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Diagnostic Report

10/9/07

Executive summary

Assignment

Perform a diagnostic inspection on the air handler system serving OR. The reported problems are slow space pull-down between surgeries involving different surgical teams with different space requirements, and poor space temperature control. Our assignment was to determine what (if anything) is wrong and to identify what can be done to improve performance.

Summary of conclusions

Design

1. Design conditions are as follows:
    a. Supply air volume: 1,700 – 2,000 CFM
    b. Exhaust air volume: 1,400 CFM
    c. Design cooling supply air temperature: 50ºF.
    d. OR-4 space conditions (design day): 68ºF at approximately 50% - 55% relative humidity.

System deficiencies

1. Supply air volume is 50% - 75% above design. The current supply volume is 2,994 CFM.
2. The full available capacity of the installed system is not being utilized to pull the space down between surgeries, and maintain space conditions during surgery. Slow pull-down and fluctuating room conditions result in discomfort.
3. Space temperature and humidity control are erratic.
4. The DX cooling system is not functioning properly and is having a negative impact of space temperature control.
5. Chilled water flow is approximately 60% of design but would not significantly affect the leaving air condition at the above mentioned design conditions.

Recommendations

It appears that the designer intended for the OR to have redundant cooling capability in the event of chiller or pump failure or failure of the DX cooling system. With that in mind, we recommend the following:

1. Clean the air handler along with both cooling coils and both heating coils. Also clean the area on top of the large air handler where the re-cool/reheat coil is installed to allow us to solder safely.
2. Install a VFD on the supply fan to allow easy speed adjustments for flow changes.

3. Reduce the supply air volume to a maximum of 2,650 CFM to keep the DX coil face velocity below 550 FPM to prevent carry-over (when the DX system is repaired).
4. Assuming the OR is currently operating at the correct pressure differential, throttle the OR exhaust slightly to keep the OR positive to the surrounding space following the supply air reduction.
5. Install a dedicated unit controller to control the pre-heat, chilled water and DX coil functions. Provide interface points for BMS to access. Leave the final reheat coil under control by the BMS to allow their space controller to directly control space temperature via reheat. This will result in very stable space control.
6. Modify the hot gas bypass system so that it operates correctly and eliminates the unintended reheat of the supply air.
7. Modify the condensing unit to provide active low ambient control down to 40º outdoor temperature to improve hot gas bypass operation during light loads.
8. Install an electronic expansion valve and an electronic hot gas bypass valve to provide more precise refrigerant control.
9. Replace the existing compressor with two scroll type compressors before it fails unexpectedly (scrolls are preferred since the current compressor is an obsolete model)

Optional recommendations

1. Re-balance the supply and exhaust to the OR in total to the original design conditions.
2. Re-balance the chilled water system (this is a dedicated system with roof mounted chillers serving the Operating suites) to bring the chilled water flow up to that shown on the submittal. This would become necessary if the hospital is going to use the spare capacity provided in the air handler.

Details and supporting information

Design

Design intent

The design intent was pieced together from various sources, documents and observations since the original plans and specifications for the 1993 renovation were not available to us. The staff did research while we were on site and located a schedule page from an old set of plans. They reported to us that the design air volume for the OR air handler was originally 1,700 CFM with 1,400 CFM of exhaust, leaving the OR positive to the surrounding area by 300 CFM.

We obtained a copy of the original equipment submittal from the manufacturer dated 1/5/93. The submittal included two capacity selections for the air handler; one which stated a "present" supply air volume of 2,000 CFM, and another stating a "future" supply air volume of 4,000 CFM. The DX re-cool/hot water reheat coil section installed downstream of the air handler was selected only for the "present" volume of 2,000 CFM. This may indicate that the original designer intended to consider other spaces for future service by the OR air handler; but the re-cool/reheat coil section was intended to serve the OR only. Supporting this is the fact that a balancing damper is installed in the supply duct between the air handler and the re-cool/reheat coil indicating that a tap may have been considered upstream of the damper.

The information that follows was taken primarily from the submittal and supplemented with data from other software in cases where the submittal data was not provided.

Installed equipment

Air handler ("future" 7/27/92)

Fan section

- Design air volume: 4,000 CFM
- Total static pressure: 6" w.c.
- Design bhp = 6.77
- Installed motor: 7.5 HP.

