N.E.A.T. NATIONAL ENVIRONMENTAL ASSESSMENT TOOLKIT MANUAL

CARNEGIE MELLON UNIVERSITY - CENTER OF BUILDING PERFORMANCE AND DIAGNOSTICS

CENTER FOR BUILDING PERFORMANCE & DIAGNOSTICS
CARNEGIE MELLON UNIVERSITY

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OVERVIEW

1. INTRODUCTION

Buildings are constructed with the assumption that they will function as designed and be operated as intended in the design. Environmental quality measurements are necessary to validate the design intent and the proper operation of the facility. Commercially available environmental sensors have been developed to measure environmental performance in thermal, IAQ, acoustics and visual qualities of a space. These sensors vary in their ease of use, data-logging capabilities and cost. To date, no integrated sensor package that includes all 4 performance areas is available on the market.

The Center for Building Performance and Diagnostics at Carnegie Mellon University has developed and is continually refining a portable indoor environmental cart, part of the National Environmental Assessment Toolkit (NEAT) effort. The current generation of the environmental cart toolkit includes sensors measuring air temperature at 3 heights, radiant surface temperature, relative humidity, carbon dioxide, carbon monoxide, volatile organic compounds, particulates, air velocity, light levels at 3 locations, a photometric camera that analyzes brightness/contrast and glare and an infrared camera. The sensor outputs are recorded using a data acquisition software with a user interface that runs on a notebook computer on the cart. An additional acoustical and thermal imaging data are also collected.

A foldable luggage carrier is used as the base for the NEAT cart. Mounting plates and telescopic poles are attached to support the sensors, a photometric camera, a notebook computer and the data terminal panel (DTP). The toolkit has a self-contained power supply, is easily maneuverable in the restricted office spaces and can be packed into one standard-sized travel suitcase for transport. It requires less than 5 minutes for assembly and disassembly.

This NEAT toolkit has been used as part of the U.S. GSA “WorkPlace 20•20”/NEAT project. The goal of the project is to investigate the relationship of physical environment, building attributes and “best practice workplace strategies” to workers performance and organizational effectiveness. The toolkit has been beta-tested at more than 30 WorkPlace 20.20 project sites in over 15 cites.

It is our objective to develop this toolkit into a robust commercial product for use by facilities management staff and other researchers. The development of easy to use, cost effective techniques for evaluating the actual thermal, acoustic, visual and air quality conditions in occupied buildings is crucial to ensure that buildings are performing to their full potential.

2. INDOOR ENVIRONMENT QUALITY STANDARDS FOR OFFICE

CATEGORIES	STANDARD GUIDELINES		SOURCES
THERMAL QUALITY			
Air Temperature	Cooling Season (0.5 clo)	76 - 82º F (RH: 30%)	ASHRAE 55 (2010)
		74 - 78º F (RH: 60%)	
	Heating Season (1.0 clo)	69 - 78º F (RH: 30%)	
		68 - 75º F (RH: 60%)	
	Floor surface temp.	66.2 - 84.2º F	
Radiant Temperature Asymetry	Warm Ceiling: < 9.0º F		ASHRAE 55 (2010)
	Cool Wall: <18.0º F		
Vertical Air T. Difference	< 5.4º F		ASHRAE 55 (2010)
Relative Humidity	≤ 65%		ASHRAE 55 (2010)
	≥ 30%		CCOHS (2006)
Air Speed	≤ 40 ft/min		ASHRAE 55 (2010)
	≤ 50 ft/min		CCOHS

CATEGORIES	STANDARD GUIDELINES				SOURCES
LIGHTING QUALITY					
Default Luminance and Luminaire intensity recommendation for VDT applications	Medium to Good	CSA/ISO Type I and Type II monitors	Positive Polarity	≤ 1500 cd/m² at 65º and above	IESNA HB-10-11 (2011)
			Negative Polarity	≤ 1000 cd/m² at 65º and above	
	Poor	CSA/ISO Type III Monitors	Positive Polarity	≤ 500 cd/m² at 65º and above	
			Negative Polarity	≤ 200 cd/m² at 65º and above	
	Luminaire Candlepower Limits		300cd @55º, 185cd @75º , 60cd @85º		
Luminance Ratio	Paper task to negative(positive) polarity VDt screen 3:1 (1:3)				IESNA HB-10-11 (2011)
	Task to immediate background surface 3:1				
	Task to dimmer(bright) distance background 10:1 (1:10)				
Maintain visual comfort	Task to delight media 1:40, Task to luminaires 1:40				IESNA HB-10-11 (2011)
	Light-source-adjacent-surfaces to light source 1:20				
Minimize veiling reflections	CSA/ISO Type I and II negative polarity monitors in critical/high situations		Bright ceiling and/or wall zone to dimmer ceiling and/or wall zone 4:1		IESNA HB-10-11 (2011)
			Bright ceiling and/or wall zone to dimmer ceiling and/or wall zone 8:1		

2. INDOOR ENVIRONMENT QUALITY STANDARDS FOR OFFICE

CATEGORIES	STANDARD GUIDELINES	SOURCES
	INDOOR AIR QUALITY	
Carbon Dioxide	700 ppm above outdoor CO_2 level	ASHRAE 62 (2010)
	< 5000 ppm	OSHA
Carbon Monoxide	< 9 ppm	EPA (IAQ spec)
	50 ppm (1 hour)	OSHA
TVOC	< 200 ug/m^3 above outdoor TVOC concentration	EPA
Particulates	PM 2.5: 1 ≤ 1,665,278 #/CF or 20 ug/m^3	Aircuity
	PM 10: ≤ 17,204 #/CF or 40 ug/m^3	
	Total Particulates: < 20 ug/m^3	EPA
	ACOUSTIC COMPONENT	
Room Criteria	≤ 40 (Open-plan offices)	ASHRAE (2010)
	≤ 35 (Private offices)	
Quality Assessment Index	≤ 5 dB	ASHRAE (2010)

3. POST OCCUPANCY EVALUATION

The environmental quality evaluation involves the environmental testing and examination of a representative sample of work stations in the work group that is being evaluated. The work group is divided into spatial zones and a minimum of 2 sample workstations are selected in each zone. Approximately 20 sample workstations are measured in one day. The division of spatial zones is based on several factors. These are:

1. Information Obtained – Based on the information obtained about the work group such as the mechanical systems in the space, occupant concerns, nature of work, decisions are made about the approximate locations of the samples, and the testing process.
2. Overall workgroup size – Approximately 30% of the total number of work stations are measured.
3. Distance from the building perimeter – the work group is divided into perimeter zones (those that are adjoining an external wall, window, or have a seated view of the window), interior zones (those that have a view of the window from the adjacent corridor), core (those that have no access to an external window)
4. Orientation (North / South / East / West) – work stations are measured in the order that the eastern section of the building is measured in the morning, followed by the northern, southern, and the western section in the evening.
5. Open vs. closed offices – In addition to zoning work stations based on location on the floor, offices are classified based on the partition type.
6. Special function spaces – Conference rooms, kitchen areas, corridors, are considered separately.

PHYSICAL MEASUREMENTS IN THE SAMPLE SPACE

The instrument cart is placed in the position of the occupants chair for 5 minutes. For the first two minutes, the sensors are allowed to acclimatize to the environment in the work space. The sensor readings of the latter three minutes are recorded at 15 second intervals and averaged to obtain the final measurements in that work station. During the time when the physical measurements are recorded in a work station, the occupant is asked to complete the ‘User Satisfaction Questionnaire’.

PHYSICAL INDICATORS/STRESSORS

An aspect of this POE project is the observation and recording of physical traces and indicators, which can either be negative or positive. The presence of a fan in a workstation indicates the inability of the central conditioning system to provide adequate cooling. In contrast, a heater indicates inadequate heating capacity. Recording the presence of the indicators, in addition to environmental instrumentation, helps the investigator assess the environmental performance of a facility.

1:OVERVIEW 2:CART 3:SENSORS 4: SURVEYS 5: TABS 5:DATA 6:INDEX

4. PARAMETERS MEASURED

INDOOR MEASUREMENTS	SPOT OF MEASUREMENT
Air Temperature Relative Humidity	1.1 Meters from floor
Carbon dioxide Carbon Monoxide Particulates Volatile Organic Compounds Air temperature Air speed	0.6 Meters from floor
Air temperature Air speed	0.1 Meters from floor
Light Level	• Work surface • Monitor • Keyboard
Surface temperature	• Partition / Internal Wall • Ceiling • Floor • Window / External Wall
Brightness / Contrast	• Luminance Image

OUTDOOR MEASUREMENTS	SPOT OF MEASUREMENT
Outdoor (measured in the morning, noon and evening)	• Air Temperature in Shade • Humidity • Carbon Dioxide • Carbon monoxide • Particulates

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5. EQUIPMENT

1. N.E.A.T CART EQUIPMENT

A. SENSORS

DESCRIPTION	MANUFACTURER	MODEL #	QUANTITY
1. CO_2	Telaire	2004	1
2. CO	Transducer	T Series	1
3. VOC	Technology		1
4. Particulate	Shinyei	PPD20V	1
5. Temperature	National	LM35	3
6. Relative Humidity	Semiconductor	HIH-3602	1
	Honeywell		

B. ELECTRONICS

1. Laptop	IBM	R5OE	1
2. Charger		FA125A#AC3	1
3. DAQ	National Instruments	6024E	1
4. DAQ Connector	National Instruments	SHC68-NT-S	1
5. Software	NI	Labview	1

C. MISCELLANEOUS

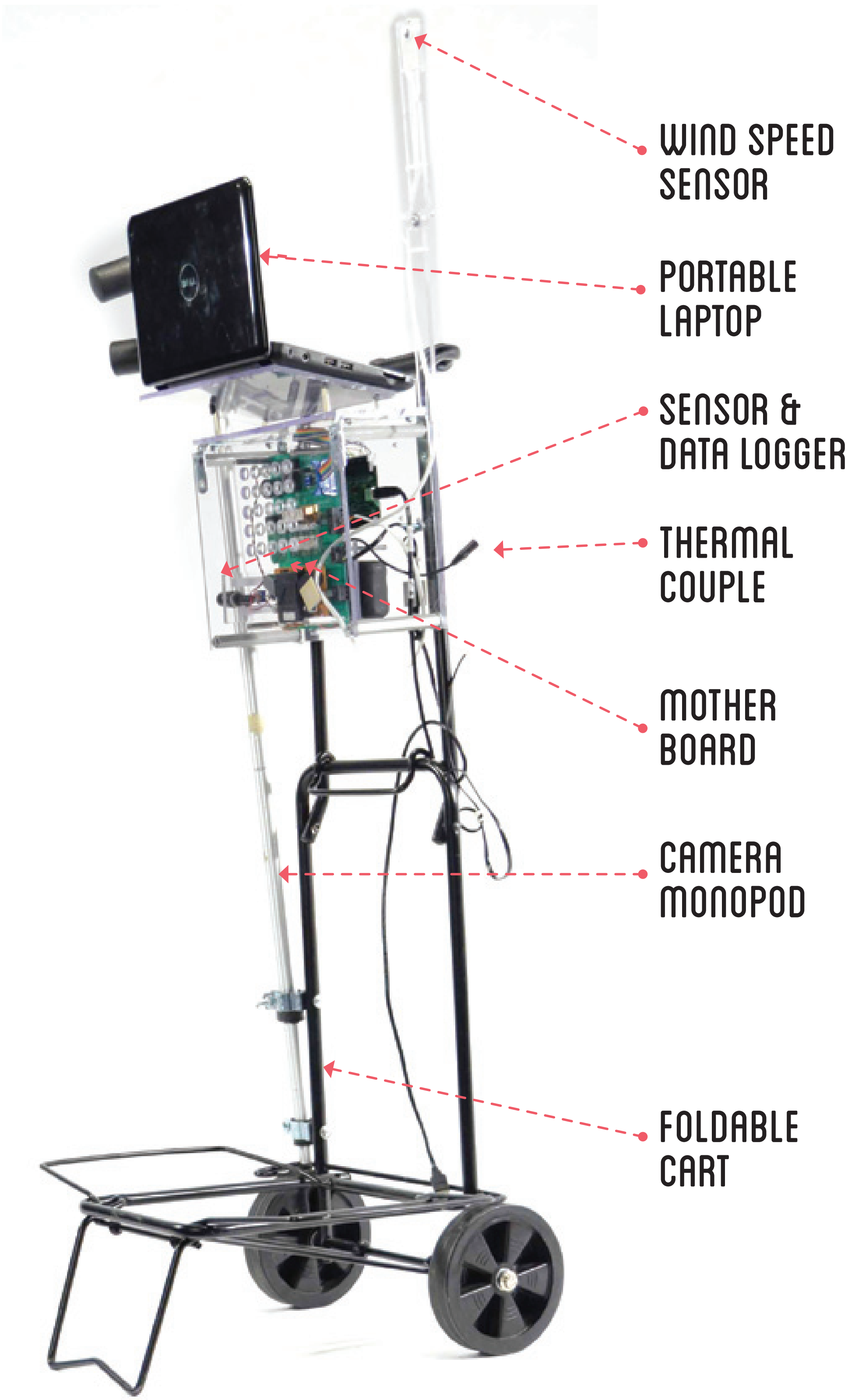
1. Battery			1
2. Battery Charger			1
3. Foldable Cart			1
4. Circuit Board	Express PCB	N/A	1

2. SENSORS & STAND-ALONE UNIT

DESCRIPTION	MANUFACTURER	MODEL #	QUANTITY
8. Handheld IR Temp	Omega	OS643	1
9. Light Meter	Minolta	D10	1
10. IQcam	Lumetrix	Lumetrix 400	1

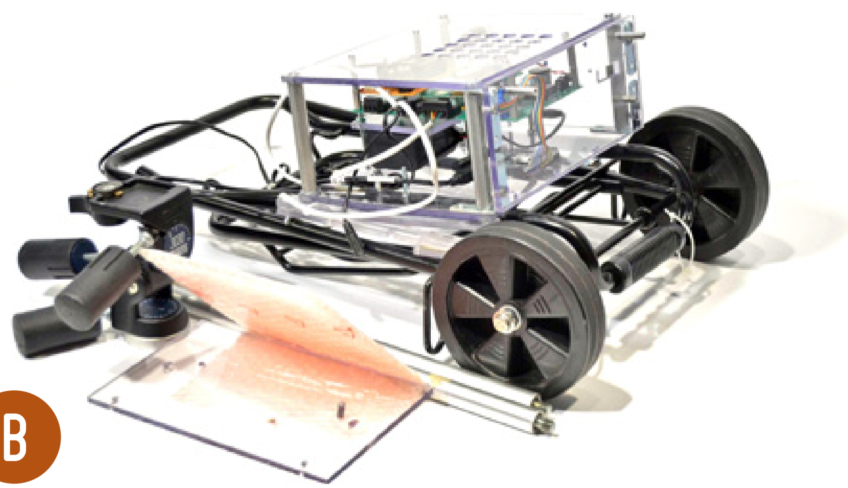
N.E.A.T CART

1. OVERVIEW



2. N.E.A.T CART ASSEMBLY

A



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C

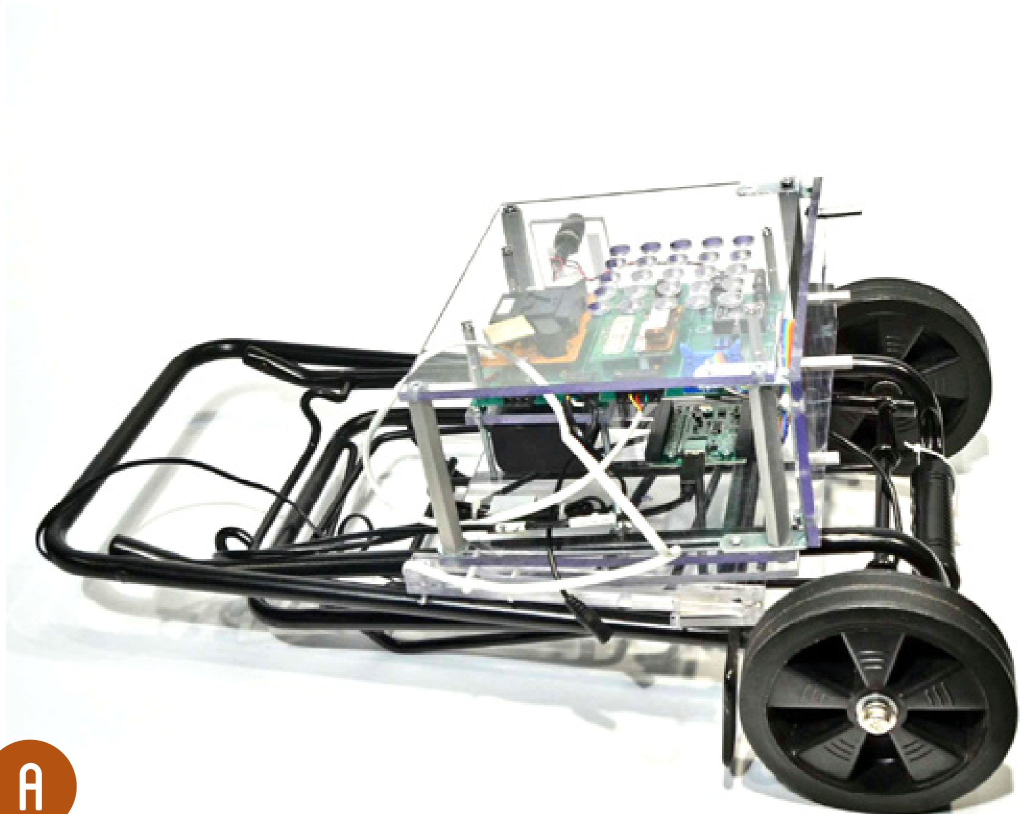
D

STEP 1: Open the suitcase. Remove the protective foam pads. Carefully unload the folded cart, tripod and acrylic computer shelf.

N.E.A.T CART

STEP 2: Assemble the camera monopod.

N.E.A.T CART



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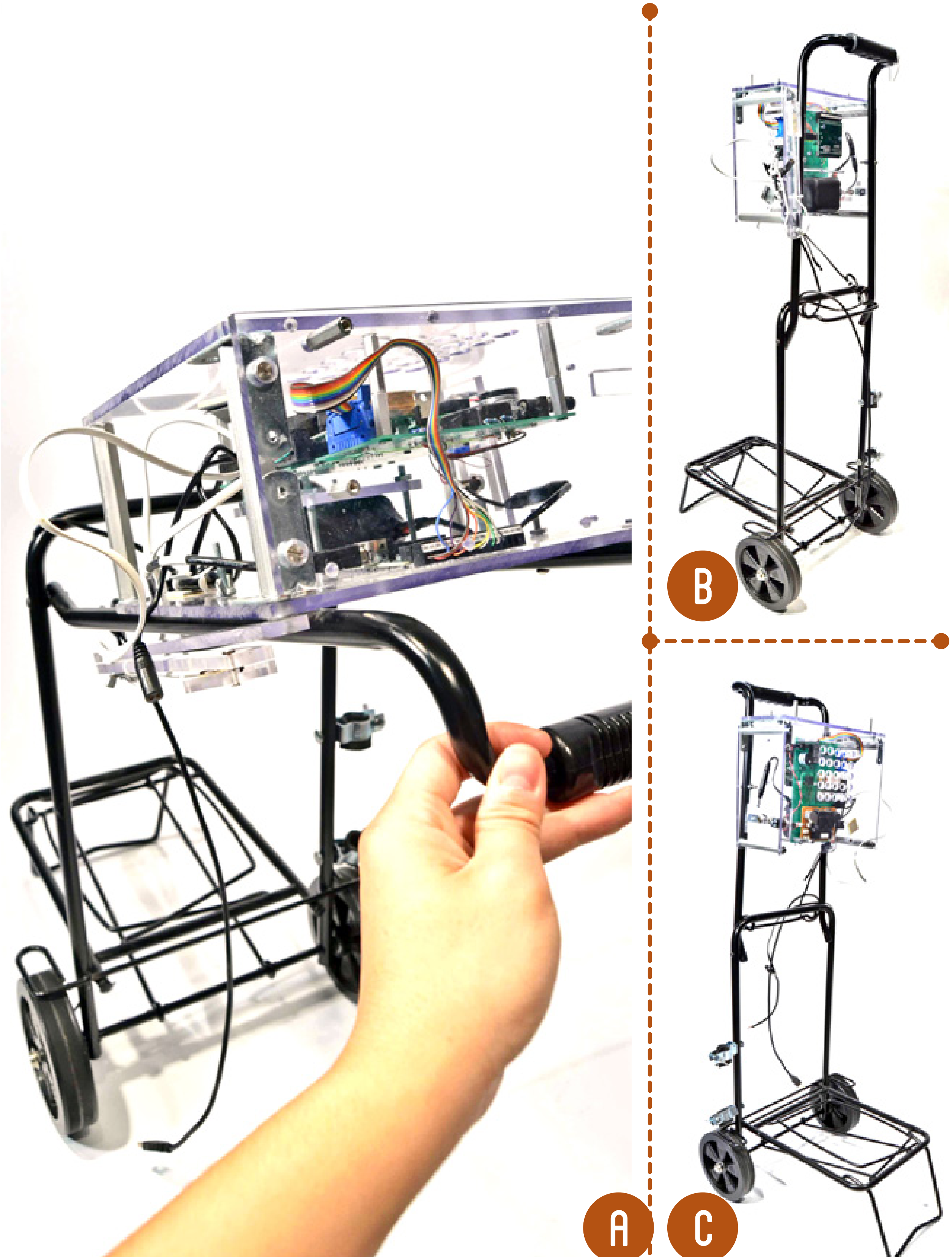
STEP 3: Unfold the cart by pulling the handle that is hinged at the wheels upward. Once done, unlatch the stand that is hinged at the horizonal cart component.

N.E.A.T CART



STEP 4: Rotate the motherboard along with the handle to standing position. Make sure everything is tightly latched before proceeding to the next steps.

STEP 5: Attach the monopod to the side of the cart. Make sure to turn the screw tightly to keep the monopod in place and ensure stability for attached camera.

N.E.A.T CART


A


B


C


D


E

STEP 6: Carefully remove the acrylic laptop tray from its protective envelope. Carefully screw it on top of the mother board using the provided toolkit.

N.E.A.T CART

STEP 7: Carefully place portable laptop on top of the tray.
Connect the motherboard with it.

ILLUMINANCE SENSOR OMEGA HHLM-1

1. INTRODUCTION

This is a hand held light meter that for the purposes of the N.E.A.T. project is meant to be an input device for the NEAT cart software. Inputting this data is a manual process described to the lower right.

0.0929 lux = 1 fc

Specifications:
200 hours life with 4 AAA batteries
Stated accuracy at 23°C ± 5°C, <70% relative humidity.

2. INSTRUCTION GUIDE

1. Set the power switch to the desired range (use range button to select x10; x100; x1,000; and x10,000 lux depending on the brightness of the space.

2. Hold the sensor head steady and make certain that no shadows from the observer are blocking the light source. Detach the sensor block and place at a distance if necessary.

3. Read the illuminance value from the display and input the appropriate value into the NEAT cart software as desribed to the right. If the magnitude of the reading is unkown press the Range button until a satisfactory reading is obtained.

For more information visit:
http://www.omega.com/pptst/HHLM-1_HHLM-1.html

TIPS

>Clean the sensor head using a damp cloth only
>Cover the sensor head when not in use to extend sensor life

Sensor
Senses the light level.
This block is detachable.

Data Display
Displays Current Measurement in lux at the set range

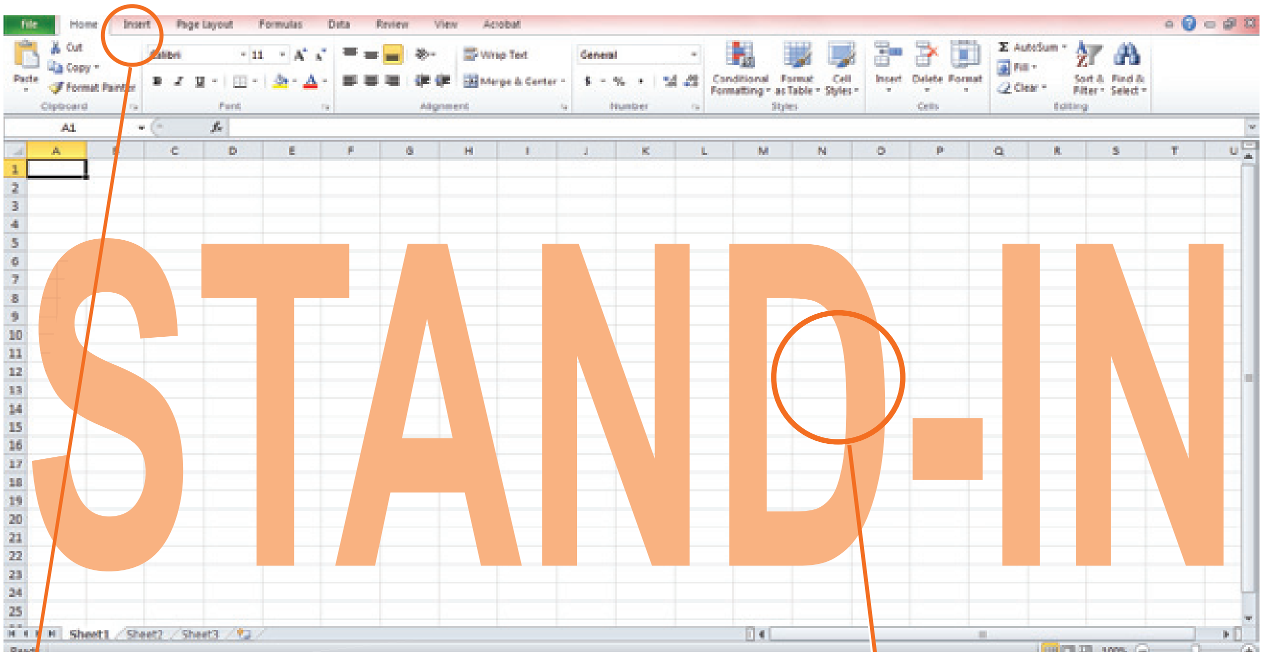
Hold
Pauses measurement gathering and displays current value

Range
Changes range of measurement (x10 to x10,000 lux). Select range then wait for it to be displayed.

Max
Displays the maximum value from the measurement period.

Hold down 2 seconds to light the data display.

Red Switch
This will turn the meter on and off as well as set the range x10 to x100.



1. Select Data Tab

Select the data tab in order to see the manual input section

2. Measure

Use the Omega HHLM-1 light meter to measure the illuminance level at the work surface and keyboard levels

3. Input Data

Input the data from the Omega HHLM-1 light meter in the illuminance section in lux.

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AUTO METER VF

1. INTRODUCTION

Ambient Light Sensor

2. INSTRUCTION GUIDE

1. Set the power switch to the desired range (use range button to select x10; x100; x1,000; and x10,000 lux depending on the brightness of the space.

2. Hold the sensor head steady and make certain that no shadows from the observer are blocking the light source. Detach the sensor block and place at a distance if necessary.

3. Read the illuminance value from the display and input the appropriate value into the NEAT cart software as desribed to the right. If the magnitude of the reading is unkown press the Range button until a satisfactory reading is obtained.

For more information visit:
http://www.omega.com/pptst/HHLM-1_HHLM-1.html

Diffuser
Mounting index

S/A/H Button

Receptor
Mounting index

Measuring Button

Metering Button

Accessory - receptor jack

Shutter speed/ frame rate display
Displays the current shutter speed or frame rate, which is set with the up/down key

Power Button

ISO button

Digital readout

Display selector button

Mode button
Displays the f-number or exposure value, in increments of 0.1 stops.

Sync terminal

THERMOGRAPHIC FLIR B300

1. INTRODUCTION

This camera is used to capture the surface temperatures of the space. Each thermographic photo will scale the temperature delta in order to capture the entire scope of surface temperatures.

2. INSTRUCTION GUIDE

1. Make sure that the camera battery has been fully charged (4 hours) and replaced within the camera body.

2. Turn the camera on with the power button.

3. Flip the camera lens down into the ready position and open the lens cap.

4. To change the displayed color scheme, press the setup button, scroll down using the joystick until palette is highlighted and firmly press the joystick down. Then use the joystick to scroll between the palette options. The rainbow setting is useful for most applications. Press setup to exit this menu after selecting the desired color palette.

5. Press the mode button to select simultaneous mode to take a digital photo at the same time as the thermographic photo. Press mode again to exit this menu.

6. Press the measure button and set the camera to measure spot. Press the measure button again to exit this menu.

7. With measure spot selected the camera will automatically chose an appropriate temperature scale for the image provided that that it has been focused. To auto-focus the camera press down the AF button. Note that this set range can be adjusted in real time with the joystick.

8. When ready press the camera trigger to take the photo and press save if it is satisfactory.

9. To transfer the image to a computer, simply connect the camera to the computer with a USB cable and make sure the camer is turned on.

For more information explore the CD from the camera case with a computer and go to the user documentation folder.

TIPS

>Make sure to Autofocus the camera before each photo you take.
>Make sure the battery is charged before use!

Joystick
Enables navigation though the camera menus.

Lens

Power
Turns the camera on and off.

Measure
Sets the automatic temperatures measurement scale method.

Mode
Changes the photo mode.

Setup
Changes the camera options.

USB Port
Connects the camera to a computer (located within the panel on the bottom of the camera)

Camera Trigger
Takes a picture that can be saved.

AF
Automatically focuses the camera.

Lens Cap

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SURFACE TEMPERATURE SENSOR OMEGA OS643

1. INTRODUCTION

This device measures the surface temperature of objects within 2m.

2. INSTRUCTION GUIDE

This device measures the surface temperature of objects within 2m.

1. Press the red “MEAS” button to turn the sensor on.

2. Wait a few moments for it to calibrate itself.

3. Move within 2m and point the sensor at the desired surface.

4. Press and hold the red “MEAS” button to measure the temperature of the surface.

5. Press the F/C button to switch from imperial to SI units or vice versa.

5. Press the light button to turn on the display area back-lights.

6. The device will turn itself off after about 30 seconds of inactivity.

*Note that the diameter of the measuring area will decrease the closer the sensor is to the subject surface

For more information visit:
http://www.manualslib.com/manual/114643/Omega-Os643.html#manual

TIPS

>Clean the sensor head using a damp cloth only
>If readings seem incorrect clean the surface of the sensor area

SENSORS HANDHELD

F/C BUTTON

This will change the units the surface temperature will be displayed in (Imperial/SI)

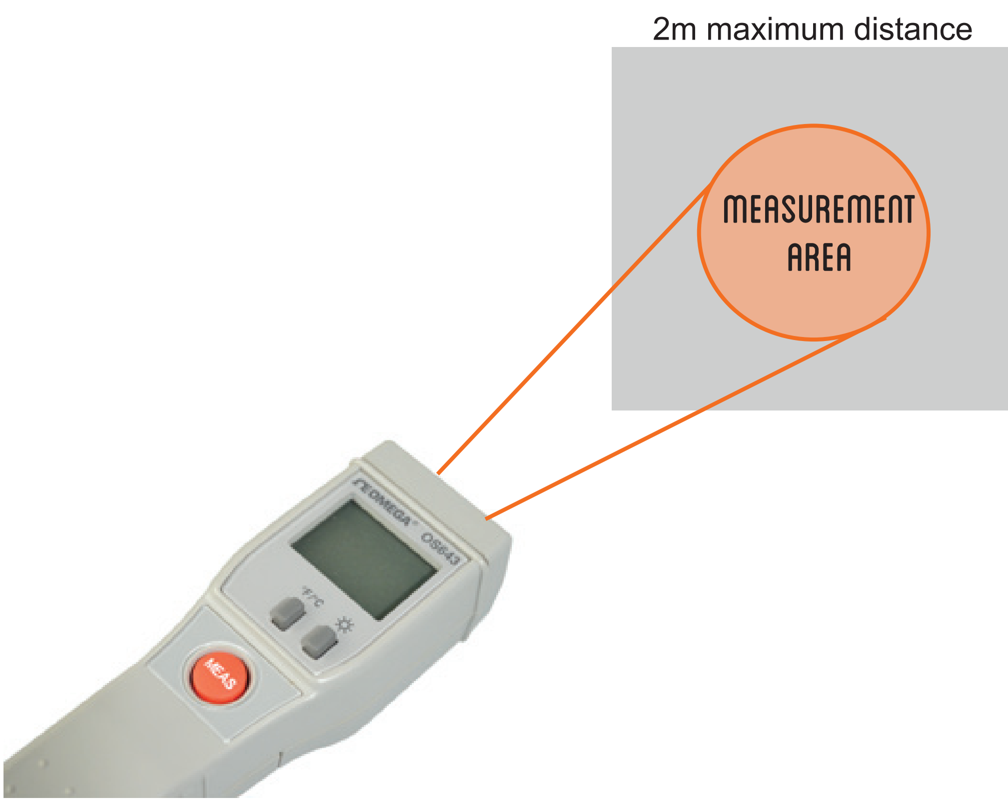
☼ LIGHT BUTTON

Turns the display backlight on

MEAS BUTTON

>Turns the device on.
>After initial calibration, press and hold to take temperature measurements.

