NE1: Seed of a living lab in NE1

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SCHOOL OF CONSTRUCTON AND THE ENVIRONMENT

April 29th, 2016

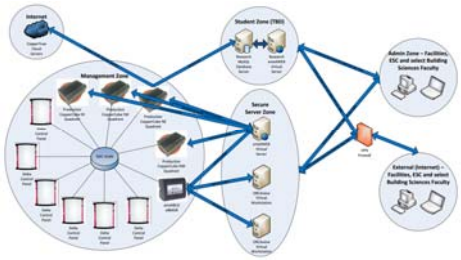
Objectives of the Project

- **Pressing Building Industry Needs for Sustainability:**
  1. Building performance measurement & verification (M&V)
  2. Building operation optimization (BOO)
  3. Building intelligence (BI)

  Little training available…
- **Opportunity:**
  - Use BCIT buildings for training & research on 1, 2, & 3
- **Objective:**
  - Plant the "seed" for using BCIT buildings for training & research on 1, 2, & 3

1 – Living Lab Tools Overview

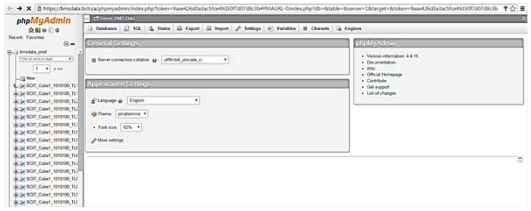
SCHOOL OF CONSTRUCTON AND THE ENVIRONMENT



Component #1: Enteliweb (Read Only)

Component #2: Kaizen (CopperTree)

Component #3: MySQL



BCIT

2 – Room NE1 - 216 Living Lab Case Study

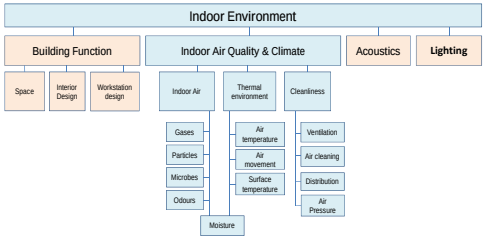
Lab: IEQ Measurement & Verification

BSCI 9170 Ventilation & Indoor Air Quality

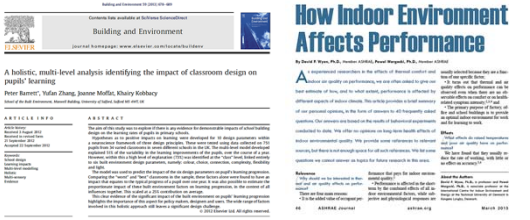
BUILDING SCIENCE GRADUATE PROGRAM

SCHOOL OF CONSTRUCTON AND THE ENVIRONMENT

Indoor Environmental Quality



Impact of IEQ on Performance



IEQ Measurement & Verification

Goal: to evaluate room IEQ by answering the following questions:

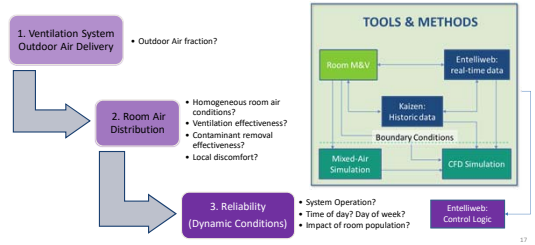
1. Ventilation: outdoor air (OA) control
   a) Is there enough amount of "fresh" outdoor air (cfm)?
   b) Is the outdoor air being delivered reliably (i.e. always?)
2. Is the outdoor air being well distributed inside the room? Is the room environmental quality uniform? Are there any stagnant air spots in the room?
   a) Thermal comfort: cold draft risks, thermal stratification
   b) IAQ: ventilation effectiveness, contaminant removal effectiveness
3. Are there any temperature drifts & ramps (i.e. exceedance hours)?
4. Is IEQ quality different in heating versus cooling?

