Title
CBE Portable Wireless Monitoring System (PWMS): UFAD Systems Commissioning Cart Design Specifications and Operating Manual

Authors
Webster, Tom
Bauman, Fred
Anwar, G.

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CBE PORTABLE WIRELESS MONITORING SYSTEM (PWMS): UFAD SYSTEMS COMMISSIONING CART DESIGN SPECIFICATIONS AND OPERATING MANUAL

T. Webster, F. Bauman and G. Anwar
Center for the Built Environment (CBE), UC Berkeley
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1 INTRODUCTION

This document is intended to provide detailed documentation of design and operating instructions for a version of the PWMS dedicated to supporting commissioning of underfloor air distribution (UFAD) systems. The specifications for this device were based on requirements for commissioning the New York (NY) Times Building in New York City. The following sections focus on the design and construction of the cart and how to operate its software tools to conduct the various tests according to NY Times requirements. However, the built-in capabilities can be easily applied to performance evaluation and commissioning for other types of UFAD systems as well as advanced systems with non-symmetrical temperature environments. Each section contains background material that describes hardware and software details. Other software and hardware components associated with this system and UFAD commissioning procedures can be found in Appendix A. Appendix B describes how a portable thermal plume generator can be made for testing in pre-occupancy conditions.

Development of PWMS technology at CBE has been supported by the California Energy Commission [Bauman 2012]

2 NOMENCLATURE

The following table contains nomenclature and acronyms that are used on all the documents related to the Cart measurement system.

Mote	Wireless communication and sensing device that used mesh network technology. Communicates data back to cart computer
Mote Map	A drawing that shows location of motes superimposed on a floor drawing
RAS	Room air stratification characterized by a temperature vs. height profile
DAQ	Data acquisition; refers to the LabView data acquisition program
Contour	Distributed temperatures for a space manifested as either an RAS profile or supply plenum temperature distribution.
Tree	Stratification measurement variable height thermocouple sensor array
Zone	HVAC control zone defined by separate underfloor plenums
Location (Point)	The floor location identified by its grid cell that is used as the reference for the location of motes in the Mote Maps and for the cart when collecting data. (Also referred to as *grid location* or sometimes *point* internally in LabView logic.)
ASH	Air super highway, the supply ducting to the low pressure plenum
iwc	Inches of water column for pressure measurements
OZ	Occupied zone, region from 4 inches to 67 inches vertically from the floor; considered the region within which the occupants live.
LPP	Low pressure plenum
DustBox	The wireless mesh network base station
Cx	Acronym for "Commissioning"
Splash	A dialogue box type screen in LabView
SZ	Refers to a single zone test; a test of one zone by itself

MZ	Refers to a multi-zone test, a group of zones tested together

3 MEASUREMENT CART OBJECTIVES AND FUNCTIONAL OVERVIEW

3.1 OBJECTIVES

The primary objective of this task is to develop and fabricate an indoor environmental measurement cart with associated sensors and software that provides information to analyze and adjust stratification in UFAD systems. The second objective is to obtain data for associated variables that will inform the results of stratification measurements. The third objective is to collect data that can be used to analyze and adjust supply plenum temperature distribution.

3.2 OVERVIEW, IMPORTANCE OF STRATIFICATION

Evaluation of stratification performance in UFAD systems requires measurement of a number of basic environmental parameters that are key to the development of stratification in occupied spaces of commercial buildings.

The cart will allow the stratification profile to be measured as well as other key parameters that help determine causes (i.e., the context) of the measured stratification, and others from which thermal comfort can be assessed.

The primary parameters of importance for evaluating stratification are:

1. Supply air temperature from the diffuser
2. Airflow from diffuser (determined by measuring plenum pressure and using diffuser performance information)
3. Room temperature profile and occupied zone gradient
4. Room temperature set point (derived from the profile at 4-foot thermostat level. Assumes that the control system is functioning properly)
5. Load, heat gain
6. The primary parameters for assessing comfort are:
7. Velocity in the occupied zone
8. Average temperature in occupied zone
9. Temperature gradient in occupied zone
10. Relative humidity
11. Radiant environment (in this case assessed by measuring floor, ceiling, wall/window surface temperatures)
12. Clothing value of occupants

The measurement cart will include devices and systems designed to acquire records and analyze real time measurements for all parameters except numbers 5 and 11; this information will need to be collected or ascertained from other sources (e.g., observation, BMS data). Means will be provided to include this information with the stratification measurements for each test location.

4 CART FUNCTIONAL DESCRIPTION

The cart consists of a method of conveyance, i.e. hand truck , converted and adapted to measuring indoor environmental parameters for UFAD systems. It includes the following components:

1. Computer: Laptop computer with Labview software suitable for logging and presenting data, also equipped to write data to media for remote storage.
2. Power supply: The entire cart system is powered by a 12 VDC battery. A battery charger allows rapid recharging of the battery at the end of a day of testing.
3. Stratification profile tree: A series of rapid response thermocouples mounted on a telescoping pole that can extend to 13 feet. Stratification to 6 feet is measured in increments of 9.6 inches; above 6 feet in increments of 12 inches. Thermocouples are also mounted at 4 inches from floor and ceiling. One additional thermocouple is available for insertion into floor diffusers to measure supply air temperature. The setup and takedown time at a given measurement location is quick, limited to the time required to expand or retract the telescoping pole and initialize the data acquisition system for that location.
4. Plenum pressure measurement: An accurate low pressure-measuring transducer for measurement of plenum-to-room differential pressure.
5. Radiant temperature: Two infrared (IR) temperature detectors oriented to measure ceiling and floor surface temperatures.
6. Relative humidity (RH): Relative humidity is not measured since the building will not be occupied during commissioning so realistic data cannot be obtained.
7. Instrumentation system interfaces: Data acquisition boards collect analog sensor data and covert it to digital input signals to LabView data acquisition and analysis software.
8. The cart can be moved freely around a room and takes up a minimum of horizontal space.

5 CART DESIGN

5.1 CART HARDWARE AND SPECIFICATIONS

Figure 1 shows an annotated photo of the fully assembled cart. Figure 81 shows the cart disassembled for shipping.

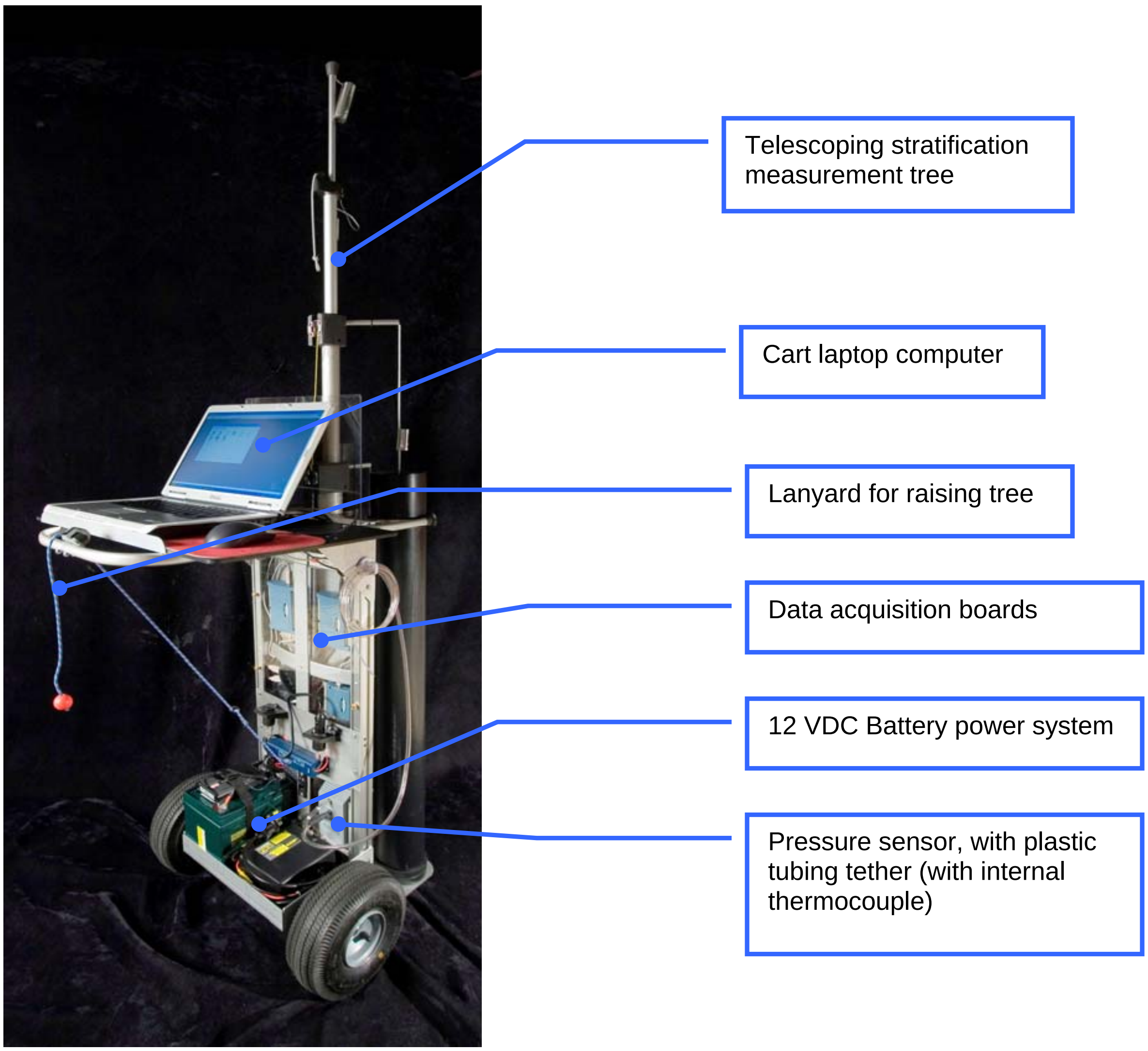

Figure 1: UFAD commissioning cart

5.1.1 POWER SUPPLY SYSTEM

One of the challenges facing the user of the cart is power management to facilitate untethered use of the cart. We have included a 34 amp hour (Ah) external battery and charging system on the cart. With this system plus the on-board extended life computer battery we estimate that the cart can be operated for 8-10 hours without re-charging. However, we have set up a default "Always On" power management scheme for the computer that preserves battery life with minimal interference to commissioning activities. Also, during periods of downtime (e.g., lunch, or other periods of non-use) the batteries can be recharged from local AC power by connecting the battery charger.

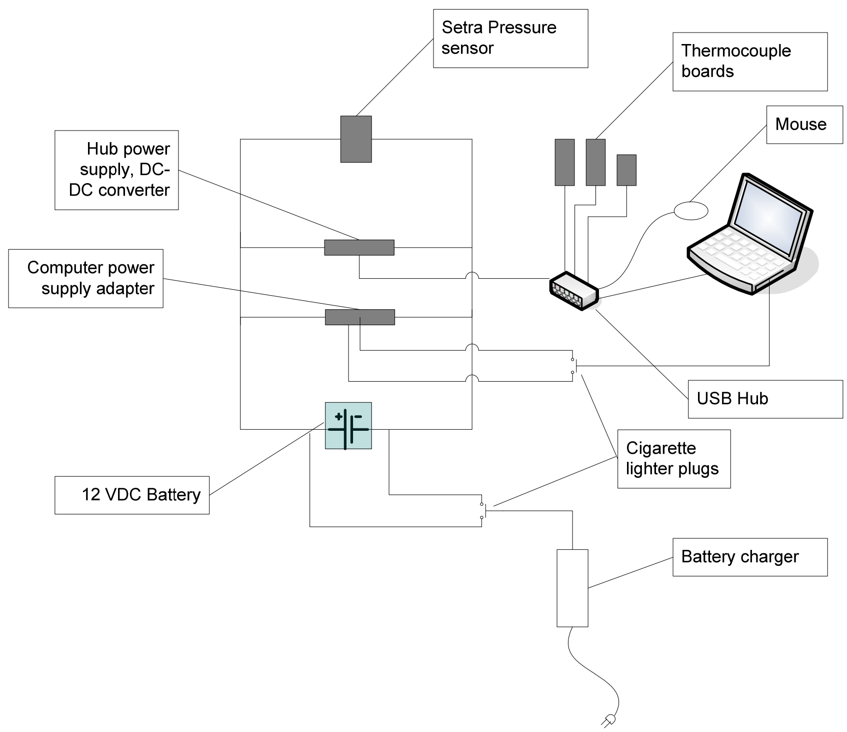

Figure 2: Cart power system schematic

Figure 3: Estimated power requirements for cart devices

			Current draw			
Load device	**Voltage**	**Powered from**	**Estimated, Amps**	**Measured , Amps**	**Operating & charging laptop Measured, Amps**	**Operating laptop Measured, Amps**
Computer	12 VDC*	Laptop and auxiliary battery	4-7.5**	Disconnected	7.6-8.6	2.4-3.2**
Pressure sensor	12 VDC	Aux Battery	0.015		0.38	0.38
Anemometers	12 VDC	Aux Battery	NA	NA		
Sensor Interface board	5 VCD	USB hub, Aux Batt	0.08			
TC interface board	5 VCD	USB hub, Aux Batt	0.14			
TC interface board	5 VCD	USB hub, Aux Batt	0.14			
Mouse	5 VCD	USB hub, Aux Batt	0.02			
Total			**4.4 - 7.8**	**0.36**	**8 - 9**	**2.8 - 3.6**

*based on nominal voltage of external battery and 50-90W power draw

** 2.4a with screen off

The cart power system is supported by the following components:

1. Laptop on-board battery, 9-cell lithium-ion extended life battery pack – Dell Inspiron Model 1705

2. Adapter, external battery to laptop – 20 VDC output, 11-16 VDC input - Lind DE2045-1320-FA
3. DC-DC converter (USB hub power)- 5-12 VDC, 2.2 amp – PowerStream, DAA-1204-2
4. External battery, sealed lead acid - 12 VDC, 34 Ah - CSB EVX 12340
5. Battery charger - 12 VDC, 10 amp – Guest Model 2611-1-B

This system operates as follows:

- The operator starts with a fully charged system with the external battery power adapter connected to the laptop.
- The external battery continuously powers all instruments (e.g., pressure sensor, USB hub) and powers the laptop and charges its battery if necessary.
- The interface boards are powered by the self-powered USB hub.
- The battery voltage can be viewed at all times that LabView is running on the configuration screen via the *External Battery Voltage* field.
- When the battery charger is connected to AC power the external battery is being charged; the battery voltage (as indicated by the voltage display) under this condition will vary between ~11.8 to 14 VDC, depending on load and battery charger mode, see Figure 4.

Figure 4: Battery charger

5.1.2 CART BATTERY SYSTEM OPERATION GUIDE & CAUTIONS

- Read safety and operating instructions for the Guest battery charger.
- Under normal conditions there is no need to change the connections of the laptop power cable or cigarette lighters. When charging, only the battery charger needs to be plugged in.
- Be sure to check that cigarette lighter connectors are plugged in properly and indicator lights are showing properly. [Left side green light, right side battery charger green and red lights]
- Check computer tray icons to be sure the battery indicator is NOT on when the laptop is connected to the external battery.
- Do not change the computer power management scheme from "Always On" without consultation with administrators.

- A flashing green light on the LIND power adapter indicates low source (battery) voltage (below ~11.8 VDC). The external 12VDC battery should be recharged as soon as possible. In this low voltage condition the laptop will draw power from its own battery and the external battery will continue to power the instruments. A warning alert is also displayed when LabView is operating.
- Under no circumstances should measurements be made at battery voltages below 10 VDC.
- **CAUTION! If the lead acid external batter swells or the smell of rotten eggs is noted; immediately disconnect the battery charger.**

5.1.3 INSTRUMENTATION SYSTEM

The cart instrumentation system consists of the following components:

1. Computer – Laptop PC 533/667 Mhz processors, 100 GB hard drive, 1GB ram, 15.4 in. WXGA Screen - (Dell Inspiron Model E1505, Duo core.
2. Thermocouple based stratification measurement tree – Type K thermocouples with 30 gauge wire mounted with mylar radiation shields.
3. Infrared temperature detectors (IRT) – Omega OS36 with accuracy of +-2% of reading or +-2°F.
4. Static pressure sensor and supply air temperature thermocouple – A Setra Model 264 bidirectional pressure sensor with range of +- 0.25 iwc and accuracy of 0.25% full scale (FS); input voltage 9-30 VDC.
5. Anemometer – A port on interface board C has been reserved for an omni-directional anemometer made by Sensor, Model HT-426 with HT-412-3 probe.
6. Thermocouples (TC) interface boards – (2) 8 channel, USB powered (5 VDC) – Measurement Computing, USB-TC for Type K. (See Figure 5)
   - Board A (#1, SN 173) services TCs numbers 8-12, the ceiling IRT and the diffuser supply temperature (SAT) as measured by the pressure sensing tube.
   - Board B (#0, SN 30) services the first seven TCs from the bottom and the floor IRT.
7. Pressure and velocity interface – 8 channel, 12-bit resolution, USB powered – Measurement Computing, USB-1208FS. (Board C (#2, SN 1), Figure 5)
8. USB hub – Four port USB 2.0 hub – Belkin F5U234v1

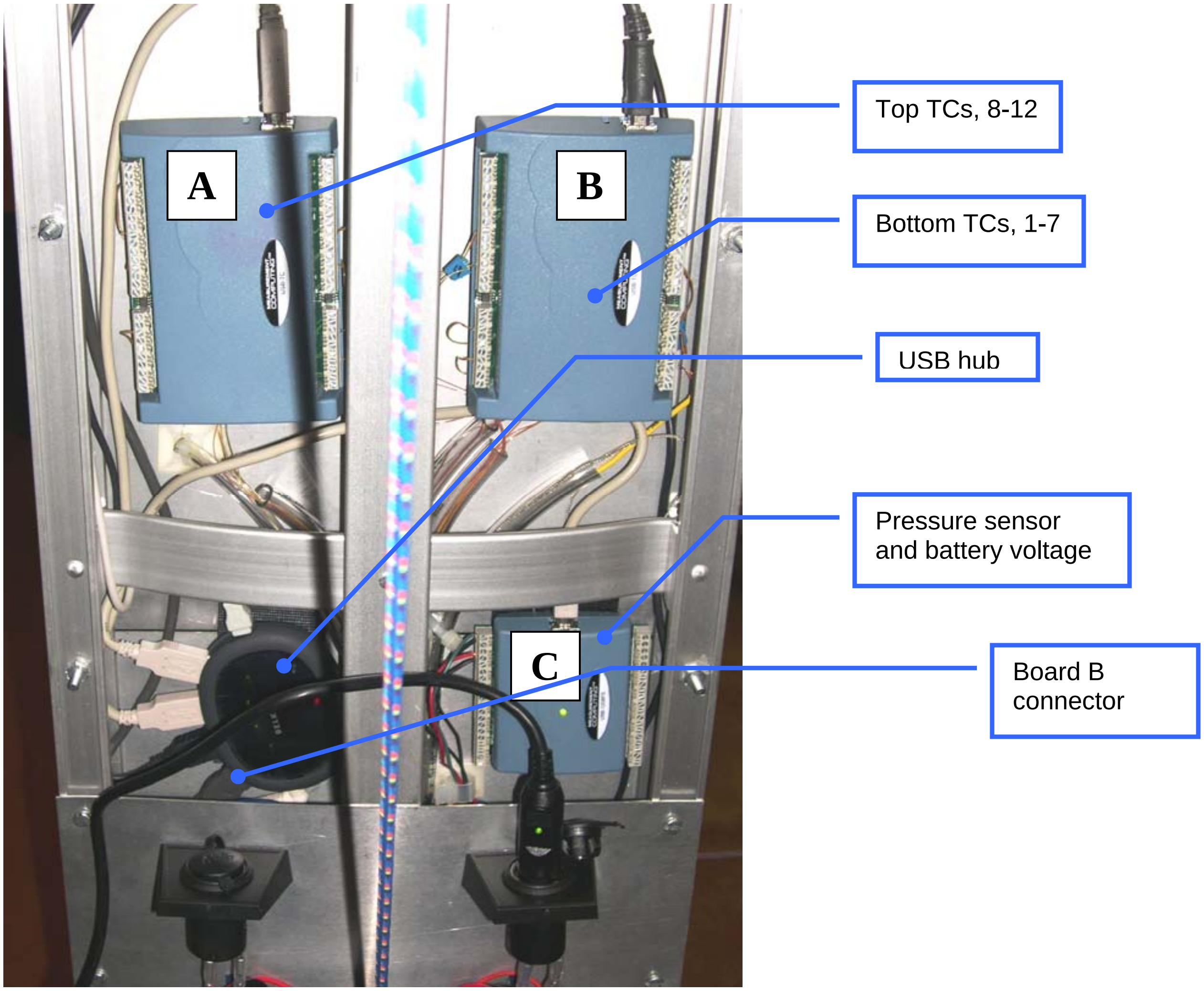

Figure 5: Thermocouple and pressure sensor interface boards

5.1.3.1 Channel Assignments

The analog inputs are configured as shown in Figure 6

Figure 6: Cart instrumentation channel assignments

Board	Channel	Measurement		Board	Channel	Measurement
USB-TC, #0	1	Tree, 4”		USB-TC, #1	0	Tree, 67”
	2	Tree, 9.2”			1	Tree, 84”
	3	Tree, 19.2”			2	Tree, 97.5”
	4	Tree, 28.8”			3	Tree, 111”
	5	Tree, 38.4”			4	Tree, 129”
	6	Tree, 48”			5	IRT, Floor
	7	Tree, 57.6”			6	Diffuser SAT
				USB-1208FS, #2	1	Pressure sensor
					2	Battery voltage

5.1.4 STRATIFICATION MEASUREMENT TREE

Stratification can be measured in any areas with height between that of the basic tower and podium spaces. For all height measurements the tree will cover all critical "must do" heights of 4", 48", 67", 84" and 4" from ceiling. All measurements between 129 inches and 133 inches do not have intermediate sensors; the upper most telescoping element is spring loaded to contact the ceiling and ensure that the top most sensor is always 4 inches from the ceiling. Figure 7 is a diagram that shows the final specifications.

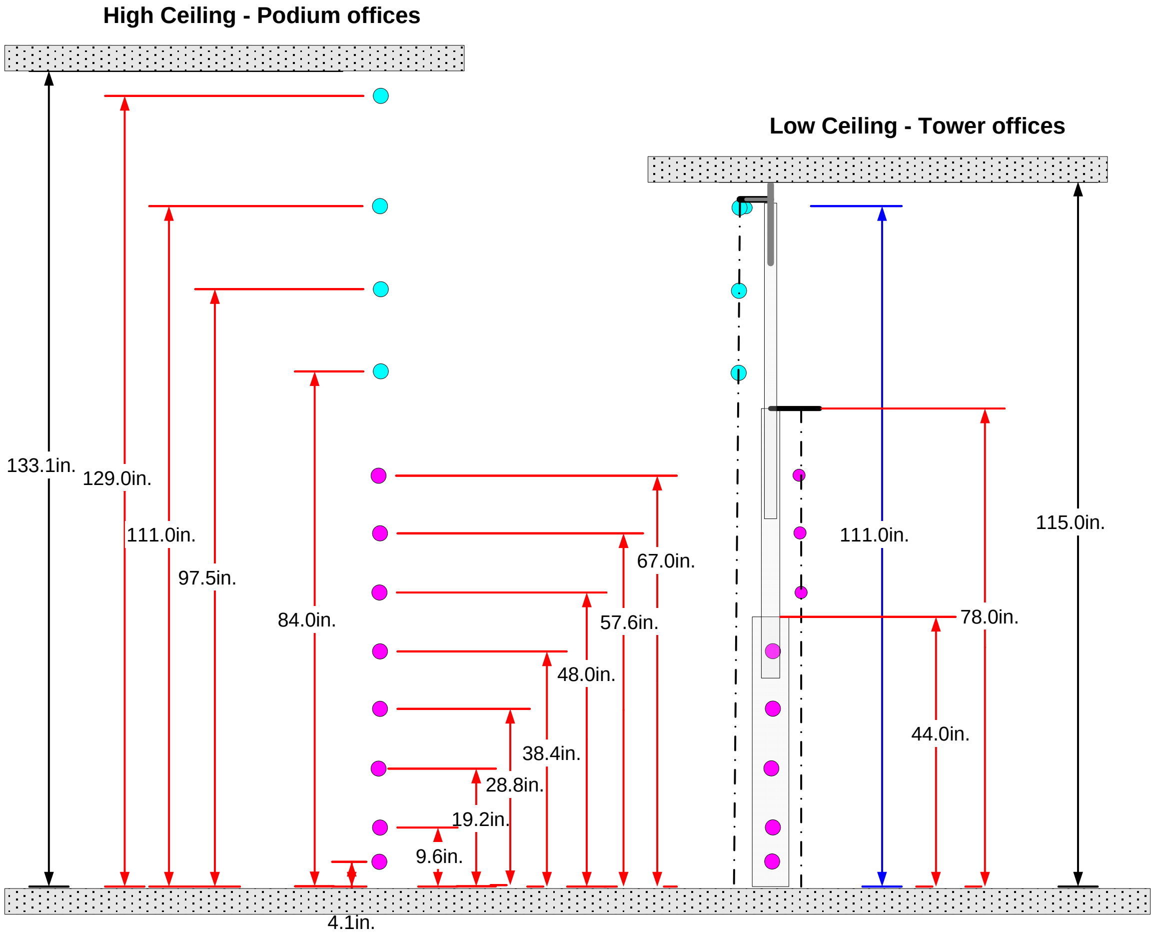

Figure 7: Tree height specifications

5.2 WIRELESS SENSOR SYSTEM

The wireless sensing system is based on Dust Networks technology provided by Federspiel Controls. The system consists of a base station enclosure we call the "DustBox" as shown in Figure 8, and 70 temperature sensing "motes" (see below). The DustBox enclosure contains the following components:

1. Computer – PC, Fanless 600 Mhz, 512MB RAM, 40 GB hard disk; running Windows XP, MySQL database, Apache Http server, Dust Networks driver.
2. Wireless data manager – Dust Networks, D1100
3. Router – WiFi plus 4 port router – Linksys WRT54GS Connects the data manager and DustBox PC and provides WiFi communications between the DustBox and the cart laptop.
4. Power supplies and power strip

Motes are small devices that use a new wireless technology called mesh networks to communicate data collected from on-board sensors back to a base station that communicates to the cart laptop via WiFi. The cart hardware (and software) system supports data acquisition of up to 70 motes that can be deployed over a broad area in the building. While these can be deployed in many places they are primarily designed to measure and report the following parameters:

1. Zone temperatures at thermostat locations (48” and 84”).
2. Diffuser supply temperature in air super highway (ASH)
3. Diffuser supply temperature in low pressure plenum (LPP).
4. Perimeter diffuser temperature at the linear bar grilles (PER).

Examples of a mote package and its deployment in a typical Titus diffuser are shown in Figure 14 and Figure 9, respectively.

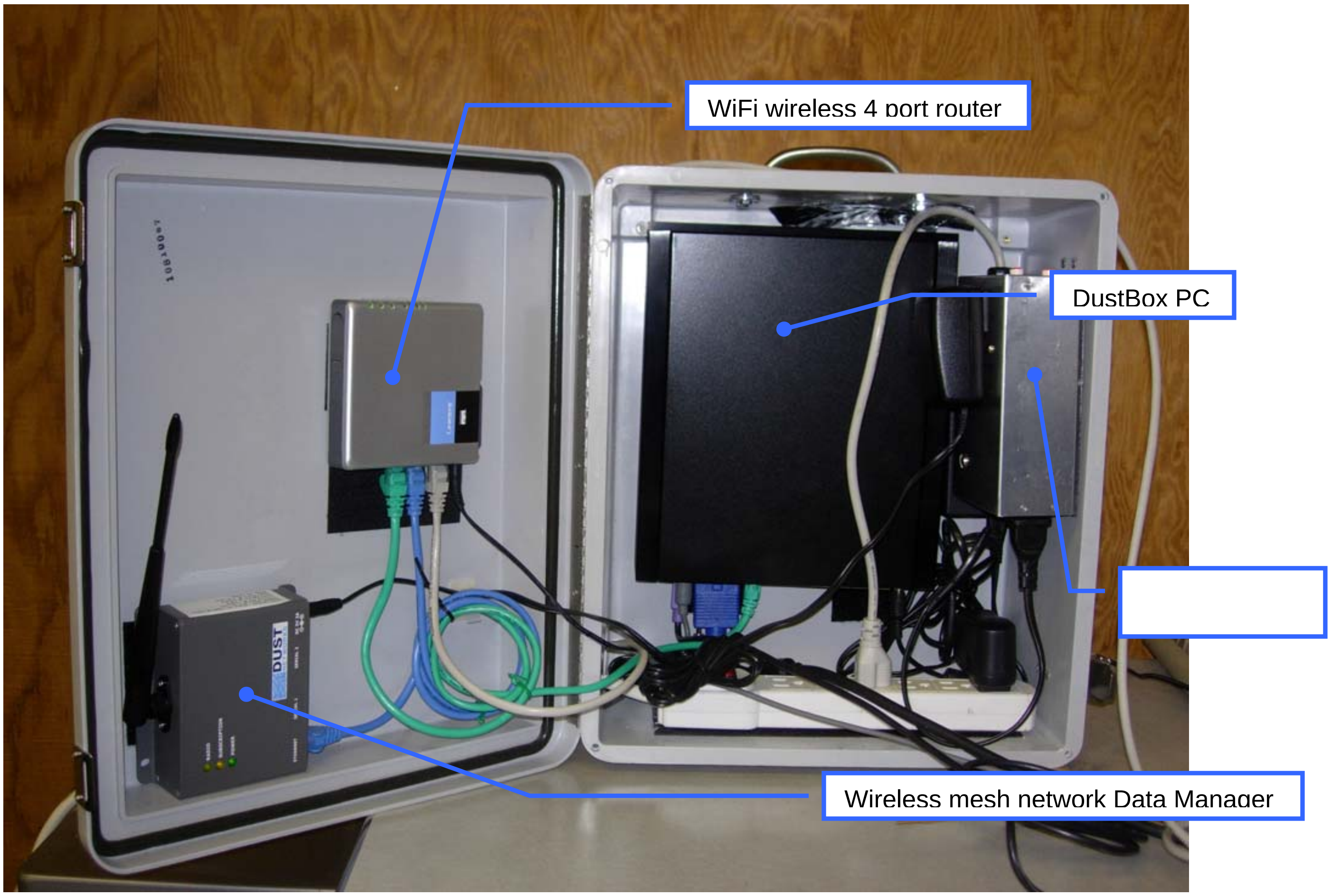

Figure 8: Wireless sensing system DustBox base station

Figure 9: Mote deployed in diffuser

5.2.1 DustBox Computer

This DustBox PC supports a MySQL database for all logged mote data and a Federspiel Advanced Control System (FACS) website that displays a list of motes with their current readings and battery information. This computer has all ancillary and unnecessary services shutoff; e.g., the display, keyboard, and mouse cannot be installed "hot", they must be attached before boot up; the computer starts automatically when power is applied. The default view for Internet Explorer is the FACS website shown in Figure 10. Click on *User Pages* then *Unit 1* to view the mote information shown in Figure 11. Double clicking on any mote in the list will bring up a view of mote logging information. Press the Refresh button under the IE View menu to update status on these screens.

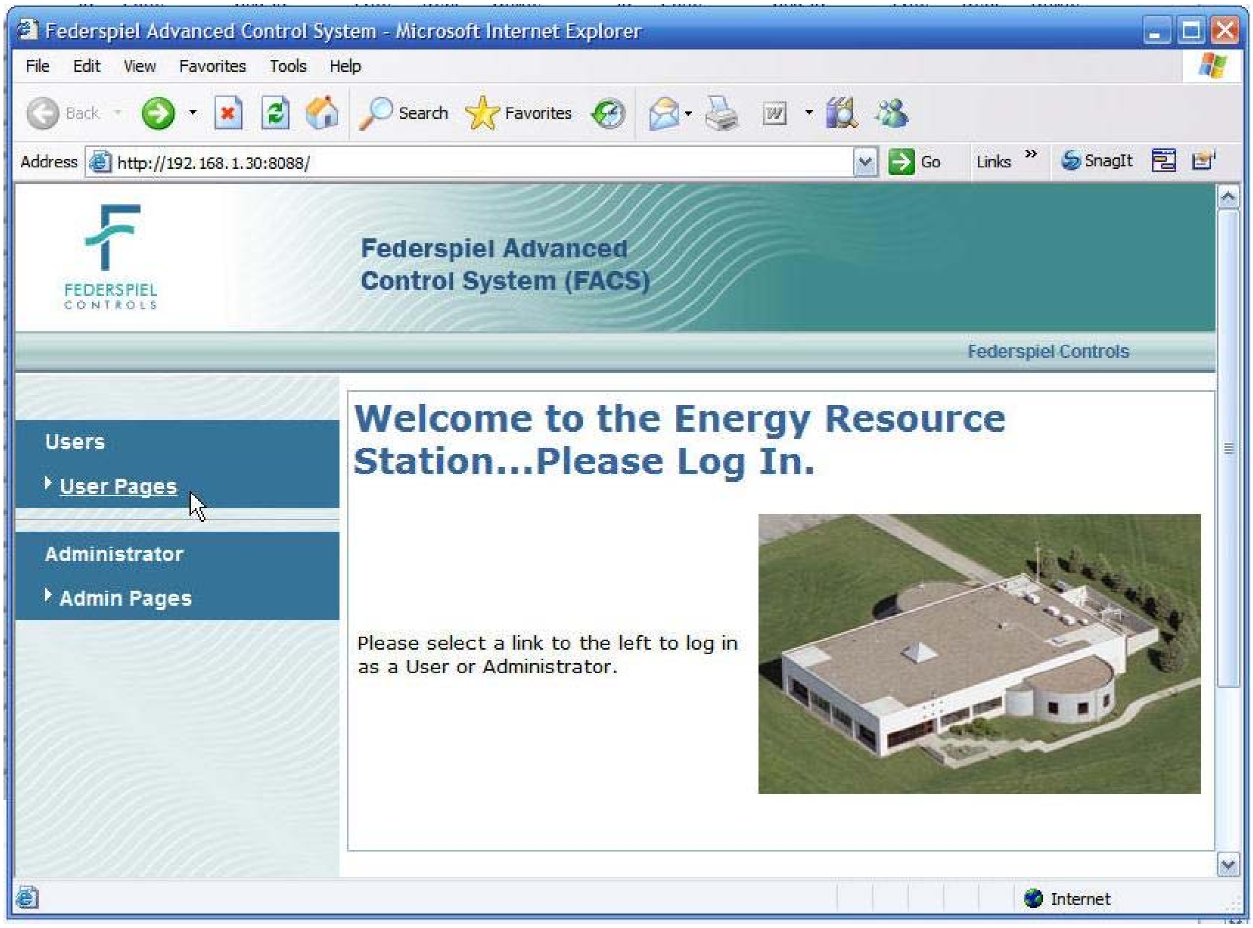

Figure 10: DustBox/FCS mote website

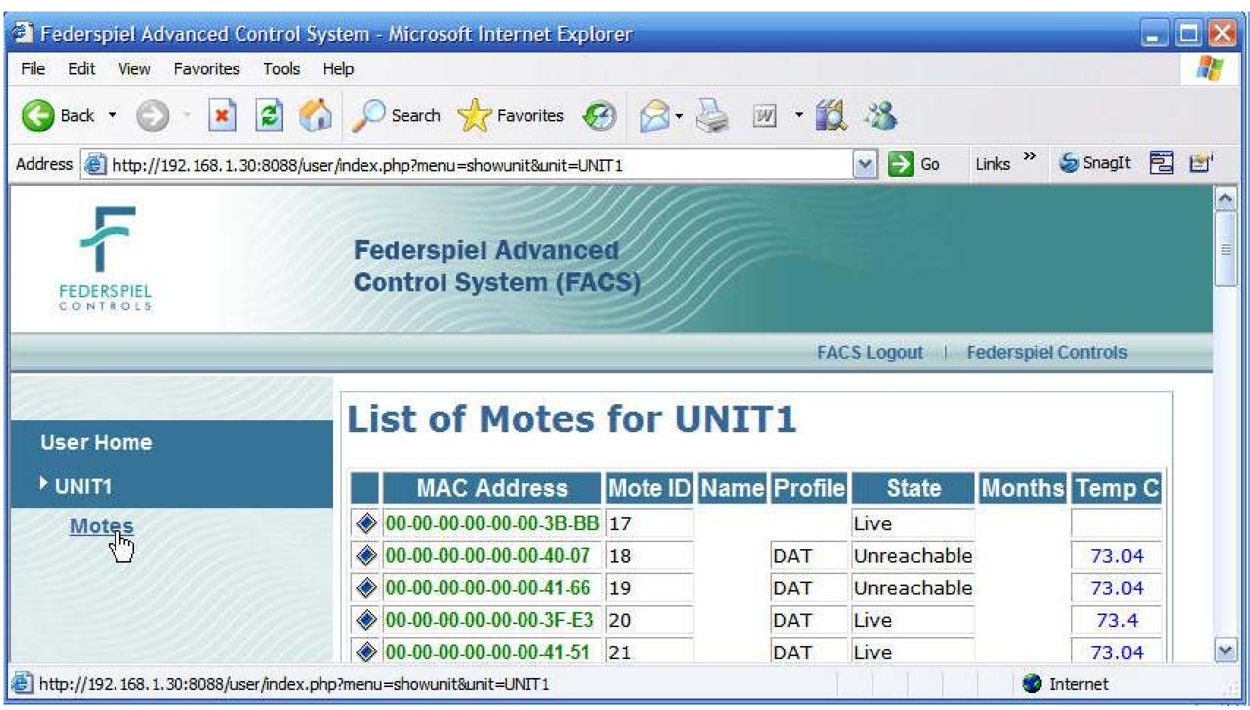

Figure 11: FCS motes display

CBE has assigned a NYT specific ID number to each Mote and has physically labeled them accordingly. These ID numbers are different from those displayed on the vendor's web site. Figure 12 is a cross reference table that coordinates the MAC address with the two sets of IDs and must be used as reference when viewing the FACS web site.

Figure 12: Mote ID cross-reference (for NYT)

NYT Mote ID	Mote MAC address	DustBox ID	NYT Mote ID	Mote MAC address	DustBox ID
1	4163	34	36	4166	19
2	3FE3	20	37	4105	41
3	4016	75	38	415C	45
4	3FEF	50	39	459E	67
5	400D	74	40	4132	60
6	4007	18	41	412D	33
7	4025	71	42	40CE	44
8	4113	43	43	4129	79
9	40F8	61	44	4124	49
10	4032	56	45	4049	56
11	3FC3	55	46	4125	68
12	4050	31	47	40C0	47
13	4146	53	48	40B3	64
14	4165	39	49	40BF	83
15	40A9	27	50	414C	36
16	403C	28	51	4151	21
17	4159	42	52	410D	81
18	4055	82	53	410F	54
19	402C	80	54	412A	25
20	40FF	32	55	4123	69
21	3FF5	58	56	40EC	70
22	404C	22	57	3FB3	26
23	3FD2	37	58	3F57	38
24	4094	46	59	409F	51
25	3F4B	40	60	3F55	86
26	3F50	78	61	415A	65
27	3F5A	62	62	411D	30
28	3FFB	66	63	4114	85
29	403F	48	64	4143	35
30	4060	77	65	4135	49
31	4072	72	66	410C	63
32	412C	76	67	3FA5	73
33	4121	52	68	4147	29
34	3FC0	24	69	412F	23
35	4162	84	70	3FA1	87

Clicking on a given mote address (for a 'Live' mote) will bring up a history log of the data being collected as shown in Figure 13 Check the time of the reading against the computer clock to be sure they are recent data. If not the database may be down or the Dust network services may not be working in which case investigate further using procedures outlined in *UFAD Commissioning Cart: System Data and Computer Management Procedures*.

