A Mechanical Engineer's Perspective on Electrical System Commissioning

Experiences and Insights Regarding Power System Integrity and Recovering from Power Failures

Presented By:
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Facility Dynamics Engineering

What We'll Cover

- The relationship between the integrity of building mechanical systems and the utility systems serving them
  - Electrical power
  - Other utilities
    - Gas
    - Chilled or hot water and steam
    - Transportation
    - Domestic water
    - Storm water and sewage

Our Perspective

- Fundamental principles
  - Basic physics
  - Common M/E concepts
- Lessons learned from experience
  - Reinforce fundamental concepts
  - New perspectives on fundamental concepts
- Insights for future improvement

Bottom Line

- Power failures ***will*** happen
- The building ***will*** recover when power is re-applied

- The only question:

So tell me, how did that work for you?

Image courtesy of Michael Fewings at http://www.strikeone.com.au/index.

How do you Define a Power Outage?

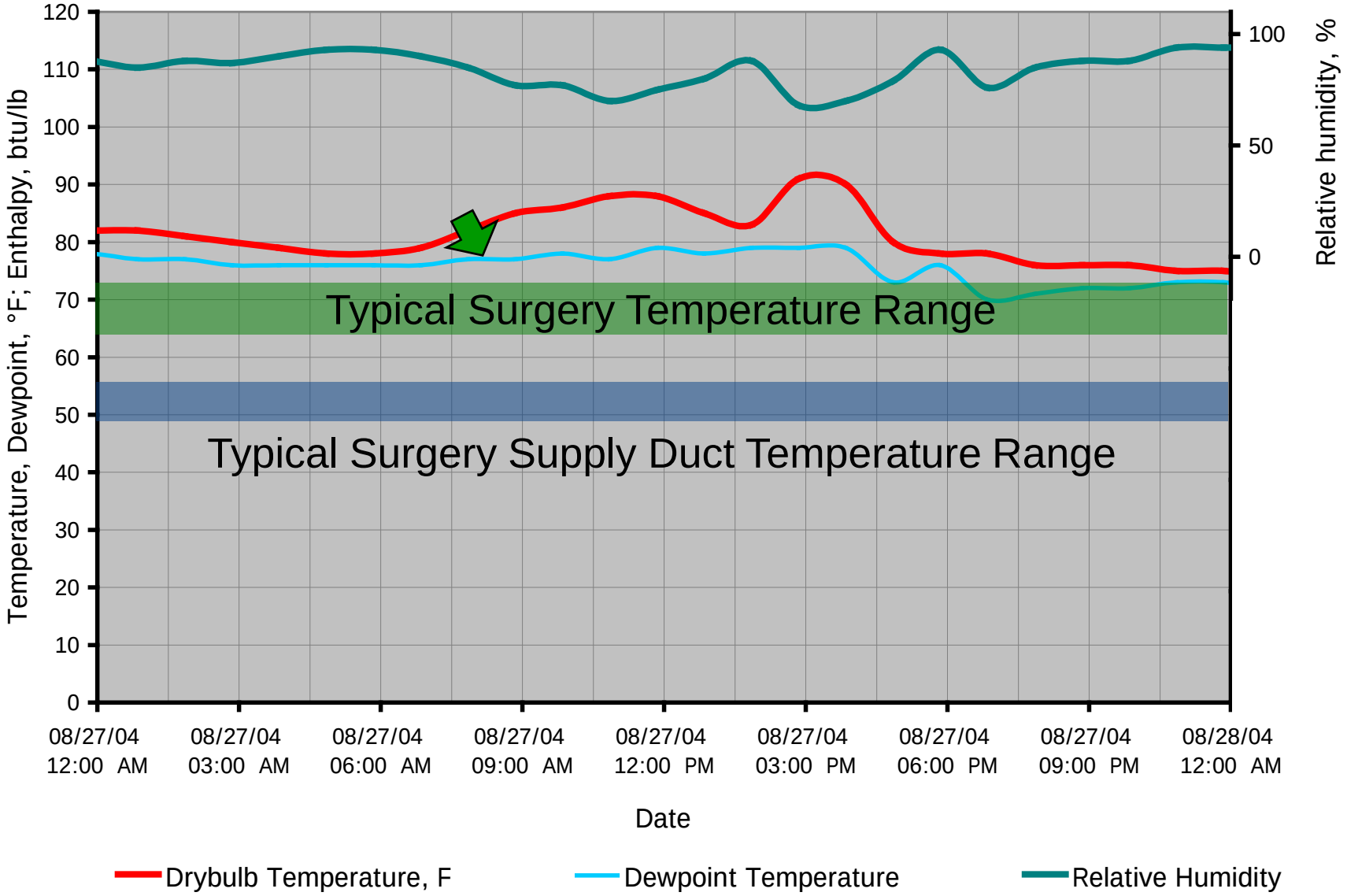
It’s a matter of your perspective

- Location of the outage
- Impact of the outage
- Ripple effects of the outage

An Example

The Setting

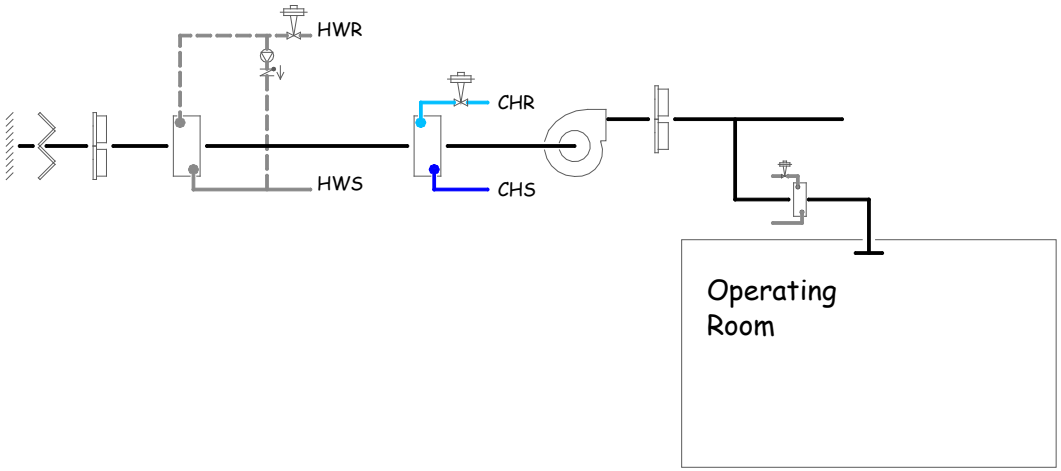
- Southern Illinois Hospital
- Hot, humid August afternoon
- Thunderstorms in the area


St. Louis Airport ASOS Data
August 2004
Temperature, Dewpoint, °F; Enthalpy, btu/lb
Relative humidity, %
120
110
100
90
80
70
60
50
40
30
20
10
0
100
50
0
Typical Surgery Temperature Range
Typical Surgery Supply Duct Temperature Range
08/27/04 12:00 AM
08/27/04 03:00 AM
08/27/04 06:00 AM
08/27/04 09:00 AM
08/27/04 12:00 PM
08/27/04 03:00 PM
08/27/04 06:00 PM
08/27/04 09:00 PM
08/28/04 12:00 AM
Date
Drybulb Temperature, F
Dewpoint Temperature
Relative Humidity

An Example

The System

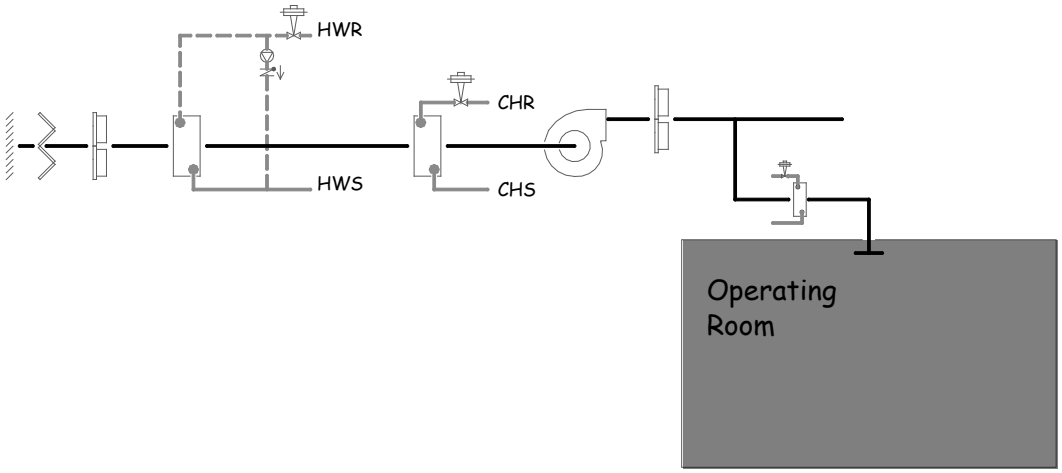
- Surgery AHU
- 100% outdoor air
- Chilled water cooling



An Example

The Event

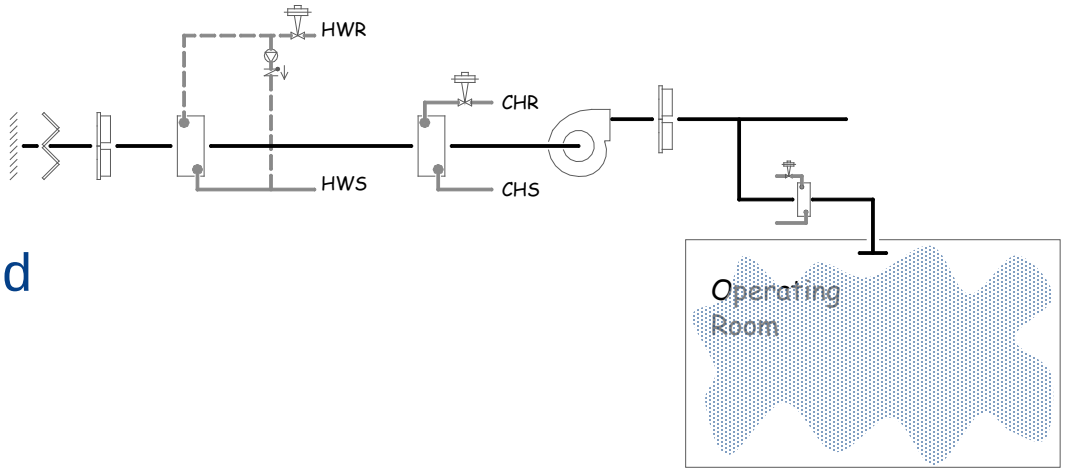
- Lightening strike knocks out the utility
  - No fan
  - No lights
  - No chilled water
- Hospital generator starts and picks up the load quickly



An Example

The Result

- Surgery lights On
- Surgery fan On
- Hot, humid air meets cold surfaces
- Rain in the OR
- Condensation on sterile supplies
- New perspective on recovering a Surgery AHU from a power outage



Lesson 1

- Restoring electrical service after a power outage can have undesirable results:
  - Electrical power is critical; thermal utilities can run a close 2nd
  - Multiple, different HVAC systems are required to control thermal and psychrometric relationships
  - Most HVAC systems run on electrical power
  - Electrical power has a direct bearing on the thermal and psychrometric relationships controlled by the HVAC systems

Lesson 2

- The functions occurring in the location impacted by a power outage need to be considered when power is restored
  - Will the recovery power source address all of the critical issues?
  - Is there a critical sequence for recovery?

