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Value-Based HVAC Equipment Selection

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How do HVAC designers select HVAC equipment? Ideally, equipment selection would be based on total life-cycle costs, but that seldom is the case. More commonly, equipment is selected based on the designer's past experience and familiarity with the product or low price. In this month's column, I will outline a better and more transparent approach to equipment selection that provides a more effective balance between first costs and equipment features and performance.

Current Practice

On design-bid-build, aka "plan & spec" (p&s), projects, equipment selection can be somewhat arbitrary. The designer usually uses products he or she is familiar with from past experience with similar projects, perhaps influenced by recent articles in professional magazines or recommendations from a supportive sales representative (rep). Seldom is equipment priced prior to selection. In fact, once listed in the equipment schedule, the product immediately becomes more expensive than it might otherwise be because the "basis of design" equipment selections end up being purchased most of the time. This is because contractors do not want to take on the liabilities and responsibilities of an alternative product ("substitution"), including secondary impacts such as changes in size, weight, power requirements, etc. Sales reps know this, so the scheduled equipment can be sold for a higher price. If the product is unique, the total price of equipment can be still higher if the rep "bundles" the equipment with other products he or she represents. If the specified product is significantly more expensive than alternatives, contractors will often propose a substitution, but this can result in arguments between the contractor and engineer about what is "equal," multiple submittal reviews, revisions to construction documents, all requiring additional time on everyone's part. Ultimately, with this approach, it is unlikely that the purchased equipment was the best selection for the project or purchased at the best price. This is not an effective way to select equipment.

On bid-design-build, aka "design/build" (d/b), projects, if there are detailed bridging documents or specifications, the equipment may already be selected with the same disadvantages as described previously for p&s projects. If the bid documents are lean and the d/b contractor is selected based on their low bid, then the equipment is usually also selected based on low price. Again, it is unlikely this results in the best equipment selection for the project.

A Better Approach

A better approach is to make major equipment selection a team effort, where the contractors, design engineer, owner, and any other members of the design

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team can participate with all performance and pricing data fully transparent. This information is collected by requesting equipment bids from manufacturers' reps using a bid form that includes performance data as well as a final fixed price. The design and construction team can then transparently discuss and weigh the advantages and disadvantages of each bid option, including price, energy performance, noise, space requirements etc., and make a final selection.

This approach is effective for selecting any equipment, but it is ideal where any of the following is true:

- The specified product is unique, especially if it can be bundled with other products.
- There are many different features among the available manufacturers that cannot be easily evaluated without knowing and weighing the costs.
- There are significant variations in performance vs. price so arbitrarily setting a single design performance in bid documents may not result in the best selection.
- Other considerations where a side-by-side comparison makes for a better selection than low bid.

Examples include chillers, boilers, custom air handlers, and large packaged air-conditioning units.

The procedure can be implemented in one of two ways, either during the design phase or after the design is complete.

Design Phase Selection

Selecting equipment during the design phase is the recommended option since it allows the design team to design around equipment selections without concern about redesigns that might be necessary if the contractor proposes substitutions. The bid should occur when equipment capacities are known and relatively firm, typically right at the start of the Construction Documents (CD) phase. Here is a summary:

1. Decide which equipment will be bid using this approach.
2. Prepare equipment specifications, as with any project. In general, the specs should not mandate specific performance, such as chiller efficiency. Efficiency will be evaluated later along with other selection criteria. However, it is desirable to specify maximum sound power levels since there are multiple ways to address sound, as discussed in the air-handler selection example below.
3. Prepare a bid form for each equipment type. The form must include price and performance data and should include other application data such as power requirements, weights, delivery information, etc. Two examples, chiller selection and custom air-handling unit selection, are discussed below.
4. Send the specs and bid forms to selected manufacturers' reps with a fixed bid period, typically two weeks. The specs and forms usually include alternates to either delete or add features the design team wants to consider. Voluntary alternates from the bidders should be encouraged. For large chillers, which are custom equipment with an extremely wide range of price and performance, bidders should be encouraged to make multiple proposals. If a consulting engineer conducts the bid, it is essential to make it clear that this bid is the only bid for this equipment; there will be no opportunity to rebid when the project is released for general contractor bidding. Reps who are not experienced with this process may consider this a "budget" and not provide competitive pricing, mistakenly thinking there will be an opportunity later to provide the "real bid" to contractors. It must be made clear that this is the "real bid." Also, bidders should be allowed to deviate from the specifications in any way provided the deviations are spelled out in the bid form. This ensures that the selection process is not skewed to any one product. Deviations from the specs are considered during the bid evaluation, just like any other selection consideration.
5. Adjust pricing if there are secondary cost impacts of some options. For example, open-drive chillers require that a fan-coil be added in the chiller room due to motor heat gain. As another example, most low mass boilers require a minimum flow bypass while a higher mass boiler may not. Note that cost is only one consideration so these adjustments may be rough order of magnitude estimates (ROMs) provided by the project estimator.
6. Collect the bids and compile into a single table to allow side-by-side comparison of the various features. Usually, the engineer also provides additional subjective information in the table, such as relative maintenance costs, prior experience with each product or manufacturer, etc.
7. Meet with all team members who care to participate to discuss the bids and make a selection. On a p&s project where contractors are not yet on board, the meeting would typically be just the engineer and

owner's representatives. On a d/b job, contractors would also participate. The selection is made by subjectively and objectively weighing the pros and cons of each option, sometimes supported by more detailed energy cost calculations. (See *Example 1* and *Example 2* below.)

8. Enter the final selection into equipment schedules and plans. The equipment can be fully coordinated with other elements of the design following the manufacturer's installation instructions without concern that a later substitution will be made.

9. (This step is only required for p&s projects.) "Flat spec" the final selection with language to make it clear that no additional proposals will be considered when the project is released for general contractor bidding. For example:

a. List the manufacturer and full model number in the equipment schedule with "NO EQUAL" listed in the Remarks column.

b. Include the equipment tag and price in the equipment specification used for the CD bid, at the very beginning of Part 1. For example:

A. Provide the scheduled chillers including the scheduled options for the following price:

1. CH-1: $101,406
2. CH-2 and CH-3: $189,450 each
3. Price includes freight, but does not include taxes.

B. Bids for other chillers will not be accepted.

c. In lieu of the Part 2 Materials Section, include a detailed submittal of the selected equipment. This will allow the contractor to coordinate rigging and other installation details. This is particularly important for products that ship in multiple sections, such as large custom air handlers.

Post-Design Selection

Sometimes, it is not possible to bid and select equipment prior to bidding the rest of the mechanical work. For example:

- Public projects may have bidding rules that do not allow the design team to bid equipment.
- Some private owners also do not allow designers to bid equipment because they do not believe the pricing will be competitive. (This is a valid concern and discussed above; as noted, the equipment reps must understand they will be given only one chance to bid.)
- In some cases, especially on public projects, the quality and other characteristics of contractors bidding the project can vary such that reps are unwilling to use the same pricing for all bidders, so firm pricing cannot be obtained until the contractor is known.
- D/b projects are often bid very early in the design process, e.g., after Schematic Design, when the HVAC system design and equipment sizes are not known well enough to get firm equipment bids.

Fortunately, it is still possible to use the procedure above with a few tweaks:

1. Decide which equipment will be bid using this approach.
2. Obtain budget prices for each piece of equipment. Typically, the equipment that is the basis of design would be priced. It is not very important to get precise pricing since the contract amount will be adjusted once final selections are made.
3. Do not include the manufacturer and model numbers in equipment schedules so it is clear final selections have not been made.
4. Stipulate the price in specifications as described in Step 9 of the Design Phase Selection procedure above. Make it clear that this price must be used in contractor bids. Also request the percentage markup the contractor applies to this equipment.
5. After the contractors are on board, bid and select equipment as described in Steps 2 to 7 of the Design Phase Selection procedure above.
6. Modify the design, if necessary, to accommodate the final equipment selection. (The possibility of design revisions is the main disadvantage of post-design bidding.)
7. Adjust the mechanical contract price by subtracting out the stipulated equipment price and adding in the final price, adjusted by the contractor markup.