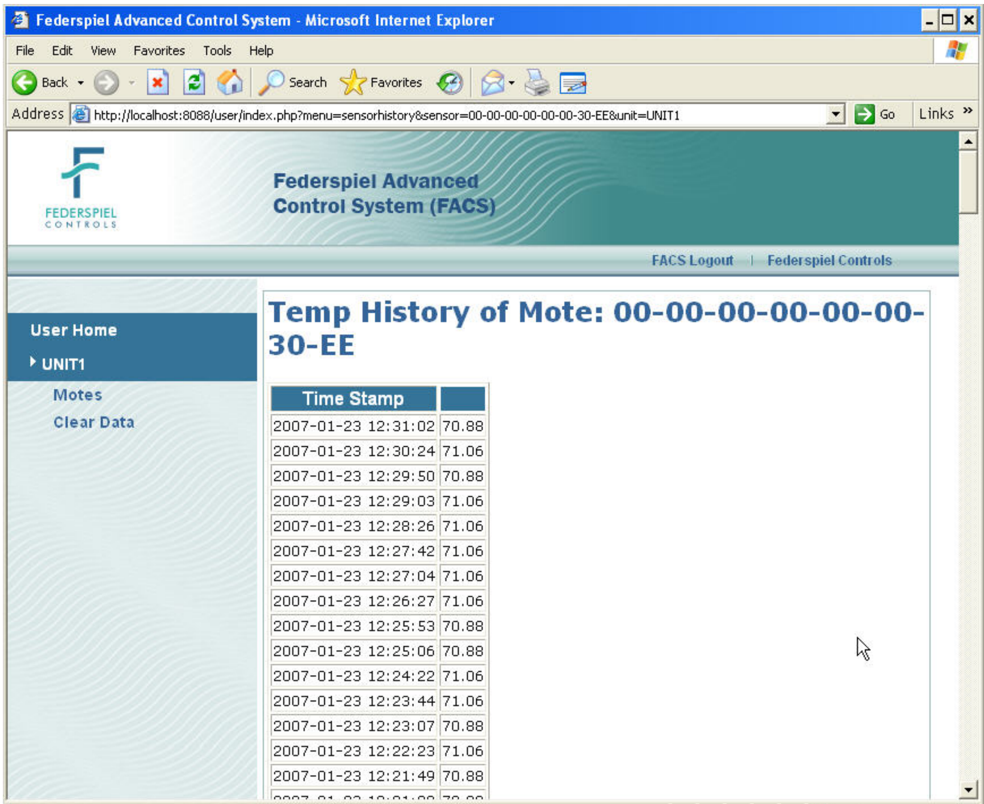

Figure 13: FCS mote history log

5.2.2 MOTES

5.2.2.1 Mote operation and LED codes

Figure 14 shows a mote. The two lights and a test button are labeled as to their function and operate as follows:

1. Test button – The test button is used to check the status as indicated by the LEDs
2. Reset – The reset hole allows the mote to be reset whereupon its radio on/off cycle is sped up to allow it to configure into the network faster.
3. LEDs -- When the Test button is pressed, mote lights operate as follows in there three possible operating states
    - Live – Green power light On, yellow link light On or flashing.
    - Deep sleep (not network connection for 10 minutes) – Green power light blinks slowly.
    - Off (sleep tool + reset) – Both lights are Off

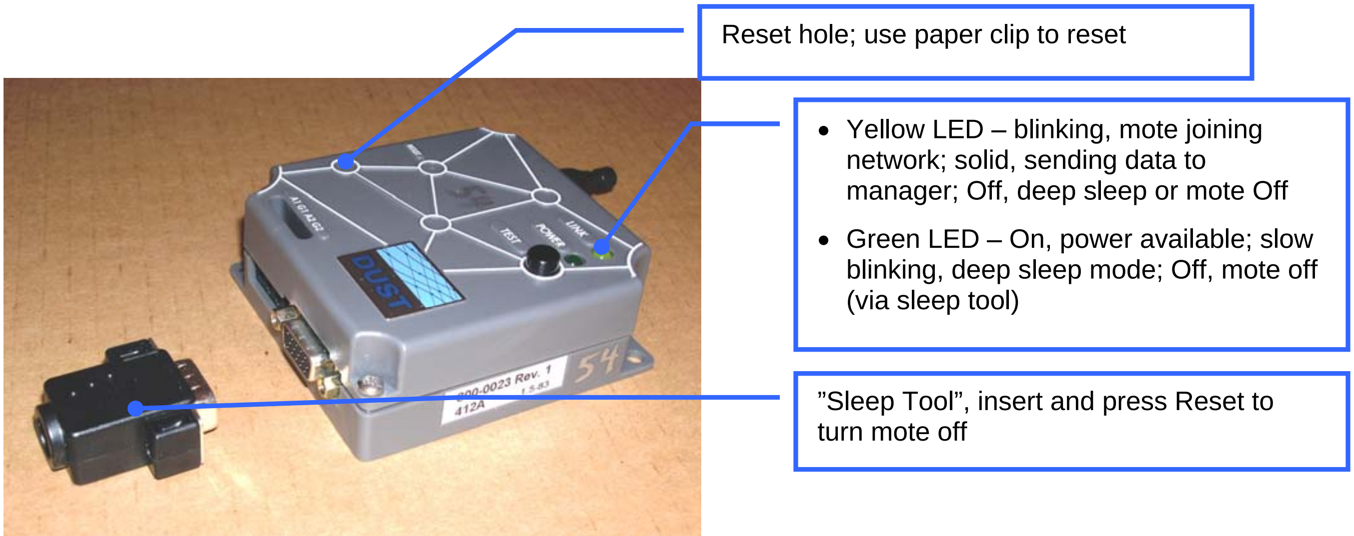

Figure 14: Mote package

Also shown in Figure 14 is the "Sleep Tool" which is used to turn motes off. Insert the tool into the connector and press the reset button. To wake up the mote, press the reset button only. While the sleep tool turns motes off, they can also enter a "deep sleep" mode if the data manager is unavailable.

5.2.2.2 Temperature sensors

The on-board sensors consist of a thermistor embedded in the microprocessor. These sensors have been calibrated to and accuracy of ~0.2°F.

5.2.2.3 Batteries

The mote and two AA batteries are mounted in a two-part rigid plastic box. The batteries can be replaced by removing the screws that hold the two halves of the plastic housing together. However, we expect that batteries will rarely have to be replaced due to the efficient communications system.

Each mote is powered by two AA Lithium batteries. When replacing use only Lithium AA batteries, Energizer e^2 Lithium or equivalent. Read instructions carefully for proper handling and insertion.

The status of the mote batteries can be reviewed by accessing the DustBox/FCS website. The default webpage for Internet Explorer takes you to this page. The battery life indicator via the DustBox website only server as an indicator; they are not accurate because they do not capture the history of previous network deployments, only the one currently being used. An operating period of at least 24 hours is required for this data to be updated.

Battery life can be preserved by turning off motes when not in use and/or turning off the network (by powering down the DustBox) when motes are still deployed but not in use (e.g., over a weekend). In the latter case, the motes will automatically enter a deep sleep state. This will require approximately one hour (for 70 motes) to startup when the manager is powered up again, but overall this can lengthen battery life significantly.

5.2.3 COMMUNICATIONS

The mesh network is a type of network that dynamically reconfigures itself so that each mote can send its message back using the most convenient route by passing its message to other nearby motes. These motes in turn pass its own message plus the one it is passing on eventually getting to the base station Data Manager where it is passed to the DustBox PC and logged into the database with its timestamp. Mote data is continuously logged to this database whenever the base station is operating. LabView queries the DustBox database whenever it requires data by requesting data backwards from a specific time, currently set to acquire three minutes of data from the database every 30 seconds.

5.2.3.1 Data Manager

The Data Manager is the primary interface to the mote network, all collected data passes through this device. The indicator lights on the Data Manager are shown in Figure 15. The top light (radio) indicates when messages are being received from motes.[1] The second light (subscription) flashes when there is a communication between the Data Manager and external devices retrieving data, in this case the DustBox PC.

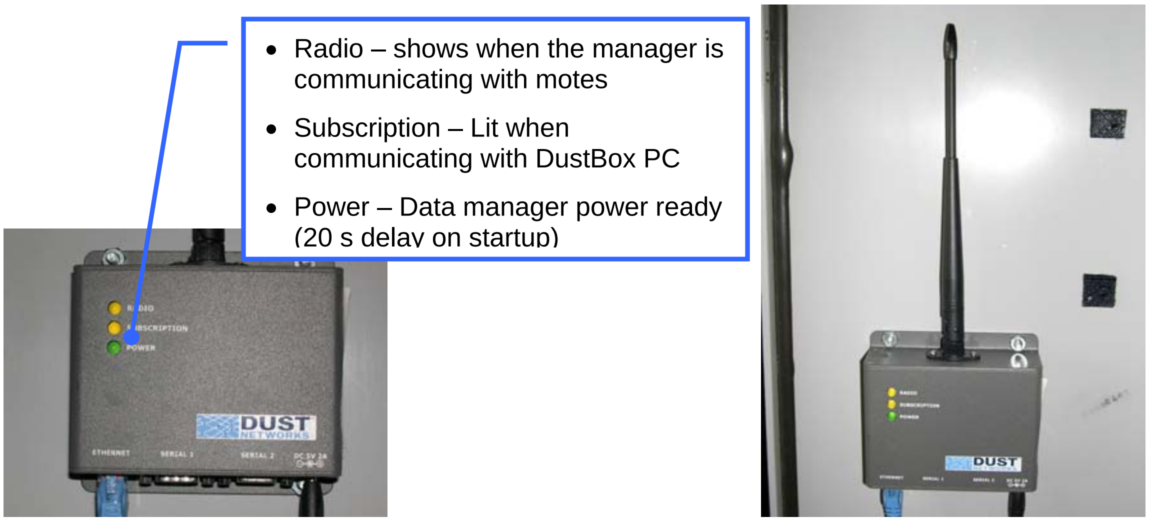

Figure 15: Wireless mesh network Data Manager

5.2.3.2 Router

The router is configured for a private network on the downstream (private network; 192.168.1.xx) side that includes the DustBox PC, Data Manager, and cart laptop via a WiFi link. The router also supports remote public network access via port forwarding to the cart laptop on ports 5900 (UltraVNC), 3389 (Remote Desktop), and 80 (http), see the companion document *UFAD Commissioning Cart: Passwords, Network configuration, and Program Paths* for user name, passwords and IP address assignments for access to these components. The IP address for this public access needs to be configured for the network environment that it lives in. The system is designed to operate without user intervention, logon, or configuration; we discourage accessing the system remotely except in unusual circumstances by administrator personnel.

5.2.4 Wireless Sensor Network Installation and Operation

To ensure proper operation of the wireless sensor network, follow the steps outlined below.

1. Install DustBox at a convenient central location on the floor so the maximum distance from the cart laptop is no greater than ~100-150 ft.[2] Review the WiFi signal strength using Windows tools as shown in Figure 18. The cart can be moved around the floor to monitor the WiFi signal strength, values below -70-75dbm may cause mote data logging problems.
2. Install sensor motes within 30-50 feet from one another. Deploy motes in an orderly manner starting near the base station and moving outward in a radial pattern.
3. Install in diffusers with antenna upright (antenna vertical, up or down) whenever possible as shown in Figure 9. Be sure the motes do not lean on their test button when deployed; the LEDs draw considerable power and can impact the battery life.

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[1] The Radio light with come on briefly as the Data Manager is starting up when it sends out a wake up call to the motes. It will stay off until motes begin sending messages back to the Manager.

[2] This distance relates to the communications over WiFi between the cart laptop and the DustBox system.

4. When installing or redeploying motes there are delays while the motes join the network. This process can take anywhere from a few minutes for small number of motes to 20-30 minutes with all 70 motes. This process can be speeded up if the *Reset* button is pressed when a mote is deployed. While waiting for motes to join the network, monitor progress at the Test Setup screen or Default Mote view in the DAQ program as shown in Figure 16 and Figure 17. Allow at least 45 minutes to an hour after deployment before concluding that a mote is non-responding.

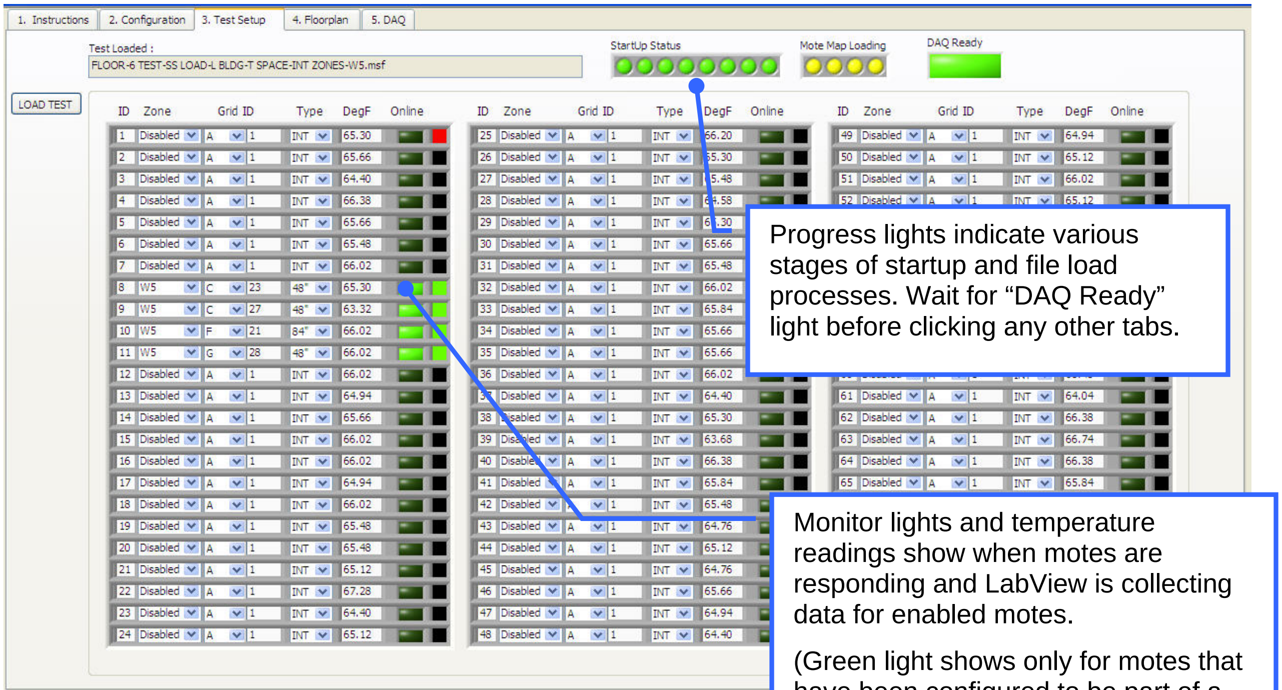


Figure 16: Test Setup screen used for monitoring mote activity

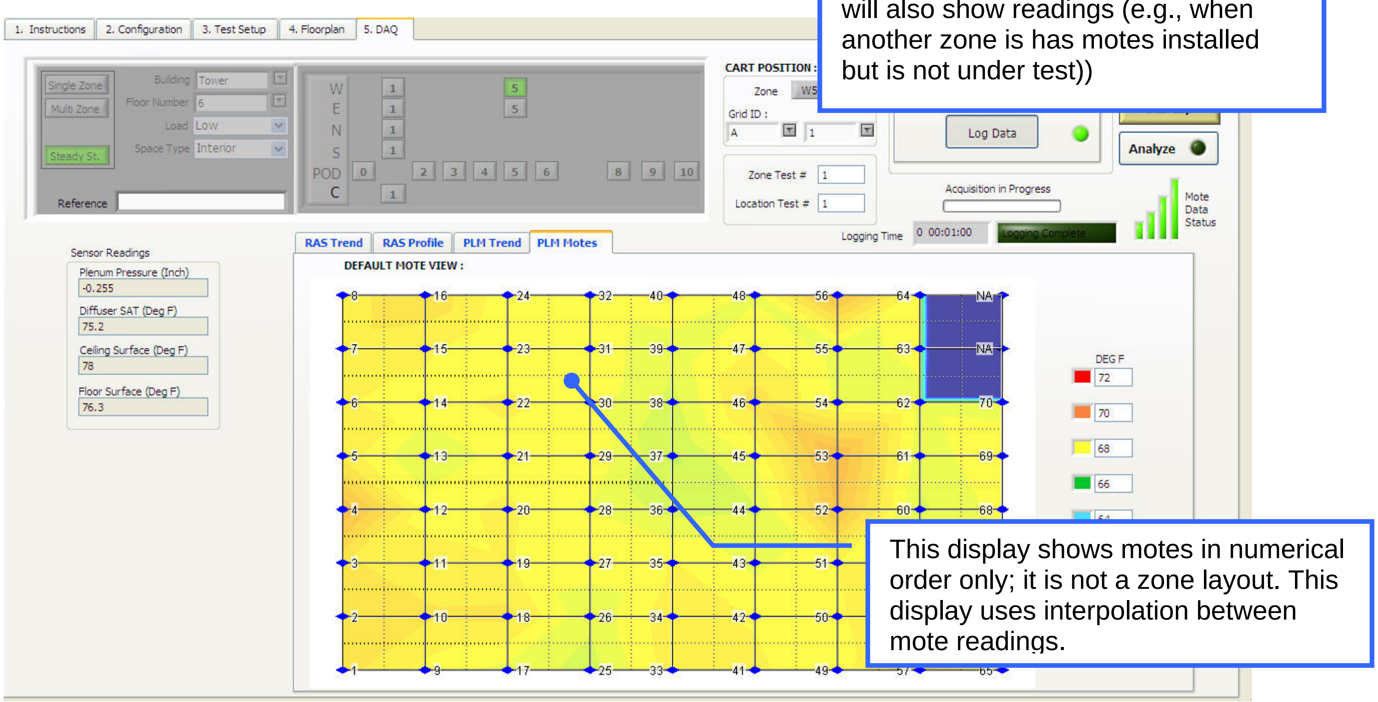


Figure 17: PLM motes default view

5. When the DustBox is temporarily shutdown (see shutdown procedure in Section 9.2) for any reason the network will take a few minutes to get re-established.

6. When the DustBox base station is moved (and while powered down) the network will require 20-30 minutes (with 70 motes) of settling time to fully reconfigure. The delay can be shortened if the DustBox remains powered during the move.
7. Performance of the data transfer between the DustBox logging database and the Cart laptop can be monitored via the Mote Data Status bars on the DAQ screen as shown in Figure 19. These bars represent a 2 minute window of requests sent to the DustBox from the Cart Laptop LabView; each unlit bar represents an error in data transfer for a single request within the 2 minute window, the more unlit bars the more errors. If all four bars are unlit it is likely that the DustBox is not responding and should be reset (shutdown and restarted per instruction. These errors result in missing data in the collection record but this fact is not reflected in the <u>Test Setup</u> screen, the data shown will be old depending on when the error occurred.
8. To preserve battery lives always turn off motes that are not in use. For motes that are deployed be sure to turn off the Data Manager (i.e., disconnect the DustBox) during periods of non-activity such as nights and weekends to put the deployed motes into deep sleep mode.

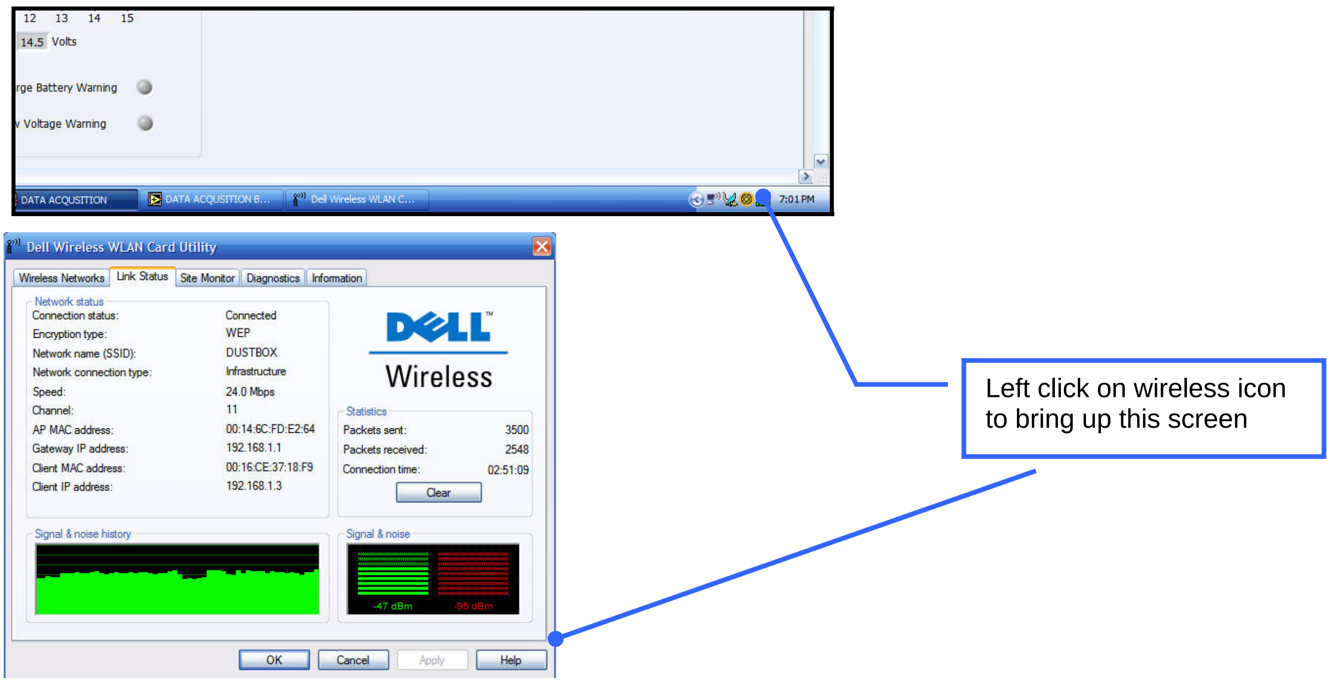


Figure 18: WiFi diagnostics screens

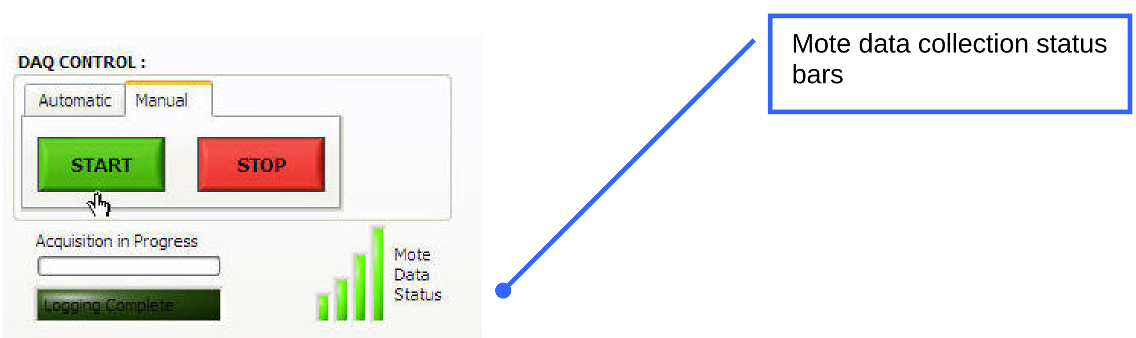


Figure 19: Motes status bars

6 CART SOFTWARE

6.1 TEST CLASSIFICATION AND SEQUENCING

The UFAD Functional Testing Procedures manual describes in detail how to conduct a UFAD Cx session. In general tests will be conducted in the order as listed below.

6.1.1 TEST TYPES

Test types identify the kind of test being conducting. Tests are further identified by their space type, i.e., the type of space being tested (interior, perimeter) or closed spaces of each type that are identified by their room numbers. Room numbers are also used to identify a zone is located within in a larger zone (e.g., conference room) or a private office in a zone that is not separately controlled.

There are four basic kinds of tests that the cart supports. Workflow diagrams for these test types are shown in Section 8.

6.1.1.1 Steady state

Steady state tests are separate and distinct from normal SZ or MZ tests. These tests run before the other more detailed tests to ensure that the system is in steady operation and free from thermal mass effects and controls cycling. Steady state tests could run for many hours or even days to trend selected data at a different sampling rate than for zone tests.

To determine steady state conditions various indicators are used where a calculation of a regression on the last N number of data points is made during the test. Once the slope of the regression is below the criteria, an alert is shown and the test is stopped (unless in manual mode which will continue until the maximum allowable time setting is exceeded). Indictors are automatically selected for all the motes designated in a steady state mote map (see below). This test is similar to a multi-zone test in that motes can be placed in any zone, although the cart will remain in one place during the test. Suggested mote placement is as follows:

- Room temperature at 84”
- Room temperature at 48”
- Perimeter diffuser temperature
- Air superhighway temperature
- Two low pressure plenum sensors, lowest and highest reading sensors
- Plenum pressure (this is automatically included, be sure the sensor tube is inserted)

Each of the steady state motes is tracked individually, when all regressions are below the steady state criteria the steady state test ends but its display is preserved (there is currently no way to view a past SS test). Steady state tests are configured during Test Setup in the MLU.

When this test type is selected the default parameters for the sampling interval and number of samples, length, and number of samples to use in the regression is loaded as shown in Figure 20.

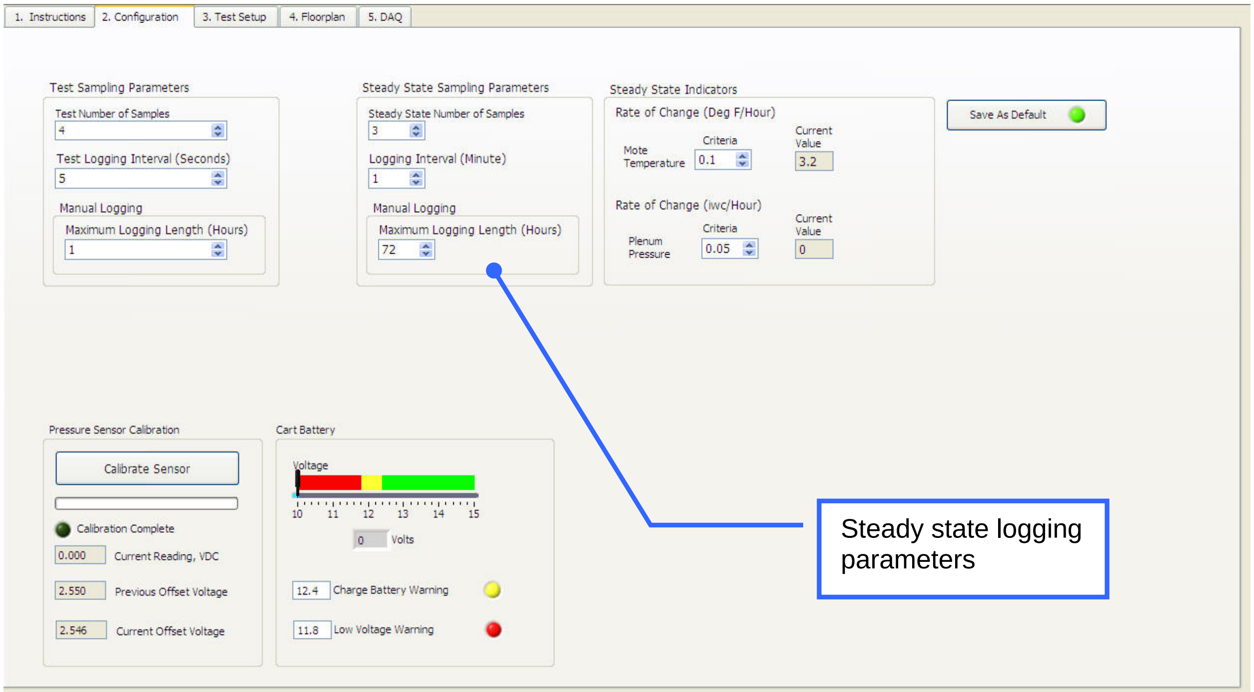


Figure 20: Configuration and logging setup screen showing steady state parameters

6.1.1.2 Single zone (SZ)

Testing of a single zone by itself irrespective of how adjacent zones are operating. For interior zone tests both the Room air stratification (RAS) and the plenum distribution are tested in tandem. As the cart is moved around to conduct tests at a number of locations in the zone, data is collected for an RAS Profile via the stratification data from the tree, other data associated with the RAS profile, and data from the wireless motes measuring conditions in the low pressure plenum (LPP). The cart locations are identified by the same grid structure that is used to locate the motes (see below).

Once all the designated locations are measured in a zone, the data is used to determine the average or characteristic profile for the zone and an average plenum distribution. This average profile is used to determine if the stratification in the zone is in compliance with the acceptance criteria. Room air stratification tests can occur in two space types: interior and perimeter (defined as the area 5 ft from the outer wall).

The average plenum distribution is used to check the compliance of the plenum conditions to the acceptance criteria. A zone must pass both RAS and plenum distribution tests to be accepted, but the operator is allowed to override a result in cases where, in his judgment, the zone is acceptable overall.

6.1.1.3 Multi-zone (MZ)

RAS testing of more than one zone at a time. Tests are designated as multi-zone tests but the procedure for collecting data is virtually identical to single zone tests except the “zone” under test is now identified by a group of zones. The resulting MZ average profile is used to check the performance of the system under simulated partial occupancy. The primary difference from a SZ test is when results are displayed in the Analysis tool. In this case all the zone RAS profiles are averaged together at the end of the testing but each zone plenum is shown independently by user selection.

6.1.1.4 Multi-single zone (MSZ)

This is an alternative to the MZ test that allows more detailed zone by zone results to be captured in the database. This test type is conducted in a very similar manner as a MZ test except after each zone is tested the test is completed and averages saved. Also, these tests require that a user code be entered into the

Reference field. Since the Reference field is searchable in the database, this code is used to retrieve results of MSZ tests in groups similar to how a retest number does in traditional MZ tests. This capability requires the refine search query to be used to focus the results to only the tests of interest as described in Section 6.8.5.2.

6.1.2 Retests

Retests are "do overs" due to mistakes, problems or, more typically, when something has been changed to improve the performance when acceptance criteria are not met. They are incremented independently but the zone retest ID is used to load the correct profiles into the Analysis program when comparing location profiles for determining zone averages. Retests are label Zone test # and Location test # In the test fields of the DAQ screen shown in Figure 21. Both of these fields default to 1 as the original test and operate as follows:

1. *Grid location retest* – A repeat test for a location that was tested previously in a zone for a given SZ or MZ test; a retest of a zone resets this counter to one. Profile averages will be displayed for retested locations as well as original locations and can be excluded from the zone average in the Analysis. The retest counter is automatically incremented whenever a location that has been tested in that zone is tested again.
2. *Zone retest* – A repeat of a SZ or MZ test; i.e., a set of location tests. There may be times when other ad hoc tests are conducted in addition to a formal retest of a zone. In this case the test should be identified by entries in the *Reference* field using descriptive text or codes.

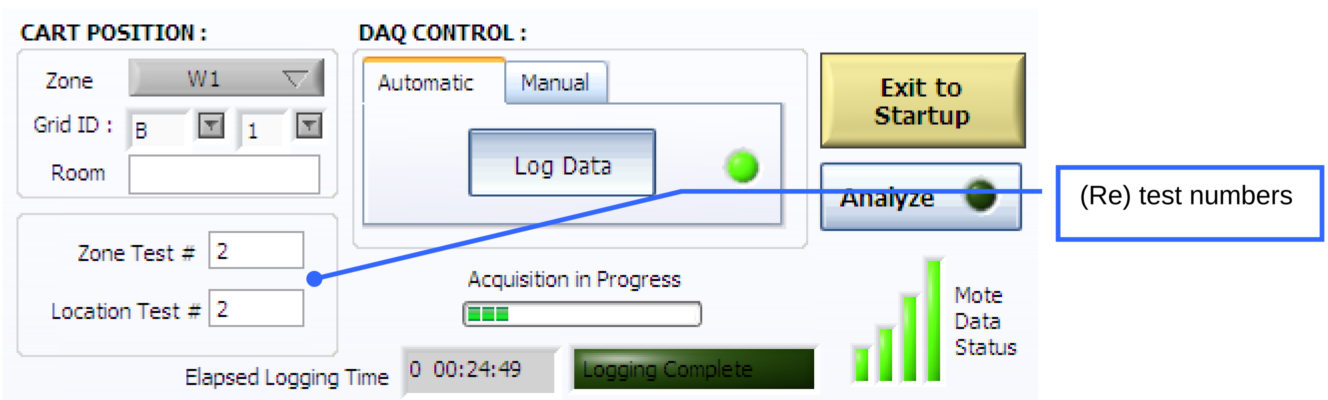


Figure 21: Element of DAQ screen showing test number fields

6.1.3 TEST IDENTIFICATION STRINGS

Whenever data from a particular test is displayed a test ID string is used to list the major test parameters as shown in Figure 22.

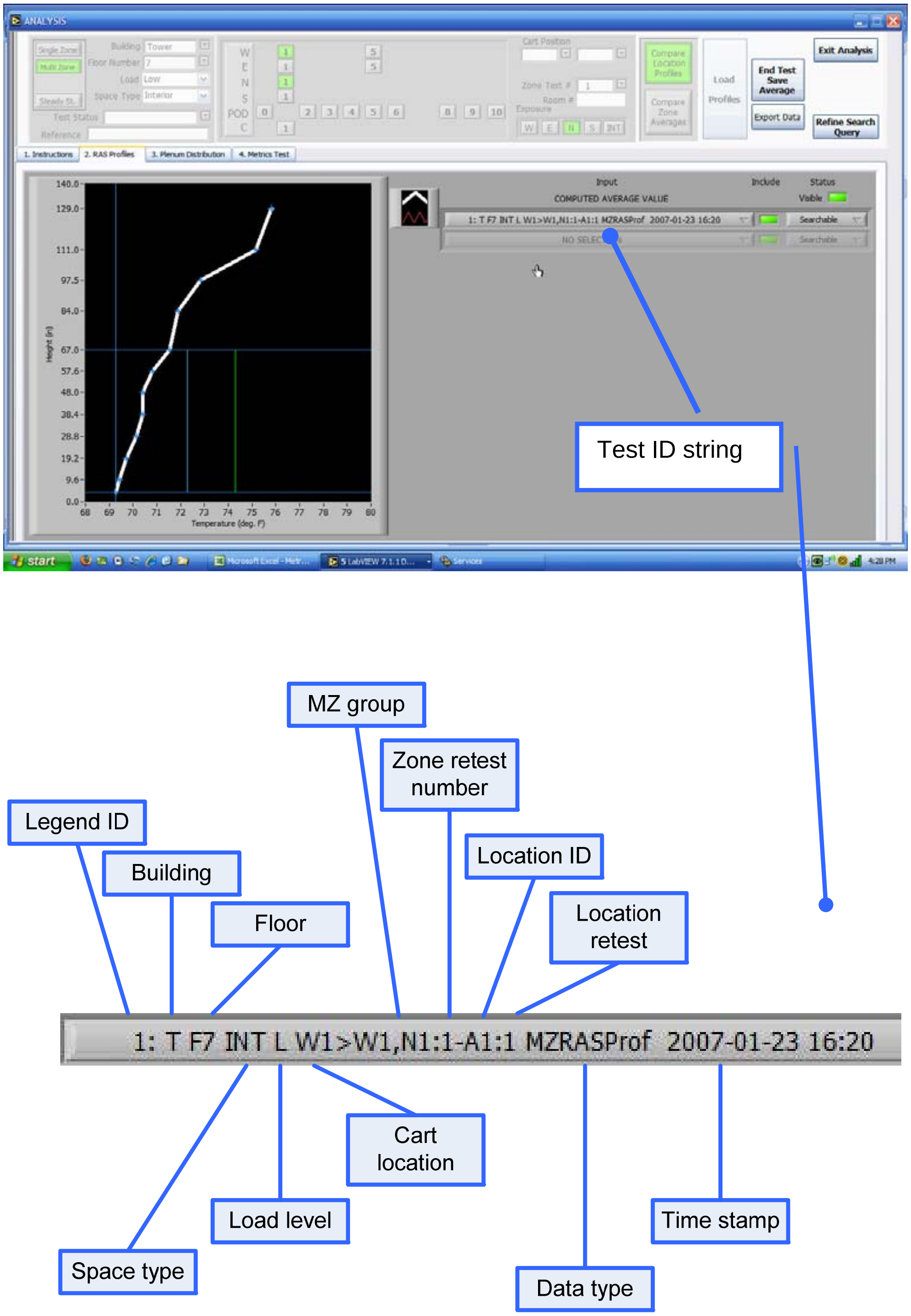


Figure 22 : Test ID string definitions

6.2 MEASUREMENT LOCATIONS GRID STRUCTURE

Cart testing and mote locations are identified with a grid structure a typical example of which is shown in Figure 23. Grid layout drawings for each floor are used with the mote layout tool (See Appendix A) to overlay mote temperatures in the DAQ and Analysis plenum distribution screens. Once created for each zone, these overlays are automatically loaded based on the selection of floor and zone parameters. .

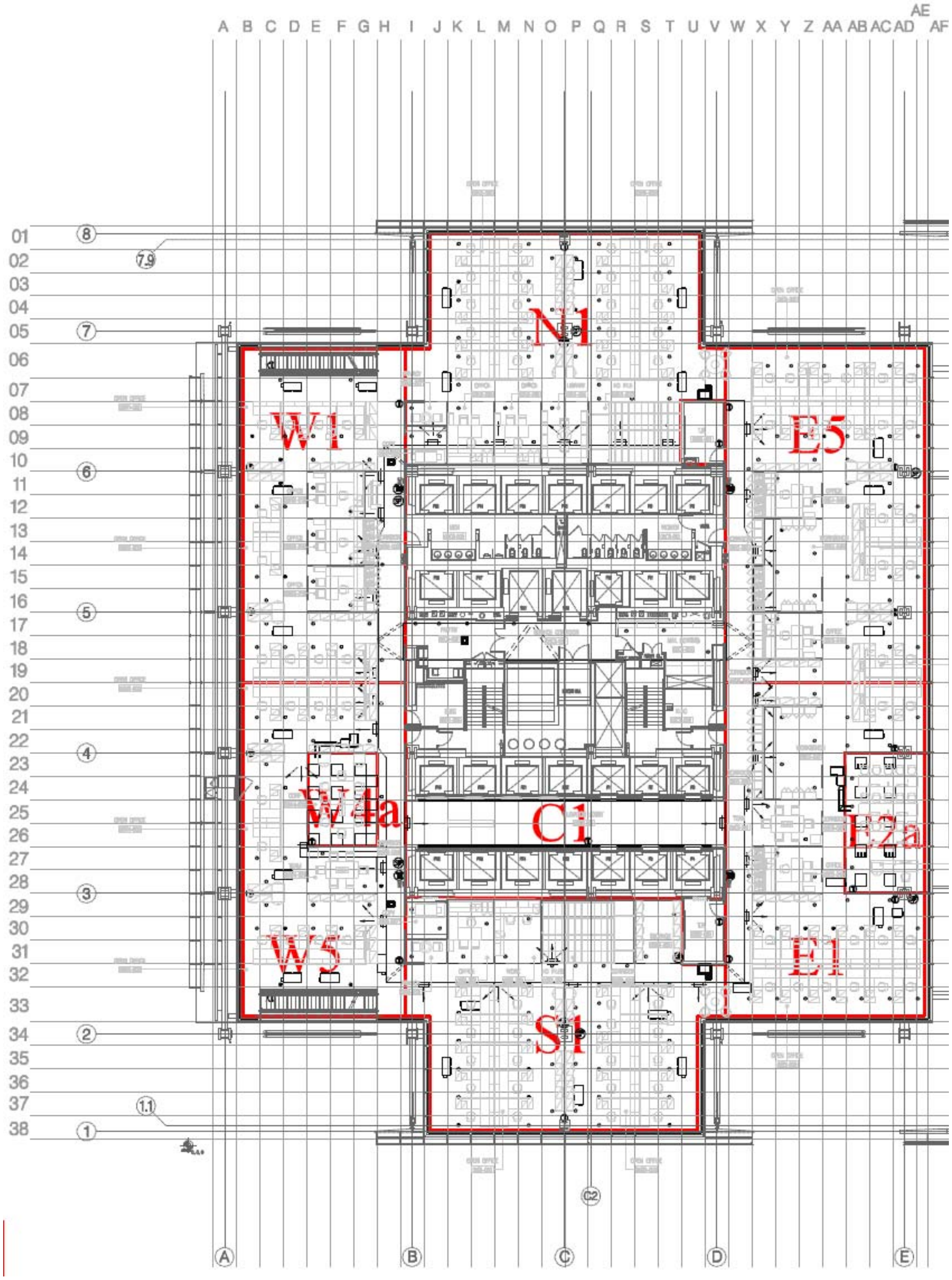


Figure 23: Testing grid structure

6.3 DATA MANAGEMENT AND ANALYSIS SYSTEM (DMAS)

The DMAS consists of the LabView user interface screens and the Data Management database. Together these provide data acquisition, storage, and analysis functions. Data is managed by a direct connection between the MySQL database (DB) using query and response strings generated by PHP scripts via http over TCP/IP protocols. The query strings are formed by inputs from setup and configuration data fields in the LabView Data Acquisition and Analysis program screens. More information about the DMAS can be found in the companion document *UFAD Commissioning Cart: Data Management System and Computer Management Procedures*. These fields provide the following functionality.

6.3.1 DMAS FUNCTIONS

6.3.1.1 Program control and startup

The DMAS is a set of executable files with an embedded LabView runtime environment. Upon startup the program offers the following options (See Figure 24):

1. Mote Layout Utility – Activates the floor/zone grid configuration utility program
2. Data acquisition – Goes to the **Data Acquisition** program
3. Analysis – goes directly to the **Analysis** program

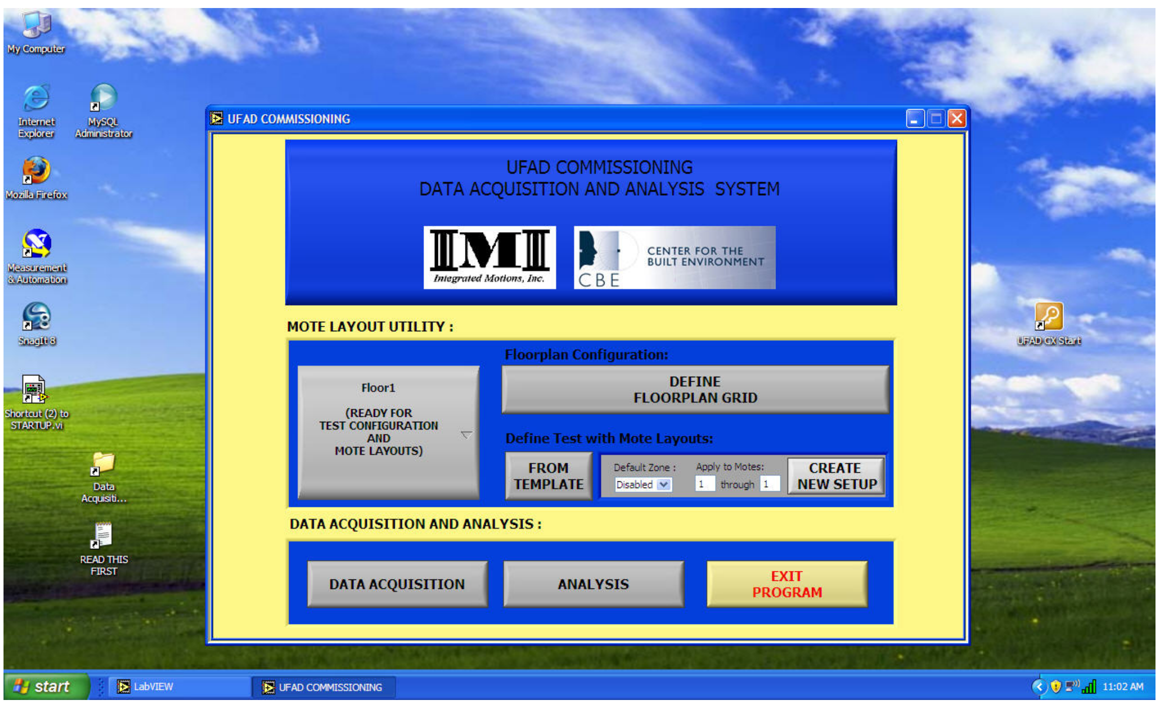


Figure 24: Startup screen

6.3.1.2 Data acquisition

Data acquisition operation

Data acquisition screens are “live” whenever LabView is activated; data is shown in real time but is not stored until logging is activated.

Drop down lists allow configuration of a single or multi-zone test for a given floor and building type to be tested for selected grid locations. At the end of each test, time averaged data from the test is appended to the database. If the specifications are not changed the test is considered a retest of the same location. The DMAS operates as follows:

- Time stamped raw data for all sensors and motes are stored in the DB for the entire logging period.
- Time averaged data for RAS profiles and other cart sensors is stored in the DB along with mote data at the end of the test based on logging specifications for all but steady state tests.
- For steady state tests, data at the end of each sample interval is used to calculate regressions for each specified mote (specified by a steady state mote template) based on steady state logging specifications.