Ventilation System

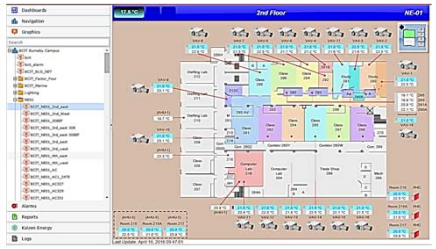
Why is Outdoor Air (OA) brought into a room?

1. OA is brought in for **ventilation/indoor air quality**
2. OA is brought in by the economizer "free-cooling cycle to meet cooling loads
3. OA is brought in to pressurize the building & control infiltration

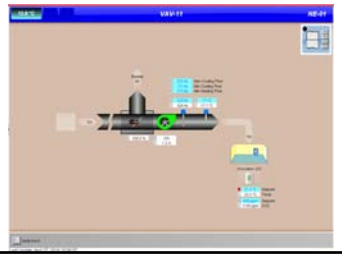
IEQ Assessment Process



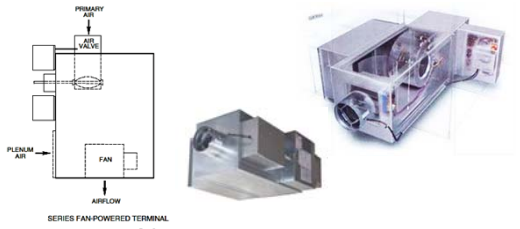
Case Study: NE1– classroom 216



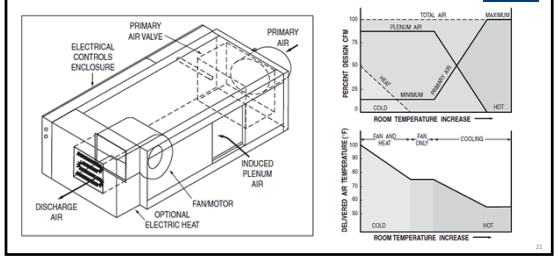
Ventilation System: VAV11



VAV11 – Series Fan Powered

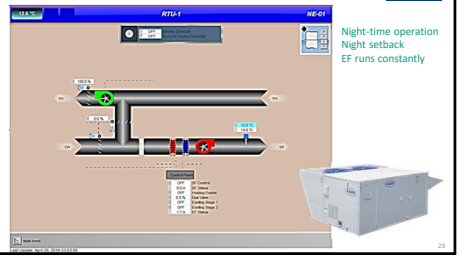


VAV11 Control Sequence

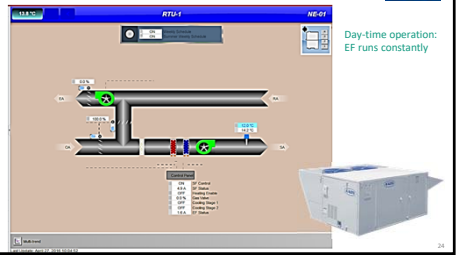


Ventilation System: VAV11 Trend Log

Ventilation System: RTU1

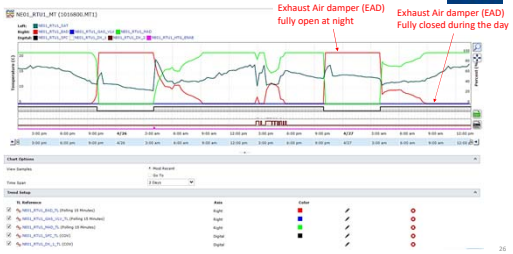


Ventilation System: RTU1

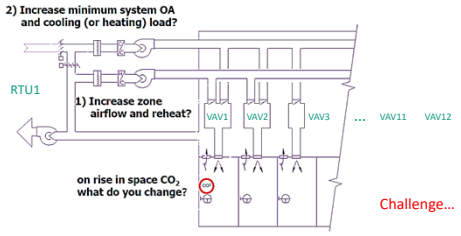


NE1 – RTU1

Ventilation System: RTU1 Trend Log

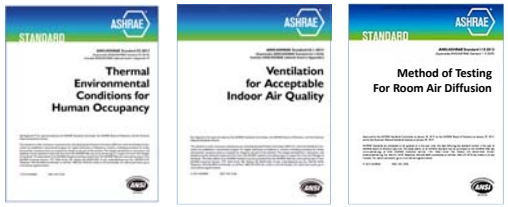


RTU1 Serves Multiple Zones: 12 VAVs



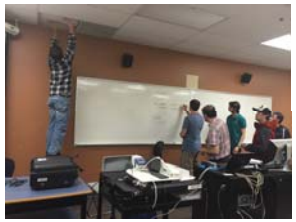
Question: How to Assess IEQ?

Protocols & Standards



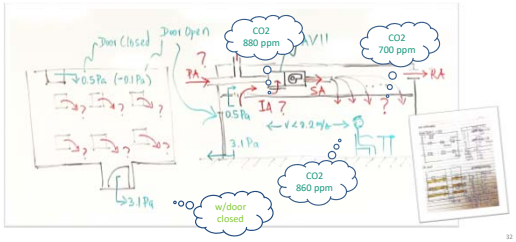
IEQ Measurement & Verification

Measuring Pressure Differential under the door…

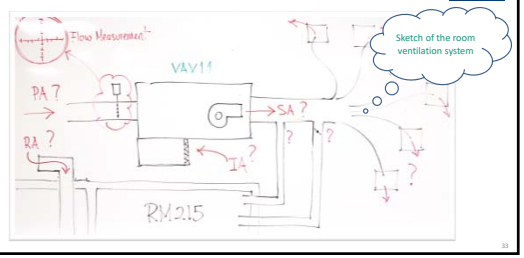


IEQ Measurement & Verification

