How to Estimate the Cost of a VAV Reheat HVAC System

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Main CSI Division: Division 23 00 00 Heating, Ventilating, and Air Conditioning (HVAC)

Specific Sub-Division: Division 23 20 00 HVAC Piping and Pumps, Division 23 30 00 HVAC Air Distribution, Division 23 70 00 Central HVAC Equipment

A Variable Air Volume (VAV) system is defined as "a system that delivers primary air at a constant temperature and varies the airflow to maintain the required space temperatures at all load conditions".[1] Office buildings experience various conditions at their exteriors; however, on the inside nearly everything produces heat. Occupants, lighting, copy machines, computers and other plug in equipment all reject heat. One method to deal with this is to use an air delivery system that will move cool air into the building to offset the heat produced by these sources. This technique may help to cool the office equipment, but a second issue of occupant comfort also exists. A VAV reheat system can help by using a rooftop air handler that draws in outside air, heats or cools it, and pushes it out to various zones throughout the building. A zone is a smaller area within the building, such as a partitioned office, with its own thermostat and temperature settings. A device called a VAV terminal box with reheat coil makes the adjustments to air flow and temperature to meet the temperature set point of each zone. See Figure 1 below for a schematic representation of the concept.

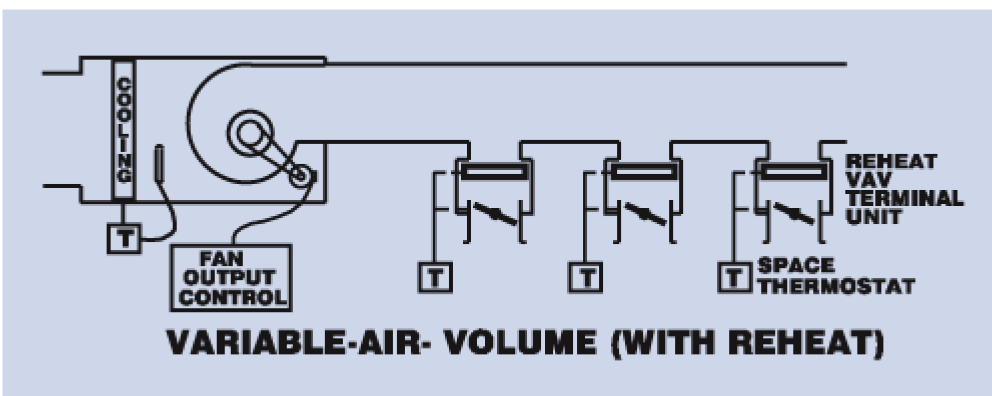

Figure 1 VAV System Schematic[2]

The VAV system works by automatically reducing or increasing the amount of cool air allowed into a space (zone). By removing less heat from a particular space, the temperature within will eventually rise. Keep in mind, everything in the office building, for the most part is producing heat. Conversely, allowing more cool air into a zone will lower the temperature. A VAV system will not be allowed to reduce the air flow to zero. Some minimum amount of air flow is necessary for ventilation. When this point is reached and a zone still requires heating, the VAV

[1] Trane Power Point, page 9, PP VAV systems, TRC014EN.ppt, 2001 American Standard Inc.
[2] Energy Efficiency Manual, page 1, Energy Institute Press, Donald R. Wulfinghoff

system will reheat the air before it is released into the space. A hot water reheat coil within the VAV terminal box accomplishes this using an automatic control valve to modulate the flow of heating water through the water coil. Take note of the fact that the reheat does not occur until the minimum air flow is reached. By far the largest opportunity for energy conservation in VAV reheat systems is minimizing the operation of the reheat coils.[3]

Section 2: VAV System Components

An HVAC system can usually be separated into two parts, wet-side (water systems) and dry-side (air systems). Major equipment for wet-side systems are chillers, cooling towers, boilers, and pumps. Major equipment serving dry-side systems are air handlers and exhaust fans with some minor equipment such-as VAV terminal boxes.

Piping systems distribute chilled or heated water around the building to serve water coils within the air handler and VAV terminal boxes. Duct systems distribute filtered, conditioned air around the building to serve various zones.

