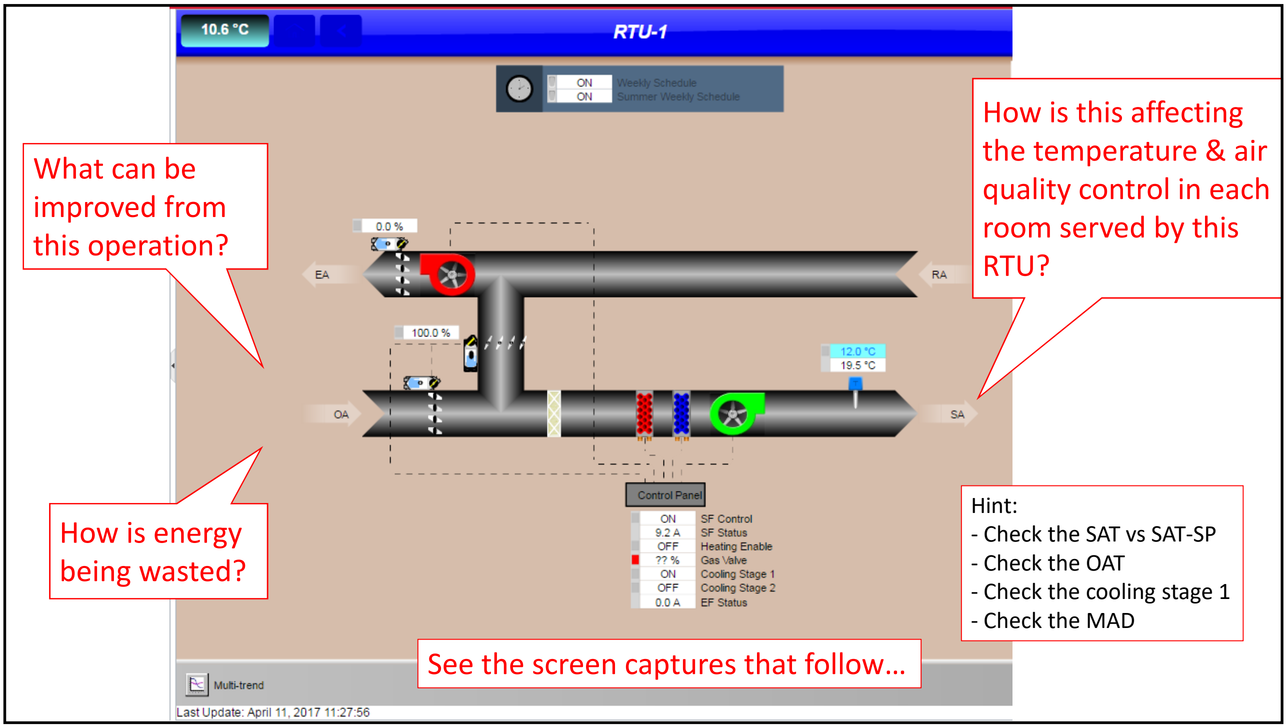
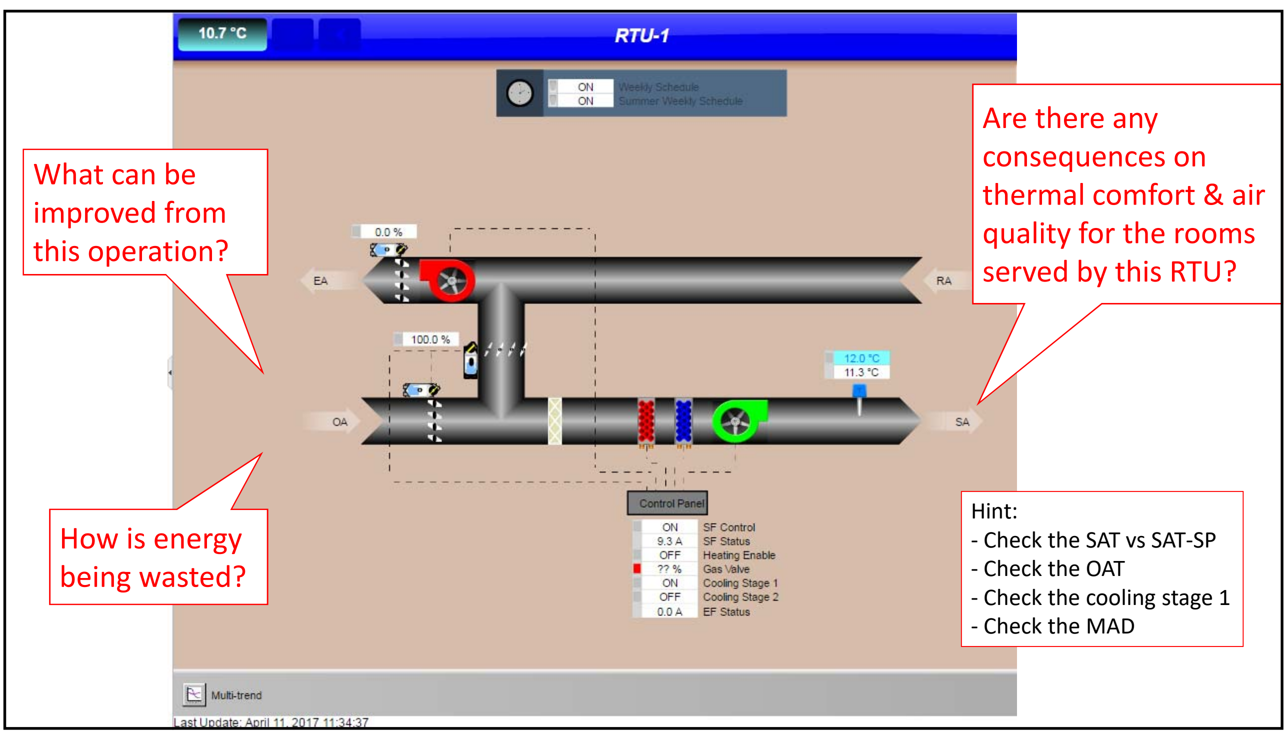
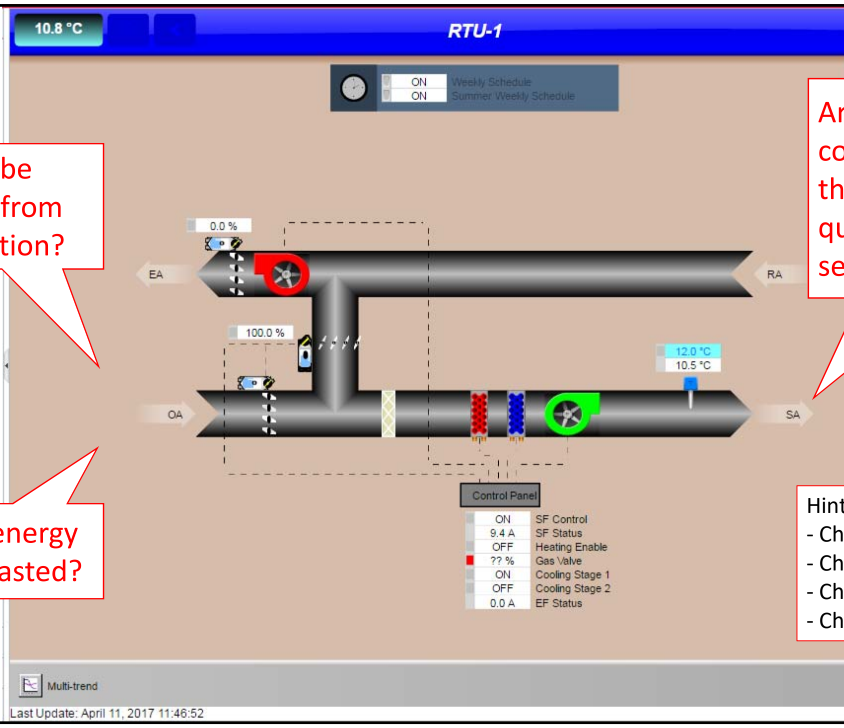