Data logging modes

Although data from the cart is logged somewhat asynchronously with mote data, the logging procedure forces concurrence; cart and mote data are averaged in the same way at the end of a test.

- "Live" mode – When logging is not being conducted, the displays show real time data.
- Automatic logging – These tests will generally be only a few minutes each (3-5 minutes), but there might be longer times in between tests. The total sample time is set by the combination of sample interval and number of samples to be used for averaging; i.e., data is only logged until enough samples have been collected to provide an average.
- Manual logging – User controlled logging period; the auto logging number of samples is used for averaging at the end of a test.

6.3.1.3 Analysis

All fields default to the setup and configuration for the most recent test. All numeric fields are text based fields that can be used to setup a DB query to import data for a zone (or zonegroup). Only 15 profiles can be loaded at one time. These profiles are selected from a dropdown list that results from the DB query. There are two types of profile comparisons that can be made.

- Compare location profiles – Loads *gird location* RAS data for either a single or multi-zone test. For the default test (current test being conducted), all grid location RAS profiles including retests are loaded into the RAS profile chart with their ID string shown in the legend.
- Compare zone averages – (for single and multiple zone RAS profiles and associated mote data) – For the default single zone case only the average or characteristic profiles are shown for all the tests conducted for the selected zone including retests. This provides a means for direct comparison between before and after tests when modifications to the system and controls have been made. The metrics section of the display includes comparisons to commissioning acceptance criteria and shows whether the test passed or failed relative to these criteria.

  Multi-zone tests are shown in the same way as single zone tests; location profiles for all zones are shown in under *Compare Locations* and for *Compare Zone Averages* all average profiles (averaged over the MZ zone group) are shown in the RAS profiles chart.

Mote data is always collected for each test. For SZ tests the mote data is averaged in the same manner as the RAS profile data, i.e., over all grid locations measured, which yields a plenum distribution characteristic distribution. For MZ tests the process is similar, each time a test is conducted at a given cart location, a set of mote data is collected for all the zones of the MZ test. When the zone test is complete, all the data collected for a given mote are averaged together. Therefore, identifying the zone where data is being collected in a MZ test requires the zone to be identified so the proper mote data can be associated with the profiles collected.

Data export

From the Analysis program any data being displayed can be exported to a .csv formatted file by pressing the *Export* button. This file contains all RAS and mote data as well as the metrics tables for the tests shown in the display. Various data sets can be displayed depending on the query settings in the Analysis page header.

6.4 DATA ACQUISITION SCREEN DESIGNS

Figure 25 through Figure 33 show screen designs for measuring a single profile (and associated data as well as mote data) for a given cart location within a zone.

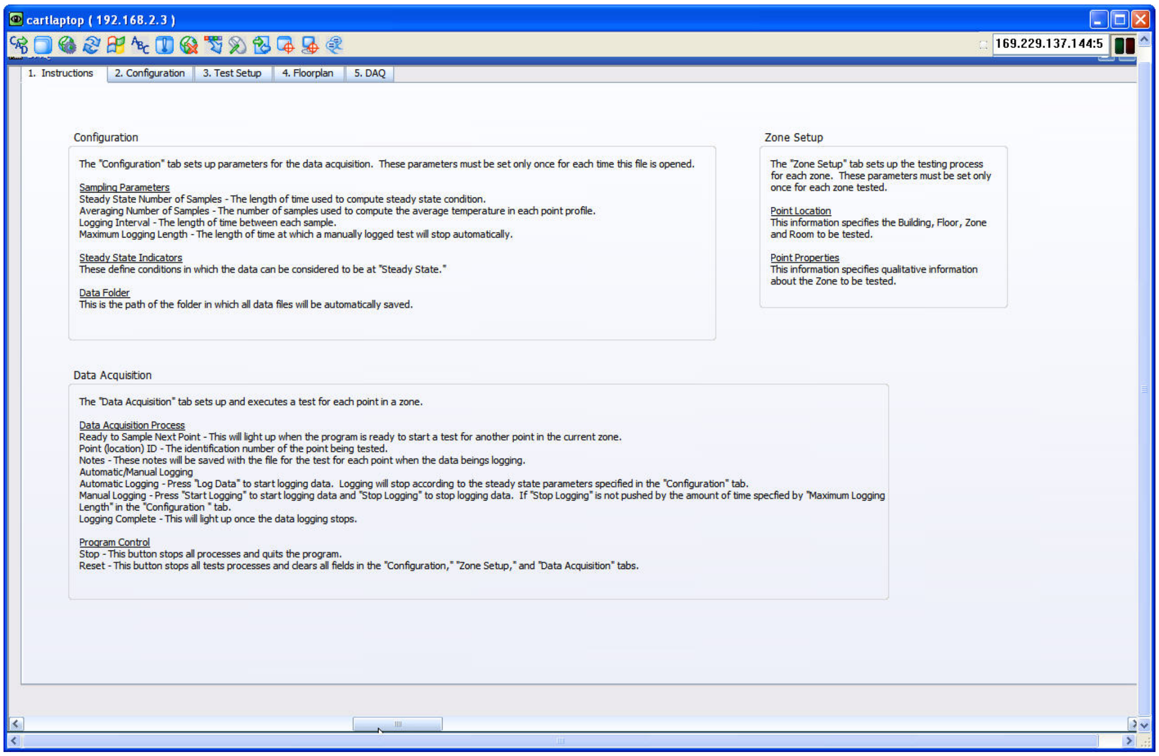


Figure 25: Data acquisition instructions screen

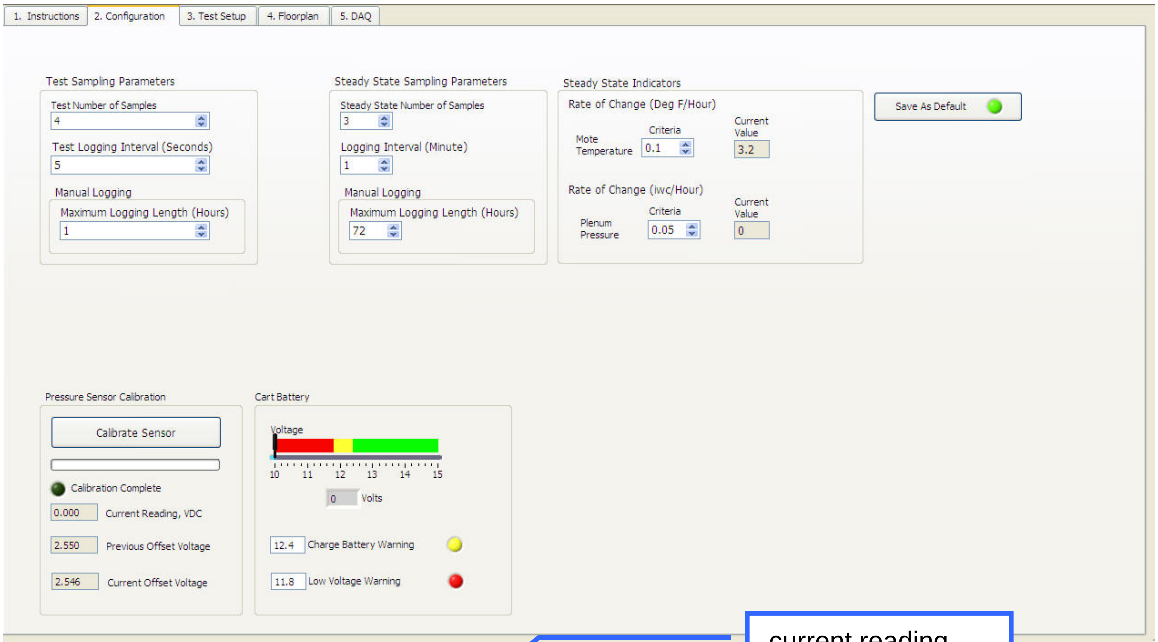


Figure 26: Configuration screen for setting test logging parameters

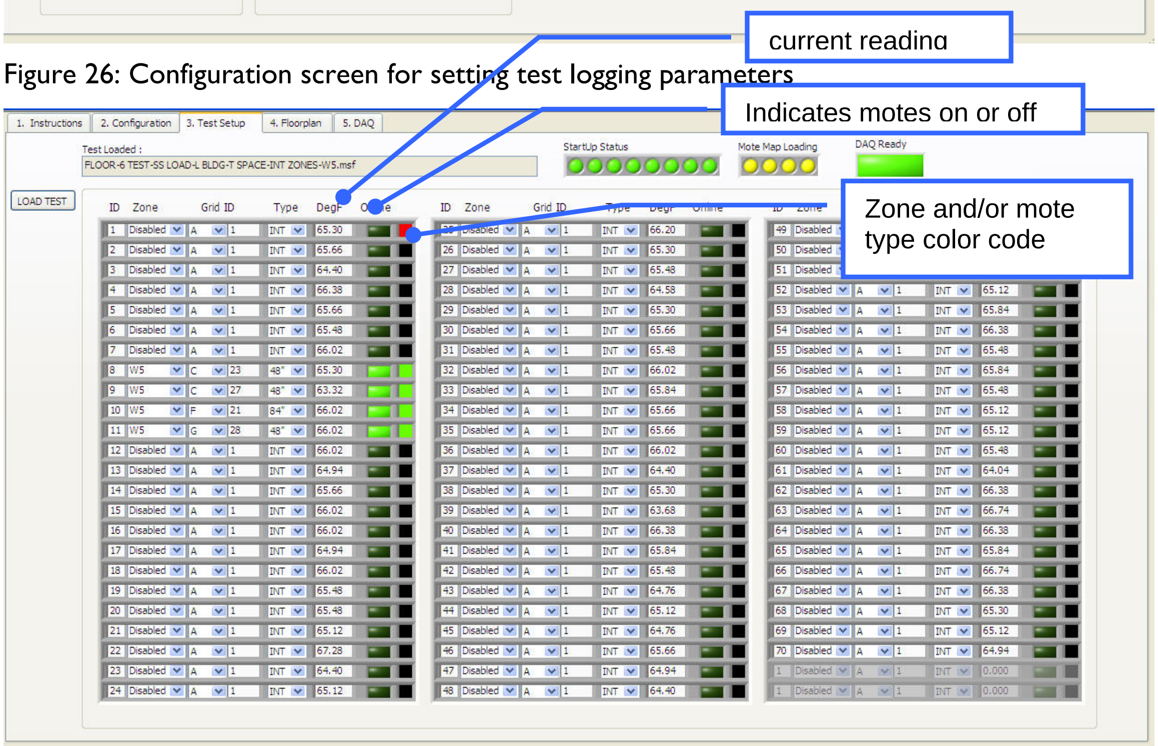


Figure 27: Test Setup screen

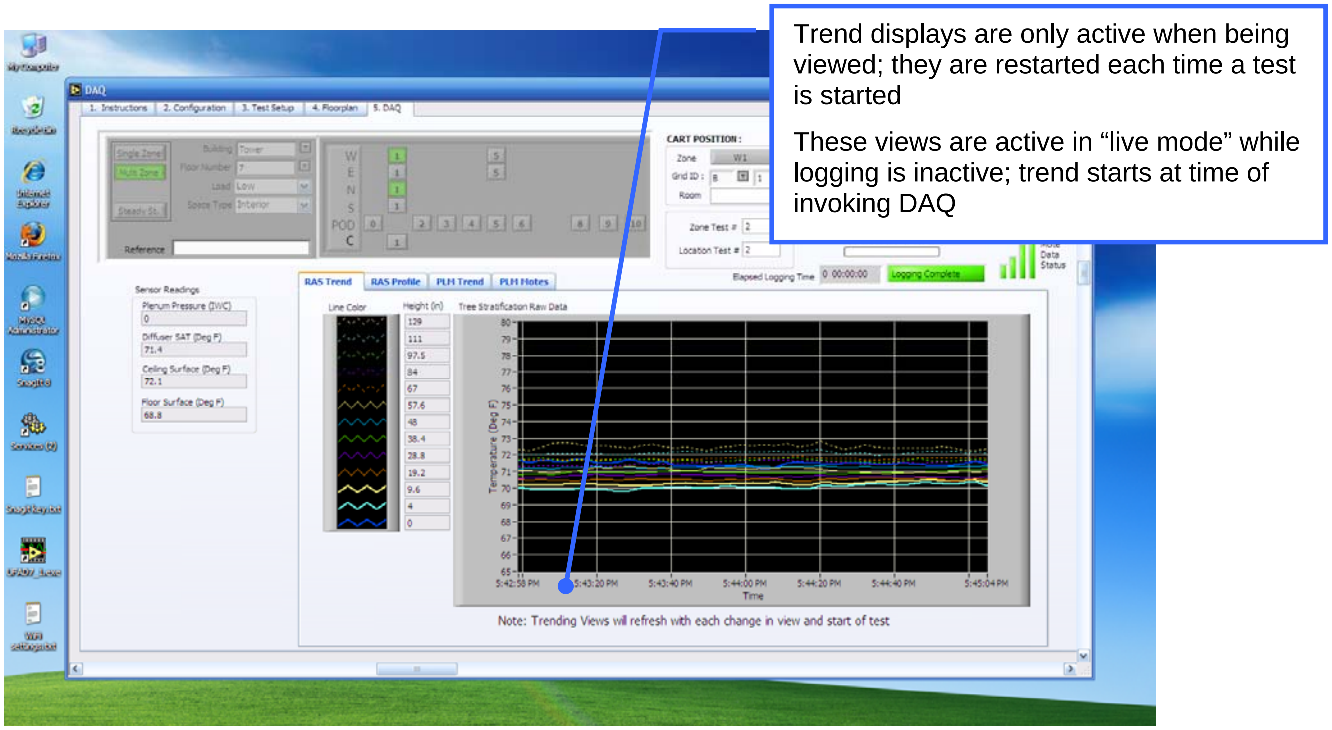


Figure 28: Data acquisition screen showing test control buttons and RAS trends for a given location

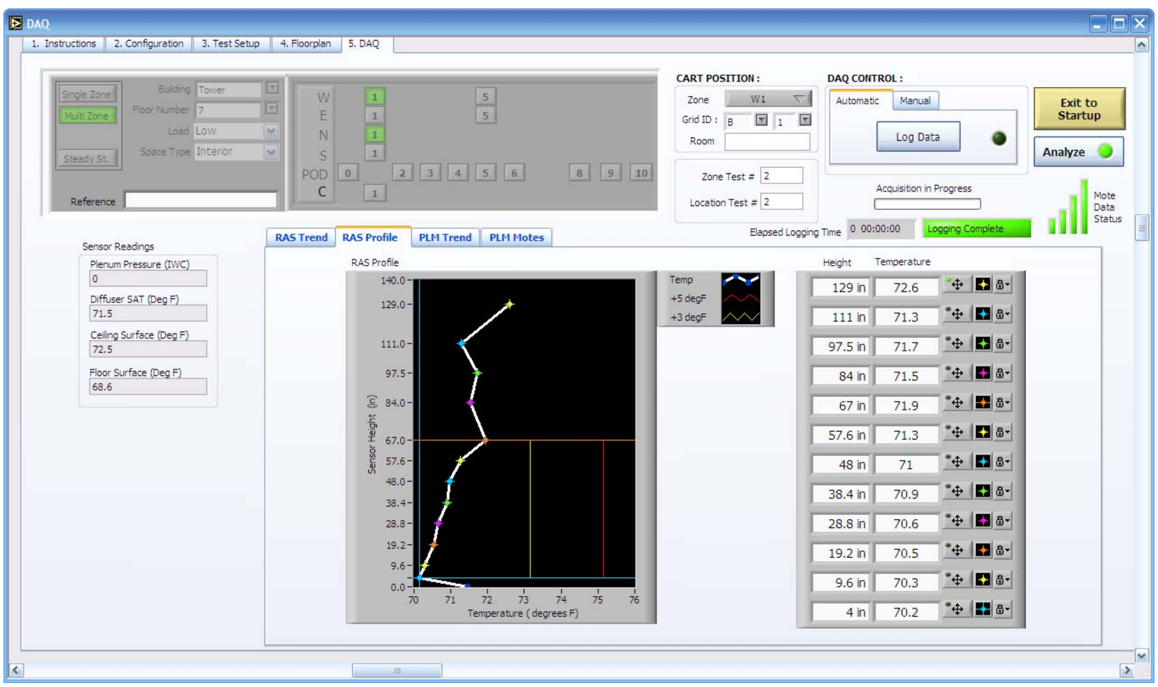


Figure 29: Data acquisition screen showing test control buttons and real-time profile test at a given location

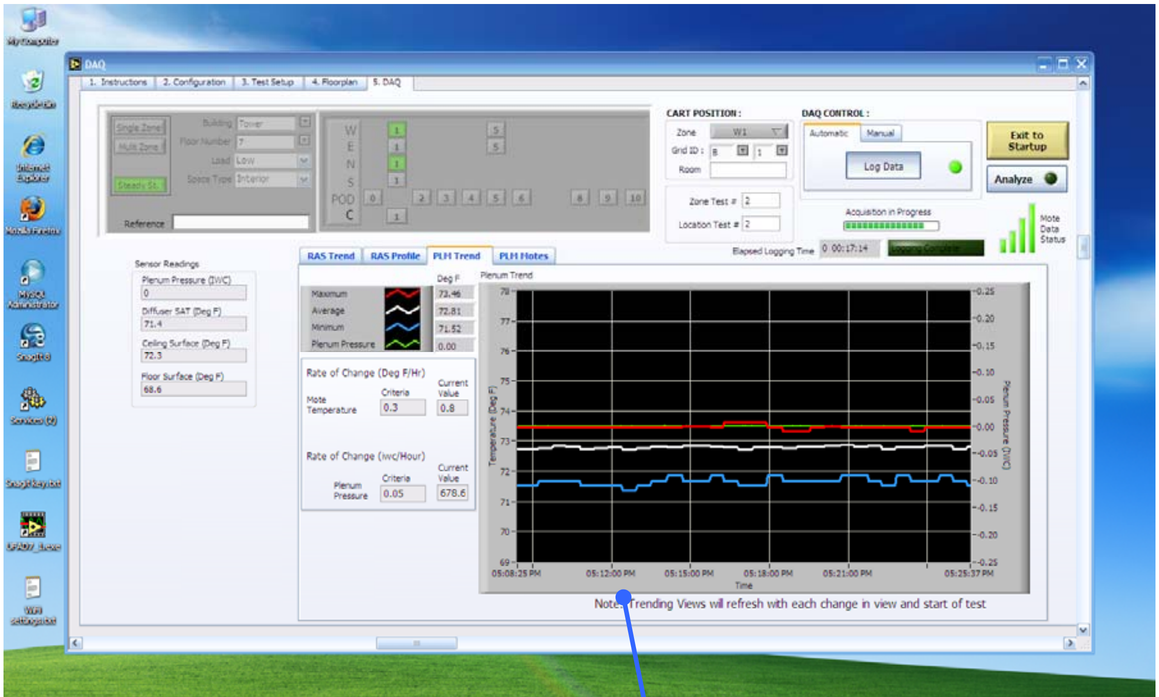


Figure 30: Data acquisition screen showing plenum trends for a given location

Trend displays are only active when being viewed; they are restarted each time the view is entered.

These views are active in "live mode" while logging is inactive.

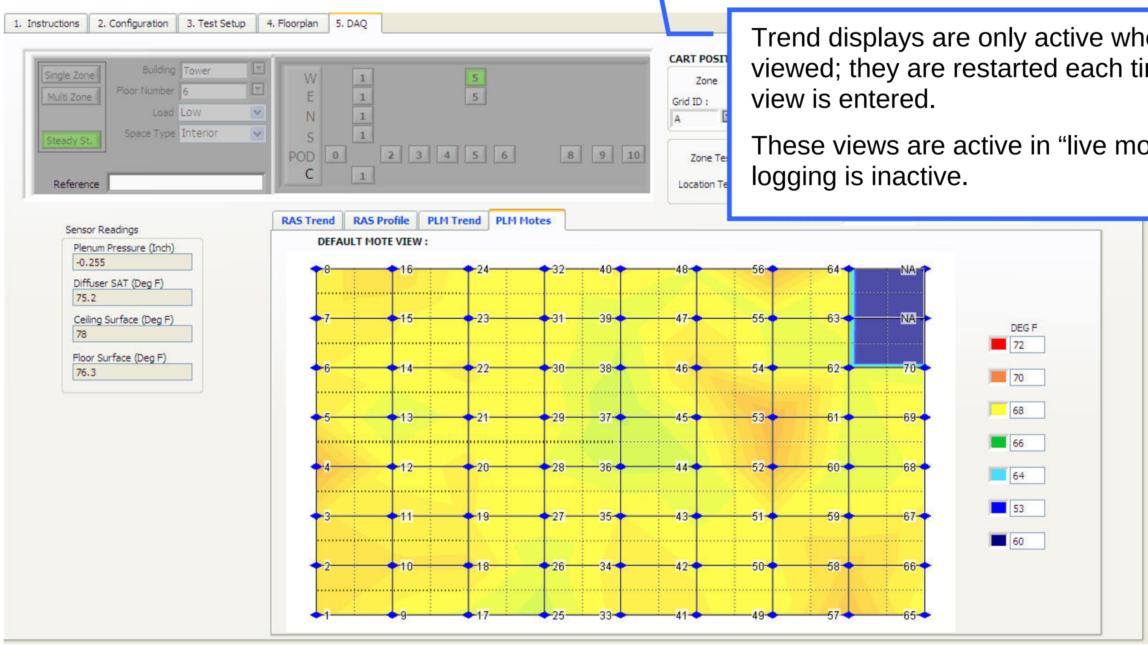


Figure 31: Data acquisition screen showing default plenum distribution for a typical test

Figure 32: Data acquisition screen mote layout view of floor; zoom all view

Figure 33: Data acquisition screen mote layout view of a zone on a floor with motes; zoom motes view

6.5 DATA ACQUISITION OPERATING INSTRUCTIONS

6.5.1 Logging Setup

Figure 34 shows the setup screen for data logging and steady state indicators.

Figure 35 and Figure 36 show typical values for these parameters. These parameters are used to configure steady state other tests and are described below. The default values for these can be modified by pressing the *Save as Default* button.

- Sample rate – This interval sets the sampling rate for all channels. This determines the frequency of data acquisition.
- Steady state number of samples (N) – This parameter is used (instead of a given time interval) to compute the rate of change of selected (from Test Setup) sensors (See Section 6.1.1) for steady state tests. The rate of change for each sensor is calculated by conducting a regression for a trend over the SS number of samples; the slope of the trend gives the rate of change. The SS calculator continuously calculates this regression on the last N samples. In Auto logging mode, the program stops when all steady state indicators are within an acceptable range. In manual mode it stops at the duration limit.
- Averaging number of samples (M) – This is the number of samples used to compute the average values for each sensor. All sensors are averaged over this number of samples at the end of the run.

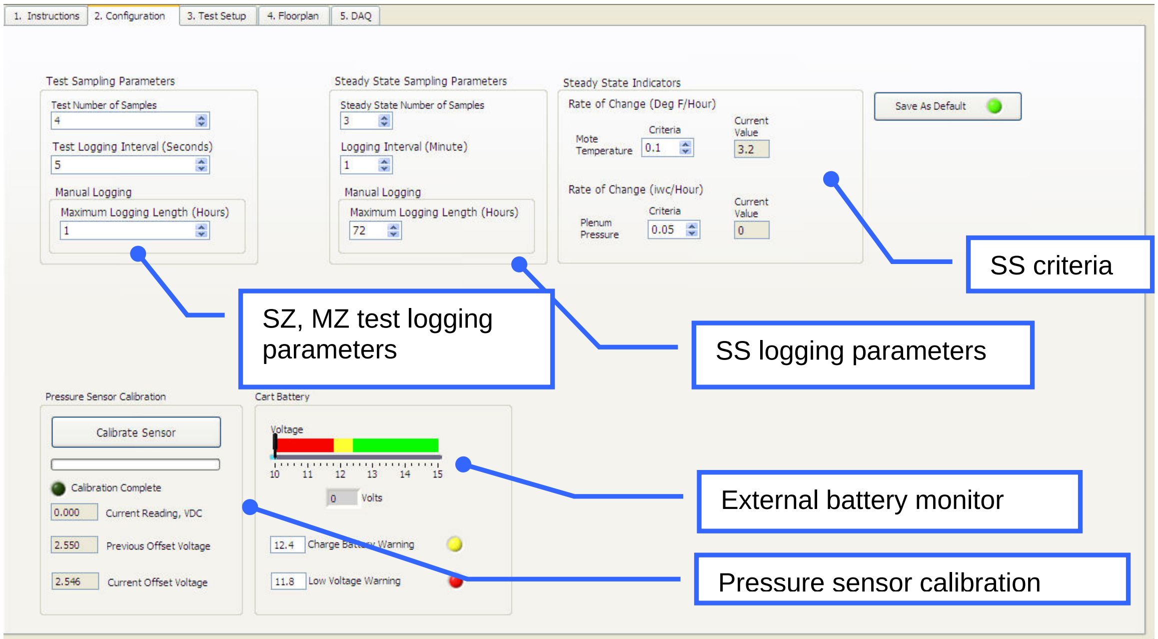


Figure 34: Configuration and logging setup screen showing logging setup parameters

Figure 35: Logging setup parameters for steady state tests

Item	9. Value	Units
Sample interval (default)	10	min
Regression number of samples	10	
Steady state indicator, rate of change – temp	0.5	°F/hour
Steady state indicator, SD – temp,	0.5	°F
Steady state indicator, rate of change – pressure	0.01	iwc/hour
Steady state indicator, SD – pressure	0.02	iwc
Auto Test Duration Limit	24	hours
Manual Test Duration Limit	72	hours

Figure 36: Logging setup parameters for profile tests

Item	10. Value	Units
Sample interval (default)	30	sec
Averaging number of samples	10	count
Auto Test Duration	5	minutes
Manual Test Duration	2	hours

6.5.2 DATA COLLECTION AND MONITORING (DAQ SCREENS)

Figure 39 shows the instructions for collecting grid location profile and mote data after the test is configured and the zone is setup. Note that the data collected includes several other parameters in addition to the RAS profile data. These data include the supply air temperature (SAT) as measured by the separate thermocouple attached to the measuring tube. Operating buttons perform the following functions:

- *Automatic logging* – Starts logging and automatically stops at end of logging duration specified in the Logging Setup screen.
- *Manual logging* – Start and Stop logging at users discretion.

6.5.2.1 Test and zone setup fields

The screen shown in Figure 38 shows the header area that contains the basic parameters that define a test. These parameters are setup automatically when a mote map is loaded in the Test Setup screen. The fields are defined as shown in Figure 38.

Zones are automatically associated with exposures (and additional search parameter) as shown in Figure 37.

Figure 37: Zone IDs and exposure assignments

Zone ID	Exposure
W1,5	West
N1	North
S1	South
E1,5	East
C1	INT
P0,2,3	North
P4,9, 10	INT
P5,6,8	South
MZ, other	NA

Figure 38: Zone test setup parameters

Test Type	Value/Definitions
• SS, SZ, MZ, PLM	check boxes, only one possible at a time

General Setup Fields	
Building	Tower, podium
Floor	1-25
Space type	INT, PER: • INT=interior wall to 5 ft from window, • PER = perimeter area to 5 ft from window
Load level	H, M, L, none: Define load level consistent with artificial loads deployment
Number of swirl diffusers	Count of number of diffusers in zone being tested
Area of zone	Estimated area of zone (correlate with zone ID)

Location Setup Fields	
• Zone	Use designated zone numbers as shown in Figure 37
• Cart location: grid/room	Cart location ID: • Grid location ID:XX.nn • Room number (text field)

Mote map/test setup templates

Mote layout templates are created by the Mote Layout Utility. The *Load Test* button on the Test Setup screen shows a list of mote layout files. **The file selected must match the floor and zone being tested.** The templates are created explicitly for a SS, SZ or MZ test. When loaded, each template automatically configures the DAQ for mote locations (zone and grid ID), mote type, type of test, and space type as shown in Figure 29. For more information see Section 7 which describes the Mote Layout Utility. These templates also define the basic test setup parameters which are automatically loaded into the DAQ header as discussed in Section 6.5.2.

Figure 39: Instructions summary for data collection at a given location

Step	Operator actions	Software actions	Comments
Check SS	Confirm that system is operating in steady state conditions	NA	• Review test setup instructions and Cx procedures • If not clear, conduct a SS test
Pressure sensor rezero	• At first test of the day (or after several days): • Install jumper between high and low port of pressure transducer • Press *Calibrate* button on **Logging Setup** screen	• Starts DAQ for pressure transducer • Writes final average zero after 30 sec. • Indicates when zero is recorded to alert operator to remove jumper	Zero is automatically used in pressure measurement
Test setup, load mote map	Select test configuration from dropdown list	Enters all header data describing a test	Mote placement templates can be retrieved, edited, and saved on *Test Setup* tab.
Locate cart	Move cart to specified grid location; monitor tree temperature display	Tree temperatures indicate when sensors influenced by air currents by distortions in profile shape	Avoid locations too close to floor diffusers
Collect data	Start DAQ (Auto, Manual)	Starts trending data for all channels.	• Logging ends automatically based on length of run specified, or manually by operator • Saves RAS, plenum pressure, IRTs, SAT, and mote data to database
Monitor logging	Monitor • Logging light • Logging complete	Green and blinking during logging, clear/off when not logging	
Review trends	Click on *RAS* or *PLM Trend* tabs	Trends are automatically shown	
	Logging complete light	Red and blinking when logging is complete, clear/off when not complete	
Analyze results	<End of zone test>	Press *Analyze* button to analyze profiles collected	Raw and averaged (over averaging period) data are saved to DB for each profile collected

6.5.2.2 Mote configuration

A network of up to 70 wireless mesh network temperature sensor motes can be deployed to measure supply plenum temperature distribution and associated variables. Figure 27 shows the configuration screen for these motes. Next to each mode ID there are a series of fields that operate as shown in Figure 40. For each SZ test motes are deployed in four locations, swirl diffusers randomly about the interior/LPP zone, ASH motes placed in high pressure diffusers or in the air stream from a Zebra damper, perimeter linear bar grilles, and in the room at 48 inches near a perimeter thermostat, and at 84 inches near the interior zone thermostat. In this case we define "interior" as the plenum space between the ASH and the linear bar grille plenum at the outer wall i.e., the low pressure plenum, LPP. "Perimeter" refers to the linear bar grilles plenum at the window. For the bar grilles we assume that two or more motes are placed at the linear bar grilles to measure the perimeter plenum temperatures; these mote readings are averaged together to provide one reading for the perimeter. At least two motes of each type should be specified in a zone test setup so metrics can be properly calculated.

Figure 40: Test Setup fields

Field	Purpose	Comment
Mote ID	Identify motes for location purposes	
Enable/disable	Actives the mote for data collection and shows the zone it which it is deployed.	If disabled, the motes should be turned off with the sleep tool. When disabled the light is off
Location ID	Grid location cell ID	Four digit Letter/numeral ID
Mote type	Identify use of mote	Options are: • ASH • INTerior plenum (in swirl diffusers) • PERimeter diffusers(at linear bar grilles) • Room, 48" • Room, 84"
Reading	Current reading	
Status	Light indicates if a deployed mote (i.e., not disabled) is reporting data or not	If enabled (i.e., has a zone number) and the light is off, the mote is non-responding and requires attention.
Location	Color code designates which motes are in the same zone	

6.5.2.3 Trending screens

Trends start (i.e., anchored on left side of time scale) either when the DAQ is started (live mode) or a test is started. Although they continuously trend when viewed they are NOT when another screen or tab is being viewed. The trend will continue when the trend screen is re-entered but there may be a noticeable gap in the traces reflecting the time the screen was not being viewed. The time axis is setup to auto-scale over a six hour window; after six hours the window scrolls to the left so the beginning time changes and the right side becomes current time. For normal tests (except for steady state tests), this display will tend to be straight lines due to the short duration of a typical test.

The user can modify the operation of these trends by turning off auto-scaling and adjusting the end points of the trend window. For example, once a test is started, changing the right hand time scale to a forward time will compress the scale of the window. When the forward time is reached the window will scroll since the scale has been set by adjusting the end points.

RAS trends

Figure 41 shows the RAS trends of all tree thermocouples. The legend on the left is a reference for the trace color coding.

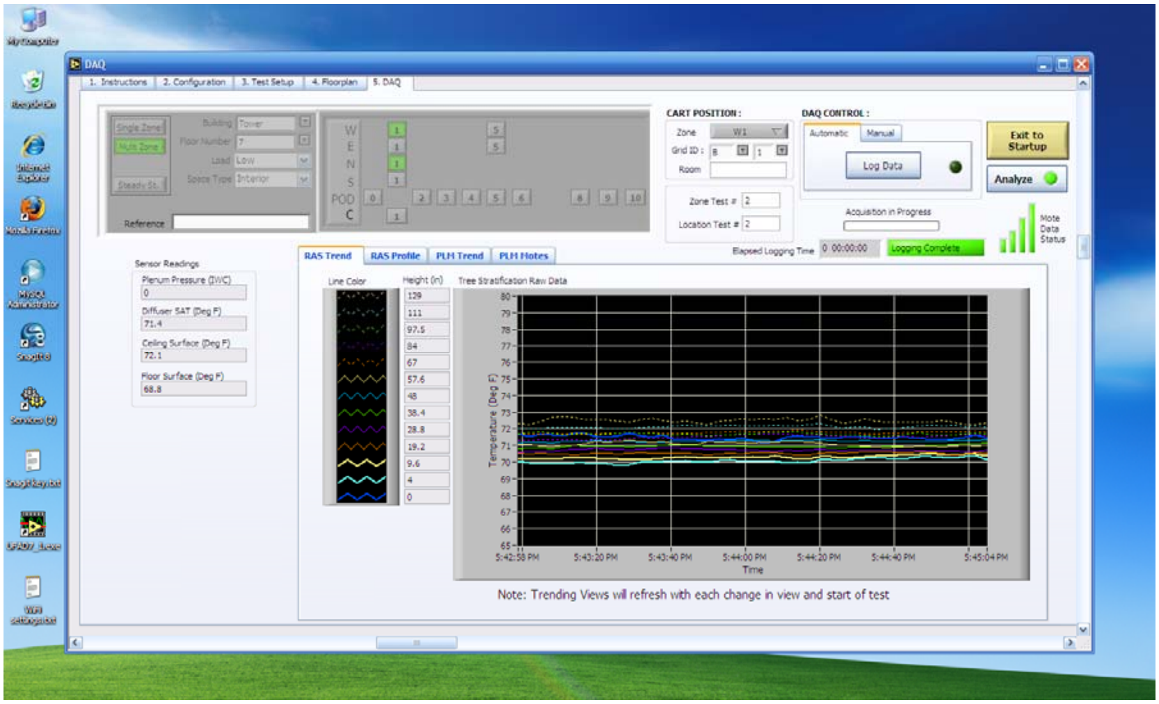


Figure 41: RAS trend screen

Mote trends

Figure 42 shows the trend display for mote data. This display shows only the minimum, maximum, and average for all the motes deployed in the plenum plus the thermostat(s) and ASH motes plus the plenum pressure. No explicit action is required for collecting mote data since it is integrated with the RAS profile data collection.

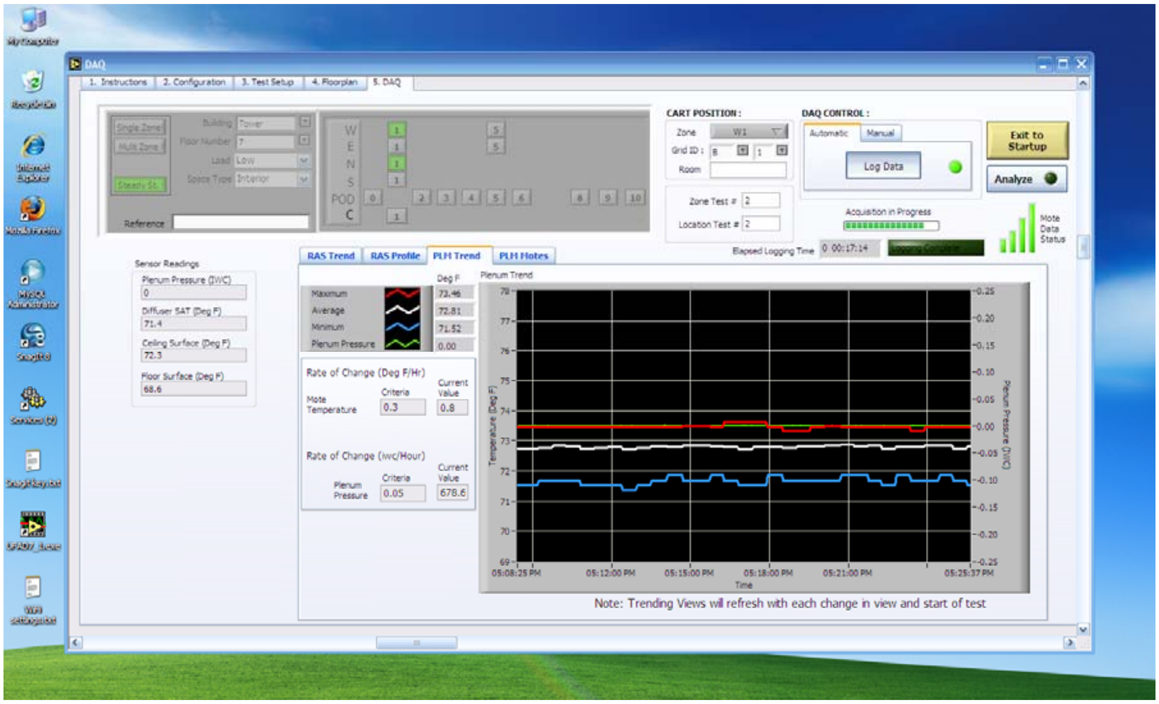


Figure 42: Mote data trend for a steady state test

6.6 ANALYSIS SCREEN DESIGNS

Figure 43 and Figure 44 show basic screen design for the Analysis.vi Labview program.

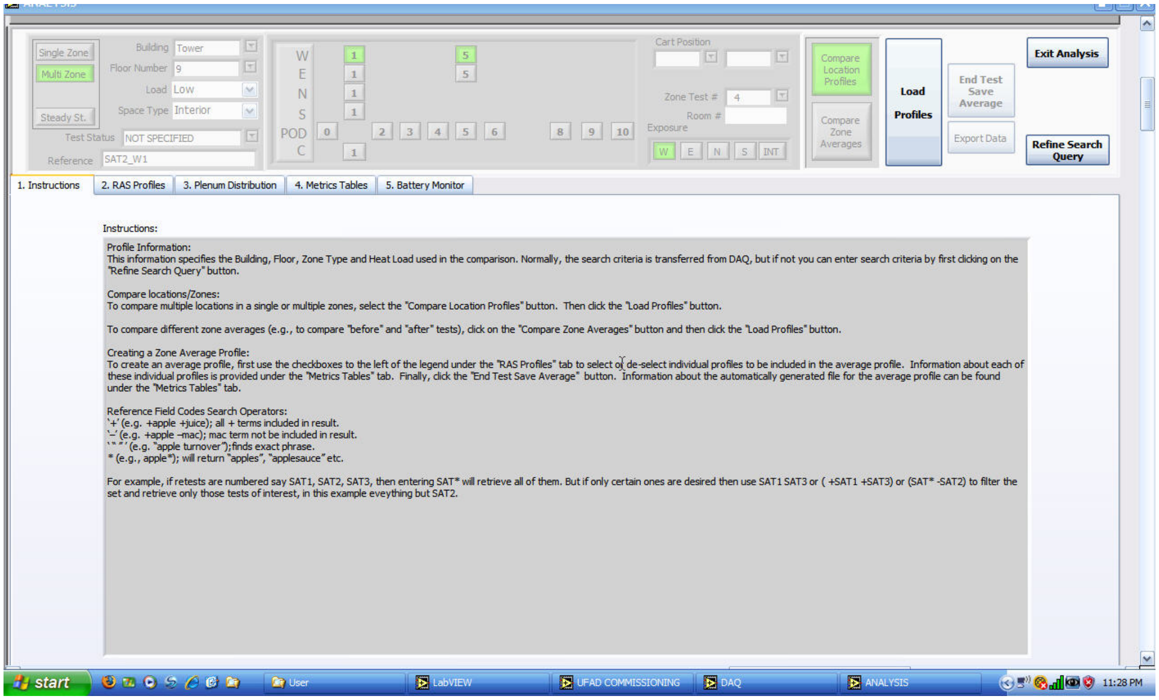


Figure 43: Analysis instructions screen

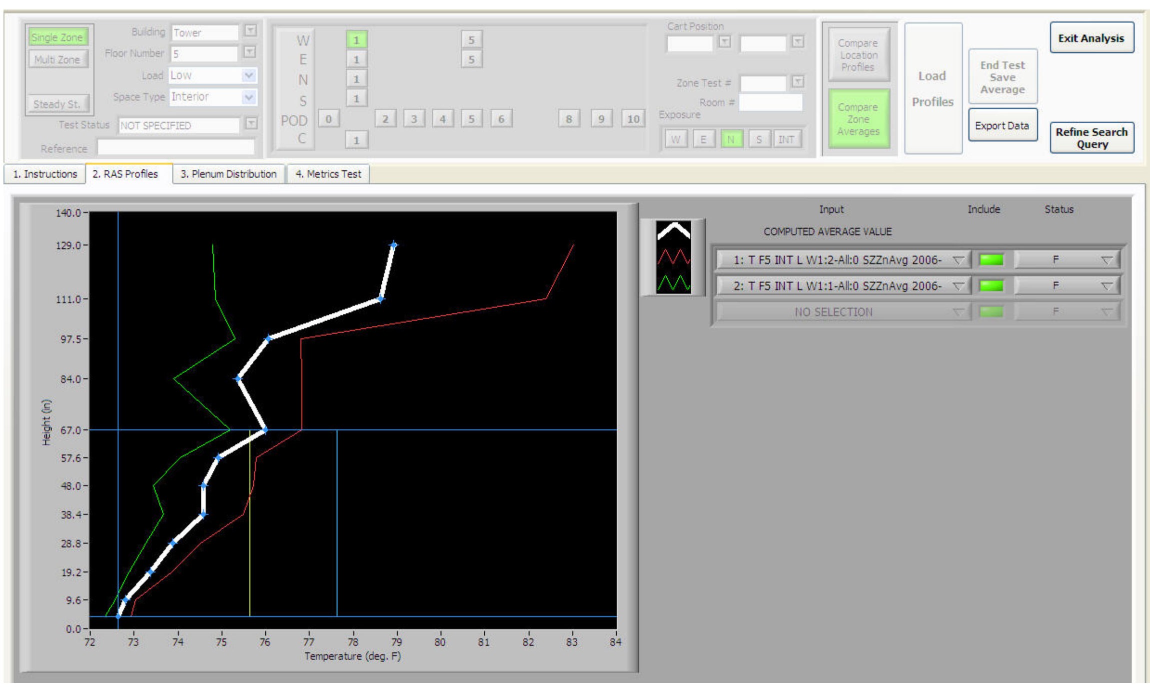


Figure 44: Screen design for multiple profiles in a given zone and zone average profile

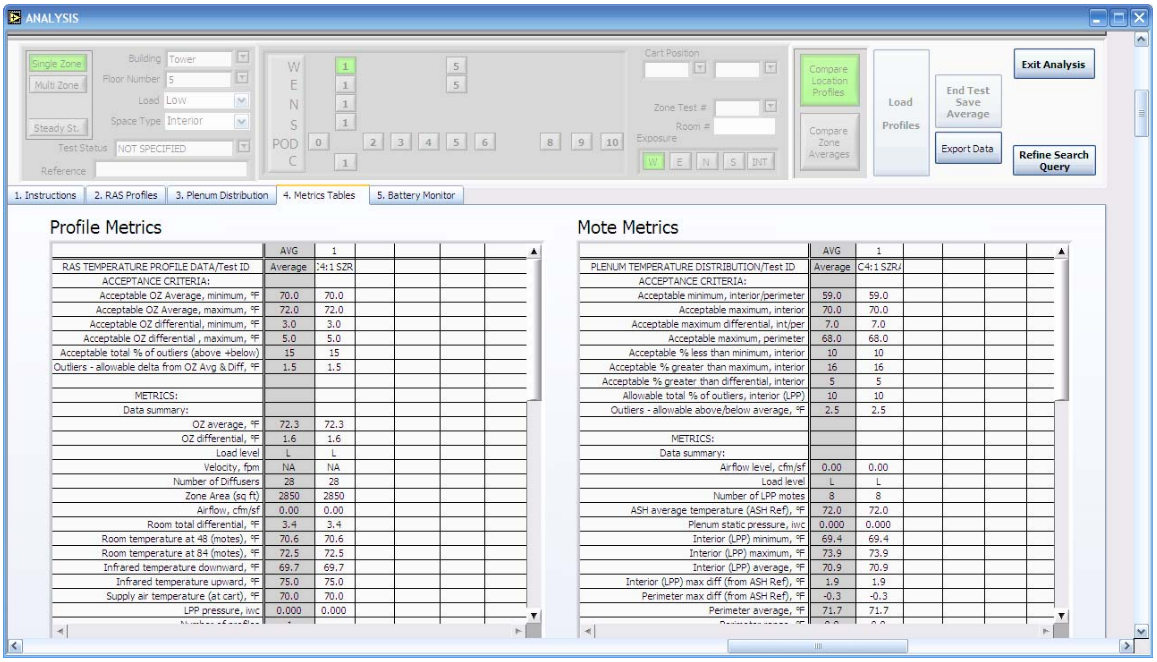


Figure 45: Metrics tables showing RAS profile and plenum distribution data summary and acceptance results; top of scroll.