Section 3: Types and Methods of Measurements

Mechanical drawings are typically drawn using 1/16th, 1/8th, or 1/4 inch per foot scale depending upon the size of the building and how the architect and engineer decide is the best way to break it up. If a buildings floor plate is very large, it is often clearer to split it in half on two drawings at a larger scale than squeeze it all on one at smaller scale. The most useful drawings for the mechanical estimator are the floor plans, mechanical equipment schedules listing all the major equipment, detail drawings, enlarged sections, and controls drawings.

Mechanical piping systems are measured from the drawings by determining the size of a specific pipe run. The nominal outside diameter is usually indicated adjacent to pipe runs on the drawing. The length can be determined by using a scale. Pipe fittings, supports, valves and specialties, are all counted and totaled. Each measured piping run of a specific size will be added to determine a total length in lineal feet (LF).

Measuring ductwork on the other hand is a significantly different process. First, the dimensions of a section of duct must be determined. Either height and width or diameter depending whether it is rectangular or round. Second, the surface area of the duct section must be calculated starting with something called “stretch-out”. Within the HVAC industry this measurement is called stretch-out because it is as if the duct section is mentally unfolded and “stretched-out” on the floor. It is more commonly recognized as the perimeter of a rectangular section or the circumference of a circular section. Surface area in square feet (SF) is then calculated by multiplying stretch-out by the length of the duct section. Finally, a factor can be applied to the surface area to determine the total weight of a duct section. The weight can then be used to determine shop fabrication time, field installation time, and raw material (sheet metal) costs.

Section 4: Specific Factors to Consider

Small projects tend to be more costly on a $/SF basis due to the inefficiencies that inevitably occur. One example, material pricing will not be as highly discounted as on larger projects. Another, crew mix may not be ideal with too few workers to allow for the use of apprentices. A

[3] Energy Efficiency Manual, page 1, Energy Institute Press, Donald R. Wulfinghoff

very small project may be limited to a foreman and journeyman. Lastly, the efficiencies of repetitive work tasks may not be realized. On the other hand, a project that is too large may experience another set of issues such as: unknown or unproven work force, dilution of management, logistical issues, “lost” workers or equipment, and travel time to and from work areas. Somewhere in the middle there is an ideally sized project where efficiency can be maximized.

Other factors that may affect project costs: aggressive scheduling causing too many workers in the same area or requiring overtime, building height causing loss of time travelling to and from work areas, multiple levels below grade, insufficient parking, site logistics, congestion and poor design documents.

Before an estimator begins the takeoff and measurement of material quantities, a few questions should be asked and answered. 1) Who is the client and what are their expectations? An important question especially if the focus is to exceed their expectations. Understanding the client, architect and engineering team may also help to inform factors within the estimate. 2) Is there any specific breakdown to the estimate? For example, is shell and core estimate to be separated from the fit-out estimate? It may be useful to structure the estimate and take-off effort a certain way to account for this. 3) What is the level of detail to be presented? The client may want a lump sum or an extremely detailed line by line estimate for reconciliation. 4) Where is the project located? This will help determine labor force availability and their rates, sales tax, logistics, and market conditions. 5) Lastly, what are the cost drivers? Typically, piping and duct installation are two of the most significant due to the high labor component and relatively large quantities; however, there may be other, project specific cost drivers worth considering.

Section 5: Estimating Major Components of a VAV Reheat HVAC System

The purpose of this technical paper is to attempt to describe a method to estimate the mechanical costs of a variable air volume ventilating (VAV) system. The scope of an entire system estimate is too large for the purposes of this paper; however, the author will exhibit the tools and techniques necessary to provide a mechanical cost estimate for all major components. The mechanical design is assumed to be at the construction documents (CD) stage.

For starters, it is usually good practice to break the estimate up into wet side and dry side costs, often the drawings are set up that way for clarity. More importantly, labor rates vary for pipefitters and sheet-metal workers so man-hours should be accounted for separately and the calculation of labor costs factored independently.

