



Basic Protocols – Thermal Comfort



THERMAL COMFORT *Advanced Level*

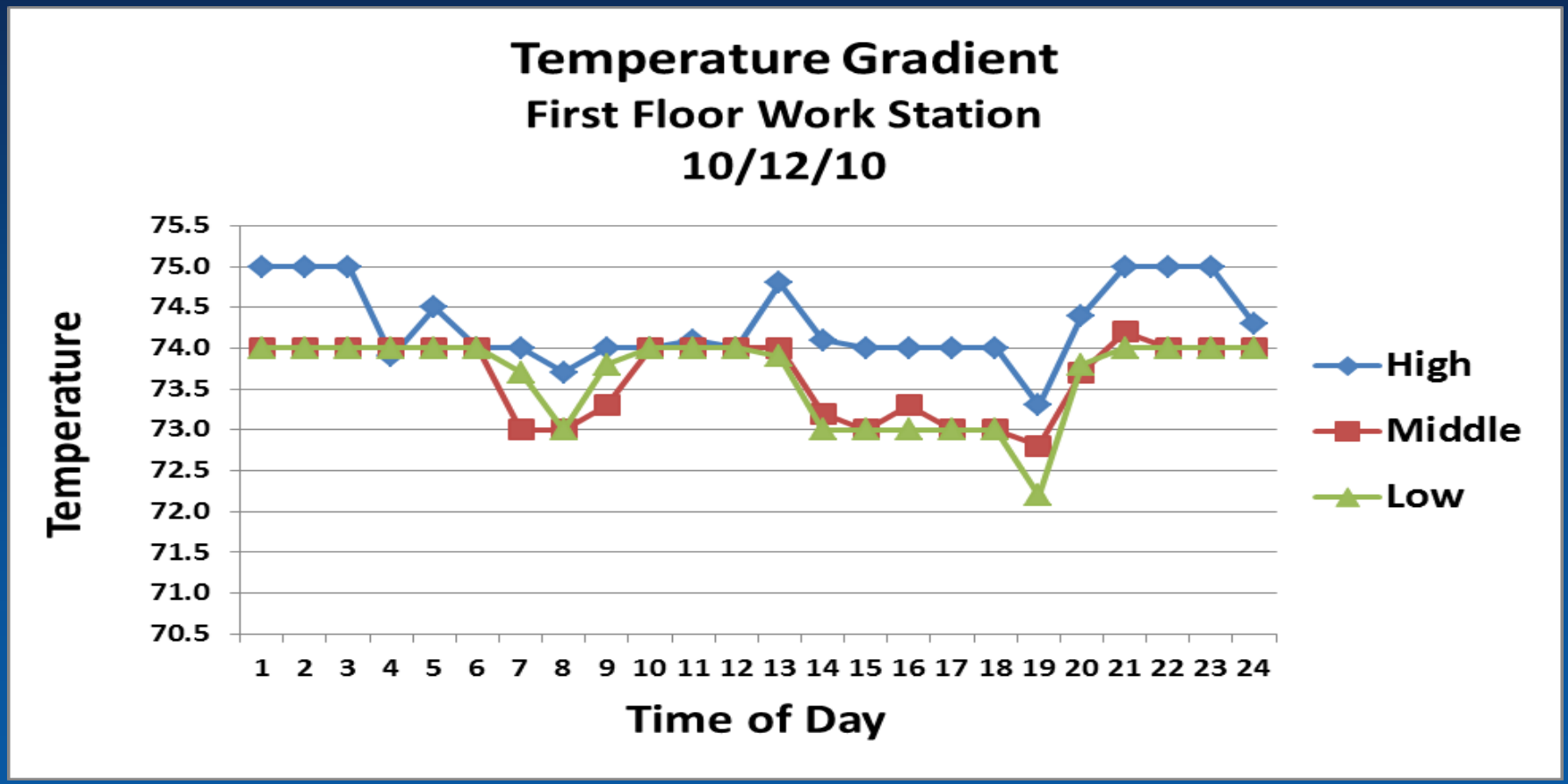
3Temperature Gradients

Head Height to Floor Level

THERMAL COMFORT *Advanced Level*

3Temperature Gradients

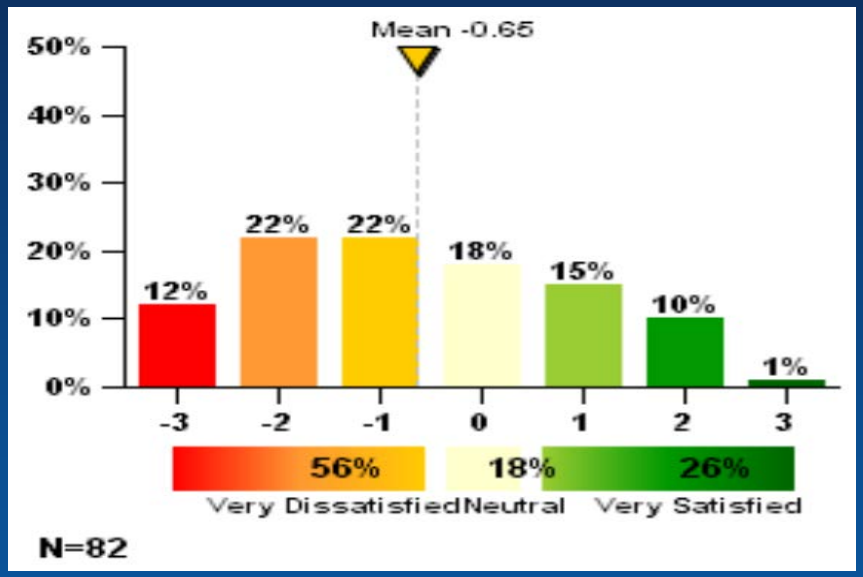
Head Height to Floor Level