Hot water pre-heat coil

- Coil construction: 1 row, 10 FPI (fins per inch), 2 pass, 10.38 sq.ft. face area, 385.3 FPM face velocity.
- Entering air dry bulb temperature: 0º
- Leaving air dry bulb temperature: 62.6º
- Hot water flow: 24.6 GPM, 200º entering to 177.2º leaving (22.8º range).
- Total sensible heat (mbh): 271.5

Chilled water cooling coil

- Coil construction: 8 row, 10 FPI (fins per inch), 10.38 sq.ft. face area, 385.3 FPM face velocity.
- Entering air condition: 95º/75º
- Cooling coil leaving air condition (draw-thru coil): 51.5º/51.4º
- Unit leaving air condition (including estimated fan heat): 56º/53.3º
- Chilled water flow: 57.3 GPM, 45º entering to 56º leaving (11º range).
- Total heat (mbh): 314.3
- Sensible heat (mbh): 188.64

Air handler ("present", 7/27/92)

Fan section

- Design air volume: 2,000 CFM.
- Total static pressure: 4" w.c.
- Design bhp: 2.69
- Installed motor: 7.5 HP

Hot water preheat coil

- Coil construction: 1 row, 10 FPI (fins per inch), 2 pass, 10.38 sq.ft. face area, 385.3 FPM face velocity.
- Entering air dry bulb temperature: 0º
- Leaving air dry bulb temperature: 82.4º
- Hot water flow: 24.6 GPM, 200º entering to 185º leaving (15º range).
- Total sensible heat (mbh): 178.71

Note: The hot water preheat coil performance data for "present" was not included in the original equipment submittal. We calculated this using a competing manufacturers' software after comparing the software results at 4,000 CFM with the submittal to ensure a reasonably accurate comparison. The result at 4,000 CFM was within 3.8% of the submittal data.

Chilled water cooling coil

- Chilled water coil: 8 row, 10 FPI (fins per inch), 10.38 sq.ft. face area, 385.3 FPM face velocity.
- Supply fan motor: 7.5 HP. design bhp = 2.69
- Entering air condition: 95º/75º
- Cooling coil leaving air condition (draw-thru coil): 47.1º/46.8º.
- Unit leaving air condition (including estimated fan heat): 50.6º/48.41º.
- Chilled water flow: 57.3 GPM, 45º entering to 51.3º leaving (6.3º range).
- Total heat (mbh): 307.95
- Sensible heat (mbh): 184.66

Note: The chilled water coil performance data for "present" was not included in the original equipment submittal. We calculated this using a competing manufacturers' software after comparing the software results at 4,000 CFM with the submittal to ensure a reasonably accurate comparison. The result at 4,000 CFM was within 2.3% of the submittal data.

Re-cool/reheat coil section

The re-cool/reheat coil section is a duct mounted DX cooling coil with a hot water reheat coil installed in series with the OR-4 air handler. This was intended for one flow only (present and future conditions did not apply).

Re-cool coil

- Design air volume: 2,000 CFM.
- DX cooling coil: 12 row, 10 FPI (fins per inch), 4.86 sq.ft. face area, 411.4 FPM face velocity with hot gas bypass.
- Refrigerant saturated suction temperature: 40º
- Refrigerant entering liquid temperature: 110º
- Entering air condition (submittal): 95º/75º.
- Cooling coil leaving air condition (submittal) (blow-thru coil):46.0º/45.8º.
- Total heat (mbh): 184.36
- Sensible heat (mbh): 106.3.
- Submittal sensible heat ratio: 57.66%
- Entering condition with fan heat (3.5º): 98.5º/75.9º.
- Coil estimated leaving condition with fan heat:47.4º/47.2º
- Total heat (mbh) with fan heat:186.15
- Sensible heat (mbh) with fan heat: 110.81
- Sensible heat ratio (mbh) with fan heat: 59.5%

Note: The entering and leaving coil conditions that include fan heat were derived by calculation for the inlet condition and using a competing manufacturers' software after comparing the software results at 2,000 CFM with the submittal to ensure a reasonably accurate comparison. The result at 2,000 CFM was within 0.3% of the submittal data.