Major Equipment Estimate Examples:

Start with the takeoff of major equipment so information can be sent out to equipment vendors early in the process. Additionally, chillers and boilers are the points of origination for chilled and heating water distribution systems. Assume a 35 ton air cooled chiller is required for this project and is listed as such on the mechanical equipment schedule. Plenty of information including manufacturer and model number would most likely be included at CD level design. Establish the unit rate (cost/ton) by adding together, equipment cost, freight, tax, installation labor cost, crane and rigging. Assume a vendor furnished quote $22,750 including freight to the jobsite. Determine installation labor either from past experience or by referring to an estimating manual such as the Mechanical Contractors Association (MCA) Labor Estimating Manual (LEM)[4]. An air cooled chiller between 30 and 45 tons will require 24 man-hours[5] to set. Contact a local crane company to request a budget price on crane and rigging costs, assume a quote of $2,500. See below for the breakdown and note the only piece missing is the labor rate.

To determine the rate, the average crew size and mix must be established. For the purposes of this estimate, it will be assumed the schedule is sufficient to allow the entire project to be completed with a wet side crew of 5 men or women. The crew mix would be one foreman, two journeyman, and two apprentices. Local pipefitter union rules would govern[6]. Assume a foreman rate of $160/hour inclusive of base, fringe, taxes, insurance, small tools, truck, overhead and profit, journeyman rate of $145/hour with the same inclusions except for the truck, and apprentice rate of $115/hr. To calculate the cost of an average man-hour, the hourly rate of each man/women on the crew would be added together and divided by the total; however, the foreman would not necessarily be engaged 100% of his/her time in productive labor operations. Assume 50% of the foreman's time is spent ordering material, filling out time cards, sorting drawings, and solving crew issues. In addition, the crew members themselves are realistically only going to be productive 7 hours of an 8 hour shift. If there are other factors causing inefficiency, they can be quantified and applied here as well. The crew cost per day can be calculated like this: ((1 x $160) + (2 x $155) + (2 x $115)) x 8hrs = $5,600/crew day. As discussed, the foreman will only be productive for 4 hours per day while the journeyman and apprentices for 7 hours each per day. Hence, the total production is: 4 hours + (7 hours x 4) = 32 man hours per crew day. The average cost per man-hour is the cost per crew-day ($5,600) divided by the number of productive hours (32 hours) = $175/hour.

	Material$	Labor/hours	Subcontractors
35 ton air cooled chiller	$22,750	24 hours	
Sales tax (8.5%)	$1,877	0 hours	
Crane and rigging	$0	0 hours	$2,500

The chiller installed cost per ton can be calculated once the cost per man-hour is applied. It would be calculated like this: ($22,750 + $1,877 + (24 x $175) + $2,500) divided by 35 tons = $31,327/35 = $895/ton. This is a useful way to enter the cost of the chiller into the estimate because it allows for adjustment later if, for example, the size of the chiller is altered due to some value engineering. Furthermore, it allows for benchmarking of chiller cost data. A similar calculation would be carried out for the remainder of the wet-side equipment such as: boiler, pumps, expansion tanks, and air separators.

Correspondingly, on the dry-side, calculation of the air handler unit rate follows: assume a 10,000 cubic feet per minute (CFM) roof-top air handler is required. Assume a vendor furnished quote including freight to the jobsite of $50,000. Add sales tax, crane and rigging costs, and labor costs, divide the total by 10,000 CFM and the $/CFM unit rate is yielded. The differences are the sources used to determine the labor to set the AHU and the calculation of the labor rate. Installation labor for a 10,000 CFM air handler can be found in the Cost Reference Manual for Sheet Metal and HVAC, a Sheet Metal and Air Conditioning Contractors National Association

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[4] Labor Estimating Manual, 2002 Edition, Mechanical Contractors Association of America

[5] Labor Estimating Manual, 2002 Edition, Mechanical Contractors Association of America

[6] Local 38 Collective Bargaining Agreement with Northern California MCA

(SMACNA) publication. From Table T-122, the estimated labor necessary to install a 10,000 CFM air handler is 20.16 man-hours[7].

	Material$	Labor/hours	Subcontractors
10,000 CFM Air handler	$50,000	20 Hours	
Sales tax (8.5%)	$4,250		
Crane and rigging	$0		$3,000

The air handler installed cost per CFM can be calculated once the cost per sheet-metal worker man-hour is applied. Assume a crew size of 7 men or women for this project and a crew mix governed by local sheet metal union requirements[8]: (1) foreman at $170/hour, (3) journeyman at $150/hour, and (3) apprentices at $95/hour. All rates are inclusive of base, fringes, taxes, insurance, small tools, truck (foreman only), overhead and profit. The average rate calculated from the above is $157 per hour. Apply the rate to the table above and the total installed cost of the air handler is $60,390 or $6.04/CFM.