10.6 °C
RTU-1
ON Weekly Schedule
ON Summer Weekly Schedule
What can be improved from this operation?
How is this affecting the temperature & air quality control in each room served by this RTU?
0.0 %
EA
RA
100.0 %
12.0 °C
19.5 °C
OA
SA
How is energy being wasted?
Control Panel
ON SF Control
9.2 A SF Status
OFF Heating Enable
?? % Gas Valve
ON Cooling Stage 1
OFF Cooling Stage 2
0.0 A EF Status
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD
See the screen captures that follow…
Multi-trend
Last Update: April 11, 2017 11:27:56


10.7 °C
RTU-1
ON Weekly Schedule
ON Summer Weekly Schedule
What can be improved from this operation?
Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?
0.0 %
EA
RA
100.0 %
12.0 °C
11.3 °C
OA
SA
How is energy being wasted?
Control Panel
ON SF Control
9.3 A SF Status
OFF Heating Enable
?? % Gas Valve
ON Cooling Stage 1
OFF Cooling Stage 2
0.0 A EF Status
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD
Multi-trend
Last Update: April 11, 2017 11:34:37

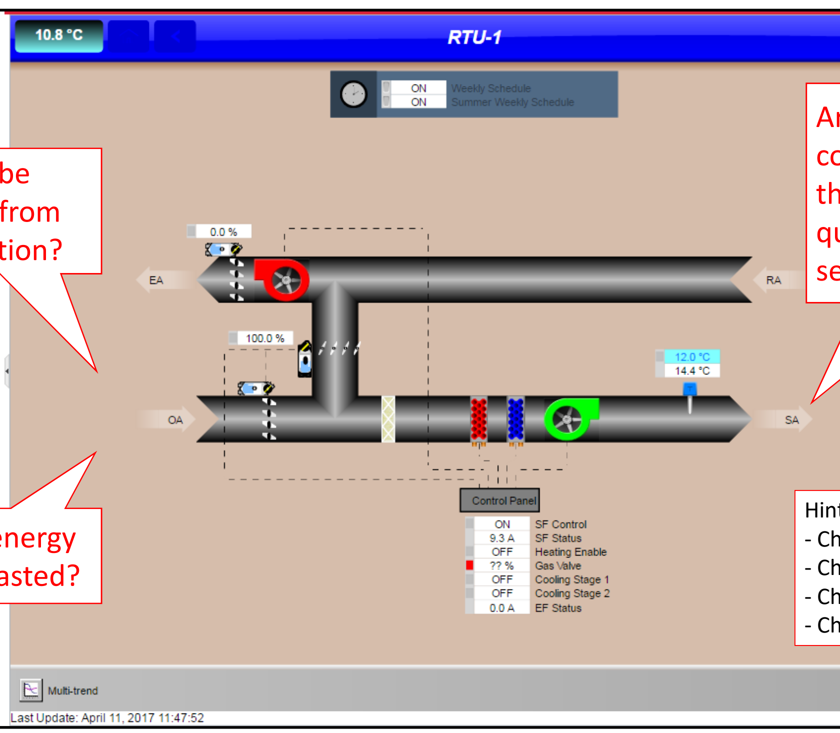


What can be improved from this operation?

Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?

How is energy being wasted?

Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD

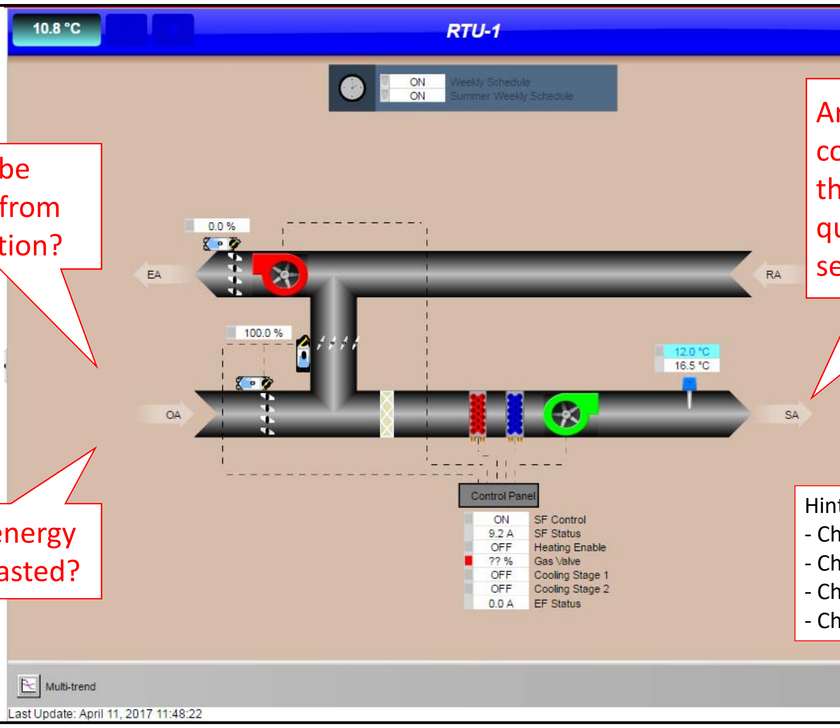


What can be improved from this operation?

Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?

How is energy being wasted?

Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD

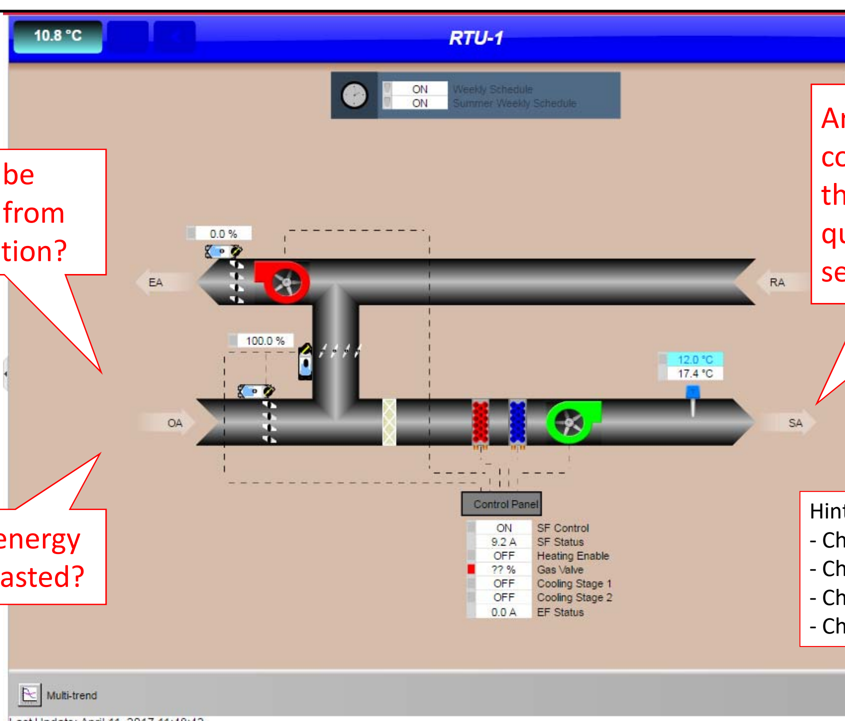


What can be improved from this operation?

Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?