Power Outage Locations

- Area wide
- Building wide
  - The central plant may be in a different building
- Localized
  - Fuse or circuit breaker trip
  - Motor failure
  - Controller failure
  - Belt or coupling failure
  - Operator error

An Example

Scrubbers critical

- Clean effluent
- Safe facility

Redundant fans = improved integrity

- Design concept

One fan fails;

the other fan starts

An Example

Scrubbers critical

- Clean effluent
- Safe facility

Redundant fans = improved integrity

- Operating reality
  - *Time delay between fan failure and back-up start = Loss of flow*
  - *Loss of flow = unsafe fab*
  - *Unsafe fab = evacuation*

Fab evacuation = $10,000 lost!

An Example

Scrubbers critical

- Clean effluent
- Safe facility

Redundant fans = improved integrity

- Operating solution
  - *Run both fans*
  - *One fan fails = 75% flow*
  - *75% flow = no fab evacuation*

No fab evacuation = happy production managers!

Lesson 3

- There are other things that can fail which will look like a power failure to the building and occupants
- Operating procedures can mitigate the impact of a power failures, especially a localized power failure, regardless of the cause
- Mitigation is good!
  - Mean time between failure running one fan with the other on standby – 2 to 3 months
  - Mean time between failure running one fan with the other on standby – 2 to 3 *years*