OPERATION DIAGRAM



FACILITY PERFORMANCE MONITOR AIRCUITY

1. INTRODUCTION

This device monitors air quality paramters from temperature and humidity to VOC and CO2 concentrations. It is meant to serve as a calibration tool for the NEAT Cart.

2. INSTRUCTION GUIDE

1. Plug in and turn on the Aircuity monitor with the power button.

All the following instructions are completed on the device's touch screen.

2. Enter the PIN number

3. Press test then select the appropriate location. For example, Carnegie Mellon University : Intelligent Workplace : NEAT Cart Test 1.

4. Press test and the monitor will start monitoring the indoor air quality parameters of the space.

5. Press stop when the measurement period has elapsed.

6. The gathered data can then be transfered wirelessly to the CMU database.

MEASUREMENT PROTOCOL

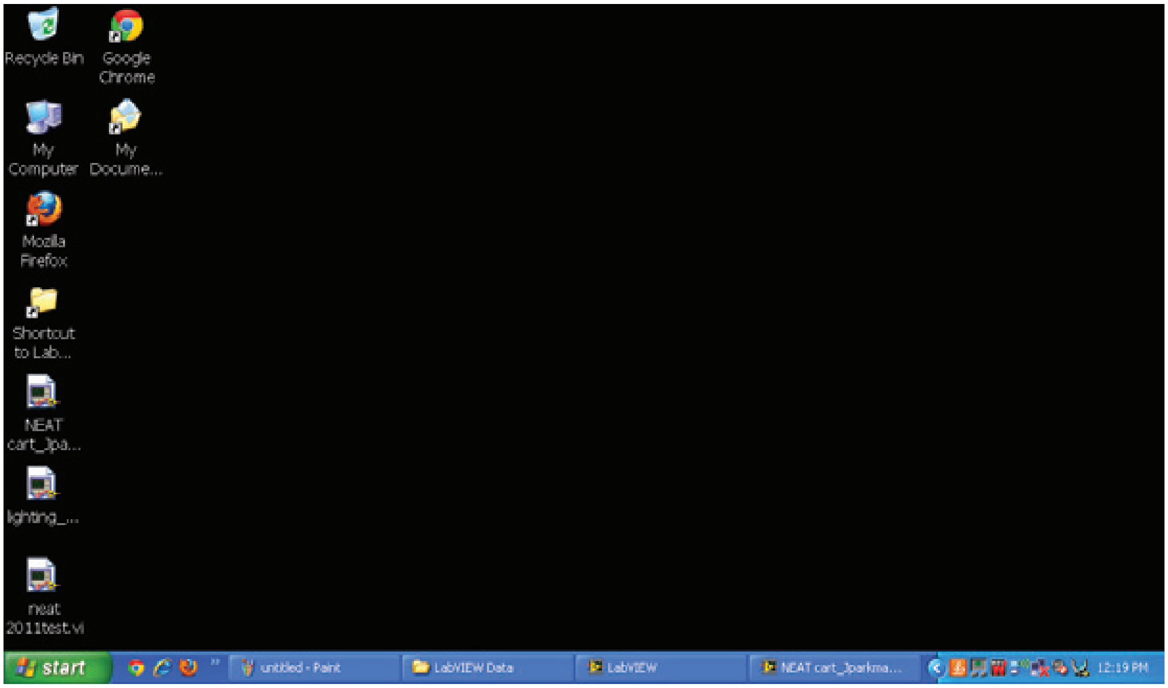
24 hour continuous measures are taken in several locations within the work group with the Aircuity facility performance monitor. This will measure temperature, relative humidity, CO2 and CO, large (PM10) and small particulates (PM25), TVOC, radon and ozone present in the space. Typically, these continuous measurement instruments are set in the most typical workstation configuration, usually interior rather than perimeter or core, and in an unoccupied workstation within an occupied work area.

TOUCH SCREEN
Perform all necessary operations with the touch screen

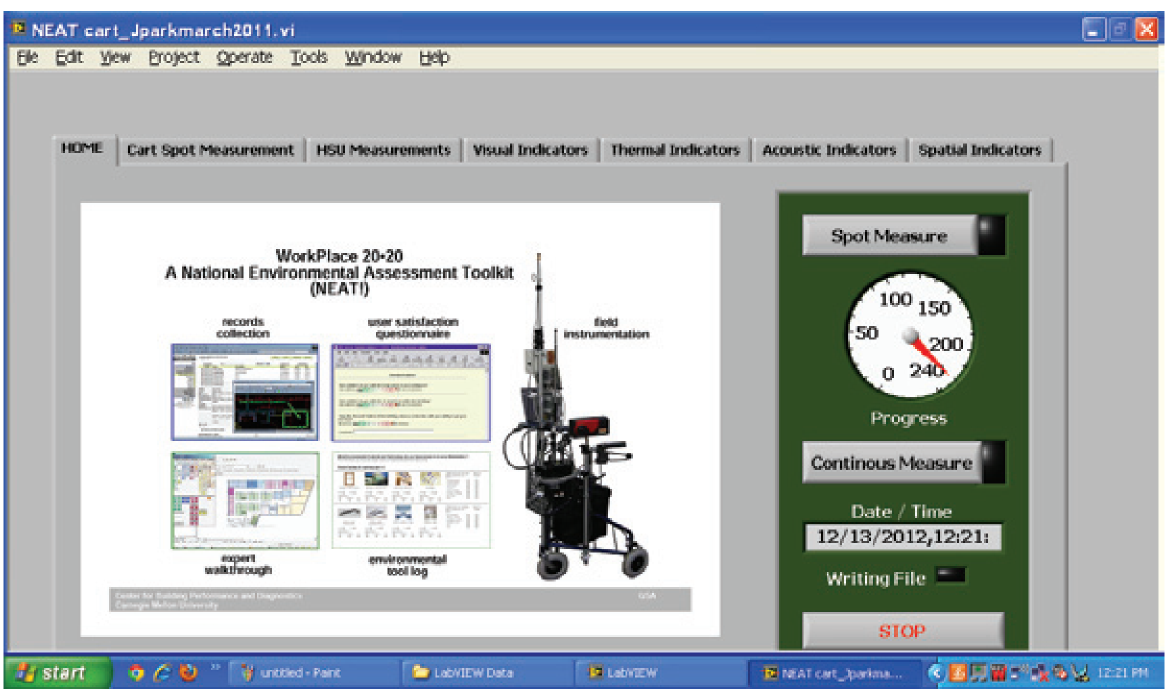
POWER
Turns the aircuity monitor on once it has been plugged in.

DATA LOGGER

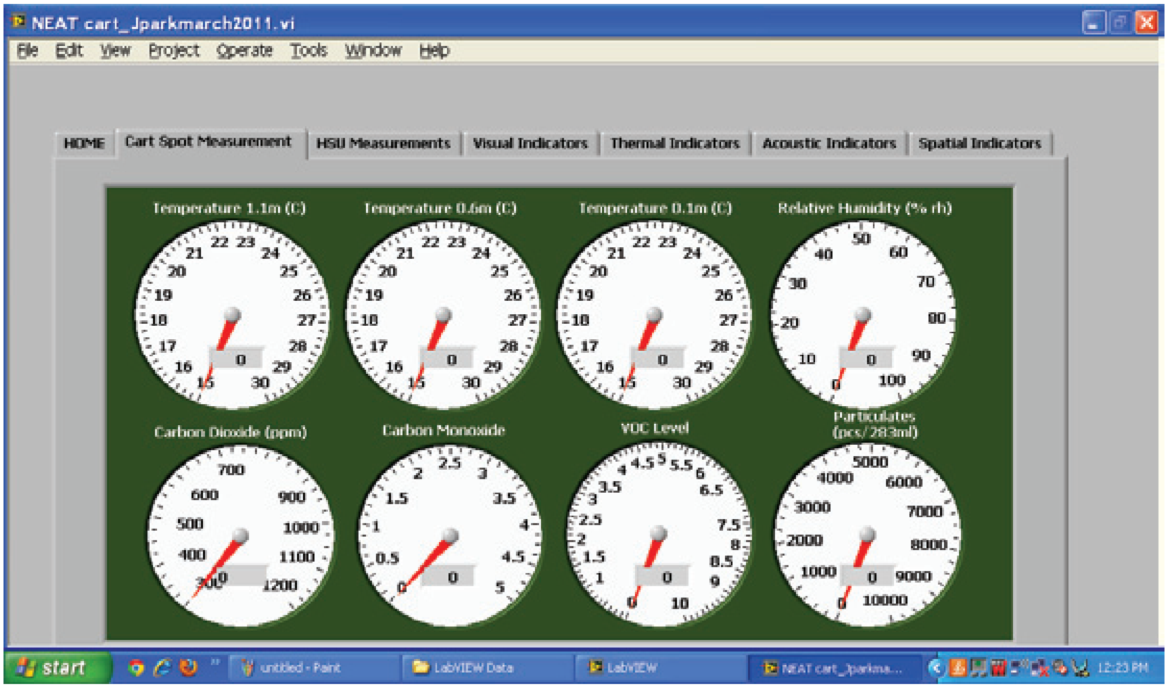
A. DATA LOGGER INSTRUCTIONS



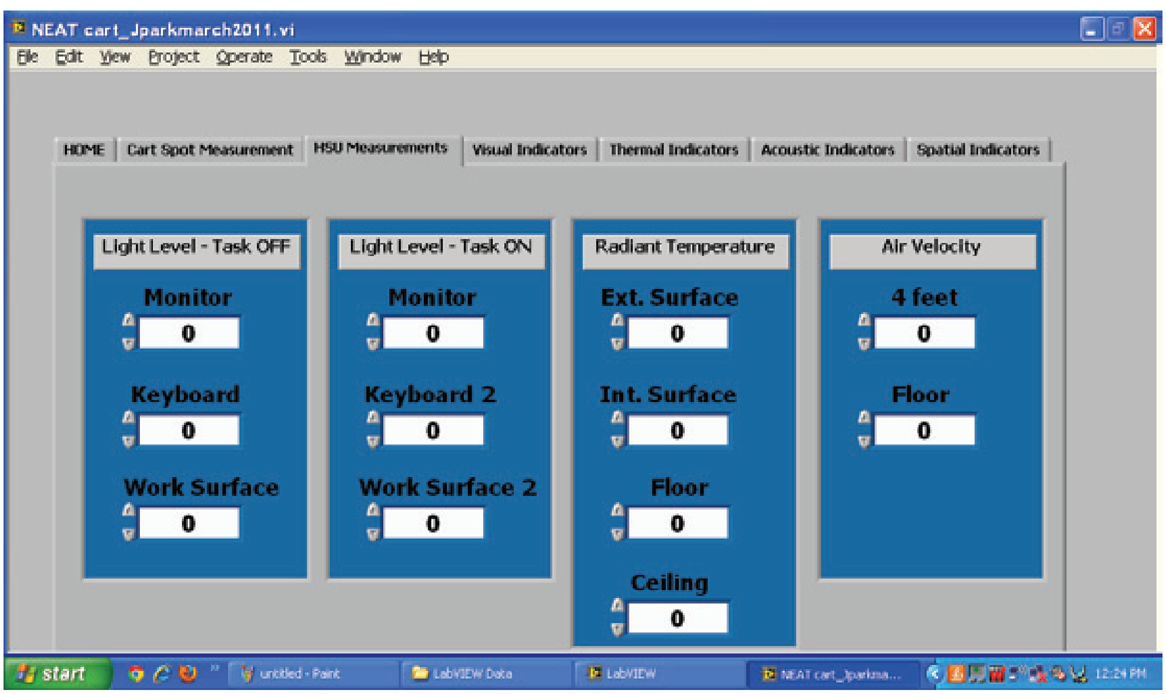
Select one of the .vi files from the desktop to start LabVIEW 8, the program used to gather measurements from the NEAT cart.



Once LabVIEW 8 is running, press the spot measure button to begin measuring. Next, select the cart spot measurement tab to observe the measurement process.



Verify that all sensors are operating properly. If there is a problem, the measurement gauge will remain at zero.

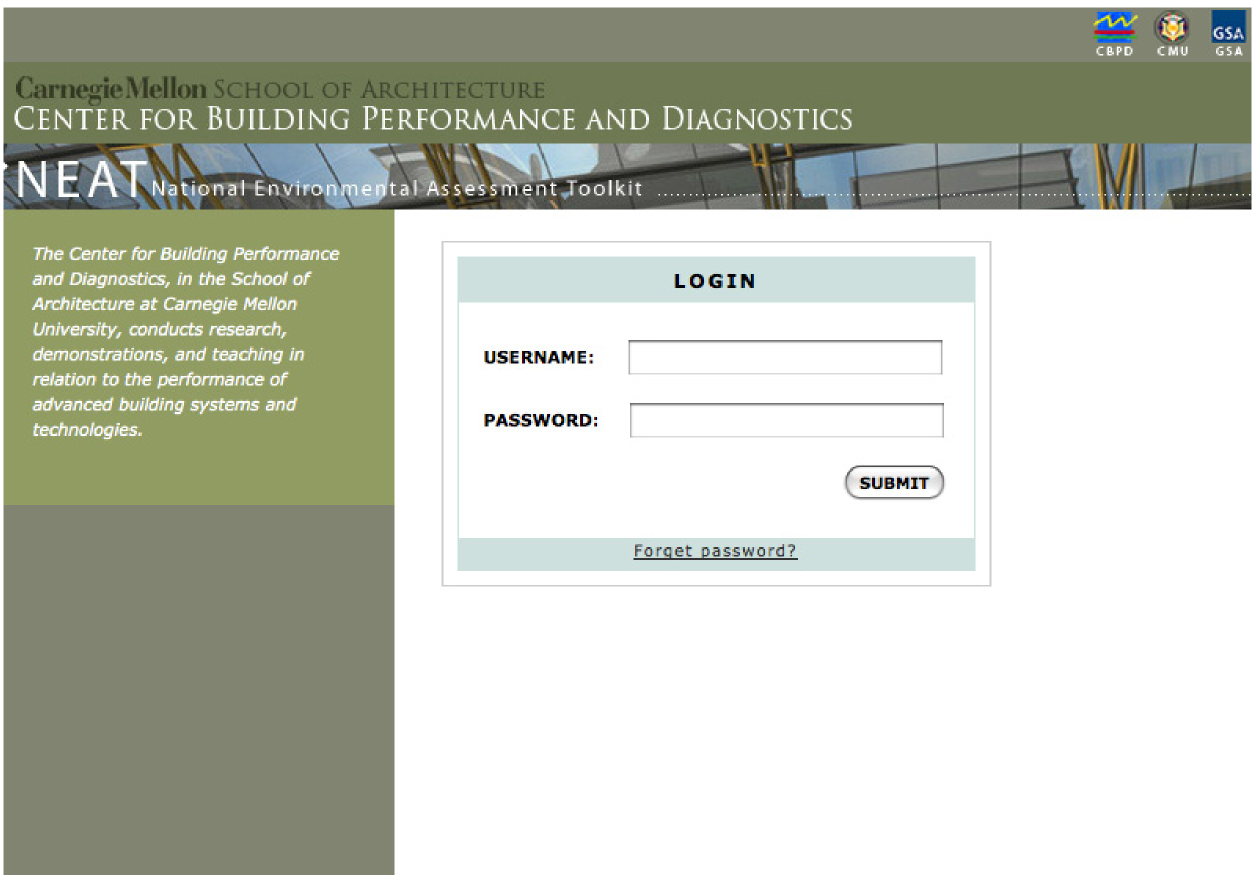


Select the HSU measurement tab to manually record the light levels. Use the Olympus HHLM-1 (03:01) to measure the light levels.

1. USER SATISFACTION SURVEYS [ON-SITE]

Initially developed by the National Research Council Canada to support the Cost-effective Open-Plan Environment (COPE) Project, this two page, 25-question survey (plus 4 demographic questions) has been modified to accommodate the NEAT Toolkit's POE parameters.

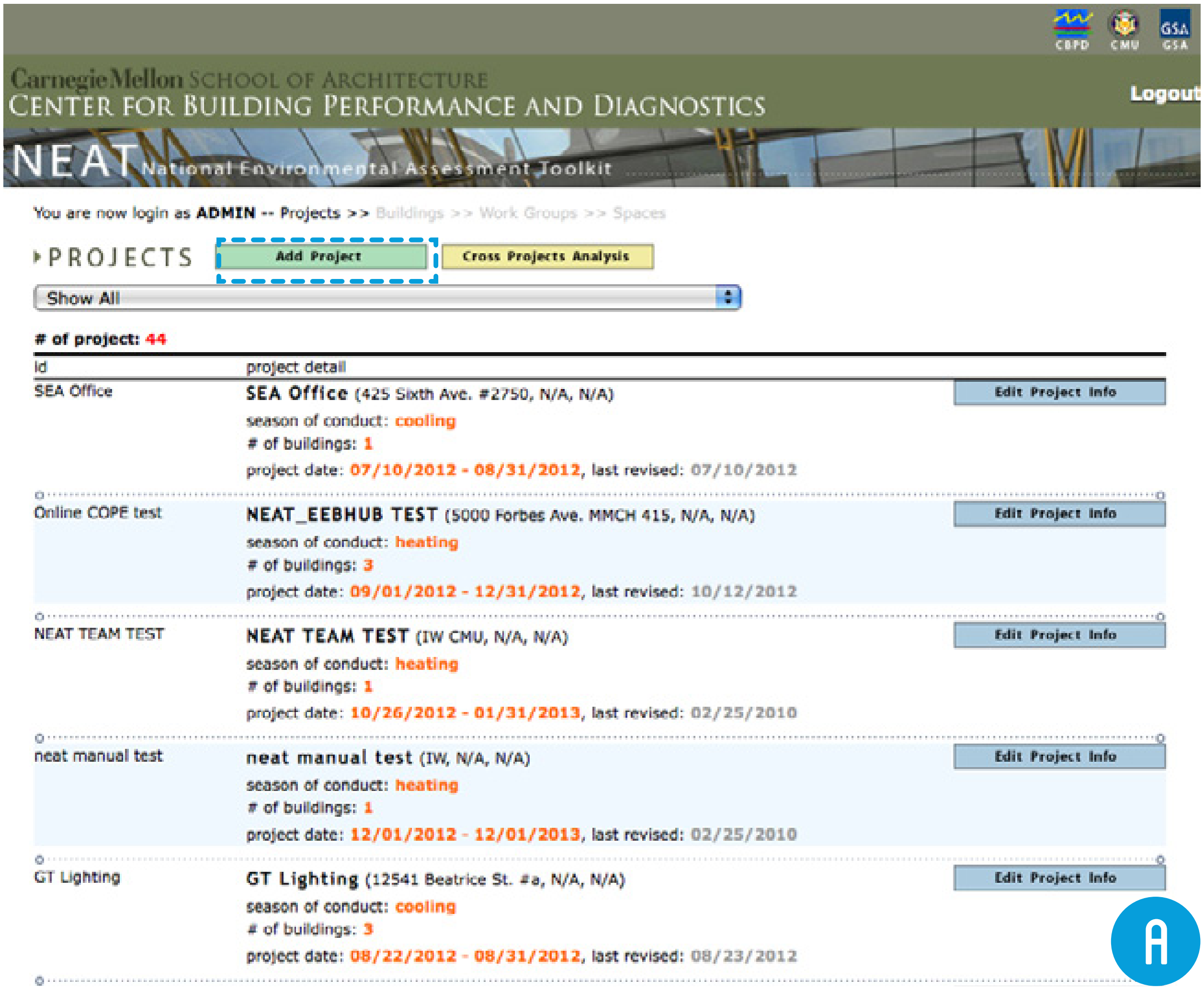
The survey addresses user satisfaction with the environmental performance characteristics of temperature, air quality, lighting and acoustics.



WEBSITE http://neat-cbpd.arc.cmu.edu/neat

USER NAME	neat
PASSWORD	neat2011

STEP 1: In order to access the short survey, you must login to the website indicated above with the provided user name and password



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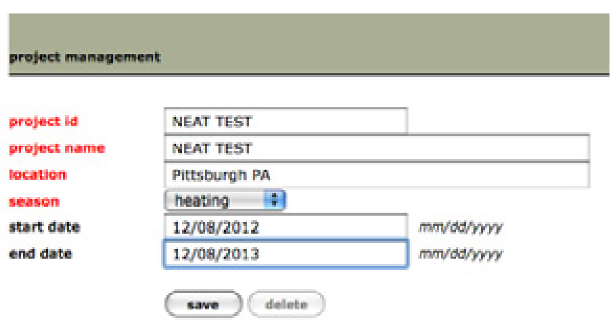

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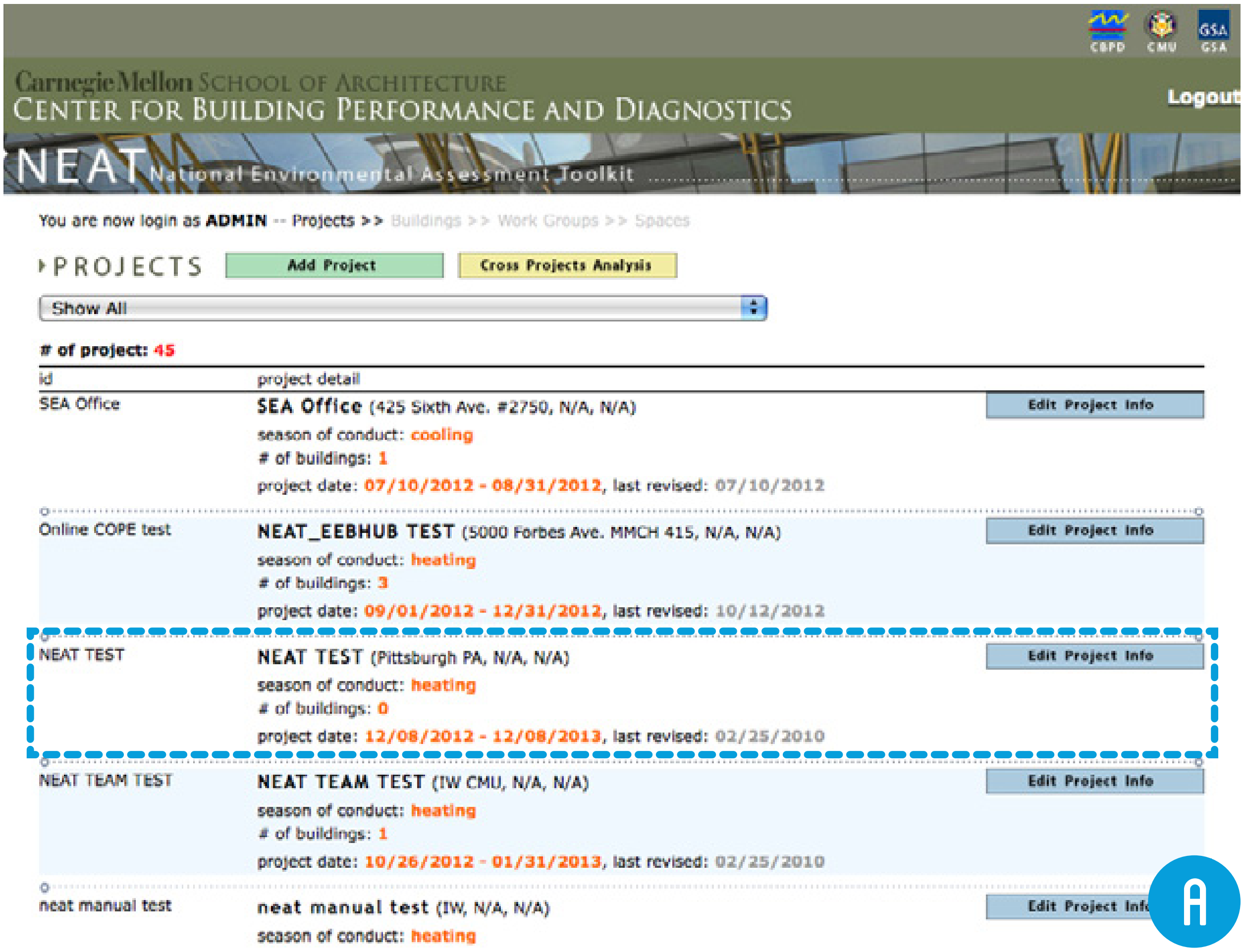
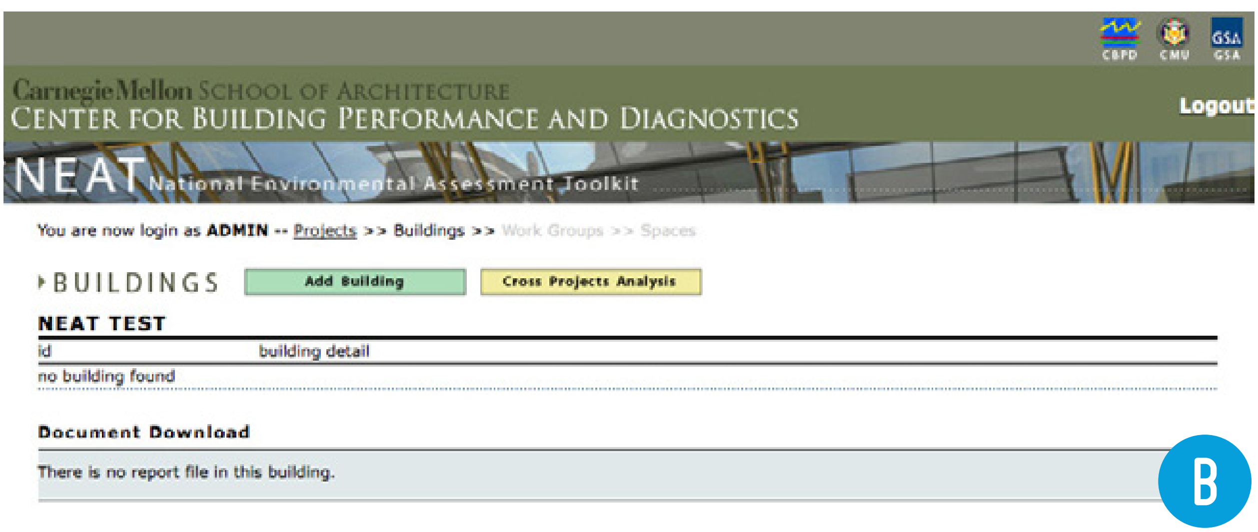
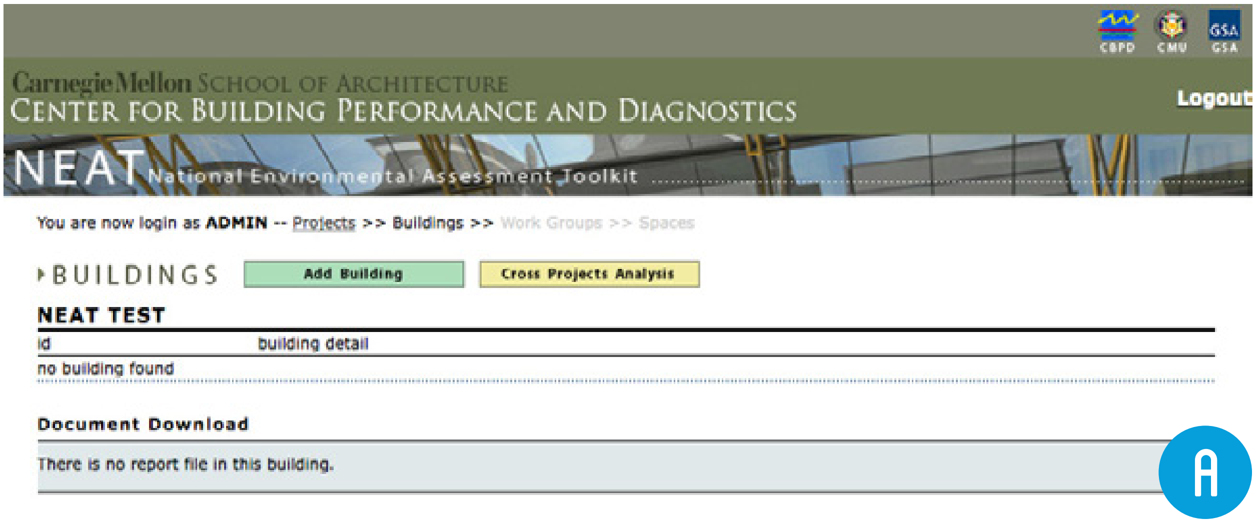
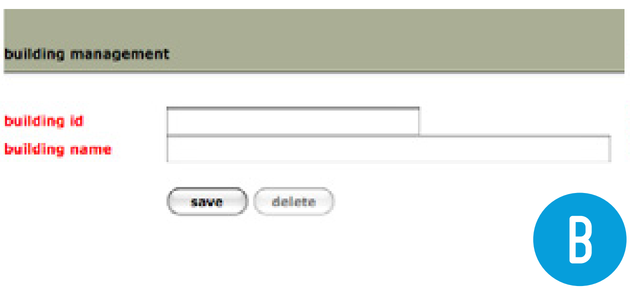
STEP 2: After successfully logging in, you then proceed to add a new project. The website will ask you to fill out the specifics for the project including ID, name, location, season and start and end dates.