How is energy being wasted?

Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD

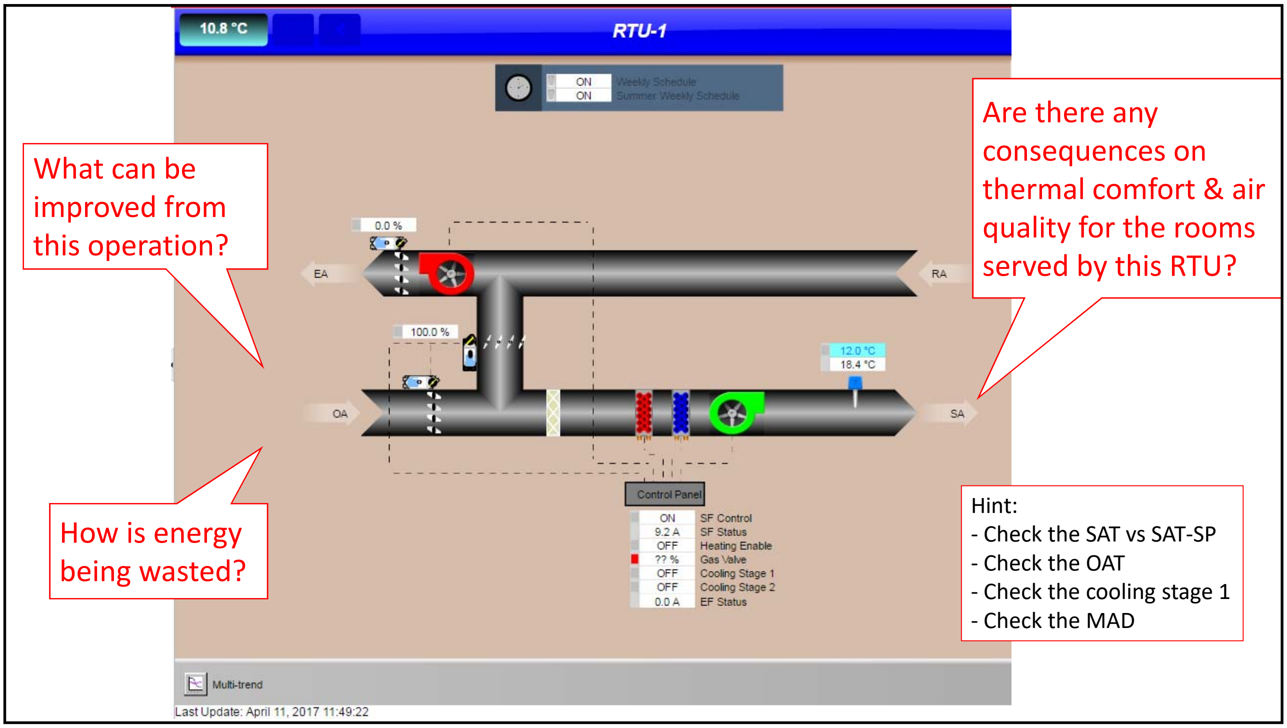


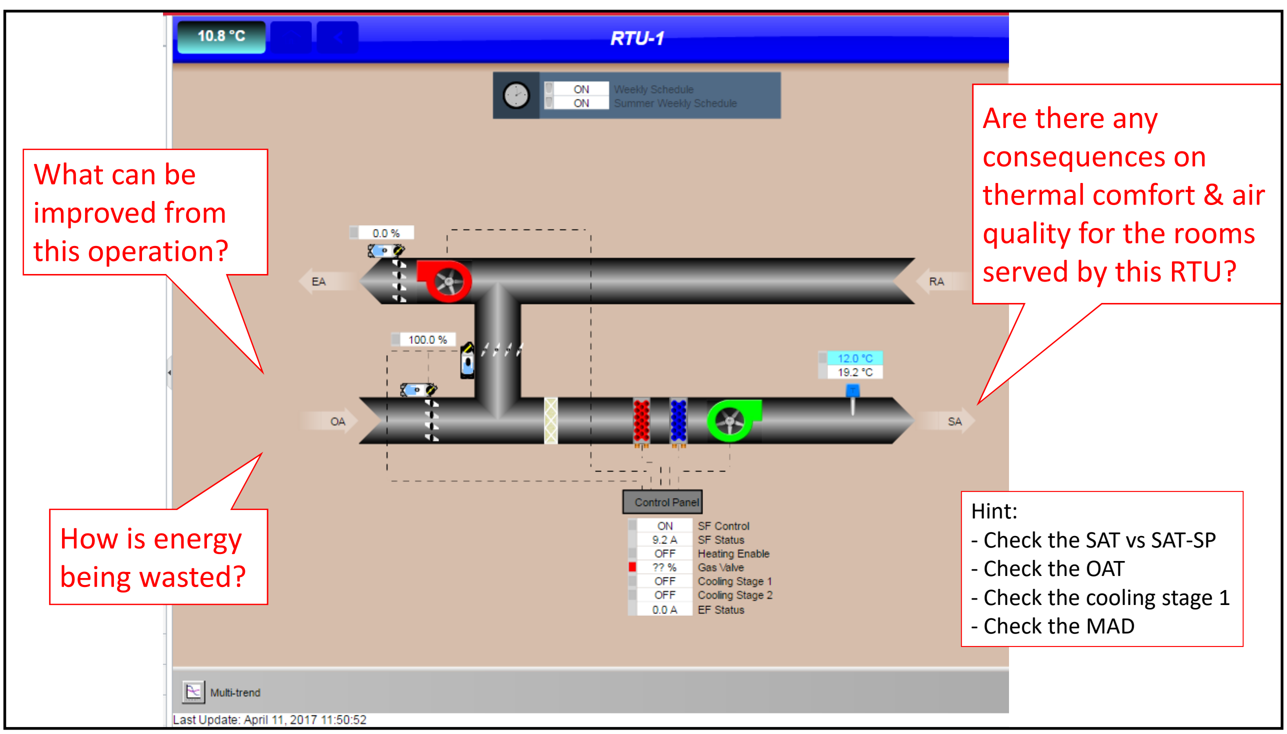
What can be improved from this operation?

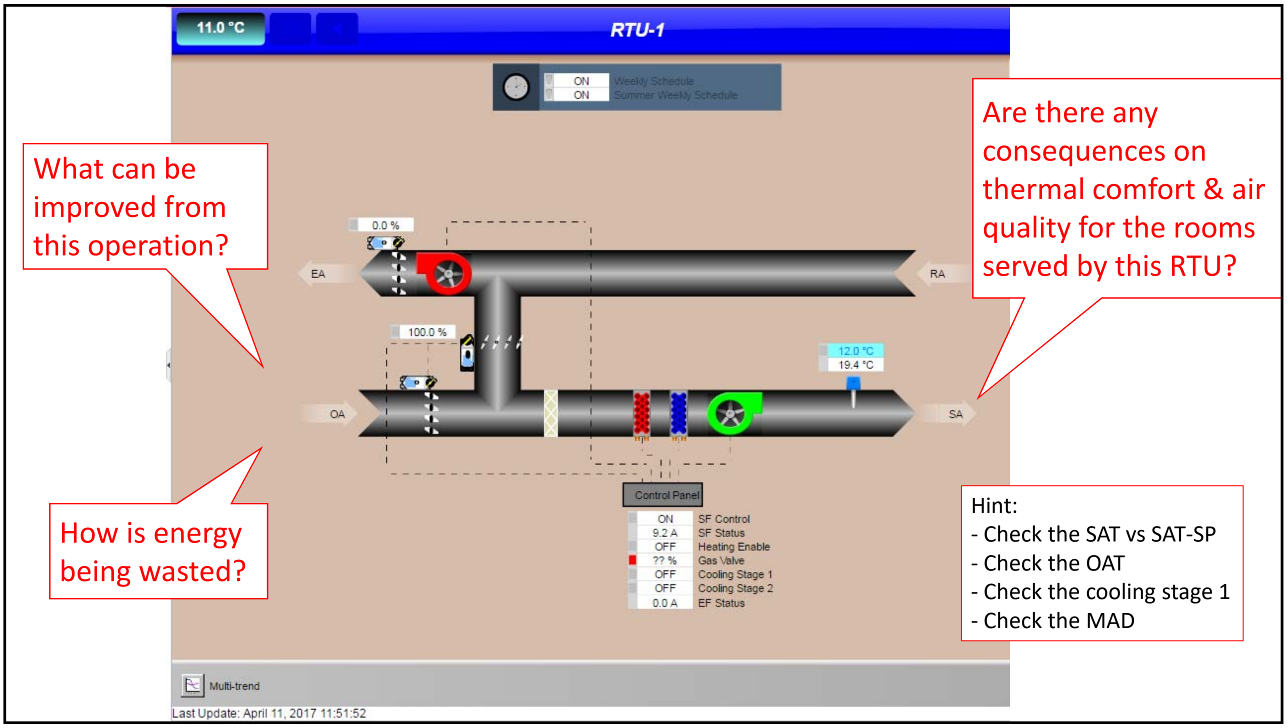
Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?