Example 1: Chiller Selection

Large chillers are the most difficult pieces of equipment to select because they are custom products with hundreds of selection permutations, so there are many variables to consider. The rigorous life-cycle cost based approach to chiller selection outlined in ASHRAE's CHW plant design manual[1] is best if the design schedule (and fee) allow, but it is time consuming for both the design engineer and chiller sales reps. This design manual also outlines a Simplified Procurement Procedure that aligns with the procedure described above. It is recommended for most projects since the extra level of effort required above the more conventional practice is minimal.

Table 1[*] shows bid results from an office building project with two chillers and a variable primary flow (VPF) distribution system. Fields marked in green are positive features while those marked in red are negative elements. The most important criteria are:

- Price
- NPLV (non-standard part load value), which is a measure of annual efficiency. It is more indicative of annual performance than full-load efficiency (kW/ton) since the chillers will seldom operate at full load.
- Unloading capability, i.e. at what minimum load can the chiller stably operate?
- Evaporator minimum flow rate. With a VPF distribution system, a lower minimum flow rate will impact chilled water pump energy use more than design evaporator pressure drop.
- Condenser water pressure drop. The condenser water pumps are constant flow so condenser pressure drop will drive condenser water pump energy.
- Refrigerant. This is an important selection criterion as we move away from refrigerants with high Global Warming Potential (GWP). Unfortunately, for some chiller types, new generation low GWP refrigerants are not yet an option, as was the case in this

TABLE 1 Example chiller bid summary.

OPTIONS	1	2	3	4	5	6
PRICING						
Tags	CH-1, CH-2	CH-1, CH-2	CH-1, CH-2	CH-1, CH-2	CH-1, CH-2	CH-1, CH-2
Price for Both Chillers (Including Freight)	$206,670	$238,210	$201,940	$318,790	$241,950	$232,350
GENERAL						
Compressor Type	Screw	Centrifugal	Open Drive Centrifugal	Dual Centrifugal	Centrifugal	Screw
Refrigerant Type	134a	134a	134a	134a	134a	134a
Bearing Type	Standard	Magnetic	Standard	Magnetic	Magnetic	Standard
Operating Weight (lbs)	17,881	12,086	19,335	12,580	16,504	15,944
Refrigerant Weight (lbs)	760	552	1,101	950	800	475
Variable Speed Drive (Y/N)	Y	Y	Y	Y	Y	Y
OPERATING CONSTRAINTS						
Capacity (% Of Design Capacity) Below Which Hot-Gas Bypass Operates (If HGBP is Provided)	10%			10%		
Capacity (% of Design Capacity) Below Which Chiller Cycles	12%	12%	15%	DNL	14%	20%
Minimum "Lift" (CWRT-CHWST) at Minimum Load °F	20.0	0.0	15.0	0.0	1.0	25.0
Maximum CHWST Reset Temperature °F	62.0	60.0	60.0	60.0	65.0	65.0
EVAPORATOR						
Design Capacity (tons)	300	300	300	300	300	300
Design CHW Flow (gpm)	288	288	288	288	288	288
Leaving CHWST °F	42.0	42.0	42.0	42.0	42.0	42.0
Entering CHWRT °F	67.0	67.0	67.0	67.0	67.0	67.0
Evaporator Passes	3	3	3	2	2	3
CHW Pressure Drop (ft)	15.9	14.4	12.7	7.4	4.8	3.0
Minimum CHW Flow Rate VPF (gpm)	114	111	112	140	184	269
Minimum CHW Flow Rate VPF (%)	40%	39%	39%	49%	64%	93%
CONDENSER						
Design CW Flow (gpm)	600	600	600	600	600	600
Entering CWST °F	76.9	76.9	76.9	76.9	76.9	76.9
Leaving CWRT °F	90.8	90.7	90.7	90.8	90.7	91.0
Condenser Passes	2	2	2	2	2	2
CW Pressure Drop (ft)	11.6	10.6	14.5	9.1	4.6	7.8
PERFORMANCE						
A-Weighted Sound Power dB(A)	84	75	80	100	79	83
Full Load amps	270	233	230	253	227	313
NPLV	0.34	0.37	0.41	0.38	0.37	0.45
Design kW	166.4	178.4	160.3	182.5	174.5	206.7
Design kW/ton	0.555	0.533	0.534	0.545	0.521	0.617