Some Systems Take Their Lesson Teaching Roll Quite Seriously

The Air Handling Unit From

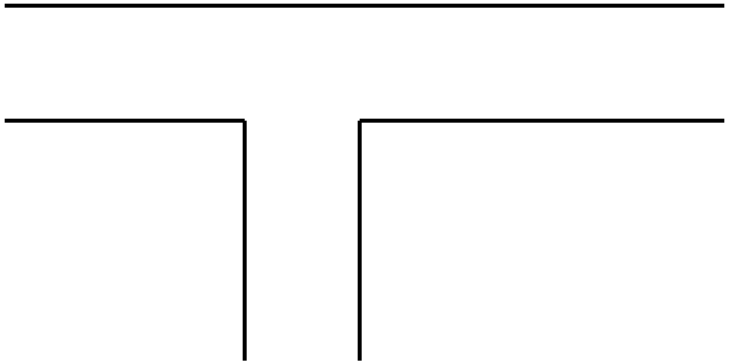

04/01/98

Mechanical and Electrical Commonalities

Both require some sort of pathway to establish and contain flow

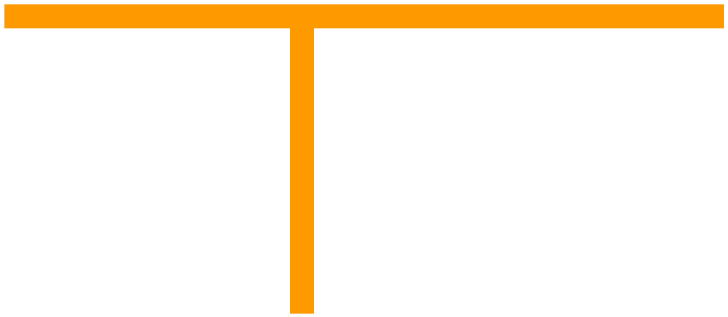
Mechanical

- Mass in pipe or duct



Electrical

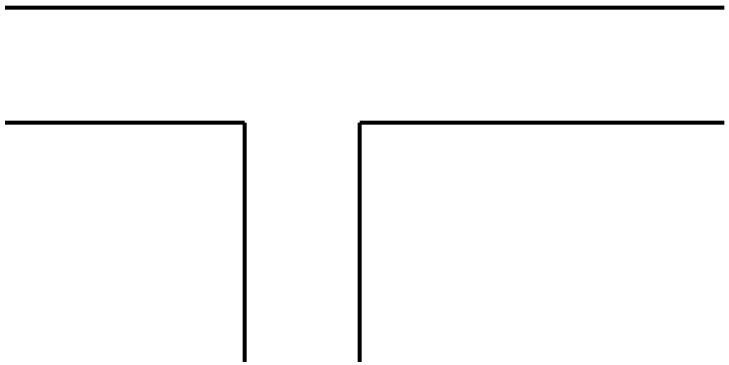
- Current in wire or cable



Conservation of Mass and Energy:
Fundamental Mechanical and Electrical Concepts

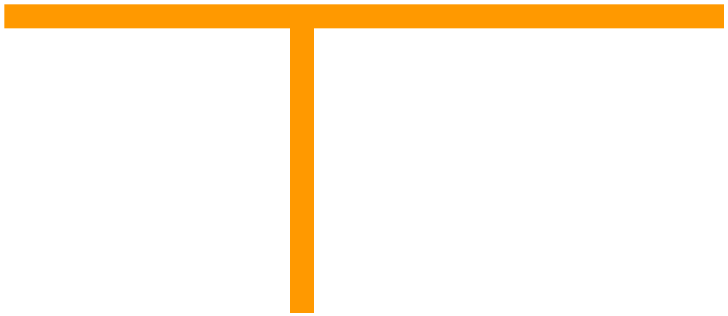
Mechanical

- Mass flow into a junction will equal the mass flow out of a junction



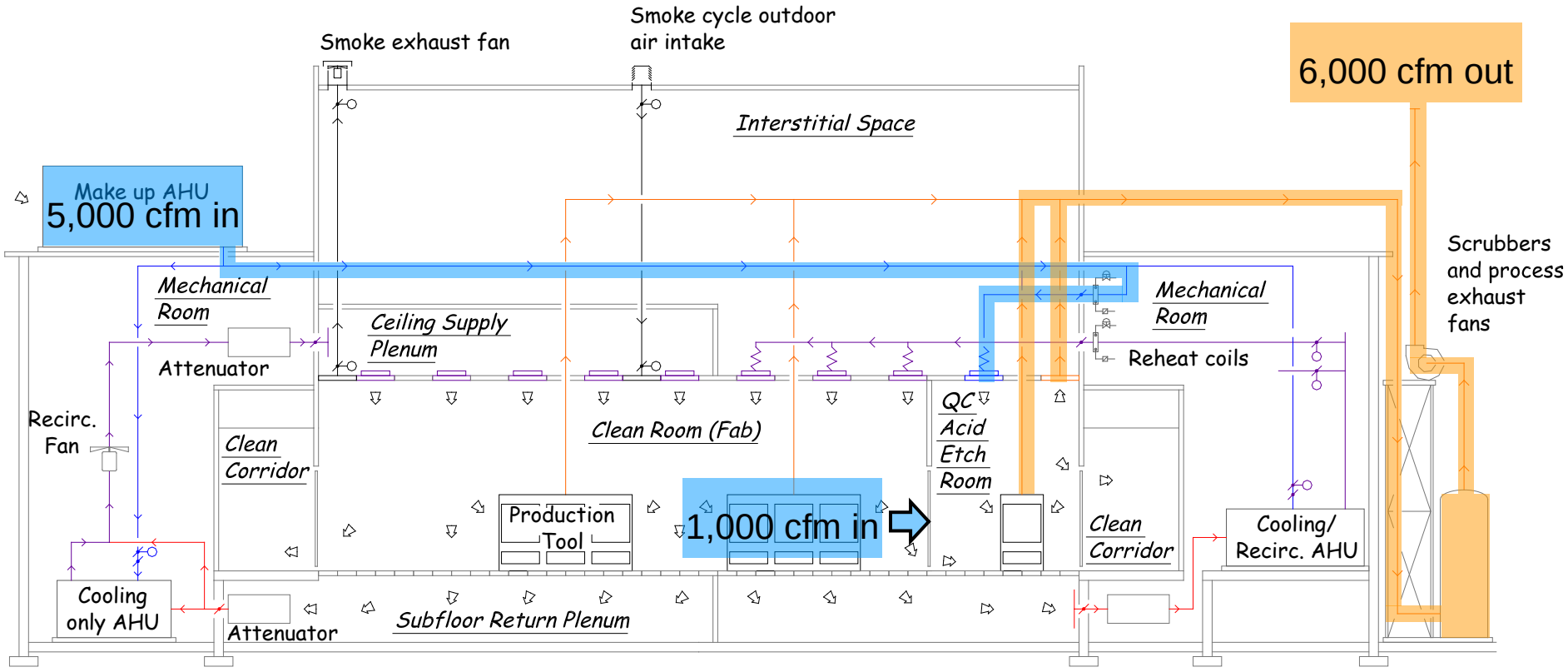
Electrical

- Current flow into a junction will equal the current flow out of a junction

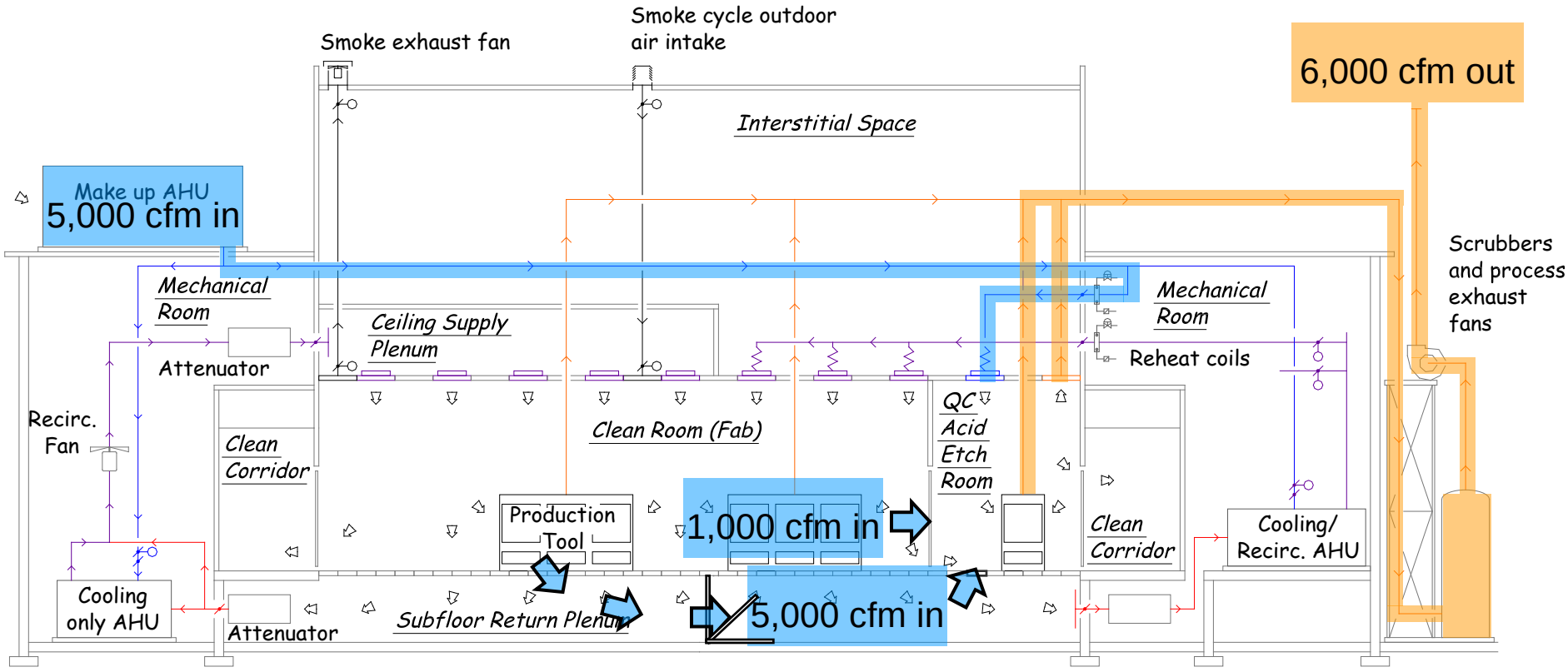


The System, Brian, and I Meet for the First Time

A Demonstration of Fundamental Principles



A Demonstration of Fundamental Principles

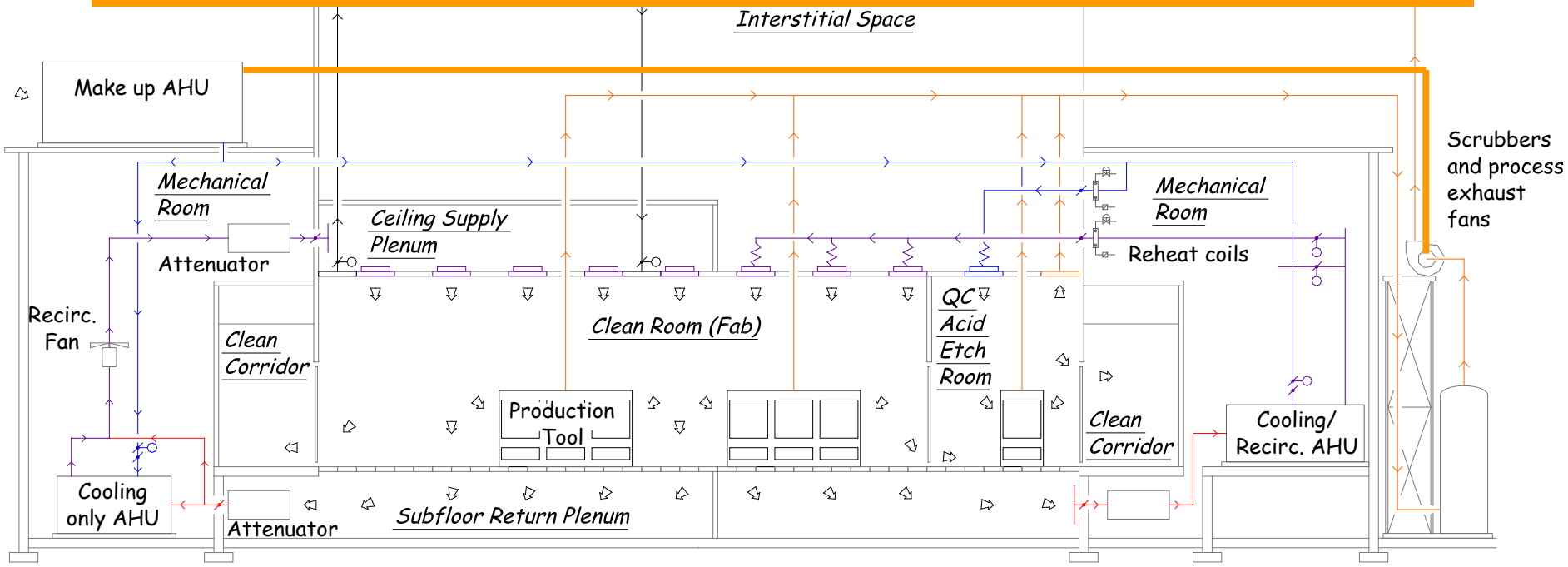


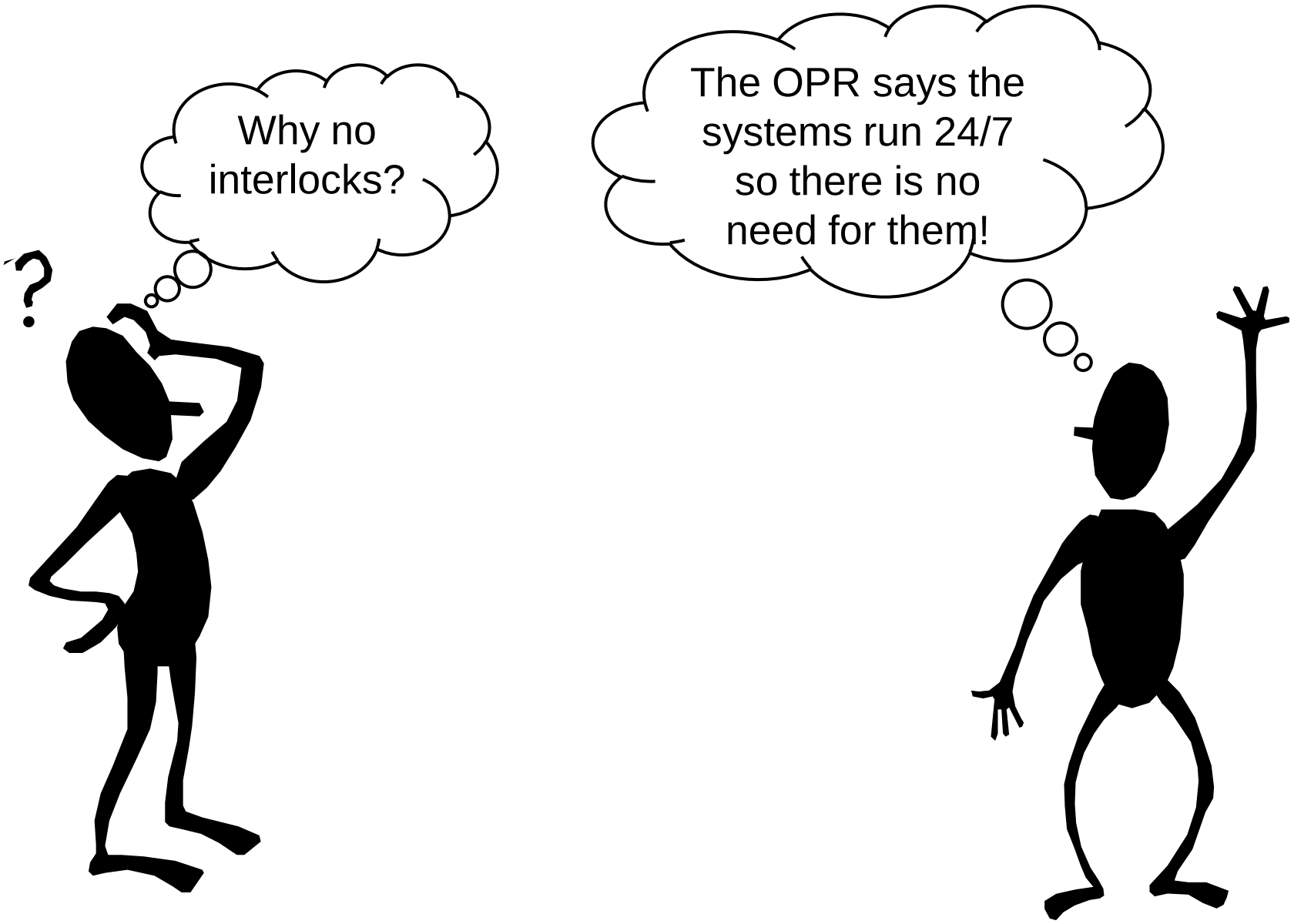
The Enabler for the Demonstration

No electrical pathway between the make up unit and the process exhaust =

No current flow between the make up and process exhaust =

NO INTERLOCKS between the make up and process exhaust




Why no interlocks?
The OPR says the systems run 24/7 so there is no need for them!

Lesson 4

- The Goes Inta's *WILL* equal the Goes Outa's
  - Uncoordinated flow = undesirable pressure
  - Power and equipment failures can caused severe pressure fluctuations in the clean room
    - Contamination issue
    - Safety issue
    - Restart issue

Lesson 5

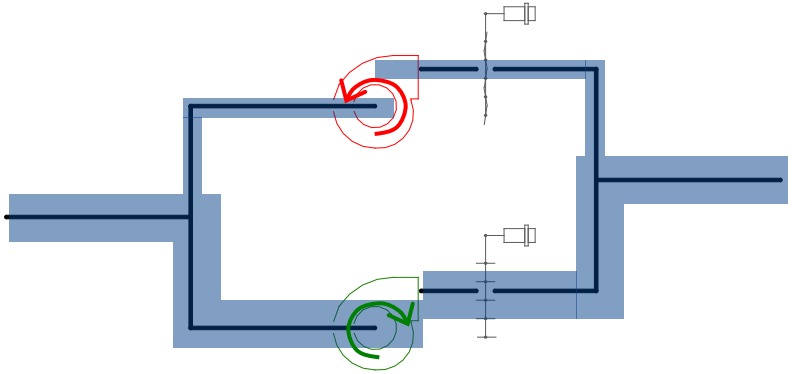
- Equipment failures can have an impact similar to a localized power failure
- The impact of a localized power failure or equipment failure can be more devastating than a total power outage

Lesson 6

- Power failures and similar phenomenon need to be considered at design;
  - Mechanical/electrical engineering coordination is important
  - Owner's Project Requirements should not be interpreted literally
  - Murphy will introduce scheduled operation even if you don't plan to do it
- Design intent should be monitored during construction

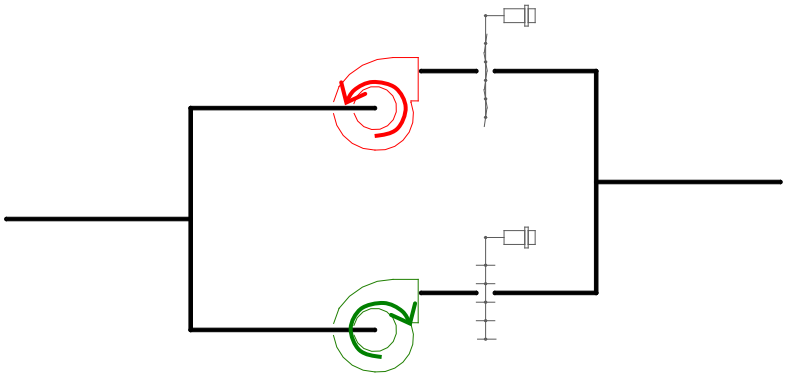
Round 2

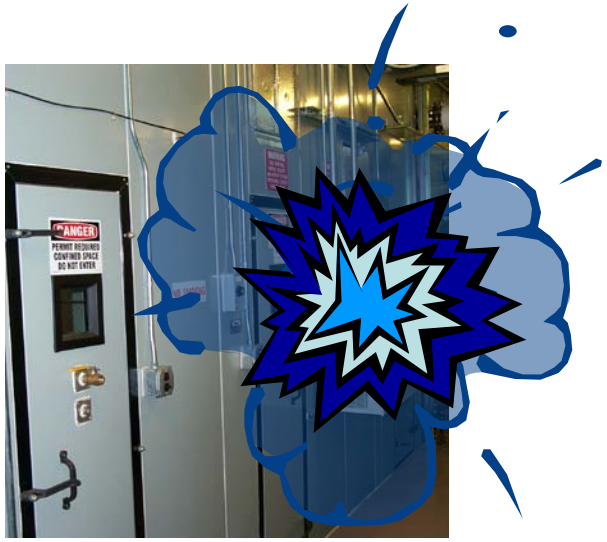
- The set-up
  - Parallel fans
  - Back draft damper equipped
  - VFD equipped
  - One fan running
  - Dampers not perfect
    - Dampers leak
    - Fan spins backwards