IEQ M&V: Boundary Conditions



IEQ M&V: Boundary Conditions



Question: How Much Outdoor Air?

Outdoor Air Calculation

Quantitative Profile (Complete for Each Zone):

Outdoor air Calculations:

Outdoor air (in percent) = $((C_s - C_r)/(C_o - C_r)) \times 100$

C_s = ppm of carbon dioxide in the supply air

C_r = ppm of carbon dioxide in return air

C_o = ppm of carbon dioxide in outside air (at outdoor air intake)

Morning

Space/Zone	% Outdoor Air (See Above) A	Total Supply Air B	Number of Occupants (peak number)* C	Supply Air Per Occupant D = B/C D	Outdoor air per occupant** E = D x (A/100) E
	100 %	1152 cfm	44	26.18 cfm	26.18 L/s cfm

Afternoon

Space/Zone	% Outdoor Air (See Above) A	Total Supply Air B	Number of Occupants (peak number)* C	Supply Air Per Occupant D = B/C D	Outdoor air per occupant** E = D x (A/100) E
	100 %	1152 cfm	44	26.18 L/s cfm	26.18 L/s cfm

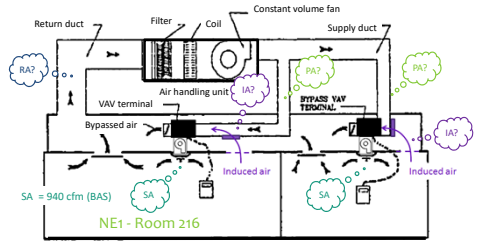
* For office space, a default value for peak occupancy may be estimated: = floor area (square feet) divided by 150.

** Should be compared with ASHRAE Standard 62-1989 (minimum of 20 cfm/occupant for office space)

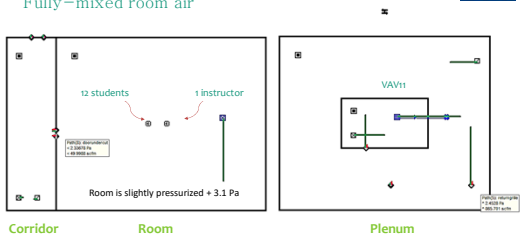
9.44 L/s

NE1 – Classroom 216

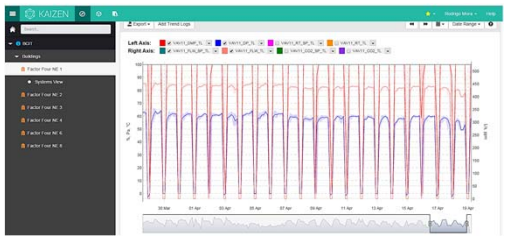
How much Outdoor Air?