Wet-side Piping Distribution System Estimate Examples:

Refer to the drawing excerpt below for the piping take-off.

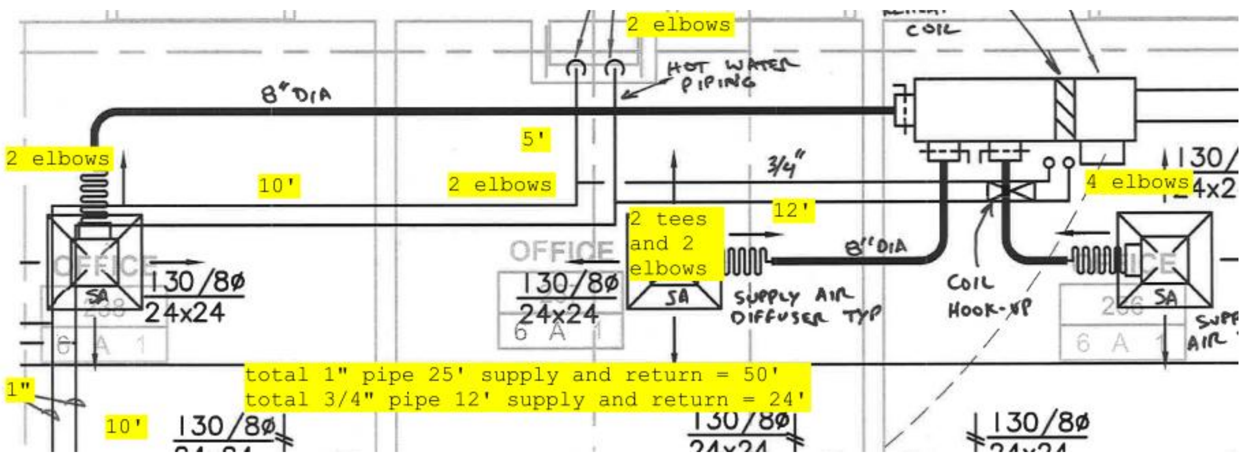

Figure 2 Taylor Engineering Mechanical Drawing Excerpt[9]

Piping Labor and Material Takeoff Sheet

Description	Qty	Labor Unit[10]	Labor Ext.	Material Unit	Material Ext.
1" Copper pipe	50	.07 hrs/ft	3.5 hrs	$1.50	$75.00

[7] Cost Reference Manual for Sheet Metal and HVAC, prepared by K-III Communications, Inc.

[8] Standard Form of Union Agreement between Sheet Metal Workers International Association, Local Union # 104 and Bay Area Association of SMACNA Chapters

[9] Drawing excerpt from Northern California Project, Designed by Taylor Engineering

[10] Labor Estimating Manual, 2002 Edition, Mechanical Contractors Association of America

1” Elbow	6	.63 hrs	3.8 hrs	$3.75	$22.50
1” Tee	2	.92 hrs	1.8 hrs	$4.42	$8.84
¾” Copper pipe	24	.06 hrs/ft	1.4 hrs	$1.72	$41.28
¾” Elbow	6	.53 hrs	3.2 hrs	$2.30	$13.80
½-2” hangers	15	1.25 hrs	18.8 hrs	$7.05	$105.75
Totals:			32.5 hrs		$267.17

If the average fitter rate ($175) is applied to the labor total above, the total labor cost for this list of material is $5,688. Add the labor ($5,688) and material plus tax ($290) and the total cost is $5,978. Determine an average cost per lineal foot of pipe by dividing the total cost by the total length of pipe (74 lineal feet) gives: $80.78/foot. Understandably, this is not a complete takeoff or an average unit rate that can be applied to all pipe on the project; however, it is useful and can be applied with reasonable accuracy to all the run-outs to VAV boxes on the project.