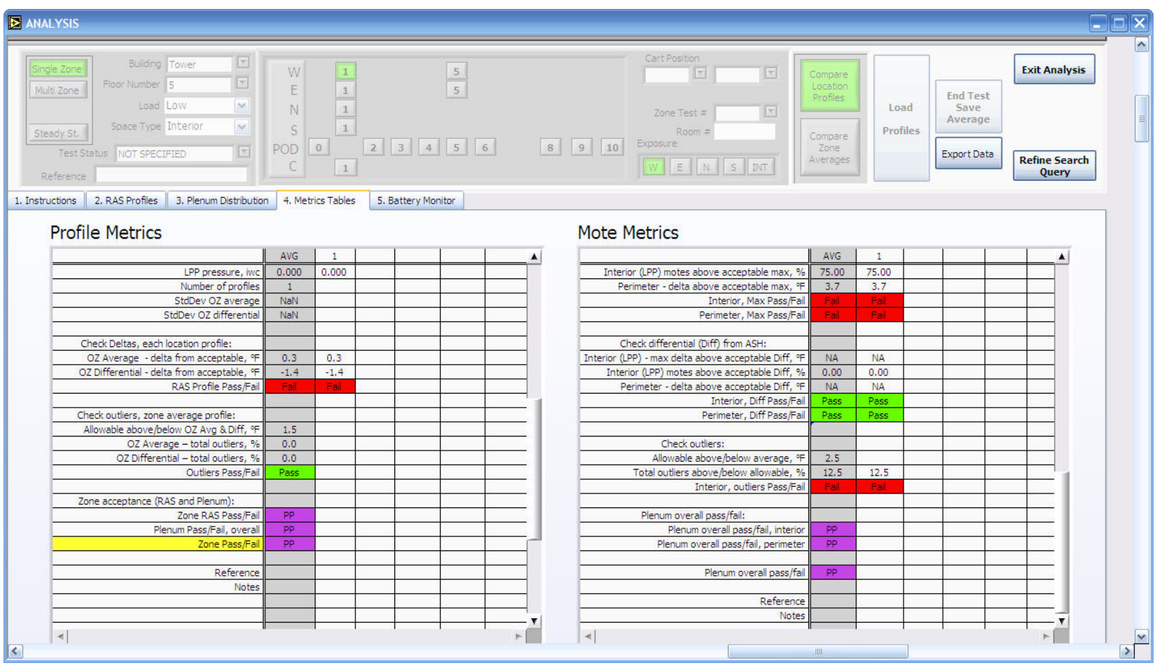


Figure 46: Metrics tables showing bottom of scroll

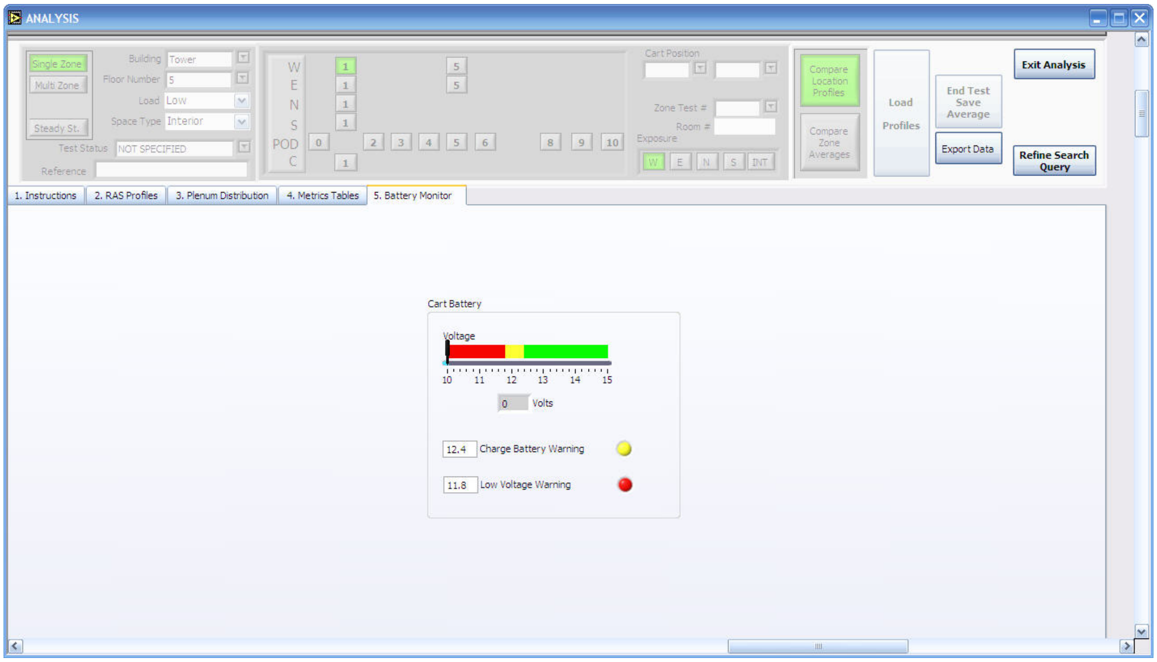


Figure 47: Analysis program battery status screen

6.7 ANALYSIS OPERATING INSTRUCTIONS

For the test currently being conducted the configuration data is ported from the DAQ.vi to the Analysis.vi. For other analysis operations data is loaded from the database using a search query.

Figure 44 shows an example screen that allows comparison of a number of profiles measured at various locations in a SZ or MZ test, or comparisons between zone averages or characteristic profiles. In the former case, this screen shows average temperatures and calculated metrics from measurements made for each test of a profile at selected grid locations.

6.7.1 SELECTION AND SEARCH FIELDS

The test type selection and search properties that define the data to be analyzed are shown in Figure 48. All numeric fields allow complex search strings (Refine search views only)

Figure 48: Analysis search fields

Test Type	
SZ, MZ, PLM	check boxes, only one possible at a time
Search Fields	
Building	Tower, podium
Floor	1-25
Zone	Using designate zone numbers from Figure 37
Space type	INT, PER
Room	enter room number
Location	grid location ID
Load level	H, M, L, none
Zone Pass/Fail/accept	• Pass (P) = all criteria must pass • PP-RAS = Partial Pass if RAS passes but plenum doesn't • PP-PLM = Partial pass if plenum passes but RAS doesn't • Fail (F) = any criteria that doesn't pass, • Partial Pass-Accept (PP-A) = operator accepts PP test • Fail-Accept (F-A) = operator accepts failed test; i.e., a forces a pass based on operators judgment • PP-A = Partial pass acceptance
Reference	Text fields to enter user reference information such as what was done to "tune" the zone or as a user code for conducting MSZ tests

6.7.2 BUTTONS AND DISPLAY OPTIONS

The buttons on the Analysis screen facilitate analysis activities as indicated in Figure 49. Note that the selection/query area of this screen is virtually identical to the Data Acquisition screen design. The selection area sets up a query for the database, the results of which are displayed in the chart area.

Figure 49: Analysis screen button functions

Button	Description	Comment
Compare Location Profiles	Used to display location profiles for a given SZ or MZ test and associated metrics	Defaults to search criteria passed from the DAQ program, or user can select a search query
Compare Zone Averages	Used to compare zone average profiles for a given zone or zone group (MZ test).	Allows comparison of zone retests as a “before and after” check on the impact of changes made to better meet the criteria.
Load Profiles	Loads type of profiles selected by two previous buttons.	
End Test/Save Averages	This button saves the average of a group of location profiles to the database and thereby signals the end of a test.	Profiles that are considered poor can be discarded from the average.
Save Status Changes		
Refine Search Query	Unlocks the search field panel	Allows for advanced searches by persons knowledgeable about the search capabilities
Exit Analysis	Exists to previous application	Either goes to DAQ or Startup Menu

6.7.3 METRICS CALCULATIONS

On the Metrics tab of the Analysis screen tables show metrics for RAS profiles and plenum distribution (see Section 6.7.6 below) for each displayed profile as shown in Figure 50 . These metrics are described in Figure 51.

Note that SZ tests are intended to support acceptance of an entire zone for both the room RAS profile and the plenum distribution. Consequently the RAS and plenum distribution metrics tables are designed to support both acceptance of each individually as well as overall (see discussion in Cx Procedures).

6.7.3.1 Using metrics tables

The metrics tables are organized to into three sections, describes as follows:

1. Acceptance criteria – These are the criteria established by the Cx specifications. These values are loaded into the Analysis program from an Excel file that is accessed and modified via the external file, Metrics Descriptions.txt. (This file can be created by changing values in the Excel spreadsheet of the same name and saving as a .txt file). These values are provided so you know what parameters were used for a given test; they are used in the calculations of pass/fail conditions for zone tests.
2. Summary data – This is a set of selected data and metrics calculated for the average data stored for a zone test for both RAS profiles and plenum distribution data.
3. Check criteria – These are the results of the measured data compared to the acceptance criteria. Data in this section shows the results of specific calculations used in the pass/fail analysis as well as the overall result of each.

As mentioned above, there are two levels of acceptance that are important to consider, individual RAS profile and plenum distribution and overall zone level. RAS and plenum distribution acceptance are combined to form the overall zone acceptance shown by the Zone Pass/Fail element at the bottom of the RAS metrics table. As shown in the tables, passing acceptance for RAS profile and plenum distribution depends on passing a number of elements of acceptance as shown in Figure 50, Figure 51 and Figure 55,

Figure 56.

To understand why a zone does not pass after first looking at the overall zone pass/fail, look at subsequently more detailed levels shown in the tables.

Acceptance metrics data is stored (and therefore can be retrieved with stored acceptance criteria with *location* profiles) for each location test. This data is only stored in zone averaged form when SZ or MZ testing is complete and the *Saved Average* button is pressed.

Figure 50: Zone test RAS profile metrics table

RAS temperature profile data			
Acceptance criteria			
Acceptable OZ Average, minimum, °F	71		
Acceptable OZ Average, maximum, °F	73		
Acceptable OZ differential, minimum, °F	3		
Acceptable OZ differential , maximum, °F	5		
Acceptable total % of outliers (above+below)	16%		
Outliers - allowable delta from OZ Avg & Diff, °F			
Metrics/Test ID	Zone Avg	Test 2	Test 3
Data summary			
OZ average, °F			
OZ differential, °F			
Load level			
Velocity, fpm			
Number of Diffusers			
Zone Area (sq ft)			
Airflow, cfm/sf			
Room total differential, °F			
Room temperature at 48” (motes), °F			
Room temperature at 84” (motes), °F			
Infrared temperature downward, °F			
Infrared temperature upward, °F			
Supply air temperature (at cart), °F			
LPP pressure, iwc			
Number of profiles			
StdDev OZ average			
StdDev OZ differential			
Check criteria			
Check Deltas, each location profile:			

OZ Average - delta from acceptable, °F			
OZ Differential - delta from acceptable, °F			
RAS Profile Pass/Fail			
Check outliers, zone average profile:			
Allowable above/below OZ Avg & Diff, °F			
OZ Average – total outliers, %			
OZ Differential – total outliers, %			
Outliers Pass/Fail			
Zone acceptance (RAS and Plenum):			
Zone RAS Pass/Fail			
Plenum Pass/Fail, overall			
Zone Pass/Fail			

Figure 51: RAS metric definitions and calculations

Metric ID	Variable ID	Definition	Comment
Acceptance criteria			
Acceptable OZ Average, minimum, °F	Toz_Avg_accept_min	Minimum average temperature 4 inches to 67 inches	Max/min defines band of acceptability of deviation from this temperature
Acceptable OZ Average, maximum, °F	Toz_Avg_accept_max	Maximum average temperature 4 inches to 67 inches	Ditto
Acceptable OZ differential, minimum, °F	Toz_Diff_accept_min	Minimum occupied zone (OZ) head-foot temperature difference	• ASHRAE definition for stratification in the occupied zone; difference between temperature at 67 inches and 4 inches from floor • Max/min defines band of acceptability of deviation from this temperature
Acceptable OZ differential , maximum, °F	Toz_Diff_accept_max	Maximum occupied zone (OZ) head-foot temperature difference	• Ditto
Acceptable total % of outliers (above+below)	%ras_out_accept	Percentage of outliers that are acceptable to exceed outlier metrics	• This parameter defines outlier tolerance limits and, depending on the number of profiles measured, the percentage of profiles allowed to exceed it. • This is a simple test of the percentage of outliers that exceed certain delta limits as defined below
Outliers - allowable delta from OZ Avg & Diff, °F	DT_out_accept	Delta temperature from OZ average and differential temperatures	A temperature spread or tolerance band is defined by this delta above and below the RAS metrics. The same delta is used for OZ average and differential
Data Summary			
OZ average, °F	Toz_Avg Toz_Avg_zn	• Averaged tree data between 4" and 67" for each profile and for the zone average. • Toz_Avg_zn = AVG(Toz_Avg of N_ras)	• Weighted average of vertical profile data for occupied zone • The zone average is the average of all Toz_Avg
OZ differential, °F	• Toz_Diff • Toz_Diff_zn	• T_ 67 – T_4 • Toz_Diff_zn = AVG(Toz_Diff of N_ras)	• Readings at 67 and 4 inches. 67 inches (1.7 m) is the top of the occupied zone, 4 inches (0.1 m) is foot level. • The zone aveage (Toz_Diff_zn) is the average of Toz_Diff over all profiles
Load level			Based on operators knowledge of load conditions
Velocity, fpm		Anemometer reading	NA
Number of Diffusers	N_diff		
Zone Area (sq ft)	A_zn		

Metric ID	Variable ID	Definition	Comment
Airflow, cfm/sf	CFMsf_zn	CFMsf_zn = 321.9*LPP_Pr^.497 * N_diff)/A_zn	Number of diffusers multiplied by manufacturers airflow data at measured pressure, divided by zone area
Room total differential, °F	DT_tot	DT_tot=Tree top – SAT = Room temperature difference	Total room temperature difference. Tree top is upper most sensor, 4 inches from ceiling
Room temperature at 48" (motes), °F	T_48	When available, show mote temperature for perimeter zone.	48 inches (1.2 m) is the height of thermostats in the *perimeter* zones near a control thermostat. The mote temperature is reported here or if more than one, the average of them.
Room temperature at 84" (motes), °F	T_84	Mote temperature for interior zone.	84 inches (2.1 m) is the height of thermostats in the *interior* zones near a control thermostat. The mote temperature is reported here.
Infrared temperature downward, °F		Infrared temperature (IRT) sensor reading at floor	Used to gauge radiation transfer to LPP
Infrared temperature upward, °F		Infrared temperature (IRT) sensor reading at ceiling	Used to gauge radiation transfer to LPP
Supply air temperature (at cart), °F	Tsat_diffuser	Room/diffuser supply air temperature	Sensor bundled with pressure tube for plenum pressure measurement in nearby diffuser
LPP pressure, iwc	LPP_Pr	Supply plenum pressure reading. LPP_Pr = m (Vx –Vo) Where m = 0.1 iwc/V and Vo = pressure sensor zero reading	Since this sensor is bidirectional it can register a negative reading. Vo is the average sensor reading during the zero operation on the Configuration screen
Number of profiles	N_ras	Number of profiles included in the average for the zone	As the number of profiles are toggled in the display, this reflects the number that are included
StdDev OZ average	SDdoz_avg	Find the SD of the OZ average of the number of profiles selected in the display	For zone average only
StdDev OZ differential	SDoz_diff	Find the SD of the OZ differential of the number of profiles selected in the display	For zone average only

Metric ID	Variable ID	Definition	Comment
Check Deltas, each location profile:			
OZ Average - delta from acceptable, °F		Toz_Avg – Toz_Avg_accept_min/max	Checks to see how far the OZ average exceeds the acceptable low and high limits. If exceeds min shows as minus, if exceeds max shows as plus, if within range, shows as zero.
OZ Differential - delta from acceptable, °F		Toz_Diff – Toz_Diff_accept_min/ max	Checks to see how far the OZ differential exceeds the acceptable low and high limits. If exceeds min shows as value with minus, if exceeds max shows the values with plus, if within range, shows as zero.
RAS Profile Pass/Fail		Check both average and differential criteria: • Pass if meets both criteria • Partial Pass (PP) if meets one criteria Fail if no criteria met	• Shown for each location profile and the zone-average profile (the latter indicates the impact on average of the variation in the location profiles. • For each profile, to receive a Pass, both criteria have to be satisfied, if neither passes it Fails, if one passes it receives a Partial Pass.
Check outliers, zone average profile:			
Allowable above/below OZ Avg & Diff, °F	DT_out_accept	Allowable delta temperature above or below OZ average and Differential	Allowable delta (deviation, spread) above and below the zone average OZ Avg and OZ Diff.
OZ Average – total outliers, %	%N_out_Toz_Avg	%N_out_Toz_Avg=COUNT(Toz_Avg<Toz_Avg_zn-DT_out_accept + Toz_avg> Toz_avg_zn+DT_out_accept)	Sum of all profiles OZ_avg exceed (above and below) the zone average OZ average.
OZ Differential – total outliers, %	%N_out_Toz_Diff	%N_out_Toz_Diff=COUNT(Toz_Diff<Toz_Diff_zn-DT_out_accept + Toz_Diff> Toz_Diff_zn+DT_out_accept)	Sum of all profiles OZ_Diff exceed (above and below) the zone average OZ Differential.
Outliers Pass/Fail		• Pass = both outlier checks less than allowable % • PP= if one passes • Fails = If both % outliers exceeds %ras_out_accept	•

Zone RAS Pass/Fail		For Zone-average profile, Check all criteria, OZ average, OZ differential, and outliers : • Pass if meets all criteria • PP if not all pass • Fail all if no criteria met	• Shown *only* for zone-average profile • For the zone average profile shown, to receive a Pass, all three criteria have to be satisfied, if none pass it Fails, if one or 2 pass it receives a Partial Pass
Plenum Pass/Fail, overall		Copies results from plenum distribution results	
Zone Pass/Fail		• P = Pass if RAS and Plenum pass • PP-RAS = Partial Pass if RAS passes but plenum doesn't • PP-PLM = Partial pass if plenum passes but RAS doesn't • Fail = Neither passes • PP-A = operator acceptance of partial pass • F-A = operator acceptance of failed test	• Shown for Average profiles only • Zone pass requires both the room profiles and all plenum distributions to pass • Operator may override a partial pass or failed test

6.7.4 RAS PROFILES, COMPARE *LOCATION* PROFILES

The search fields on the Analysis screen are text based and allow for complex searches of the DB to be made. However, the primary purpose of the *location profiles* display (activated by selecting the *Compare Location Profiles* button) is to show all the profiles for the currently being conducted SZ or MZ test from which the average zone profile can be constructed. Various comparisons can be made by clicking the check box next to the ID string. The average profile for the zone test can then be saved by pressing the *End Test/Save Averages* button. The instructions for using this feature are summarized in Figure 52.

Figure 52: *Location* profiles display instructions

Operator actions	Software actions	Comments
For current zone under test (and end of SZ/MZ test), press *Load Profiles*	All location profiles (including location retests) for a given SZ or MZ test are returned to the 15 slots in the legend and in the dropdown list which is accessed by clicking on a legend test down indicator	• 15 maximum profiles • Location profiles can be viewed repeatedly as the zone test is being conducted

Select profiles to be included in average or to be discarded using *Searchable* drop down menu	• *Accept* includes profiles to be averaged together to form zone average profile
	• *Disable* removes profile from future filtered sets
		• Selected profiles are used to calculate average profile and associated metrics.
		• *Disable* is intended to remove "bad" data from being retuned from the DB.
		• The RAS display test legend is arranged as follows:
		  • Most recent tests first
		  • Only most recent retest is shown as active

Press *End Test/Save Average* button	• Calculates zone characteristic profile and associated metrics based on selected location profiles. • Stores metrics in DB for each location test.	Saves all averaged data (RAS and mote) for zone characteristic that can be used for future zone average comparisons.

6.7.5 RAS PROFILE, COMPARE *ZONE AVERAGE* PROFILES

The *Compare Zones* tab in the screen shown by Figure 44 is intended to allow zone average profiles from various SZ or MZ tests to be compared to one another and to the acceptance criteria. The primary purpose is to compare original and retests to one another to determine the impact of changes and adjustments in system operating parameters. The table section on the Metrics tab contains the metrics and Pass/Fail indictors to show if the test met acceptance criteria.

For this level of analysis the search criteria in the header section defaults to that of the current setup in the DAQ. The search queries are grayed out to restrict access to them thereby reducing confusion and thus simplifying the daily testing tasks. Instructions for using this feature are summarized in Figure 53. These procedures are the same for SZ and MZ tests.

Past data (other than currently conducted tests) can be viewed using the Analysis program in standalone mode. In this case the mote profile needs to be loaded to define the SZ or MZ test to be viewed. When in this "viewing" mode, zone average profiles cannot be saved, for obvious reasons.

Figure 53: RAS zone profile comparisons instructions

Operator actions	Software actions	Comments
For current SZ or MZ configuration shown as default in search fields, press *Load Profiles*	Selected profiles (retests) are loaded into the chart area along with test ID string and table data	The search/selection fields are automatically filled for test currently specified in the DAQ.vi
Modify current test specifications shown in setup fields to filter profiles from the database.	A list of returned test ID strings appear in the dropdown list for each legend field; selecting one loads its profile into the display	Profile and mote metrics tables are loaded for each test selected along with Pass/Fail results. Includes criteria and acceptance results based on criteria used at time of test (not currently active criteria)
'Forced' acceptance	A dropdown field next to the legend allows the Pass/Fail to be overridden by the operator	Allows operator to make "judgment call" about accepting a zone

6.7.6 PLENUM DISTRIBUTION COMPARISONS

Once the data have been collected for a given plenum test or re-test, the summary data is displayed in a table format under the Metrics tab as shown in Figure 55 and Figure 57. For the temperature distribution displays, each zone of a SZ or MZ test has its own custom template. When SZ tests are displayed at the location profile level by pressing the *Load Profiles* button, all of the plenum distributions corresponding to each of the RAS profiles shown in the RAS display are listed in the plenum display legend. For MZ tests all RAS profiles for all zones included in the MZ zone group are shown and the plenum distributions for each zone are listed under the selection dropdown. Figure 54 shows an example of the plenum distribution display based on a loaded template. Each mote object color is referenced to the color scale on the right.

For the *Compare Zone Averages* level, only one plenum display is shown that represents the average of all the location distributions collected during a SZ or MZ set of tests. Note that when more than 15 tests are returned (location profiles or zone averages) the drop down list can be used to view tests after the 15th.

The plenum distributions can be viewed by selecting a test from the dropdown list shown in Figure 54. The specification for the selected test includes the zone where the cart made the measurements so only the motes in this zone are shown. In the Compare Profiles display all the tests for the given zone are displayed so the differences between individual tests can be observed by selecting a test from the list. Selecting "All Motes" shows all the plenum distributions for the zone (SZ test) or all the zones (MZ test) at once. Under Compare Zones these displays show the average of the individual tests conducted in that zone. In this case for a MZ test, the RAS profile is the average for all the zones, and the plenum distributions show the zone by zone averages. (For the metrics tables, all plenum data is averaged together as if it were all one zone. A summary of plenum metrics definitions and calculations is shown in Figure 55 and definitions of all parameters are shown in Figure 56.

Figure 56.

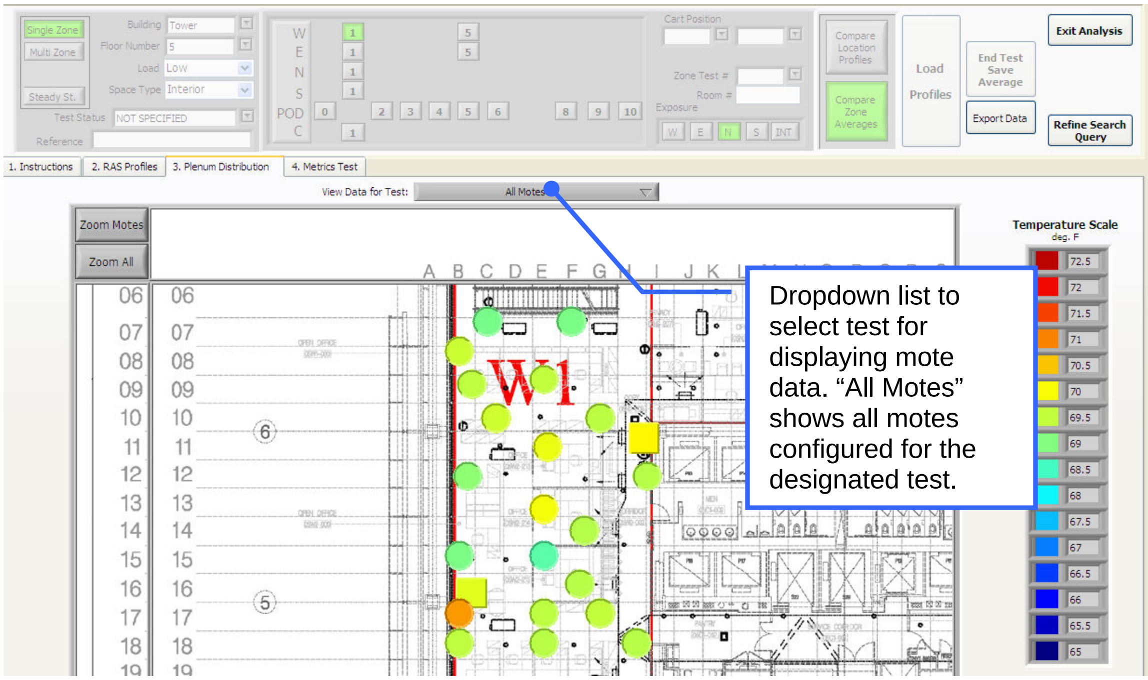


Figure 54: Typical mote display showing mote layout and their temperatures

Figure 55: Plenum test metrics table

Plenum temperature distribution			
Acceptance criteria			
Acceptable minimum, interior/perimeter, °F	59°F		
Acceptable maximum, interior, °F	70°F		
Acceptable maximum differential, int/per, °F	7°F		
Acceptable maximum, perimeter, °F	68		
Acceptable % less than minimum, interior	10%		
Acceptable % greater than maximum, interior	16%		
Acceptable % greater than differential, interior	5%		
Allowable total % outliers, interior (LPP)	10%		
Outliers - allowable above/below average, °F	1.5		
Metrics/Test ID	**Average**	**Test 1**	**Test 2**
Data summary			
Airflow level, cfm/sf			
Load level			
Number of LPP motes			
ASH average (ASH Ref), °F			
Plenum static pressure, iwc			
Interior (LPP) minimum, °F			
Interior (LPP) maximum, °F			
Interior (LPP) average, °F			
Interior (LPP) max diff (from ASH Ref), °F			
Perimeter max diff (from ASH Ref), °F			
Perimeter average, °F			
Perimeter range, °F			
StdDev of LPP motes			
Check Minimums			
Interior (LPP) - max delta below acceptable min, °F			
Interior (LPP) motes below interior minimum, %			
Perimeter - delta below acceptable min, °F			
Interior, Min Pass/Fail			
Perimeter, Min Pass/Fail			
Check Maximums			
Interior (LPP) - max delta above acceptable max, °F			
Interior (LPP) motes above acceptable max, %			

Perimeter - delta above acceptable max, °F			
Interior, Max Pass/Fail			
Perimeter, Max Pass/Fail			
Check differential (Diff) from ASH Reference			
Interior (LPP) - max delta above acceptable Diff, °F			
Interior (LPP) motes above acceptable Diff, %			
Perimeter - delta above acceptable Diff, °F			
Interior, Diff Pass/Fail			
Perimeter, Diff Pass/Fail			
Check outliers			
Allowable above/below average, °F			
Total outliers above/below allowable, %			
Interior, outliers Pass/Fail			
Plenum overall pass/fail			
Plenum overall pass/fail, interior			
Plenum overall pass/fail, perimeter			
Plenum Pass/Fail, overall			

Figure 56: Plenum metrics definitions and calculations

Plenum temperature distribution			
Item		**Definition**	**Comment**
Acceptance criteria			
Acceptable minimum, interior/perimeter, °F	T_min_accept	Minimum acceptable temperature in interior (LPP) or perimeter plenums	Use same criteria for minimums in interior and perimeter plenums. Not likely to be an issue for perimeter plenums.
Acceptable maximum, interior, °F	Tlpp_max_accept	Maximum acceptable temperature anywhere in the LPP	Temperatures that exceed this maximum in too may areas may result in overheating problems. Generally, this is not a problem if these 'hot spots' are not excessive
Acceptable maximum differential, int/per, °F	T_diff_accept	Maximum difference between any LPP or perimeter measurement and the ASH reference	Exceeding this maximum differential indicates that thermal decay is excessive and airflows need to be increased
Acceptable maximum, perimeter, °F	Tper_max_accept	Maximum acceptable temperature in perimeter plenum	Perimeter maximum is important indicator of performance of perimeter system.
Acceptable % less than minimum, interior	%lpp_min_accept	Acceptable percentage of readings in LPP less than minimum acceptable	See calculations below
Acceptable % greater than maximum, interior	%lpp_max_accept	Acceptable percentage of readings in LPP greater than minimum acceptable	See calculations below
Acceptable % greater than differential, interior	%lpp_diff_accept	Acceptable percentage of differentials in LPP greater than acceptable differential	See calculations below
Allowable total % outliers, interior (LPP)	%lpp_out_accept	Acceptable % of total LPP motes that can be outliers	User adjustable entry.
Outliers - allowable above/below average, °F	DTlpp_out_allow	Delta temperature above and below plenum average outside of which a temperature is an outlier	Defines band of acceptability around LPP average
Metrics/Test ID			
Data summary			
Airflow level, cfm/sf		CFMsf_zn = 321.9*LPP_Pr^.497 * N_diff)/A_zn	Estimated airflow based on calculations of diffuser airflow based on pressure divided by the zone area
Load level		High, Medium, Low	as defined by Cx agents
Number of LPP motes	N_lpp_motes	Number of motes deployed in the interior LPP	Comes from zone tables in configuration screen

Plenum temperature distribution			
Item		**Definition**	**Comment**
ASH average (ASH Ref), °F	Tash_avg	average of motes designated as ASH	ASH reference temperature, most likely two readings
Plenum static pressure, iwc		Plenum pressure as measured by the cart	
Interior (LPP) minimum, °F	Tlpp_min	Minimum temperature reading of LPP motes	Find minimum LPP temperature reading
Interior (LPP) maximum, °F	Tlpp_max	Maximum temperature reading of LPP motes	Find maximum LPP temperature reading
Interior (LPP) average, °F	Tlpp_avg	Average of LPP motes	Find average of all LPP readings
Interior (LPP) max diff (from ASH Ref), °F	Tlpp_diff_max	Tlpp_diff_max = Tlpp_max – Tash_avg	Find the maximum differential in LPP
Perimeter max diff (from ASH Ref), °F	Tper_diff_max	Tper_diff_max = Tper_max – Tash_avg	Perimeter differential from ASH average temperature
Perimeter average, °F	Tper_avg	Average of motes designated as perimeter	Find average of motes of type PER.
Perimeter range, °F	DT_min/max_per	DT_min/max_per = Tper_max – Tper_min	Find difference between maximum and minimum readings for perimeter motes
StdDev of LPP motes	SD_lpp		Standard deviation of all mote readings in zone for SZ test or zones for MZ test
Check Minimums			
Interior (LPP) - max delta below acceptable min, °F	Tlpp_min_maxDT	Tlpp_min_maxDT = (Tlpp_min_accept – Tlpp_min	Acceptable minimum minus lowest temperature in LPP
Interior (LPP) motes below interior minimum, %	%lpp_min	%lpp_,min = COUNT[IF(Tlpp_min_accept – Tlpp) > 0)] / N_lpp_motes	Percent of all readings that fall below the acceptable minimum
Perimeter - delta below acceptable min, °F	Tper_min_DT	Tper_min_DT = Tper_avg – T_min_accept	Find how low the perimeter average is below the acceptable minimum. Perimeter average minus acceptable minimum. Use minus sign on value if below zero.
Interior, Min Pass/Fail		Fail = IF(%lpp_min > %lpp_min_accept)	Fails if % below acceptable minimum is greater than % minimum criteria
Perimeter, Min Pass/Fail		Fail = IF(Tper_min_chk < 0)	Fails if perimeter difference below acceptable min is less than zero
Check Maximums			
Interior (LPP) - max delta above acceptable max, °F	Tlpp_max_maxDT	Tlpp_max_maxDT = (Tlpp_max – Tlpp_max_accept)	Highest temperature in LPP minus acceptable maximum. Show plus and minus signs on value

Plenum temperature distribution			
Item		**Definition**	**Comment**
Interior (LPP) motes above acceptable max, %	%lpp_max_DT	%lpp_,max_DT = COUNT[IF(Tlpp –Tlpp_max_accept) > 0)] / N_lpp_motes	Number of LPP motes reading greater than the acceptable maximum divided by total number of motes
Perimeter - delta above acceptable max, °F	Tper_max_DT	Tper_max_DT = Tper_avg – Tper_max_accept	Perimeter average minus acceptable perimeter maximum. Show plus and minus signs on value
Interior, Max Pass/Fail		Fail = IF(%lpp_max > %lpp_max_accept)	Fails if '% above acceptable maximum' is greater than % maximum criteria
Perimeter, Max Pass/Fail		Fail = IF(Tper_Dtmax_chk > 0)	Fails if perimeter 'difference above acceptable max' is greater than zero
Check differential (Diff) from ASH Reference			
Interior (LPP) - max delta above acceptable Diff, °F	Tlpp_diff_max	Tlpp_diff_max = (Tlpp_max – Tash_avg) – T_diff_accept	Amount that maximum differential exceed acceptable maximum differential
Interior (LPP) motes above acceptable Diff, %	%lpp_diff_chk	%lpp_,diff_chk = COUNT[IF(Tlpp – Tash_avg) – T_diff_accept) > 0)] / N_lpp_motes	Number of LPP differentials greater than the 'acceptable maximum differential' divided by total number of LPP motes
Perimeter - delta above acceptable Diff, °F	Tper_diff_chk	Tper_diff_chk = (Tavg_per – Tash_avg) – T_diff_accept	Deviation of perimeter average differential from ASH above acceptable differential
Interior, Diff Pass/Fail		Pass = IF[%lpp_diff_chk < %lpp_diff_accept]	Pass if percentage of Differentials is less than allowable, fails otherwise
Perimeter, Diff Pass/Fail		Pass = IF[Tper_diff_chk<T_diff_accept]	Passes if the perimeter differential is less than acceptable differential
Check LPP outliers			
Allowable above/below average, °F	DTlpp_out_allow		Repeat from above
Total outliers above/below allowable, %	%Lpp_out_DT	%Lpp_out_DT=(COUNTIF (Tlpp > Tlpp_avg +Tlpp_out_allow + Tlpp <Tlpp_avg - DTlpp_out_allow))/Nlpp_motes	Sum all temperatures above and below plenum average by the outlier allowable average
Interior, outliers Pass/Fail		Pass=IF[%Lpp_out_DT<%lpp_out_accept]	Passes if the percentage of outliers is less than allowable, fails otherwise.

Plenum temperature distribution			
Item		**Definition**	**Comment**
Outliers Pass/Fail		Pass = IF[%Lpp_out_DT< %lpp_out_accept]	Passes if the % outliers is less than allowable %, otherwise fails
Plenum overall pass/fail			
Plenum overall pass/fail, interior		• Pass = all criteria pass • Partial Pass = one or more criteria does not pass • Fail = No criteria pass	Check minimum, maximum, differential, and outliers
Plenum overall pass/fail, perimeter		• Pass = all criteria pass • Partial = one or more criteria does not pass • Fail = all criteria fail	Check minimum, maximum, differential
Plenum Pass/Fail, overall		• Pass = both interior and perimeter pass • PP = if only one passes • Fail = both fail	

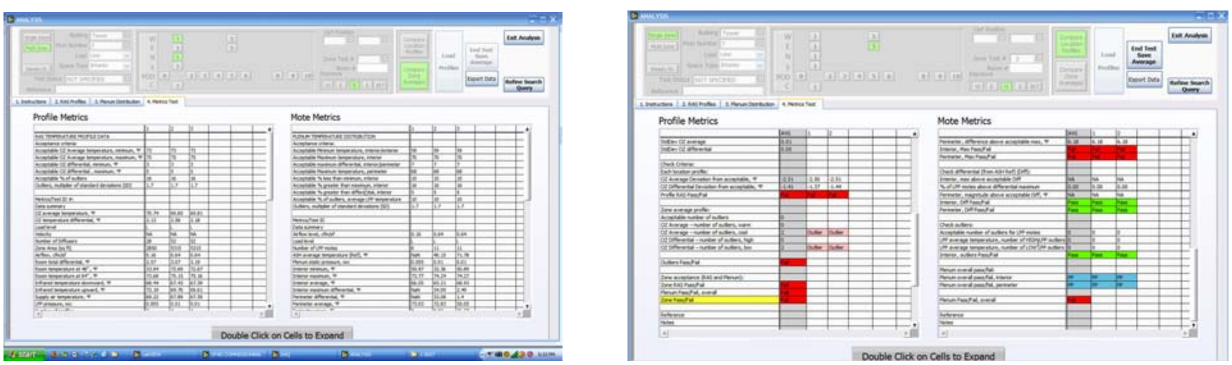


Figure 57: Metrics table displays

6.8 ANALYSIS OF RESULTS

6.8.1 SUMMARY OF RAS PROFILE AND PLENUM DISTRIBUTION RESULTS

6.8.2 SZ

Mote temperatures used in the metrics tables are averaged together to provide a representative distribution based on all the tests conducted in a zone. Figure 58 shows a diagram of how the average distribution is determined:

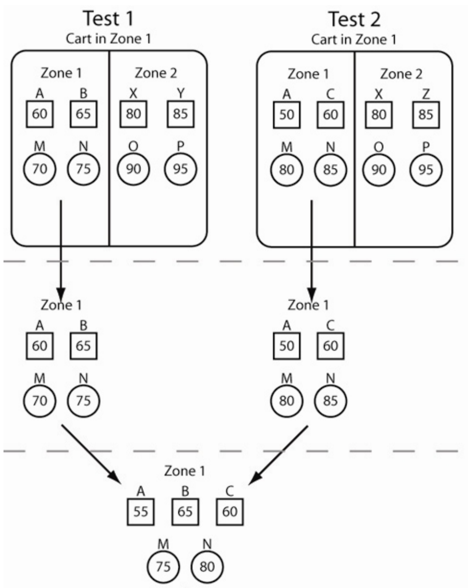


Figure 58: SZ mote calculation procedures (shapes indicate mote types, letters indicate mote grid locations)

RAS and plenum distribution metrics for each location test as well as the averaged results are stored in the database when the *Complete Test/Save Averages* button is pressed.

6.8.3 MZ

Multizone tests are conducted by performing tests in each zone of a MZ configuration but the test is not completed until all the zone location profiles have been collected. In this case the mote temperatures are all averaged together as shown in Figure 59 below; i.e., once a test is completed and saved in the DB, it only saves an average (by mote type) of ALL the zones and therefore looses the more detailed zone by zone data that went into making it up.

