Case Study : The Effective Use of an Extensive Logical Rule Based Data Analytics Approach in Establishing Root Cause of Performance Issues in Widespread Deployments of Unitary Space Air Conditioning Units

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Abstract :

Today a significant percentage of office spaces are air conditioned using widely deployed unitary systems, either Fan Coil Units (FCU) or Variable Air Volume (VAV) boxes, to achieve high degrees of air conditioned zonal control. However establishing a near realtime overall control monitoring regime to ensure proper control adherence across such large estates can be difficult, or possibly unattainable, where the number of units could effectively run into the hundreds, if not the thousands.

And, as is outlined in the problem definition section of this paper, compounding normal operational control issues such as system tuning and hardware failures, with inbuilt design limitations and poor building fabric issues, coupled with embedded deep rooted and undetected commissioning problems, and all functioning within a dynamic operational environment, one can see that the task of effective and timely root cause analysis can be an extremely difficult one [1].

Having being challenged with such a problem environment, the author attempts, through presentation of a series of actual real life working examples, to offer the reader the case for use of an effective and efficient aggregated data driven analytical approach, which includes temporal and geo spatial visualisation techniques, that makes the identification of the fundamental root cause problems, and system interactions (positive and negative) within this complex operational environment analysis, possible.

The presented approach therefore offers the SME community a means to detect the current underlying problems without the need for deployment of costly disruptive diagnostic procedures or preventative maintenance regimes. Such an approach also demonstrates the flexibility to cater for future problem diagnosis scenarios where the underlying logical rules built within the underlying architecture can be written, tested and deployed in a timely fashion. Finally it is contended that this targeted aggregated data driven fault diagnosis approach is equally applicable in any other situation which entails wide spread deployment of energy assets, for example, high volume deployments of store refrigeration units used within the Retail sector [2].

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1.0 Case Study: Problem Landscape Defined

IBM Research recently moved into a retrofitted existing facility on the IBM Technology Campus in Dublin, Ireland

As part of the design objectives, air conditioning was provisioned through an extensive network of local Fan Coil Units (FCU's) reference Fig 1 ground floor, allowing for an enhanced user comfort experience, with the heating and cooling energy provisioned through the central hot water (LPHW) and chilled water (CHW) systems respectively.

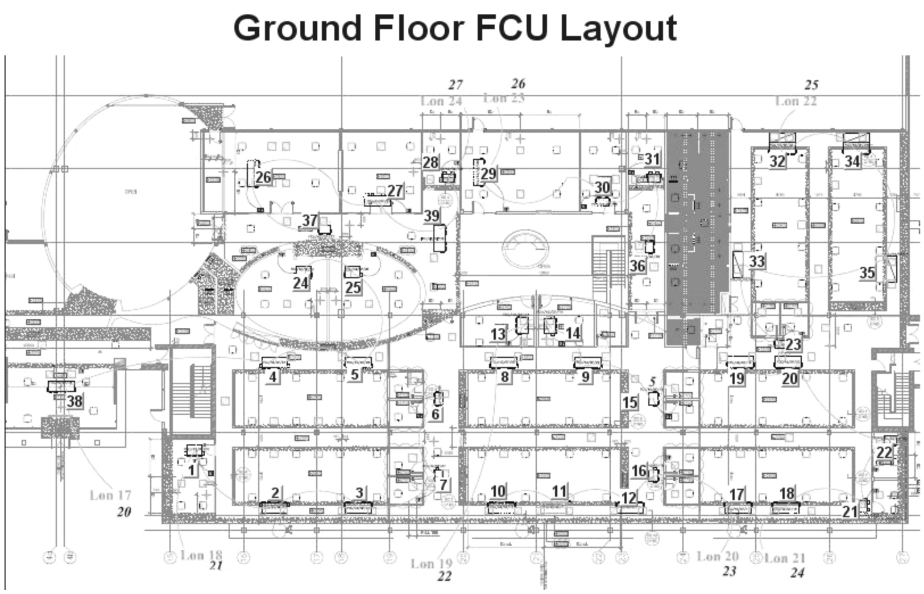


Fig 1 : Ground Floor Fan Coil Unit Spatial Floor Plan : U1 to U33

Over the intervening settling in period there were a number of problems forthcoming regarding the performance of these units, manifested as a series of user complaints in particular areas of the building where individuals were reporting feeling cold/uncomfortable at specific desk space locations.