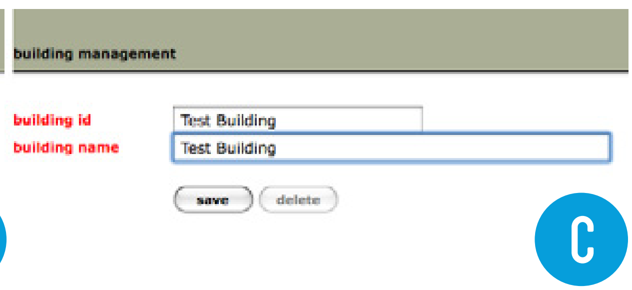


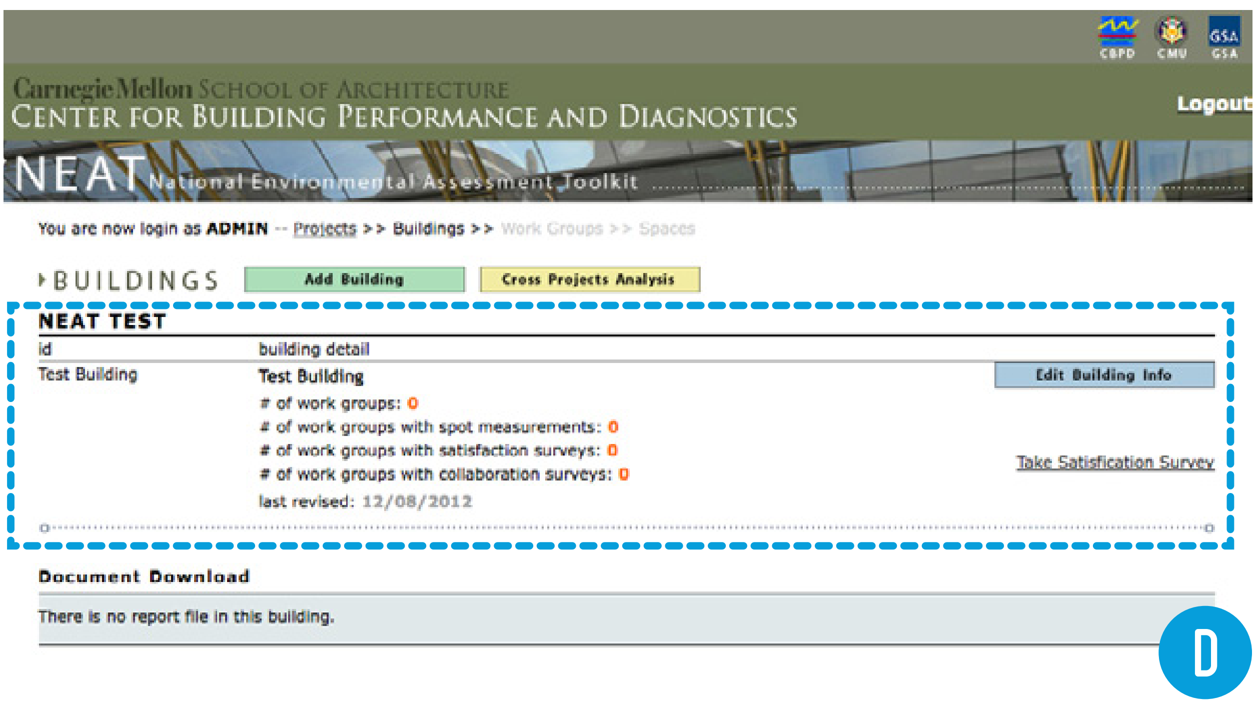


STEP 3: After filling out project specifics, you will then be redirected back to the previous window. Click on the newly-created project section to add a new building

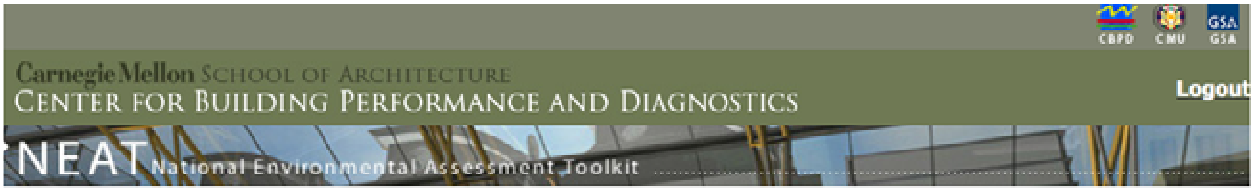








STEP 4: After inserting building ID and building name, a new section for your building will be created. Click on “Take Satisfaction Survey” to proceed to the survey



You are now login as **ADMIN** -- Projects >> Buildings >> Survey

Please check the appropriate box

1(Very Unsatisfactory),...,4(Neutral),...,7(Very Satisfactory)

	1	2	3	4	5	6	7
1. Light on desk for paper-based tasks(reading and writing)	○	○	○	○	○	○	○
2. Overall air quality in your work area	○	○	○	○	○	○	○
3. Temperature in your work area	○	○	○	○	○	○	○
4. Aesthetic appearance of your office	○	○	○	○	○	○	○
5. Level of privacy for conversations in your office	○	○	○	○	○	○	○
6. Level of visual privacy within your office	○	○	○	○	○	○	○
7. Amount of noise from the other people's conversations while you are at your workstation	○	○	○	○	○	○	○
8. Size of your personal workspace to accommodate your work, materials and visitors	○	○	○	○	○	○	○
9. Amount of background noise (i.e. not speech) you hear at your workstation	○	○	○	○	○	○	○
10. Light for computer work	○	○	○	○	○	○	○
11. Amount of reflected light or glare in the computer screen	○	○	○	○	○	○	○
12. Amount of the direct glare (high luminance'sthat are visible from a viewer's position; example: unshielded luminaire) from light fixtures	○	○	○	○	○	○	○
13. Amount of the direct glare (high luminance's that are visible from a viewer's position; example: a sunlit surface) from daylight	○	○	○	○	○	○	○
14. Air movement in your work area	○	○	○	○	○	○	○
15. Your ability to alter physical conditions in your work area	○	○	○	○	○	○	○
16. Your access to a view of outside from where you sit	○	○	○	○	○	○	○
17. Distance between you and other people you work with	○	○	○	○	○	○	○
18. Quality of lighting in your work area	○	○	○	○	○	○	○
19. Frequency of distractions from other people	○	○	○	○	○	○	○
20. Degree of enclosure of your work area by walls, screens or furniture	○	○	○	○	○	○	○

Rank order importance

1(Most important),2,...,6,7(Least important)

	1	2	3	4	5	6	7
Noise Levels	○	○	○	○	○	○	○
Temperature	○	○	○	○	○	○	○
Privacy	○	○	○	○	○	○	○
Air Quality/Ventilation	○	○	○	○	○	○	○
Size of work space	○	○	○	○	○	○	○
Window access	○	○	○	○	○	○	○
Lighting	○	○	○	○	○	○	○

STEP 5: Have the occupants fill out the survey, as shown on these two pages, and submit after they are finished.

Age

- ○ 18 - 29
- ○ 30 - 39
- ○ 40 - 49
- ○ 50 - 59
- ○ 60 - 69
- ○ 70+

Gender

- ○ Female
- ○ Male

Job category

- ○ Administrative
- ○ Technical
- ○ Professional
- ○ Managerial

Highest education level

- ○ High School
- ○ Community College
- ○ Some University
- ○ Bachelor degree
- ○ Graduate degree

Please check the appropriate box

1(Very strongly disagree),...,4(Neither agree nor disagree),...,7(Very strongly agree)

	1	2	3	4	5	6	7
My department/agency is a good place to work	○	○	○	○	○	○	○
I am satisfied with my job	○	○	○	○	○	○	○

Please check the appropriate box

1(Very unsatisfactory),...,4(Neutral),...,7(Very satisfactory)

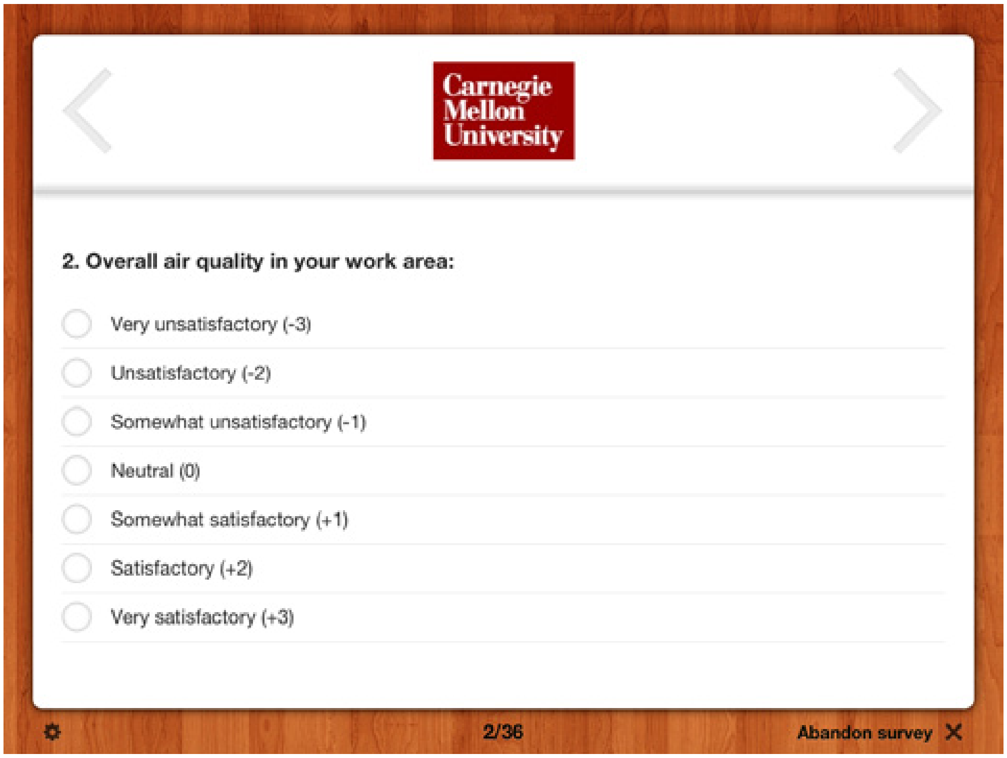
	1	2	3	4	5	6	7
Effect of environmental conditions in your workstation on personal productivity	○	○	○	○	○	○	○
Indoor environment in your workstation, as a whole	○	○	○	○	○	○	○

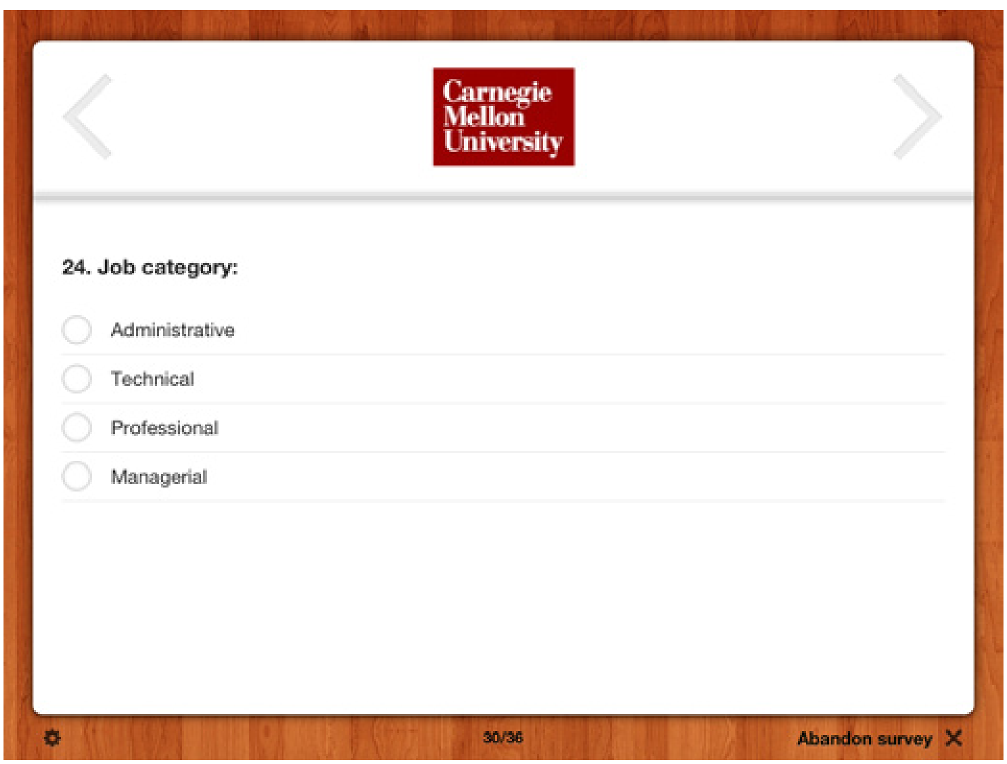
Please add any comments that you would like to share with us related to your work environment:

Submit

SURVEYS ONSITE I-PAD

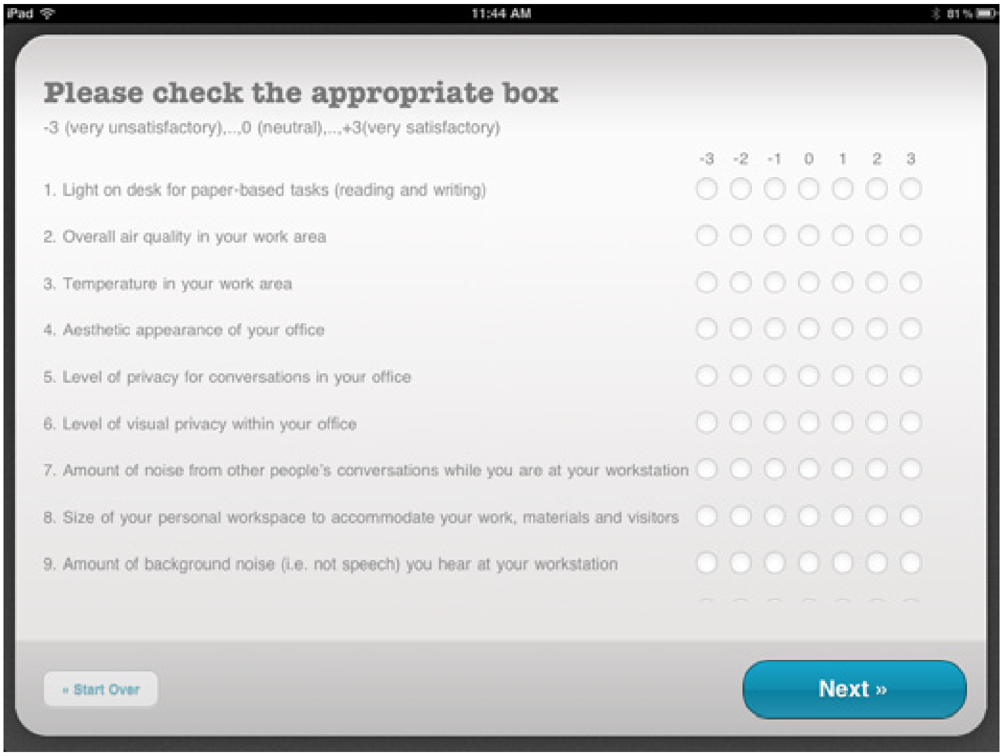
2. 1. ON-SITE USER SATISFACTION QUESTIONNAIRES FOR I PAD

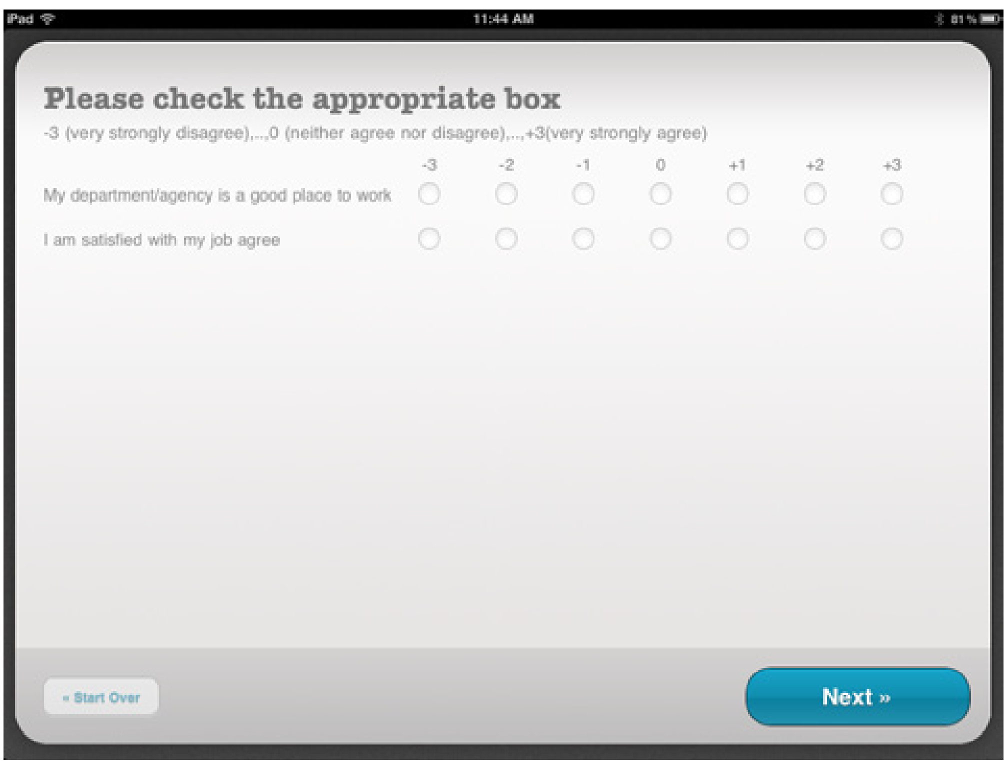




TIPS: Have the occupants fill out the survey through this i Pad application and submit after they are finished.

2. 1. ON-SITE USER SATISFACTION QUESTIONNAIRES FOR I PAD





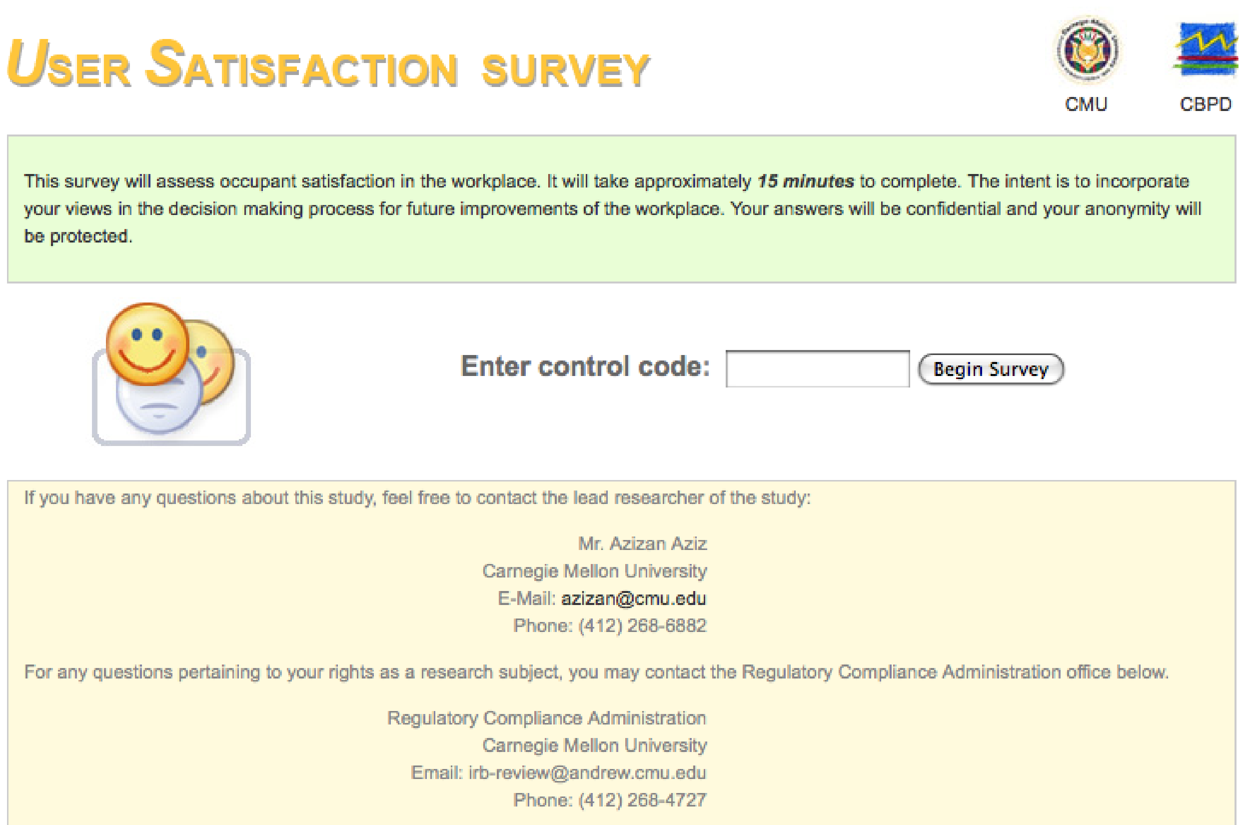
TIPS: Different user interface for the i Pad application survey

1:OVERVIEW
2:CART
3:SENSORS
4: SURVEYS
5: TABS
5:DATA
6:INDEX

3. CBE USER SATISFACTION SURVEY [LONG-TERM PERCEPTION]

A 68-question user-satisfaction survey has been developed to evaluate occupant satisfaction with personal workstation spatial characteristics, thermal comfort, air quality, lighting and views, acoustic quality, and building maintenance. In addition, a series of questions about the functionality, community, and well being of occupants capture satisfaction beyond the environmental characteristics.

This survey is distributed via the internet to all employees in the workgroup being studied, typically before the field evaluation is undertaken. The survey ensures that the satisfaction of a greater number of occupants is collected, and that their annual and seasonal perspective is captured.



USER SATISFACTION SURVEY

CMU CBPD

This survey will assess occupant satisfaction in the workplace. It will take approximately ***15 minutes*** to complete. The intent is to incorporate your views in the decision making process for future improvements of the workplace. Your answers will be confidential and your anonymity will be protected.

Enter control code: [ ] Begin Survey

If you have any questions about this study, feel free to contact the lead researcher of the study:

Mr. Azizan Aziz
Carnegie Mellon University
E-Mail: azizan@cmu.edu
Phone: (412) 268-6882

For any questions pertaining to your rights as a research subject, you may contact the Regulatory Compliance Administration office below.

Regulatory Compliance Administration
Carnegie Mellon University
Email: irb-review@andrew.cmu.edu
Phone: (412) 268-4727

WEBSITE	http://neat-cbpd.arc.cmu.edu/ensa
CONTROL CODE	sat333101

STEP 1: In order to access the long survey, you must login to the website indicated above with the provided control code.

USER SATISFACTION SURVEY

Problems?

Section 1 of 8 Group:Test Participant: sat333101

I. Description

1. What is the name of your department? [ ]

2. How long have you worked in this building?

0 year 0 month

3. How would you describe the work you do?

- Executive / Managerial
- Professional / Technical
- Clerical / Support
- Other (please specify)

4. What is your gender?

- Female
- Male

5. What is your age?

- Under 21 years
- 21 to 30 years
- 31 to 40 years
- 41 to 50 years
- 51 to 60 years
- 61 to 65 years
- Over 65 years

Clear Form Proceed

Section 1 of 8

Section 2 of 8 Group:Test Participant: sat333101

II. Nature of Work

6. How many hours do you work in a typical work week? [0] hours/week

7. In a typical work week, how many hours do you spend at the following places?

At my workstation	0	hours/week
Away from my workstation but in the building	0	hours/week
Away from the building (offsite meetings, travel, etc.)	0	hours/week
Working at home	0	hours/week

8. How much time do you spend on the following work activities every week?

Working alone	0	hours/week
Working in a group	0	hours/week

III. Individual Workstation Characteristics: part 1

9. How would you describe your workplace type?

- A. Individual closed office
- B. Shared closed office
- C. Open-plan office/ cubicle with partitions
- D. Other

10. What is the rough dimension of your individual workspace?

[0] feet by [0] feet

11. Where is your workstation located? *(Please check all that apply)*

- Near a meeting room
- Near an open meeting space
- Near a common break area
- Near a printer/ copier area
- Near a main corridor/ walkway
- Next to exterior window
- With seated view of window across corridor or other workstation
- No window view

1:OVERVIEW
2:CART
3:SENSORS
4: SURVEYS
5: TABS
5:DATA
6:INDEX

12. Which of the following items do you have in your workstation? *(Please check all that apply)*

- [ ] Flat screen monitor
- [ ] Older tube monitor
- [ ] Printer
- [ ] Scanner
- [ ] Fax machine
- [ ] Coffee/ tea maker
- [ ] Microwave/ toaster oven
- [ ] Refrigerator
- [ ] Plants
- [ ] Air freshener
- [ ] Headphones
- [ ] Door/ sliding screen
- [ ] Operable window
- [ ] Window blinds
- [ ] Air supply vent(s)
- [ ] Thermostat
- [ ] Light switch
- [ ] Light dimmer
- [ ] Fan

III. Individual Workstation Characteristics: part 2

13. What type of lighting is provided in your workstation? *(Please check all that apply)*

- [ ] Overhead light
- [ ] Desk lamp with fixed arm
- [ ] Desk lamp with articulated arm
- [ ] Under-cabinet light

14. How satisfied are you with the following physical characteristics of your workstation?

	Very Dissatisfied	Dissatisfied	Somewhat dissatisfied	Neutral	Somewhat satisfied	Satisfied	Very Satisfied
Workstation size	●	○	○	○	○	○	○
Workstation layout	○	●	○	○	○	○	○
Color of finishes (wall, carpet, etc)	○	○	○	○	●	○	○
Quality of finishes (wall, carpet, etc)	○	○	○	○	●	○	○
Worksurface quantity	○	○	○	○	○	●	○
File storage quantity	○	○	○	○	○	○	○
Your Chair	○	○	○	○	○	○	○
Meeting space within workstation	○	○	○	○	○	○	○
Number and location of electrical outlets	○	●	○	○	○	○	○
Number and location of voice/ data outlets	○	○	○	○	●	○	○
Wireless network	○	○	○	●	○	○	○

15. How satisfied are you with the following environmental quality of your workstation?

	Very Dissatisfied	Dissatisfied	Somewhat dissatisfied	Neutral	Somewhat satisfied	Satisfied	Very Satisfied
A. Air movement	○	○	○	○	○	○	◉
B. Air freshness	○	◉	○	○	○	○	○
C. Odor free	○	◉	○	○	○	○	○
D. Heating	◉	○	○	○	○	○	○
E. Cooling	○	◉	○	○	○	○	○
F. Humidity	◉	○	○	○	○	○	○
G. Daylighting	○	◉	○	○	○	○	○
H. Electric lighting	○	◉	○	○	○	○	○
I. Visual privacy	◉	○	○	○	○	○	○
J. Acoustic privacy	○	○	○	○	○	○	○
K. Noise distraction	○	○	○	○	○	○	○

16. How convenient do you find the following support services on the floor of your building?

	Very Inconvenient	Inconvenient	Neutral	Convenient	Very Convenient
Location of meeting rooms or open meeting areas	◉	○	○	○	○
Location of copier/ printer area	○	○	○	○	○
Location of kitchen/coffee area	○	○	○	○	○
Location of file and storage supplies	○	○	○	○	○
Location of break areas	○	○	○	○	○

17. Please indicate your preffered place(s) to engage in casual conversation and collaborative work *(Please check all that apply)*

For casual conversations:

- ☐ Office/ cubicle
- ☐ Meeting rooms
- ☐ Opening meeting areas
- ☐ Common copier/ printer areas
- ☐ Kitchen/ coffee areas
- ☐ Circulation areas
- ☐ Other (please specify)

For collaborative work:

- ☐ Office/ cubicle
- ☐ Meeting rooms
- ☐ Open meeting areas
- ☐ Common copier/ printer areas
- ☐ Kitchen/ coffee areas
- ☐ Circulation areas
- ☐ Other (please specify)

Clear Form | Back | Proceed

18. Please check the amenities that are available in or nearby your building *(Please check all that apply)*

- ☐ Daycare
- ☐ Healthcare
- ☐ Café/ Cafeteria
- ☐ Gym/ Recreation center
- ☐ Travel office
- ☐ Dry cleaning
- ☐ Banking/ ATM
- ☐ Convenience stores
- ☐ Free parking

19. How do you evalutate the following features of the building?

	Very inadequate	-	Neutral	-	Very adequate	N/A
Availability of meeting rooms	○	○	○	○	○	○
Variety of places for different collaborative work	○	○	○	○	○	○
Arrangement and furnishing of meeting rooms or open meeting areas	○	○	○	○	○	○
Tools and technology in meeting rooms or open meeting areas	○	○	○	○	○	○
Outdoor break work areas	○	○	○	○	○	○
Security	○	○	○	○	○	○
Emergency evacuation	○	○	○	○	○	○
Cleanliness	○	○	○	○	○	○
Recycling	○	○	○	○	○	○

20. Would any of the following factors also affect your motivation and ability to get the job done?

	Not at all	Somewhat critical	Critical	Very critical
Salary	○	○	○	○
Fringe benefits	○	○	○	○
Management style	○	○	○	○
Closed office space	○	○	○	○
Workstation size	○	○	○	○
Workstation layout and furnishing	○	○	○	○
Places for collaborative work	○	○	○	○
Thermal quality	○	○	○	○
Air quality	○	○	○	○
Operable window	○	○	○	○
A window with view	○	○	○	○
Electric lighting quality	○	○	○	○
Daylight quality	○	○	○	○
Acoustic quality	○	○	○	○

21. **Which of the following conditions support your collaboration/interaction with co-workers?**

	Does not support	Somewhat support	Support	N/A
Workstation near co-workers	○	○	○	○
Co-workers in open-plan workstations	○	○	○	○
Meeting space within workstation	○	○	○	○
Meeting space near workstation	○	○	○	○
Availability of meeting rooms	○	○	○	○
Place to sit down in copier/printer areas	○	○	○	○
Place to sit down in kitchen/coffee areas	○	○	○	○
Organized opportunites for interaction	○	○	○	○

Clear Form | Back | Proceed

VI. General Description Comments - part2

22. **How frequently do you experience the following health problems in your workstation?**

	Always	Daily	Several times/ week	Seldom	Never
Unusual fatigue	○	○	○	○	○
Sleepiness	○	○	○	○	○
Feeling of stress	○	○	○	○	○
Irritability	○	○	○	○	○
Headaches	○	○	○	○	○
Tired or strained eyes	○	○	○	○	○
Dry, itching, or irritated eyes	○	○	○	○	○
Stuffy or runny nose	○	○	○	○	○
Sore or dry throat	○	○	○	○	○
Coughs	○	○	○	○	○
Shortness of breath	○	○	○	○	○
Dry, itchy skin	○	○	○	○	○
Sore neck	○	○	○	○	○
Sore shoulders	○	○	○	○	○
Sore wrist	○	○	○	○	○
Back pain	○	○	○	○	○

23. **How frequently do you experience the following feelings at work?**

	Never	Seldom	Sometimes	Always
Feeling excited about work	○	○	○	○
Feeling supported by co-workers	○	○	○	○
Feeling well-informed about current projects/activities	○	○	○	○
Feeling part of collaborative efforts	○	○	○	○
Feeling disorganized	○	○	○	○
Feeling valued by management	○	○	○	○
Looking forward to working in this building	○	○	○	○
Feeling safe and secure to be in this building	○	○	○	○

Section 2 of 8 Group: Test Participant: sat333101

II. Nature of Work

6. How many hours do you work in a typical work week? [0] hours/week

7. In a typical work week, how many hours do you spend at the following places?

At my workstation	0	hours/week
Away from my workstation but in the building	0	hours/week
Away from the building (offsite meetings, travel, etc.)	0	hours/week
Working at home	0	hours/week

8. How much time do you spend on the following work activities every week?

Working alone	0	hours/week
Working in a group	0	hours/week

Clear Form | Back | Proceed

TABS

A. TECHNICAL ATTRIBUTES OF BUILDING SYSTEMS INTRODUCTION

Apart from the field measurements from the sensors and the surveys, documenting the Technical Attributes of Building Systems (TABS) is an important part of the post occupancy evaluation.

B. THERMAL & AIR QUALITY TABS

By floor or by zone, circle the existing physical attributes affecting user satisfaction and field measurements; if multiple conditions exist, add % of workstations affected by each; add real specifications if available at end of each row

Size of Zone in core (#people/thermostat)	> 75 people	25-75	15-25	
Core System Type: Yr major maintenance	Package unit	VAV	CV	
Core: Level of Control for open workstations	Hidden thermostat	Locked but visible thermostat with setpoint	Locked but visible with setpoint & status	
Core: Level of Control for closed offices/meeting	Hidden thermostat	Locked but visible thermostat with setpoint	Locked but visible with setpoint & status	
Diffuser density	>5 occupants per diffuser	3-5 occupants per diffuser	2 occupant per diffuser	
Diffuser alignment	Poor alignment, high panels, cluttered	Poor alignment, med panels, cluttered	Poor alignement, low panels	
Perimeter System Type: Yr major maintenance	Central control. entire facade	Central control, multiple facades	Central control, multiple units	
Seasonal switchover	Set days fall and spring	As needed, <4 per year		
IAQ/OA mgmnt Dehumidification Y/N Floor by Floor AHU: Y/N Economizer: Y/N	No OA		10 cfm/person	
	No filter	<80% filter	80% filter	
		Spray humidification	Steam humidification	
Return air density	<1/100	1 per 25-100		
Dedicated exhausts	No dedicated spaces or Exhausts for copy/kitchen		Some dedicated spaces No exhausts for copy/kitchen	
Level of maintenance HVAC system	rate maint.	maintenance as needed	2-3 years	
Pollution Source mgmt	Circle all that apply: No pesticides, low VOC paints, low VOC fabrics/carpets, benign adhesives, remote outgassing, No occupancy w/ dedicated ventilation during renovation, green cleaning products			
	1	2	3	
Window quality (Cold, heat, air & sun)	1 pane			
	Leaky/draft			
	No shading, typ E/W	No shading, typ N/S	Low solar t, low views	
Windows controls % of workstation <20 ft from window _____%	% of wall glazed _____% Circle all that apply: low solar transmission glass, high visible transmission glass, User controls: roller/mesh shades, blackout shades, vertical blinds, horizontal venetian blinds, dominant north & south facing windows, external overhang/awning/trellis, light shelf, operable windows.			