Round 2

- Spinning motors not connected to the grid are generators
  - Out of phase
  - No voltage regulation
- If a VFD is engaged against a reverse spinning motor
- And the VFD has not been programmed properly
- Then the magic blue stuff in the drive gets released





A Related Topic

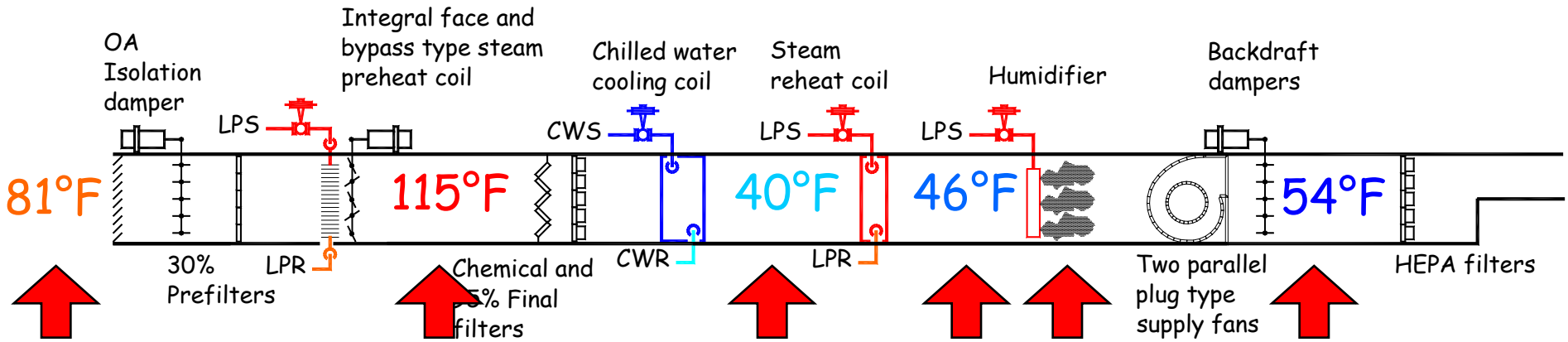
- Spinning fans represent stored energy in the form of rotating mass
- Engaging a spinning fan motor across the line:
  - Immediately synchronizes the motor speed with the grid synchronous speed
  - Breaks belts
  - Shears shafts and hub bolts
  - Causes fan wheels to exit the AHU casing

Lesson 7

- Drive and starter control and programming can be critical
  - Recovery mode after a power failure
  - DC injection braking before starting
  - Time delays between speed changes for multi-speed motors
- Training and placarding are important
  - Factory representatives may understand drives but not HVAC equipment and system dynamics

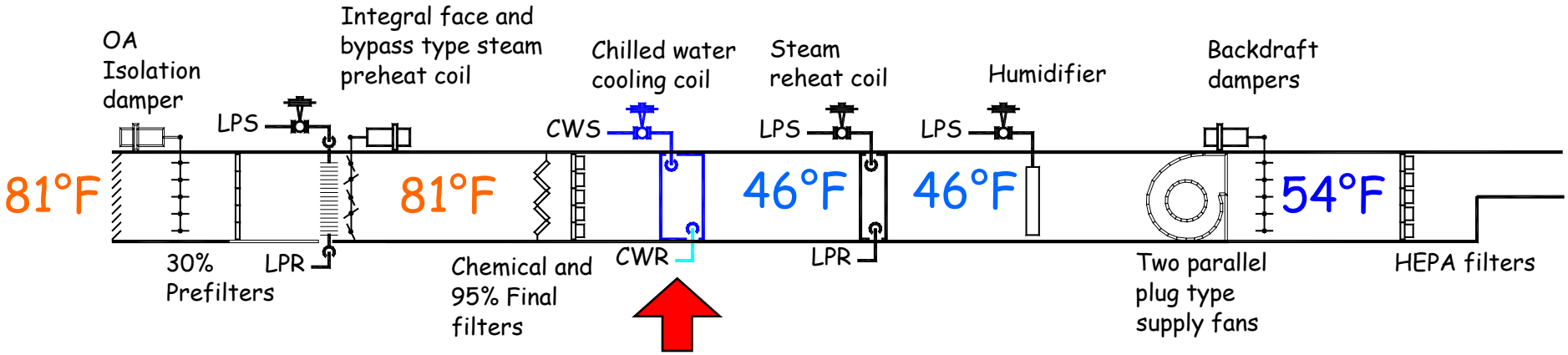
Round 3

The space is under control so everything's fine, right?



- Clean room conditions on spec at 68°F, 1/-1-1/2°F, 45% +/-3% relative humidity.
- Entropy of the Universe – Going Up a bit faster than necessary!

Making Sense Saves Cents



- Reduced operating cost – about $7,000 per month
- Cost of corrections:
  - About $500 in parts
  - 80-100 man hours of labor

See *Commissioning to Meet Space (Clean Room) Qualification Criteria vs. Energy Consumption Optimization Focused Commissioning* at www.PECI.org for a paper that looks at this in more detail

Lesson 8

- Commissioning procedures and efficiency will often take back seat to business and financial pressures
- Contractual boundaries do not make good operating boundaries

Power Sources

- Normal power
  - Provided by a public or private utility company
  - Single source or multiple feeds for each site
  - Reliable, but not perfect
    - Thunder storms
    - Ice storms
    - Interactions with automobiles and trucks
    - Operator errors

Power Sources

- Emergency generators
  - Cover public utility failures
  - Typically start and assume the load in 10 seconds or less
  - Capacity targeted to critical loads
    - Life support
    - Patient care
    - Critical processes
  - Still a momentary loss of power

Power Sources

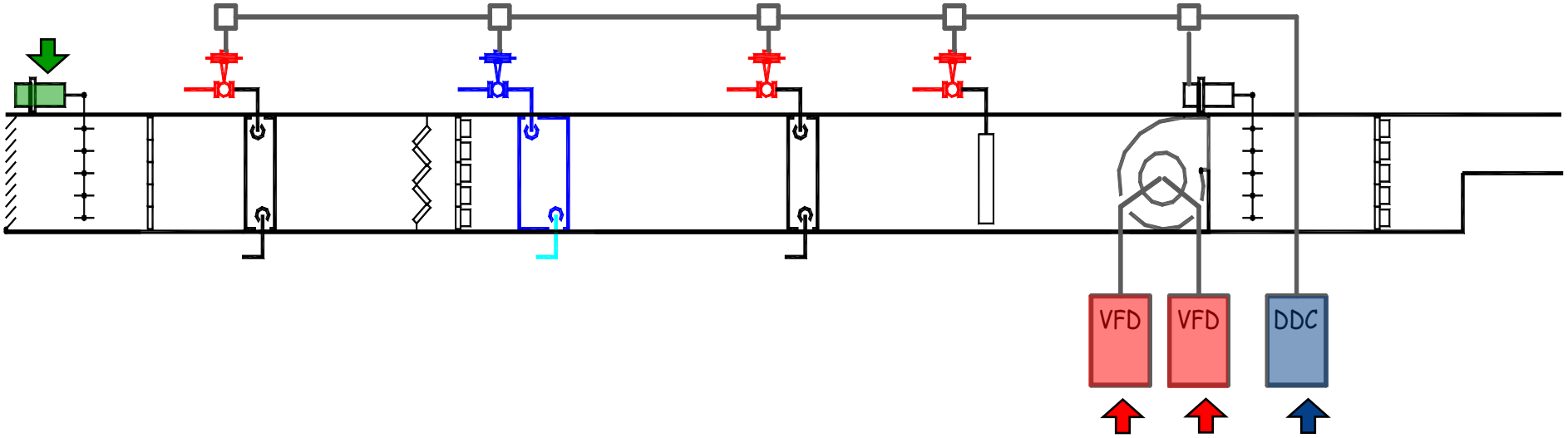
- Uninterruptible Power Supplies (UPS)
  - Load sees no power failure
  - Can be used in conjunction with emergency generators
  - Protect loads where even a short disruption could cause
    - Injury or loss of life
    - Equipment failures
    - Loss of data
    - Business disruption

Power Sources

- Cogeneration plant
  - Similar to emergency generators but always on line
  - Coordinated with:
    - Utility system
      - Sell power
      - Limit demand
    - Process loads requiring heat concurrently with power

A Retrocommissioning Discovery

Interlocked with
normal power



Served by Emergency Generators

Served by a UPS

Lesson 9

- Business and financial pressures can make critical issues seem less critical
  - Example – 1 system with three different power sources
- Murphy and Mother Nature will occasionally point these things out

Power Outage Duration

- Long term
  - Minutes, hours or days
    - Equipment spins down to a stop
    - Problems occur at the load because of the unanticipated loss of service
    - Problems occur with equipment when service is restored
  - “Single Phasing” may occur

Power Outage Duration

- Short term
  - Fractions of a second
    - No immediate impact at the load served
    - Machinery never stops spinning
    - Problems occur due to the uncoordinated response of different technologies
  - Potentially devastating

KSA Facilities Power “Blip” Response Procedure

Why the Scramble?

