ARE 346P

HVAC Project

Comparison of Revit MEP Automatic Duct Sizing and Equal Friction Method Manual Calculations

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Project Statement

The purpose of our project is to perform air distribution system design for a sample building HVAC system. This will be done through traditional methods involving determination of airflow requirements, diffuser selection, diffuser and duct layout, and duct design to properly size and balance the system. The importance of air distribution is to create the proper combination of temperature, air velocity, and air contaminant concentrations in occupied zones of conditioned space (Kuehn, 1998). These properties are extremely important to occupant comfort since both temperature and air velocity contribute to how warm or cold an occupant feels, and air contaminants in the air we breathe is a health concern.

A second objective of our project is to analyze the accuracy of automated duct design software compared to traditional duct design methods. Building Information Modeling (BIM) software is becoming increasingly popular among owners, contractors, and designers because of its ability to store data, make computations, and perform clash detection based on the properties and geometry of three-dimensional building elements. As mentioned above, one such computational function of BIM software is the ability to automatically size ductwork based on the volume flow rate at the diffusers and desired pressure loss. This function may be a useful tool for making engineering calculations in a much quicker and more efficient manner; however, we are skeptical of the accuracy of such automatic computations. For this reason we will generate a BIM model of our sample system in a commonly used BIM software, Autodesk Revit MEP 2010. We will then apply its automatic duct sizing function to generate ducts sizes and compare the results to the results we calculate based on the textbook method for duct design. This comparison is important because although technology is a useful and efficient tool, it can develop reliance by the user and produce costly results through software errors and mistakes by inexperienced users. The following is a list of outcomes we aim to produce through this project:

- BIM model of architectural layout for the given sample building
- Diagram of zoning layout for the sample building
- Table of given airflow requirements for each of the sample building zones
- Diffuser layout and types for the sample building
- Duct layout including locations of VAV boxes for sample building zones
- Duct design including duct material, shape, and sizing including all connections
- Sample calculations for textbook duct sizing method
- Spreadsheet of textbook calculations for *all* ducts and connections including pressure losses for each duct and fitting
- 3D diagram of automated duct sizing layout for system using Autodesk Revit MEP 2010
- Table of ducts and fittings including types and sizes from BIM automated duct design
- Comparison of textbook calculated duct design versus automated software design

Building Description

Since each wall of the two story building experiences different loading patterns and the core experiences no solar gains at all, it was separated into four perimeter office zones and one central zone to allow better control over solar gains . Initially the zones were divided radially as shown below in Zone Layout A; however, to accommodate corner offices the divisions were adjusted to Zone Layout B.

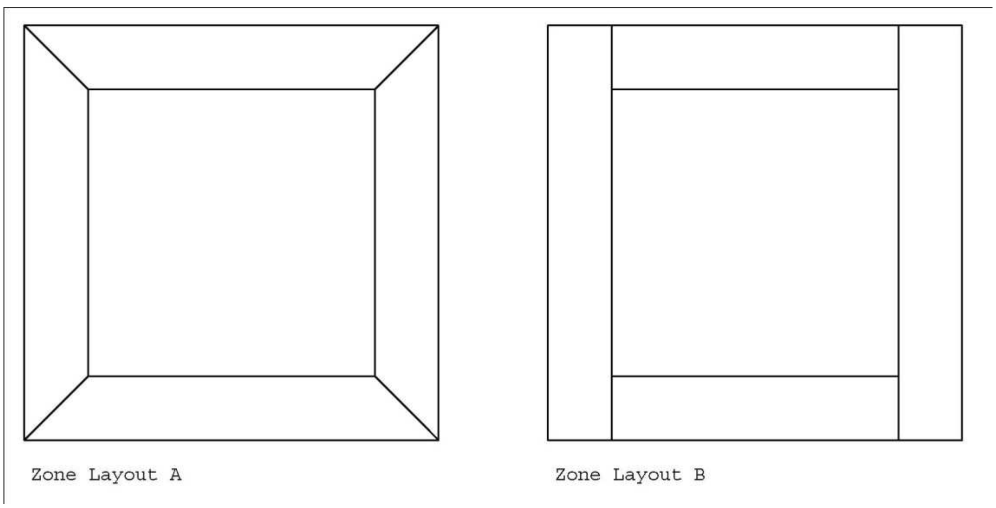

Figure 1: Zone comparison for layout purposes

Since the corner offices experience solar gains from two different directions we attached them to the east and west zones which carry the most extreme peak loads from direct sunlight.