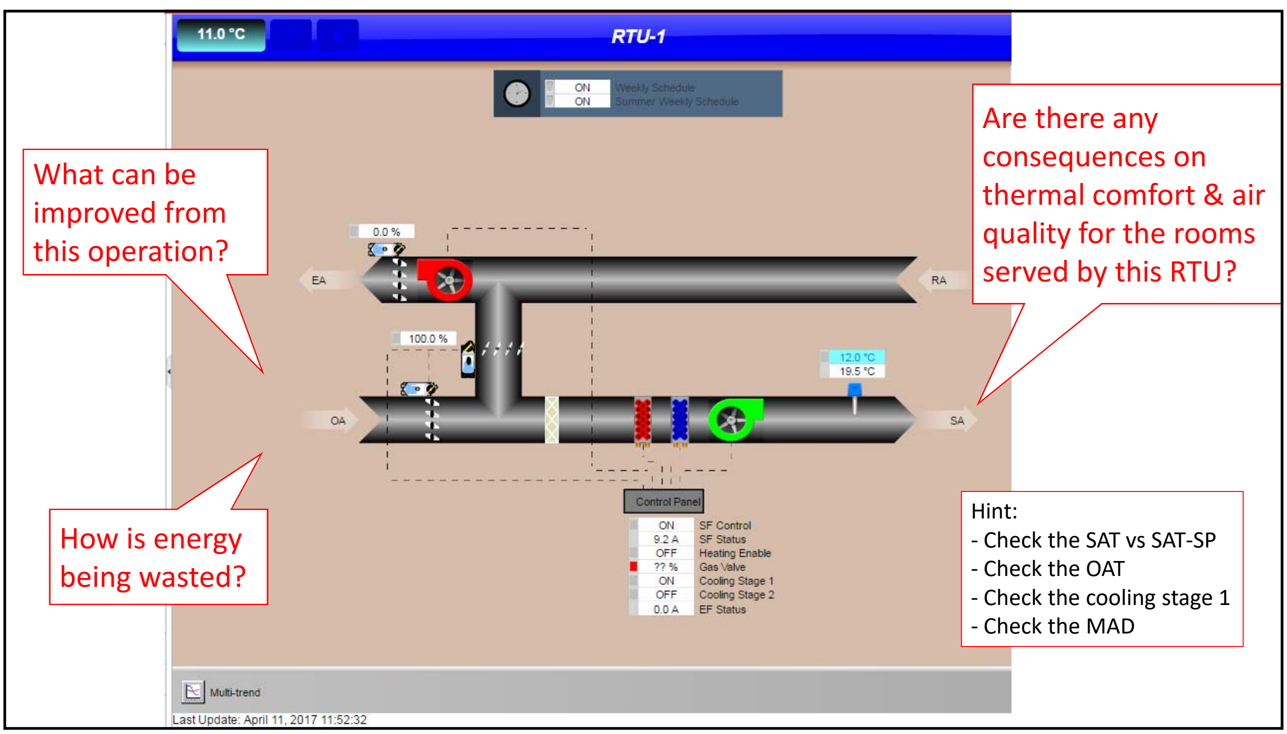
How is energy being wasted?

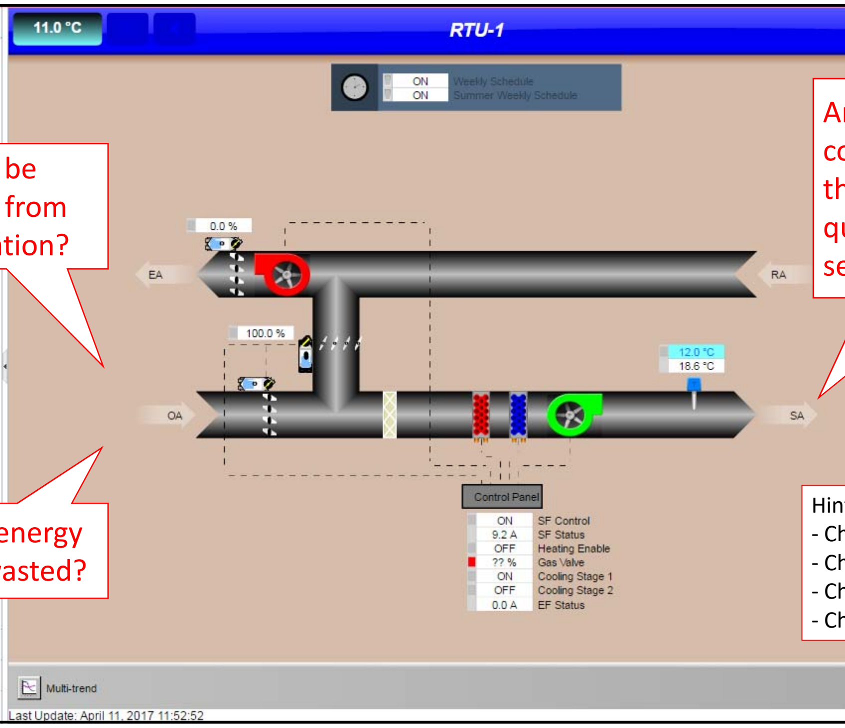
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD


10.8 °C
RTU-1
ON Weekly Schedule
ON Summer Weekly Schedule
What can be improved from this operation?
Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?
0.0 %
EA
RA
100.0 %
12.0 °C
18.4 °C
OA
SA
Control Panel
ON SF Control
9.2 A SF Status
OFF Heating Enable
?? % Gas Valve
OFF Cooling Stage 1
OFF Cooling Stage 2
0.0 A EF Status
How is energy being wasted?
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD
Multi-trend
Last Update: April 11, 2017 11:49:22


10.8 °C
RTU-1
ON Weekly Schedule
ON Summer Weekly Schedule
What can be improved from this operation?
Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?
0.0 %
EA
RA
100.0 %
12.0 °C
19.2 °C
OA
SA
Control Panel
ON SF Control
9.2 A SF Status
OFF Heating Enable
?? % Gas Valve
OFF Cooling Stage 1
OFF Cooling Stage 2
0.0 A EF Status
How is energy being wasted?
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD
Multi-trend
Last Update: April 11, 2017 11:50:52