TABS

10-15	5-10	2-5	Individual control
VAV w/ terminal reheat	mult. mixing boxes	Local A.C.	Seperate thermal & ventiala-tion/UFA
	Accessible thermostat with setpoint	Accessible thermostat with setpoint & status	Individual or Group temp/volume control Air: direction/ speed control
	Accessible thermostat with setpoint	Accessible thermostat with setpoint & status	Individual or Group temp/volume control Air: direction/ speed control
1 occupant per diffuser	2 diffusers per occupant	>2 diffusers per occupant or 2 relocatable	
Good alignment, high panels, clutteres	Good alignment, med, panels	Good alignment, low panels	Occupant relocatable, UFA
Central control, indiv. units	Local control, 2-3 shared	Local Control, indiv	Seperate thermal, vent. & indiv. control
Whole bldg, as often as needed	Each zone, as often as needed	Each zone continuous control	Each occ. continuous control
	20 cfm per person		30 cfm per person
85% filter	90% filter	95% filter	>95% HEPA filter
Electrostatic humidification		CO_2 sensors + central OA control	CO_2 sensors/local OA control
1 per 10-25		1 per 5	1 per person
	All dedicated spaces, some with exhausts for copy/kitchen		All dedicated spaces with exhausts for copy/kitchen
annual maint	annual maint w/ EMCS moni-toring	Annual Cx Commissioning	Continuous Cx
4	5	6	7
2 panes		3 panes	superwindows
mod tight			tight
	Low solar t, good views	Group internal shades	Indiv. internal shades

C. LIGHTING TABS

By floor or by zone, circle the existing physical attributes affecting user satisfaction and field measurements; if multiple conditions exist, add % of workstations affected by each; add real specifications if available at end of each row

Circle answers for both open and closed offices, with annotations if different

Ceiling Fixture Type & Shape **Ceiling height: ______**			2x2	
Ceiling Light Lens Type	Flush / K-12 prismatic lens	Flush / K-16 prismatic lens	Small cell parabolic	
			Specular	
Ceiling Light Lamps **#/ fixture _________** **(CRI_____________)**	Incandescent	T-12		
Ceiling Light Ballast Type	magnetic	hybrid	High-output electronic	
Alignment w/workstations **sq. ft./fixture____________**	<50%	60%	70%	
Level of ceileing light control	**Select level of control:** Floor by floor only, >10 workstations only, 2-10 workstations only, Individual **Select all types of control available:** on-off, step dimming, continuous dimming, timers, daylight sensors, occupancy sensors			
Furniture/light distribution	**Identify panel heights:** ________% at ____________ft., ________% at ____________ft. **Identify panel color:** light, medium, dark **Identify level of clutter for ceiling light distribution** bins, cabinets, high density **and misalignment:** low clutter, medium, high			
Type of computer screens	Old CRT	Old CRT with polarizing	VDT with polarizing	
Task Lights	**Identify number per workstation:** 0, 1, 2, 3, 4 and percent with those numbers **Identify mobility:** fixed underbin, fixed desktop, relocatable desktop, articulated arm desktop, articulated arm relocatable desktop **Identify ballast/lamp type:** magnetic ballast T-12, incandescent, halogen, electronic ballast T-8, T-5, compact florescent			
Daylight effectiveness	**percent with seated view of window _______%** **average maximum distance to window _________**ft. **window dimensions:** punched windows, band of windows, curtain wall, curtain wall with clerestory **glass light transmission:** mirror glass, <25%, 25-50%, >50% visible transmission			
Window controls **___ # of occupants share?**	No controls	Roll-down opaque shades	Roll down mesh shades	

Watts/sq.ft with tasks lights off ____________ and on ______________

% of workstations with physical indicators of visual concern: taped over light fixtures, light shields, polarizing screens, personal task lights, taped over windows

2x4 or I/I-D w/ hot spots	1 x4	I-D w/out hotspots	I-D ambient & task
Medium cell parabolic	I-D in 2x2 or 2x4 inset	I-D in 2x2 or 2x4 inset	
Matte	Semi-pecular		
T-8		T-5, CFL	
Electronic Instant start	Electronic rapid start	Auto-Dimming Electonic	User-Dimming Electronic
80%	90%	100%	Relocatable ceiling fixtures
VDT	Flat screen laptop	Flat screen desktop	Plasma screen
Vertical blinds	Horizontal, venetial blinds	External shading and internal blinds	Light shelf and internal blinds

D. ACOUSTIC TABS

By floor or by zone, circle the existing physical attributes affecting user satisfaction and field measurements; if multiple conditions exist, add % of workstations affected by each; add real specifications if available at end of each row

#___________ open workstations **#__________ closed workstations**
#___________ open meeting spaces **#__________ closed meeting**

Ceiling Height _______ft & Ceiling Quality	Hard surface or open without acoustic material	Floating acoustic elements	Painted acoustic tile	
Floor quality	Hard surface throughout	Carpet in circulation areas		
Open plan partitionn thick-ness & quality		1 inch	1.5 inch	
		Empty inside		
		Hard surface		
Partition height inches & number of sides/workstation (note % of each)	No partitions	1 side (heights?_______)	2 sides (heights?________)	
Overhead bins (# of each)		0	1	
Closed office/rooms wall quality		Relocatable wall not tight with floor or ceiling	Demountable partition wall tight with floor & ceiling	
Side/density of open work-stations (Gross sqft/wkst_________)	≤36 sqft workstation size	<48 sqft	<64 sqft	
Distributed Noise: % of workstations <20 ft from open meeting, coffee, copy, main circulation	>40% of workstation W? in 20ft	20-40% of workstation	10-20% of workstation	
HVAC Noise	Low frequency rumble	Noticeable hiss/squeak/clang/tone	Cycling	
Masking Sound Y/N?	Too loud >50 dB (A)	Too quiet <30 dB (A)	Noticeably unbalanced	
Office Protocols	**Identify those in practice:** no using speaker phones, quiet phone ringers no using headphones use of headphones no conversations adjacent to individual workstation no interruptions if _________________________ other: ______________________________			

#___________open copy

#___________closed copy

#__________ open kitchen

#___________closed kitchen

	Acoustic plaster	Metal or wood slats with fiberglass	Mineral acoustic tile	Fiberglass acoustic tile
	Thin carpet throughout			Thick carpet with padding
	2 inch	2.5 inch	3 inch	4 inch
	Insulation inside			Insulation and foil/board inside
	Perforated surface		Fabric surface	
	3 sides (Height?________)	3.5 sides (heights?________)		4 sides (heights?_________)
	2	3		
	Gypsum board on wood stud, tight with floor & ceiling	Gypsum board on metal stud, tight with floor & ceiling	Gypsum board on insulated stud, tight with floor & thru ceiling	Fixed, tight with floor and slab above
	<80 sqft	<100 sqft	<150 sqft	>150 sqft
	2-10% of workstation			<2% of workstation
	Even/quiet sound			

1:OVERVIEW
2:CART
3:SENSORS
4: SURVEYS
5: TABS
5:DATA
6:INDEX

E. SPATIAL ERGONOMIC TABS

By floor or by zone, circle the existing physical attributes affecting user satisfaction and field measurements; if multiple conditions exist, add % of workstations affected by each; add real specifications if available at end of each row

#___________ open workstations #__________ closed workstations
#___________ open meeting spaces #__________ closed meeting
gross sqft per person ____________

Typical open workst. sizes give actual size and % of each	<36 sqft eg 6x6	<50 sqft eg 7x7	<64 sqft eg 8x8	
Typical closed workst. sizes give actual size and % of each	<64 sqft eg 8x8	<80 sqft eg 8x10	<100 sqdt eg 10x10	
Partition height (inches) & number of sides (note % of each)	No panels	1 sides (heights?_____)	2 sides (heights?______)	
Worksurface and 15-20 ft >20 feet Reconfigurability give % of workstations	<5 feet surface		5-10 ft	
	_________ total # of worksurfaces per average workstation: _________# panel hung, _______# on wheels, _______# freestanding/occupant relocatable, other:__________			
Storage per workstation (linear feet of shelf, drawer)	<10 ft	10-15 ft	15-20 ft	
Ergonomic support (>90% of workstations)	**Circle # of adjustments:** adjustable seat pan height; adjustable lumbar support; adjustable keyboard tray with mouse; articulated keyboard support with mouse pad; adjustable chair arms; adjustable seat pan depth; adjustable monitor ht/direction, ergonomic training/breaks			
	1	2	3	
Connectivity/ mobility	Average workstation connectivity available: ______# data, ______# voice, _______# power; wireless throughout building Y/N; wireless on campus Y/N			
Seated Views	<20%	>20%	>40%	
Disruption from Circulation/ Wayfinding	Receptionist? Y/N Clear Signage for Visitors wayfinding? Y/N % of desks visually open to circulation aisles? (visitors in workers line of sight)			
Group Meeting space	Floor area dedicated to shared open and closed meeting spaces ___________sq.ft. ____% of floor For given ___________ # of closed meeting spaces: identify distribution of sizes/ # chairs:_______			
Individual Meeting Space	For _________ # of all workstations: identify: ________ # with 1 guest chair, ________# with 2 guest chairs, ________# with guest table and chairs.			
Local Copy/printing areas	identify # of copy/printing areas in the following locations: ______# at individual's desk; ______# at empty workstation; ______# in circulation areas; ______# in dedicated open spaces; ______# in dedicated rooms. Of dedicated copy/printing spaces and/or rooms, identify if break areas include adequate material layout space Y/N; dedicated exhaust Y/N; windows Y/N;			
Quality of Finishes and Furnishings	Verry ragged, dirty and moldy	Very ragged and dirty	Old, worn not especially clean	
Building amenities	Circle amenities within building or 3 blocks walk: cafeteria, gift store, gym, daycare, café, travel office, dry cleaning, ban free parking, eldercare, outdoor break/work areas, other:			
	None	Cafeteria only	3	

	<80 sqft eg 8x10	<100 sqdt eg 10x10	<120 sqft eg 10x12	>120sqft
	<120 sqft eg 10x12	<150 sqft	<200 sqft	>200 sqft
	3 sides (heights?_______)	3.5 sides (heights?______)		4 sides with door (heights?_______)
	10-15 ft		15-20 ft	>20 ft
	20-25 ft	25-30 ft	30-35 ft	>35 ft
	4	5	6	7
	>50%	>60%	>80%	100%
	Old, worn but clean	Relatively new, clean	New, cheap quality, flimpsy	New, high end quality
k,				
	4	5	6	>7, including daycare

1. N.E.A.T ONLINE DATA DISPLAY OVERVIEW

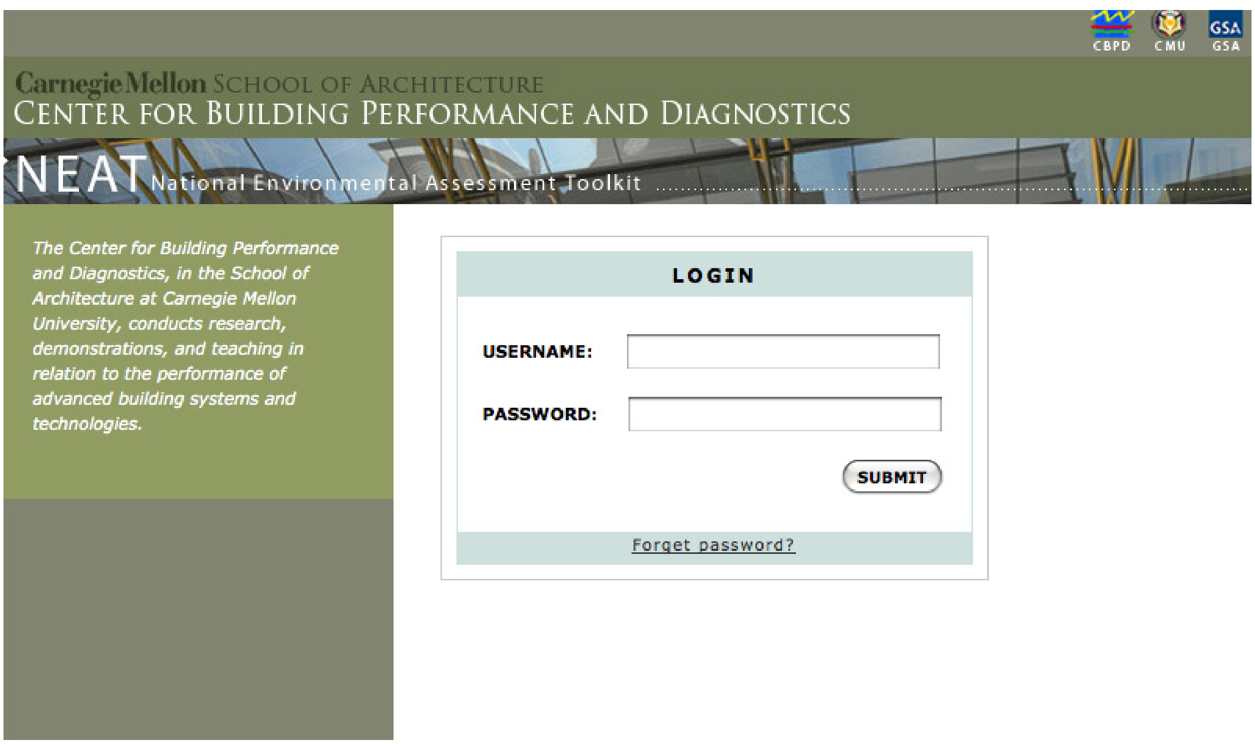
PART I: Cross-sectional measurement results display
Goal: To provide data display for selected spot measurement parameter across all sites or for selected sites (Default: for all sites)

PART II: Comparison
Goal: To provide comparison of selected
- Spot Measurement Parameter
- On-site Survey Question Response

according to:
- workstation location (perimeter vs. interior/core)
- workstation type (open vs. closed)
- TABS, e.g. mechanical system type, enclosure type

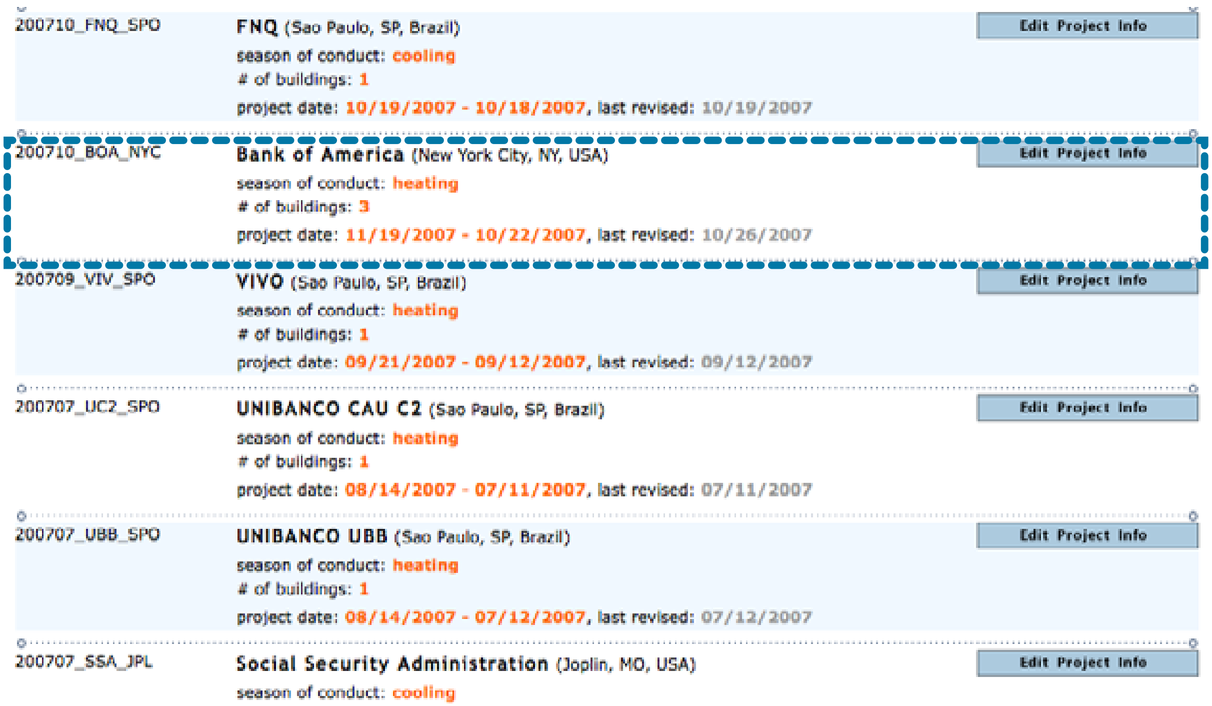
PART III: Correlation between objective and subjective parameters
Goal: provide correlation analysis between selected spot measurement parameter and selected on-site survey question response.

2. N.E.A.T ONLINE DATA ACCESS

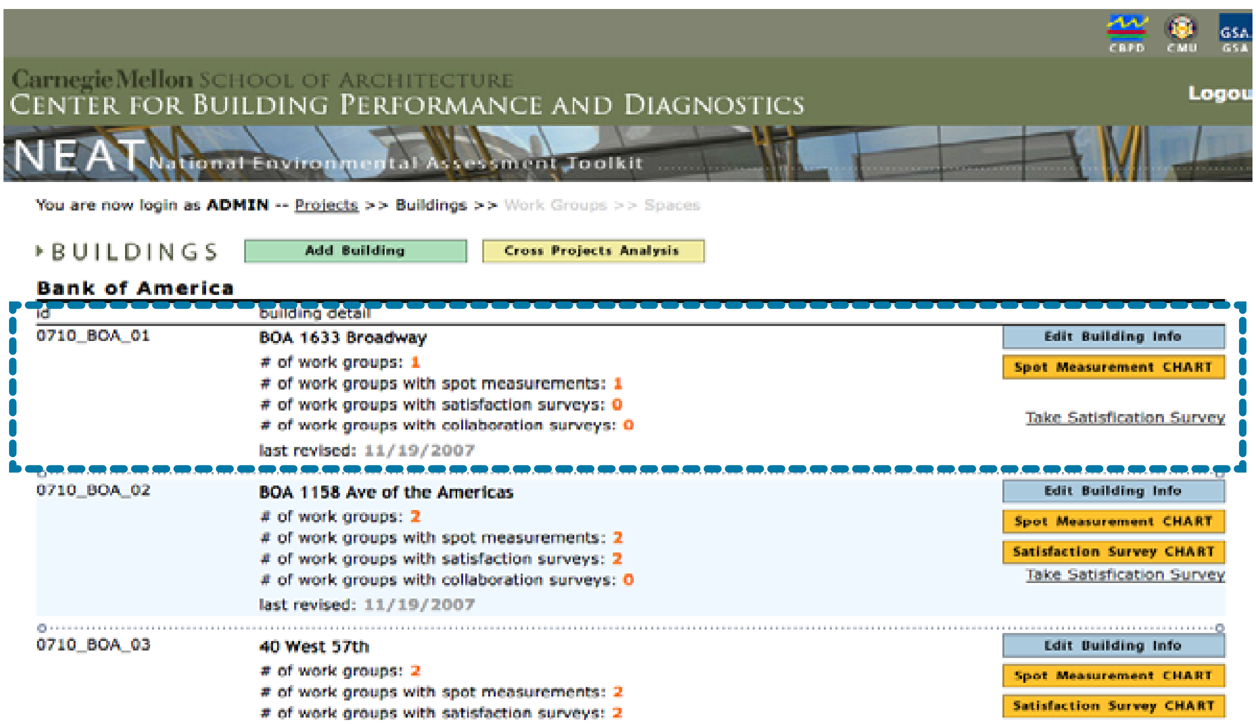


STEP 1: In order to access or upload data to your project, you must log onto the CBPD website the provided user name and password from previous section

DATA

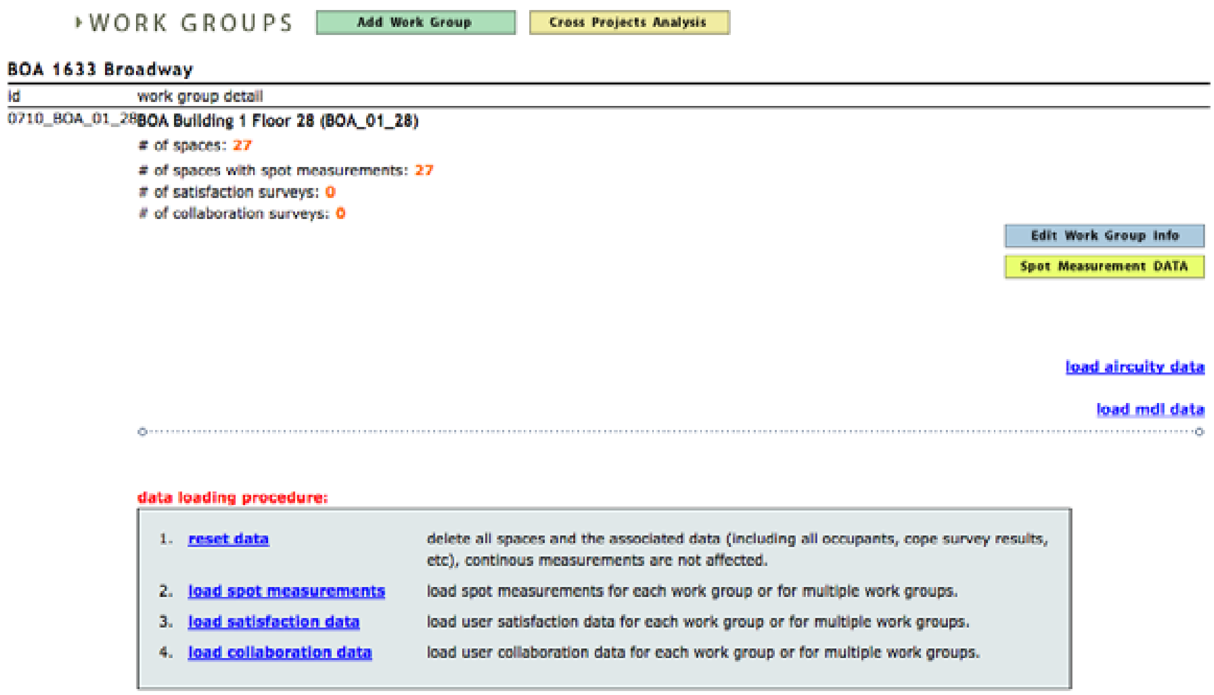


STEP 2: After successfully logging in, you will be directed to the project list window. You then can select specific project for detailed results. For instructional purpose, Bank of America in New York is selected.

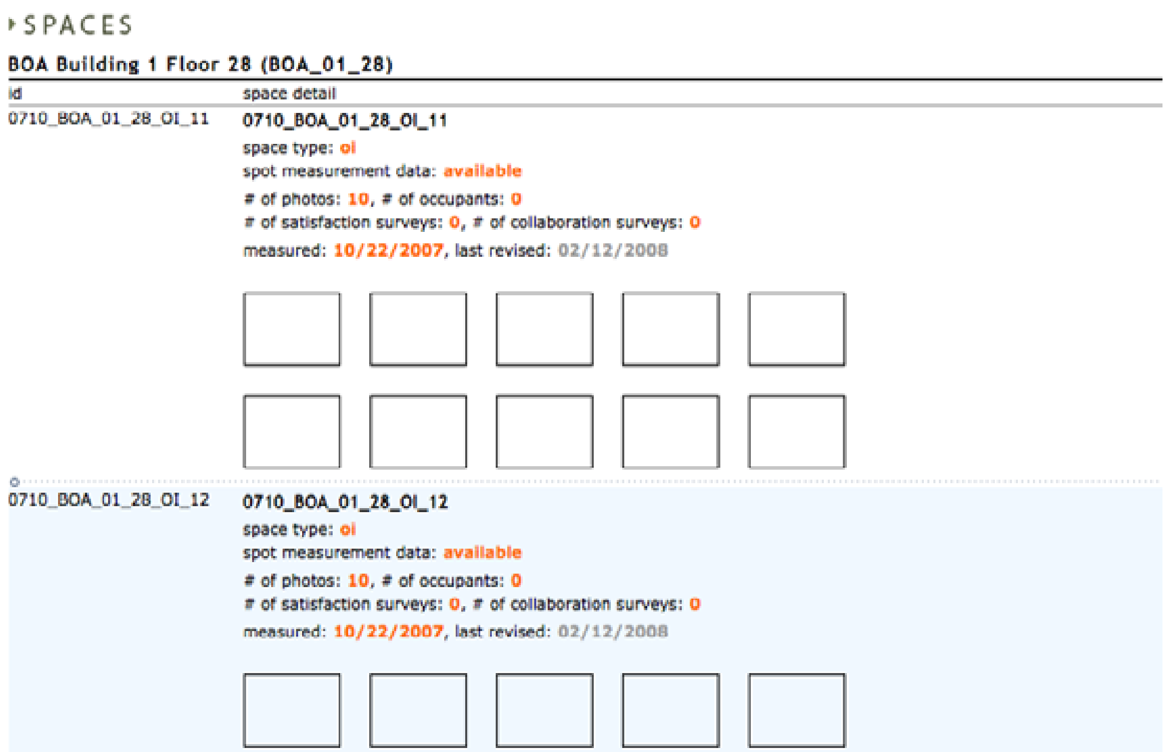


STEP 3: In order to access or upload data to your project, you must log onto the CBPD website the provided user name and password from previous section

DATA

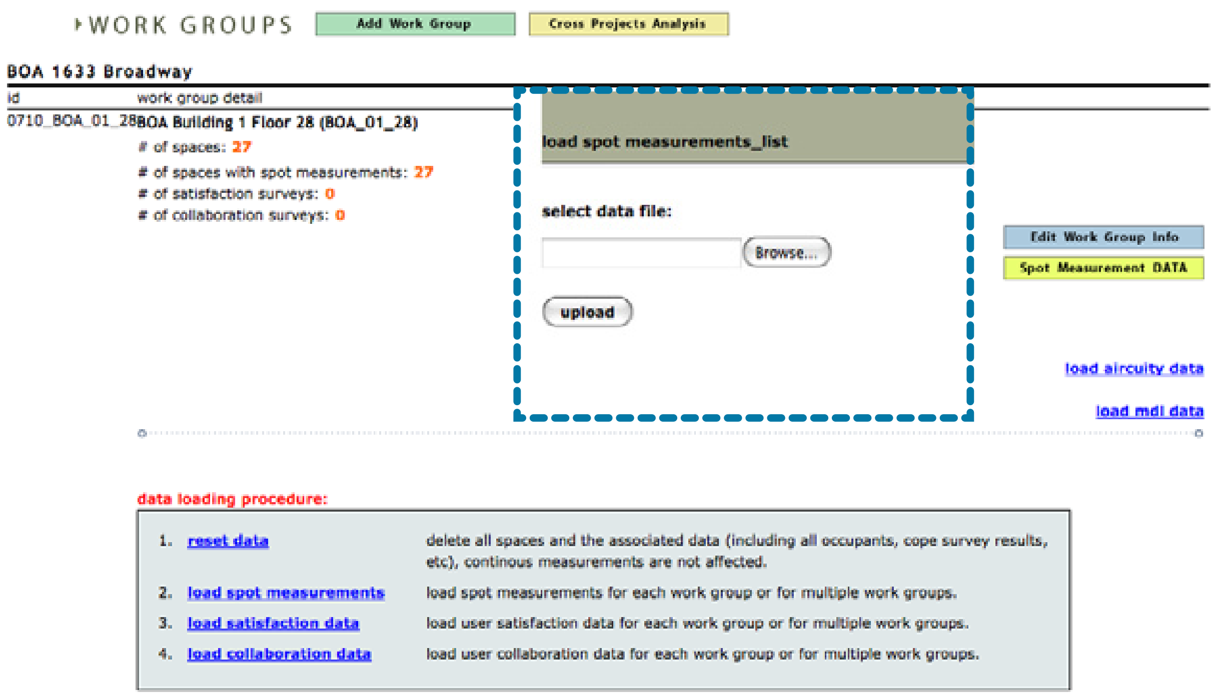


STEP 4: After selecting a specific work group, you then will be redirected to a page that shows the number of spaces and responses for COPE on-site survey for that particular group.

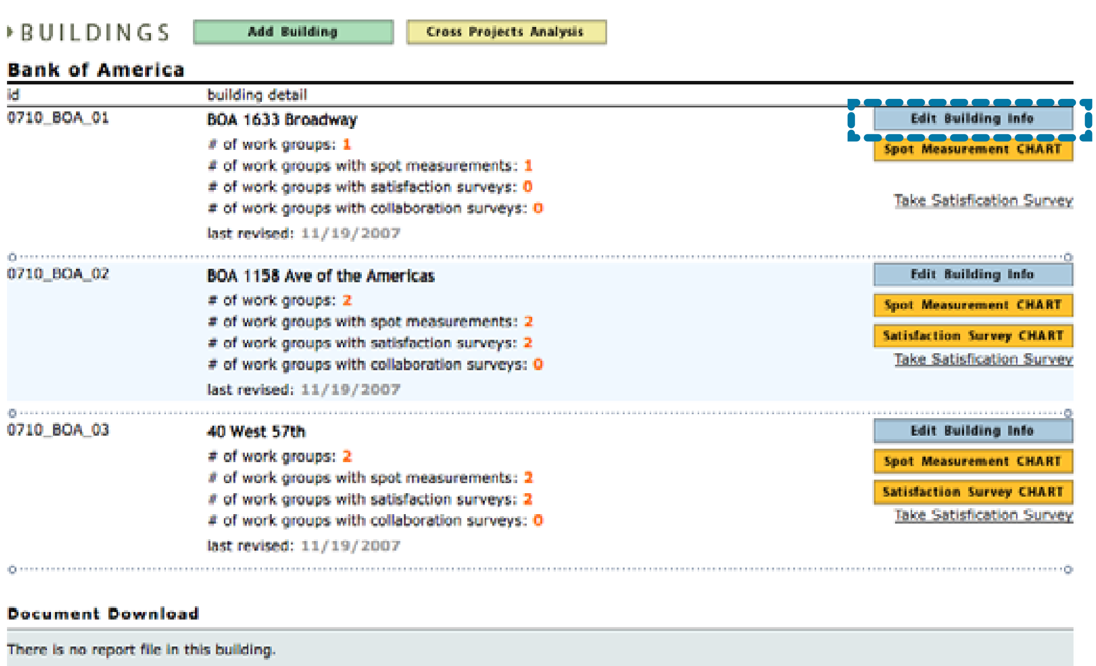


STEP 5: After clicking the number of spaces, the website will then show different types of space and their results of spot measurement as well as pictures.

DATA



STEP 6: Raw data formatted by Excel are directly inserted into the system. Invalid or incorrectly-formatted data are filtered and the user will be alerted to the problematic elements of data.