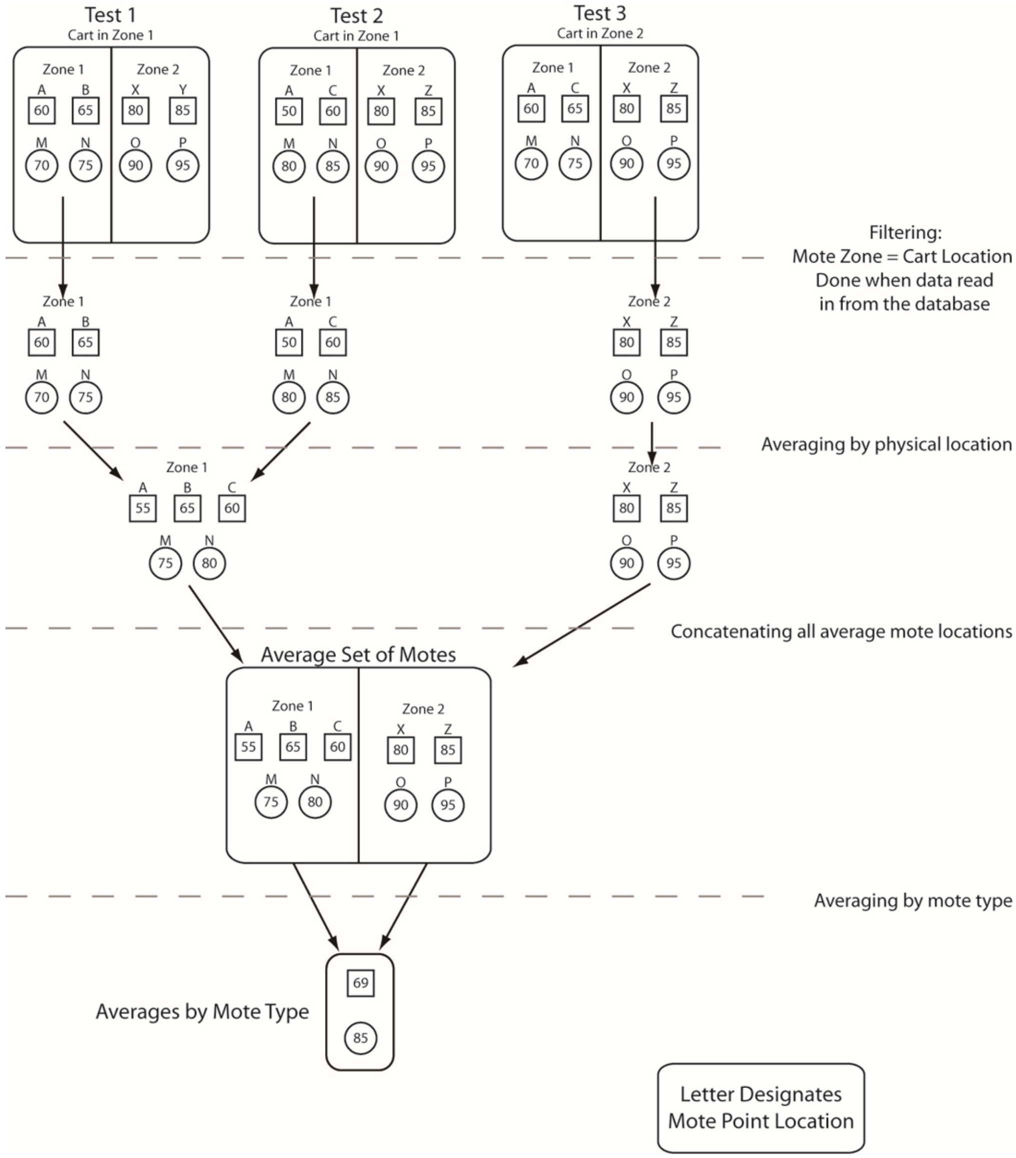


Figure 59: MZ test mote calculation procedure

6.8.4 MSZ RESULTS

The diagrams below illustrate how the results for multi-single zone(MSZ) tests are displayed. This type of test is very similar to a MZ test except it results in more detailed zone by zone information and acceptance metrics that are retrievable with the same degree of detail as a SZ test.[3] Similar to MZ tests, MSZ tests are conducted by collecting data from a number of locations in a zone. However, as part of the setup for these tests a Usercode is entered into the Reference field in the DAQ operations panel as shown in Figure 60. This usercode is intended to identify different test conditions representative of "before" and "after" tests so that all zones for a MZ configuration can be grouped under one usercode for a given test condition. Tests are then conducted in multiple locations in each zone and then completed by pressing the *Complete Test/Save Averages* button in analysis after that zones profiles are loaded. This creates an

[3] Recall that for a MZ test, once a test is completed (i.e., data is collected in multiple locations in all zones) and saved in the DB, it only saves an average of ALL the zones and therefore looses the more detailed zone by zone data that went into making it up.

averaged condition for the multiple locations just like in a SZ test that is saved in the database with all metrics specific to that zone.

This process results in detailed profiles, mote displays and metrics data for each zone that can be retrieved by searching the database using the appropriate Reference field Usercode as described in Section 6.8.5 below. Now when "before" and "after" tests are compared, the comparison can be made on a zone by zone basis and the differences noted. This comparison process is achieved by clicking on and off various tests listed in the legend under the RAS Profile tab. For RAS profiles the average profile can be switched off since it is not relevant to the comparison.

Note (as shown in Figure 61) that the motes displays do not show accurate results when both the "before" and "after" profiles are shown together since each zone will then show the average of these two tests. The metrics tables, however, show the zone by zone results and are the best way to compare results between zones. By showing one test condition at a time (again by clicking off and on the relevant tests) the mote displays show the zone results accurately.

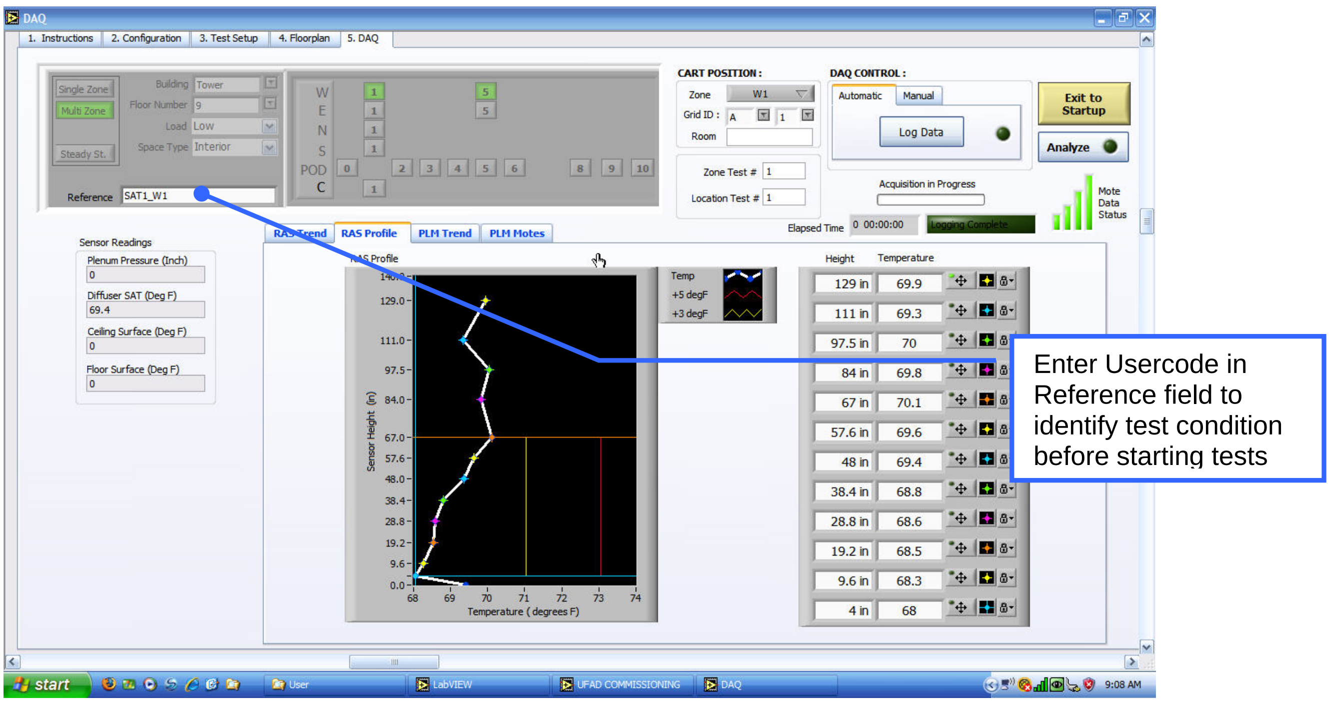


Figure 60: MSZ test setup showing Usercode in Reference field

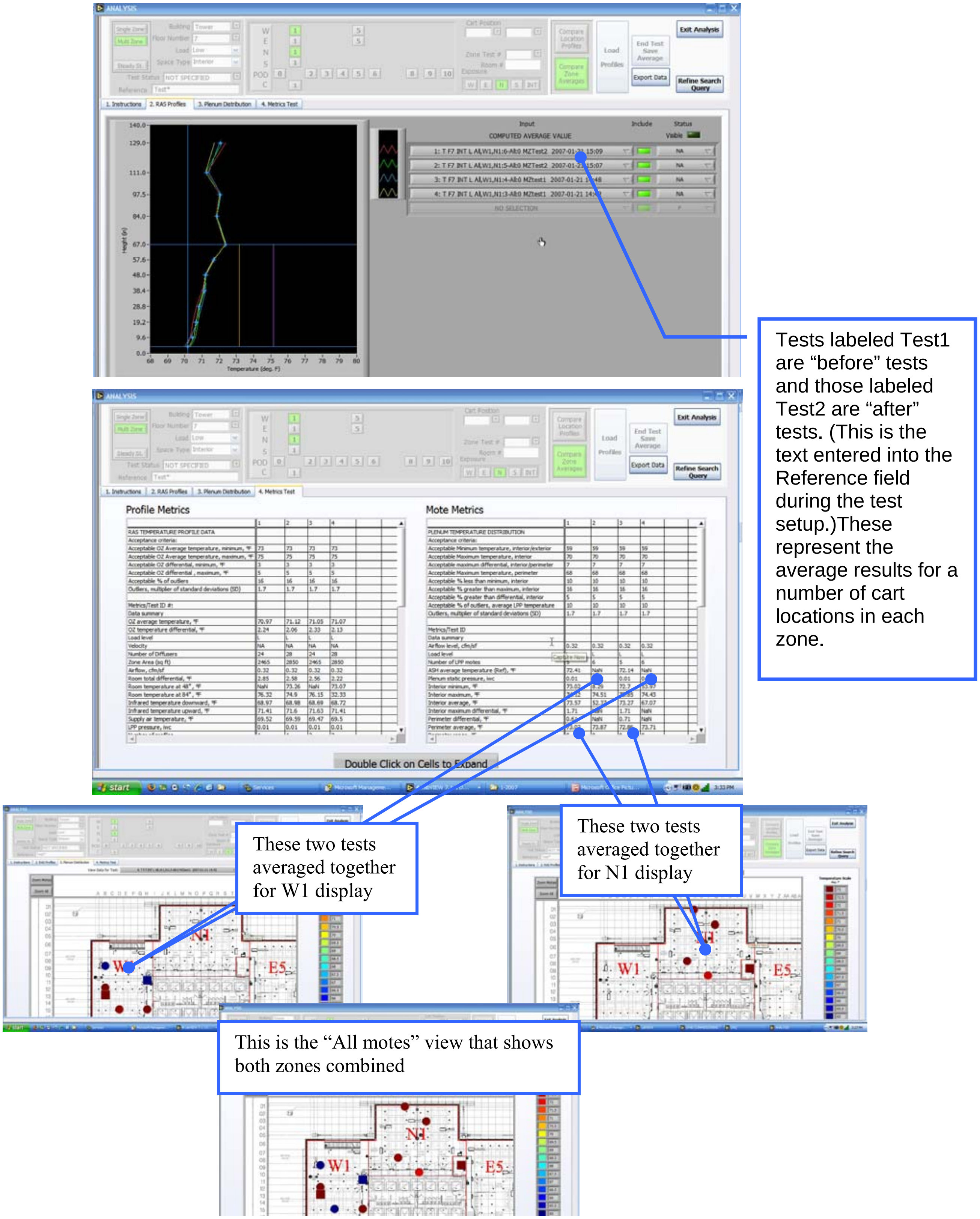


Figure 61: Illustration of MSZ results

An overview of how the mote temperatures are calculated is shown in Figure 62

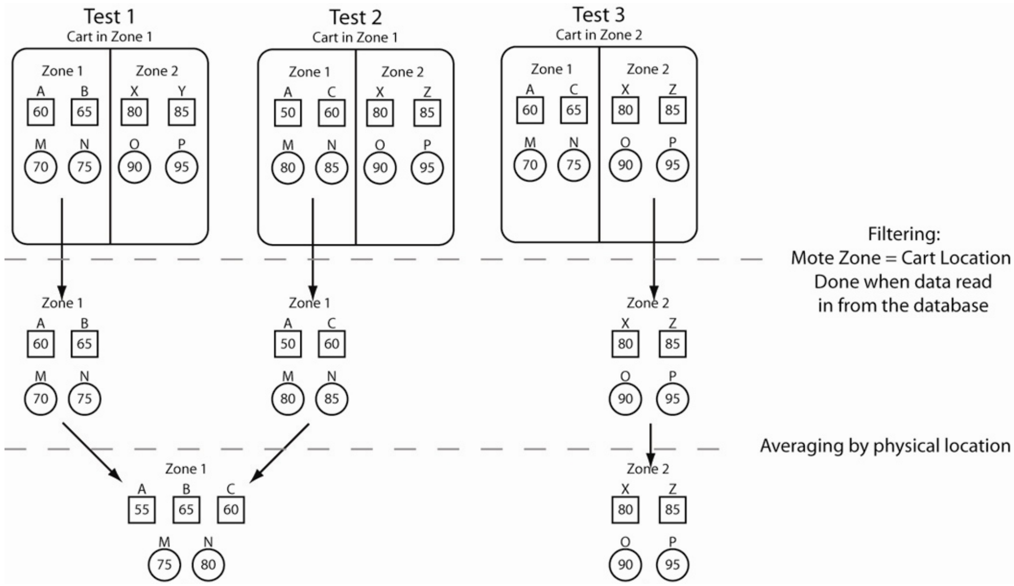


Figure 62: MSZ mote calculation procedures

6.8.5 ADVANCED SEARCHES

The header section of the Analysis screen forms a powerful search mechanism which allows just about any combination of location RAS profiles (and associated plenum profiles) to be retrieved from the DB and displayed side by side in the chart area along with the test ID string. This may be useful for more extensive analyses and comparisons by appropriately skilled individuals but is not intended for normal day to day use during testing. Results from these queries can yield a large number of responses that may overwhelm the capability of these tools. We recommended that more sophisticated database analysis tools be developed to support these types of analyses.

6.8.5.1 Search parameter summary

Figure 65 shows all parameters stored in the database and can thus be used for queries. However, the table also shows those parameters that are readily available to the user via the fields in the Analysis user search panel (Figure 63) and similar user operations panel in the DAQ program (Figure 64) Searches must use the valid parameters established for each of the parameters as shown in the description column in table…Drop downs on the search panel restrict the entries of many of these parameters to assist the user in keeping entries consistent and searches more narrowly focused. See below for search rules.

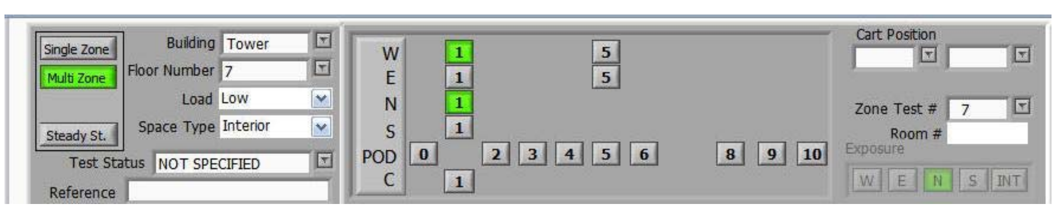


Figure 63: Analysis user search panel

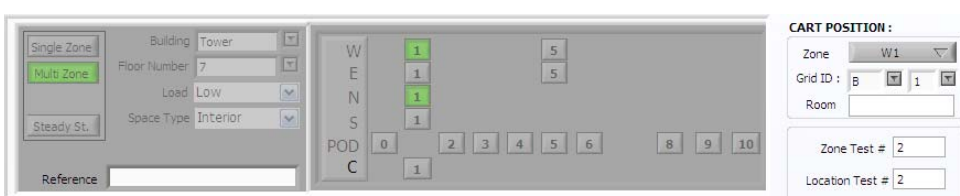


Figure 64: DAQ user operations panel

Figure 65: Database parameter summary

User panel field name	Database name	User Panel?	Description	Comment
Test type	Test type	Yes	One of "SS", "SZ", "MZ", or "PLM".	
Timestamp	Timestamp		yyyy-MM-dd hh:mm	
Building	Building	Yes	One of "T" or "P".	
Floor	Floor	Yes	A signed integer.	
Room	Room	Yes	Text up to 8 characters.	Searchable as multiple strings using commas as separators
Exposure	Exposure		One of "N", "E", "S", "W", or "I".	Not available for search, for reference only
Zone name	Zone name	Yes	One character followed by unsigned integer.	e.g., W5
NA	Zone group		Comma separated zone name(s).	
Space type	Zone type	Yes	One of "PER", "INT", or "NA".	
Cart position (Grid ID)	Point name	Yes	One of "All" or up to two characters followed by unsigned integer.	e.g., AB23
Location test #	Point retest ID	Yes	An unsigned integer.	
Zone test #	Zone retest ID	Yes	An unsigned integer.	
Load	Load condition	Yes	One of "H", "M", "L", or "N".	N= None, no load
Reference	Reference number	Yes	A text string.	Used for MSZ test filtering; see search rules below.
NA	Data type		One of "DAQ", "RASProf", or "ZnAvg".	
Test status	Pass/fail indicator		One of "P", "F", "PP", "F-A", "PP-A", "NA", or "Disabled".	
Note (Startup splash)	Description	Yes	A text string	Only accessible on a test by test (i.e., location test) basis. Completed tests show note of tests included in the averages. This is not a searchable parameter

6.8.5.2 Reference field codes and search rules

Usercodes

User codes can be any string of letters and numbers and (some) symbols. Due to the way the test ID works for Zone Average profiles, it is useful to include in the usercode the zone ID for the MSZ test. The first part of the code can be a cryptic identifier of the type of study that is being conducted for which comparisons are to be made later. For example, if the SAT is to be varied between sets of tests to determine an optimum value then the tests could be identified by usercodes such as SAT1, SAT2 etc. or SAT63, SAT65. Adding the zone ID the entire usercode could be SAT63_W1. Since these codes are entered into the DAQ Reference field by the user you should be careful to make the syntax exact and consistent for the set of tests being conducted. However, the user must remember to change the zone number when entering a new zone.

Do not, however, conduct searches with the operators (i.e., entering Analysis from Startup instead of via DAQ) and then complete a test using *Complete Test Save Averages* button. This results in the test ID string incorporating the search parameters instead of the intended Reference Usercode.

Search rules

1. All fields left blank or contain an * only will not be included in a search and therefore default to be inclusive of anything entered into those fields; i.e., it will not be part of the filtering.
2. The reference field can be used for narrowing a search to specific sets of tests. User codes should be constructed of English language types of words at least 4 characters long with spaces in between. Be careful about using special characters. "Full text" searches are used to retrieve information (along with the configuration data in the upper search panel). With this search technique (similar to how Google works) words of the user code are considered to be 'OR'd' together meaning that all instances of any word will be returned. This basic rule can be modified using the following search operators:
   - No operator (e.g. apple banana) – at least one term included in result; ranks higher if more than one term included in result.
   - '–' (minus sign) >> excludes words from search [e.g. +apple –mac); mac term not be included in result]
   - ' " " ' (double quote marks) >> exact search for all words included [e.g. "apple turnover"); finds exact phrase]
   - '*' (asterisk) >> wildcard [e.g., apple*); will return "apples", "applesauce" etc.]
   - Caveats: If the specified search criteria is a common English word (e.g. "the", "a"), or it appears in more than half of all the entries, then no results will be returned.
3. Retest numbers can be used instead of or in conjunction with the Reference field to filter tests. The Test # field is a full text search field so you can enter various combinations of test numbers; e.g., 25, 27 or 25-27 etc. The (re)test numbers can be found in the test ID string by looking at the entire set of tests for a floor and then noting the ones of interest to narrow a search.
4. The following screen shots show how these operators can be used. The most useful forms are *, -, +. In addition, this field contains default delimiter codes (~Ref Start~ and ~Ref End~) when no test is entered that can be useful as part of a filter if tests with and without usercodes are to be examined. For example, to separate MSZ restests; if retests are numbered say SAT1, SAT2, SAT3, then entering SAT* will retrieve all of them. But if only certain ones are desired then use SAT1 SAT3 or (+SAT1 +SAT3) or (SAT* -SAT2) to filter the set and retrieve only those tests of interest.

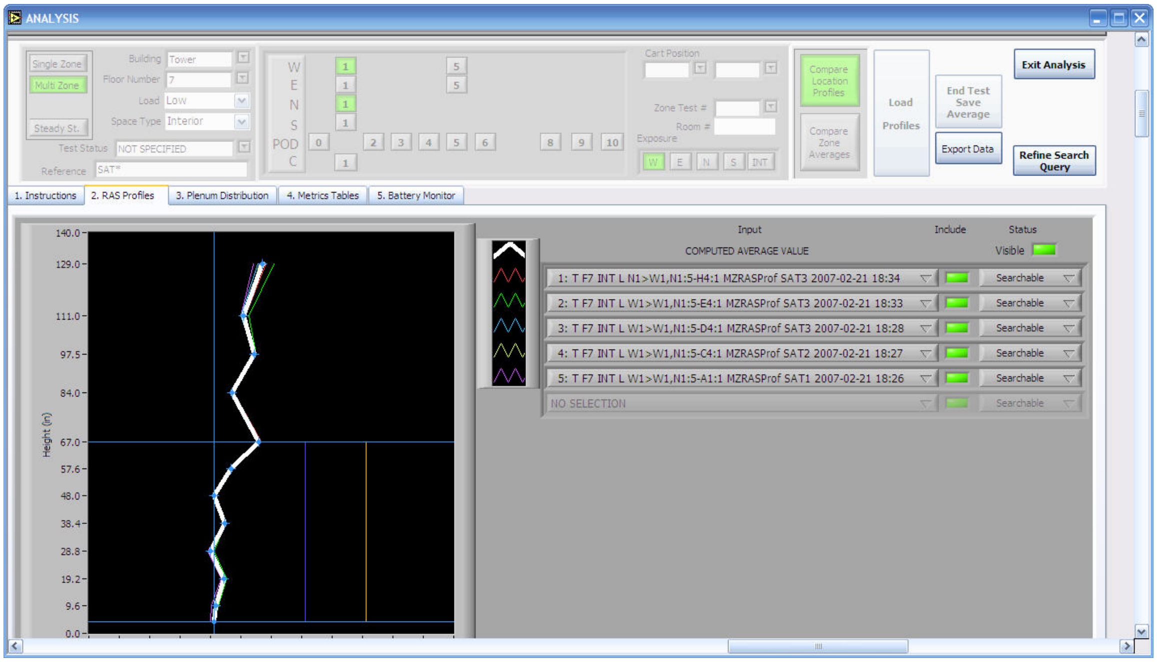


Figure 66: Search for all usercodes starting with "SAT" (uses * wildcard)

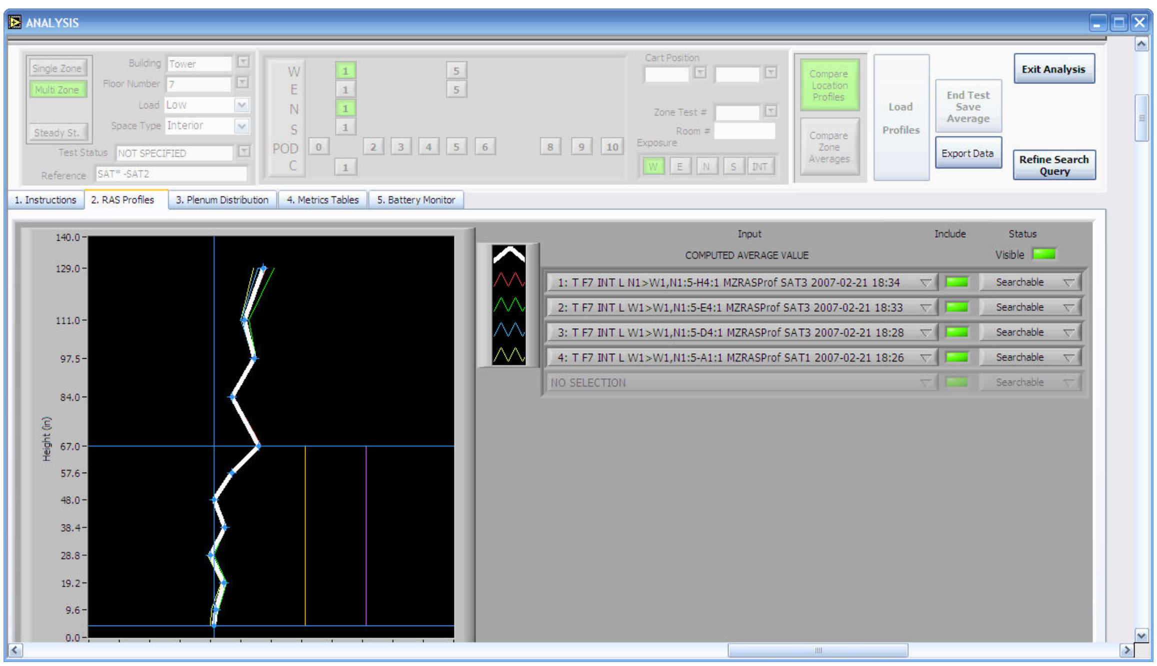


Figure 67: Search using minus (-) operator to filter certain tests

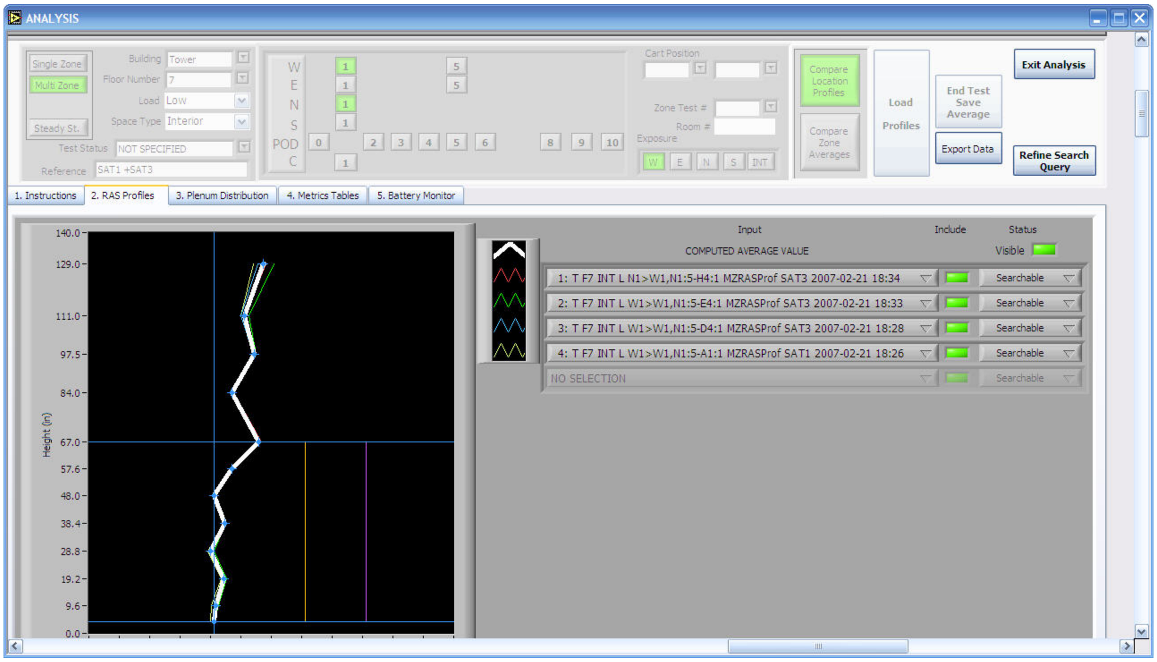


Figure 68: Search with usercode operators

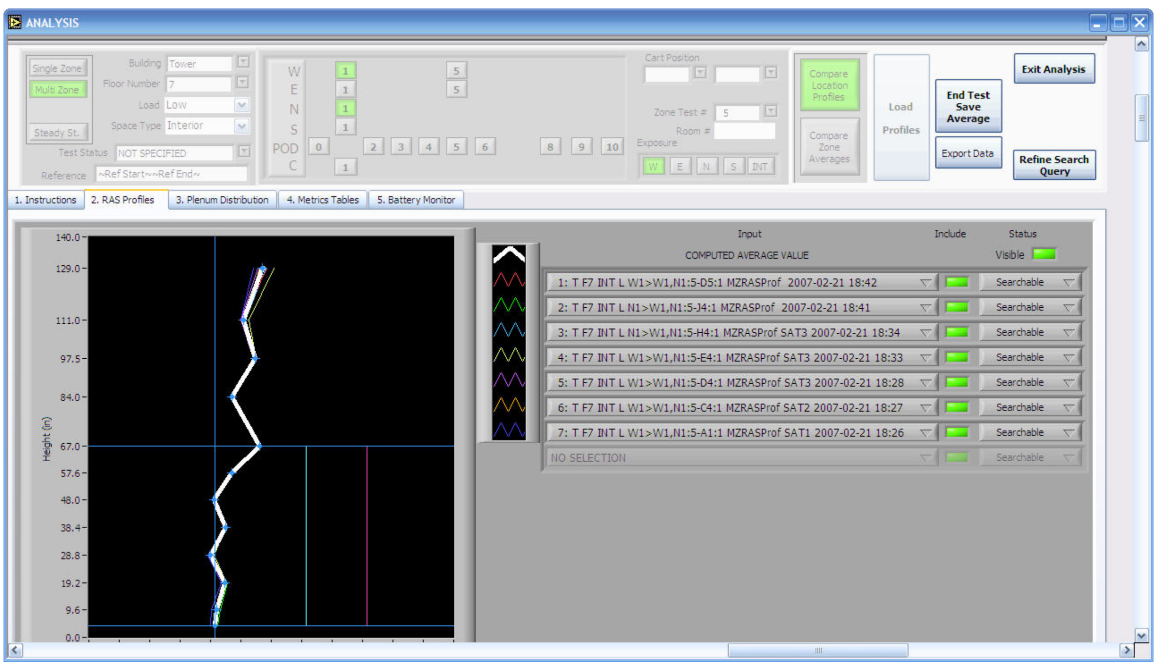


Figure 69: Searches using default delimiter codes (returns all tests, just as a blank field does)

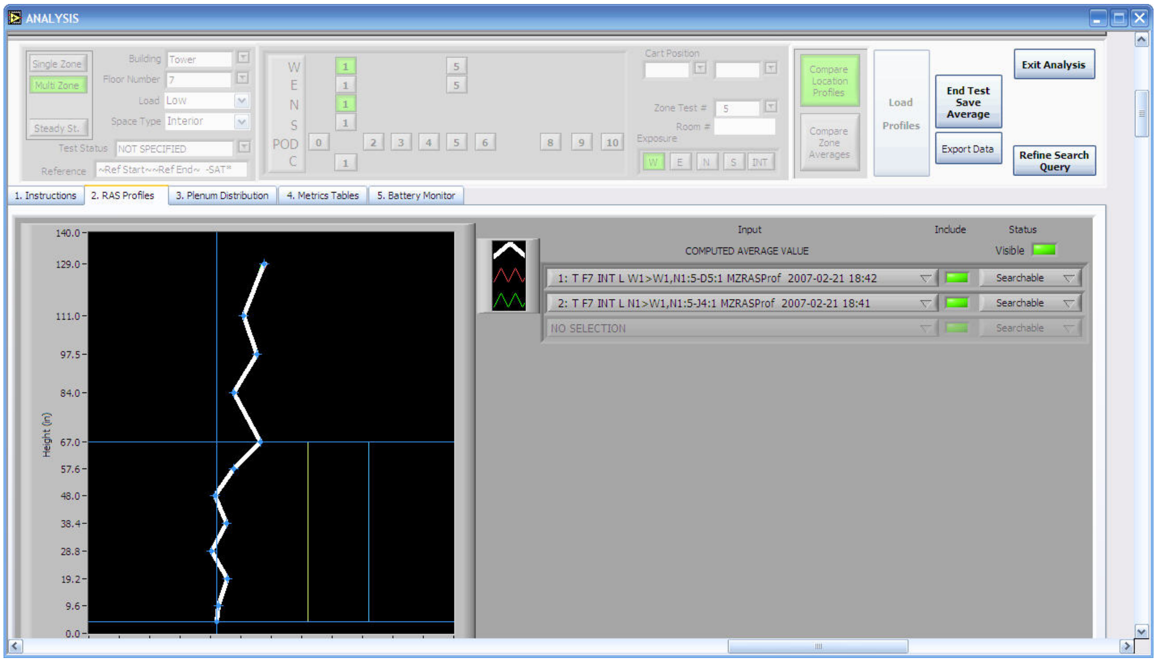


Figure 70: Search using default delimiter codes and usercode operators to return only non-usercode tests

7 MOTE LAYOUT UTILITY (MLU)

The MLU is designed to allow a drawing of a floor plan with a location grid line structure to be imported into LabView where it can be overlaid with objects located within the reference grid structure that represent mote temperature. All functions of the MLU are accessed through the Cx Program Control screen shown in Figure 71

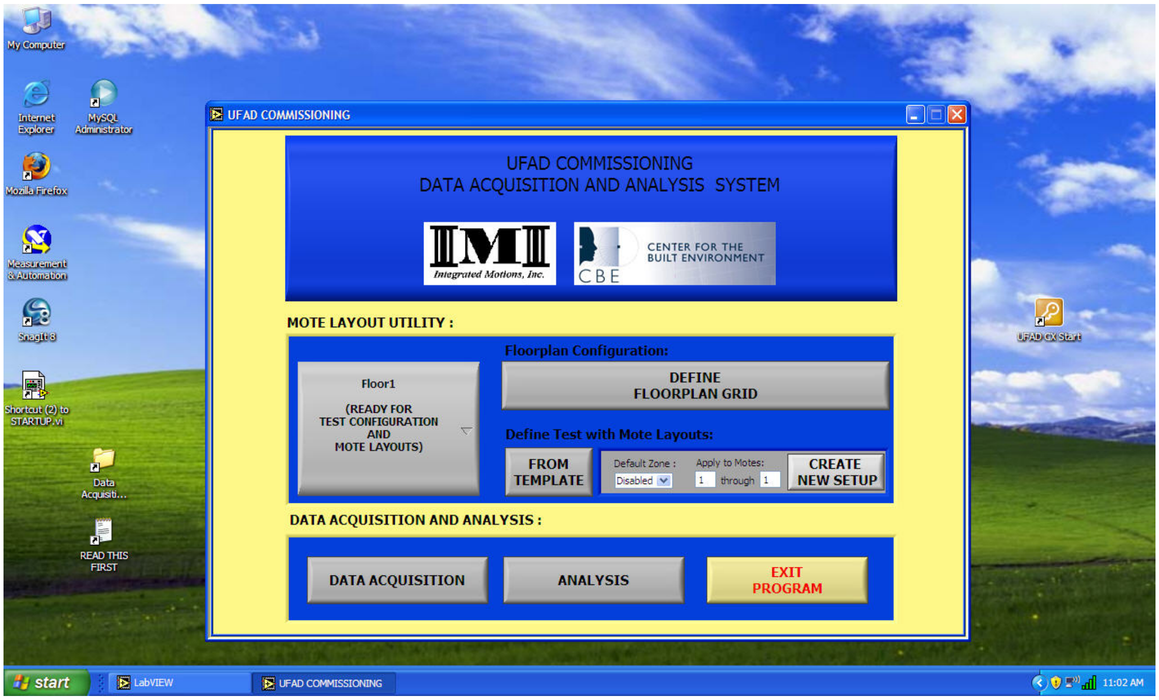


Figure 71: Cx Program control/startup screen

7.1 FLOOR SETUP

7.1.1 File Conversion

LabView requires floor drawings to be in .png format. These files can be created with the correct resolution by converting .pdf files in PhotoShop as follows:

1. Use .pdf floor plans that cover the entire floor grid.
2. Open .pdf file in Adobe Acrobat
3. Save file in .png format
4. Open .png file in Photoshop
5. Go to Image menu and click on Image size. In the dialog box set width and height to 3000 and 2267 (or as whatever it results to when width is 3000) respectively. Leave Interlace off.
6. Save to filename that can be identified as LabView ready .png file.
7. Open the file in the MLU.
8. Note that the grid array limits are contained in a System file named Floor Plans.txt. These can be changed in the corresponding Excel file and then saved to .txt format to overwrite the default file.

7.1.2 NAVIGATION

To navigate in any drawing display follow the steps listed below.

Zooming

1. Hold down CTRL key + mouse left button. Moving the mouse up and releasing will zoom in, and moving the mouse down and releasing will zoom out.
2. Hold down the <SPACE BAR> + mouse left button, then drag the mouse to another point which will define a bounding box. When the mouse button is released, the view will zoom to the area.

Panning

1. Click and hold on a point and drag mouse and then release button - this will pan the image.

7.1.3 DEFINE PARAMETERS

To define the grid structure first click on the *Establish Floor Grid* button as shown in Figure 71. This takes you to the screen shown in Figure 72. At the top of the MLU tool screen there are a series of *Define Parameter* buttons. When Quick Setup *Enable* button is pressed, the parameters to be defined sequence automatically to the next once one is finished; otherwise each of these parameters can be set manually. The parameters scale the grid structure so that the mote objects can be placed accurately.

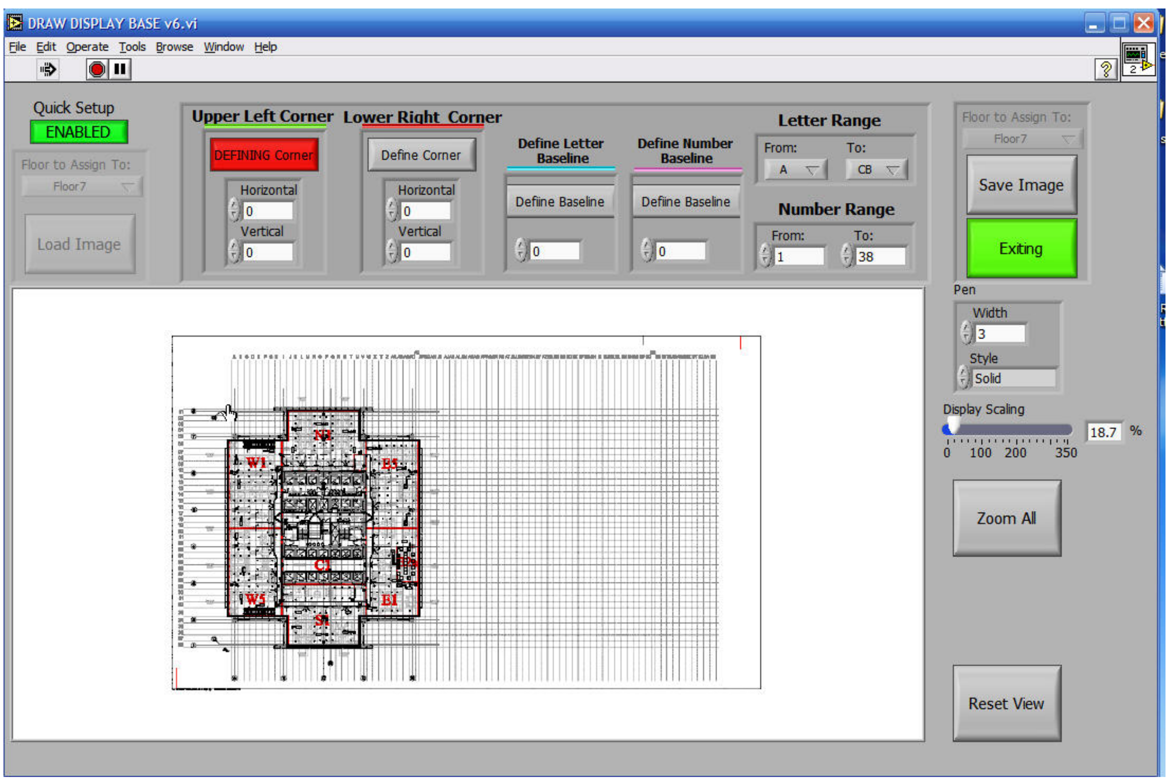


Figure 72: Mote Layout Utility showing steps to define the grid structure

To place each parameter on the drawing, press the Shift key click the left mouse button once the cursor is in the correct location (e.g., top corner of grid).

When all parameters are defined click the *Save Image* button. This creates two file types that save the scaling data; *.FCF and *.FLP.

7.1.4 TEST SETUP

From the LabView Cx Program Control screen first select a floor by pressing the *Select Floor* button. To layout motes on the floor grid drawing first load the .msf file previously created for the floor of interest by pressing either the *New Layout* or the Make *from Template* button. This brings up the mote layout utility screen shown in Figure 73.