11.0 °C
RTU-1
ON Weekly Schedule
ON Summer Weekly Schedule
What can be improved from this operation?
Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?
0.0 %
EA
RA
100.0 %
12.0 °C
19.4 °C
OA
SA
How is energy being wasted?
Control Panel
ON SF Control
9.2 A SF Status
OFF Heating Enable
?? % Gas Valve
OFF Cooling Stage 1
OFF Cooling Stage 2
0.0 A EF Status
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD
Multi-trend
Last Update: April 11, 2017 11:51:52


11.0 °C
RTU-1
ON Weekly Schedule
ON Summer Weekly Schedule
What can be improved from this operation?
Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?
0.0 %
EA
RA
100.0 %
12.0 °C
19.5 °C
OA
SA
How is energy being wasted?
Control Panel
ON SF Control
9.2 A SF Status
OFF Heating Enable
?? % Gas Valve
ON Cooling Stage 1
OFF Cooling Stage 2
0.0 A EF Status
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD
Multi-trend
Last Update: April 11, 2017 11:52:32

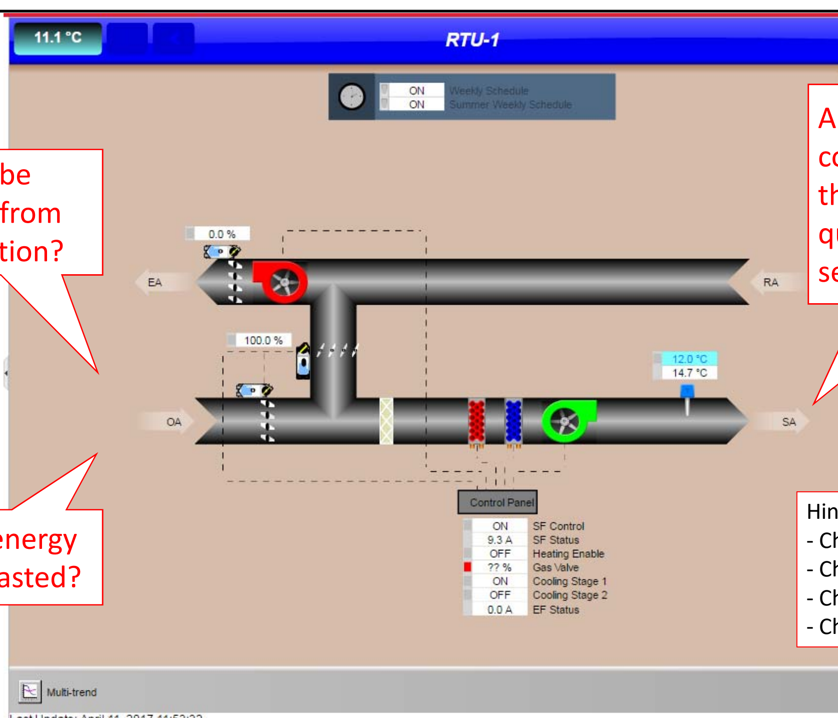


What can be improved from this operation?

How is energy being wasted?

Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?

Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD

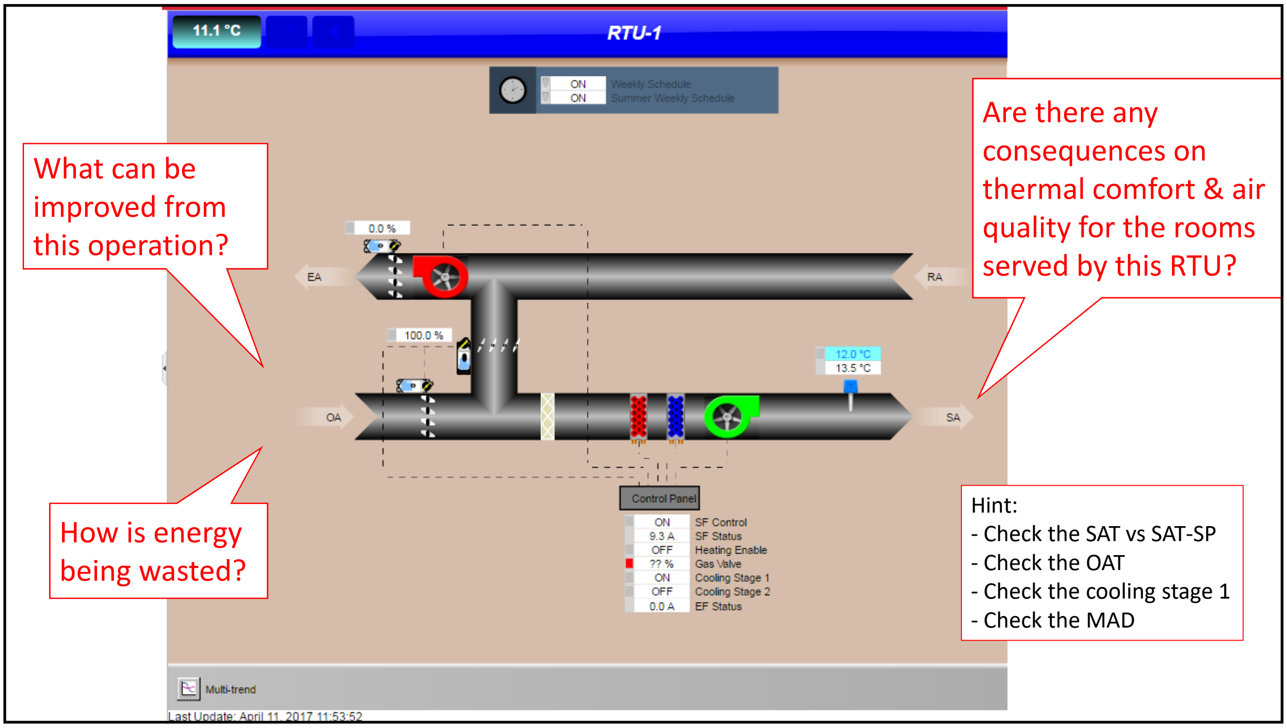


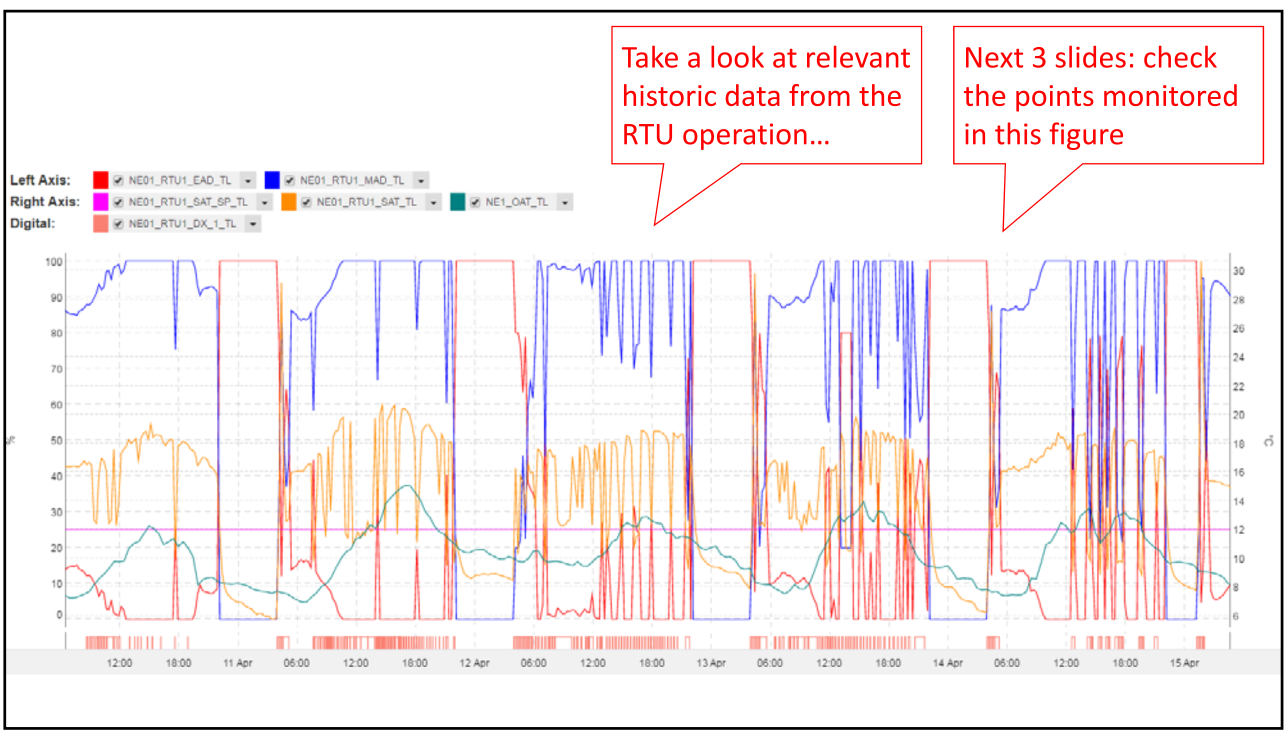
What can be improved from this operation?