[*] The actual bid form includes much more information than shown here. Rows not relevant to this article were eliminated.

example project.

- Compressor type.

Other factors such as space required, sound power, and weight can also be factors on some projects, but not this particular project. Minimum lift is a factor on projects with integrated waterside economizers, but this project included airside economizers so minimum lift was not a factor.

In this case, the design team selected Option 1 for the following reasons (*Table 1,* Page 57):

- It cost the least to purchase and install. Option 3 has the lowest price for the chiller, but it has an open drive so there is a secondary cost to install a cooling system in the chiller room.
- It is likely to be the most energy efficient option because it has the lowest NPLV, unloads well, and has a low evaporator turndown, somewhat offset by higher condenser water pump energy.
- It has screw compressors, which generally are less expensive to maintain than centrifugal compressors, especially those without magnetic bearings.

TABLE 2 Maximum AHU sound power levels.

		MAXIMUM SOUND POWER LEVEL (DB)						
	Frequency	63	125	250	500	1,000	2,000	4,000
AH-1, 2	Supply Air Opening	90	88	96	84	80	79	75
	Return Air Opening	92	90	85	82	79	80	73

Example 2: Custom Air-Handling Unit Selection

Custom air-handing units (AHUs) significantly benefit from performance-based bidding because they have so many design options. Bid specs must include some limits, e.g., maximum coil and filter face velocities, the minimum number of fans in fan arrays, the minimum number of variable frequency drives (VFD), maximum width, length and height, etc. Another key element to specify is maximum sound power by octave band at the unit return air inlet and supply air outlet, data determined by the project acoustical consultant based on the actual layout of the AHUs and proximity to occupied spaces (*Table 2*). AHU manufacturers can meet noise targets in many ways, including increasing the number of fans in the array, increasing the size of internal elements such as coils, filters, dampers, air openings, etc., to minimize internal pressure drop, or adding sound attenuators.

Meeting acoustic goals played a role in the AHU bid summarized in *Table 3*.† The manufacturer of AHU Option 3 probably tweaked the number of fans and internal equipment sizes and pressure drops until the AHU was able to meet the specified sound power limits without requiring a supply air sound attenuator. The result was a reasonably priced AHU with better energy performance than the competition. Option 1 had the lowest price but significantly worse energy performance due primarily to higher internal component pressure drops, including that of a supply air sound attenuator. The project team opted to select Option 3 accordingly.

Conclusions

Selecting equipment using performance-based bids has several advantages, including:

- Without the pressure of the conventional low-bid process, equipment can be selected based not only on low price, but also on features and performance that the design team and owner believe justifies the price premium. Energy efficiency and manufacturer's reputa-

† The actual bid form includes much more information than shown here. Rows not relevant to this article were eliminated

tion are examples of characteristics that cannot be rigorously evaluated with the conventional low-bid selection procedure.

- Competition is improved because there is no "basis of design" selection, which can carry a premium price because of the costs and risks of substitutions.
- Proprietary and unique features of one manufacturer can be considered without worrying that the price will be inflated because the reps know these features are unique. To maintain competition in a conventional bid, unique features of one manufacturer cannot be specified, potentially losing desirable enhancements.
- If the equipment is selected in the design phase, it can be fully incorporated into the design, possibly minimizing space requirements (it is not necessary to provide more space to allow for the flexibility of entertaining alternative manufacturers at bid time), eliminating related equipment that may not be necessary with the selected product (such as field installed sound attenuators, minimum flow bypasses), and eliminate redesign costs that often occur in the normal bid process should a significant change in equipment selection occur post-bid.
- "Bundling" of unique products with other products reps may represent is eliminated.
- Contractors find this approach helps at bid time because all major equipment pricing is fixed. There is no scramble to find the lowest equipment bidder and determine if the proposed product meets specifications, nor any need to disaggregate bundled pricing. Contractors also know that it allows the submittal phase of the project to be completed quickly with little or no conflict, and there will be no substitutions and the disruptions they can cause.