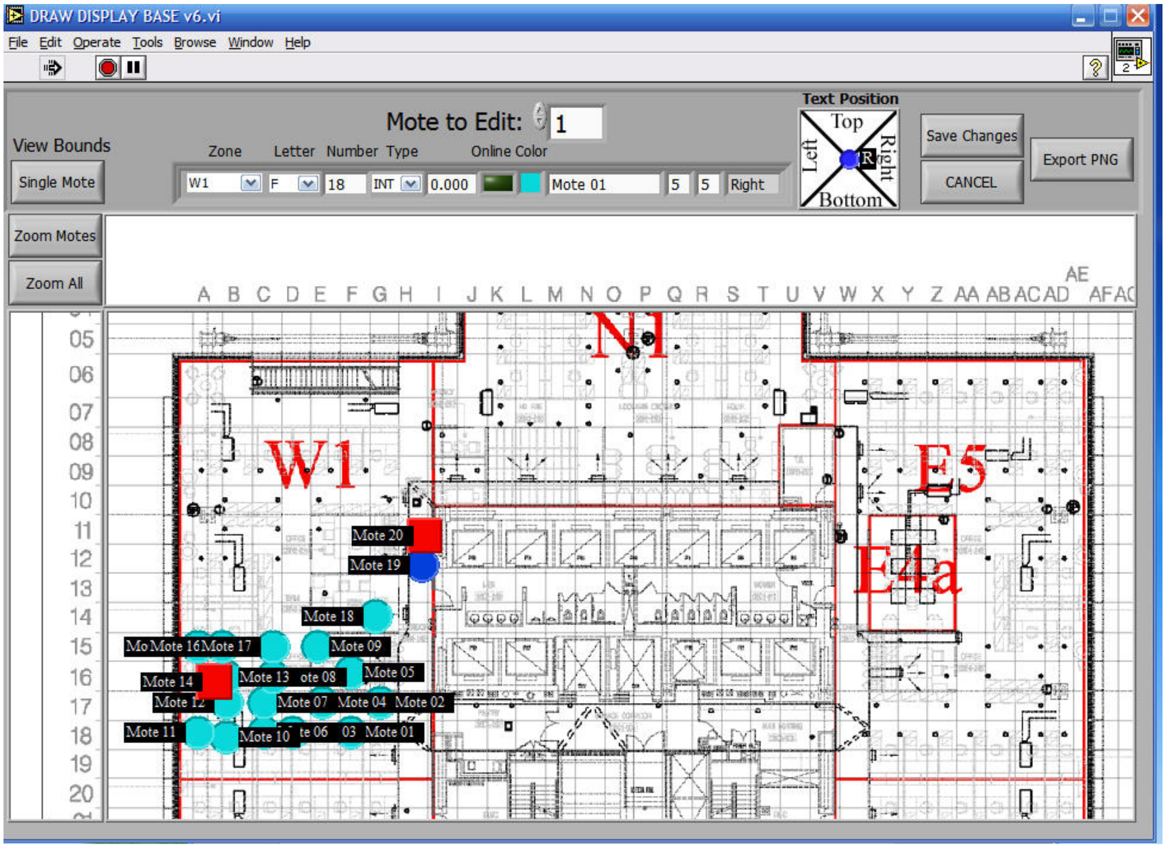


Figure 73: Mote layout screen

Navigation

The same zooming and panning methods are used for navigating in these screens as described in Section 7.1.2.

7.1.4.2 Text

You can add text to each object using the following rules.

Rotating

1. Shift +Alt keys +Left mouse button rotates a mote to the text position.
2. You can also position text for the selected mote by clicking the text position icon in the upper right.

Hiding and revealing

Pressing the Alt key + Left mouse button with the cursor on a mote allows you to toggle the text display on and off.

7.1.4.3 Mote Selection and placement

Selecting a mote

1. Double click a mote and that mote will become the active mote for editing.
2. Shift + Double click on a mote; this will make the selected mote active AND then zoom into full frame.

Placing motes

1. Major Grid: Shift +Alt + Control + left mouse click the center of the grid where you want to place the mote object. The corresponding grid letter and number will be filled in on the grid edit bar drop downs.
2. Subgrid: Shift + left mouse button click shifts the active (the mote selected in the line number) mote within the subgrid for its grid letter and number. It will snap to the nearest available grid reference. If you do not click within the constraints of the stated grid letter and number, the mote will not be redefined.

   Note: The subgrid is a 10ft x 10ft grid the overlays a nominal 5ft x 5ft grid cell thus overlapping the adjoining cells by of ¼ to ½ of a cell . Coordinates 5-5 are the center of the grid cell; 0,0 is upper left corner. The subgrid adjustments allow you to visually place the mote outside of the grid square designated (this provides added flexibility should the user have a floor plan where there are some grid squares that are wider than others). However, when close to non-standard cells (e.g., AE) it may not be possible to place the mote exactly on the diffuser desired. The mote location specification, however, will be accurate and can be used to reference the location of the mote.

7.1.4.4 Save changes/test setup

Clicking on the *Save Changes* button allows you to save your mote setup work and automatically create a file name along with the test setup parameters using the test setup panel shown in Figure 74 with the following format and the file extension .msf (Test Setup file):

<Bldg>_<Floor>_<Zone(s)>_<user text>

where,

<Bldg> = Tower or Podium

<Floor> = Floor number

<Test type> = Type of test to be conducted: SZ, MZ, SS

<Load> = Load level: L, M, H, None

<Zone(s)> = Zone designation (e.g., W1 or P9) for SZ tests and zones (e.g., W1 W5 E5) for MZ tests

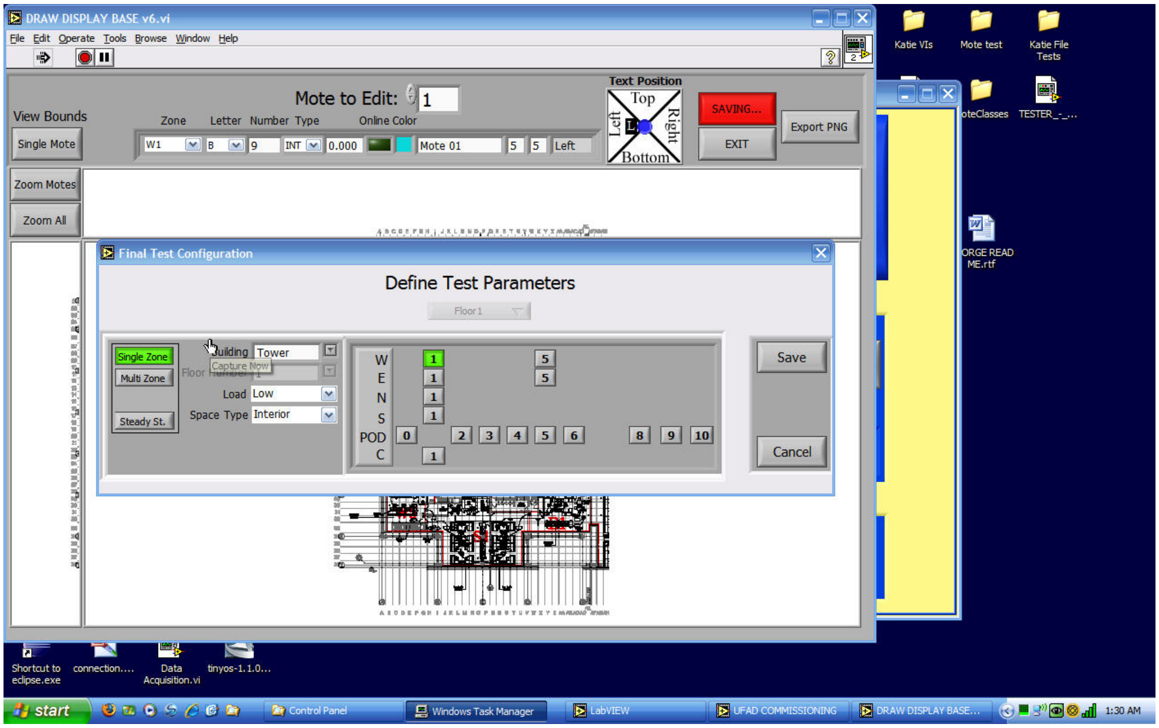


Figure 74: MLU test setup splash

After the file *Save* button is pressed the automatically generated file name is shown. This name can be annotated by appending test after the file name shown after entering a space.

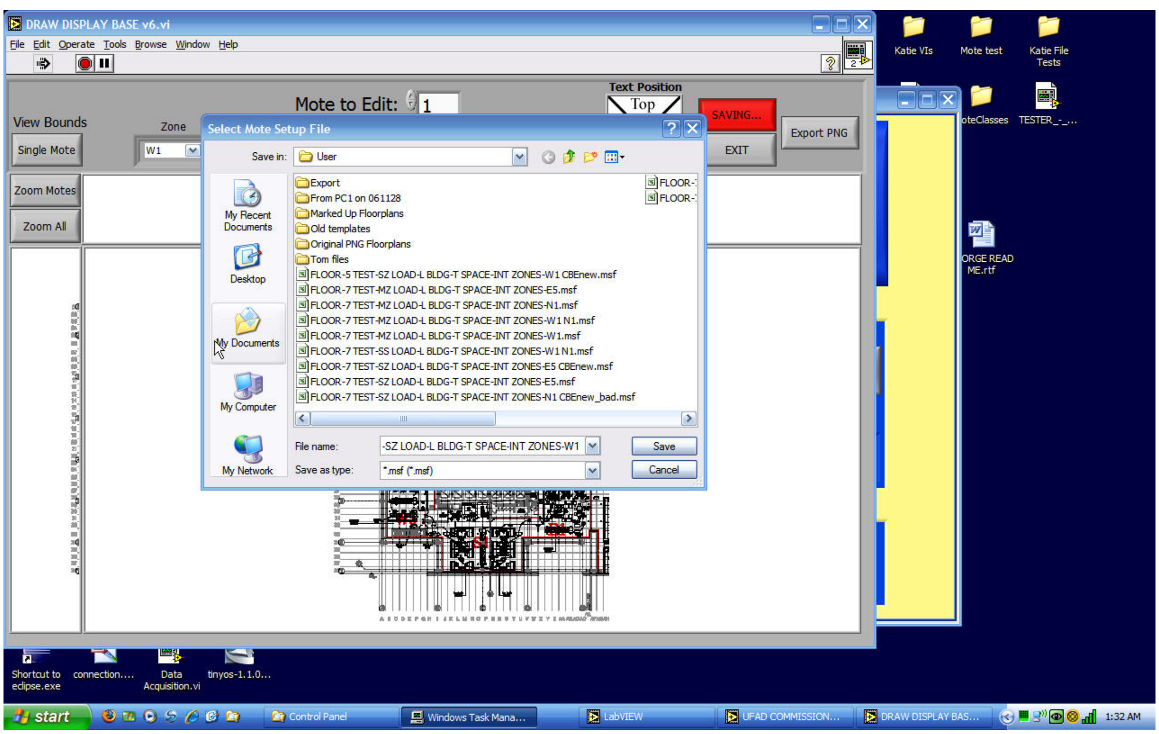


Figure 75: MLU file saving

These parts of the filename are parsed when a file is loaded in the Test Setup screen and helps define a test. For example, a SZ vs MZ test is determined by the number of zones included in the mote setup; the MLU automatically includes the zones that motes are placed in during mote placement. All of these pre-selected parameters are not changeable in the DAQ screen and appear grayed out.

When the file is saved press the *Exit* button to quit the MLU.

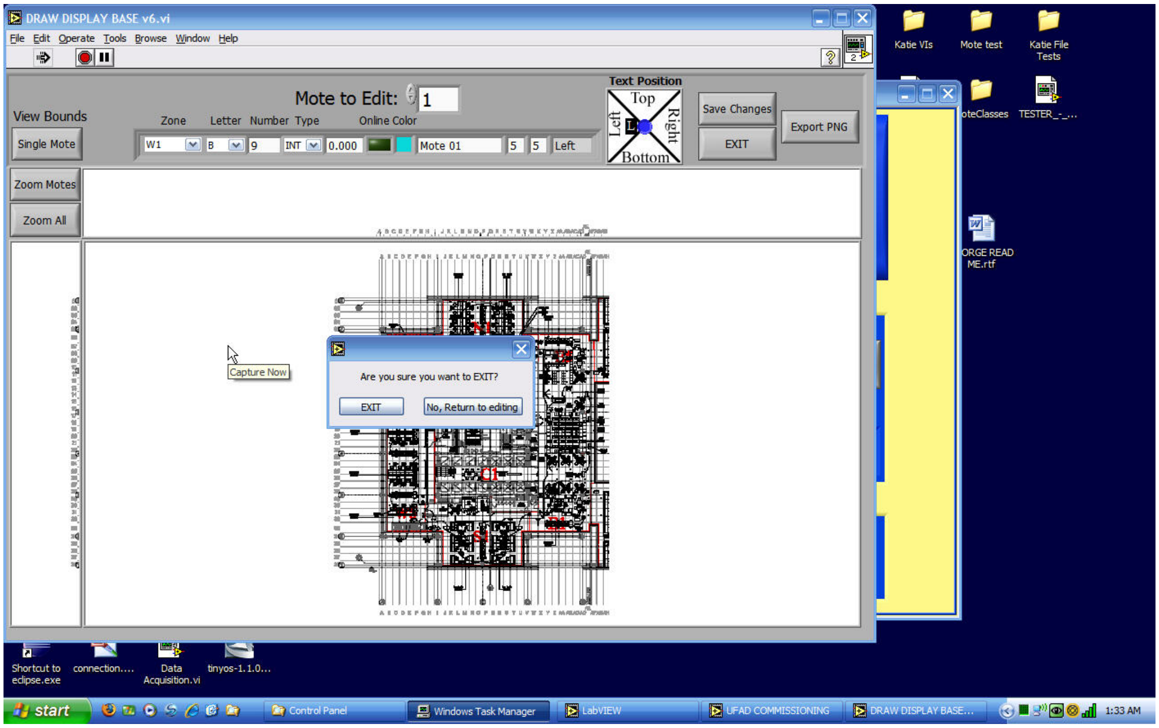


Figure 76: MLU exit

7.1.4.5 Export files

When you press the *Export PNG* button a .png file is created that shows the mote layout superimposed on the underlying building drawing.

7.1.5 VIEWING MODE

Viewing mode occurs in the Data Acquisition and Analysis programs. Navigation within these displays can be done using the following methods.

Zooming & panning

Use the same methods as described in Section 7.1.2.

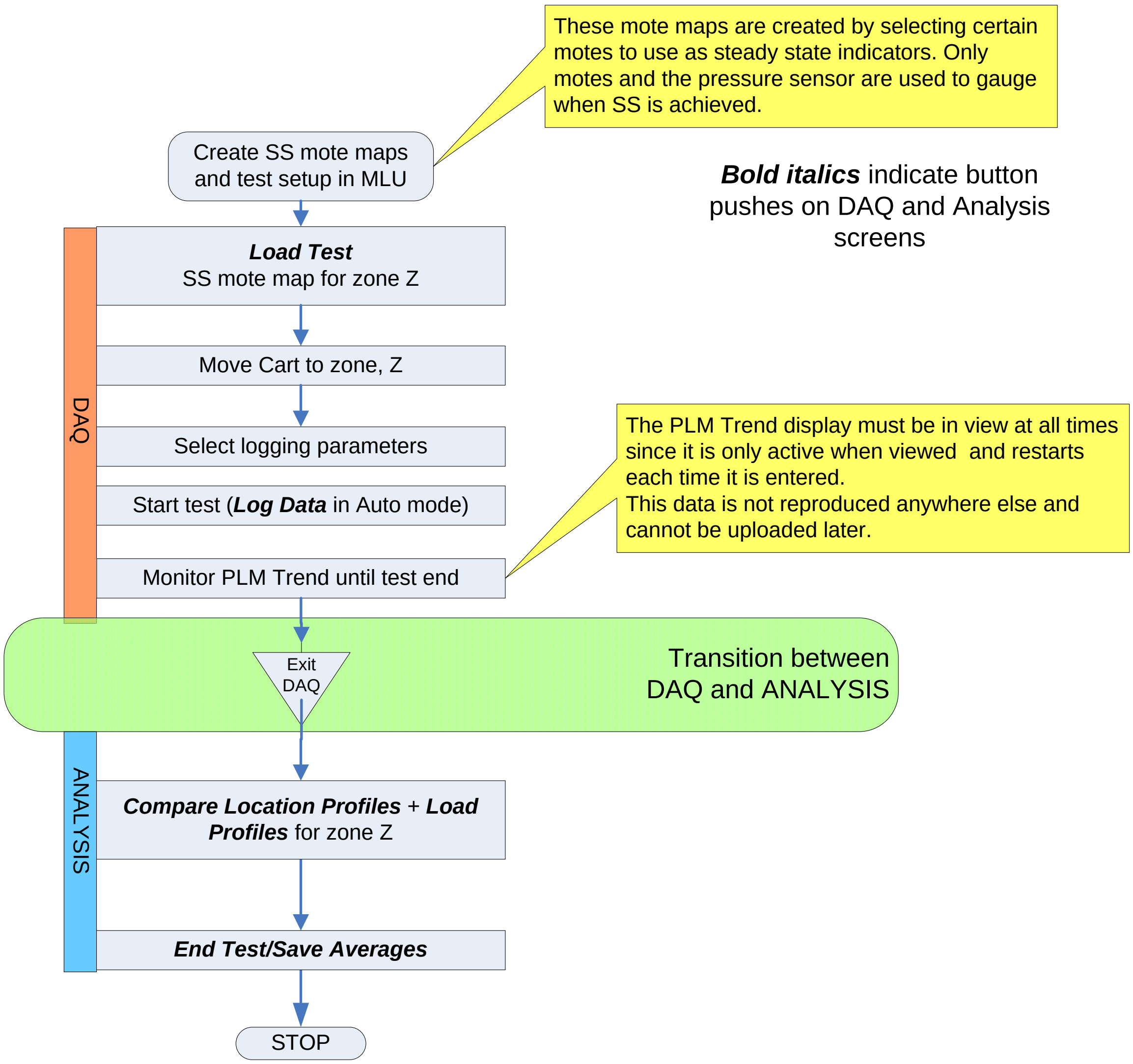
Text Reveal

Hold down the Alt key and then place the cursor on the mote and left click the mouse. Descriptive Text will appear for that mote. Click again and it will be hidden. If you are viewing in DAQ, the text will remain visible until the mouse button is released, when on the next temperature update the text will be hidden again.

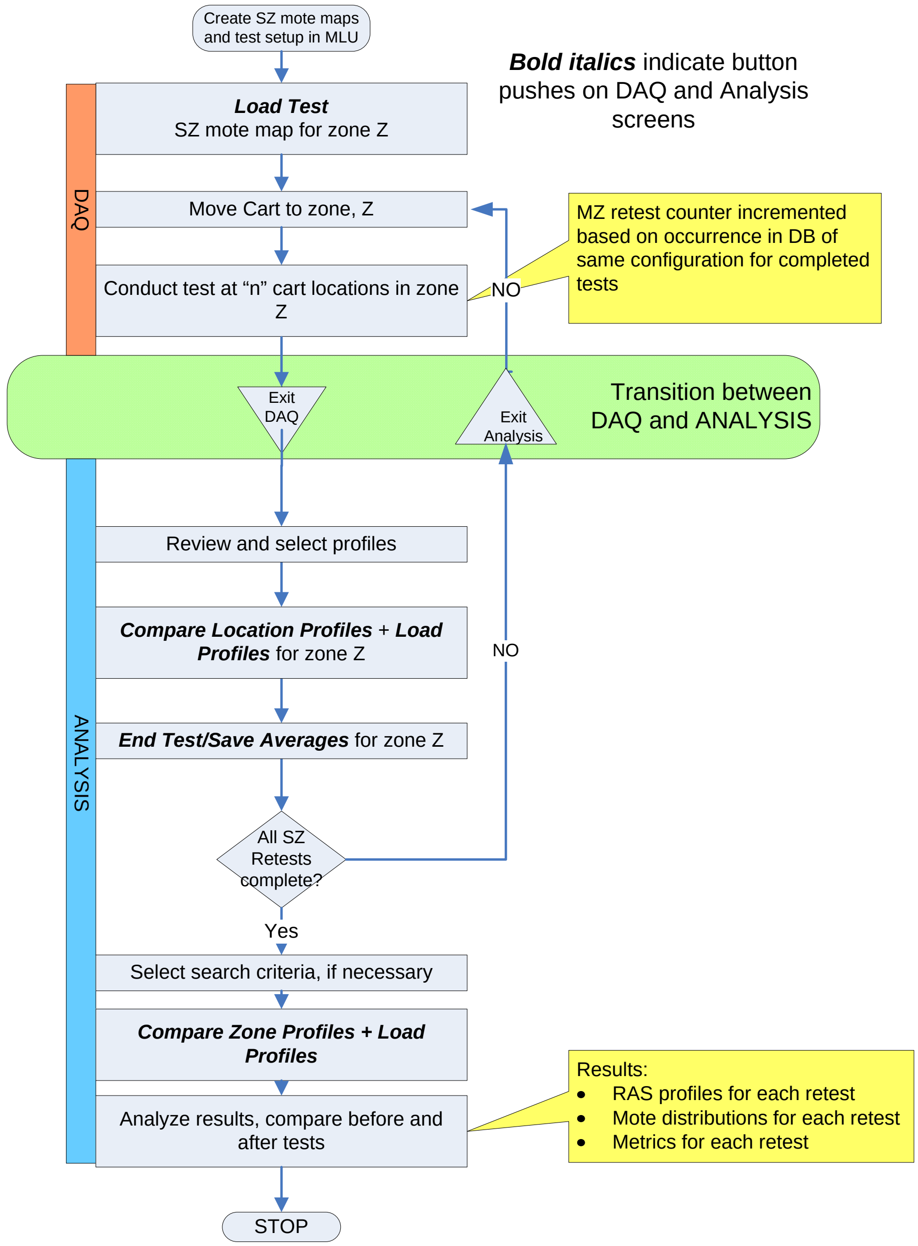
8 WORKFLOW PROCEDURES

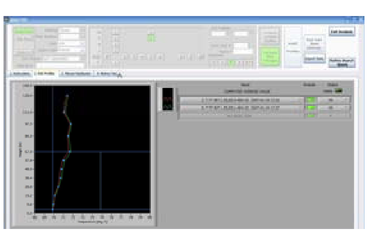
The following flow diagrams show the major steps necessary to conduct a test of the test types shown. Also indicated is as summary of the type of results to be expected.

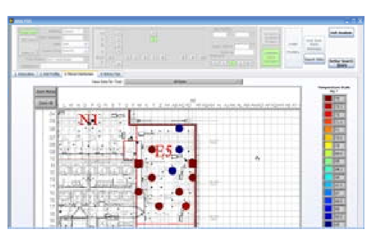
8.1 STEADY STATE (SS)



8.2 SINGLE ZONE (SZ)

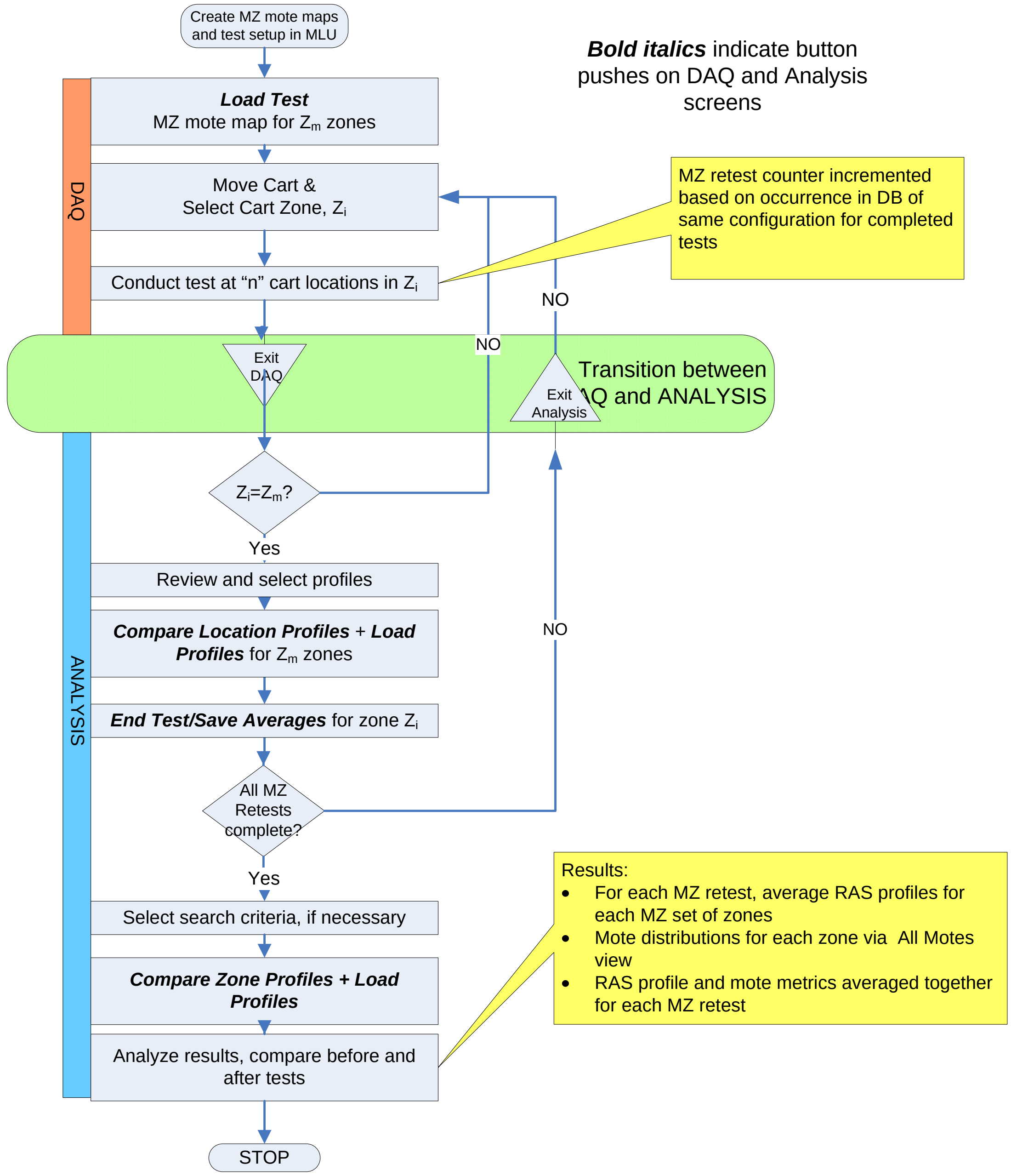


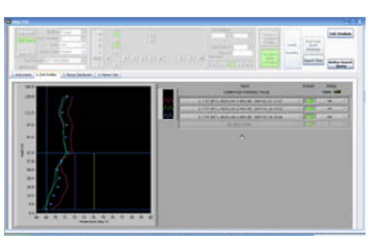

RAS Profiles


Plenum distribution


RAS and plenum metrics

8.3 MULTI-ZONE (MZ)



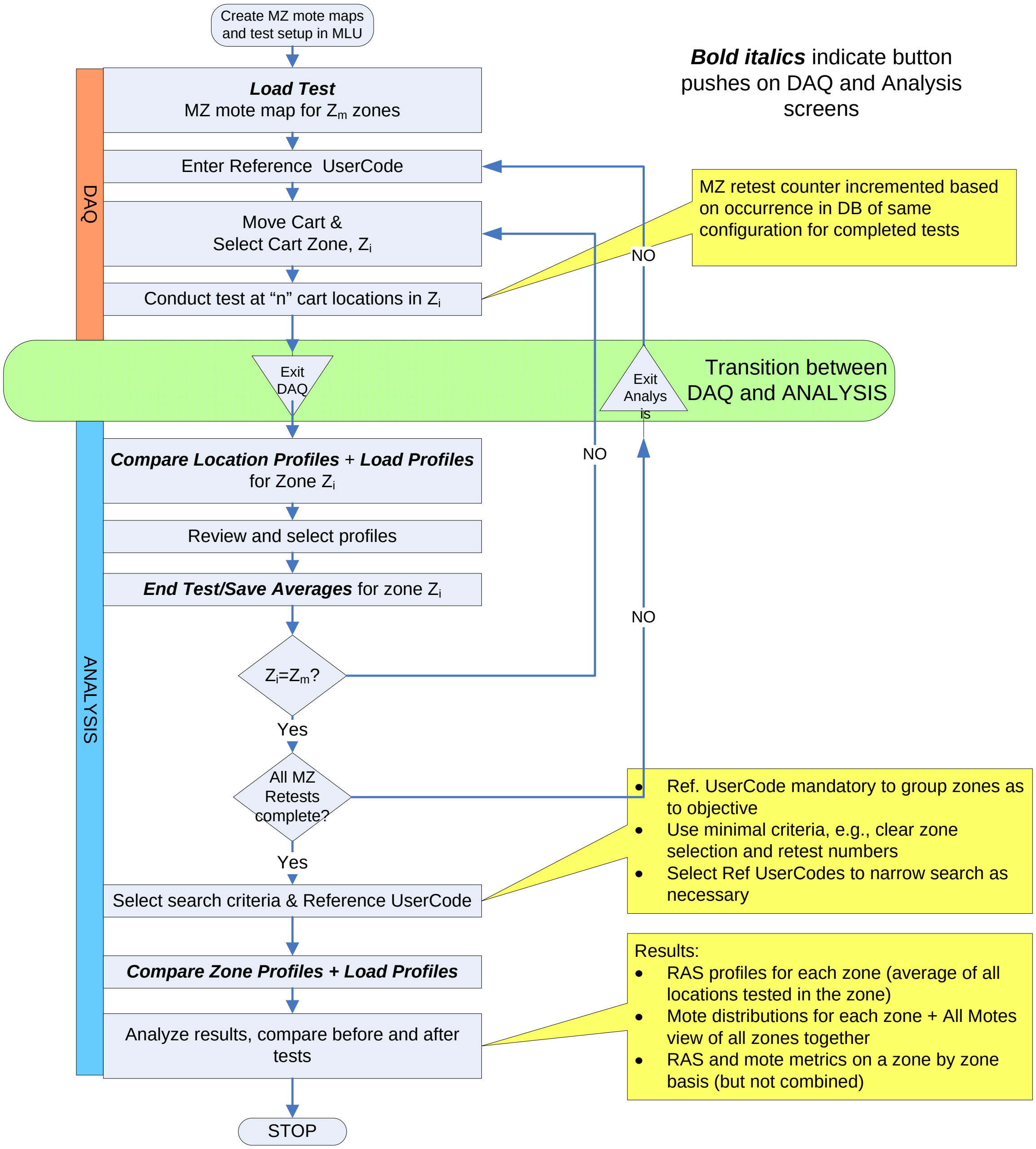


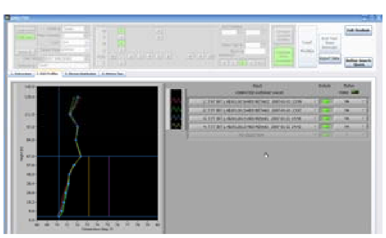
RAS Profiles

Plenum Distribution, all motes

Metrics, compare retests

8.4 MULTI-SINGLE ZONE (MSZ)





RAS Profiles

Plenum Distribution, one zone

Metrics, all zones

9 TROUBLE SHOOTING PROCEDURES

9.1 USB

The USB is not a rebuts industrial bus so it requires that you take precautions to prevent problems with the LabView software:

1. Only unplug the single connection to the computer when the computer is off.
2. It is important that all devices to be connected before booting up LabView. Always check the USB hub lights when booting up the computer. Occasionally the USB bus fails to recognize a connected device. Even more occasionally a light will go out with the computer running. When this happens one of the lights on the hub will be out/unlit. First try to restart the computer. If that does not work, slowly pull out the USB plug from the device and/or the hub, and then re-insert it. You should hear the distinctive sound from the PC when this happens.
3. The USB hub is a self-powered hub meaning it requires an external source of power instead of the 5 VDC bus power the USB provides as a default for connected. Check that the red power on lamp is lit, and if not connect/reconnect the power plug to the hub, or troubleshoot the power supply (blue unit).

9.2 DUST NETWORK

You should consider the following when troubleshooting the wireless mote network.

1. Be sure the motes do not lean on their test button when deployed; the LEDs draw considerable power and can impact the battery life.
2. If data is not received from all motes after 4 logging cycles (~120 sec, and Mote Data Status bars are off on the DAQ screen), open the DustBox and check the Data Manager lights; if the *Subscription* light is off, there is a problem with the connection to the DustBox PC. Try re-booting the DustBox using procedure described below. If this does not correct the problem, check the DustBox FCS website for database errors; the motes data will not be accessible. If errors exist contact the system administrator.
3. If a mote is not disabled (i.e., not deployed in which case it should be turned off) and its status indicator on the Test Setup screen is off it is either turned off (with sleep tool), out of range or its battery is dead. Check the unit by first pressing the Reset with a paper clip and then checking the Test light to see if the batteries are good (i.e., the green power light is on).
4. The DustBox PC should be shutdown using normal PC shutdown procedures as opposed to simply unplugging it. This procedure requires that the PC be accessed remotely via the Cart laptop using the installed remote access software VNC. Details of this procedure are described in *UFAD Commissioning Cart: System Data and Computer Management Procedures*. Using this procedure reduces the chances of corrupting the database. If the database becomes corrupted or fails to run, there are some basic administrative procedures to use to determine the cause as outlined also in *Cx Cart Data and Computer Management.*

10 CART ASSEMBLY INSTRUCTIONS

The following set of annotated photos describes the assembly/disassembly of the cart for shipping purposes. The major steps are:

1. Remove computer table
2. Coil and wrap cables and mouse and secure to cart
3. Remove plexiglass screen

4. Dissemble power system (this will not be necessary in the future due to the nature of the shipping container).
5. Secure power cables and pressure tube.

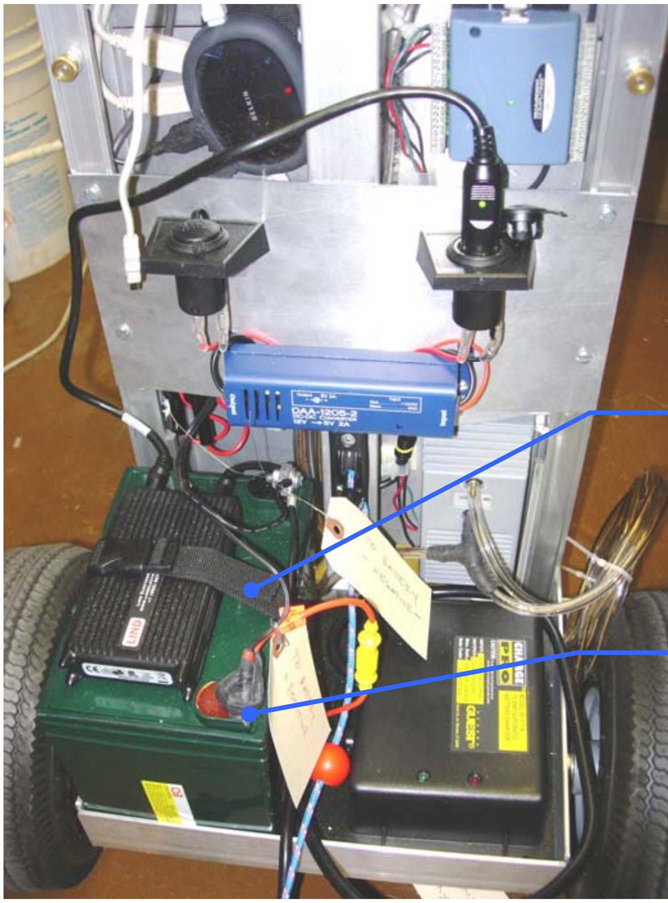


Figure 77: Cart power system fully assembled

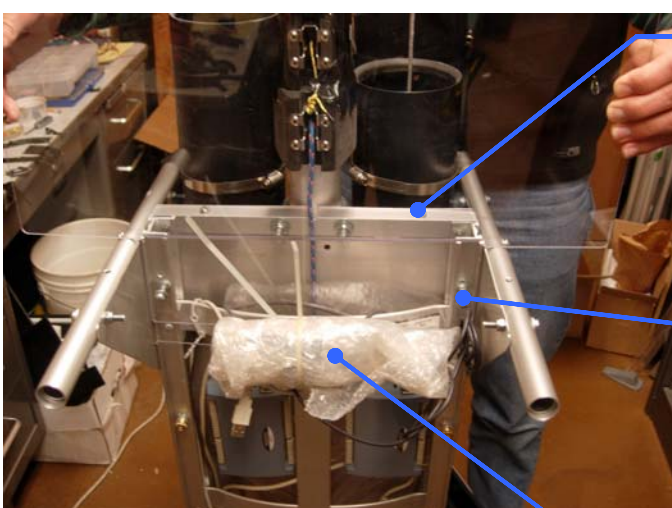


Figure 78: Screen disassembly

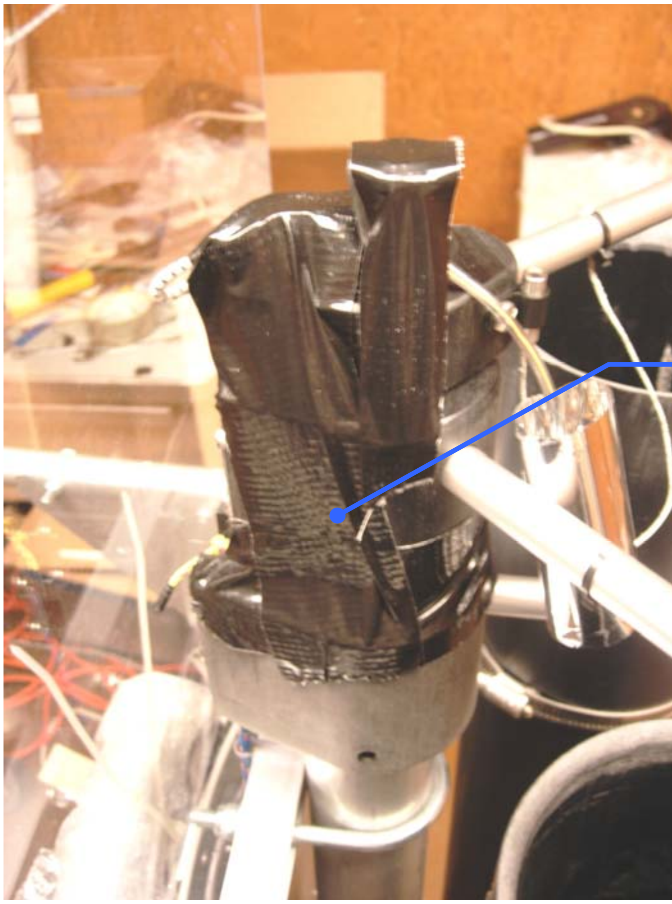


Figure 79: Securing the tree head

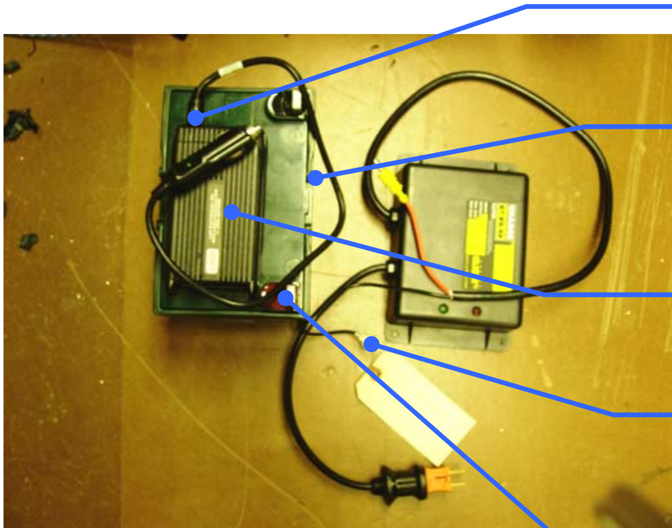


Figure 80: Battery and charger disassembled

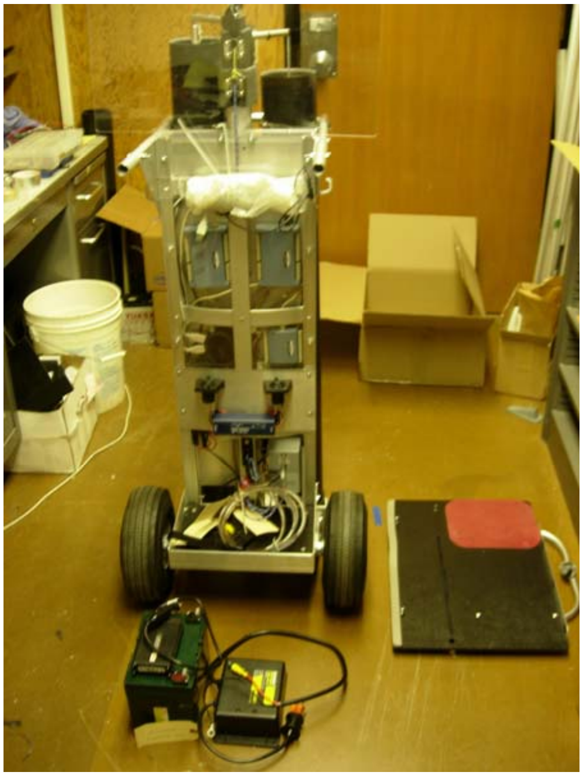


Figure 81: Cart disassembled ready for shipping

Figure 82: Cart installed in shipping crate

11 REFERENCES

Bauman, Fred, Tom Webster, Stefano Schiavon, Hui Zhang, Edward Arens, Kwang Ho Lee*, Tyler Hoyt, Darryl Dickerhoff, Timothy Moore†, Wilmer Pasut, Sabine Hoffmann, Tiefeng Yu, and Elliot Nahman. University of California, Berkeley. 2012. *Advanced Design and Commissioning Tools for Energy-Efficient Building Technologies*. Final report for California Energy Commission. Center for the Built Environment, University of California, Berkeley.

APPENDIX A
UFAD COMMISSIONING CART: SYSTEM DATA AND COMPUTER MANAGEMENT PROCEDURES

Y. Yuan, T. Webster
2/20/2007

A1. INTRODUCTION

This document describes the data acquisition architecture and associated data management and software maintenance procedures used with the UFAD commissioning cart described in the body of this document.

A2. HARDWARE AND SOFTWARE REQUIREMENTS

The hardware requirements for managing the profile data include the cart laptop, an Internet web and database archive computer, and a portable storage device.

Cart laptop PC3 is located on the cart and is assumed to have a reliable power source (i.e., external battery). There is no guarantee that it has any connectivity with any networks. This laptop runs LabView and MySQL database server, and Apache HTTP server with the PHP module. Optionally, it also has the phpMyAdmin database administration software. The optional software makes database administration and debugging much easier. Besides LabView, all other software are open source and freely available on the Internet. The appendix contains a list of these software and how to obtain them.

Laptop PC2 is located remotely in the NYT offices. This computer serves as a database archive and a backup for PC3. It is configured exactly like PC3 and is connected to the internet in NYT offices. Backup databases will be uploaded to CBE computers from this internet connected machine. PC2 can also be used to conduct offline analyses,[4] export data, and operate the Mote Layout Utility to prepare image files for the cart laptop.

The *portable storage device* can be a USB flash drive, external hard disk, or any other portable non-volatile storage device. The purpose is to transfer store backup copies of the MySQL database (created as described below) from cart laptop PC3 to laptop PC2.