Room Air & CO2 Balance Simulation:
Fully−mixed room air

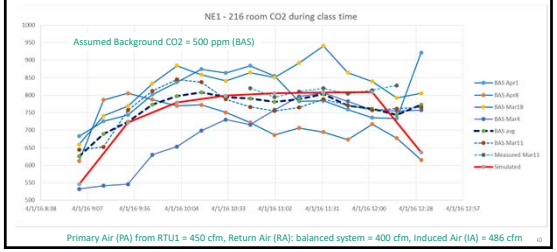


Historic BAS Data to Calibrate Simulations



Historic BAS Data to Calibrate Simulations

Simulation: fully−mixed room air
Calibrated model using BAS data



Primary Air (PA) from RTU1 = 450 cfm, Return Air (RA): balanced system = 400 cfm, Induced Air (IA) = 486 cfm

Outdoor Air (OA) fraction?

OUTDOOR AIR REQUIREMENTS [ASHRAE STANDARD 62.1-2013]

ASHRAE 62.1:	l/s/person	l/s/m2		
Requirements:	5	0.6	Room area:	90.25 m2

Room population	Occupants (L/s)	Area (L/s)	Total OA (L/s)	Total OA (cfm)	
12	60	54.15	114.15	242	Required for 12 people
30	150	54.15	204.15	432	Required for 30 people

OUTDOOR AIR ESTIMATED BASED ON OCCUPANCY & CO2 CONCENTRATION

$$Q_o = \frac{r}{(C_s - C_o)} = \frac{0.25\ L/min}{(0.00082 - 0.0004)(60s/min)} \approx 10\ L/s \approx 20\ cfm/person$$

Outdoor Air estimated for 12 people = 240 cfm (to maintain steady-state CO2 concentration = 820 ppm)
Calculated Room Primary Air (PA) = 450 cfm (from fully-mixed room air simulation)
Estimated Outdoor Air Fraction = 53%

The same amount of OA is maintained for a room with 30 people. Therefore the resulting CO2 concentraiton should be:
CO2 concentration with 240 cfm OA for a room with 30 people = 921 ppm (OA fraction = 53%)

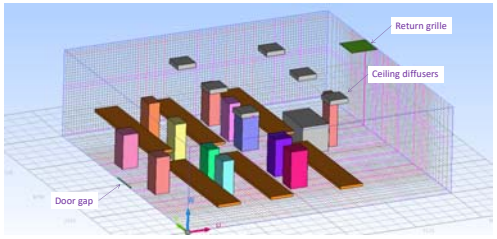
Question: Room Air Distribution?

CFD Simulation
Room Air distribution: Local IEQ / Microclimates

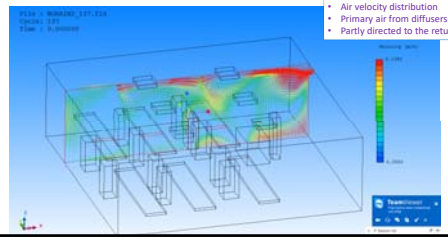
Model Calibration:

- Measure:
  - Room air temperatures in a grid pattern
  - Air speeds in grid pattern
  - CO2 in supply, return, and occupancy area
  - Wall temperatures (infrared camera)
  - Supply & return air temperatures
  - Supply & return air flows
  - Air pressure differentials at door undercut & other openings
- Obtain BAS data during this period