- Issues like the EPI make up AHU/EPI process exhaust interlocks
- Uncoordinated responses of mixed technologies
  - Magnetic starts would ride through it
  - Electronic starts may or may not trip
    - Programming issues
    - Product issues
  - Tripped electronic starters may or may not automatically reset

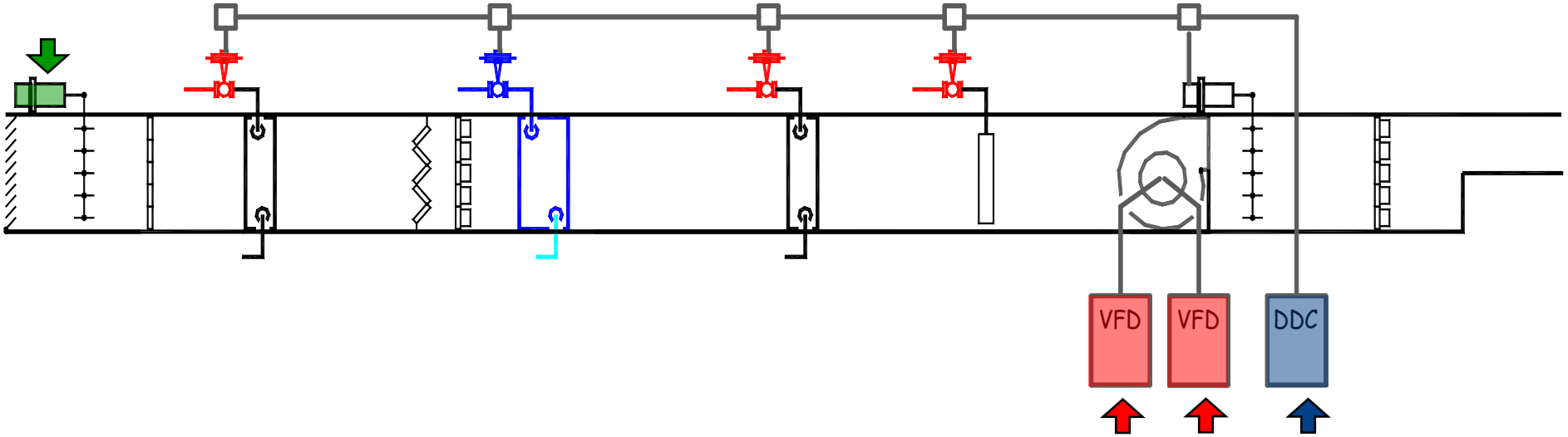
Lesson 10

- Failing to OFF on a power failure with a manual recovery can be safer than an automatic restart
- Automated or manual, the restart procedure is lengthily and complex
- It takes a only a minor event to knock a 300,000 sq.ft. plant off line (power “blip” = 5-10 cycle)
- A manual restart is a major event
  - 6-8 hours
  - Operators called in off shift

Lesson 11 (Round 4)

Two Power “Blips” a Few Seconds Apart

The first “blip” disrupts the interlock circuit and the dampers start to drive closed *quickly*



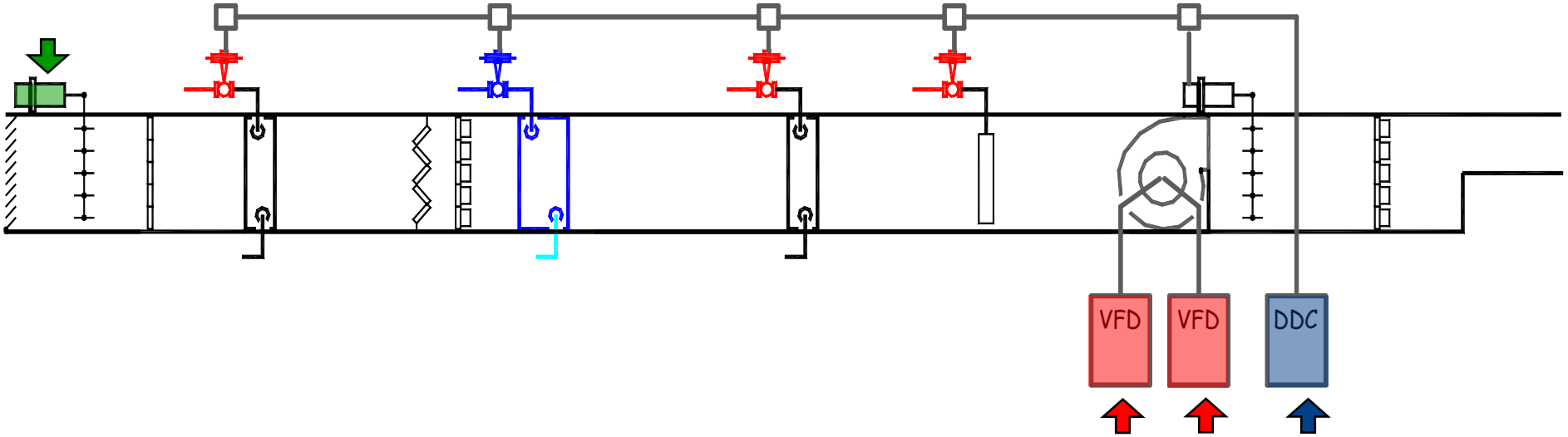
The emergency generators start and pick up the fan VFD loads and latch on for a minimum run time

The control system knows nothing

Lesson 11 (Round 4)

Two Power “Blips” a Few Seconds Apart

After the first blip, the dampers start to drive back open, but more slowly than they close



One drive is off; programmed to not automatically restart

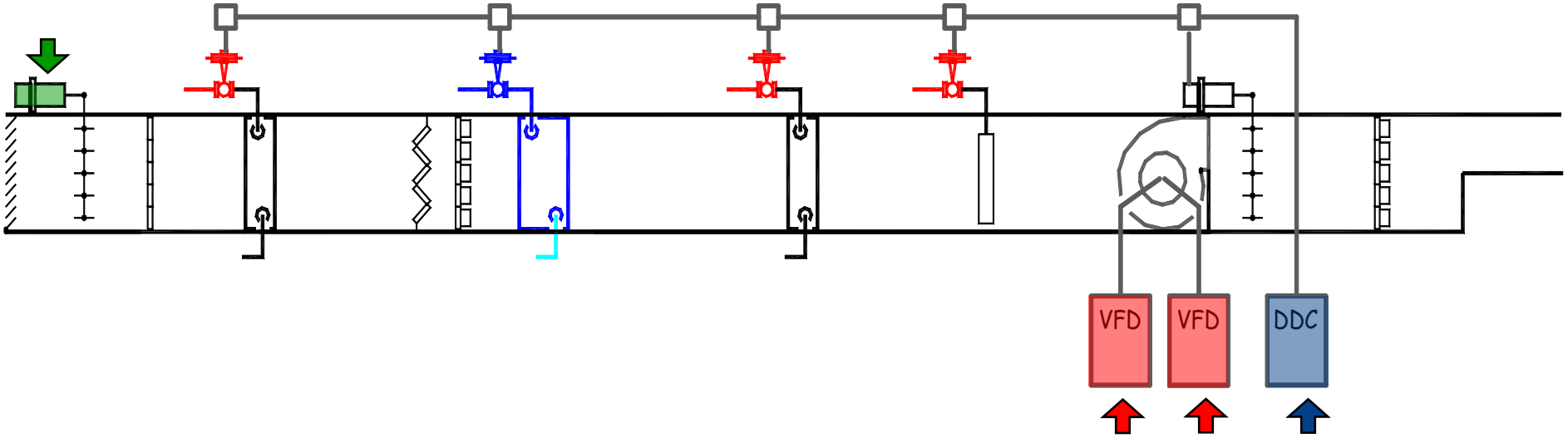
One drive is on; inadvertently programmed to automatically restart

Controls run as if nothing happened.

Lesson 11 (Round 4)

Two Power “Blips” a Few Seconds Apart

The second “blip” interrupts the interlock again, the dampers, which were not fully open drive quickly closed again. Intake plenum pressures start to get very negative



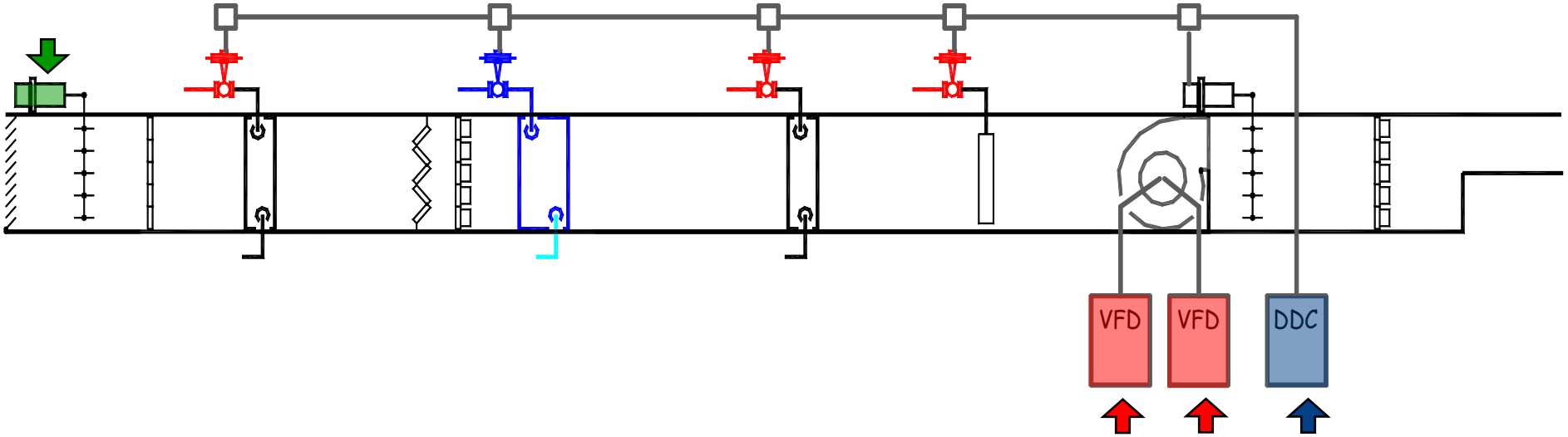
One drive remains off. Controls run as if
One drive remains on. nothing happened.

Lesson 11 (Round 4)

Two Power “Blips” a Few Seconds Apart

After the second “blip” the dampers can not drive open because the actuators can’t overcome the forces associated with the negative plenum pressures and the racking of the damper frames that they are staring to produce.

Limit switch hysteresis allows the operating fan to remain on line.



The fan speeds in an effort to compensate for the restriction created by the partially open damper.

Controls respond to falling fab pressure

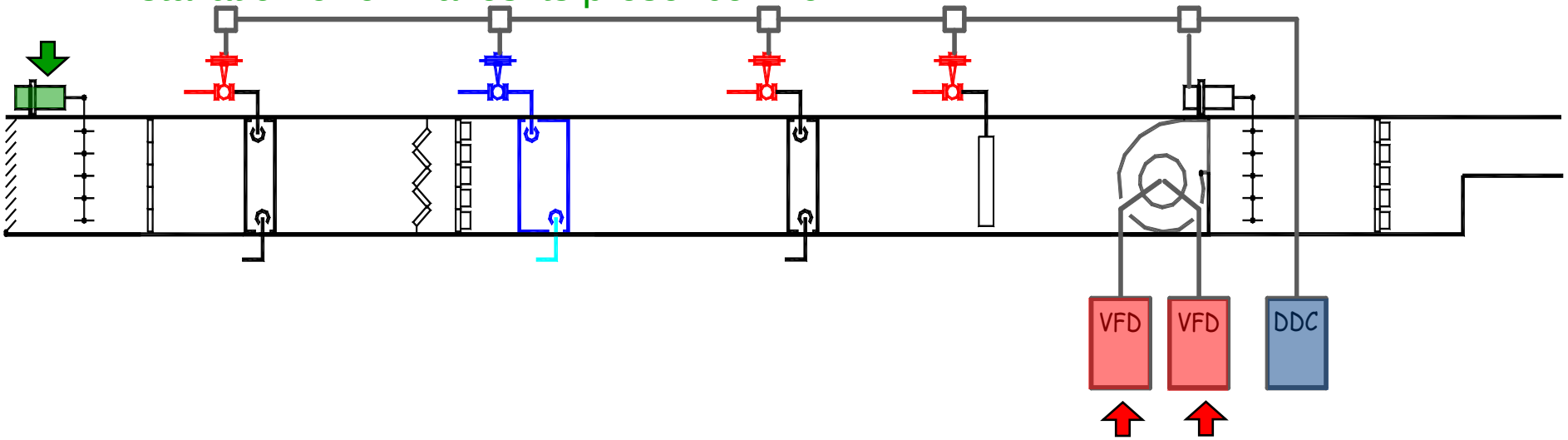
Lesson 11 (Round 4)

Two Power “Blips” a Few Seconds Apart

The second fan at full speed drives makes the over-powered, racked damper issue worse.