INDOOR AIR QUALITY *Basic Level*

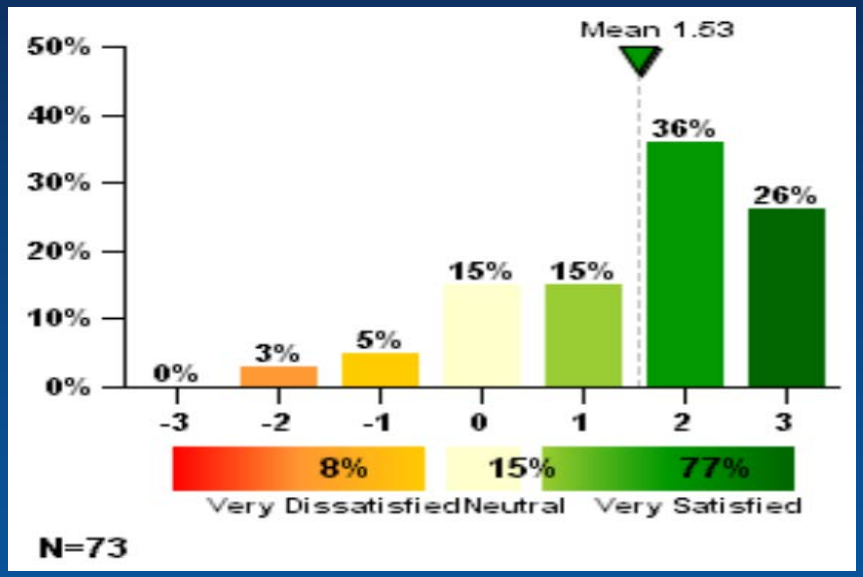
*1*Occupant Survey Results

Pre-Renovation: 2005



26 % Satisfied

Post-Renovation: 2010

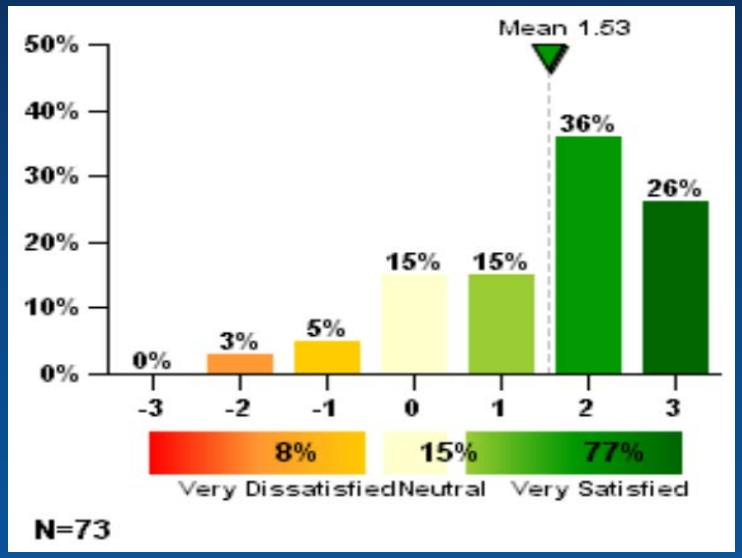


77% Satisfied

INDOOR AIR QUALITY *Basic Level*

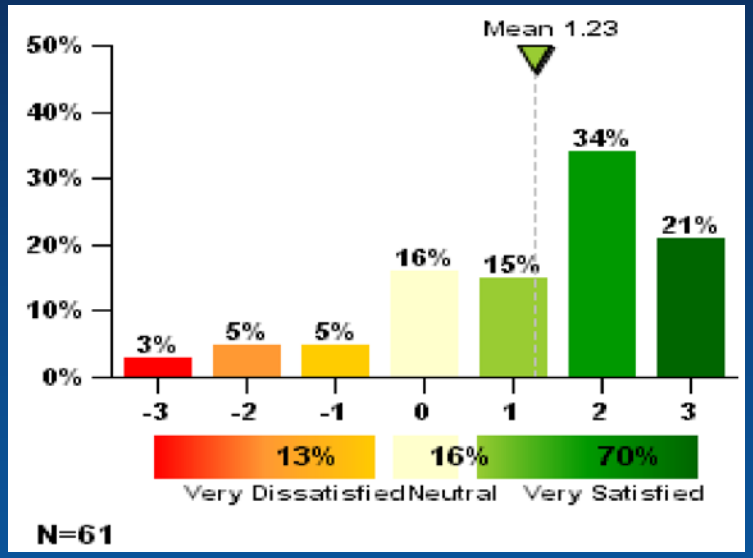
*1*Occupant Survey Results