STEP 7: After successfully uploading raw data collected from various sensors and the N.E.A.T cart, you should be able to access a variety of spot measurement charts, as indicated in Index section

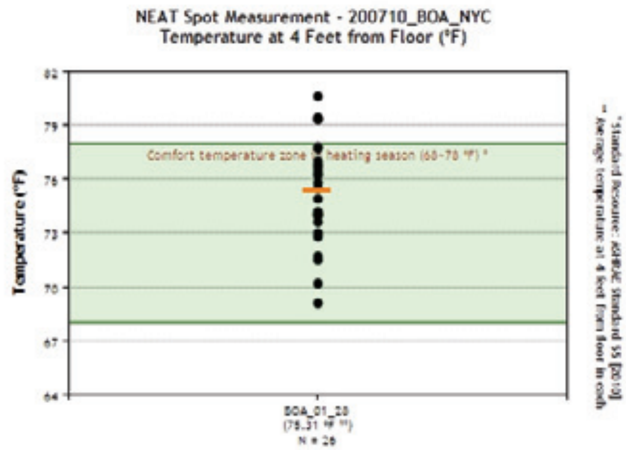
1. SPOT MEASUREMENT CHARTS

Temperature at 4 Feet from Floor

SOURCE DATA

BOA_01_28: 73.6, 76.3, 70.2, 76.2, 74.1, 71.7, 77, 76.7, 74, 75.5, 77.7, 79.4, 71.5, 72.8, 74.9, 69.1, 76.5, 73, 74, 79.3, 77.8, 76.8, 80.6, 74.2, 79.4, 75.8

Mean: 75.31, Min: 69.1, Max: 80.6
Percentage Within Comfort Zone: 84.62%

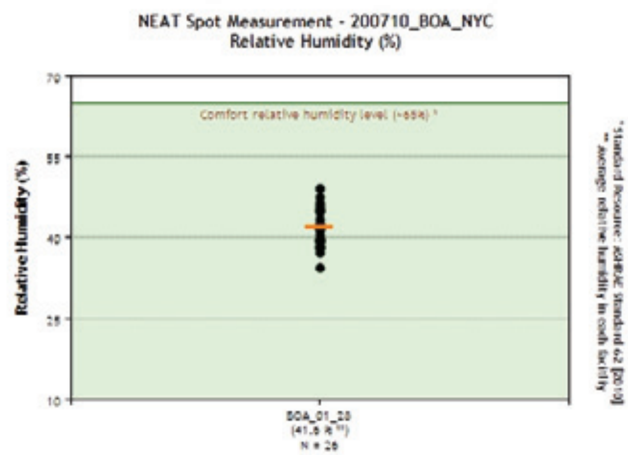


Relative Humidity

SOURCE DATA

BOA_01_28: 42.1, 39.6, 46.3, 39.6, 45.1, 44.7, 39, 40.5, 41.8, 41.6, 38, 38.3, 45.1, 45.8, 41.7, 49.1, 39.6, 47.5, 41.5, 37.2, 39.6, 39.3, 34.4, 43.4, 38.2, 42.5

Mean: 41.6, Min: 34.4, Max: 49.1
Percentage Within Comfort Zone: 100%

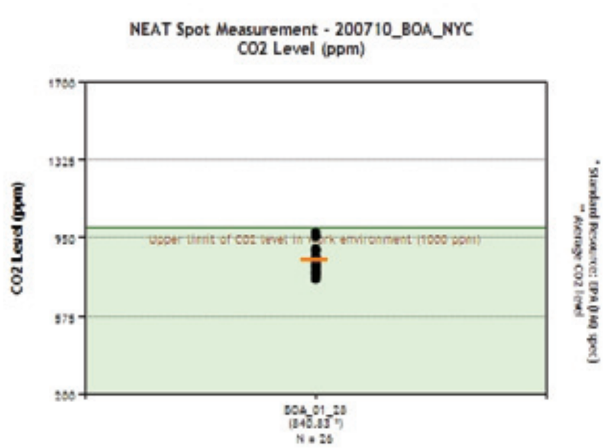


Concentration of CO_2

SOURCE DATA

BOA_01_28: 959.4, 844.5, 854.5, 763.6, 852.7, 891.4, 899.6, 977.2, 753.9, 775.8, 784.6, 814.4, 828.4, 842.8, 828.6, 812.7, 786, 849.2, 892.1, 812.3, 862.2, 845.1, 788, 784.1, 955, 803.5

Mean: 840.83, Min: 753.9, Max: 977.2
Percentage Within Comfort Zone: 100%



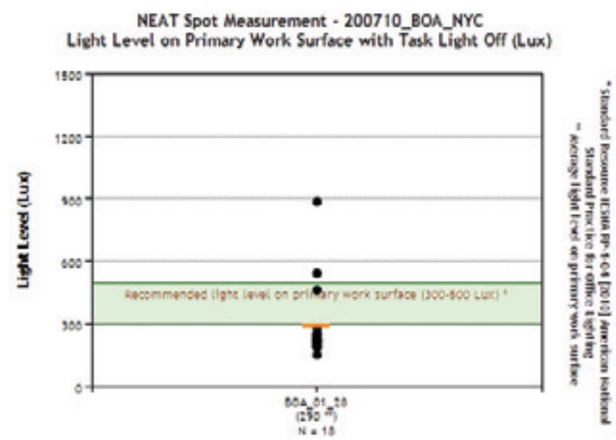
1. SPOT MEASUREMENT CHARTS

Light Level on Primary Work Surface with Task Light Off

SOURCE DATA

BOA_01_28: 233, 218, 196, 210, 192, 190, 154, 280, 219, 230, 219, 254, 545, 465, 250, 887, 251, 227

Mean: 290, Min: 154, Max: 887
Percentage Within Comfort Zone: 5.56%

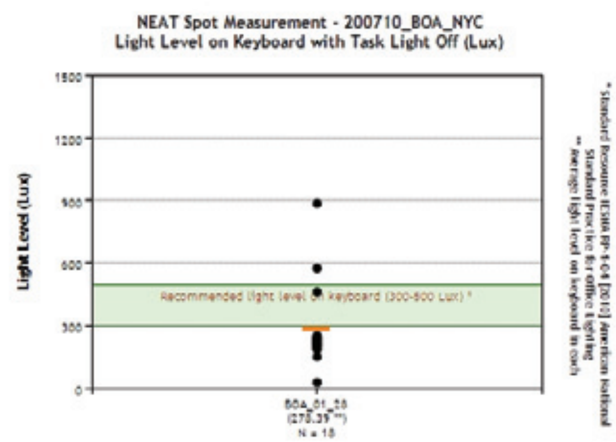


Light Level on Keyboard with Task Light Off

SOURCE DATA

BOA_01_28: 30, 218, 214, 210, 192, 190, 154, 237, 219, 230, 205, 254, 577, 465, 250, 887, 243, 236

Mean: 278.39, Min: 30, Max: 887
Percentage Within Comfort Zone: 5.56%

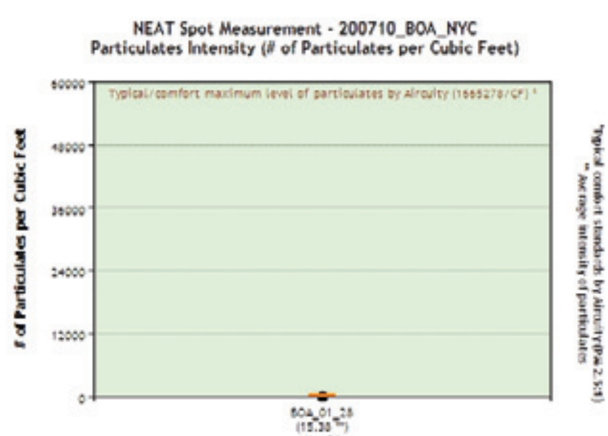


Particulates Intensity

SOURCE DATA

BOA_01_28: 0, 0, 0, 0, 0, 7, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 221, 0, 0, 0, 0, 0, 172, 0, 0, 0

Mean: 15.38, Min: 0, Max: 221

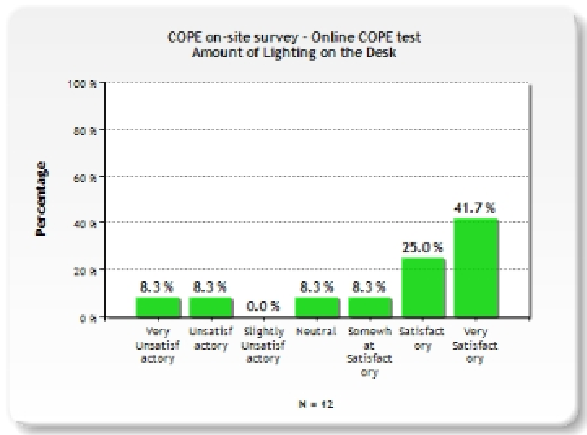


2. SURVEY RESULTS

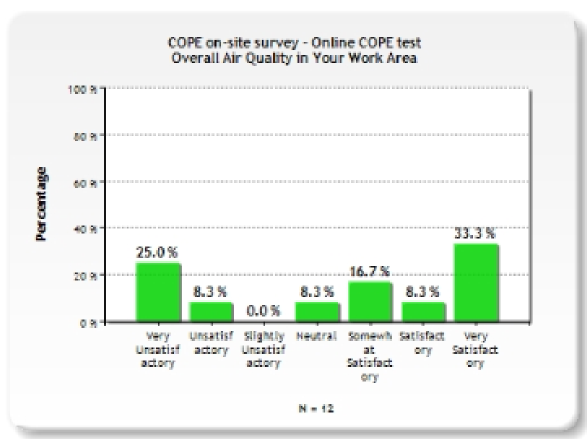
Results from On-Site User Satisfaction Survey

(Sample Size - IW_jp:12)

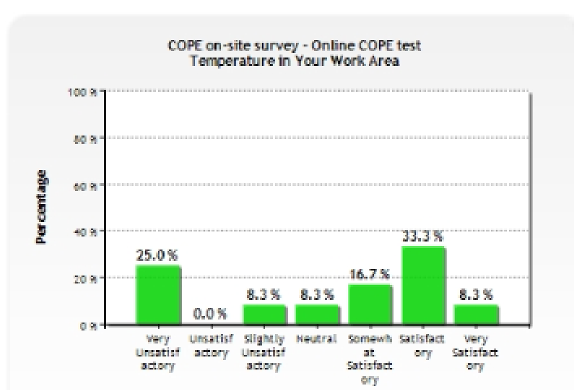
1. Amount of light on desk



2. Overall air quality in work area

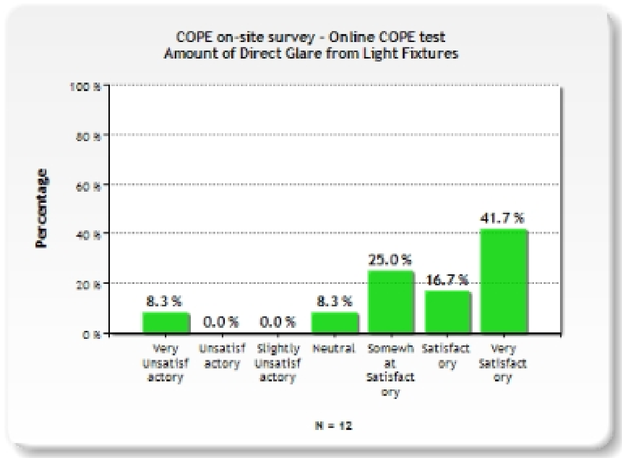


3. Temperature in work area

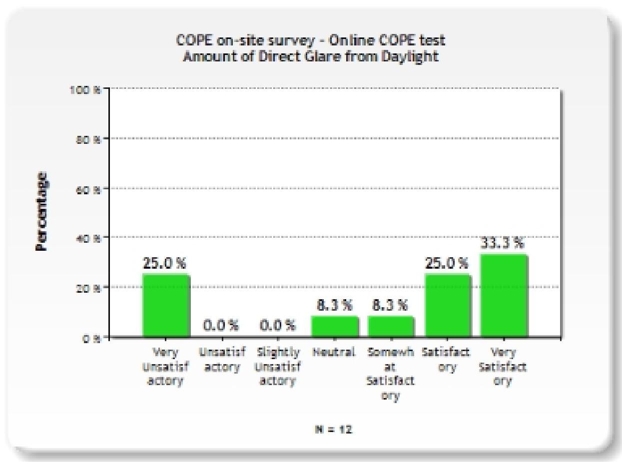


2. SURVEY RESULTS

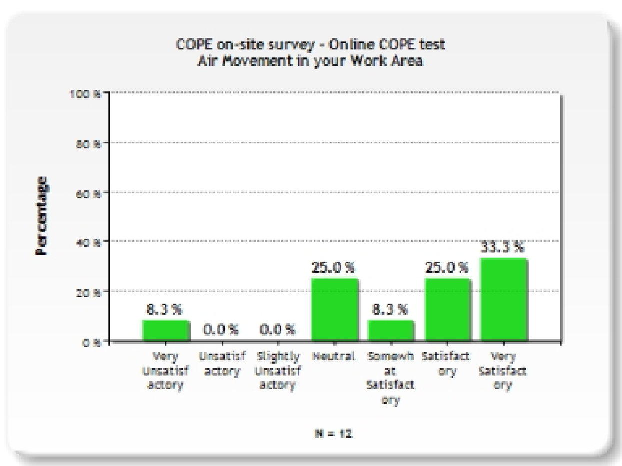
11b. Amount of direct glare from light fixtures



11c. Amount of direct glare from daylight



12. Air movement in work area



Attachment 2

CAADRIA Conference Paper

R. Stouffs, P. H. T. Janssen, S. Roudavski, B. Tunçer (eds.), *Open Systems: Proceedings of the 18th International Conference of the Association of Computer-Aided Architectural Design Research in Asia CAADRIA 2013,* 000–000.

ENERGY PERFORMANCE MODELING OF AN OFFICE BUILDING AND ITS EVALUATION

Post occupancy evaluation and energy efficiency of the building.

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Abstract. Energy performance modelling on commercial buildings provides an insight into understanding their efficiency and sustainability as well as helping meet certification standards such as USGBC LEED. However, the results from the modelling need to be validated via a post-construction evaluation, which quantify the discrepancy between the predicted energy usage and the actual energy consumed. In the present study, an existing office building, located in Pittsburgh was taken as an example building to examine how well the model predicts the energy usage. The results from the modelling have been compared with the actual usage appeared in the gas and electricity bills over two years (2010-2011). There was a significant amount of discrepancies 60% lower electricity usage and 123% higher gas usage in the simulation. It infers that that occupant behaviour and building construction practices may have significant impacts on the energy usage of a building. Accordingly, the design of a building needs to be incorporated with occupants' behaviours and interaction with their indoor environment to minimize over-redundancy. Additionally, it would be better that building codes and certification standards, include requirements for best practice at construction sites to ensure proper installation and storage of materials.

Keywords. Building performance evaluation; Energy modelling; Energy usage; Post occupancy evaluation; Indoor environmental quality (IEQ).

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1. Introduction

1.1. ENERGY USE IN BUILIDNGS

There is often a significant discrepancy between the designed and the actual total energy use in buildings. The reasons for this difference are in general poorly understood, and often have more to do with the role of human behaviour than the building design.

One of the major barriers for achieving the goal of substantially improving energy efficiency of buildings is the lack of information about the factors determining the energy use of the building. In general, building energy consumption is mainly influenced by six factors shown in table 1 (IEA, 2009)

Table 1. Main factors that influence building energy consumption

Building-related factors	1) Climate 2) Building envelops 3) Building energy systems
User-related aspects	4) Building Operation and Maintains (O&M) 5) Occupant's Behavior 6) Indoor Environmental Quality (IEQ)

A limitation of current research would be that it focuses mostly on building-related factors climate, building envelope, technical building attributes of building systems rather than human-related. All of the factors, however, including building operation, occupants' activity and behavior, and indoor environmental quality, need to be analyzed using real measured energy consumption data. It is important to collect data on actual built environment in terms of understand and interpret building energy usage as the differences in indoor climate which can cause huge differences in energy consumption. (IEA, 2009, Effinger et al, 2012)

1.2. INDOOR ENVIRONMENTAL QUALITY AND ENERGY SAVINGS

Post occupancy evaluation (POE) is one of the most important efforts for energy consumption reduction while enhancing indoor environmental quality and occupant satisfaction. Raftery et al pointed out that user interview and user pattern would be a one of the important factors for total energy consumption modeling and adjustment of error (Raftery, 2009). Measured field data on IEQ, user satisfaction and the technical attributes of building systems (TABS) supports ongoing opportunities for energy conservation while meeting IEQ standards. The CMU team has field findings for GSA portfolio (GSA, 2009) of offices that include 4 % total energy savings by raising summer set points, 40 % lighting energy savings by reducing ambient lighting and 25 % reduction in lighting energy by daylight harvesting.

1.3. OBJECTIVES AND GOALS

The goal of this study is better understanding and strengthening the knowledge for the effectiveness of the total energy usage in buildings through analyses of energy usage and expenses, sustainable practices and construction, and the indoor environment quality.

We highlight areas of efficient performance, as well as deficiencies within the building. Following our assessment, we provide strategies that can improve its energy efficiency, occupant comfort and the building's marketability through additional LEED certification. These strategies will also factor in the cost of adopting the recommendations to provide the building owner with insights into the return from such investments, since not all benefits are quantifiable.

2. Methods

Our approach, assessing the overall performance of the TAI+LEE commercial building is to focus on three areas: thermal envelope, energy usage and indoor environment quality.

The energy usage comparison was conducted through the use of gas and electricity bills dating back to May 2010. This data was then compared to the energy simulation conducted using eQUEST DOE-2 based simulation modelling tool and normalized for the heating and cooling degree-days to determine how well the building was actually performing. The data from the energy bills were also inputted into REM/Rate^{TM} software to provide a HERS rating, as well as quantify our own recommended retrofit strategies.

To evaluate the thermal envelope, we used a thermo graphic camera to take pictures of the building exterior, work areas and the wall connections of the entire indoor space in order to identify areas of heat loss within the building. We also researched the components of the building and their respective U-Values to compare with our actual findings from the pictures taken.

Lastly, indoor environmental quality field measurements were taken over two days in the TAI+LEE office building. The first measurements were taken on April 2nd, 2012, and the second set on April 17 and 18, 2012. Both were workdays with a number of employees present in the office.

On the first day, thermo graphic pictures, digital photos, surveys and NEAT cart measurements were taken for all rooms and spaces, including the basement.

The subsequent days were used to capture additional thermo graphic and digital pictures, conduct interviews, distribute longer occupant surveys, and setup the 24-hour Airquity measuring system.

3. Analysis of Current Condition

3.1. BUILDING INFORMATION

The building in this case study is TAI + LEE Architects in Pittsburgh, PA. Its current building owner occupies this architecture firm. It has 1 ½ floor plus a basement. The total floor area is 1,650 ft^2 with a conditioned volume of 23,100 ft^3. The total wall and window area is 2,716 ft^2 and 182 ft^2, respectively. When the TAI+LEE group took over the building it had to be completely gutted. It was not originally insulated and the roof had caved in. Therefore, they had to start from scratch by reconstructing the floor, walls and roof.

Figure 1. Photos of TAI+LEE: front of the building and interior work area (2012).

3.2. BUILDING ATTRIBUTES AND CONTROLS

The radiant floor system serves as the primary heating unit for the building. It has a much smaller rated output of 42 kBTU/h versus 117 kBTU/h for the standard building. Its performance ratings are 96 for the EFF and 17 for the EER, compared to 80 and 8.9 for the traditional unit.

TAI+LEE also installed a supplemental air heat pump to heat and cool the building during extreme weather conditions. Although this system was installed to operate under the most inefficient conditions, it is a high efficient system with a variable speed blower motor and is rarely used throughout the year.

The building is ventilated using two ERV systems, one in the basement (130cfm) and one on the first floor (200cfm) above the bathroom. The unit in the basement must be in constant operation to help control for humidity.

However, the unit in the first floor is not used as often, since it is sufficient to manually ventilate the space by opening the windows on the north and south walls and the skylights.

Interviews conducted with the employees revealed that the indoor thermal controls were complicated to use, and most preferred to leave it alone. There are multiple devices for controlling various systems in the building. When the building was first finished, the central thermostat did not have an automated timer. This resulted in a significant time lag between when it was turned on and when the radiating floors would come into effect. A workaround for this was to turn on the heat pump while the radiating floor system took time to ramp up. Consequently, this resulted in higher electricity use until they installed an automated mechanism that set the temperature to 72°F at 6 AM in the morning and 65°F after 8 PM and on weekends.

The Mitsubishi controller is responsible for the ERV, AC and heater. Under normal conditions, passive techniques for ventilation are used, such as opening the skylights or front and rear windows. We noticed that the employees rarely used this control due to its multiple settings and the necessity to readjust once comfort level is reached. Although they prefer passive techniques, it has its own inconveniences, as workers tend to stay focused until the thermal comfort is unbearable. When the ceiling fan was turned on, it made a significant positive impact for air circulation.

4. Energy Analysis and Results

4.1. COMPARISON OF SIMULATION AND ENERGY BILL

An energy simulation was conducted on TAI+LEE via eQUEST software and was compared against a reference case commercial building with the same floor area, volume and weather conditions (Pittsburgh). Table 2 shows the detailed information of baseline data and current project. This building has a 36% lower average u-value for the entire building (0.051 btu/hr-ft2-f), with increased R-values coming from the roof, floor and windows construction. In addition, it employs a more efficient and smaller HVAC system due to the improved thermal envelope. Combine that with only 2% total duct leak, compared with the expected 11% for the reference commercial building, TAI+LEE outperforms the reference case by 52% on cost and 32% on electricity use over the course of the year.

Although the simulation shows that the TAI+LEE building surpasses the reference commercial building, we wanted to compare the actual performance of the building to the simulated results. Based on the gas and electricity bills, TAI+LEE used a total of 130,807 and 103,171 kBTUs for the years 2010-2011 and 2011-2012, respectively. The simulation estimated a total energy usage of 101,184 kBTUs. However, the HDD and CDD for 2008 may be different than those for which we analyzed. Therefore, we normalized each year's total energy usage by its respective HDD and CDD and separated it by electricity and gas use (Figure 2) Electricity was 60% lower, while gas was 123% higher than the simulation values.

Comparing their EUI to the 2003 CBECS data for office buildings, TAI+LEE fell within the 25th percentile for electricity use (6.98 kWh/sq. ft.). However, their natural gas (47.09 cf/sq. ft.) put them in the 50-75th percentile range. This agrees with the findings above that they are using electricity efficiently, but gas use is suboptimal - possibly due to leaks within the thermal envelope.

Table 2. Energy simulation comparison between baseline building and current building

Description	**Baseline Case**	**Current builidng**
Weather file	PTTSBRGH.ET1	PTTSBRGH.ET1
Floor Area, ft²	1650.0	1650.0
Surface Area, ft²	6016.0	6016.0
Volume, ft³	23100.0	23100.0
Total Conduction UA, Btu/h-F	484.1	307.2
Average U-value, Btu/hr-ft²-F	0.080	0.051
Wall Construction	Code, R=9.7	triplebrick+foam, R=20.7
Roof Construction	R20polyiso, R=20.1	R30polyiso, R=29.5
Floor type, insulation	Crawl Space, Reff=24.0	Crawl Space, Reff=31.9
Window Construction	3026 wood code, U=0.35,etc	3070 wood kolbe, U=0.26,etc
Window Shading	None	None
Wall total gross area, ft²	2716	2716
Roof total gross area, ft²	1650	1650
Ground total gross area, ft²	1650	1650
Window total gross area, ft²	158	309
Windows (N/E/S/W:Roof)	9/0/12/0:0	11/0/8/5:3
Glazing name	codedouble, U=0.35	kolbe, U=0.26
Operating parameters:		
HVAC system	DX Cooling with Gas Furn	DX Cooling with Gas Furn
Rated Output (Ht/SC/TC),kBtu/h	117/48/64	42/28/37
Rated Air Flow/MOOA,cfm	1962/248	1873/120
Heating thermostat	72.0 °F, no setback	72.0 °F, setback to 67.0 °F
Cooling thermostat	76.0 °F, no setup	76.0 °F, setup to 81.0 °F
Heat/cool performance	eff=80,EER=8.9	eff=96,EER=17.0
Duct leaks total %	11/10	2/0
Peak Gains; IL,EL,HW,OT; W/ft²	1.00/0.33/0.26/1.52	0.75/0.10/0.26/1.25
Added mass	none	none
Daylighting	no	no
Infiltration, in²	ACH=1.0	ACH=0.3
Results:		
Energy cost	1.500$/Therm,0.100$/kWh	1.500$/Therm,0.100$/kWh
Simulation dates	01-Jan to 31-Dec	01-Jan to 31-Dec
Energy use, kBtu	306455	101184
Energy cost, $	$6153	$2558
Total Electric (**), kWh	27160	18405
Internal/External lights, kWh	5011/2226	3758/675
Heating/Cooling/Fan, kWh	0/3503/3135	0/1562/1485
Hot water/Other, kWh	0/13286	0/10926
Peak Electric, kW	11.8	5.7
Fuel, hw/heat/total, kBtu	6680/207098/213777	6680/31701/38380
Emissions, CO2/SO2/NOx, lbs	61750/238/139	29269/150/80

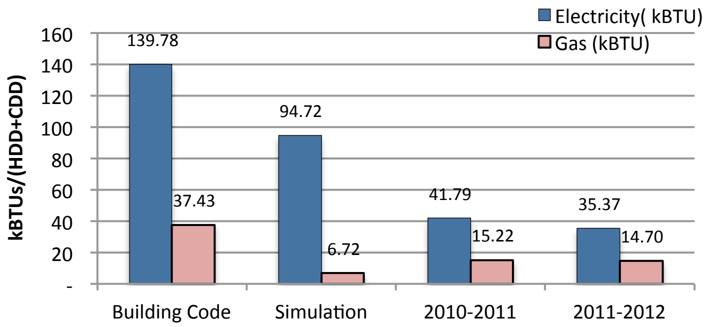
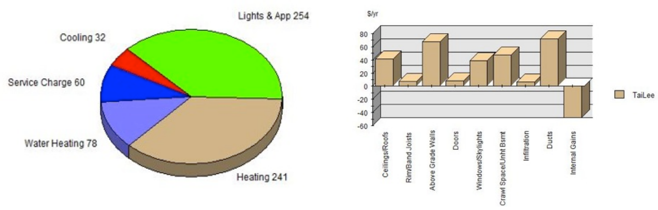


Figure 2. Normalized Energy Usage

4.2. ESTIMATION OF ENERGY CONSUMPTION

We performed REM/Rate simulation to estimate the current energy cost. Also adding a green roof increase a performance of roof envelopment. Adding a green roof under their PV panels, as well as filling out the rest of their roof space with both components would increase the efficiency at which PV panels perform, generate more electricity, and reduce the heating and cooling load of the building.



Total: $665/year, HERS Index: 85

Figure 3. Rem/Rate modeling: Current Energy Cost

When we performed a REMRate, the summation of all our recommendations amounted to an annual savings of $179, and improving our HERS index from 85 to 71. It is uncertain whether the REMRate model was able to capture benefits such as the reduction in heating and cooling load, but it also does not take into account the water runoff saved from employing a green roof. Because this renovation is such capital intensive, TAI+LEE must perform a thorough investigation of its benefits before proceeding.

5. Building Envelop

5.1. THERMAL ENVELOP

The envelope of the building was constructed with high-quality, low U-Value materials. The Kolbe windows are double-paned argon filled gas, while the walls, roof and floor were constructed from low-waste wooden joists with Tripolymer foam insulation and minwool batt. The table 3 outlines the U-Value associated with each component of building.

Table 3. U-Value of thermal envelope

Components	U-Value
Windows: Double-pane argon filled gas	0.260
Roof: Wooden joists with Tripolymer foam insulation	0.028
Walls: Wooden joists with Tripolymer foam insulation	0.05
Basement Concrete Wall	0.630
Floor: MinWool Batt	0.072

One method to understand the large discrepancy among gas usage is to assess the office building's thermal envelope. This helps to identify the spots at which heat leaks out of the building, thereby forcing the heating unit to work more. A thermo-graphic camera identified multiple spots of heat loss on the front sidewall of the building.

In 2008, a blower door test was performed for this building. The simulated infiltration was 0.3 ACH, but the results from the test returned 0.4 ACH. The leaks, which were from the wire installations of the solar PV panels located on the second floor, were supposedly fixed shortly thereafter. However, Figure 4-1 still shows some residual heat loss at the junction between the roof joist and the wall. Also, there are additional leaks in the conference room as seen in Figure 4-2. Overall, the majority of the leaks occur in the north wall/area of the building.

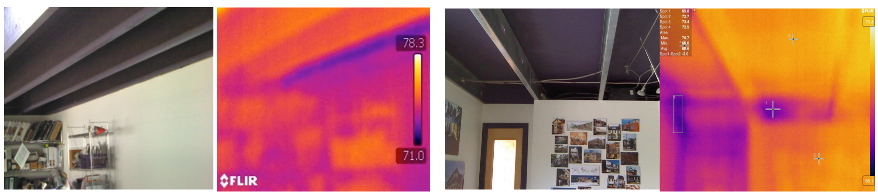


Figure 4. Thermal image of loft ceiling (4-1), and conference room (4-2)

5.2. IEQ EVALUATION: THERMAL QUALITY

In order to enhance the environmental profile of the work group beyond the descriptions possible with spot measurements, twenty-four hour continuous measurements were taken in one location of the office. An Aircuity Optima system is utilized to measure temperature, relative humidity, CO_2, CO, large and small particulates, TVOC, radon, and ozone. In this study, we are focused on thermal environmental qualities and findings. Table 4 shows the indices and user comfort standards for IEQ field measurement.

Spot and 24 hour continuous air temperature measurements (1.1m, 0.6m, 0.1m) ranged between 68-78°F (average 73°F), comfortably within the seasonal comfort zone. Although all measurements fell within the comfort zone, we noticed the loft area was quite warmer than the first floor. The space is currently used only as a storage area.

Table 4. The measurements taken at each workstation, as well as calculated variables

Measures taken and units	*Standards/ Thresholds*
Temperature at 4, 2, 0 feet °F (spot and 24 hour continuous)	ASHRAE 55-2010 heating season
Horizontal radiant temperature difference °F	ASHRAE 55-2010 heating season
Vertical radiant temperature difference °F	ASHRAE 55-2010 heating season
Relative humidity % (spot and 24 hour continuous)	ASHRAE 62-2010

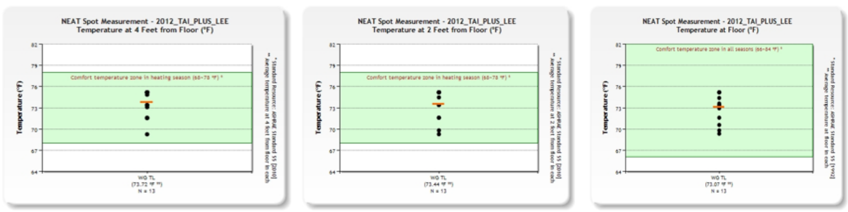
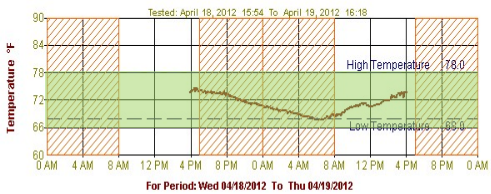


Figure 5. Spot measurement result: Temperature at 4ft, 2ft and 0ft from floor



	Temp. (°F)
Average Values	72
Extreme Values	68-75
Typical/Comfort	71 - 74
Recommended	68 - 78

Figure 6. 24-hour continuous measurement result

6. Summary and Conclusion

The TAI+LEE commercial building was a well-thought out and executed retrofit on dilapidated garage storage. Its use of high-quality, sustainable materials and selection of HVAC components are impressive. The electricity EUI was excellent as it fell within the 25th percentile of office buildings surveyed in the 2003 CBECS, and outperformed its energy simulation in 2008. In regards to the indoor environment quality, all measurements were within the comfort range and all employees enjoyed working in the building.