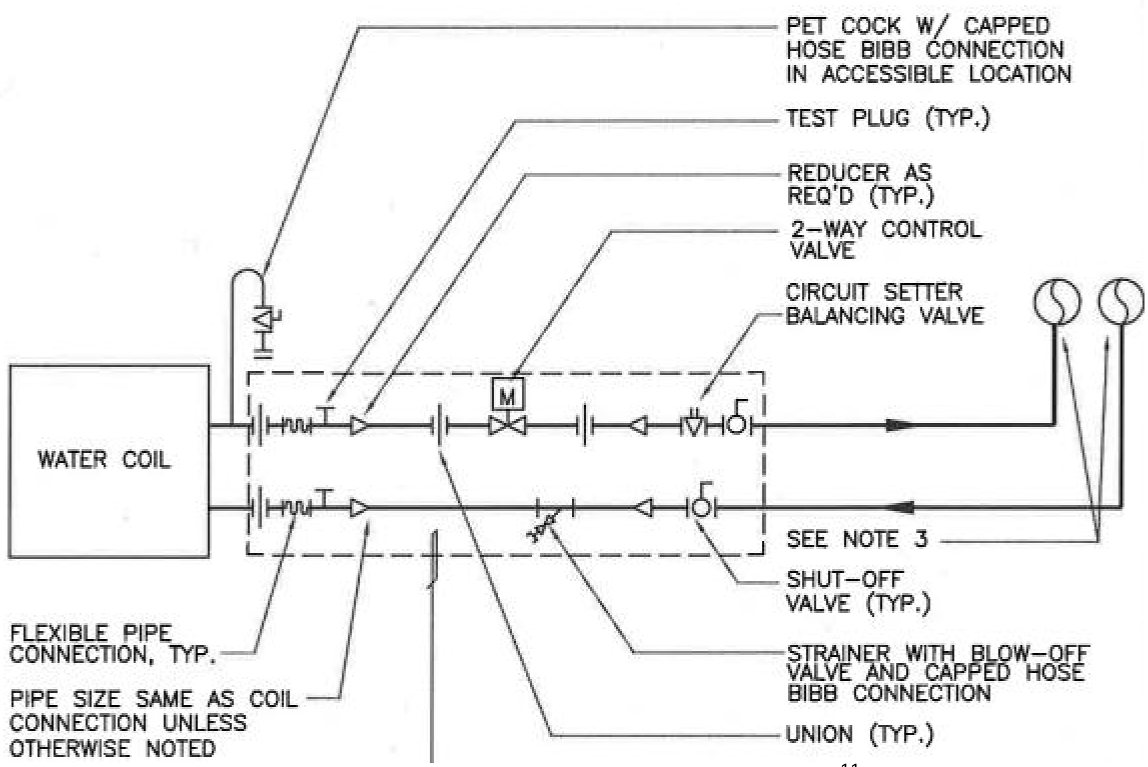

Figure 3 Taylor Engineering Drawing Excerpt[11]

The coil hookup indicated on Figure 2 above is further detailed in Figure 3. Fortunately, MCAA LEM provides a quick solution for this with labor tabulations of typical coil hookups. In this case, a 3/4” two-way coil requires 15.61 hours to build and install inclusive of the items shown[12]. A total cost for each coil hookup is calculated using the average labor rate ($175), multiplied by the estimated hours (15.61), and added to the total material cost (assume vendor quote of $300) of the items shown. Total coil hookup cost is $3057. Finally, complete heating water system cost can be determined using a similar approach applied to the heating water mains,

[11] Drawing excerpt from Northern California Project, Designed by Taylor Engineering
[12] Labor Estimating Manual, 2002 Edition, Mechanical Contractors Association of America

boiler and pump connections. Add to the system total subcontractor costs such as insulation and testing and balancing, general requirements such as job trailer and supplies.

Likewise, chill water system costs are determined by measuring the chill water mains routed between the chiller, chilled water pumps, and chilled water coil located in the air handler and employing a process similar to that outlined above.