CFD Simulation
Room Air distribution: Local IEQ / Microclimates



CFD Simulation
Cooling
Room Air distribution: Local IEQ / Microclimates



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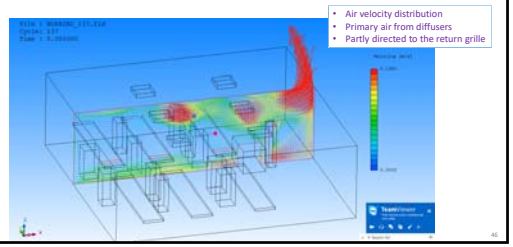

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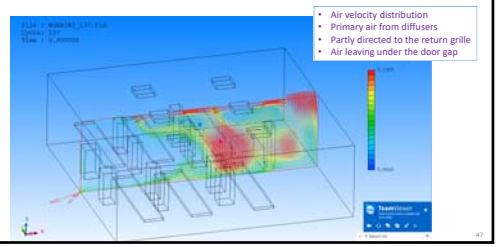

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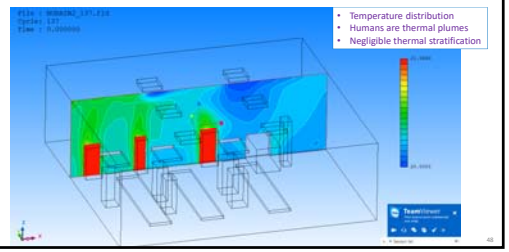

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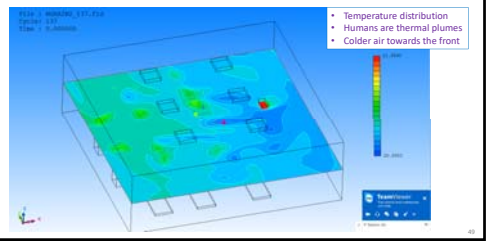

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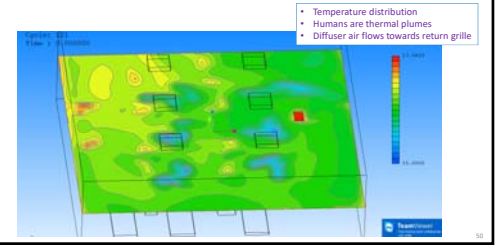

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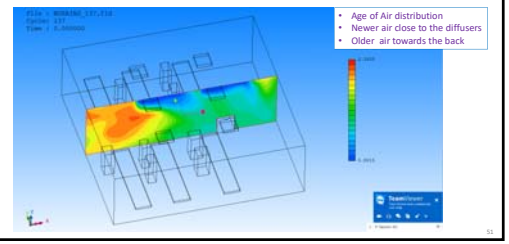

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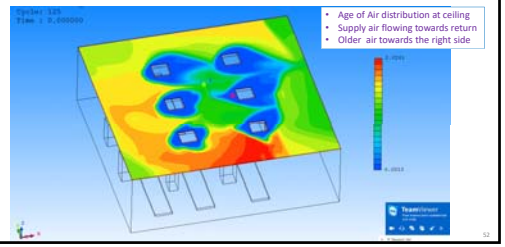

CFD Simulation
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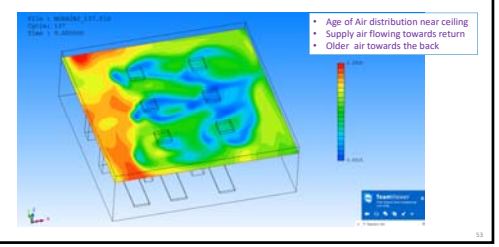
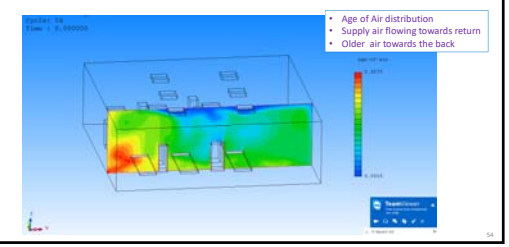