A3. DATA ACQUISITION

Data is acquired from the sensors by a data acquisition device, and transmitted in digital form to LabView via the serial (COM) or USB port. In LabView, the data can be processed, displayed to the user, and exported to a temporary data file.

A4. DATA STORAGE AND RETRIEVAL

After the user finishes a test in LabView, the data is saved to the MySQL database on the cart laptop. First, LabView connects via HTTP to a PHP script hosted on the local computer and sends the test information (from cart sensors and the wireless sensor network, including all the header information and data) to it. Next, the PHP script verifies the information, constructs the SQL queries, and stores the information in the database. Finally, the script returns its status (e.g. “finished”, “error”) to LabView.

[4] During offline analysis it will be possible to override an acceptance thus causing a change in the database that would not be recorded in the Cart laptop DB.

When the user wishes to retrieve a test, he/she can enter search criteria into LabView, which will retrieve the tests in the database matching those criteria. The user can then view the results of the test and use it for analysis. Similar to storing data, LabView connects to a PHP script to request a list of tests matching some criteria or test data from a particular test. The PHP script will construct the proper SQL queries, and return the results from the MySQL database.

A5. DAILY WORKFLOW

In a typical day, the user should run the LabView software to take measurements as described in the accompanying *UFAD Commissioning Cart: Design and Operating Manual*. At the end of a test, the user can decide whether to save or discard the data. If something seriously wrong has occurred during the test, the data should be immediately discarded.

If the user wishes to retrieve the data for a test to do analysis, or to view a list of tests in the database, he/she should first enter criteria for the relevant tests. Then, LabView will return the tests in the database matching those criteria. Some options have been restricted to prevent an overly broad set of data returned. If the list of tests returned is still too broad or too narrow, the user can adjust the search criteria and search again until a satisfactory list of tests is returned. To retrieve the data associated with a test, the user selects a test from the list and adds it to the analysis graph. At that time, the data will be retrieved from the database.

At the end of every day of testing the database shall be transferred to the backup laptop (PC2). This backup file shall be maintained in an archive folder; it shall also be restored to PC2 using the MySQL procedures shown below.

SYSTEM DIAGRAM

Figure 83 illustrates the data flow in the DMAS. Note that VNC Servers are install on PC2 and PC3 to allow remote access and for file transfers. Remote access may be required for remote debugging purposes.

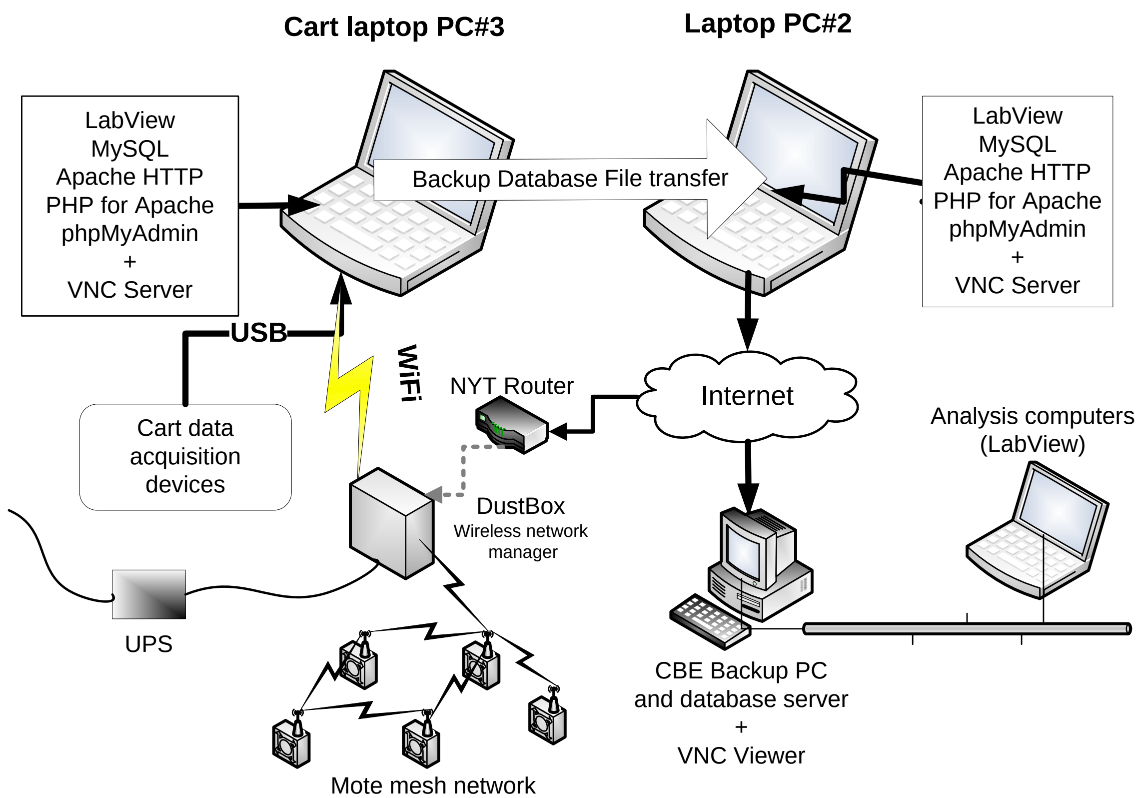


Figure 83: DMAS data management schematic

Besides the offsite CBE computers, there are three computers in the system: 1) Primary cart laptop, 2) Laptop backup and archiving laptop; 3) DustBox PC as shown in Figure 83.

A6. COMPUTER MANAGEMENT PROCEDURES

FILE TRANSERS AND SOFTWARE MAINTENANCE/UPGRADES

Figure 83 shows the overall data management system. Support from CBE will be provided via the links shown in the schematic. In general, the process is to transfer backup database files to CBE via VNC file transfer. Using VNC CBE can also provide program updates to the laptop(s) when they are connected to the NYT network.

These upgrades shall be made whenever they are available and shall be made to both computers.

LAPTOP REPLACEMENT PROCEDURES

If it becomes necessary to replace the Cart Laptop (PC3) with the backup laptop (PC2) it is only necessary to switch the two computers once the following steps have been taken:

1. Restore the latest database from PC3 to PC2
2. Ensure that PC2 has all the latest LabView and associated files.

Under normal conditions these procedures should not be necessary if upgrades and restores are maintained as outlined above.

The USB connector should always be connected and disconnected while the PC is Off.

ADMINISTRATION PROCEDURES

LAPTOP FILE STRUCTURES

The computers are configured with only the software components that are pertinent to the taks of operating the cart and conducting tests with LabView. They are partitioned into three drives:

- C: …Used only for operating system and associated software
- D: …Application (LabView) program files only
- E: … User working files only

The file structure for LabView and associated external files is shown in Figure 84. There are a number of external files used for special purposes and are listed and described in Table 1.

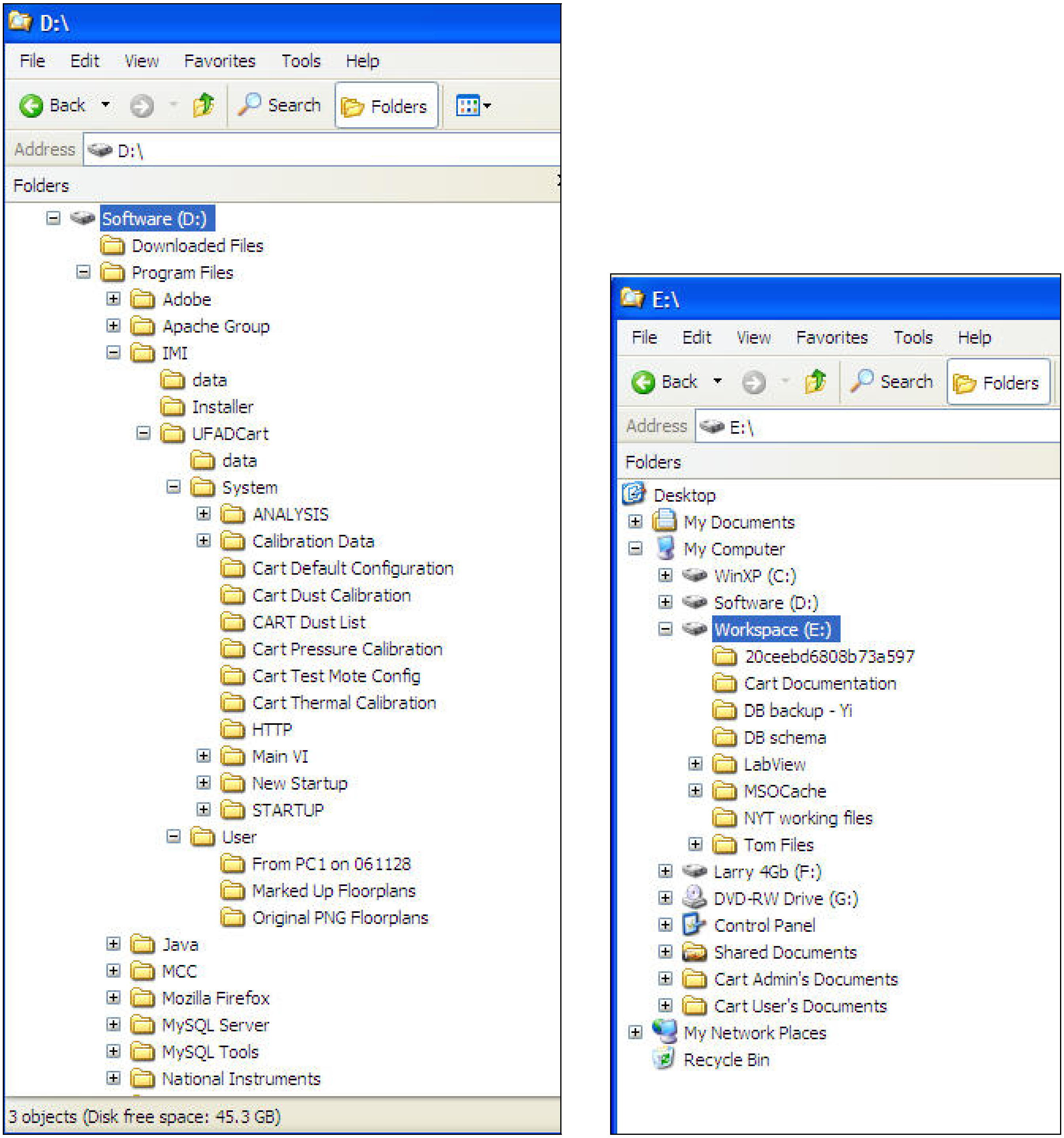


Figure 84: Laptop file structure of D: and E: drives, respectively

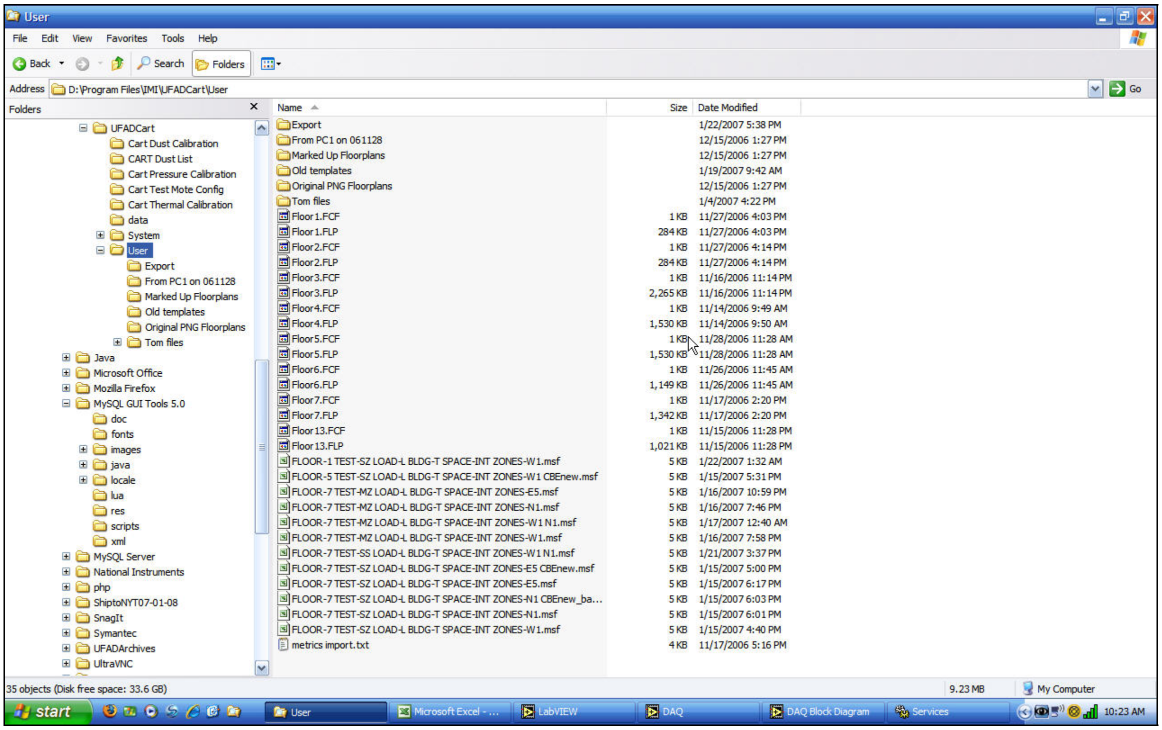
Data Files

The files included in the User section of Table 1 are shown for reference purposes only. These files are generated by the MLU but you may want to clear out some of the *.msf files to reduce clutter. When deleting .msf files be careful not to delete the .FCF, and .FLP files.

The files shown in the System section of Table 1are available to administrative level personnel to customize certain aspects of the programs. Those identified as Excel format are used as text format. Make modifications in the excel file (since it is easy to read) and then export as a comma separated file to over write the text file:

There are additional files to support calibration; these files should not be modified.

There are two folders where the files exist: 1) User and 2) System as indicated in Table 1 and following screen shots.



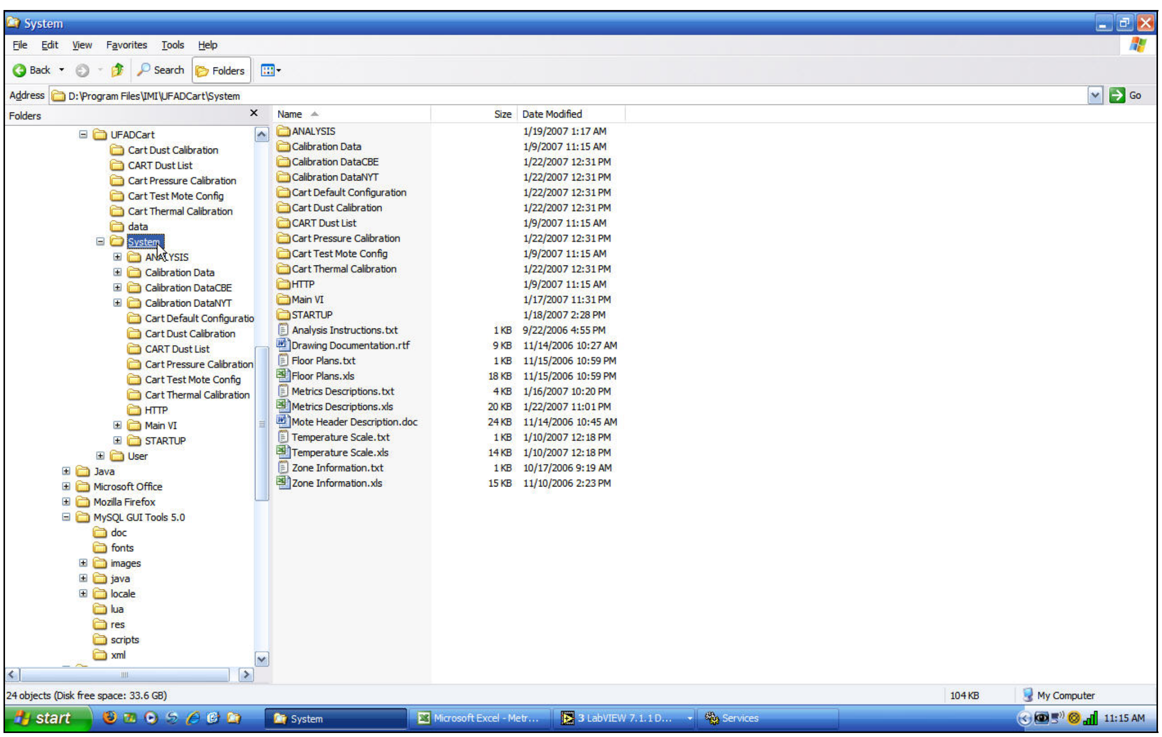


Table 1: External files used by Labview

Folder/File	Purpose	Comments
D:\Program Files\IMI\UFADCart\User		
*.FCF	Scaling data for mote layouts (MLU generated file)	Comma separated spreadsheet files that contain formatted scaling information for .FLP files
*.FLP	PNG formatted images of each floor supporting mote layouts (MLU generated file)	These files require a matching FCF file
*.msf	Test setup/configuration files created by the MLU (MLU generated file)	These files are independent from FCF and FLP files. i.e. if the scaling of a floorplan or the actual floorplan image changes they will not be effected as long as the user properly configures the new floorplan.
Original PNG Floorplans	*.png files used to create floor plan layouts in MLU	Created via PhotoShop from .pdf floor layouts with grid structure
D:\Program Files\IMI\UFADCart\System		
Metrics Descriptions (Excel)	Contains the row descriptions for the mote and tree data metrics tables	**ONLY CHANGE THE CRITERIA VALUES.** Any other changes will cause malfunction!!!!
Zone Information (Excel)	Lists zone areas and numbers of diffusers to be used with zone airflow calculations based on plenum pressure	This file should be updated as numbers of diffuser are finalized
Floor Plans (Excel)	Contains the acceptable letter and number ranges for the MLU floor configuration utility	
Temperature Scale (Excel)	Contains the minimum and maximum temperatures to be displayed on the mote legend	Affects the color range and its associated temperature.
Analysis Instructions (Text)	This text that will appear in the instructions window for the Analysis screen.	Can be modified to reflect current procedures

LAPTOP SECURITY

The cart computers currently (January 2007) do NOT have antivirus (AV) or sophisticated firewalls installed. Only the default Windows firewall is working. DO NOT add AV or firewall software on these computers; to do so will severely compromise the performance of LabView, even if the AV software is dormant.

DUSTBOX

The DustBox contains four devices as shown in Figure 85: WiFi Router, Dust Data Manager, Embedded PC, and Time Delay Relay unit. These devices work in concert with one another to manage communications between the cart and the DustBox (WiFi) and gather data from the motes (Dust Data Manager). The PC runs a MySQL database to log data collected from the motes. There is customized software that runs several services that attempt to ensure the operation of the data collection and storage during situations when devices may not be functioning properly or are out of synchronization during startup, loss of WiFi links, network problems, power spikes etc. In addition, the PC reboots itself after 24 hours of continuous operation that will interrupt data logging for about 2 minutes.

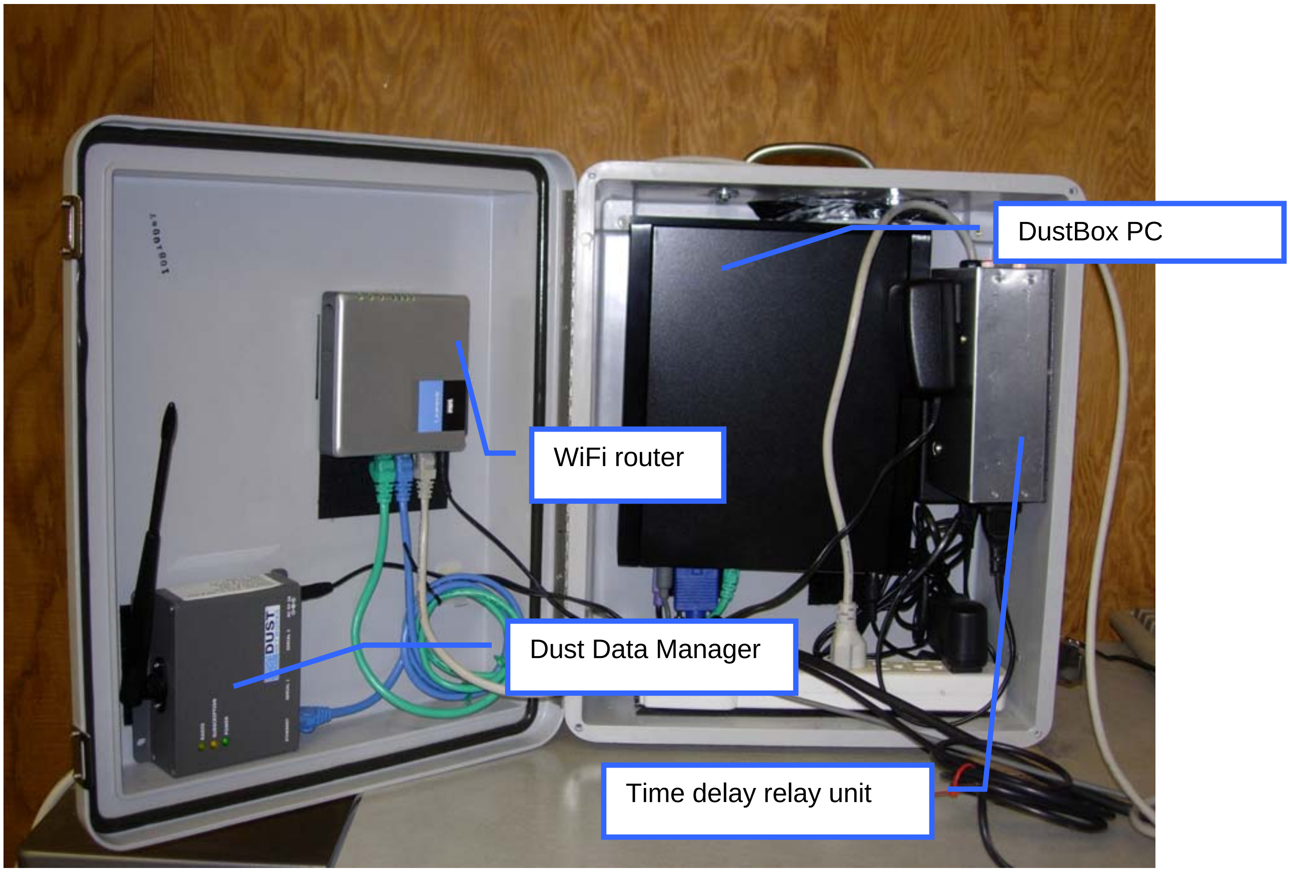
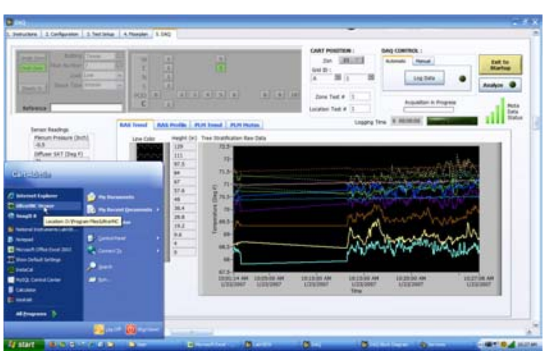


Figure 85: DustBox showing all components (CBE version)

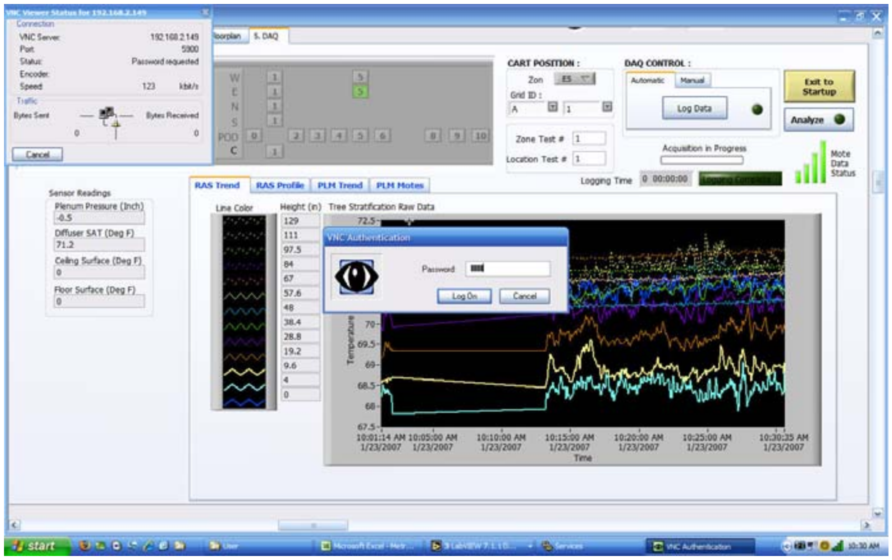
DustBox PC Shutdown/reboot

To prevent software degradation and database corruption, it is essential that the DustBox PC be shutdown gracefully using normal computer exiting procedures. Follow these steps:

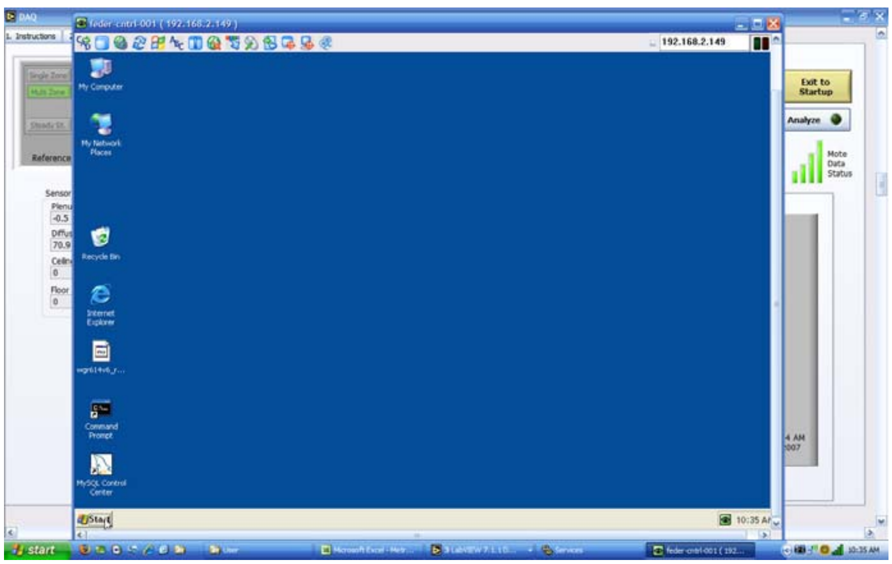
1. From the Cart laptop, run VNC Viewer with DustBox PC IP address (192.168.1.30)



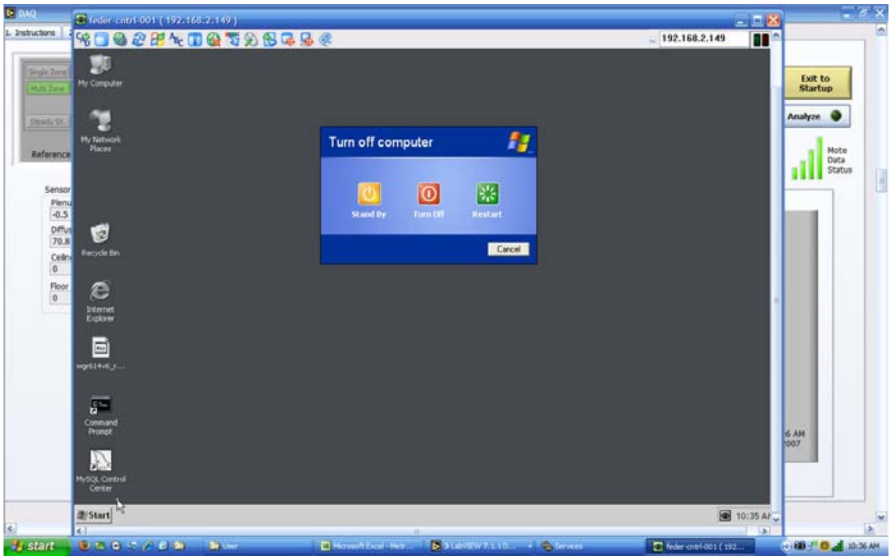
2. Logon to the DustBox PC using the VNC password (nytcbe).



3. Go to the Start menu on remote (DustBox) computer and click *Turn Off Computer*



4. Click on the *Turn Off* (for shutdown) or *Restart* (for reboot) button. This will cause the link VNC link to close.



5. After PC shutdown turn off the DustBox power at the UPS on/off button. The DustBox can be reactivated by turning the UPS on.
6. During Reboot a time delay relay device starts the devices in the following proper order; .Router, immediately; Dust Manager, ~30sec; PC ~6 minutes from time that power is activated. Figure 87 is an annotated photo that shows this device as mounted in the DustBox.

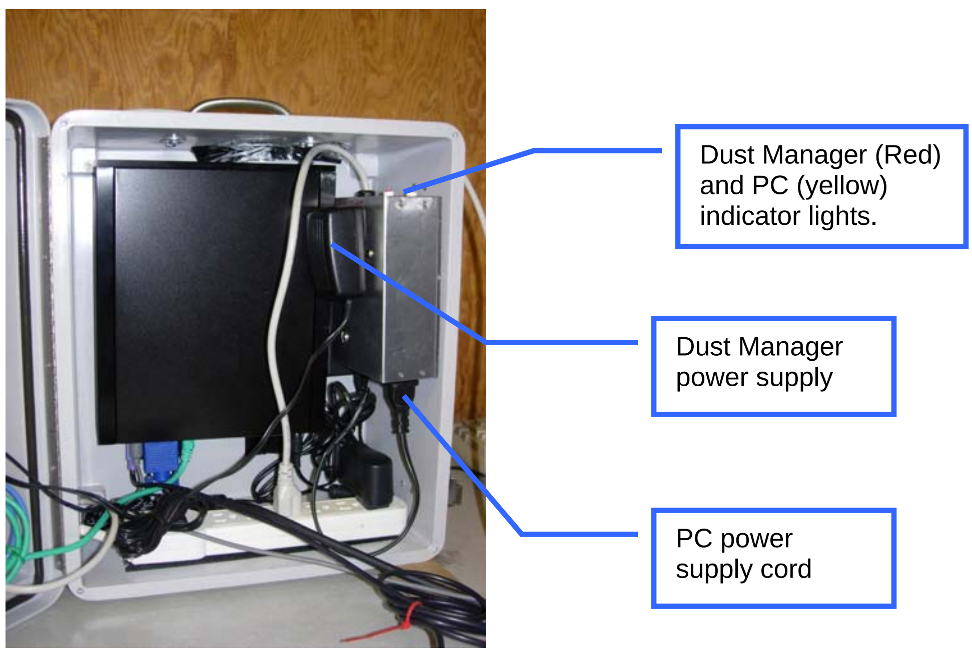


Figure 86: DustBox relay unit mounted and connected in DustBox cabinet

DustBox troubleshooting

If WiFi service is operating, and the Online indicator lights on the Test Setup screen are off, it is likely that the database is not logging. If the data in the database is more than 3 minutes old, zeros will be placed in the data fields on the Test Setup screen. It is likely that the DustBox subscription light will be off indicating that data is not being acquired by the DustBox PC. The DustBox data logging requires that certain services be operating in the DustBox PC as shown in Figure 87, namely the FACS Dust service and MySQL. The FACS Monitor service attempts to restore FACS Dust service if it stops for some reason. In addition, if, for any reason the FACS services fail to start, Windows will check it after two minutes and attempt to restart it. After the third try, Windows will reboot itself. This provides some redundancy with the Monitor as one backup, Windows Restore another. If it fails to run on a restart, there is likely something more seriously wrong, rather than just a DB timing issue, or a DLL that failed to load on startup.

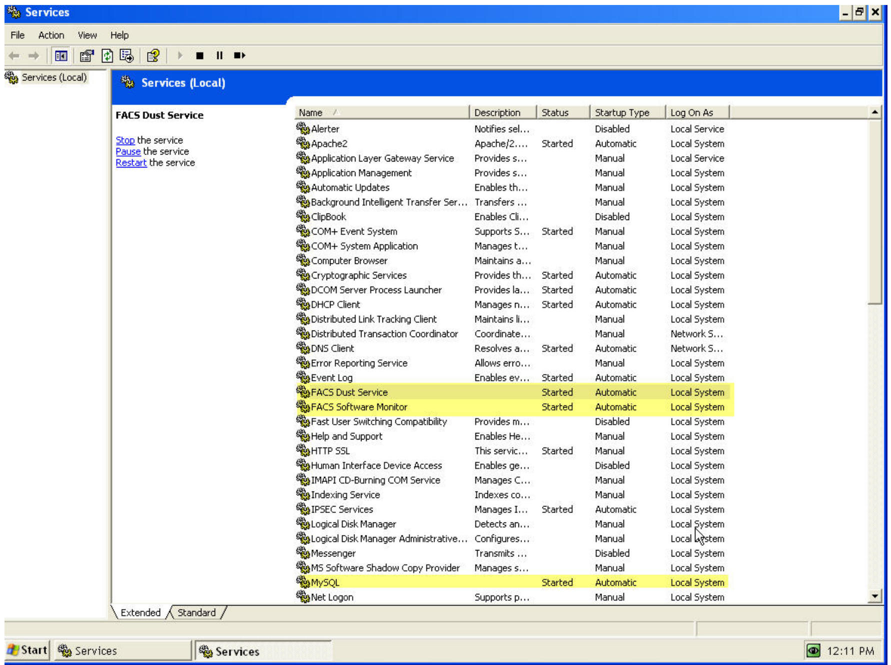
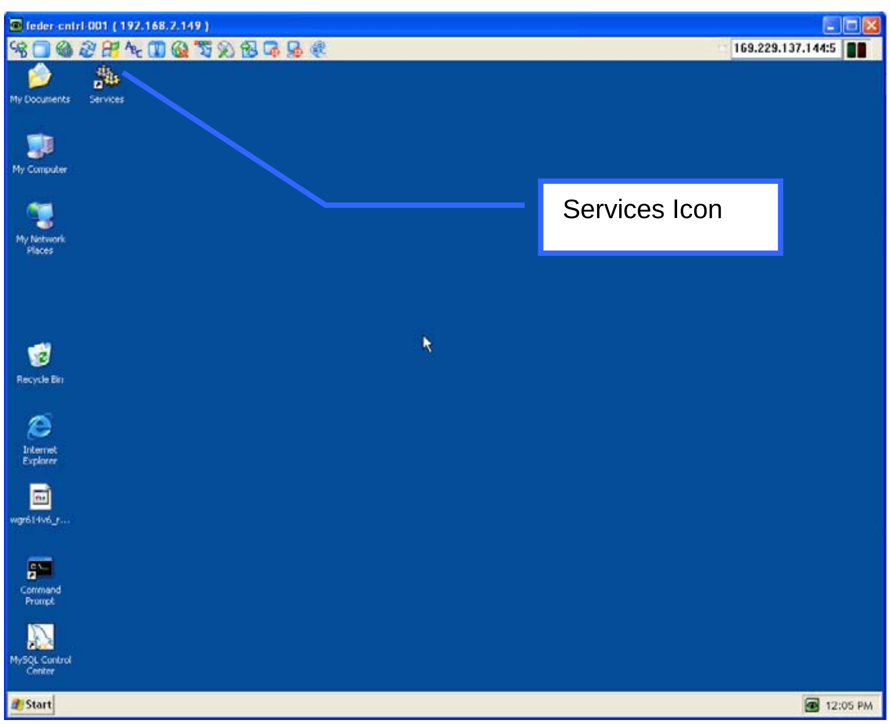


Figure 87: DustBox services

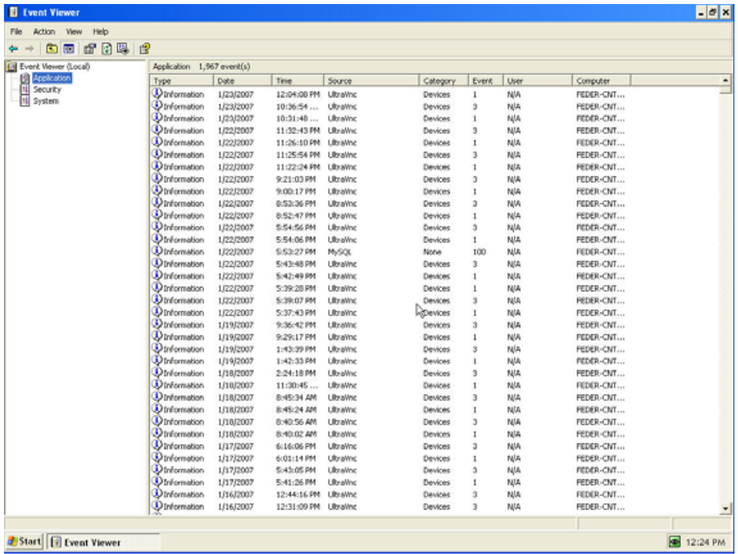
If the database is down take the following steps:

1. Using VNC remote access, logon to the DustBox PC via the cart laptop (See section above).



2. Click on the Services desktop icon. This will show a list of Windows services. Find the FACS services and check their status (see Figure 87). They should indicate that they have been started.

3. If the services are NOT started, go to the Window Event Viewer by clicking on: Start/Settings/Control Panel/Administrative Tools/Event Viewer.



4. Check for errors related to DustBox services etc. Sometimes the FACS services fail because a Windows DLL or some other (e.g., MySQL library fails to load) fails.

5. Try restarting the FACS services. If it fails to start, contact CBE.

FACS software updates

Note that if the FACS software is updated for any reason, VNC needs to be removed and reinstalled after the upgrade using the following procedure.

1. Shutdown the dust box PC remotely with VNC in the normal way.

2. Connect a keyboard, mouse, and monitor to the DustBox PC. Restart the PC by removing and replacing the PC power plug.

3. Login to the PC using username: Admin, password: cj081395

4. As shown in the screen shot below, find and click on the Remove WinVNC Service

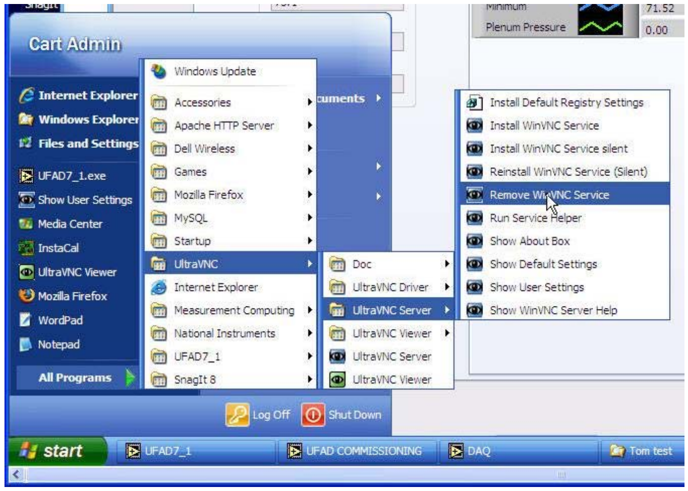
5. Reboot the PC.

6. In VNC menus below, find and click on Install WinVNC Service

7. Shutdown and reboot PC

8. Test connection with cart laptop VNC viewer; be sure the File Transfer works. These last steps I will also check from here.

9. remove keyboard, mouse, monitor connections



MySQL Database Backup & Restore Procedures

The following procedure can be used to backup the cart laptop (PC#3) MySQL database to second (remote) computer (i.e., cart laptop PC#2). This computer will serve as an archive for the cart database and as a file transfer point for CBE access to these archived files as needed. To ensure against loss of data this procedure should be done at the end of every day of testing.

Backup

1. This procedure must be done by an administrator with root access to the database on cart laptop PC#3.
2. Double click the MySQL Administrator icon on the desktop.
3. A dialog box will be displayed that looks similar to that shown in Figure 88

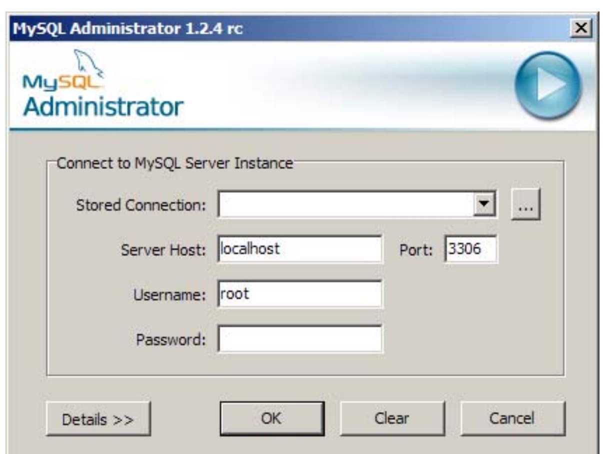


Figure 88: MySQL administrator startup dialog box

4. Enter the following and click OK.
   Server Host: **localhost**
   Username: **root**
   Password: <root password, see password documentation>
5. This will launch the MySQL Administrator user interface shown in Figure 89 and connect to the database.

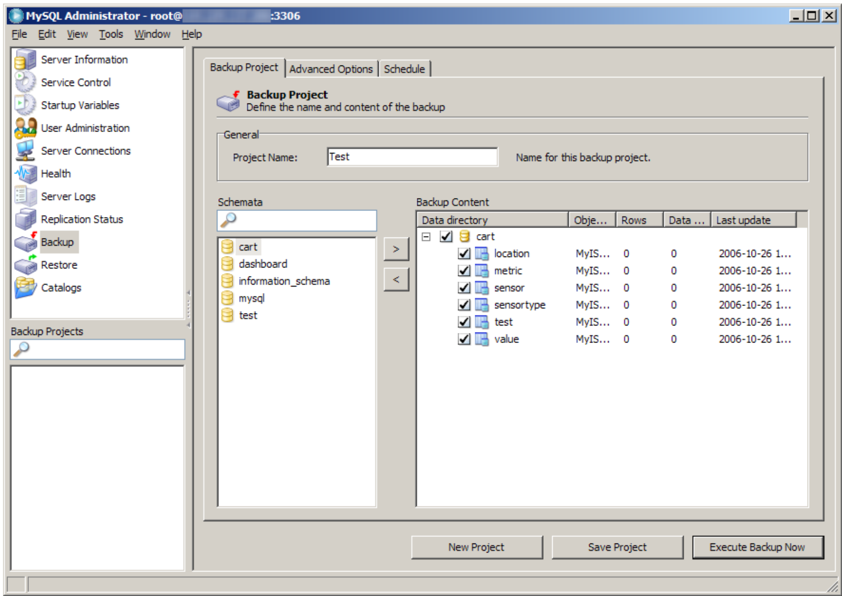


Figure 89: MySQL administrator interface

6. Select the *Backup* button on the left side panel.
7. Click *New Project* at the bottom, and all the fields will be enabled.
8. Enter a project name at the top, then select ***cart*** under *Schemata*, and click the > *button* to add it to the *Backup Content*. The database (cart) and all the tables in it (location, metric, etc) should be checked. When you're finished, the screen should look like that shown in Figure 89. Click *Execute Backup Now* button at the bottom.
9. Select a directory and enter a file name in which to store the backup. If storing to the local hard disk, it is recommended the backup file be stored on the E: drive, as that drive is dedicated to saving work files. The file should have a .sql extension because it contains SQL commands that are used to reconstruct the database.
10. If everything is done, you will get a Backup Finished dialog box like that shown in Figure 90.