How is energy being wasted?

Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?

Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD


11.1 °C
RTU-1
ON Weekly Schedule
ON Summer Weekly Schedule
What can be improved from this operation?
Are there any consequences on thermal comfort & air quality for the rooms served by this RTU?
0.0 %
EA
RA
100.0 %
12.0 °C
13.5 °C
OA
SA
How is energy being wasted?
Control Panel
ON SF Control
9.3 A SF Status
OFF Heating Enable
?? % Gas Valve
ON Cooling Stage 1
OFF Cooling Stage 2
0.0 A EF Status
Hint:
- Check the SAT vs SAT-SP
- Check the OAT
- Check the cooling stage 1
- Check the MAD
Multi-trend
Last Update: April 11, 2017 11:53:52


Take a look at relevant historic data from the RTU operation...
Next 3 slides: check the points monitored in this figure
Left Axis: NE01_RTU1_EAD_TL NE01_RTU1_MAD_TL
Right Axis: NE01_RTU1_SAT_SP_TL NE01_RTU1_SAT_TL NE1_OAT_TL
Digital: NE01_RTU1_DX_1_TL
12:00 18:00 11 Apr 06:00 12:00 18:00 12 Apr 06:00 12:00 18:00 13 Apr 06:00 12:00 18:00 14 Apr 06:00 12:00 18:00 15 Apr

The Air Handling Unit (AHU)

Equipment	Point	Type	Function	Typical values
Dampers			Regulate pressures, supply temperatures, & CO2 levels	
OAD	Position: modulate to maintain fresh air intake	AO	Outdoor air intake responds to MAT, OAT, CO2 Morning purging	Min, Max, Modulate (%)
MAD	Position: interlocked with OAD (reverse acting)	AO	Maintain MAT at/above set point Prevent freezing damage of coils	Min, Max, Modulate (%)
EAD	Position: interlocked with OAD (direct acting)	AO	Relief pressure from the building	Min, Max, Modulate (%)
Fans			Maintain building air flows and pressures	
Supply Fan	Enable (control: CO)	BO (CMD)	Start constant speed fan	ON/OFF
	Status: current (Amps)	AI	Feedback from the fan to make sure is running	(A)
	Speed (variable speed) / feedback	AO/AI	Maintain system pressure to respond to demand	(%)
Return Fan	Enable (control: CO)	BO (CMD)	Start constant speed fan	ON/OFF
	Status: current (Amps)	AI	Feedback from the fan to make sure is running	(A)
	Speed (variable speed) / feedback	AO / AI	Modulates to follow the supply air damper	(%)
Exhaust Fan Relief Fan	Enable (control: CO)	BO (CMD)	Start constant speed fan	ON/OFF
	Status: current (Amps)	AI	Feedback from the fan to make sure is running	(A)
	Speed (variable speed) / feedback	AO / AI	Maintain building pressure within acceptable range	(%)

The Air Handling Unit (AHU)

Equipment	Point	Type	Function	Typical values
Temperatures			Remain within acceptable ranges	
AHU	SAT: supply air temperature	AI	Respond to building/occupancy set points (SP)	> 13°C
AHU	SAT_SP supply air temperature set point	AV	Calculated (reset) dynamically based on space temperature & space set point, with limits determined by OAT (OAT reset)	
AHU	MAT: mixed air temperature	AI	Modulate dampers to maintain SAT SP minus 1°C (fan gain) Prevent coils from freezing	> 12°C > 2°C
Coils			Heat or Cool the air	
Heating Coil Valve (HCV)	Enable (control: CO)	BO (CMD)	Enable valve to open	ON/OFF
	Percent open (control: CO)	BO (CMD)	Control flow of water to the coil	%
	Stage (control: CO)	BO (CMD)	Enable various stages of heating	ON/OFF
	Supply water temperature	AI	Temperature of water to the heating coil	40°C
Cooling Coil Valve (CCV)	Enable (control: CO)	BO (CMD)	Enable valve to open	ON/OFF
	Percent open (control: CO)	BO (CMD)	Control flow of water to the coil	%
	Stage (control: CO)	BO (CMD)	Enable various stages of cooling	ON/OFF
	Supply water temperature	AI	Temperature of water to the cooling coil	11°C

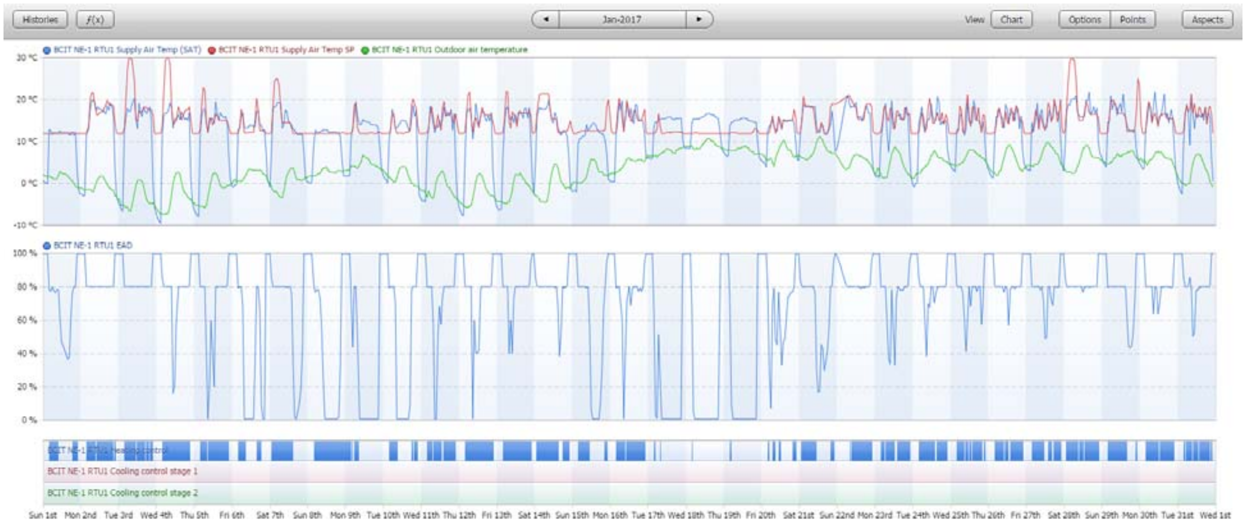
The Air Handling Unit (AHU)