Intake plenum pressures drop significantly.

An installation error makes its presence known.



Operators, under pressure to not loose the fab, reset the drive that is off line. It restarts and comes up to full speed.

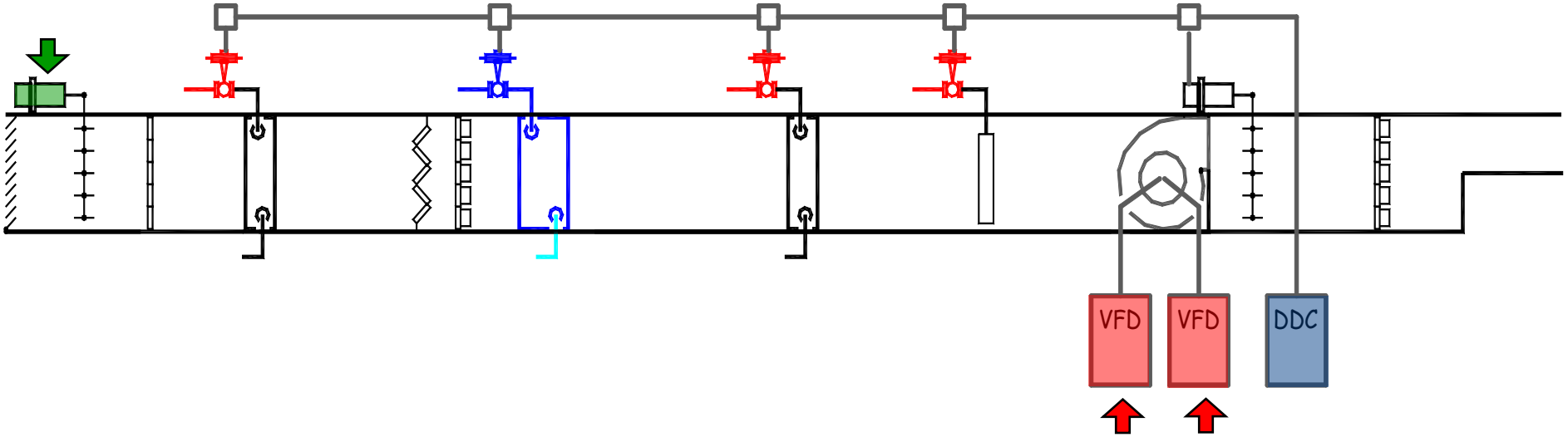
The Installation Error

Multi-section dampers require reinforcement between sections

- One quarter inch steel reinforcing plate between sections
- “Kicker” braces to corner joints are an alternative approach

Lesson 11 (Round 4)

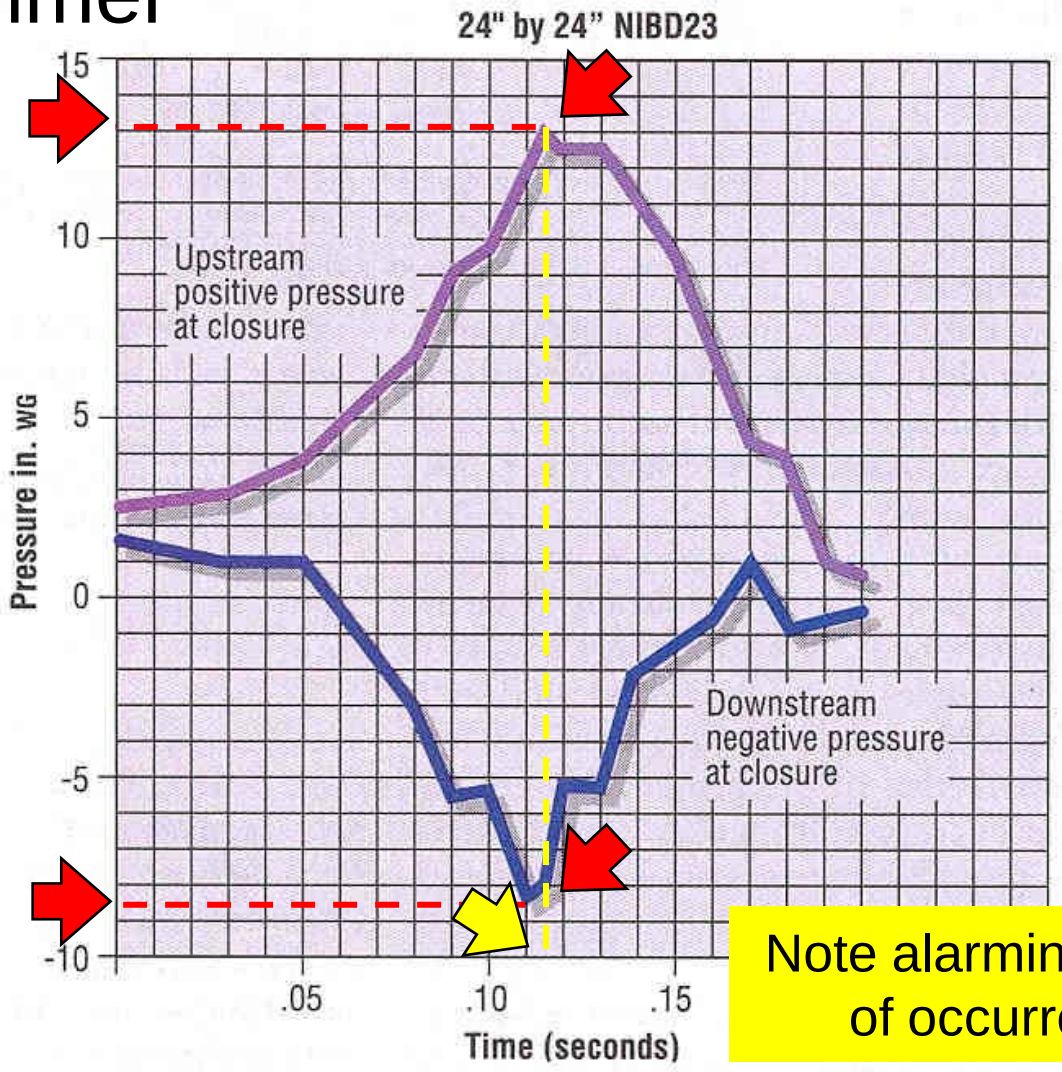
Two Power “Blips” a Few Seconds Apart



No restriction to air flow + full speed fans = sudden flow surge

Sudden flow surge + expansive AHU end casing area = air hammer

Air Hammer



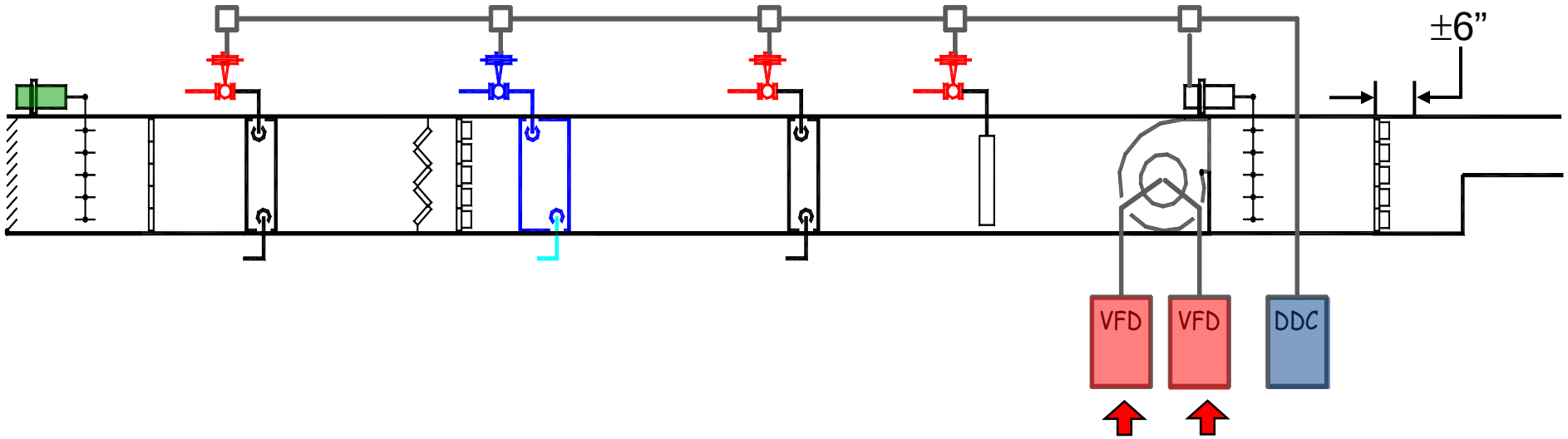
Note alarming magnitude

Note alarming speed of occurrence

Images courtesy Ruskin's catalog

Lesson 11 (Round 4)

Two Power “Blips” a Few Seconds Apart



Air hammer + Another installation error = BIG Problem

Installation Error #2

A Tek Screw and A Bolt ***Are Not*** The Same

Tek Screw

Bolt

When Assembling An AHU, A Tek Screw and A Bolt *Are Not* The Same

The discharge section of the casing had been assembled with Tek Screws, not the bolts provided by the factory (red heads in the picture)

- The only section not assembled correctly
- Factory prestart inspection was done
  - Visual inspection
  - Negative pressure test
    - Leakage
    - Deflection

Lesson 12

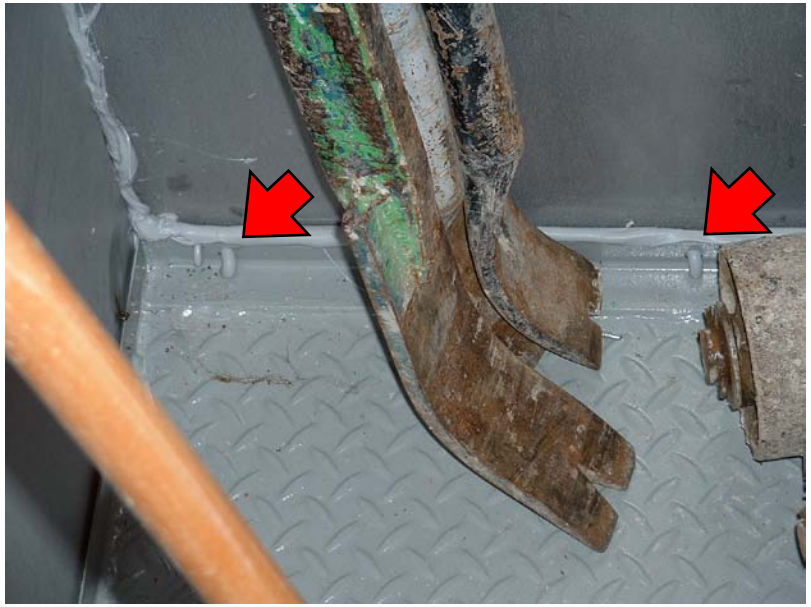
A skilled team of operators can work miracles

- Cut out collapsed damper
- Pulled the blown apart sections back together and bolted them up
- Fab back under positive pressure in about 2 hours
- Particle counts back to production levels in about 6 hours

Lesson 13

Even the factory guys miss stuff

- The difference between a Tek Screw head and a bolt head is subtle
- Informs the construction observation process for subsequent work



Our Improvements and Repairs

- Replaced the collapsed damper sections with properly reinforced dampers
- Installed pressure relief doors

Our Improvements and Repairs

- Control modifications
  - Better limit switches and limit switch arrangements
  - Rewired interlocks to be effective in all selector switch positions
  - Provided controller input monitoring fan power supply

Control Systems and Power Loss

Knowledge of loss of power

- How does the controller know power was lost?
- Which power losses matter?
  - Controller power?
  - Equipment power?
  - Network power?
  - Building power?