Identifying the root cause of these problems by the Subject Matter Experts (SME) turned out to be very difficult, time consuming and costly. From extensive deep dive analysis over the subsequent investigation period, it become apparent that the problem turned out to quite a complex one, spread over a number of intersecting problem areas, and highlighted the need, and benefit, of the development of a building data driven analytics approach to overall timely problem diagnosis, and subsequent efficient problem intervention and fix.

An overview of the problem landscape is summarised as follows

1.1. Move In System Start Up Commissioning Debug & System Tuning Issues

As with any large scale deployment of unitary controllers, the likelihood of system problems slipping through the commissioning process is high, and the ability to detect and single out these issues quickly in the presence of the myriad of startup problems is essential.

Valve head swapping or unseating, sensor positioning or failure, or unit tuning issues are common problems that may go undetected for some time. Equally tuning of individual FCU’s is normally only carried out once the users have been in situ for some time, so identifying units requiring tuning ahead of receiving user complaints is important from a user satisfaction perspective.

1.2 LPHW and CHW FCU Provisioning Issues

Central to assessing performance of an air conditioning system is in establishing its ability to provide adequate separate hot water and chilled water energy supply to the individual FCU's when demanded. While the commissioning process is designed to initially balance and verify proper hot water and cold water pump control strategy implementation, ongoing verification of adherence to this control strategy, or validating speed and sensitivity of response on the pumping side to loop changes is necessary to ensure that adequate energy (heating and cooling) is provided at all times to the FCU estate.

Secondly contamination issues that cause the mesh filters in the cooling and heating circuits of individual FCU's to block, causing energy starvation, is a known and troublesome problem when FCU’s are provisioned in modified legacy LPHW and CHW systems.

1.3 FCU System Capacity/Building Fabric Insulation/Air Infiltration Issues

Determining underlying air conditioning provisioning issues relating to the structural environment in which the FCU assets perform can be difficult to ascertain as the following section outlines. Influences of Building Insulation Fabric Heat Loss/Gain are of particular concern particularly in a retrofit environment where it is unlikely that there would significant investment in building fabric enhancement. Overlaying of Wind Speed and Wind Directional data is also used to assess possible additional air infiltration problems with the building fabric.

And separating out possible FCU/VAV Unit performance limitations in the early days of occupancy is important to ensure ownership and adequate closeout by the M&E design teams.

2.0 Case Study Unitary Analytics Approach Detail

2.1 Data Acquisition Architecture

As part of IBM's Research efforts in Smart Buildings, and creation of our Living Lab [3] work on commenced on developing out additional series of effective data lead building energy asset related analytics, as a followon to successful commercialisation of Green

Sigma™ analytics deployed in IBM's smart building product offering in the last 18 months [4].

And while automated fault detection and diagnosis in the HVAC environments have been in place for some time [5][6] – applying the approaches in larger scale deployments of unitary systems has been constrained primarily due to the high volume and disparate nature of the underlying data structures, and associated integration costs, particularly evident in retrofit environments [7]

2.2 Unitary Systems Data Acquisition Targets

In order to maximise the impact and potential coverage of the rule based analytics, and coupled with the previous successful experiences of applying similar type rule logic to the AHU environment based on existing Building Management Systems, a limited set of data objects, detailed in Table 1 below were targeted for acquisition to form the basis of the analytics rule logic.