Hot water reheat coil

- Design air volume: 2,000 CFM.
- Hot water reheat coil: 1 row, 10 FPI (fins per inch), 4.86 sq.ft. face area, 411.4 FPM face velocity.
- Entering air dry bulb temperature: 55º
- Leaving air dry bulb temperature: 87.8
- Hot water flow: 4.5 GPM, 200º entering, 167.4º leaving (32.6º range).
- Total sensible heat (mbh): 71.06

Re-cool condensing unit

- Model number:RC-151-58
- Serial number: 22965-01-01
- Voltage: 460/3/60
- Cooling capacity at 40º evap/130º condensing temperature (submittal coil conditions) (mbh): 175
- Cooling capacity at the operating point (approximate balance point) between the coil and the condensing unit (43º evap./130º condensing temperature) (mbh): 186.4.

- Unit compressor: Copeland model 3DTA-150E-TFD, three cylinder nominal 15 HP discuss compressor with one stage of unloading (one of three cylinders (33% capacity reduction) controlled by suction pressure).

Assumptions on the design (cooling side)

1. The designer likely specified 1,700 CFM for the supply volume but selected the air handler for 2,000 CFM to provide some safety factor.
2. Since both the chilled water coil and the DX re-cooling coil were selected for full capacity, it appears that 100% cooling redundancy was designed into the supply serving the OR.
3. The design air temperature leaving the mechanical room on a 97º/75º day appears to have been between 48º and 51ºF.
4. The designer likely intended either the chilled water coil or the DX coil to be in operation at any one time except possibly on days exceeding design conditions.
5. It is likely that chilled water was the primary source of cooling with the DX system acting as a backup and probably with automatic changeover.
6. Assuming the designer anticipated holding the relative humidity in the room between 50% and 55%, the resulting space temperature would fall between 67º and 70ºF on a design day (using the design conditions on the submittal).
7. When outdoor conditions were below design, the capability would exist to lower the space sensible temperature below 67ºF.
8. Based on the information gathered, the assumed design condition for the OR-4 space is:
   a. Supply air volume: 2,000 CFM
   b. Exhaust air volume: 1,700 CFM
   c. Summer supply air temperature: 50ºF.
   d. OR space conditions (design day): 68ºF at approximately 50% - 55% relative humidity.

Notes on design conditions

1. Standard conditions at that time meant that these conditions (based on history) would only be exceeded for a small percentage of the hours in the month. The old publications aren't handy; however, current standards allow selection of 0.4%, 1% or 2% of the hours in July (2.9 hours, 7.2 hours and 14.4 hours respectively) where the stated conditions may be exceeded.

Field measurements

Overview

We setup our test equipment and observed this system operate while we recorded several sets of readings and measured both air and water flows. During these tests the chilled water 3-way valve was manually opened to allow full flow through the coil. During our day of testing, the DX condensing unit ran 100% of the time loading and unloading except when turned off by us for testing. Room temperature control was left under automatic control since surgery was in progress.

Field air handler readings

Description	*Set #1*	*Set #2*	*Set #3*	*Set #4*
Comment	Initial readings			Cond. unit off
Time	10:00	12:00	14:00	14:15
Airflow (CFM)	2,994	2,994	2,994	2,994
AH Entering air temp	72.3º	73.4º	73.6º	73.3º
AH Entering air RH	47.4%	47.1%	53.6%	54.8%
AH leaving air temp	53.3º	53.4º	54.4º	54.5º
AH leaving air RH	81.5%	81.7%	81.1%	81.2%
Chilled water flow (GPM)	36.8	34.9	35.0	35.0
Entering water temp	42.6º	42.7º	42.9º	42.9º
Leaving water temp	48.3º	49.1º	49.7º	49.2º
Water temp difference	5.7º	6.4º	6.8º	6.3º
DX coil leaving temp	49.9º	48.6º	58.2º	54.5º
Temp difference across DX coil (+ -)	-3.4º	-4.8º	+3.8º	0º
Reheat coil leaving temp	51.3º	65.3º	63.5º	54.6º
Calculations				
CW coil mbh based on water measurements	104.9	111.7	119.0	110.3
Air handler net mbh based on air readings (includes fan heat)	76.49	82.87	95.15	95.03