Post-Renovation: 2010



77 % Satisfied

Post-Renovation: 2013



70% Satisfied

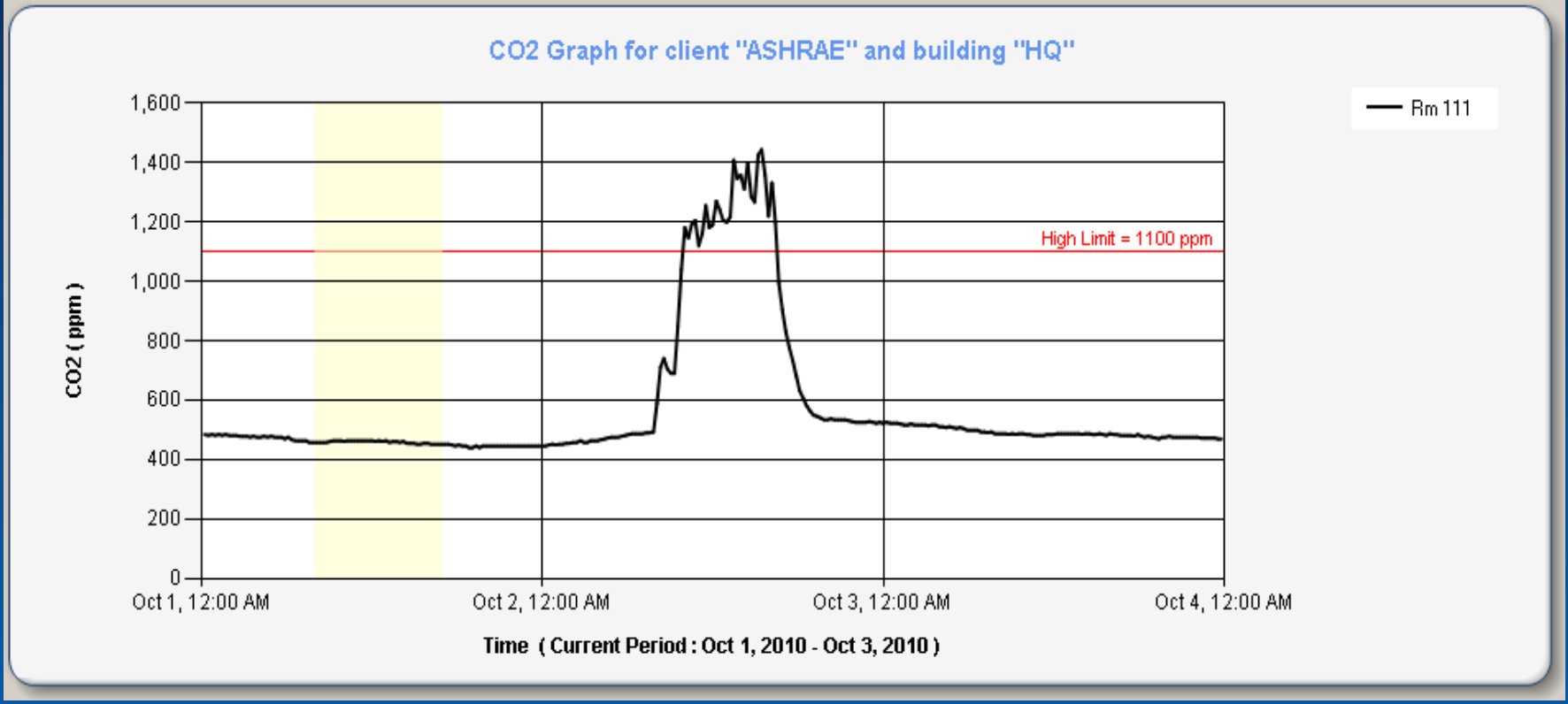
INDOOR AIR QUALITY *Basic Level*

*1*Ventilation Rate Measurement at OA Intake

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

INDOOR AIR QUALITY *Advanced Level*