With that said, there were some points that we found that could have been improved. The natural gas EUI did not perform as well, since it fell within the 50-75th percentile of the 2003 CBECS.

Comparative analyses showed that energy usage discrepancies between the predicted and actual usages were significant. Based on the gas and electricity bills, the building used a total of 130,807 and 103,171 kBTU for the years 2010-2011 and 2011-2012, respectively whereas the simulation predicted a total energy usage of 101,184 kBTU.

Since the Heating Degree Day (HDD) and Cooling Degree Day (CDD) may vary year by year, each year's total energy usage was normalized by its respective HDD and CDD and separated it by electricity and gas use. Although the model relatively well-predict the total energy usage, larger discrepancies were found in separated terms predicting 60% lower electricity usage and 123% higher gas usage in the simulation. In general a building simulation analysis is expected to predict the usage in less than 10% of error. One method to understand the large discrepancy among gas usage is to assess the office building's thermal envelope. This helps to identify the spots at which heat leaks out of the building, thereby forcing the heating unit to work more. A thermo-graphic camera identified multiple spots of heat loss on the front sidewall of the building.

It infers that that occupant behavior and building construction practices may have significant impacts on the energy usage of a building. Accordingly, the design of a building needs to be incorporated with occupants' behaviors and interaction with their indoor environment to minimize over-redundancy. Additionally, it would be better that building codes and certification standards, such as USGBC LEED, include requirements for best practice at construction sites to ensure proper installation and storage of materials.

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Attachment 3

PLEA Abstract

INTEGRATED IEQ ASSESSMENT METHODS FOR OCCUPANT COMFORT: FROM DATA ACQUISITION TO VISUALIZATION

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[1]Carnegie Mellon University, USA, [2]University of Sheffield, UK, [3]Gehry Technologies, USA

ABSTRACT

Indoor environmental quality (IEQ) of buildings can have strong effects on occupants' productivity and health. Post occupancy evaluation (POE) and associated processes have been emphasized as a crucial stage for energy conservation and occupants' comfort and satisfaction of the building. A holistic POE includes measured field data on IEQ, user satisfaction assessment and the field records of technical attributes of building system.

Preliminary research has shown that POE may support opportunities for energy conservation while meeting or exceeding IEQ standards. Generally speaking, IEQ assessments, such as measurement of visual quality, thermal quality, air quality, acoustic quality, etc., are time-consuming and labour-intensive. One favourable approach is to overlay measured data with building floor plans or building system drawings. This approach enables the visualisation of the built environment performance in a more apprehensible fashion.

Current practice of mapping measured data with existing building components is manual and lack of flexibility of accommodating time-series building performance measurement. In order to support POE, we propose an integrated process to automate the measured field data mapping to assist building performance visualisation.

For the demonstration, we take the lighting quality measurement on two selected subjects, one unoccupied LEED gold certified building and an occupied office building in Los Angeles, California, USA. The outcomes are presented to show how measured performance data can be updated with the associated building elements automatically. Advantages and limitations of this approach for improving the workflow of IEQ are also discussed.

KEYWORDS:

indoor environmental quality; post occupancy evaluation; evaluation toolkit; data acquisition; data visualization

CONFERENCE TOPIC: D-4

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Attachment 4

Tai+Lee Environment Quality Report

Indoor Environmental Quality Report:
Office Retrofit Project for TAI+LEE Architects, Pittsburgh, PA

May 2012

Azizan Aziz, Vivian Loftness
Jihyun Park, Erica Cochran, Kevin Li, Carl Covington

School of Architecture
Building Performance and Diagnostics
Carnegie Mellon University

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1. Introduction

The building in this case study is TAI + LEE Architects in Pittsburgh, PA. This architecture firm is based in a commercial office building that used to be a detached garage. Steve Lee and Yoko Tai are architects that believe in green design and wanted this office building to reflect that philosophy. They felt that this retrofit project was their way to “walk the talk” in green design.

Figure 1 Detached Car Garage

Figure 2 Office Building

The goal of the TAI+LEE Architects Building Retrofit project is to evaluate the effectiveness of the initial retrofit renovation of this building through analysis of energy usage and expenses, sustainable practices and construction, and the indoor environment quality. We will highlight areas of efficient performance, as well as deficiencies within the building. Following our assessment, we will provide strategies that can improve its energy efficiency, occupant comfort and the building’s marketability through additional LEED certification. These strategies will also factor in the cost of adopting the recommendations to provide the building owner with insights into the return from such investments, since not all benefits are quantifiable.

2. Methodology

Our approach to assessing the overall performance of the TAI+LEE commercial building is to focus on three areas: thermal envelope, energy usage and indoor environment quality.

To evaluate the thermal envelope, we used a thermo graphic camera to take pictures of the building exterior, work areas and the wall connections of the entire indoor space in order to identify areas of heat loss within the building. We also researched the components of the building and their respective U-Values to compare with our actual findings from the pictures taken. In addition, we interviewed Stephen, Yoko and Nina Baird, who supervised an energy simulation and conducted a blower door test of the building, to gain further understanding of historical issues.

The energy usage comparison was conducted through the use of gas and electricity bills dating back to May 2010. This data was then compared to the energy simulation conducted in 2008 and normalized for the heating and cooling degree-days to determine how well the building was actually performing. The data from the energy bills were also inputted into REMRate to provide a HERS rating, as well as quantify our own recommended retrofit strategies.

Lastly, measurements were taken over two days in the TAI+LEE office building. The first measurements were taken on April 2^{nd}, 2012, and the second set on April 17 and 18, 2012. Both were workdays with a number of employees present in the office.

On the first day, thermo graphic pictures, digital photos, surveys and NEAT cart measurements were taken for all rooms and spaces, including the basement.

The subsequent days were used to capture additional thermo graphic and digital pictures, conduct interviews, distribute longer occupant surveys, and setup the 24-hour Airquity measuring system.

Table 1 Environmental quality measures taken

	Indices	*Measuring items*	*Unit*	*Spot measurements*	*Continuous measurements*	*User surveys*
1	**Thermal quality**	*Temperature* *Relative humidity*	*°F* *%*	√ √	√ √	√
2	**Air quality**	*CO_2* *CO* *TVOC* *Radon* *Ozone* *Particulates*	*ppm* *ppm* *index* *pCi/L* *ppm* *#/ft^3*	√ √ √ - - √	√ √ √ √ √ √	√
3	**Lighting quality**	*Illuminance* *Glare* *Luminance Ratio*	*lux* - -	√ - √	- - -	√
4	**Daylight and Views**	*Glare* *Access to a view* *Space appearance*	- - -	- - -	- - -	√
5	**Acoustic quality**	*RC/NC/NBC* *QAI*	- -	√ √	- -	√
6	**Spatial quality**	*multiple variables*		- -	- -	√
7	**Overall satisfaction**	*Multiple variables*	-	-	-	√

Table 2 The measurements taken at each workstation, as well as calculated variables

Measures taken and units (spot measurements unless noted)	***Standards/ Thresholds***
Temperature at 4 feet °F (spot and 24 hour continuous)	ASHRAE 55-2010 cooling and heating season
Temperature at 2 feet °F	"
Temperature at floor level °F	"
Horizontal radiant temperature difference °F	"
Vertical radiant temperature difference °F	"
Relative humidity % (spot and 24 hour continuous)	ASHRAE 62-2010
CO_2 concentration ppm (spot and 24 hour continuous)	ASHRAE 62-2004, EPA IAQ specifications
CO concentration ppm (spot and 24 hour continuous)	EPA IAQ specifications
Small particulates #/ft3 (24 hour continuous)	HPSH based on EPA IAQ specifications
Large particulates #/ft3 (24 hour continuous)	HPSH based on EPA IAQ specifications
TVOC index (24 hour continuous)	EPA IAQ specifications
Ozone (24 hour continuous)	EPA IAQ specifications
Radon (24 hour continuous)	EPA IAQ specifications
Light level on primary work surface (w/ task light off) lux	IESNA 10-11
Light level on keyboard (w/ task light off) lux	"
Light level on Monitor (w/ task light off) lux	"
Light level on primary work surface (w/ task light on) lux	"
Calculated luminance/ Brightness contrast ratio	IESNA 10-11
Background noise level RC/NC/NBC)	ASHRAE Applications Handbook 2010
Background noise quality (QAI)	"

2.1 The NEAT Workstation Sampling Strategy- Spot Measurements

A National Environmental Assessment Tool (NEAT) instrument cart has been developed with GSA support to measure temperature at three heights, relative humidity, CO_2, CO, total particulates, and VOCs. Attached to this cart are hand held instruments for light levels, radiant temperature, and air velocity, as well as an equipment data logger, a PDA, and a camera.

A detailed manual has been written to define each step of the workstation sampling strategy, in order to ensure consistency in data collection. As an overview: The instrument cart is placed in the position of the occupant's chair for approximately fifteen minutes for each room sampled. For the first few minutes, the sensors are allowed to acclimatize to the environment in the space. Immediately thereafter, hand held readings of light levels, radiant temperature, and air velocity are logged into the data logger. Then, automated sensor readings to temperature at three heights, relative humidity, and air quality indices are taken over the next four minutes, and fifteen-second intervals, and averaged to obtain the final measurements in that workstation. Before leaving the room, two digital pictures are taken with a fish eye lens to capture brightness contrast, and many conventional digital photographs are taken to record the workstation configuration and furniture as well as the primary work surfaces. Environmental indicators revealing local control or modification of lighting, thermal, indoor air quality, acoustic, and spatial conditions are logged into the data logger as well.

2.2 Aircuity Continuous Measurement Sampling

In order to enhance the environmental profile of the work group beyond the descriptions possible with spot measurements, twenty-four hour continuous measurements were taken in one location of the office. An Aircuity Optima system is utilized to measure temperature, relative humidity, CO_2, CO, large and small particulates, TVOC, radon, and ozone. Typically, these continuous measurement instruments are set in the most typical workstation configuration, usually interior rather than perimeter or core rooms, and in an unoccupied space within an unoccupied work area. In our case, we situated the Aircuity in an empty work desk in the northern half of the building.

Figure 3 Spot measurement with NEAT cart

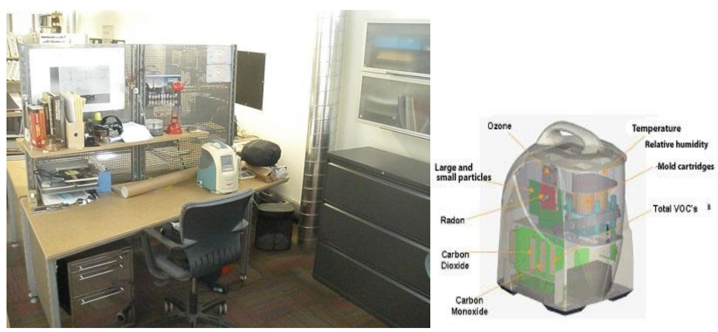


Figure 4 Continuous measurement with Aircuity Optima

2.3 User Satisfaction Questionnaire

During the time when the physical measurements are recorded, the occupant is asked to complete a 'User Satisfaction Questionnaire' related to today's specific environmental conditions, as compared to annual satisfaction questionnaires. The COPE Questionnaire was developed by the National Research Council Canada to support the Cost-effective Open-Plan Environment (COPE) Project. Using iPad mobile tablet, 25-question survey (+ 4 demographic quest ions) has been utilized by the NRC in their ongoing research about measured environmental performance and simultaneous levels of user satisfaction in various open plan office environments. A few questions have been modified as the result of recommendations from the lighting research group of Public Works Government Services Canada, and ongoing input in field use. The questionnaires were distributed to the range of end users: the TAI+LEE staff in the offices.

All of the NEAT and Aircuity Optima measurements, the COPE user satisfaction questionnaires, and the environmental indicators identified are linked in database for comparative analysis. The analysis uses descriptive statistics for side by side comparisons of measured conditions across venues, user satisfaction across venues, and the comparisons of measured conditions and user satisfaction. Regression analysis was explored, but the variability of locations and activities along with the sample size made statistical significance less reliable. These analyses led to a series of findings and recommendations that have been divided into the chapters that follow.

3. Building information

TAI+LEE Architects is located in Pittsburgh, PA in the Polish Hill district an occupied by its current building owner. It has 1 ½ floor plus a basement. The total floor area is 1,650 ft^2 with a conditioned volume of 23,100 ft^3. The total wall and window area is 2,716 ft^2 and 182 ft^2, respectively.

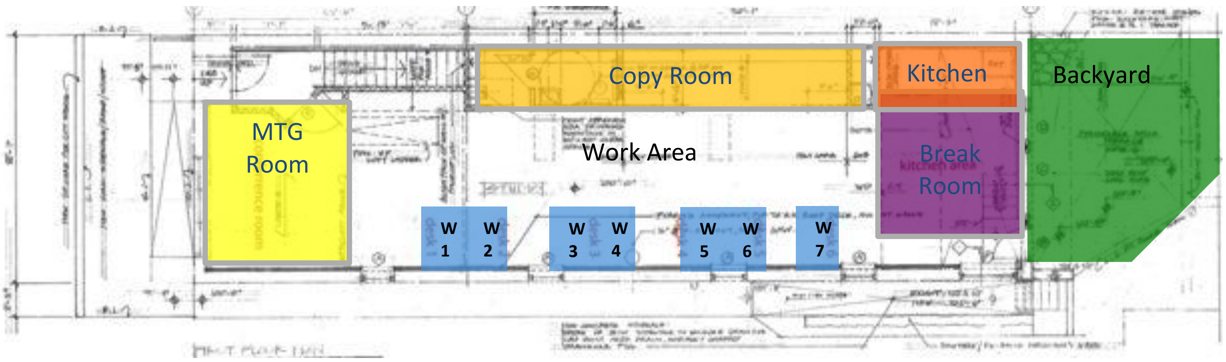


Figure 5 Floor plan

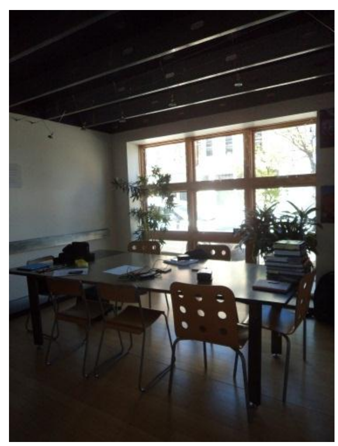


Figure 6 Front of building **Figure 7 Interior work area**

Figure 8 Meeting area

When the TAI+LEE group took over the building it had to be completely gutted. It was not originally insulated and the roof had caved in. Therefore, they had to start from scratch by reconstructing the floor, walls and roof.

4. Analysis of Current Condition

4.1 Equipment and Controls

The radiant floor system (Figure 9) serves as the primary heating and cooling unit for the building. It has a much smaller rated output of 42 kBTU/h versus 117 kBTU/h for the standard building. Its performance ratings are 96 for the EFF and 17 for the EER, compared to 80 and 8.9 for the traditional unit.

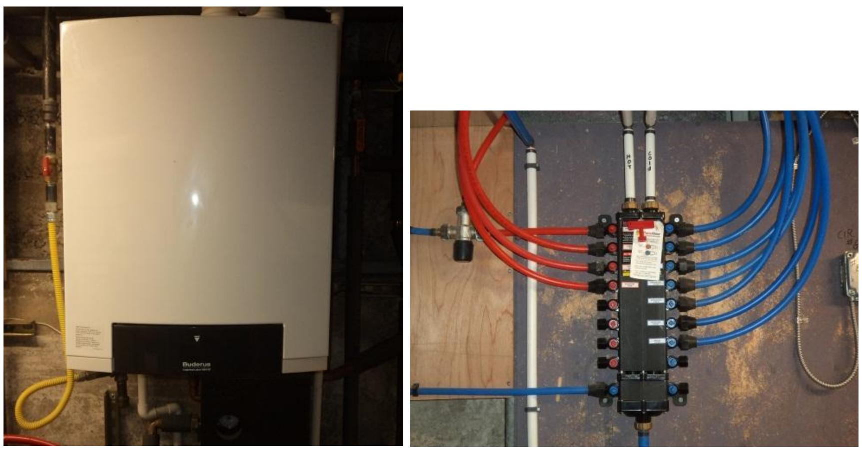


Figure 9: Radiant floor system

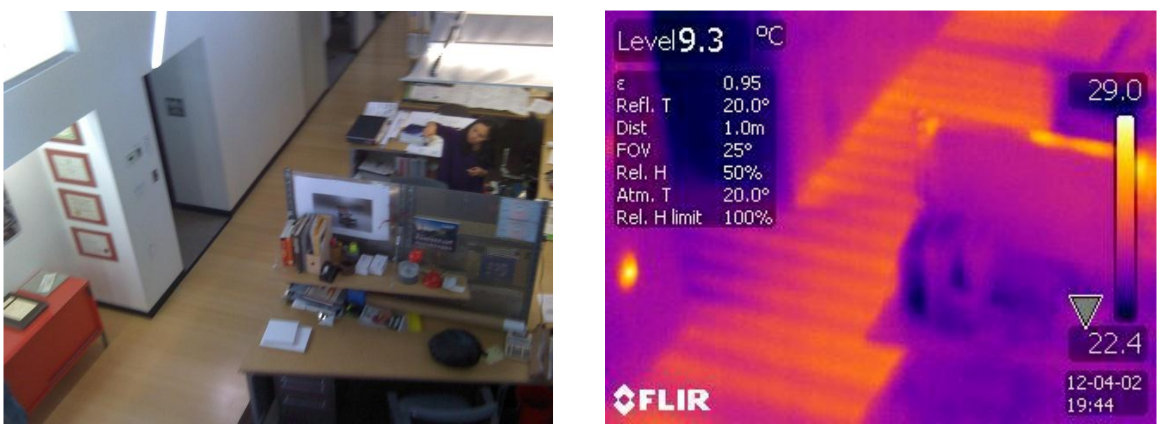


Figure 10: Radiant floor and thermal graphic image

TAI+LEE also installed a supplemental air heat pump (Figure 11) to heat and cool the building during extreme weather conditions. Although this system was installed to operate under the most inefficient conditions, it is a high efficient system with a variable speed blower motor and is rarely used throughout the year.

The building is ventilated using two ERV systems, one in the basement (130cfm) and one on the first floor (200cfm) above the bathroom. The unit in the basement (Figure 12) must be in constant operation to help control for humidity. However, the unit in the first floor is not used as often, since it is sufficient to manually ventilate the space by opening the windows on the north and south walls and the skylights.

Figure 11 Bryant FE4A Air Heat Pump

Figure 12 ERV system in Basement

Interviews conducted with the employees revealed that the indoor thermal controls were complicated to use, and most preferred to leave it alone. Looking at Figure 13, there are multiple devices for controlling various systems in the building. When the building was first finished, the central thermostat did not have an automated timer. This resulted in a significant time lag between when it was turned on and when the radiating floors would come into effect. A workaround for this was to turn on the heat pump while the radiating floor system took time to ramp up. Consequently, this resulted in higher electricity use until they installed an automated mechanism that set the temperature to 72°F at 6 AM in the morning and 65°F after 8 PM and on weekends.

The Mitsubishi controller is responsible for the ERV, AC and heater. Under normal conditions, passive techniques for ventilation are used, such as opening the skylights or front and rear windows. We noticed that the employees rarely used this control due to its multiple settings and the necessity to readjust once comfort level is reached. Although they prefer passive techniques, it has its own inconveniences, as workers tend to stay focused until the thermal comfort is unbearable. When the ceiling fan was turned on, it made a significant positive impact for air circulation.

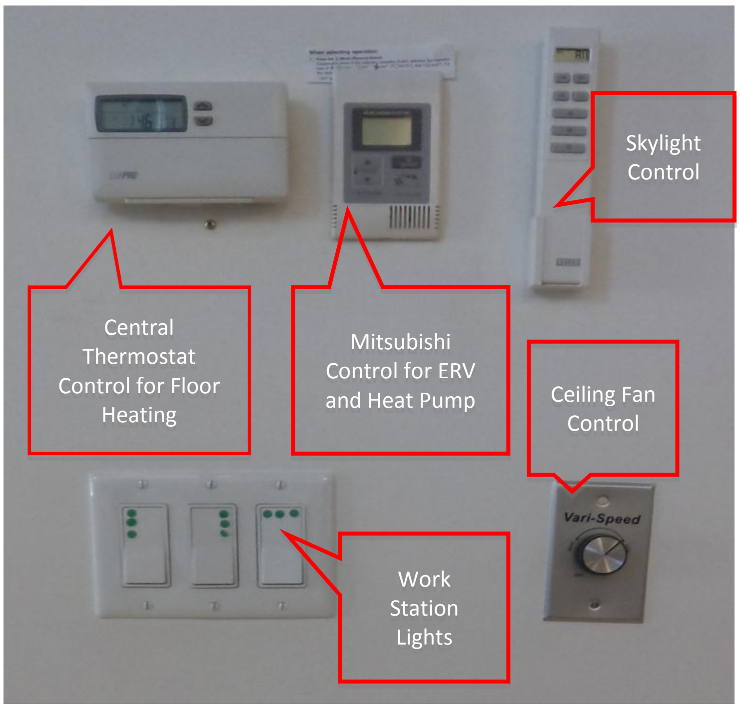


Figure 13 Central control area of building

4.2 Thermal Envelope

The envelope of the building was constructed with high-quality, low U-Value materials. The Kolbe windows are double-paned argon filled gas, while the walls, roof and floor were constructed from low-waste wooden joists with Tripolymer foam insulation and minwool batt. Table 3 outlines the U-Value associated with each component of building. Based on these given values, it was estimated that the building had a seasonal heat loss of 83 MBtu. If we were to use a set of cost-friendlier components, the calculated heat loss would be 103 MBtu.

Table 3 : U-Value of thermal envelope

Components	*Existing U-Value*	*Budget U-Value*
Windows: Double-pane argon filled gas	0.260	0.350
Roof: Wooden joists with Tripolymer foam insulation	0.028	0.048
Walls: Wooden joists with Tripolymer foam insulation	0.05	0.09
Basement Concrete Wall	**0.630**	**0.630**
Floor: MinWool Batt	0.072	0.072

In 2008, a blower door test was performed for the TAI+LEE building. The simulated infiltration was 0.3 ACH, but the results from the test returned 0.4 ACH. The leaks, which were from the wire installations of the solar PV panels located on the second floor, were supposedly fixed shortly thereafter. However, Figure 14 still shows some residual heat loss at the junction between the roof joist and the wall. Also, there are additional leaks in the conference room as seen in Figure 15. Overall, the majority of the leaks occur in the north wall/area of the building.

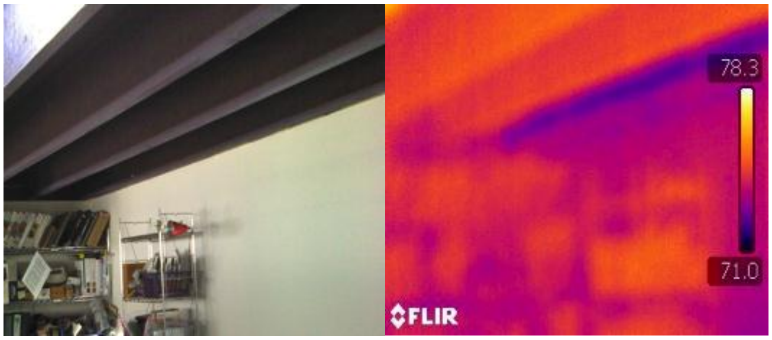


Figure 14 Thermal image of loft ceiling

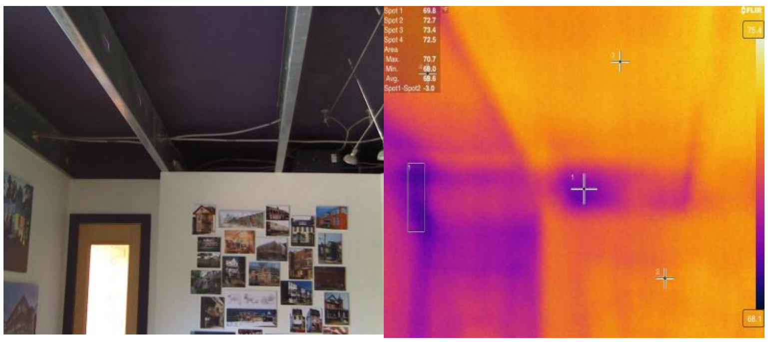


Figure 15 Thermal image of conference room

4.3 Energy Usage

An energy simulation was conducted on TAI+LEE in 2008 and was compared against a reference case commercial building with the same floor area, volume and weather conditions (Pittsburgh). TAI+LEE has a 36% lower average U-Value for the entire building (0.051 Btu/hr-ft2-F), with increased R-Values coming from the roof, floor and windows construction. In addition, it employs a more efficient and smaller HVAC system due to the improved thermal envelope. Combine that with only 2% total duct leak, compared with the expected 11% for the reference commercial building, TAI+LEE outperforms the reference case by 52% on cost and 32% on electricity use over the course of the year.

Although the simulation shows that the TAI+LEE building surpasses the reference commercial building, we wanted to compare the actual performance of the building to the simulated results. Based on the gas and electricity bills, TAI+LEE used a total of 130,807 and 103,171 kBTUs for the years 2010-2011 and 2011-2012, respectively. The simulation estimated a total energy usage of 101,184 kBTUs. However, the HDD and CDD for 2008 may be different than those for which we analyzed. Therefore, we normalized each year's total energy usage by its respective HDD and CDD and separated it by electricity and gas use (Figure 16) Electricity was 60% lower, while gas was 123% higher than the simulation values.

Comparing their EUI to the 2003 CBECS data for office buildings, TAI+LEE fell within the 25th percentile for electricity use (6.98 kWh/sq. ft.). However, their natural gas (47.09 cf/sq. ft.) put them in the 50-75th percentile range. This agrees with the findings above that they are using electricity efficiently, but gas use is suboptimal—possibly due to leaks within the thermal envelope.

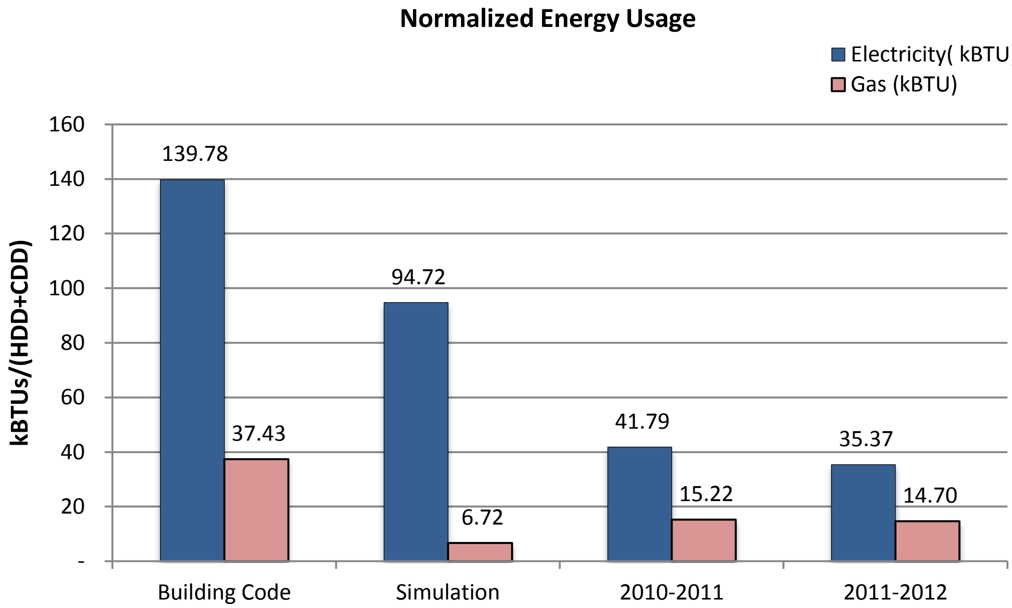


Figure 16 Normalized Energy Usage Comparison

4.4 Ergonomics

Although each workstation is structured the same, the type of chair used varied from basic to ergonomically advanced depending on the worker's preference. Currently, workstations 1 and 2 are using basic office chairs, while workstations 3 and 4 offer more adjustments and lumbar support, as shown in (Figure 17, 18). Workstation 4 contains the most advanced office chair with breathable mesh seating, multiple tilt adjustments and arm rests. Generally, employees are supplied with basic chairs, but must purchase their own if they want one with more ergonomic support. During the employees' drafting process, it is difficult for them to obtain the proper back support and alignment due to the table angle and the need to focus on details in various locations of the drafting table (Figure 19). More customizable drafting chairs, adjustable tables and proper ergonomics training would be beneficial to improving the work space comfort level.

Figure 17: Workstation 1 and 2 chairs

Figure 18 Workstation 3 and 4 chairs

Figure 19 Drafting posture

5. IEQ Measurement

5.1 Thermal quality

1) Objective and Subjective Findings: Temperature and Relative Humidity

Spot and 24 hour continuous air temperature measurements (1.1m, 0.6m, 0m) ranged between 68-78°F (average 73°F), comfortably within the seasonal comfort zone.

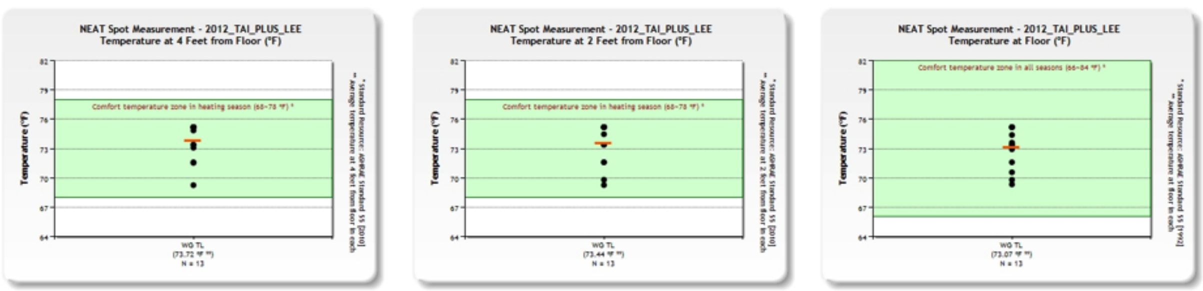
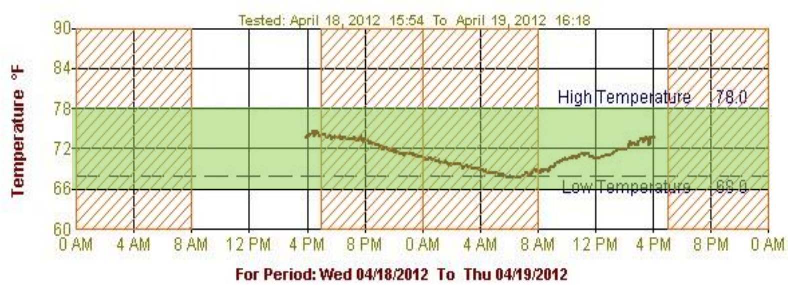


Figure 20 NEAT Spot measurement result: Temperature at 4ft, 2ft and 0ft from floor



	Temp. (°F)
Average Values	72
Extreme Values	68-75
Typical/Comfort	71 - 74
Recommended	68 - 78

Figure 21 Aircuity 24hour measurement result

Conference room, work stations and break area were evenly and adequately conditioned. User surveys demonstrated all employees were satisfied, although 20% of them were only somewhat satisfied. There may be certain work stations that can heat up more than others due to the sun shining through one of the west wall windows. Proper shading for these windows can rectify such slight discomfort. Although all measurements fell within the comfort zone, we noticed the loft area was quite warmer than the first floor. Fortunately, the space is currently used only as a storage area.