421_U1_DAT	Discharge Air Temp
421_U1_RAT	Return Air/Zone Temp
421_U1_TEMP_SPT	Temp Set Point
421_U1_CLG_VLV	FCU Cooling Valve %
421_U1_HTG_VLV	FCU Heating Valve %
421_U1_FAN_SPD	Fan Speed
W_STN_OAT	Outside Air Temp
W_STN_Wind_SPD_Avg	Wind Speed Avg
W_STN_Wind_SPD_Dir	Wind Speed Direction

Table 1 : Data Object Set Used for Rule Based Analytics within FCU's[2]

With this limited data object set, in Dublin, it was possible to generate over 25 separate logical rules that were used to establish almost extensively individual and collective FCU control adherence and performance, and helped identify underlying issues, directly or indirectly related to the FCU's, as the case study scenarios below will demonstrate.

However this paper attempts only to cover just three real instantiations of the rule logic applied in the Dublin site to demonstrate the possible value, effectiveness, and potential for such a time series data aggregation diagnostic approach in the large scale scale deployment of air conditioning unitary controller systems. This work will also lay the foundations for future optimisation of the FCU environment, and will include more effective response criteria e.g. moving beyond static Zone Temp setpoint control environments, and moving towards a more dynamic and user comfort centric focus.

[2] A similar limited set of objects is likely to apply to VAV boxes

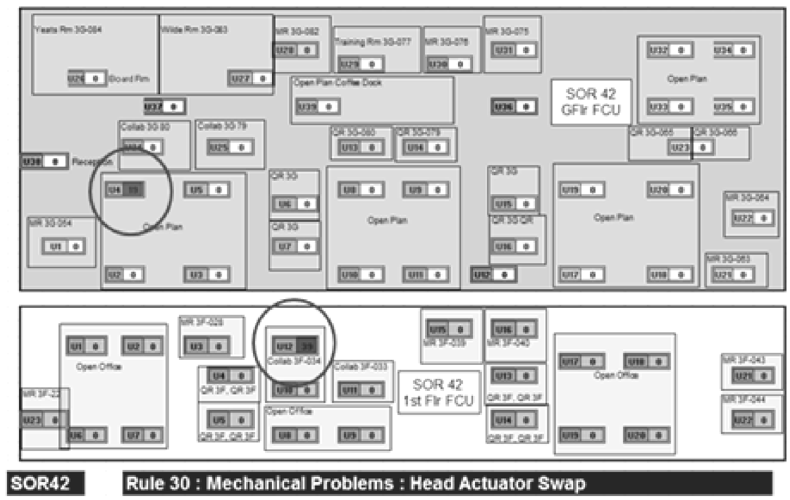
3.0 Case Study Applied Analytics Approach Examples

3.1 Example Scenario 1

Problem Detection : Identification of Units with Post Commissioning Problems

Rule Logic *:* AND (FAN_SPD>0, DAT>35, CLG_VLV>10,HTG_VLV=0)

Problem Diagnosis : From applying the rule logic outlined above, and reviewing the underlining data in Fig 2 below, almost immediately it becomes apparent that several units, U4 on the ground floor and U12 on the first floor, have their cooling and heating valve heads swapped. Similar type rule logic can be deployed to pick up on other types of typical post commissioning problems, like unseated head valves, or temperature sensors.



Rule 30 Analytic Alert : Problem Units

Rule 30 Logic : AND(FAN_SPD>0 ,DAT>35, CLG_VLV>10, HTG_VLV=0)

Month	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Day	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Hour	6	6	6	6	7	7	7	7	8	8	8	8	9	9	9
15 Min Interval	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2
Day of the Week	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed	Wed
Wind_Speed (m/s)	4.1	4.5	3.5	6.7	4.8	4.2	2.9	4.8	7.8	7.9	9.4	7.8	3.5	4.0	8.1
Wind_Speed_Dir	170	177	179	183	180	180	157	194	175	177	176	168	197	204	176
OAT (deg C)	-	10.2	10.3	10.4	10.3	-	10.2	10.2	10.3	10.3	10.3	10.0	10.0	10.1	10.2