Control Systems and Power Loss

What happens when the power is lost and will it be automatic or manual?

- Controller power failure recovery
- Network power failure recovery
- Equipment power failure recovery
- Building power failure recovery

Control Systems and Power Loss

Is the response for recovering on an emergency power source different from what is to happen when normal power is restored?

Control Systems and Power Loss

Trade-offs:

- Complexity vs. reliability
- Complexity vs. cost
- Complexity vs. operability
- Complexity vs. persistence
- Complexity vs. risk

Testing Places Equipment at Risk

Prototypes require testing

- Well thought out systems and equipment can still have problems
- Test results = information for moving forward
- Balance cost vs. benefit
  - Implications of failure
  - Complexity
  - Rigor
- Plan, plan, plan

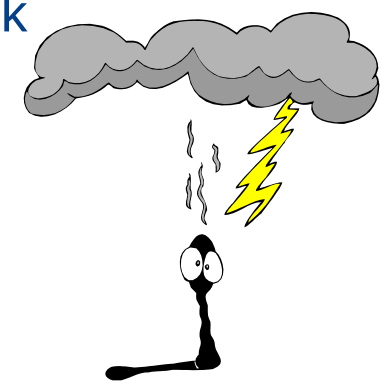
Power Failure Recovery Testing Options

Commissioning Provider Performs Testing

- Balance risks vs. benefit
- Managed approach
  - Provider schedules test
  - Rehearsal possible
  - Intervention possible if things go amuck

Mother Nature Performs Testing

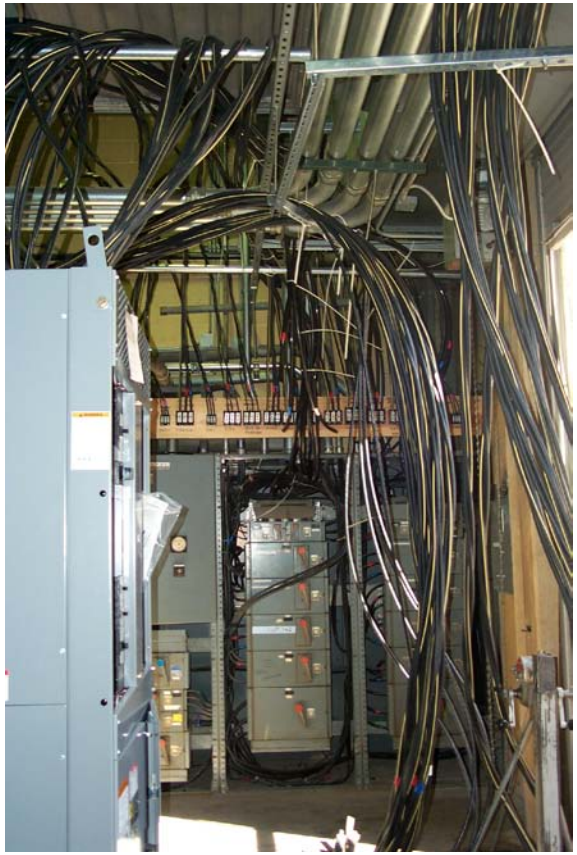
- No concern for risk or benefit
- Unmanaged approach
  - Planetary alignment schedules test
  - Unannounced
  - Things go amuck



The Best of Plans Can Fail

Hospital Emergency Power System Upgrade

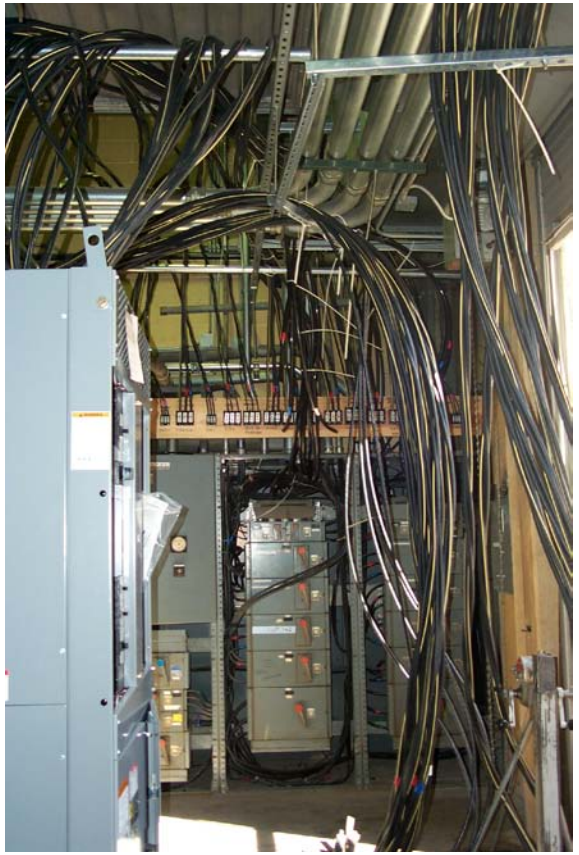
- Existing configuration (1969)
  - 1 Emergency generator
  - 1 Emergency branch
- New configuration (1989)
  - 2 Emergency generators
  - Life safety branch
  - Critical branch
  - Equipment branch



The Best of Plans Can Fail

Complex Change-over

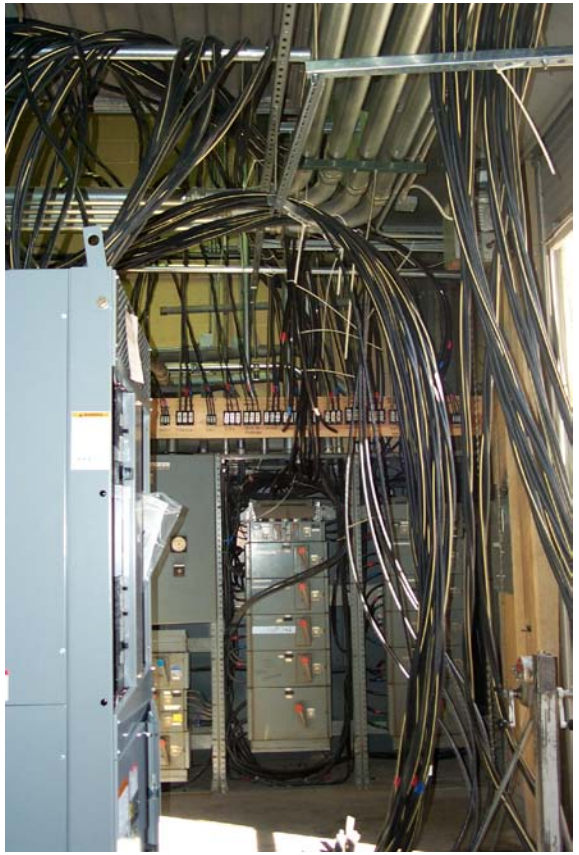
- Juggling:
  - Ongoing operation
  - Space and equipment room reconfiguration
  - New construction
- Temporary feeds for many loads
- Existing emergency branch stands alone for about 15 minutes
  - Temporary generator carries load



The Best of Plans Can Fail

Preparation:

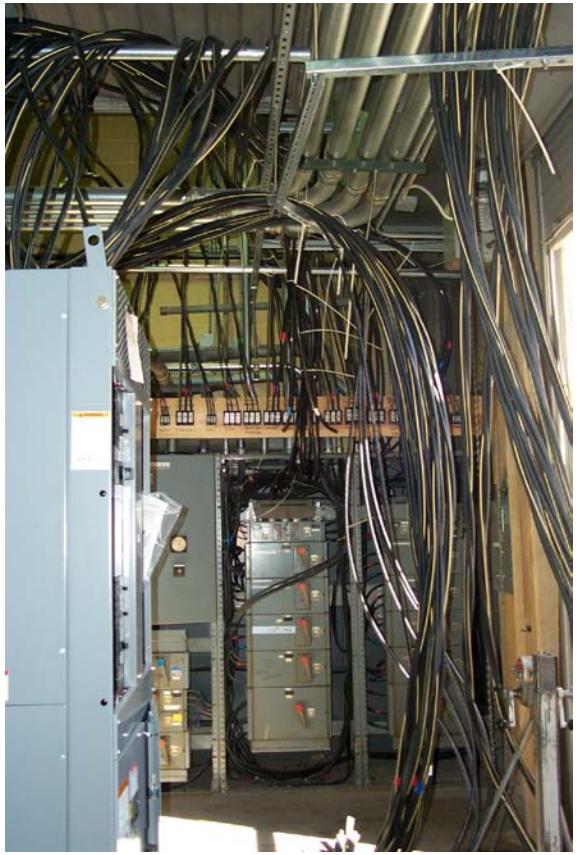
- Temporary generator on site for over a week in advance
- Operated daily for 30-60 minutes to verify reliability
- Operated under load to verify reliability
- Checked and re-checked re-connection plan
- Rehearsed



The Best of Plans Can Fail

Day of change-over:

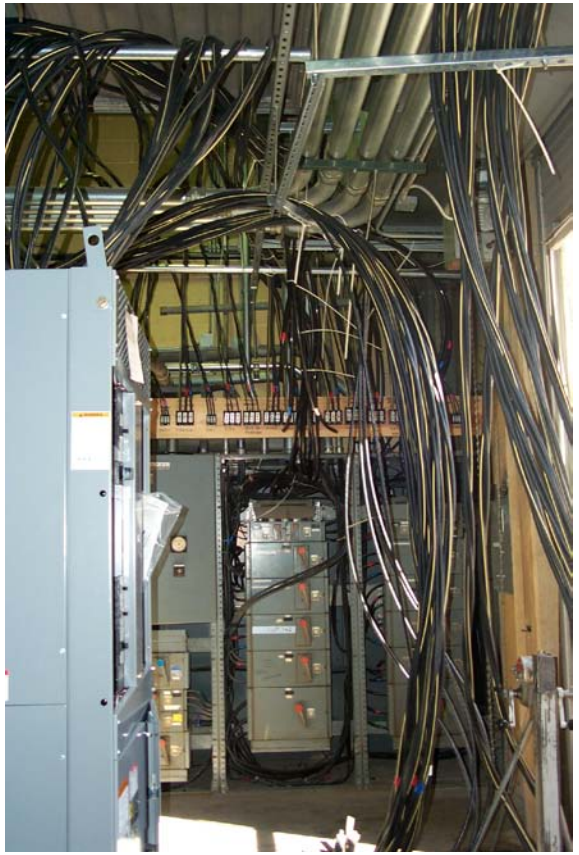
- Start temporary generator
  - Run for 30 minutes
  - Transfer load and run under load for 30 minutes
  - Staff standing-by monitoring temporary generator
- Open breaker to existing generator
- Begin transfer process
- Temporary generator high temp warning light comes on