*3*Continuous Measurement of CO_2 Education Center Conference Room



LIGHTING *Basic Level*

1Illuminance Measurements in Representative Spaces

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

LIGHTING *Basic Level*

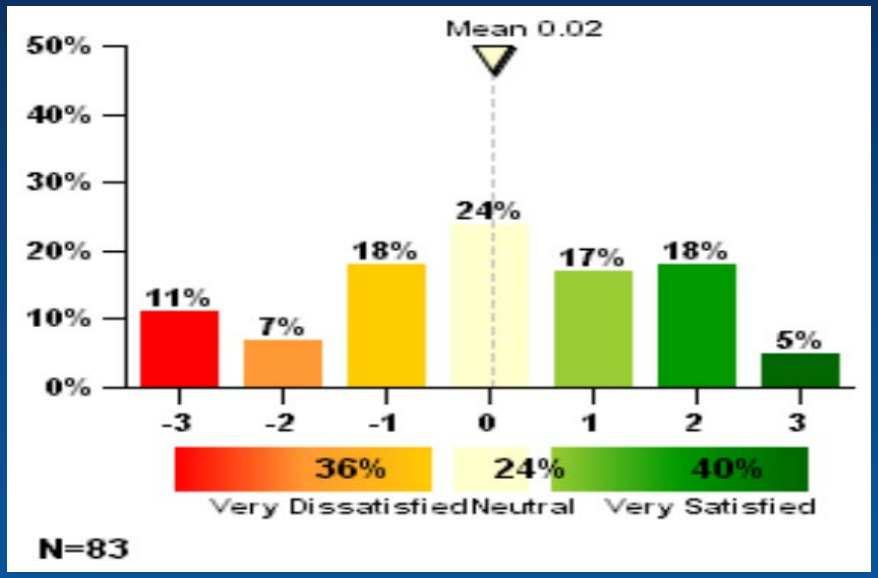
*1*Illuminance Measurements (fc) in Representative Spaces