Equipment	Point	Type	Function	Typical values
Other				
Air System	System Pressure (variable speed supply fan)	AO	Maintain system pressure downstream of supply fan to respond to zone air demands	300 Pa
Air System	System Pressure Set point	AV	Calculated (reset) dynamically to respond to zone demands	
freeze stat	Freeze stat	BI	Protect the coils from freezing Hardwired with supply air damper When below set point triggers an alarm	
Filter bank	Differential pressure	AI	Records the differential pressure at the filter bank Set to filter manufacturer pressure and limit	
AHU return	CO2 set point (SP)	AO	Sets the set point of CO2 at the return air of AHU	1000 PPM
AHU return	CO2 high	AI	Records the CO2 at the return air of AHU	1400 PPM
AHU supply	RH SP	AO	Sets the set point for supply RH	50%
AHU supply	RH	AI	Records the supply RH	40%
Zone	Air temperature	AI	Programmable Thermostat	22°C
Zone	Air temperature set point	AO	Set based on occupancy/schedule	21°C
Zone	Air relative humidity	AI	Humidistat	50%

Typical AHU Sequence of Operations (SOO)

1. Fan system will be enabled by a weekly schedule
2. The OAD will ramp open to 100% for a start up purge for 10 minutes, only if OAT is above 10°C
3. The EAD will modulate to follow the OAD
4. The dampers are hard wired to the supply and return fans. Once the dampers are proven open via end-switches, the SF will start as well as the RF
5. The air dampers will modulate to maintain the MAT set point and the CO2 set point. The CO2 sensor will take precedence and when satisfied the MAT set point will be maintained
6. The OAD will always maintain minimum position
7. If the RT is less than the OAT and the MAT set point is less than the OAT the OAD will go to its minimum position
8. The SAT set point will be reset based on space air temperature and space air temperature set point. The SAT set point will have a minimum and maximum based on the OAT
9. The MAT set point will maintain the SAT set point minus 1°C
10. The heating valve will modulate to maintain SAT set point
11. The cooling valve will modulate to maintain SAT set point
12. The cooling valve will not open when the heating valve is open

RTU1 Historic Trend Log Data: Jan 2017 (heating)



Outdoor reset SAT_SP / But SAT cools down quickly because EAD (OAD) is fully open / Then Heating kick in & OAD closes
Conclusion: dampers not modulating properly, & cause SAT to fluctuate rapidly & heating to kick in more than necessary…

RTU1 Historic Trend Log Data: last week of Mar. 2017 (cooling)

- It seems that EAD (OAD) is in reversed mode
- Cooling: fully open at night & fully closed in the day
- MAD 100% open means that all warm air is returned back & needs cooling

RTU1 Historic Trend Log Data: 1st week of Apr. 2017 (cooling)

- It seems that EAD (OAD) is in reversed mode
- Cooling: fully open at night & fully closed in the day
- MAD 100% open means that all warm air is returned back & needs cooling

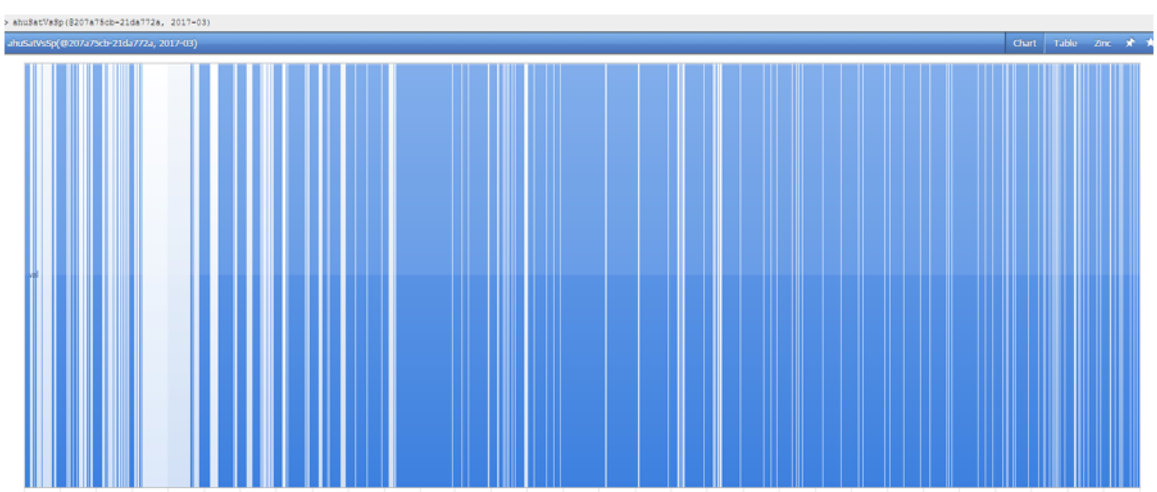
RTU1 Historic Trend Log Data: 2nd week of Apr. 2017 (cooling)

- It seems that EAD (OAD) is in reversed mode
- Cooling: EAD fully open at night & mostly closed in the day
- MAD almost 100% open means that all warm air is returned back & needs cooling

Find Periods when SAT is not meeting Set Point

```
/*
Find periods of time where SAT of AHU is out by 2 degrees from SAT setpoint
Runs on all AHU equipment
Leaves 10 minutes period for AHU to start up
*/

(equip, dates, dur:10min) => do

  // Read all points and assign to variables
  sat: read(discharge and temp and sensor and hisEnd and equipRef==equip.toRecId, false)
  satSp: read(discharge and temp and sp and hisEnd and equipRef==equip.toRecId, false)
  if (sat == null or satSp == null) return null// If one of the points does not exist in the equip then exit the function

  hisRead([sat,satSp],dates)// Read the history of the required points for the date passed in by the Spark engine
  .hisInterpolate // Interpolate the his data to bridge any misaligned data
  .map(row => {ts:row->ts,val: abs(row["v0"] - row["v1"]) > 2}) // Iterate over the rows of data to create a new grid of times when the spark is true
  .hisFindPeriods((val, ts, his) => val)// Filter out only true periods of time
  .hisFindAll(p => p > dur)// Find all periods that are more than the given duration

 end