Field air handler reading notes

1. The air handler leaving air temperature and relative humidity were taken at a single point in the discharge air stream immediately after the final filter bank. This reading includes fan heat. A single point reading is not representative of the air condition after a cooling coil (unless it is well mixed downstream) and allows for fairly significant error when calculating coil performance. For true coil capacity calculations, a multi-point temperature and humidity traverse is required.
2. Through the course of the day, we observed varying degrees of reheat across the DX cooling coil. At one point (when not taking a formal set of readings) we observed 54º leaving the air handler and 70.2º leaving the DX coil (16.2º pickup) before the reheat coil.
3. For reading sets 3 and 4, the instrument measuring the air handler leaving air condition was relocated to a different spot in the air stream.

Field condensing unit readings (single set)

Description	*Reading set #1*	*Reading set #2*
Compressor suction pressure	62 psig	65 psig
Saturated suction temperature	35º	37.5º
Suction line temperature	43.5º	44.4º
Suction superheat	8.5º	6.9º
Compressor discharge pressure	155 psig	235 psig
Saturated discharge temperature	85º	112º
Discharge temperature	118.5º	161º
Discharge superheat	33.5º	49º
Liquid line temperature	83.6º	89.7º
Approximate subcooling	1.4º	22.3º
Liquid line sight glass	Glass etched (not visible)	Glass etched (not visible)
Hot gas bypass feeding	Yes	Yes
Compressor loaded or unloaded	Unloaded	Loaded

Field condensing unit reading notes

1. The compressor crankcase heater is not wired.
2. The compressor crankcase was very cool during operation indicating poor refrigerant control.
3. The compressor has a slight detectable knock when unloaded.
4. The compressor has a 2005 serial number indicating that it has been replaced.
5. Sub-cooling is approximate since we did not have a pressure reading at the liquid line temperature point.
6. Compressor superheat is low.

Conclusions based on field measurements and design analysis

1. The equipment installed is adequate in size and configuration to provide very low supply air temperatures to the space. Low and steady supply temperatures will result in quicker space cool down times between surgeries and more stable room conditions during surgery.
2. Control of the supply air temperature to the space (along with dehumidification) is currently not maintained at a steady low temperature. Providing a steady low supply air temperature (say 45º) would allow the space to cool down quickly (faster than it currently does) and stabilize.
3. With the current equipment, the final permitted supply air temperature will likely be determined by possible condensation on the exterior of the supply duct as it passes through other spaces and the final permitted OR relative humidity.
4. The current control strategy does not take advantage of the full capability of the installed equipment. Fluctuating discharge air temperatures cause the current control system to move around trying to compensate which results in poor space temperature and humidity control.
5. Temperature control of the discharge air supplying the space is not adequate. In order to provide quick cool down and space humidity control, the discharge air temperature prior to the final reheat coil must be held constant. This will allow the reheat coil to maintain a close space temperature tolerance and space RH to remain in the 50% - 55% range.

6. If the chilled water and DX systems are to operate in concert, control changes, including control strategy are required.
7. Airflow to the OR is approximately 50% higher than design (if 2,000 CFM is considered the design).
8. Chilled water flow is approximately 60% of the flow noted in the submittal (for 4,000 CFM). Using competitive coil software, this flow will maintain the required 50º air handler leaving air temperature at 2,000 CFM, but will be about 4º-5º high at the current air volume of 2,994 CFM.
9. The DX re-cool coil and condensing unit are contributing very little. At 2,000 CFM, the condensing unit and coil were designed to carry the full load. As it is currently operating, it is at times actually having a fairly significant negative impact since the hot gas which is intended to match the capacity with the load is actually heating the air stream.
10. The compressor in the condensing unit has been replaced within the last two years indicating that this system may have a history of failures.
11. The current compressor has a slight "knock" when operating unloaded. There appears to be life left in the compressor however this is a sign of wear typically caused by a lack of lubrication.
12. The face velocity on the re-cool coil is currently 616 feet per minute at the measured flow of 2,994 CFM. If the DX system were operating properly, coil carry-over would likely result if the DX system were operated without the pre-conditioning provided by the chilled water coil (it could occur even with the pre-conditioning). Coil carry over could saturate the interior of the re-cool/reheat section which is not desirable.

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