Rule 30 : Mechanical Problems : Head Actuator Swap

421_U12_DAT	41.8	42.5	43.5	43.6	43.2	43.8	43.7	43.7	43.3	43.3	43.7	43.6	43.6	43.8	43.8
421_U12_RAT	24.6	24.7	24.7	24.8	24.9	25.0	25.2	25.2	25.2	25.2	25.2	25.2	25.3	25.4	25.4
421_U12_TEMP_SPT	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5	23.5
421_U12_CLG_VLV	44.0	80.7	98.7	98.7	98.7	98.7	98.7	98.7	98.7	98.7	98.7	98.7	98.7	98.7	98.7
421_U12_HTG_VLV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
421_U12_FAN_SPD	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0

Fig 2 : Identification of Units with Head Actuator Swap Problems

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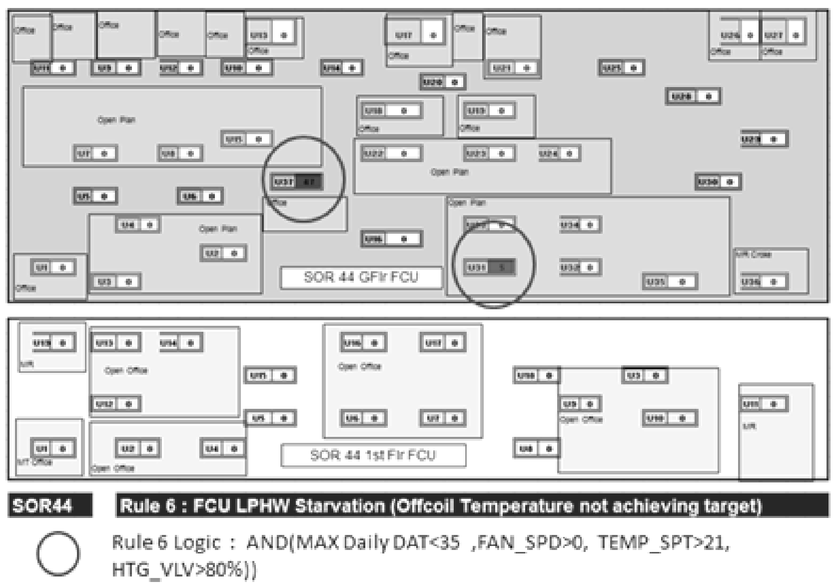
3.2 Example Scenario 2

Problem Detection : Identification of LPHW branches or individual FCU's with Possible Starvation Problems

Rule Logic : AND (Max Daily DAT<35, FAN_SPD>0, TEMP_SPT>21, HTG_VLV>80)

Problem Diagnosis : Applying the rule logic outlined above, and in Fig 3 below, over time it is evident from the spatial visualisation of rule invocation that there are possible strainer blockage problems with U37 and U31 on the Ground Floor, particularly when such alerts repeated over several days, as was the case in this example. Beyond the resolution of immediate user comfort issues, the cost avoidance associated with removing the need for ongoing visual inspection of the strainer units across the entire estate is of added benefit[1]



Month	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Day	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Hour	5	5	6	6	6	6	7	7	7	7	8	8	8	8
15 Min Interval	2	3	0	1	2	3	0	1	2	3	0	1	2	3
Day of the Week	Fri	Fri	Fri	Fri	Fri	Fri	Fri	Fri	Fri	Fri	Fri	Fri	Fri	Fri
Wind_Speed (m/s)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wind_Speed_Dir	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OAT (deg C)	9.5	9.6	9.4	9.4	9.3	9.5	9.6	9.8	10.0	10.1	10.1	10.2	10.2	10.4

Rule 6 : FCU LPHW Starvation (Offcoil Temperature not achieving target)														
44G_U37_DAT	20.9	21.7	22.3	22.8	23.0	23.0	22.9	23.2	23.4	23.6	24.0	24.4	24.7	24.4
44G_U37_RAT	18.6	19.0	19.3	[illegible]	19.8	19.9	20.0	20.2	20.3	20.5	20.6	20.9	21.1	20.9
44G_U37_TEMP_SPT	24.0	24.0	24.0	24.0	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
44G_U37_CLG_VLV	0.0	0.0	0.0	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44G_U37_HTG_VLV	100.0	100.0	100.0	100.0	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3
44G_U37_FAN_SPD	100.0	100.0	100.0	[illegible]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Max Daily DAT 25.8														