2) Main factors for positive thermal condition

- effective radiant floor system
- thoroughly and evenly conditioned first floor
- well insulated thermal envelope

5.2 Air Quality

1) Objective and Subjective Findings: Ventilation, CO2, Particulates, TVOC

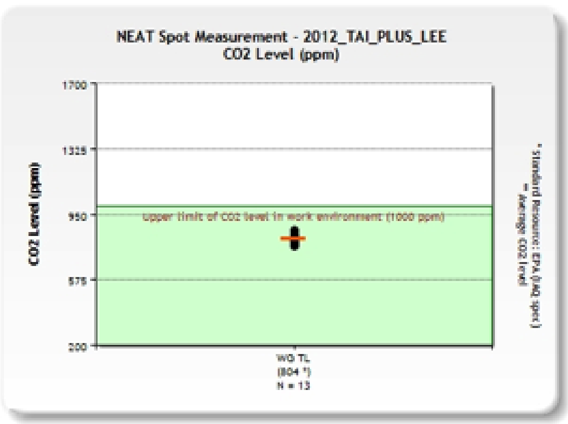


Figure 22 NEAT Spot measurement result: CO2 concentration

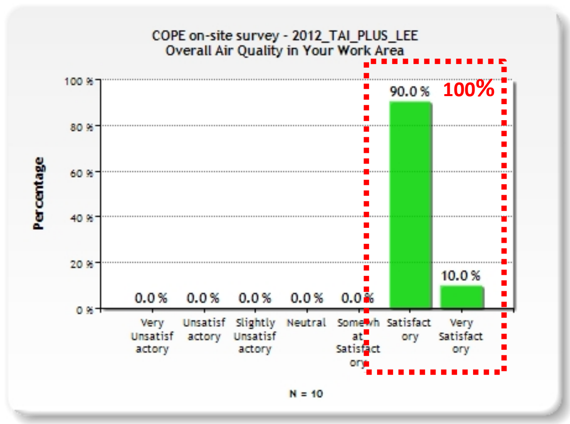
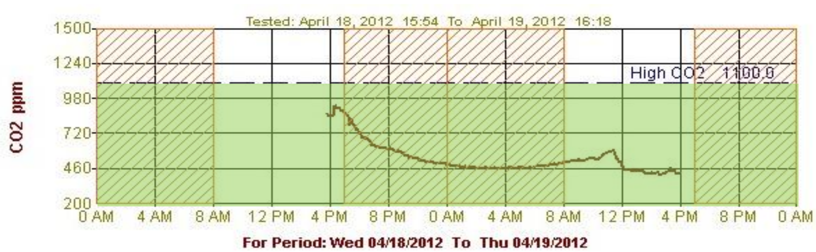


Figure 23 NEAT Spot measurement result: Overall air quality in your work area

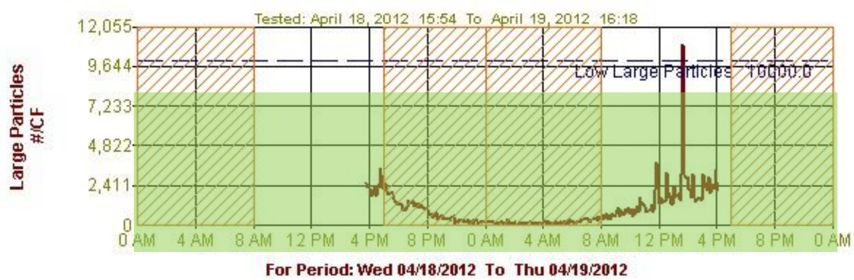


	CO2. (ppm)
Average Values	850
Extreme Values	953
Typical/Comfort	< 1100
Recommended	< 1100

Figure 24 Continuous measurement result: CO2 concentration

Table 4 Air quality: Continuous Measurements

Event / Season	*Area*	*Air Cleanliness*			*Building Pollutants*		
		PM 10 (µg/m3)	**PM 2.5 (µg/m3)**	**TVOC (index)**	**CO (ppm)**	**Radon (pCi/l)**	**Ozone (ppm)**
TAI+LEE/ Winter	***Office***	*9*	*5*	*6*	*0*	*0*	*0.007*
Typical/Comfort		**< 40**	**< 20**	**< 10**	**< 3**	**< 2**	**< 0.1**
Recommended		**< 40**	**< 20**	**< 35**	**< 9**	**< 4**	**< 0.1**



The spot and 24 hour continuous CO_2 measurements all fell within the comfort zone. However, given the fact that the building contains a high ceiling and there were only four occupants at the time of measurement, the spot CO_2 levels ranged on the high side. Yet all employees responded with a *satisfactory* or *very satisfactory* score on the surveys. Our own experience in the building indicated that there could have been more ventilation throughout the space. Although the building systems offer many solutions to ensure proper ventilation, we noticed they were not often employed during our visits.

2) Main factors for indoor air quality

- ERV system.
- kick-out windows.
- operable skylights with remote controls.
- ceiling fans.

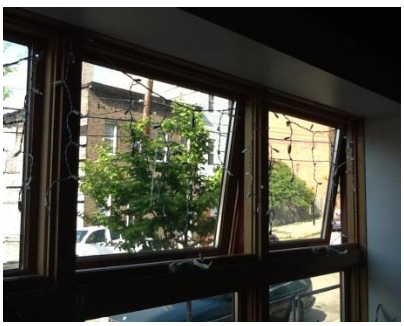


Figure 25 kick-out windows

Figure 26 Operable skylight

Figure 27 Ceiling Fan

5.3 Visual Quality

1) Objective and Subjective: Lighting, Daylighting and Views

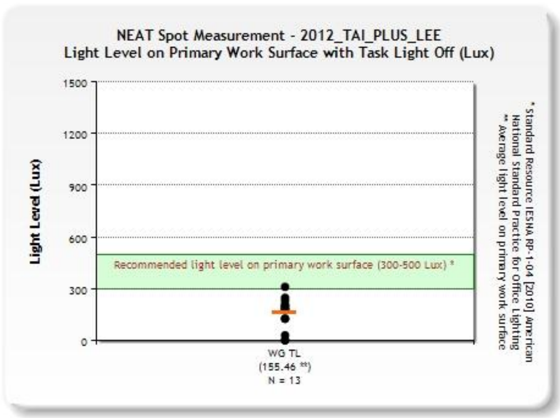


Figure 28 NEAT Spot measurement result: Light Level on Primary Work Surface

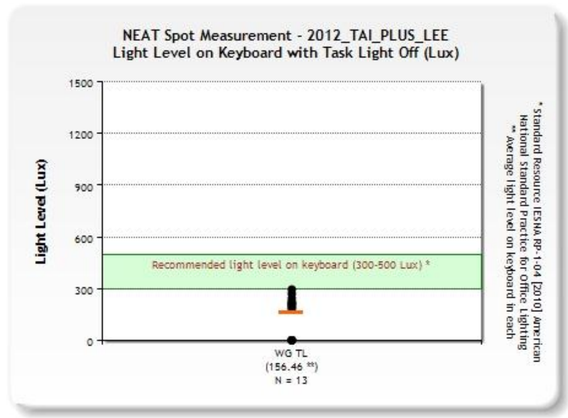


Figure 29 NEAT Spot measurement result: Light Level on Keyboard

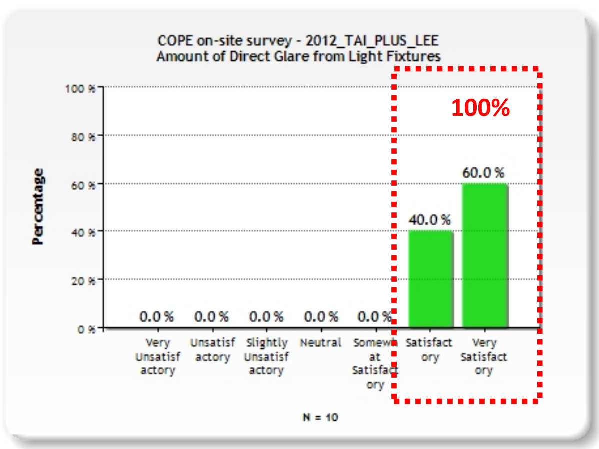


Figure 30 NEAT Spot measurement result: Amount of direct glare from lighting fixtures

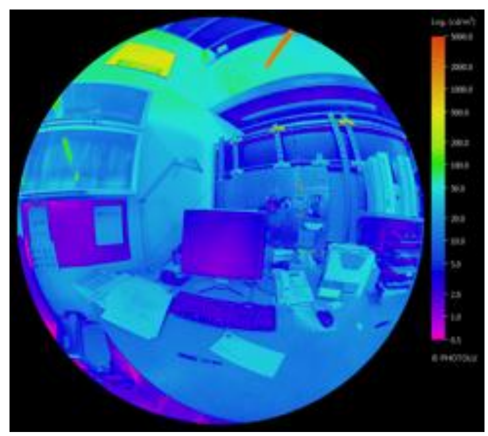


Figure 31 Photolux image on workstation

Measurements for illuminance and luminance levels were excellent and were corroborated by the user surveys, in which 60% responded with *very satisfactory* and 40% with *satisfactory*. Specifically, the layout of the work stations were well designed with computer monitors facing away from the west wall windows. The addition of the light softener fabric screen also provided employees with ideal lighting condition for work. However, we found that when the lights were turned off, the space was extremely dark, suggesting not enough day lighting within the work stations.


Figure 32 Lighting fixtures and softner(fabric screen)

2) Main factors Visual Quality

- Layout of workstation.
- Light softener (fabric screen).

5.4 Acoustic Quality

3) Objective and Subjective Findings: Background Noise, Room Criteria

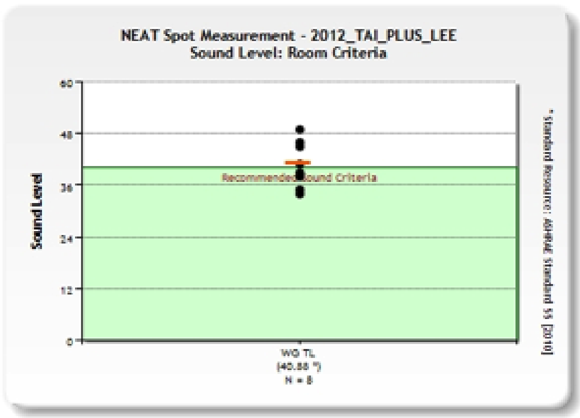


Figure 33 NEAT Spot measurement result: Room Criteria

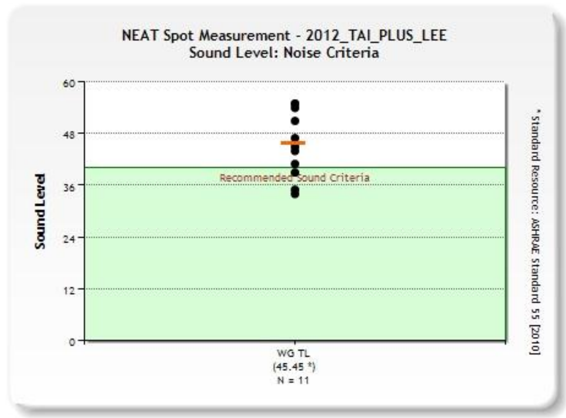


Figure 34 User satisfaction survey: Noise Criteria

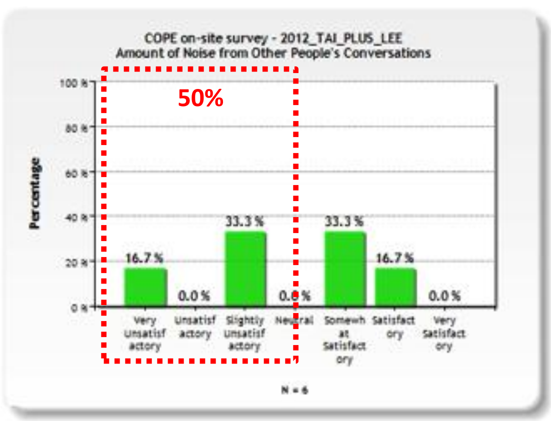


Figure 35 User satisfaction survey:

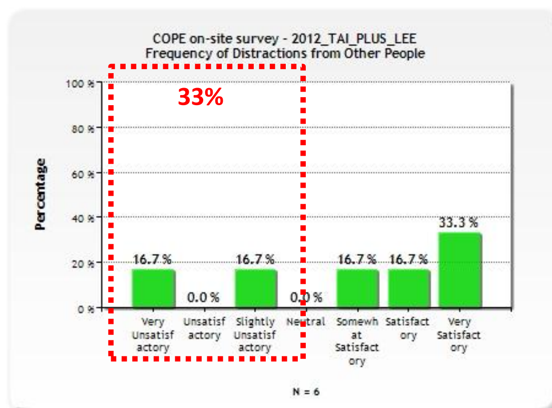


Figure 36 User satisfaction survey: Frequency of distractions from other people

The acoustic quality had the poorest performance within the IEQ field measurements. Only 30-40% of the spot measurements fell within the comfort zone, which was also expressed by the employees with 50% feeling the amount of noise coming from other people's conversations were unsatisfactory. This can be attributed to the open office layout, the construction materials of partitions separating each work station and lack of sound dampeners to mitigate drifting conversations.

4) Main factors Acoustic Quality

- Open-office layout.
- Materials of screen.
- No sound dampener.

Figure 37 Partition on workstation

6. Recommendations

After accessing the HVAC and lighting systems, thermal envelope and indoor environmental quality of the entire building, we have come up with five possible retrofit solutions that can improve the energy efficiency and indoor comfort of the space. These recommendations focus around windows/ventilation, lighting and plug loads, control systems, green roof and ergonomic comfort. In addition, we also assessed the possibility of obtaining LEED EBOM certification and the types of renovations for earning Gold or Platinum.

6.1 Windows/Ventilation

The current ERV provides good ventilation in the office, but we noticed that the office didn't take full advantage of passive strategies to cool and ventilate the space. The windows on the western facing wall are inoperable and don't currently have any shading devices on them which could help reduce additional heat in certain work stations. Redi Shade Blinds, which cost $20 per blind, can help to increase thermal comfort, while still letting sunlight in. Since the wind in Pittsburgh primarily comes from the west this could be an opportunity to install operable windows to passively cool and ventilate the office.

Figure 38 Glare from windows

Figure 39 Windows on western Wall

The windows on the second floor across from the balcony are operable but they are too high and unreachable, so they are never opened. If these windows were used to their full potential they would assist in passively ventilating and cooling the office. We suggest putting the windows on the same system as the skylights or investing in a latch and pole system which allows the windows to be opened from the ground floor.

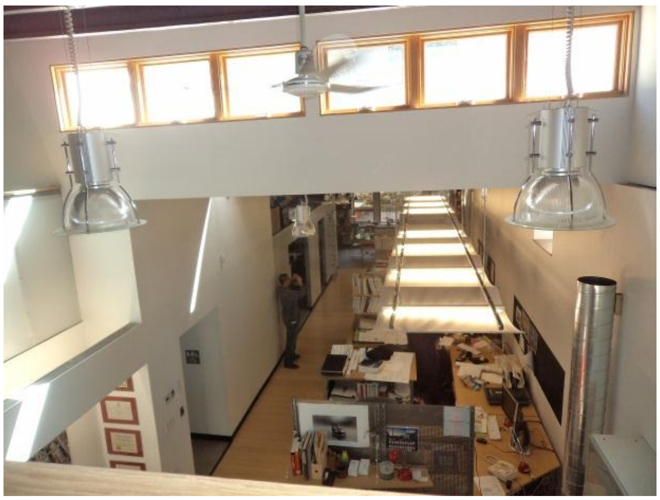


Figure 40 Windows across from balcony

Figure 41 Opening window with latch

6.2 Lighting/Plug loads

The current setup consists of eight 2-lamp ballasts spread over the five work desks. There are two light switches, each controlling four of the ballasts with T5 28W Linear Fluorescent lamps. One possibility to save energy from their lighting is to use fluorescent dimming systems, since not all work desks are occupied at all times. The ability to adjust lighting would save energy and also improve the comfort levels based on individual employee preferences. Specifically, the Sylvania 51358 2x28T5 Dali Dimming System is currently priced at $147 each, which would total to $1176 to replace the eight ballasts. Also, we must include five dimmer controls for each work desk, which can total $250 at $50 each. Combining this with three Tork In-Wall Daylight Sensors at $125 each, the total amount of this system would be nearly $2000. Given four fulltime employees and eight lighting ballasts, we estimate consumption would drop by half, since they can turn off the ones that are not in use. Assuming 260 workdays in a year, 10 work hours per day and 28W fluorescent tubes, they would save roughly an additional $44/year. Therefore, we would not suggest for them to proceed with retrofit due to its long payback period. However, it would have been a more viable option at the time of the initial retrofit when Steve Lee was still deciding on the lighting systems.

6.3 Simplify Control Systems

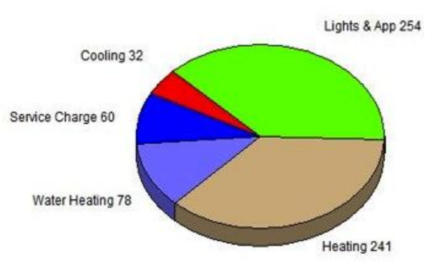
The appearance of multiple controls mounted on the wall can be daunting for new and existing employees. Currently, the central thermostat control for floor heating does not need to be adjusted, since it is running on a timer and thermostat. The Mitsubishi control can adjust the A/C, fan and heating, but is rarely used due to its complexity and the employees' aversion to making too many adjustments. Our first recommendation is to provide another training session solely for the Mitsubishi control and to educate them on the situations for appropriate use.

Although employing a consolidated automation control system would not be practical under current conditions, this could have been an option during the initial retrofit. Integrating once of these systems would remove the wall full of controllers and consolidate it into one touchscreen unit. The HAI Omni IIe Controller with Enclosure would be a nice addition that allows occupants to adjust lighting, manage the HVAV system, entertainment (music) and serves as a security system. Combine that with the HAI OmniTouch 5.7 Color Touchscreen, the total cost of both units would be roughly $2000. The primary benefit of such a system would be difficult to quantify, but can provide much more convenience and comfort for employees, thereby increasing productivity, and additional security for the building.

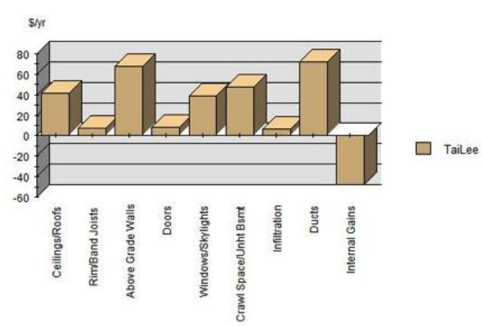
6.4 Green Roof

Adding a green roof under their PV panels, as well as filling out the rest of their roof space with both components would increase the efficiency at which PV panels perform, generate more electricity, and reduce the heating and cooling load of the building. However, the exact effects of a green roof are hard to quantify and an extensive green roof system can cost between $8 - $20/sq. ft., translating to $10-20k for taking up half of their roof space.

When we performed a REMRate, the summation of all our recommendations amounted to an annual savings of $179, and improving our HERS index from 85 to 71. It is uncertain whether the REMRate model was able to capture benefits such as the reduction in heating and cooling load, but it also does not take into account the water runoff saved from employing a green roof. Because this renovation is such capital intensive, TAI+LEE must perform a thorough investigation of its benefits before proceeding.

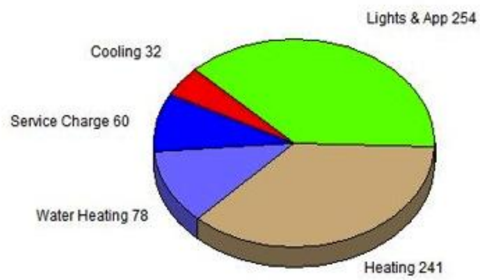


Total:$665/year, HERS Index:85
Annual Energy Cost ($/year)

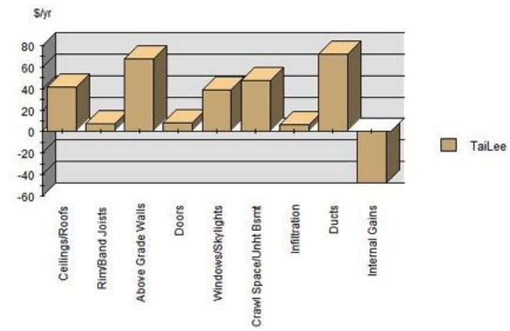


Annual Heating Cost ($/year)

Figure 42 RemRate modeling: Current Energy Cost



Total:$665/year, HERS Index:85
Annual Energy Cost ($/year)



Annual Heating Cost ($/year)

Figure 43 RemRate modeling: Proposed Energy Cost

Figure 44 TAI+LEE roof

Figure 45 Green roof image

6.5 Ergonomics

Due to the policy that employees are responsible for their own comfort as it relates to seating, it is difficult for TAI+LEE to invest in better, more ergonomic chairs. As a compromise, they may offer to invest in supplemental lumbar support cushions that can be placed in their current chairs. Also, ergonomic classes or education on proper stretching and workspace setup would also help.

As an improvement to their initial renovation, we would suggest installing adjustable drafting desks to fit the various sizes of employees, and even offering a standing option desk to enable more blood flow into the legs.

Figure 46 Drafting posture

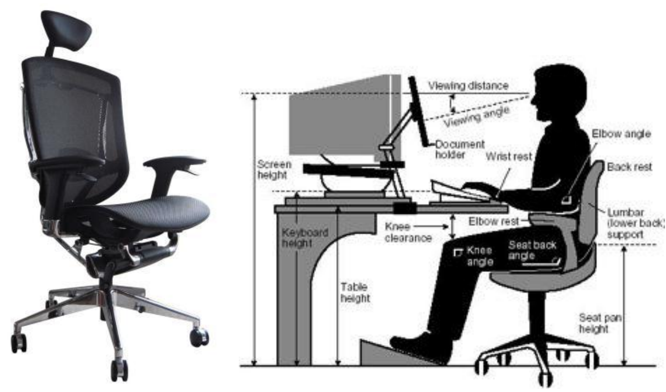


Figure 47 Ergonomic chair and posture

7. Financing

The possible funding options for the recommendations given above include rebates, renewable energy credits (RECs) and loans. Rebates would offer help with the lighting and additional solar PV renovations, while RECs provide a steady revenue stream for the electricity generated by the PV panels. Although there were no options that explicitly fund green roof, we found two possible loans, where green roof may qualify. Table 5 provides a summary of the funding available for the recommendations listed above.

Table 5 Outline of funding options for recommendations

Types of Incentives	*Program*	*Item*	*Amount*
Rebates	Duquesne Light Company - Commercial and Industrial Energy Efficiency Program	Light sensors; ballast dimming system	\$10-40
	Pennsylvania Sunshine Solar Rebate Program (Waiting list system)	Commercial PV	\$0.50 - \$0.75/W DC (35% of installed cost)
	Pennsylvania Sunshine Solar Rebate Program (Waiting list system)	Solar Thermal	35% of installed cost (\$50k max)
RECs	Pennsylvania Public Utilities Commission - Solar Alternative Energy Credits	Photovoltaic	\$0.12 - \$0.17/kWh
Loans	Small Business Pollution Prevention Assistance Account Loan Program	Green Roof	Up to 75% of total eligible project cost
	Pennsylvania Green Energy Loan Fund	Green Roof	Range from \$100,000 to \$2.5M

8. LEED Certification

TAI+LEE is currently rated with a LEED Gold certification under the New Construction category. However, we also estimated the certification level if they were to apply for LEED EBOM. Our findings indicate that they would fall somewhere between silver and gold, depending on how they score under Portfolio Manager's rating system. Unfortunately, the program required a minimum space of 5000 sq. ft. in order to provide a baseline, and therefore was unable to obtain a score. The other categories the building had difficulty obtaining points were *Water Efficiency* because they didn't have any landscaping and *Sustainable Sites* because there business and building was too small to establish a significant alternative commuting transportation program.

LEED 2009 for Existing Buildings: Operations & Maintenance
Project Checklist

Project Name
Date

Y	?	N			Points
7	15			**Sustainable Sites**	Possible Points: 26
4	4		Credit 1	LEED Certified Design and Construction	4
1	1		Credit 2	Building Exterior and Hardscape Management Plan	1
			Credit 3	Integrated Pest Mgmt, Erosion Control, and Landscape Mgmt Plan	1
	7		Credit 4	Alternative Commuting Transportation	3 to 15
			Credit 5	Site Development—Protect or Restore Open Habitat	1
	1		Credit 6	Stormwater Quantity Control	1
			Credit 7.1	Heat Island Reduction—Non-Roof	1
1	1		Credit 7.2	Heat Island Reduction—Roof	1
1	1		Credit 8	Light Pollution Reduction	1
1	4			**Water Efficiency**	Possible Points: 14
Y			Prereq 1	Minimum Indoor Plumbing Fixture and Fitting Efficiency	
1	2		Credit 1	Water Performance Measurement	1 to 2
	2		Credit 2	Additional Indoor Plumbing Fixture and Fitting Efficiency	1 to 5
			Credit 3	Water Efficient Landscaping	1 to 5
			Credit 4	Cooling Tower Water Management	1 to 2
	25			**Energy and Atmosphere**	Possible Points: 35
Y			Prereq 1	Energy Efficiency Best Management Practices	
Y			Prereq 2	Minimum Energy Efficiency Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
	10		Credit 1	Optimize Energy Efficiency Performance	1 to 18
	2		Credit 2.1	Existing Building Commissioning—Investigation and Analysis	2
	2		Credit 2.2	Existing Building Commissioning—Implementation	2
	2		Credit 2.3	Existing Building Commissioning—Ongoing Commissioning	2
	1		Credit 3.1	Performance Measurement—Building Automation System	1
	2		Credit 3.2	Performance Measurement—System-Level Metering	1 to 2
	6		Credit 4	On-site and Off-site Renewable Energy	1 to 6
			Credit 5	Enhanced Refrigerant Management	1
			Credit 6	Emissions Reduction Reporting	1
	4			**Materials and Resources**	Possible Points: 10
Y			Prereq 1	Sustainable Purchasing Policy	
Y			Prereq 2	Solid Waste Management Policy	
			Credit 1	Sustainable Purchasing—Ongoing Consumables	1
	1		Credit 2.1	Sustainable Purchasing—Electric-Powered Equipment	1
			Credit 2.2	Sustainable Purchasing—Furniture	1
			Credit 3	Sustainable Purchasing—Facility Alterations and Additions	1
	1		Credit 4	Sustainable Purchasing—Reduced Mercury in Lamps	1
			Credit 5	Sustainable Purchasing—Food	1
				Materials and Resources, Continued	
	1		Credit 6	Solid Waste Management—Waste Stream Audit	1
	1		Credit 7	Solid Waste Management—Ongoing Consumables	1
			Credit 8	Solid Waste Management—Durable Goods	1
			Credit 9	Solid Waste Management—Facility Alterations and Additions	1
6	11			**Indoor Environmental Quality**	Possible Points: 15
Y			Prereq 1	Minimum IAQ Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
Y			Prereq 3	Green Cleaning Policy	
	1		Credit 1.1	IAQ Best Mgmt Practices—IAQ Management Program	1
	1		Credit 1.2	IAQ Best Mgmt Practices—Outdoor Air	1
1	1		Credit 1.3	IAQ Best Mgmt Practices—Increased Ventilation	1
			Credit 1.4	IAQ Best Mgmt Practices—Reduce Particulates in Air Distribution	1
			Credit 1.5	IAQ Mgmt Plan—IAQ Mgmt for Facility Alterations and Additions	1
	1		Credit 2.1	Occupant Comfort—Occupant Survey	1
	1		Credit 2.2	Controllability of Systems—Lighting	1
	1		Credit 2.3	Occupant Comfort—Thermal Comfort Monitoring	1
1	1		Credit 2.4	Daylight and Views	1
1	1		Credit 3.1	Green Cleaning—High Performance Cleaning Program	1
1	1		Credit 3.2	Green Cleaning—Custodial Effectiveness Assessment	1
1	1		Credit 3.3	Green Cleaning—Sustainable Cleaning Products, Materials Purchases	1
			Credit 3.4	Green Cleaning—Sustainable Cleaning Equipment	1
1	1		Credit 3.5	Green Cleaning—Indoor Chemical and Pollutant Source Control	1
			Credit 3.6	Green Cleaning—Indoor Integrated Pest Management	1
	2			**Innovation in Operations**	Possible Points: 6
			Credit 1.1	Innovation in Operations: Specific Title	1
			Credit 1.2	Innovation in Operations: Specific Title	1
			Credit 1.3	Innovation in Operations: Specific Title	1
			Credit 1.4	Innovation in Operations: Specific Title	1
	1		Credit 2	LEED Accredited Professional	1
	1		Credit 3	Documenting Sustainable Building Cost Impacts	1
				Regional Priority Credits	Possible Points: 4
			Credit 1.1	Regional Priority: Specific Credit	1
			Credit 1.2	Regional Priority: Specific Credit	1
			Credit 1.3	Regional Priority: Specific Credit	1
			Credit 1.4	Regional Priority: Specific Credit	1
14	61			**Total**	Possible Points: 110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Figure 48: LEED EBOM scoring for TAI+LEE

9. Summary and conclusion

The TAI+LEE commercial building was a well-thought out and executed retrofit on dilapidated garage storage. Its use of high-quality, sustainable materials and selection of HVAC components are impressive. The electricity EUI was excellent as it fell within the 25th percentile of office buildings surveyed in the 2003 CBECS, and outperformed its energy simulation in 2008. In regards to the indoor environment quality, all measurements were within the comfort range and all employees enjoyed working in the building.

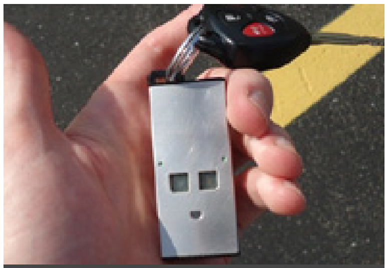
With that said, there were some points that we found that could have been improved. The natural gas EUI did not perform as well, since it fell within the 50-75th percentile of the 2003 CBECs. That followed our findings that their natural gas use amounted to 123% more than what their energy simulation estimated. A possible reason for this may be the leaks found within the north wall of the building. Also, the controls for all the systems, skylights and fans are a bit intimidating and the staff should be retrained on when they should make adjustments to the Mitsubishi control system. Ergonomics could be improved for employees with additional lumbar cushions and proper education on seating posture and stretches. Some of our recommendations may not be practical given the costs required and the marginal benefits they provide, but would be good to know going forward for future retrofit projects.