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

ACOUSTICS *Basic Level*

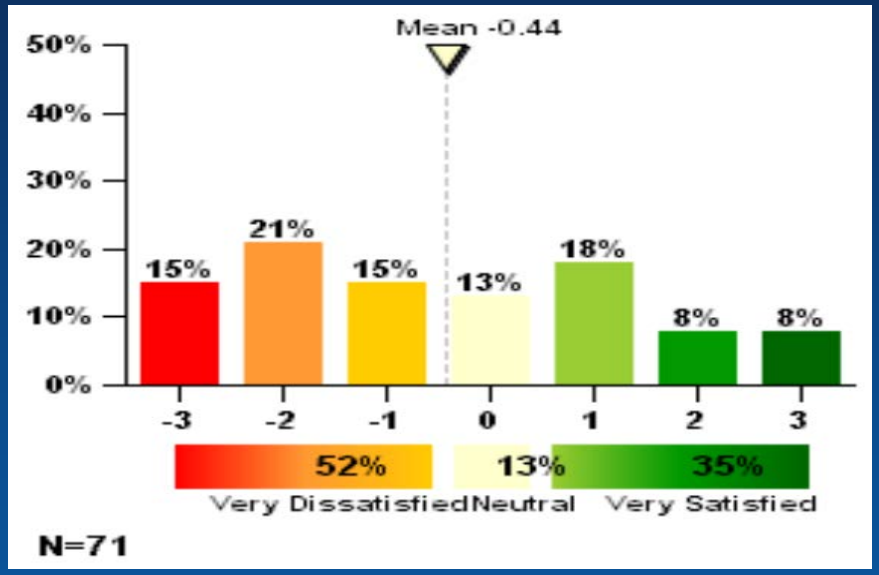
*1*Occupant Survey Results

Pre-Renovation: 2005



33 % Satisfied

Post-Renovation: 2010



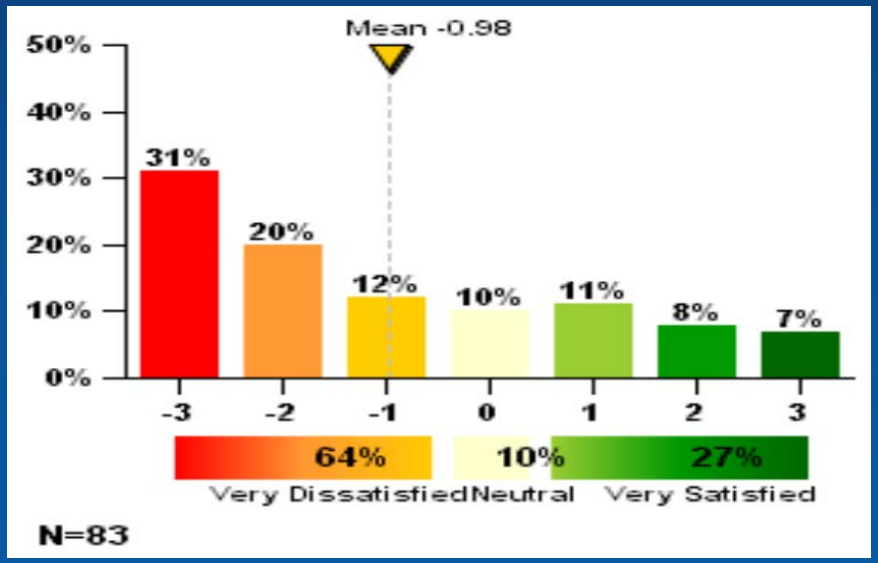
29% Satisfied

ACOUSTICS ***Basic Level***

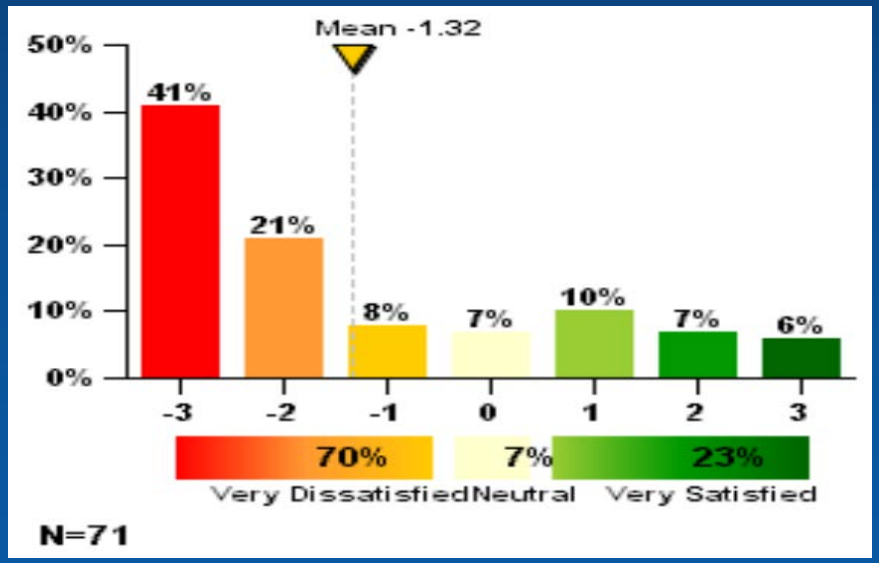
*1*Occupant Survey Results

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

Pre-Renovation: 2005



Post-Renovation: 2010



QUESTIONS??

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