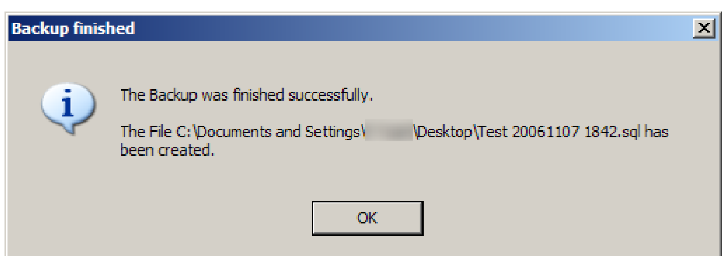


Figure 90: Backup finished dialog box

Restore

The database needs to be restored on the backup computer (PC2) on a regular basis to ensure it is up to date in case it is needed to replace PC3. (This same procedure will be used to restore the DB for use by CBE.)

1. Transfer the backup file from the cart laptop computer (PC3) to the backup/archive computer (PC2) using an external hard drive or USB memory stick.
2. Backup the DB currently on PC2 prior to restoring the latest one. This will preserve any changes made during analyses.

3. Empty the database on PC2.
4. Restore the current backup DB to PC2.

Empty

This procedure is used ONLY to empty the database on PC2 before a new backup is restored.

1. Boot up the Internet Explorer browser and enter http://localhost/mysql. Log in to phpMyAdmin using the PC administrator password.
2. Select the "cart" database on the left hand side dropdown. The right hand side will then refresh to show the tables in the "cart" database.
3. On the right side, click "Check all", which will select all of the tables
4. Select "Empty" from the drop down box to the right. **Make sure you select "Empty", not "Drop" (which is right below Empty in the list). Drop deletes the table.**
5. Look for the confirmation: "Do you want to TRUNCATE location; TRUNCATE metric; ....". Click Yes.
6. After being returned to the page with a list of tables, you should note that the number of records for each table is now 0.
7. Click the green Exit button on the left side to log out.

APPENDIX A1 – SOFTWARE SOURCES

1. Apache HTTP Server

   Author: Apache Software Foundation

   Download: Apache HTTP Server 2.0 or 2.2 at http://httpd.apache.org/download.cgi

   Documentation: http://httpd.apache.org/docs/

2. MySQL Database Server

   Author: MySQL AB

   Download: MySQL 5.0.18 at http://dev.mysql.com/downloads/

   Documentation: http://dev.mysql.com/doc/

   Licensing: Commercial use of MySQL requires a commercial license. See http://www.mysql.com/company/legal/licensing/commercial-license.html

3. PHP module for Apache

   Author: The PHP Group

   Download: PHP 5.1.2 ZIP package at http://www.php.net/downloads.php

   Documentation: http://www.php.net/manual/en/

4. phpMyAdmin

   Author: phpMyAdmin Development Team

   Download: phpMyAdmin 2.7.0-pl2 at http://www.phpmyadmin.net/home_page/downloads.php

   Documentation: http://www.phpmyadmin.net/home_page/docs.php

APPENDIX B
THERMAL PLUME GENERATORS FOR UFAD SYSTEM COMMISSIONING

T. Webster, H. Jin, K. Weeks, M. Martinez

9/28/06

B1. INTRODUCTION

The objective of this study was to determine the plume-generating characteristics of the heat loads of a commercial office workstation typical of those being deployed in modern office buildings and to replicate these thermal plumes as closely as possible with compact portable devices. The devices need to be simple, durable, and as economical as possible to be viable as a tool for commissioning the UFAD system in large office zones.

B2. METHODS/MODEL DEVELOPMENT

LOADS ANALYSIS

Figure 91 below shows the various heat-generating components of a standard workstation and the power drawn by each. Each load's full power is included in the total specified for the artificial loads with the exception of the miscellaneous loads. We estimate that a standard workstation will only operate about half of the possible 150W of miscellaneous loads at any given time. Thus, the total power to be drawn by the artificial loads is 264 W, or ~2.6 W/ft^2 if we assume 100 ft^2 per workstation. This load is only about 60% of a typical office specified cooling design load of 4.25 W/ft^2 for people and equipment (overhead lighting loads are ignored for comparison purposes). If we round up to 3 W/ft^2 to account for the addition of printers and copy machines etc. and number of heaters required for typical tower and podium zones is shown in Table 2 assuming each device operates at 125 W (rounded down from 132 W).

WS load summary — Assumes two equal sources with same rad/conv split

	W, ea.	WS Diversity	Total Load, W	% Conv.	Conv load, plume	Rad load	Device 1		Device 2		Totals
							conv	rad	conv	rad	
Person	75	1	75	40%	30		15	23	15	23	
Misc loads (e.g., printer, chargers, etc.)	150	0.5	75	95%	71		36	2	36	2	
CPU Power	75	1	75	95%	71		36	2	36	2	
Monitor power	30	1	30	65%	20		10	5	10	5	
Task light	9	1	9	90%	8		4	0	4	0	
Total WS power/Avg % conv.	339		264	**76%**							
Convective plume loads/Avg % conv			114	51%	200		100		100		200
Radiant					64			32		32	64
Check total											264
						Total	132		132		
						% rad	24%		24%		

Figure 91: Typical workstation components and basic artificial load specifications

Table 2: Number of artificial loads required for zone simulation

	Small zone	Large zone
Area, Ft^2	3350	6000
Total load @ 3 W/ft^2, W	10050	18000
Number of load devices at 125	80	144

W per device		

Also shown in Figure 91 for each component is the percentage of heat that is dissipated via convection vs. radiation. The prototype artificial loads needs to approximate the average convective/radiative split of the complete workstation, which was calculated to be 76% conductive/24% radiative as shown.

DEVICE DEVELOPMENT

An analytical model was developed to facilitate the design of prototype vertical flat plate devices. This model is documented in Appendix A. The final equations are used to calculate power density vs. surface temperature and percentage radiation vs. surface temperature.

Using the model equations we constructed various prototype artificial load devices to 1) validate the model, and 2) produce a model that meets the specifications described above. Study of the plume behavior of a typical workstation resulted in the decision to split the total workstation load between two identical devices, so that one could be placed under the desk (to simulate the loads for the computer CPU and other miscellaneous loads located there) and the other in front of the desk. The device, shown below in Figure 92, consists of two silicon rubber strip heaters (supplied by HiHeat Industries) mounted with high temperature RTV adhesive to a 14 inch square, 14 gauge (0.078 inches) thick galvanized steel plates. Galvanized steel has an emissivity in the infrared range of ~0.25. The heaters are 2 x 10 inches, rated at 100 W each at 120 VAC.

Figure 92: Example prototype artificial Load Device

TESTING PROCEDURE

The plume behavior of the artificial loads was tested using a full-scale mock-up. Two workstations were set up side-by-side in a laboratory space with restricted supply air to the room to minimize air currents. As shown in Figure 93, one workstation consisted of a thermal manikin replicating human heat production, a CPU under the desk and a 19 inch flat screen monitor on the desk. The other workstation consisted of two artificial loads, one placed under the desk and one placed approximately 2-3 ft away from the first one where a chair would be located. Power was supplied to the artificial loads by a variac set to operate at the same overall power as the workstation, ~180 W (the load actually varies between about 180 to 210 W depending on computer activities).

Figure 93: Side-by-side comparison of artificial loads (left) and real workstation loads (right).

Surface temperature measurements were taken on a 4x4 grid over the face of the artificial load plate. We used a smoke generator to simultaneously feed both workstations. Once equilibrium was reached, the plume sizes and strengths were compared. Figure 94 shows an image of the smoke test underway.

Figure 94: Side-by-side comparison of plumes generated by artificial loads (left) and real workstation loads (right), using smoke for visualization.

B3. RESULTS AND DISCUSSION

DESIGN AND VALIDATION

To validate the model, we compared the results from HiHeat data for a single heater mounted vertically at an estimated emissivity of 0.9. Figure 95 shows a plot of power density vs. surface temperature for surface emissivity of 0.90 comparing manufacturer's catalog data for HiHeat strip heaters.[5]

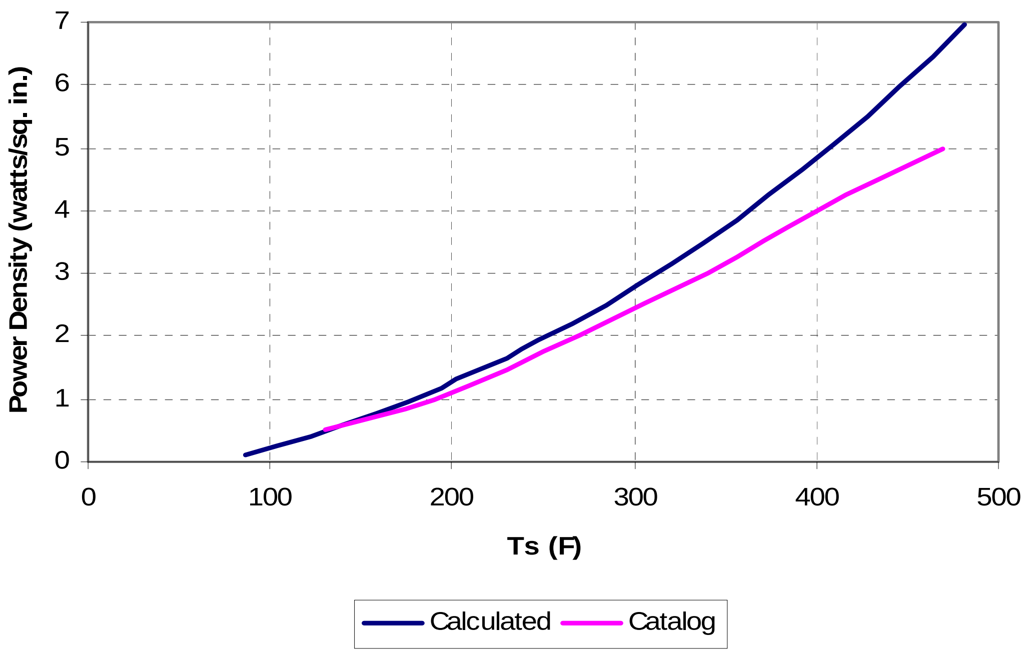


Figure 95: Power density curves for e=0.90

Figure 96 shows the percentage radiative power vs. surface temperature for an emissivity of 0.90. Note that the curve minimum is about 55.5% at a surface temperature of ~175°F. It is clear from this result that high emissivity surfaces will not allow us to reach our target of 24% radiation. Figure 97 shows a similar chart for emissivities in the range of 0.25 to 0.50. Note that our goal of 24% is almost achieved at an emissivity of 0.25, about the same as galvanized steel plate. Figure 98 shows power density curves for a full range of emissivities.

From these results we calculated that a 14x14 inch plate with two 2x10 strip heaters operating at a total of 125 W would produce nearly the correct radiative split. The effective emissivity of the plate is actually ~0.33 due to the combination of e=0.90 for the heaters and e=0.25 for the plate. Figure 99 shows test results compared to the model for this effective emissivity at two different power densities.

[5] HiHeat uses area from one side only to calculate power density, even though heat is transferred from two sides. We modified our calculations to report in the same way.

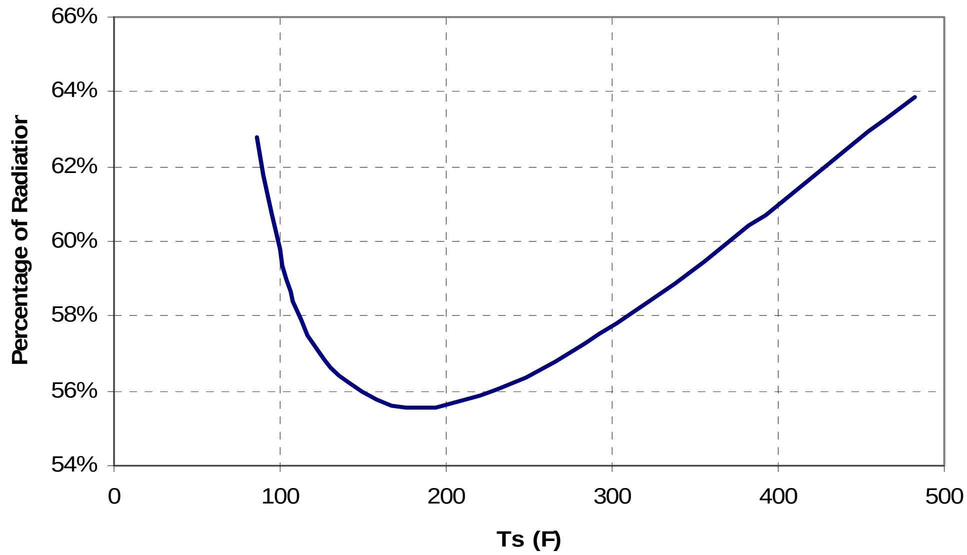


Figure 96: Radiative split vs. surface temperature for e=0.90

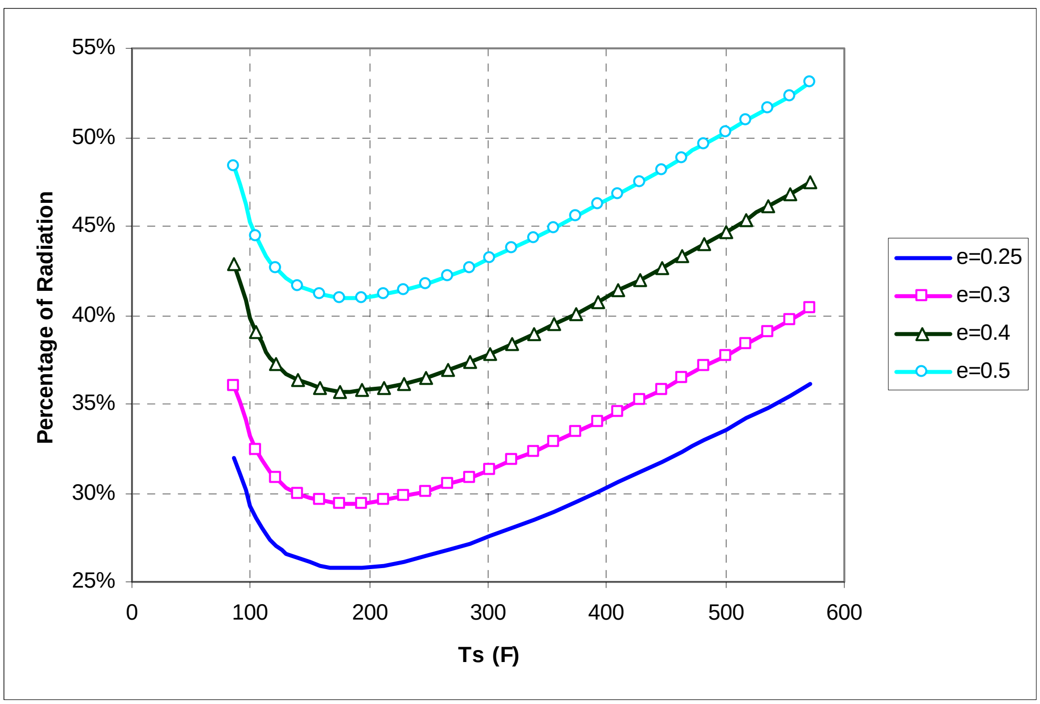


Figure 97: Radiative splits vs. surface temperature for low emissivities

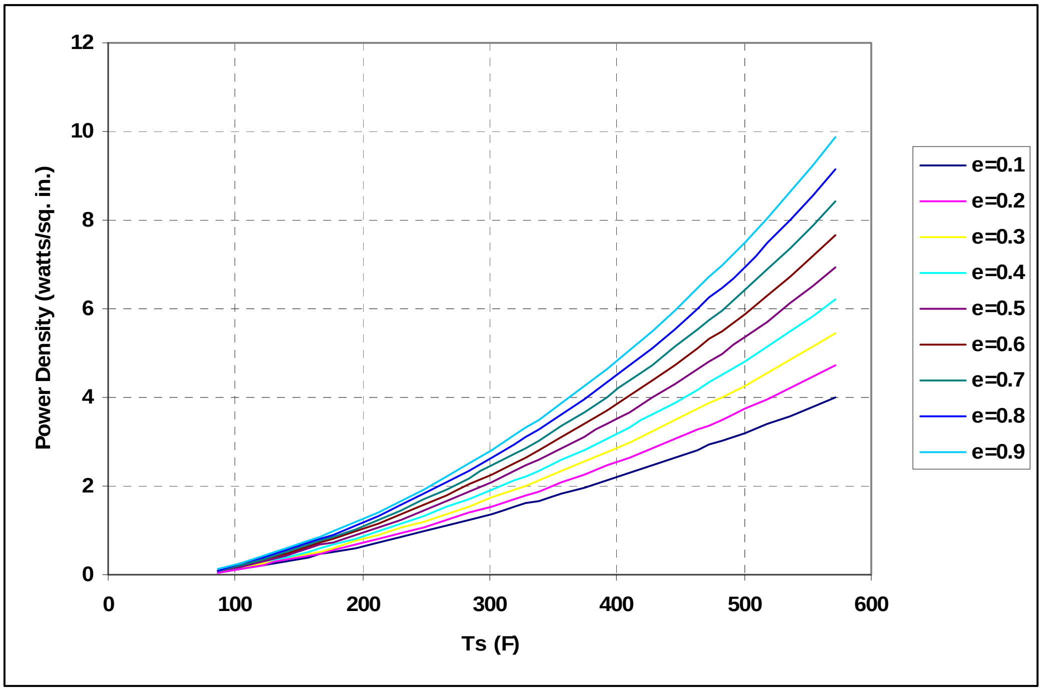


Figure 98: Power density curves vs. surface temperature for all emissivities

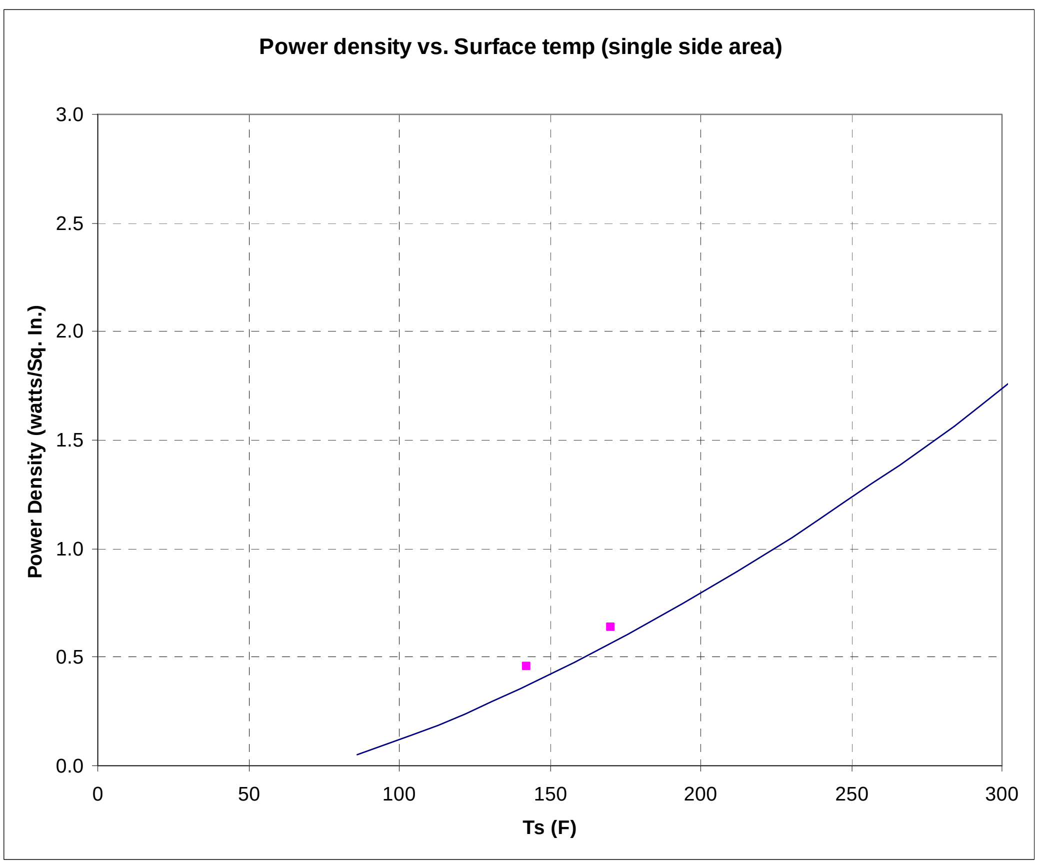


Figure 99: Comparison of prototype test to model, e=.33

CFD SIMULATION AND FINAL DESIGN

To optimize the design for temperature uniformity, size, thickness and heater placement we simulated the plate with CFX using the final design parameters: 14 in x 14 in x .078 in galvanized steel of 125 W per plate and desired surface temperature of ~175°F, and emissivity of 0.33. Figure 100-Figure 102 shows the results for several options. From these figures it is clear that the arrangement shown in Figure 102 provides the most uniform surface temperature for steel with an estimated minimum to maximum surface temperature difference of about 55°F and a maximum of at the heaters of ~205°F. Figure 103, which shows the same heater arrangement as Figure 102 but with 0.125 inch thick aluminum plate, we have included as a reference for the best uniformity; this temperature difference is about 35°F.

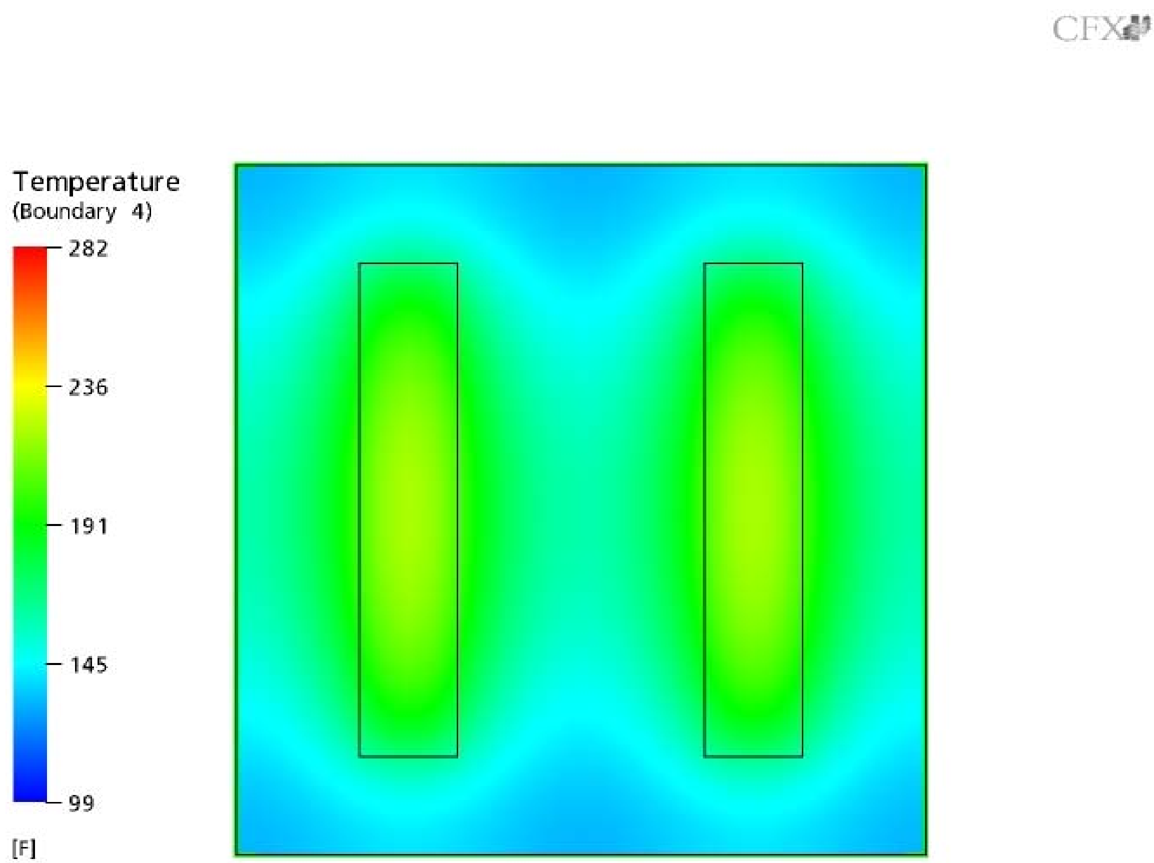


Figure 100: Two 2x10 inch heaters, 5-inches apart at 125 W total power input – 169°F average surface temperature

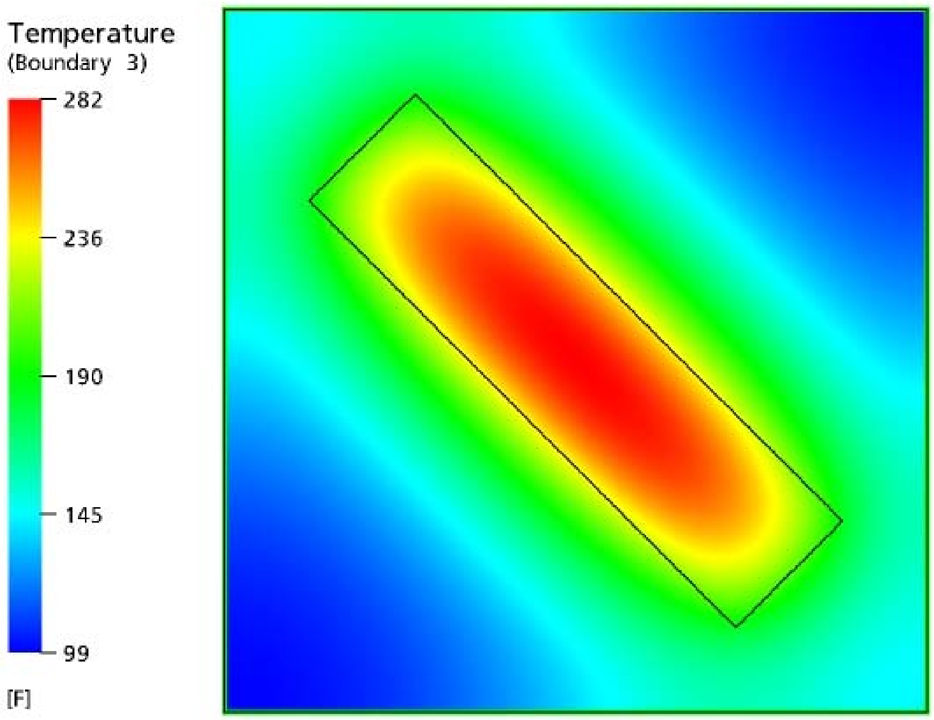


Figure 101: One 3x12 inch heater, diagonal at 125 W total power input – 166°F average surface temperature

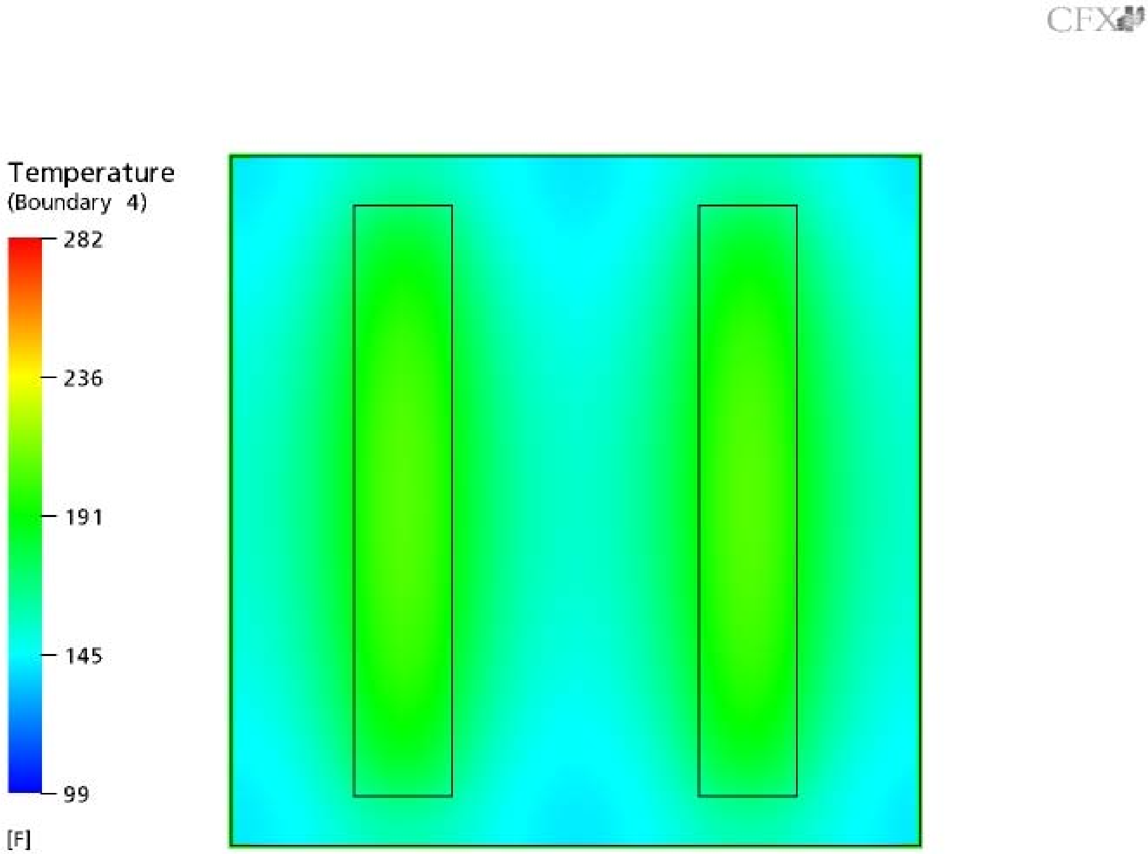


Figure 102: Two 2 x12 inch heaters, 5-inches apart at 125 W total power input – 167°F average surface temperature

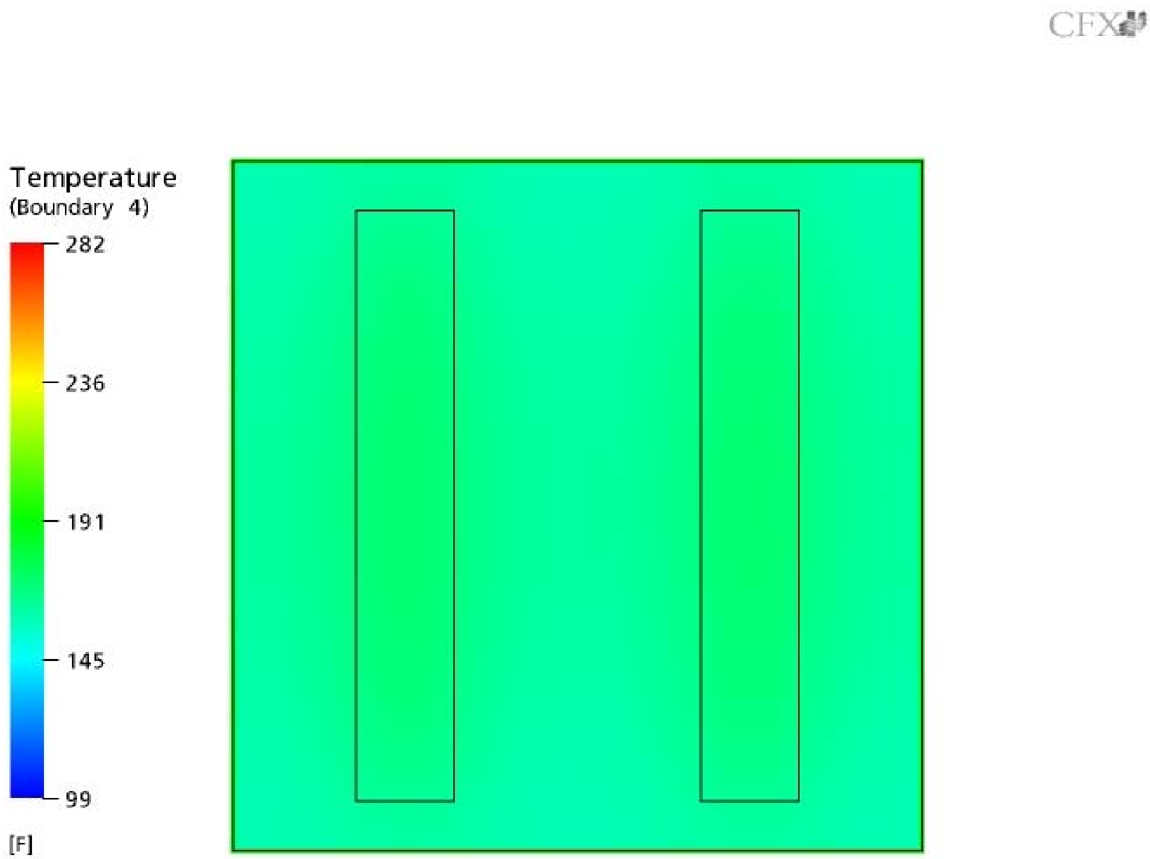


Figure 103: Aluminum 0.125” thick plate, two 2 x12 inch heaters, 5-inches apart at 125 W total power input – 167°F average surface temperature

Appendix B1 - Equations

Convective heat transfer

$$q_c = h_c A_s (T_s - T_\infty)$$

Where

h_c = convection coefficient

A_s = surface area

T_s = surface temperature

T_∞ = air temperature

The definition Nusselt number gives,

$$h_c = \frac{Nu_L \cdot k}{L}$$

Where

Nu_L = Nusselt number

k = thermal conductivity

L = characteristic length

Empirical correlation for external flow of vertical plate:

The correlation that may be applied over entire range of Rayleigh number (Ra_L) was recommended by Churchill and Chu (1975) and is of the form,

$$Nu_L = \left\{ 0.825 + \frac{0.387 Ra_L^{1/6}}{\left[1 + (0.492/Pr)^{9/16}\right]^{8/27}} \right\}^2$$

where

Ra_L= Rayleigh number

Pr = Prandtl number

The definition of the Rayleigh number is,

$$Ra_L = Gr_L Pr = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha}$$

Where

Gr_L = Grashof number

g = gravitational acceleration

β = volumetric thermal expansion coefficient

T_s = surface temperature

T_∞ = air temperature

L = characteristic length

ν = kinematic viscosity

α = thermal diffusivity

The radiative heat transfer of small object in a large cavity

$$q_r = \sigma\varepsilon A_s\left(T_s^4 - T_\infty^4\right)$$

where

σ = Stefan-Boltzmann constant

ε = emissivity of the small object

A_s = surface area

T_s = surface temperature

T_∞ = wall temperature, assumed equal to the air temperature

Ratio of radiation against total power

$$\frac{q_r}{q_c + q_r} = \frac{\sigma\varepsilon\left(T_s^4 - T_\infty^4\right)}{h_c\left(T_s - T_\infty\right) + \sigma\varepsilon\left(T_s^4 - T_\infty^4\right)}$$

Total power density

$$\frac{q_c + q_r}{A_s} = h_c\left(T_s - T_\infty\right) + \sigma\varepsilon\left(T_s^4 - T_\infty^4\right)$$

APPENDIX B2 - SPECIFICATIONS

INTRODUCTION

The following specifications are for artificial load devices to be used to generate thermal plumes equal to approximately half of the heat loads of a typical commercial office building workstation. Two devices will be installed at each workstation during commissioning of the underfloor air distribution system (UFAD) system to generate thermal plumes of the proper size and strength. One device shall be placed on the floor under the desk or work surface and one on the floor in front of the desk in the area where an employee would sit as shown in Figure 104. Loads shall be plugged into a 120 VAC source during testing.

Figure 104: Proper installation of two loads at one workstation.

DEVICE CONSTRUCTION

Each artificial load device should be constructed as follows:

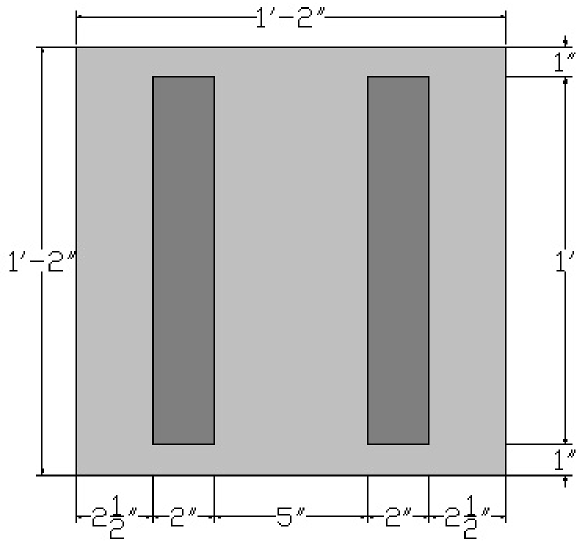


Figure 105: Assembly dimensions: 14” plate with correct placement of 2x12” heaters

Plate

Material: 14 ga. galvanized steel sheet metal

Size: 14 in. x 14 in. x .078 in. thick

Heating Elements

Quantity: 2 per plate, mounted on same side as shown in Figure 105

Material: silicon rubber heaters with 2 ft leads, 12 ga high temperature coating (per sample provided). (To be furnished with cord and 120 VAC male connector by client)

Size: 2 in x 12 in. each

Power Density: 62.5 W ± 3% per heater at 120 VAC (total of 125 W per plate)

Stand

Quantity: One per plate

Material: An insulating material such as wood

Size: Large and heavy enough to hold the device securely upright and off of the floor, ensuring that the hot plate surface does not contact carpet or furniture. Suggested dimensions are 5.5 in. x 5.5 in. x 1.5 in. (can be made from a standard piece of 2x6 lumber).

Groove: A groove .078 in. wide should be cut in the stand such that the device plate can fit tightly in. The groove must be deep enough to hold the plate upright but not so deep as to cover up a significant amount of the plate’s surface or contact the heating elements or leads wiring. No more than 0.5 in. of the heated plate should be covered by the stand when they are assembled. Suggested groove depth is 0.5 inch.

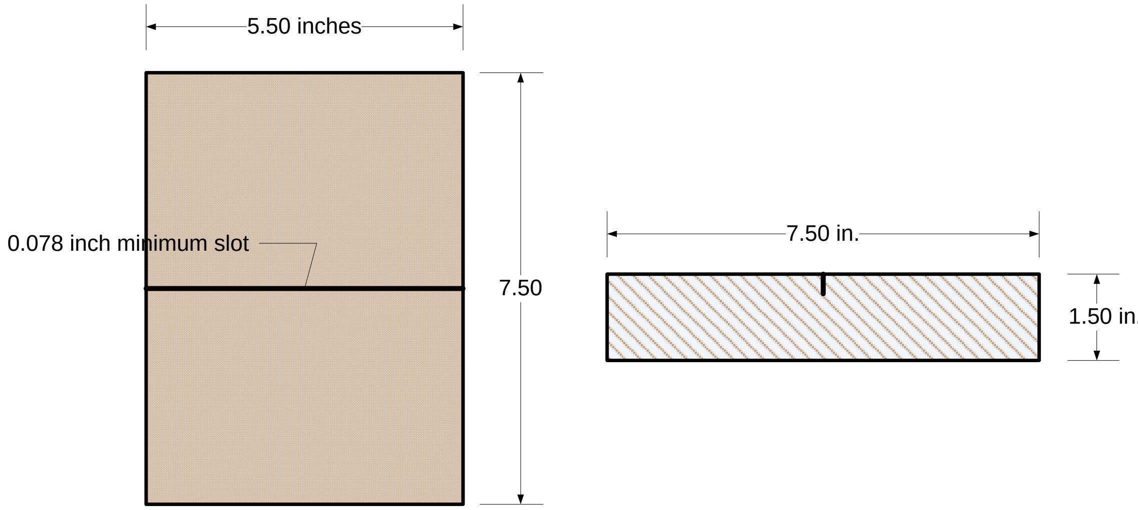


Figure 106: Stand Dimensions, view from top/plan view (left), view from side/elevation view (right)

ASSEMBLY

Layout: Heaters should be attached vertically with plug ends at bottom, and should be spaced 5 inches apart relative to the center line of the plate.

Adhesive: Heaters should be securely attached to plate with a monolithic coating of RTV adhesive (fully cover the back of each heater with RTV before attaching).

Wiring: the two heaters on each device should be connected in **parallel to achieve a total power per device of 125 W.**

Stand: Each assembled device should be placed securely in a stand such that the plate is roughly vertical and will not tip over when left alone.

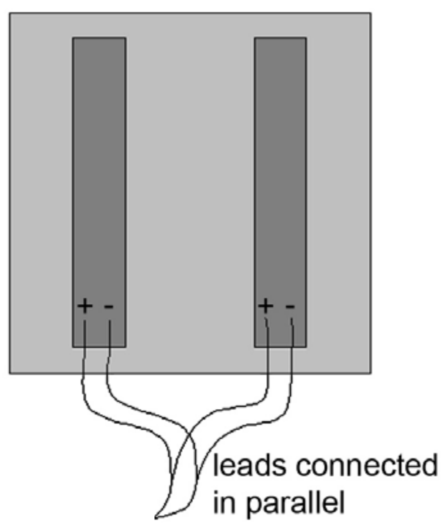


Figure 107: Schematic showing electrical wiring of device

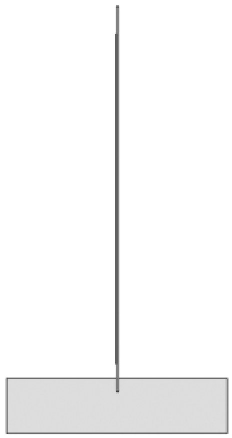


Figure 108: Schematic of heating plate mounted in stand (side view)