Dry-side Distribution System Estimate Example:

The same example, expanded to show dry-side features will be used to exhibit costs associated with the dry-side systems. Refer to Figure 4 below. Duct sizes are shown on the drawing and sections are measured as follows:

Duct run size	Length(L)	Stretchout (SO)	Surface area (LxSO)
30” x 16”	30 ft	7.7 feet	231 square feet (SF)
10”	10 ft	2.6 feet	26 SF
18” x 8”	3 ft	4.3 feet	13 SF
8”	31 ft	2.1 feet	65 SF
Total Surface Area:			335 SF

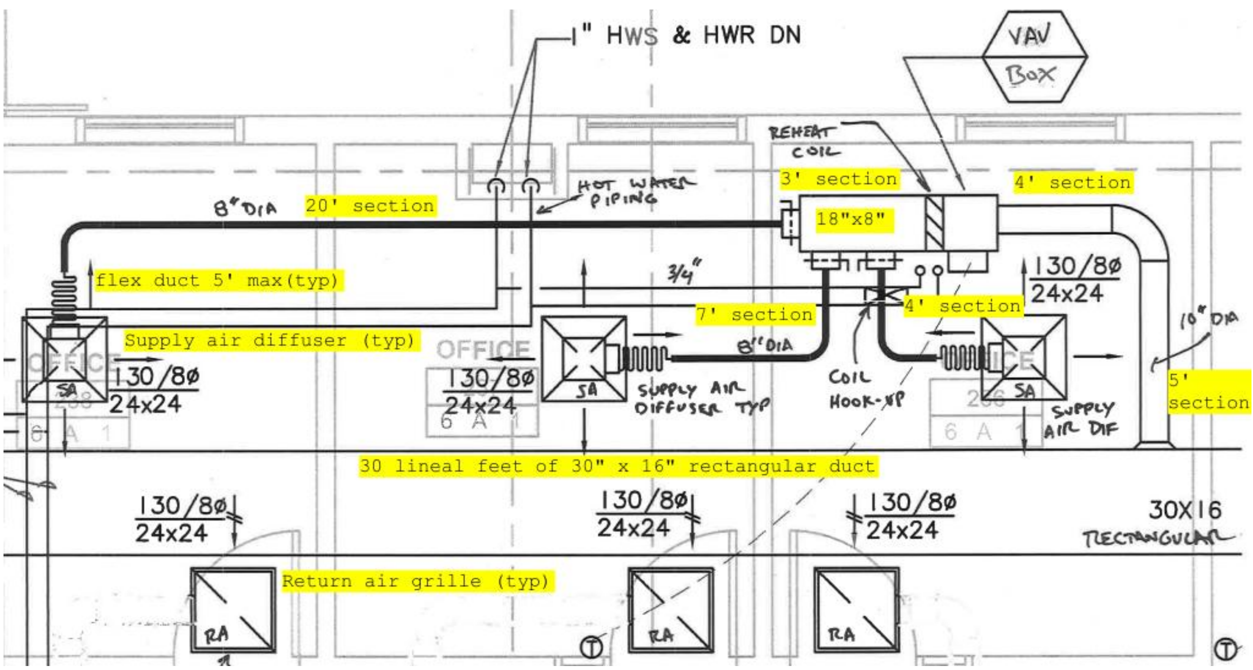

Figure 4 Taylor Engineering Mechanical Drawing Excerpt[13]

[13] Drawing excerpt from Northern California Project, Designed by Taylor Engineering

The surface area is a used to determine the amount of duct insulation or duct lining that will be required. Assume a local insulation subcontractor has provided a unit rate budget quote to install duct insulation of $4/sf. The insulation cost for the ducts shown is 335 x 4 = $1,340. More importantly, the surface area figures calculated above will be used to determine both shop labor to fabricate and field labor to install. Labor is calculated using the tables in the SMACNA Cost Reference Manual as follow:

Duct run size	Surface Area	Ratio (lbs/sf)	Weight	Shop rate	Shop labor
30" x 16"	231 SF	2.7	624 lbs	155 lbs/hr	4.03 hrs
10"	26 SF	1.4	36 lbs	105 lbs/hr	.34 hrs
18" x 8"	13 SF	1.4	18 lbs	113 lbs/hr	.15 hrs
8"	65 SF	1.4	91 lbs	102 lbs/hr	.89 hrs
Totals:			769 lbs		5.4 hrs

Use the total weight plus a waste factor of 10% to calculate the cost of the material. Assume a material price including tax and freight of $0.8/lb so the total material cost is $677. Assume a shop labor rate of $150/hour which is slightly lower than the field rate calculated above since shop crew mix and labor practices are more efficient in a shop setting. Total labor cost is calculated as $810.