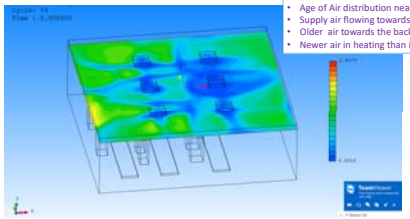
CFD Simulation
Heating
Room Air distribution: Local IEQ / Microclimates



CFD Simulation

Heating

Room Air distribution: Local IEQ / Microclimates



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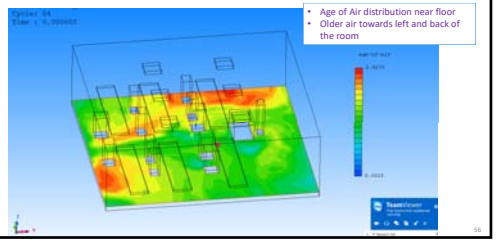


ASHRAE Standard 55:

Dynamic: Temperature Drifts & Ramps

Over a period no greater than 15 minutes...

Allowable Cyclic Operative Temperature Variation

Allowable Peak-to-Peak Variation in Operative Temperature, °C (°F)
1.1 (2.0)

Over a period exceeding 15 minutes...

Limits on Temperature Drifts and Ramps

Time Period, h	0.25	0.5	1	2	4
Maximum Operative Temperature Change Allowed, °C (°F)	1.1 (2.0)	1.7 (3.0)	2.2 (4.0)	2.8 (5.0)	3.3 (6.0)

Conclusions

- The IEQ in the room seems acceptable (for 12 people)
- The air in the room is homogeneous
- The air speeds are generally low, below 0.2 m/s
- No thermal stratification or cold air drafts
- The CO2 concentration is acceptable for a low occupancy of 12 people. How about a full occupancy, i.e. 30 people?
- Age of air is acceptable
- Possible stagnant air spots in the back & sides of the room
- Next Occupant Perception/Satisfaction surveys

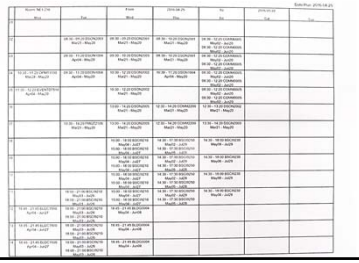
Question: What Happens when the Room is Full?

Effect of Room Population

- BSCI 9170 is a small class: 11 students + instructor = 12
- NE1–216 has capacity for about 30 people!
- Can we assess the room IEQ under full occupancy?

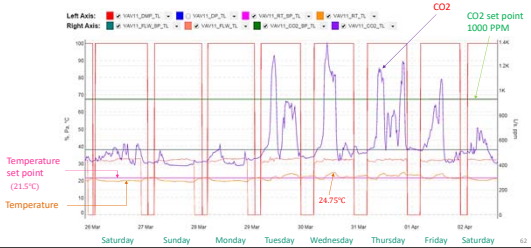
- Need historic data on room air temperature & CO2

Timetable Room for NE1–216

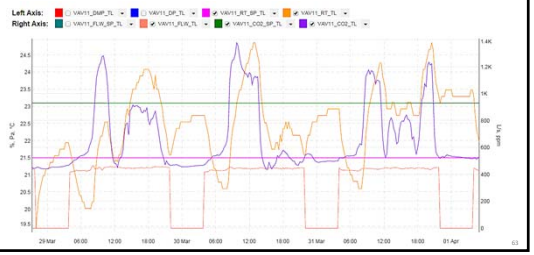


Room weekly IEQ profile:

NE1–216 March 26th to April 2nd



A Closer Look at March 29th, 30th, 31st



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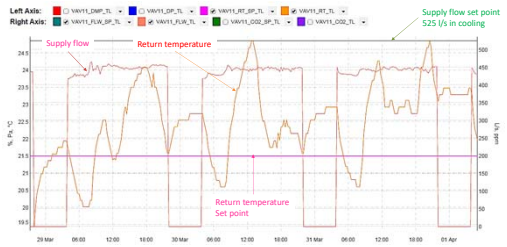
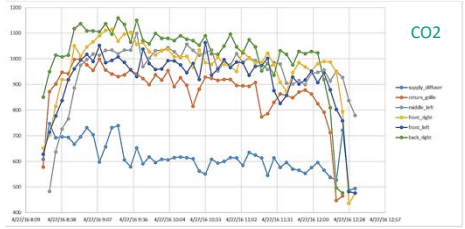
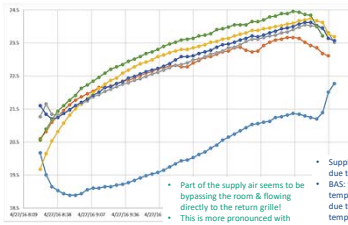


Measurements
Full Wednesday Morning class: 8:30 to 12:30



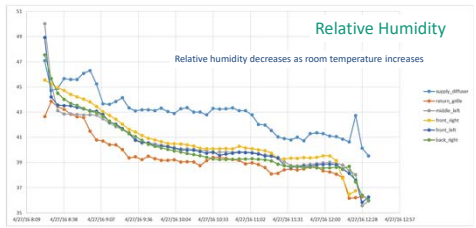
Part of the supply is bypassing the room & flowing directly to the return grille (confirms CFD)!

Measurements
Full Wednesday Morning class



- Part of the supply air seems to be bypassing the room & flowing directly to the return grille!
- This is more pronounced with warmer supply air
- Supply temperature increases due to induced room air
- BAS: the RTU1 supply temperature is also increasing due to increasing outdoor air temperature
- Free-cooling: no refrigeration

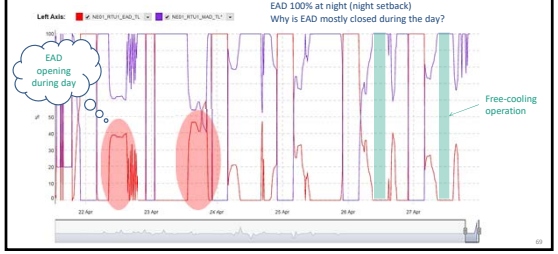
Measurements
Full Wednesday Morning class



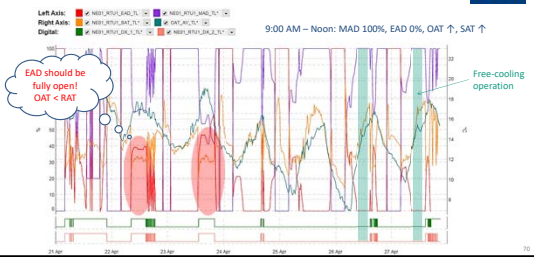
Question: Reliability under Dynamic Conditions?

System-level Operation...

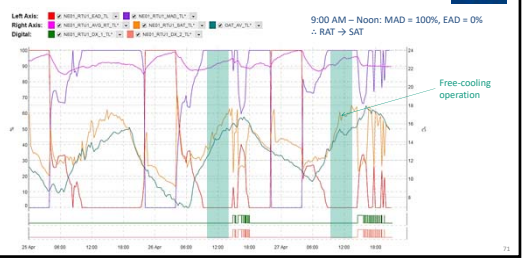
RTU1 – EAD & MAD Operation



RTU1 – EAD & MAD Operation



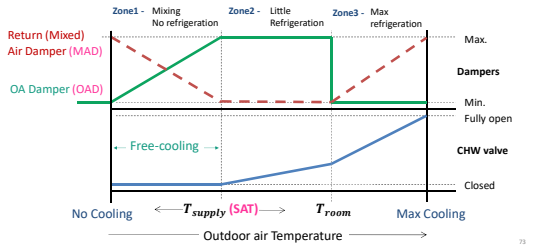
RTU1 – EAD & MAD Operation



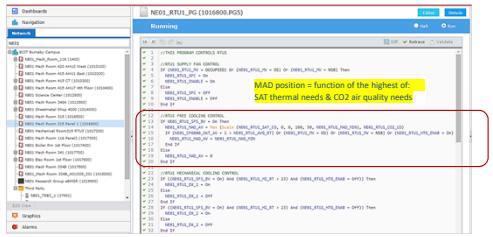
Why Is Outdoor Air Damper (OAD = EAD) at minimum During High Demand for outdoor air?