```

Example periods SAT not meeting set point:
March of 2017

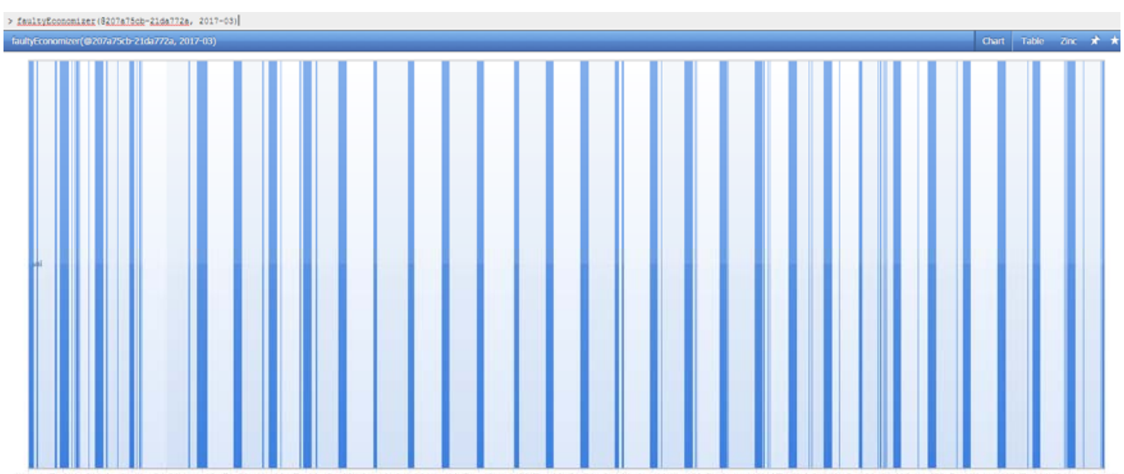


Find Periods when OAD is fully open (> 80%) & causing SAT to fall below set point minus 2℃

```
/*
Find periods of time where the economized cycle is not working peoperly:
- The Outdoor Air Damper (OAD) is fully open
- The Supply Air Temperature (SAT) is below set point
*/

(equip, dates, dur:10min) => do

  // Read all points and assign to variables
  sat: read(discharge and temp and sensor and hisEnd and equipRef==equip.toRecId, false)
  satSp: read(discharge and temp and sp and hisEnd and equipRef==equip.toRecId, false)
  oad: read(exhaust and damper and hisEnd and equipRef==equip.toRecId, false)
  if (sat == null or satSp == null or oad == null) return null// If one of the points does not exist in the equip then exit the function

  hisRead([sat,satSp, oad],dates)// Read the history of the required points for the date passed in by the Spark engine
  .hisInterpolate // Interpolate the his data to bridge any misaligned data
  .map(row => {ts:row->ts,val: (row["v1"] - row["v0"]) > 2 and oad > 80%}) // Iterate over the rows of data to create a new grid of times when the spark is true
  .hisFindPeriods((val, ts, his) => val)// Filter out only true periods of time
  .hisFindAll(p => p > dur)// Find all periods that are more than the given duration

 end
```

EAD (& OAD) fully open (> 80%) and supply air temperature below set point

Example periods: OAD > 80% open & causing SAT to fall below set point minus 2℃ (March 2017)



Conclusions

- Due to internal loads, cooling is requested by the building zones served by RTU
- RTU: mechanical cooling is kicking in unnecessarily…
- The exhaust air damper (EAD) is fully closed (0%), while the mixed-air damper (MAD) is fully open (100%), producing full recirculation of warm interior air
- This is causing full mechanical cooling to be used, without any need!
- The outdoor air temperature (OAT) is suitable for economizer (free-cooling) operation
- By modulating the EAD to fully close & MAD to fully open (100%) free cooling can be achieved
- SAT is not meeting setpoint during long periods. Consequences: making terminal VAV units work harder, and/or not meeting room thermal comfort
- Furthermore, no outdoor (fresh) air is being delivered by the air handler! Therefore inadequate indoor air quality are expected in the rooms… To be verified…
- Solution: RTU sequences of operation (SOO) need to be reprogrammed
- The air handler (RTU) is not capable of implementing more advanced sequences of operation to deliver comfort and IAQ with minimal use of mechanical energy
- Future: a new air handler can implement more advanced SOO. See next slide 36…

Air-side economizer Control (free cooling)

Outdoor air is cold enough to offset internal loads but perhaps colder than needed, therefore mixing brings OA to required condition

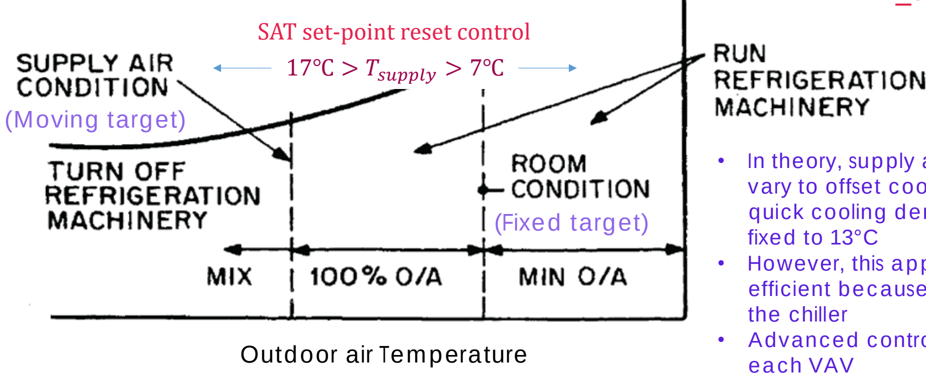
E.g. OAT = 7°C

Outdoor air is not cold enough to offset internal loads (refrigeration is still needed). But 100% OA minimizes refrigeration

E.g. OAT = 16°C

Outdoor air is too warm, we don't want to use it for cooling

E.g. OAT = 24°C



Example:

SAT_SP = 13°C

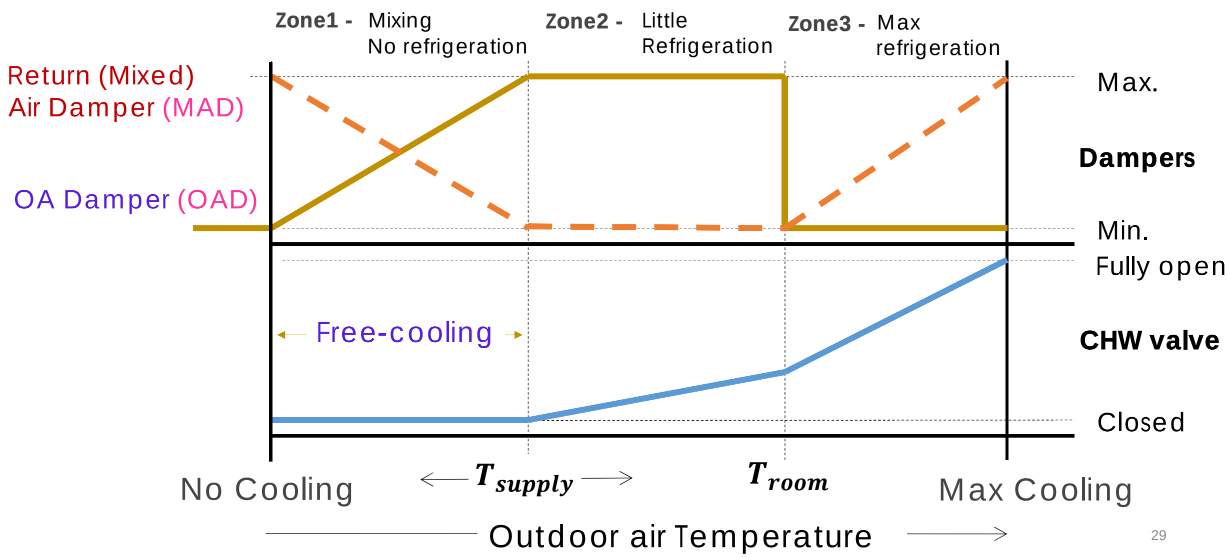
RT = 23°C

RT_SP = 21°C

- In theory, supply air temperature (SAT) can vary to offset cooling loads. However, for quick cooling demand response it is mainly fixed to 13°C
- However, this approach is not energy efficient because it puts high demand on the chiller
- Advanced control: SAT reset, by polling each VAV

28

Air-side economizer Control (free cooling)



29

30

ADVANCED SEQUENCES OF OPERATION

HEATING/COOLING (to minimize system energy: chiller/compressor, AHU fan):

- Air-Side Economizer (free-cooling)
- System pressure set-point reset control
- Supply air temperature set-point reset control

VENTILATION (to maintain ventilation effectiveness, while minimizing energy):

- Demand controlled ventilation (DCV) - Resets zone outdoor airflow (Voz) as zone population or effective OA per person varies (zone-level control)
- Ventilation reset control (VRC) - Resets outdoor air intake flow (Vot) in multiple-zone systems as system ventilation efficiency (Ev) varies (system-level control)
- Ventilation optimization - Combines DCV & VRC for multiple-zone (VAV) systems