Fig 3 : Spatial Representation of Possible LPHW Strainer Problem

[1] ***Actual cost estimate for entire building strainer inspection was over €10k – effective application of data analytics as above was shown to reduce number of subsequent inspections, representing a 70%-80% reduction in costs due to these starvation events.***

3.3 Example Scenario 3

Problem Scenario : Identification of Fabrication Heat Loss/Design Capacity Issue during winter period where outside air temperature < 5 deg C

Rule Logic : AND (OAT<5, FAN_SPD>80 , DAT>35, HTG_VLV>50)

Problem Diagnosis : From applying the following rule logic outlined above, and in Fig 4 below, it is evident from the spatial visualisation of the rule alerts that there is a possible fabric problem given that 80% of the first floor perimeter units are displaying significant heating load and through separate rule logic application it was determined that 50% of these units were actually failing to maintain target setpoints.

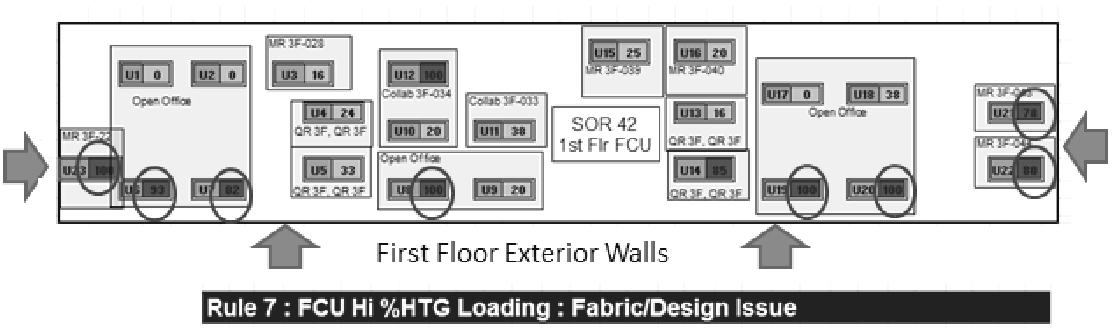


Fig 4 : Spatial Representation of Possible Fabric/FCU Design Capacity Problem

4.0 Conclusion

Targeted rule based data driven analytics for large scale deployment of energy assets is a cost effective way of managing, and in time, optimising the performance of the estate.

In fact properly architected, such an approach allows for almost realtime development and deployment of additional rules with little or no cost or delay, to give incremental valued insight into the systems performance. And in contrast, given the potential sheer numbers involved, without the presence of such data driven analytics approaches to fault detection and diagnosis, large scale deployments of unitary systems will continue to underperform. Also the need for proper geo-spatial representation to compliment the analytics findings will be essential in order to capture the wider impact of nonperforming assets.

Equally the inclusion of future covariates, including critical external conditions, physical geo spatial information, localised presence detection, and actual user comfort conditions which would include desk based stratified temp sensing, will in time, lead to a more accurate and powerful analytical insight into air conditioning provisioning in the future.

References

1. “Analytics and Visualisation for Intelligent Buildings” John Petze, Skyfoundry, Realcomm Webinar Feb 2013

2. “Tesco uses big data to cut cooling costs by up to €20m” ComputerWeekly.com 22 May 2013

3. Property Weekly.Com IBM Press Release Intelligent Building Solutions “Need to Know IBM’s Living Lab” 26 Oct 2012

4. IBM Product Release Intelligent Building Solutions “Green Sigma™ Analytics Rules Updated for IBM TRIRIGA Energy Optimisation 1.1”, 6 Jul 2012

5. Scheina J. et al “A rule-based fault detection method for air handling units”, Energy and Buildings, Vol 38, Issue 12, December 2006

6. Pakanen J., Sundquist T.,“Automation-assisted fault detection of an air-handling unit; implementing the method in a real building” Energy and Buildings Vol 35, Issue 2, February 2003

7. Brady N. “Making Your Building Smarter : The Retrofit Challenge”, ICEBO 2012