The weight to surface area ratio is determined from Tables and Appendices in HVAC Duct Construction Standards.[14] Due to its larger size, a thicker duct wall dimension is selected for the 30 x 16 section to avoid the addition of reinforcements. Shop and field labor rates are found in the CRM[15]

Field installation labor is also calculated using the rates listed in tables of CRM[16]

Duct run size	Surface Area	Ratio (lbs/sf)	Weight	Field Rate	Field Labor
30" x 16"	231 SF	2.7	624 lbs	51 lbs/hr	12 hrs
10"	26 SF	1.4	36 lbs	12 lbs/hr	3 hrs
18" x 8"	13 SF	1.4	18 lbs	29 lbs/hr	1 hr
8"	65 SF	1.4	91 lbs	16 lbs/hr	6 hrs
Supports and miscellaneous			material allowance $250		4 hrs
Totals:			769 lbs		26 hrs

From the tabulations above, the field labor total to install the duct shown on Figure 4 above is 26hrs. The total field labor cost is $157 x 26 = $4082. Another useful unit rate can be calculated

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[14] HVAC Duct Construction Standards Metal and Flexible, Third Edition - 2005
[15] Cost Reference Manual for Sheet Metal and HVAC, prepared by K-III Directory Corporation for SMACNA
[16] Cost Reference Manual for Sheet Metal and HVAC, prepared by K-III Directory Corporation for SMACNA

once the total cost is determined. Add shop material ($677), field material ($250), shop labor ($810) and field labor ($4,082) then divide the total by total weight (769 lbs). Cost per pound is calculated as $7.57 per pound of duct. Assume Figure 4 is a fairly accurate representation of the system as a whole, and after the remainder of the ductwork show on the drawings is measured, this unit rate can be used to determine duct distribution system cost. Lastly, the remaining items shown on Figure 4 must be counted, priced and installation labor applied to complete the estimate. Supply diffusers and return air grilles are assumed to cost $45 each and require ½ hour for installation, so a suitable unit rate for them is $124 each. The terminal box installation labor can be found in Table T-138 of the CRM, assume an 800 CFM unit. The estimated installation rate is 3.5 man-hours[17]. Another vendor quote would reveal the cost of an 800 CFM terminal box to be roughly $500. Total installed cost of the terminal box is $1,092.

Calculate the total cost of the work shown on Figure 2 and Figure 4 by adding together all the components from above. Some minor cost are assumed and added for completeness. Refer to the tabulation below.

Description	Qty	Unit	Rate	Cost
Heating water piping, <= 1"	74	LF	$80.78	$5,978
Coil Hookup	1	EA	$3,057	$3,057
Pipe insulation (allowance)	74	LF	$11	$814
Sheet-metal Duct	769	LBS	$7.57/lb	$5,821
Flex duct (allow 5'/diffuser)	30	LF	$15/lf	$450
Volume dampers (1/SA diffuser)	3	EA	$65	$195
Diffusers and grilles	6	EA	$124	$744
Duct Insulation	335	SF	$4	$1,340
VAV terminal box	1	EA	$1,092	$1,092
Total:				$19,491

The total cost includes markups such as overhead and profit as detailed previously in the labor rate calculations. However, each project should be evaluated for risk factors that may require some additional adjustment as noted in Section 4 above. Additionally, any special rental equipment needs such as welding machines and scissor lifts, general requirements such as office trailer and supplies will need to be assessed and added. To check this number, employ a rule of thumb 700 SF/zone for an average office building. The total costs from above represent the cost for one zone. To derive an average cost $/SF, divide the total ($19,491) by the area of a zone (700 SF), hence $28/SF. Historically, in Northern California VAV systems serving office buildings run $35 to $45 per SF. $28/SF seems low; however, the equipment costs and main distribution could easily add $5 to $10/SF to the cost.

[17] Cost Reference Manual for Sheet Metal and HVAC, prepared by K-III Directory Corporation for SMACNA