- MAD ↔ EAD (OAD) logic operation is designed to meet the highest of two needs:
- **Thermal zone needs:** free−cooling operation
  - Supply Air Temperature (SAT) responds to the thermal needs from the zones
- **Indoor air quality needs:** highest CO2 feedback from all the zones (VAVs served by the RTU)
  - RTU1 serves 12 VAVs
- Logic:
  - If SAT is too high versus SAT set point, then
    Cool more, i.e. bring more outdoor air, close MAD
  - If CO2 feedback is too high versus CO2 set point, then
    Bring more OA, i.e. close MAD

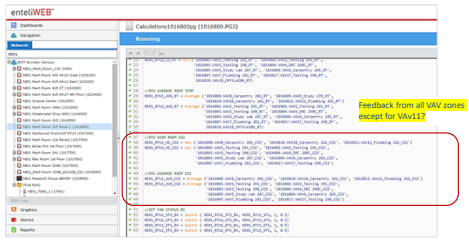
RTU1 - Free Cooling Control



RTU1 - Free-Cooling Operation Control

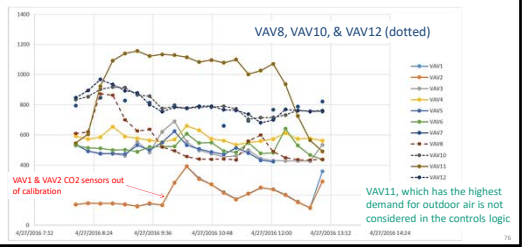


RTU1 - IAQ CO2 Control

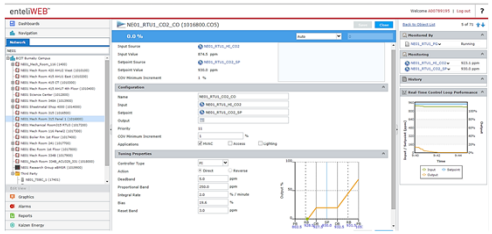


RTU1 - CO2

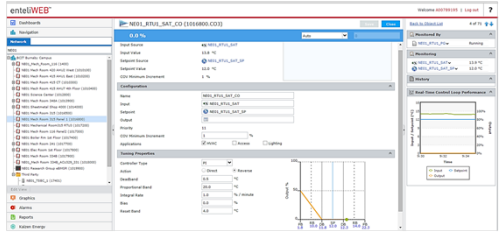
High Limit is based on 3 VAVs Only:



RTU1 – CO2 Control



RTU1 - SAT Control



Conclusions

- The study was conducted in the spring, under prevailing free-cooling HVAC operating conditions
- Under low occupancy, the room IAQ is acceptable
  - Proof: no complains from students or instructor
- Improvements in room air distribution can be made
  - E.g. four small return grilles laid out to replace single one
- Under full occupancy the IAQ declines
  - It seems that the controls system is not responding adequately to the space demands in free-cooling operation:
    - SAT: MAD has direct relation to SAT, should be inverse... further work...
    - CO2: MAD has direct relation to CO2, should be inverse... further work...
- In general, the OAD is not opening enough as it should when occupied: i.e. zones 1 & 2 of free-cooling cycle

Next Steps

- Deeper study of control logic of the whole multi-zone system served by RTU1
- Study RTU & VAV control sequences
- Study the pressure dynamics in the duct system
- Pressure independent VAV?
- Study operation of all the VAVs (zones) services by RTU1
- Maybe the reheat zones are controlling the amount of outdoor air. These zones are at the perimeter & need heating
- Are there any VAV zones starving?
- Automated Fault-Detection & Diagnostics (AFDD) algorithms
- Work with BCIT Facilities to learn while helping optimize systems' operation though course and research projects