In short, compared to conventional practice, this equipment selection procedure provides the most flexibility in selecting the right product for the project, enhances fair competition among manufacturers, and reduces conflict and disruptions during construction.

References

1. ASHRAE. 2017. *Fundamentals of Design and Control of Central Chilled-Water Plants.* Atlanta: ASHRAE. ■

TABLE 3 Example custom air handler bid summary.

OPTIONS	1	2	3
AHU Tags	AH-1, 2	AH-1, 2	AH-1, 2
Price for Both AHUs (Including Freight)	$936,400	$1,158,800	$1,069,820
GENERAL (EACH AHU)			
Number of Shipping Sections	5	5	5
Total Operating Weight, All Sections (lbs)	96,286	77,290	87,290
SUPPLY FAN PERFORMANCE (EACH AHU)			
Plenum Fan Array (Quantity Wide × Quantity High)	7 × 3	7 × 3	8 × 3
Quantity of VFDs	3	3	3
Airflow (cfm)	145,000	145,000	145,000
ESP (in. H_2O)	2.50	2.50	2.50
TSP in. H_2O)	5.37	5.12	4.68
Total Fan Break Horsepower (BHP)	180.2	174.2	153.4
RELIEF FAN PERFORMANCE (EACH AHU)			
RF Orientation (Return or Relief)	Relief	Relief	Relief
Plenum Fan Array (Quantity Wide × Quantity High)	7 × 3	7 × 3	8 × 3
Quantity of VFDs	3	3	3
Airflow (cfm)	125,000	125,000	125,000
ESP (in. H_2O)	0.50	0.50	0.50
TSP (in. H_2O)	0.85	1.03	0.86
Total Fan Break Horsepower (BHP)	32.2	40.5	35.9
COOLING COIL PERFORMANCE (EACH AHU)			
CHWST (F)	42.0	42.0	42.0
EADB (F)	77.0	77.0	77.0
EAWB (F)	63.0	63.0	63.0
LADB (F)	52.9	52.9	52.9
Coil Face Velocity (fpm)	552	528	543
Coil Rows/fpi	8 Row/8 Pass 10 fpi	8 Row/8 Pass 10 fpi	8 Row/8 Pass 10 fpi
Water Flow Rate (gpm)	372.5	382.9	340.0
Water Pressure Drop (ft H_2O)	14.0	8.0	12.3
Air Pressure Drop (in. H_2O)	1.40	1.03	1.01
CHWRT (F)	64.0	63.4	66.1
FILTER PERFORMANCE (EACH AHU)			
Airflow (cfm)	145,000	145,000	145,000
Filter Face Velocity (fpm)	537	494	483
Prefilter Type	2 in. Pleat	2 in. Pleat	2 in. Pleat
Prefilter Minimum MERV	6	6	6
Prefilter Clean Pressure Drop	0.31	0.29	0.28
Final Filter Type	15 in. Bag	15 in. Bag	15 in. Bag
Final Filter Minimum MERV	13	13	13
Final Filter Clean Pressure Drop	0.40	0.48	0.34
SOUND ATTENUATORS			
Internal Return Air Attenuator Length (ft)	None Required	None Required	None Required
Return Air Attenuator Pressure Drop (in. H_2O)	0.0	0.0	0.0
Internal Supply Air Attenuator Length (in.)	24.0	36.0	None Required
Supply Air Attenuator Pressure Drop (in. H_2O)	0.15	0.31	0.0