The Best of Plans Can Fail

Response to warning:

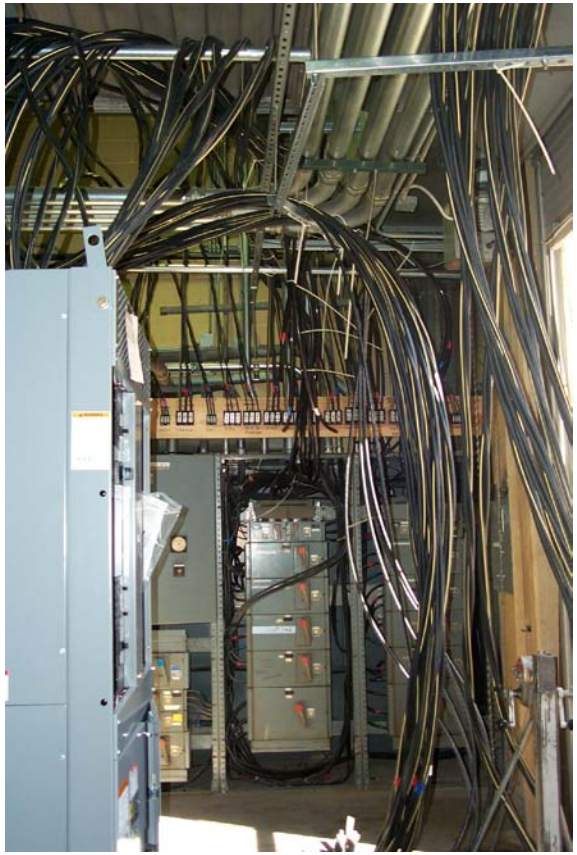
- Re-close the breaker to the existing generator which had not been disconnected as of the time
- Breaker hangs up and won't re-close
- Temporary generator shuts down on high temperature alarm
- Black hospital



The Best of Plans Can Fail

Response to alarm:

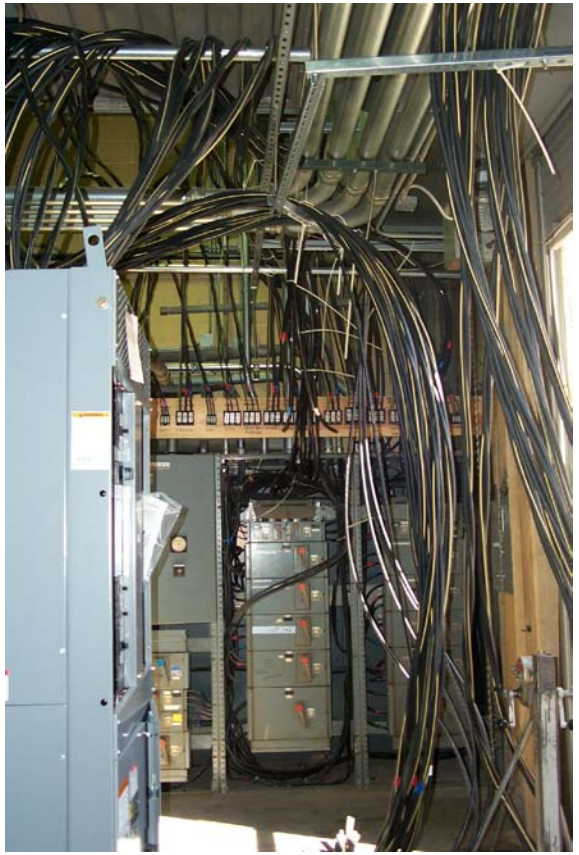
- Joe runs to figure out how to jump out the high temperature switch
- Electricians start to reconnect normal power wiring just removed
- Jerry studies the generator breaker with a flashlight
  - Sees a hung-up link
  - Reaches in with a screwdrive and releases it
- Breaker slams home
- Existing generator started



The Best of Plans Can Fail

Normal power restored

- Begin to breath
- Discover bad engine temperature switch
- Regroup and re-plan



The Best of Plans Can Fail

Lessons

- Skilled operators are priceless
- Even when you have thought of everything, there can still be one other thing
- A risk that has existed for 20 years un-manifested is still a risk

Bottom Line

- Power failures ***will*** happen

  sometimes, in an unanticipated fashion
- The building ***will*** recover when power is re-applied

  sometimes, in an unanticipated fashion

- The only question:

So tell me, how did that work for you?

Image courtesy of Michael Fewings at http://www.strikeone.com.au/index.

Resources

Good Electrical Engineers

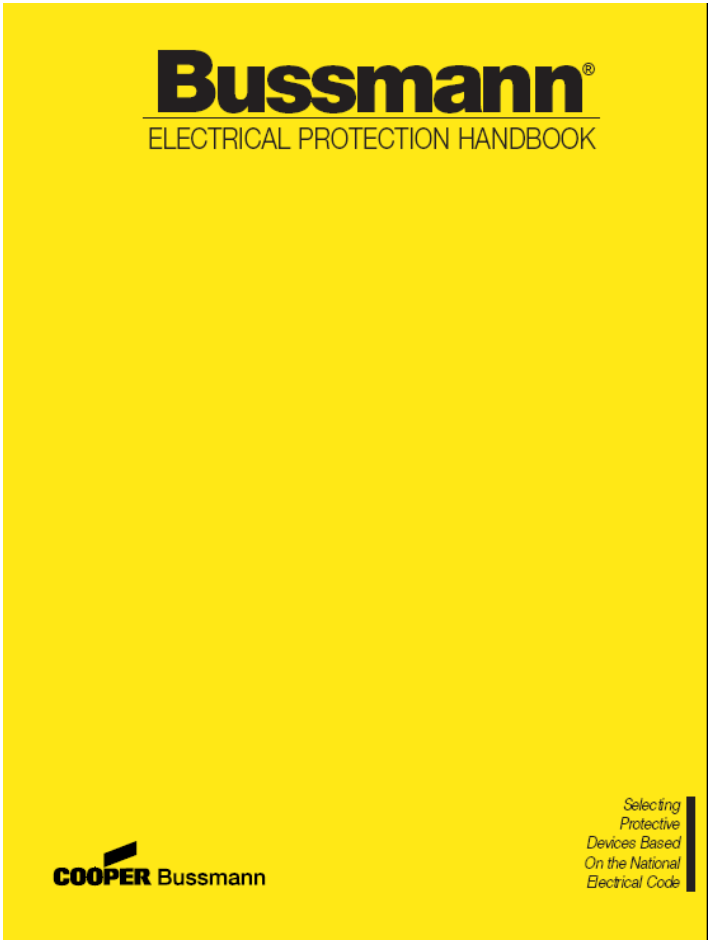
Resources

NETA

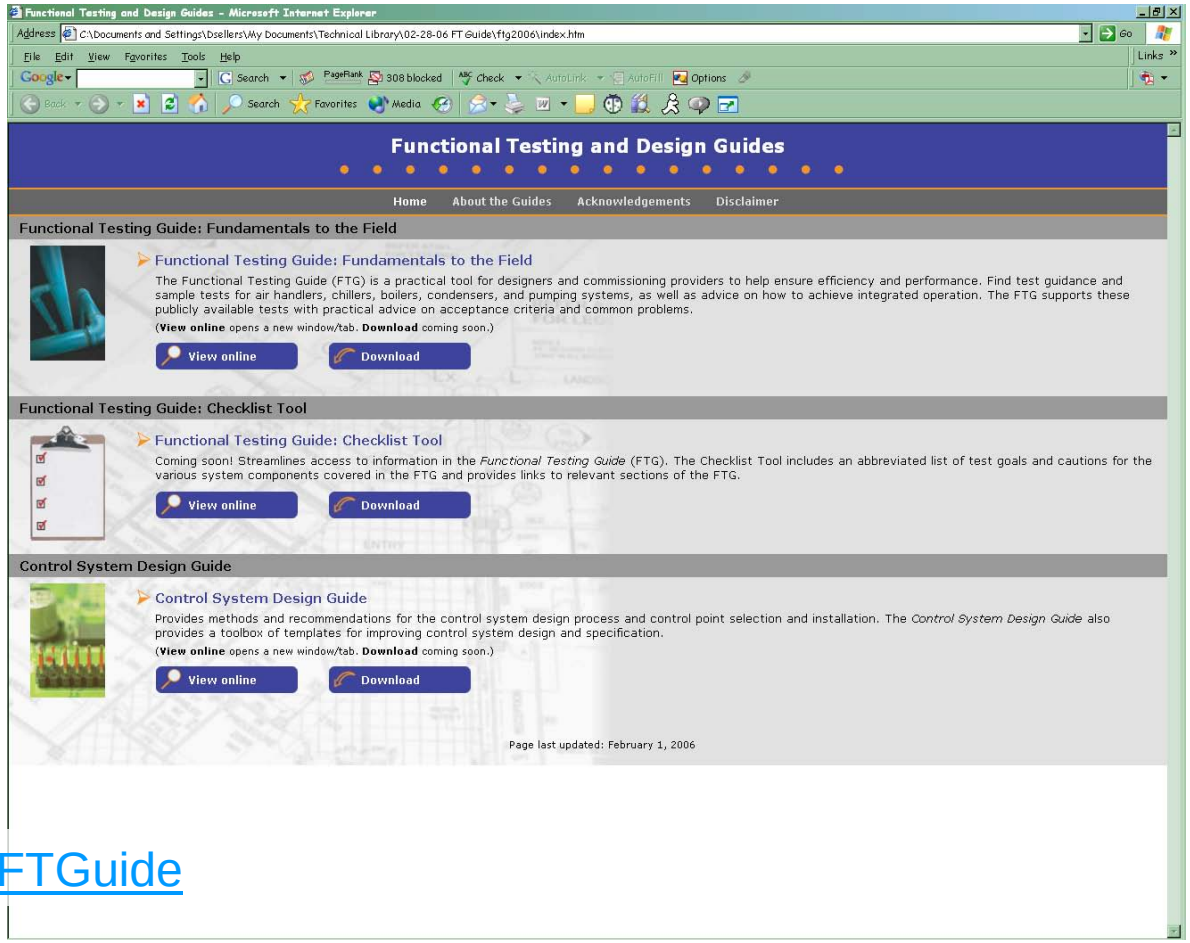
Resources

Bussmann Electrical Protection Handbook

www.bussmann.com



Resources



www.PECI.org/FTGuide