Attachment 5

iPad/iPhone IEQ sensors

SENSOR APPLICATIONS FOR iPHONE, iPAD, ANDROIDS and LAPTOPS

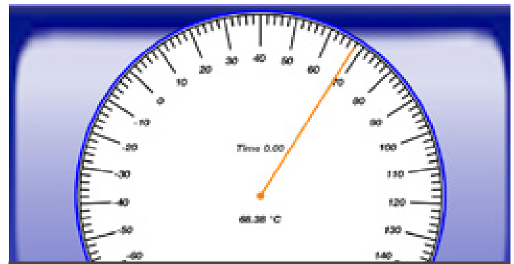
IAQ apps



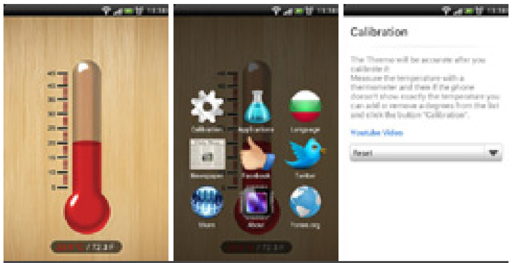
	AppliedSensor Indoor Air Monitor	Sensodrone	EcoSENSE
General Information	This sensor is for computers, not smart-phones	For iPad, iPhone, Android, Blackberry Possibilities to connect to social media and share your findngs	For Android phones
Data storage	●	●	●
Wireless		●	●
Needs Sensor	●	●	●
Sensor Price	$39.50	$175.00	–
Range	450-2000ppm CO2 equiva-lents	- Reducing Gas Sensor: 5-1000ppm - Oxidizing Gas Sensor: 0-5ppm - TEMPERATURE: -20oC to + 60oC	- CO = 1 to 1000 ppm, - NOx = 0.05 to 5 ppm, - Noise = 30 to 140 db, - Humidity = 0 to 100% RH, - Temperature = -40 to +125°C (-40 – +257°F)
Factors measured	VOCs detected: - alcohols - aldehydes - ketones - organic acids - aliphatic - aromatic hydrocarbons	- Precision Gas Sensor (CO, H2S, Alcohol, Hydrogen, others) - Oxidizing gases (Ozone, NO2, etc.) - Reducing gases (meth-ane, alcohols, other hydro-carbons, - Temperature - Humidity - Pressure - Infrared Temperature	- Carbon monoxide (CO) - Nitrogen oxide (NOx) - Noise - Temperature - Humidity
Website	ecjoa.xdrnb.servertrust.com/ProductDetails.asp?ProductCode=IAM	www.kickstarter.com/projects/453951341/sen-sordrone-the-6th-sense-of-your-smartphoneand-be	www.sensaris.com/prod-ucts/senspod/

			
			
Eco_2SENSE	**Eco_3SENSE**	**EcoPM**	**RemPod**
For Android phones (Calibrated)	For Android phones (Calibration Curve)	For Android phones (Particulate Matter)	For Android phones (Calibrated)
●	●	●	●
●	●	●	●
●	●	●	●
–	–	–	–
- 0-5000ppm	- O3 = 10 to 10000 ppb - UVA+UVB+UVC = 220-370 nm - Humidity = 0 to 100% RH - Temperature = -40 to +125°C (-40 – +257°F)	- particles size = minimum 1µ	- Alpha, Beta and Gamma rays = 18 CPS/mR/hr
- Carbon dioxide (CO2)	- Ozone (O3) - Luminosity (UVA, UVB, UVC) - Temperature - Humidity	- PM 2.5 - PM 10	- Radiations (alpha, beta and gamma)
www.sensaris.com/prod-ucts/senspod/	www.sensaris.com/prod-ucts/senspod/	www.sensaris.com/prod-ucts/senspod/	www.sensaris.com/prod-ucts/senspod/

TEMPERATURE apps

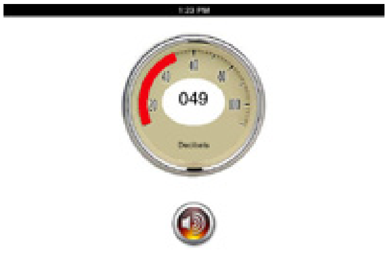
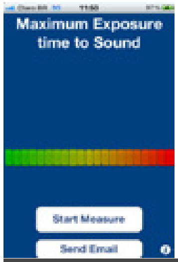


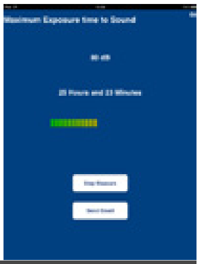
	iCelsius	Mobile Science Temperature
General Information	transforms your iPhone / iPad and iPod touch into a digital thermometer.	for iPhone, iPad and iPod touch
Air Temperature	●	●
Surface Temperature		
Needs Sensor	●	●
Sensor Price	$99 with RH / $49 without RH	any thermcouple
Software	●	●
Data storage	●	●
Wireless		
Manufacturer's description	Range: -22°F to 158°F Accuracy: ±1.8°F (over whole range) 0-100% RH ±3% typical	Record temperature using a thermistor circuit connected to the headset port
Website	www.icelsius.com	apple apps store



BlueTherm	CIGARAlert	Thermo app
for Android	CigarAlert is a USB device with a digital sensor that is designed for cigars monitoring	for Android
●		●
●		
●		
–	–	–-
●	●	●
●	●	
●	●	●
- BlueTherm™ Probe Bluetooth air or gas and surface temperature probes - Response time less than 0.5 of a second - securely transmits data up to 20 m - eliminates wires, cables+connectors - Bluetooth wireless technology - probe Ø4.5 x 130 mm	- The USB device reads the humidity and temperature levels every 4 seconds - CigarAlert software provides a large display of the current humidity and temperature levels	- Android Thermometer measure the room temperature - Android Thermometer - After the installation go to Menu > Calibration > and follow the instructions - The application can be moved on SD Card (Android 2.2 or high)
www.etiltd.com	http://cigaralert.com/	android apps store

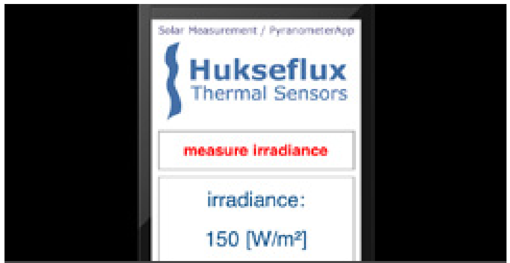
ACOUSTIC apps

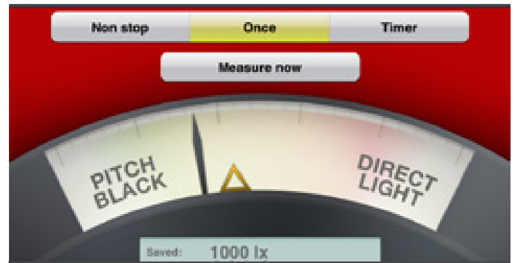





	Decibel 10th	SoundMeter	Max_DB_Time
General Information	for iPhone, iPad, iPod touch	For iPad, iPhone, iPod touch and Android	for iPhone, iPad, iPod touch
Need Sensor			
Sensor price	–	–	–
Data storage	●		●
Wireless	●	●	●
Frequency Range	4-20 Hz	1-10 Hz	no information
Manufacturer's description	- Display the average peak and max values - Plotted history of the average values - Record and export the data to email	- Range from 45-85dB - Recored over 1 second	- Measures volume of sound, calculated their value in dB - Generates an email with the values obtained
Website	apple apps store	apple apps store	apple apps store

LIGHT apps





	Pyranometer	LuxMeter
General Information	for iPhone, iPad, iPod touch	for iPhone, iPad and iPod touch
Subjective	Irradiance	lux
Need sensor		
Sensor price	–	–
Data storage	●	●
Wireless	●	●
Manufacturer’s description	An application to measure the solar radiation	Use the camera of iphone or ipad2/new to measure the light intensity
Website	www.susanpesman.nl	apple apps store

Attachment 6

"IEQ and its Impact on Energy" White Paper

__Attachment 1__

Post occupancy evaluation (POE) measures that save energy:
How do we achieve 20% energy savings with scalable technologies?
Indoor Environmental Quality (IEQ) and its impact on energy

Quarterly 4, 2012

Energy Efficient Buildings Hub
Subtask 5.3: Energy Use, IEQ and Occupancy Satisfaction Tool Kit [NEAT]

Carnegie Mellon University
Center for Building Performance and Diagnostics

Azizan Aziz, Vivian Loftness
Jihyun Park, Erica Cochran

Subtask 5.3: *Energy Use, IEQ and Occupancy Satisfaction Tool Kit [NEAT]*, Carnegie Mellon University

How do we achieve 20% energy savings with scalable technologies? IEQ and its impact on energy!

Post occupancy evaluation (POE) is one of the most important efforts for energy consumption reduction while enhancing indoor environmental quality and occupant satisfaction. A conventional POE toolkit does not normally capture ECMs. To properly capture ECMs, three critical parameters are addressed in the NEAT Toolkit; energy consumption, indoor environmental quality (IEQ) and occupant comfort and satisfaction. The Toolkit focuses on **total building performance evaluation** by integrating energy consumption, indoor environmental quality and occupant satisfaction.

In order to meet DOE's **20% energy savings with scalable technologies**, subtask 5.3 is refining and expanding the energy audit and evaluation utilizing 4 different techniques.

1. TABS (Technical Attributes of Building Systems) and CBAR - *ongoing*
2. Utility bill and BMS trending – *whenever available*
3. Simulation analysis - *ongoing*
4. Sensors and Metering Technologies – *to be integrated*

First, TABS is one of the existing tools in the NEAT Toolkit. TABS is a field data collection tool used by the team to collect technical information and physical characteristics of the building, for example window types (operability, # panes, air tightness, etc), lighting systems (LPD, fixture and lamp type, ++), mechanical systems (diffuser density, controls, source type, ++) and other technical attributes. CMU is also partnering with DOE/PNNL Commercial Builidng Asset Rating [CBAR] Program, which is developing a tool to assess building energy performance, to streamline TABS with CBAR.

Secondly, utility bills and trended energy consumption data are collected whenever available. Often times, these data are not available for older buildings in campus settings and federal sector buildings. The TABS and measured IEQ data are utilized to develop an energy model to predict energy consumption and to investigate discrepancies as illustrated in figure 1.

Finally, we are in the early stages of identifying portable sensors and metering technologies to capture on-the-spot and continuous energy consumption (electricity, gas, and other fuel types). CMU plans to collaborate with teams in subtask 2.4 "*Energy Auditing Tool for Commercial Building"* to integrate their tools for seamless data collection, transfer and analysis into NEAT's field instrumentation and database.

The CMU team will continue to collaborate and provide expertise to other Hub members for the rest of year 2. In year 3, we plan to expand our collaboration to meet Objective 4 "*Inform, train, and educate people about proven energy saving strategies and technologies whether they design, own, construct, maintain, or occupy buildings*". The ultimate goal for the Toolkit is a cost-effective commercial product to be used by facility managers (and student + researchers) to conduct POE and provide recommendations for ECMs.

Why it is important to undertake IEQ measurements and occupant satisfaction relative to AER?

1. **Code Compliance.** One major driver for AER investment is when buildings no longer meet code. Today's codes have both hard metrics in thermal, air, lighting and acoustic requirements by building type and user satisfaction requirements (typically 80% for thermal). When areas of buildings fall short, the building owner will want to upgrade with the most energy and IEQ effective solutions.
2. **IEQ is a market driver today.** Leading companies competing for the best graduates have found that the quality of the work environment is a factor in attraction. Building owners reaching for higher IEQ will undertake investments in energy conservation.
3. **IEQ metrics and user satisfaction reveal energy waste.** The following illustrations show how thermal, visual, and air quality measurements linked to user satisfaction and/or technical attributes of buildings reveal opportunities for energy conservation.
4. **IEQ metrics are key to simulation model calibration**. Field data is critical to calibrating energy models (P. Raftery, 2009), (L. O. Degelman, 20--).
5. **Portable toolkits reduce Cost.** Permanently installed onsite IEQ monitoring may be cost prohibitive for a large number of facilities. A significant number of existing buildings, especially older and smaller facilities, do not have BMS and IEQ monitoring installed, thereby making a portable Toolkit necessary to generate ECMs. The portability of the Toolkit also affords instrumentation at various spaces within a building that are not instrumented. In addition, a number of IEQ standards only require spot instrumentations.
6. **Energy actions must sustain or improve comfort and satisfaction**. The relationship of energy use, IEQ and occupant comfort, satisfaction and productivity will provide optimal ECMs.

The following are a few examples to illustrate the relationship of IEQ, occupant comfort and energy consumption that can be derived from an integrated Toolkit

1. **Thermographic camera**: The use of thermographic cameras in field studies identifies areas of heat loss and heat gain in the building facade, HVAC and lighting equipment, as well as system integration weaknesses that may affect comfort and energy use.

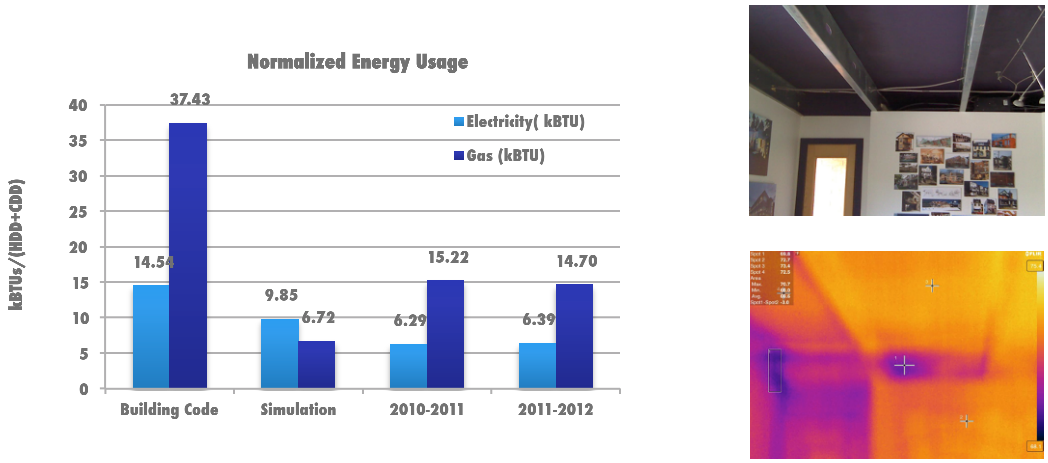


Figure 1. Gas usage 123% higher than simulation, but electricity 36% lower. Possibly due to leakage in thermal envelope (L. O. Degelman, 20--; Park, 2012b)

2. Measured **field data on IEQ**, **user satisfaction** and the technical attributes of building systems [**TABS**] supports ongoing opportunities for energy conservation while meeting IEQ standards. The CMU team has field findings for GSA portfolio [2] of offices that include:
   - *4 % total energy savings by raising summer set points.*
   - *40 % lighting energy savings by reducing ambient lighting.*
   - *25 % reduction in lighting energy by daylight harvesting*

3. Continuous **temperature measurement** at Building 101 reveals night and weekend setbacks could reduce energy consumption

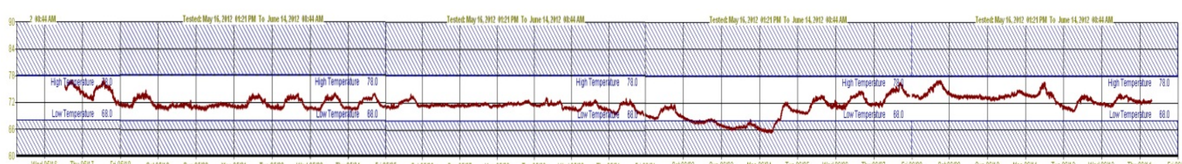


Figure 2 IEQ Assessment of Navy Yard Building 101 (May 16, 2012 – June 14, 2012)

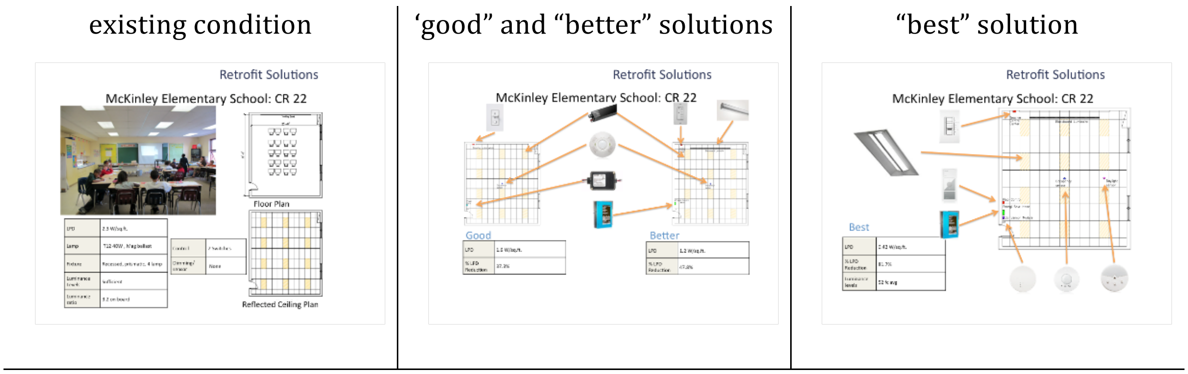


Figure 3 McKinley Elementary School: Lighting Retrofit (N. Papi Reddy SoArch, 2012)

4. **Light level measurements** and **TABS** analysis triggered recommendations towards lighting energy reduction in western PA area schools and several area offices. The best solution reduces lighting power density by 82%.

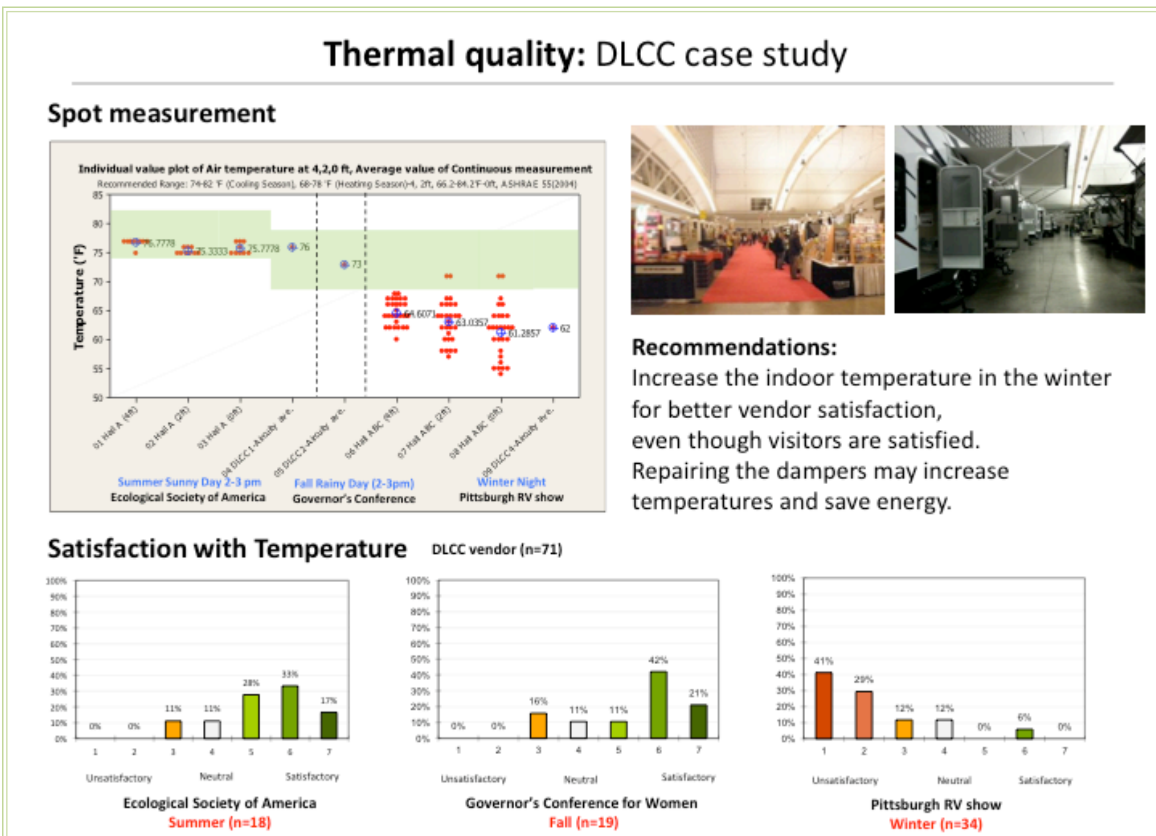
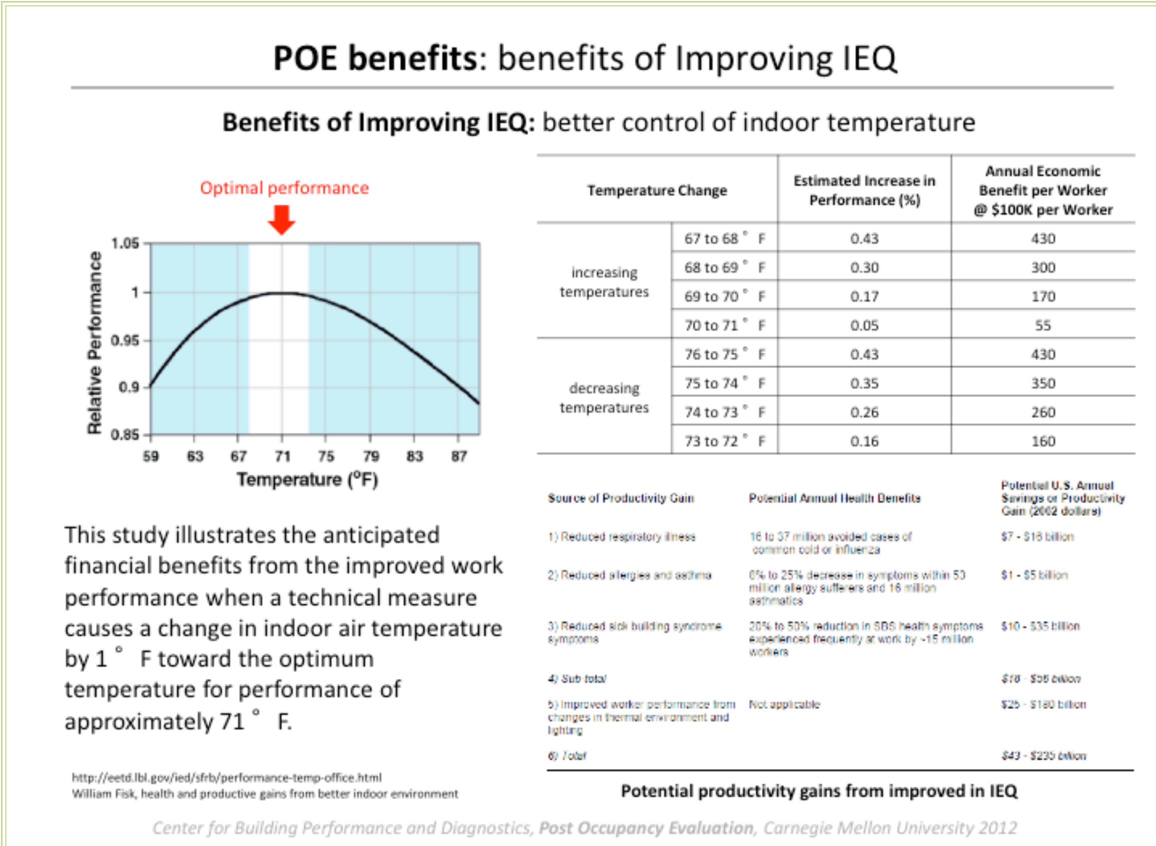


Figure 4 David L. Lawrence Convention Center[DLCC] Building in Operation Study(GBA, 2011)

5. **Temperature measurements** and **occupant satisfaction surveys** reveal too cold temperatures at DLCC and collaborating with CJL engineers, we discovered dampers that are perpetually in open position, which is not detected even though the facility has its own BMS *[4]*.



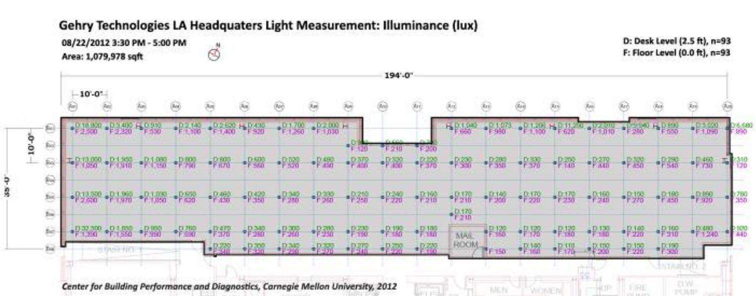
Temperature Change		Estimated Increase in Performance (%)	Annual Economic Benefit per Worker @ $100K per Worker
increasing temperatures	67 to 68 ° F	0.43	430
	68 to 69 ° F	0.30	300
	69 to 70 ° F	0.17	170
	70 to 71 ° F	0.05	55
decreasing temperatures	76 to 75 ° F	0.43	430
	75 to 74 ° F	0.35	350
	74 to 73 ° F	0.26	260
	73 to 72 ° F	0.16	160

Source of Productivity Gain	Potential Annual Health Benefits	Potential U.S. Annual Savings or Productivity Gain (2002 dollars)
1) Reduced respiratory illness	16 to 37 million avoided cases of common cold or influenza	$7 - $16 billion
2) Reduced allergies and asthma	0% to 25% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	$1 - $5 billion
3) Reduced sick building syndrome symptoms	20% to 50% reduction in SBS health symptoms experienced frequently at work by ~15 million workers	$10 - $35 billion
4) Sub total		*$18 - $56 billion*
5) Improved worker performance from changes in thermal environment and lighting	Not applicable	$25 - $180 billion
6) Total		*$43 - $235 billion*

Figure 5 Financial benefits from improved performance within temperature comfort bands(Fisk, 2011)

6. **Temperature setpoints** have been studied to understand the correlation between building **occupants performance** and **thermal comfort**.

7. A lighting study was conducted in Gehry Technologies unoccupied office (core and shell). **Glare and illuminance levels** were measured in the facility. Illuminance levels (measured on a grid) were provided to the simulation team to calibrate their **energy model** and *Radiance*, **lighting simulation tool**. Measured illuminance levels range up to 16,000 lux along the perimeter and excessive glare was identified at various locations in the facility. The immediate recommendation is to provide solar and daylight control using blinds and light redirection devices, such as light shelves, to reduce light levels while maintaining views and at the same time reduce glare.



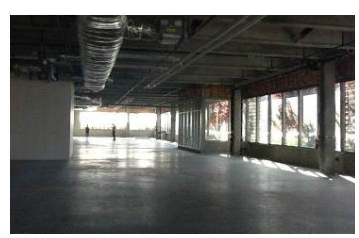


Figure 6 Light level measurement in Gehry Technologies unoccupied office (Park, 2012a)

The following table lists IEQ performance areas (visual quality, thermal quality, air quality and acoustic quality) that are critical to ECMs.

Topic	***Indices***	***Aspect of Performance***	***Potential Energy Savings***
Visual quality	• Light level on primary work surface (w/ task light off) • Light level on keyboard (w/ task light off) • Light level on Monitor (w/ task light off) • Light level on primary work surface (w/ task light on) • Calculated luminance/ Brightness contrast ratio • Access to a view • User surveys	• Good day light levels without shadowing (from furniture, adjacent structure or people) • Good day light levels at multiple work surface possibilities without shadowing • No brightness contrast greater than 3 to 1 near and 10 to 1 far surrounds. • No direct or reflected glare from daylight (with personal controls) • Good seated views of nature or ground plane (viewing cone key) • High visible transmission of glass • Good seated views of distant horizons • Good daylight redirection and diffusion • Good solar heat control in hot periods while maintaining daylight and view • Good solar heat collection in cold periods while maintaining daylight and view. • Personal controls of light and sun levels to match activity, time of day, clothing, personal comfort • Good electric light levels without shadowing (from furniture, adjacent structure or people) • Good electric light levels at multiple worksurface possibilities without shadowing • Good electric light color rendition and 3-d modeling • No reflected glare from electric light • No direct glare from electric light • Separate control of light levels for computer/ambient and paper based tasks (two levels of ambient control) • Articulated arm and/or relocatable high efficiency task lights (unless daylight is adequate) • Good electric light control for effective use of daylight • Good electric light control for lighting only those surfaces that need light • Daylit circulation, stairs and support areas • Daylit circulation, stairs and support areas with electric light off. • Operational energy use (as compared to connected energy x maximum on during office hours)	• 40% lighting energy savings by reducing ambient lighting(GSA, 2009) • 25% reduction in lighting energy by daylight harvesting (GSA, 2009) • 65% decrease in lighting energy consumption following a lighting retrofit with high-efficiency fixtures and full-spectrum fluorescent lamps National Lighting NLB (1988) • Post occupancy, in 2008, the New York Times building achieved 70% lighting energy savings without affecting the design luminance level of 500 lux at workstations(Lee, 2006) • 64% lighting energy savings in buildings with effective daylighting due to clear glass and perimeter access, as compared to buildings with deep floor plans and/or tinted glass(Bordass, 1999) • 35% lighting energy savings due to the use of daylight-linked dimming devices in daylit narrow plan buildings. Energy savings ranged from 31% to 48% in the absence of blinds, and from 24% to 37% when 45° fixed blinds were present(Schrum, 1996) • 22% reduction in overall energy use in daylit schools over non-daylit schools(Nicklas, 1996) • 48% lighting energy savings in buildings with a lighting power density of 1.5 W/sf, and average 49% lighting energy savings and 13% cooling energy savings in building with a lighting power density of 2.5 W/sf, due to the introduction of roof monitors with daylight dimming controls(Fontoynot M., 1984)

Topic	***Indices***	***Aspect of Performance***	***Potential Energy Savings***
Thermal quality	• Temperature at 4 feet (spot and 24 hour continuous) • Temperature at 2 feet • Temperature at floor level • Vertical radiant temperature difference • Relative humidity (spot and 24 hour continuous) • Air velocity • User surveys	• Separate ventilation and thermal conditioning • Heating only when and where needed with individual control • Cooling only when and where needed with individual control • radiant temperature management through quality windows and walls • solar heat gain management in warmer periods • Avoided drafts from air diffusers or windows • Individual control of temperature +/- 2C (fully functional) • Individual control of temperature by set point with readouts (a level of accountability) • Individual ability to establish set-back, broad band conditions when occupied • Individual controls of windows for natural cooling through convective heat exchange in mild or cooler periods • Control of windows for rapid management of overheating in spaces • Individual control of windows for convective cooling of the body • Operational energy use (as compared to connected energy x maximum on during office hours) • heating system generation efficiency • cooling system generation efficiency • Heat recovery from heating/cooling generation	• 4% total energy savings by raising summer set points(GSA, 2009) • 40% energy for wider (18C-30C) dead band and 30% energy for narrower (20C-28C) dead band than the conventional dead band (21.5C-24C)(Zhang, 2009) • 18%, 1%-15%, and 7% improvement in employee productivity during morning, afternoon, and evening periods respectively, due to temperature ranges of 26°C – 28°C for morning periods, and 24.5°C – 26°C for afternoon and evening periods, as compared to the baseline temperature condition of 23°C(Ngarmpornprasert, 2009) • 16.5% reduction in sensible energy demand and a 13% reduction in indoor pollutant concentration due to under floor air delivery - temperature differences between the supply air and the nearby return grille averaged 0.7 to 2.9°C(Wright, 1996)
Air quality	• CO_2 concentration ppm (spot and 24 hour continuous) • CO concentration ppm (spot and 24 hour continuous) • Small particulates (24 hour continuous) • Large particulates (24 hour continuous) • TVOC ,Ozone, Radon (24 hour continuous) • User surveys	• Individual controls of windows for natural ventilation without cold drafts • Adequate operable windows for rapid management of C02 and other toxicity in spaces (high occupancy, VOC materials) • Ability to turn off mechanical ventilation • Adequate ventilation supply to the occupant nose, as measured by C02 delta with outside • No PM 2.5, PM 10 of concern • No TVOC of concern • No ozone of concern • adequate humidity management • Heat/coolth recovery from exhaust air	• 6% reduction in heating energy use, a 10% reduction cooling energy use, and 1% reduction in ventilation energy use, for a ventilation supply rate of 10-12 cfm/person, as compared to 20 cfm/person(Eto, 1988) • 4% savings in building cleaning costs due to the installation of standard air filters in a single-pass filtration system(Bekö, 2008)

Topic	***Indices***	***Aspect of Performance***	***Potential Energy Savings***
Acoustic quality	• Background noise level (RC) • Background noise quality (QAI) • User surveys	• No damaging constant sounds over 80 dBA • No damaging low frequency sounds over 45 dBA • No wearing rumbles, pings, squeels etc (measured as a delta over time in specific frequencies) • Background sound levels below30dBA • Background to conversation sound level delta below 10dB • Managed room reverberation • Measured reduction in conversation clarity from adjacent offices • Measured reduction in conversation clarity from circulation and support areas • Ability to open windows without noise from rooftop or ground equipment	• 6% increase in individual productivity, a $0.10/sf savings in annual energy use, and a $0.13/sf savings in annual maintenance expenditures with a new acoustic ceiling(Romm, 1999) • 23-150% improvement in recall among children placed in a 42-44 dBA quiet study environment, as compared to children exposed to traffic and aircraft noise at 55 and 66 dBA.(Hygge, 2003)

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