When placing the diffusers we simplified constructability by selecting all 24 inches square units and considered a throw of 15 feet in each direction. Since our largest office is approximately 15 feet by 20 feet we were able to comfortably place one diffuser in each office. After subtracting a perimeter hall space from the central zone we were left with a space of approximately 60 feet by 60 feet in which four diffusers were placed so that each contributes to an area of 30 feet by 30 feet. We then added two diffusers to the hall space on opposing ends of the building. Although the hallway layout does not meet the requirements for throw, the main purpose of this consideration is for air mixing in a space inhabited by stationary people. Therefore, we concluded that this requirement could be overruled for the sake of economy in a space where people spend a short amount of time in transit. We did however provide a similar proportion of diffusers to floor area as we did in the central space to be sure that enough air was supplied.

The most challenging aspect of this design was how to split five branches of ducts from one vertical chase inside limited plenum space. A chase in the center of the building would have likely required either two separate VAV boxes or overlapping ducts in order to feed the central zone without branching from the chase at two separate vertical heights. We approached this problem by placing our chase in the corner of the central zone. By offsetting it from center we were able to run one small branch to the central zone and two larger branches which then split into the four perimeter zones. Our return air was then fed back to the two air handling units through the plenum space.

Methodology

An outline of our methodology for this project is as follows:

1. Draft sample building using Autodesk Revit Architecture BIM software.
2. Link Autodesk Revit Architecture building to Autodesk Revit MEP BIM software.
3. Design schematic diffuser layout and place diffusers in BIM model.
4. Design schematic duct layout and connect unsized ductwork to the placed diffusers in the BIM model.

5. Calculate airflow to the diffusers and assign airflow properties to each diffuser.
6. Size the ductwork using Autodesk Revit MEP automatic duct sizing function.
7. Generate spreadsheet to calculate duct sizing and pressure loss using textbook methods and produce example calculations for the textbook method used.
8. Compare the output of BIM automated duct design to our textbook method calculations.

The key assumption we made when calculating the airflow to the diffusers was that each diffuser had equal airflow requirements. We calculated airflow to each diffuser by dividing the total airflow requirement for each zone by the number of diffusers in that zone. Additionally, the airflow requirements for each zone prior to dividing by the number of diffusers were calculated using the equation:

$$q = Q/\rho c_p \Delta t$$

where,

Q = *cooling load per zone (Btu)*

Δt = *temperature difference (20 °F)*

ρ = *density of air (0.076 lb/ft^3)*

c_p = *specific heat of air (Btu/lb°F)*

q = *air volume flow - (cfm – ft^3 per minute)*

All ducts were assumed to be round sheet metal ducts. We also assumed an open plenum return air ventilation system would be used so only supply air duct design was performed.

The spreadsheet used for our calculations was designed using equations and diagrams from the textbook based on the equal friction method of duct design shown in Example 18.9 of the textbook. We worked backwards to design the ductwork in each zone by starting with the airflow requirements and pressure losses at each diffuser. We then calculated the airflow requirements through each duct and fitting by adding the volume flow rates of all subsequent ducts in the direction of flow. From there, we calculated duct sizes based on air quantity (CFM) and a desired friction loss of 0.2 inches of water per 100 feet of duct. Since Figure 18.18a of the textbook was difficult to include in our spreadsheet calculations, we used the equation:

$$\Delta p = (0.109136\ q^{1.9}) / d_e^{5.02} \quad (1)$$

where:

Δp *= friction (head or pressure loss) (inches water gauge/100 ft of duct)*

d_e *= equivalent duct diameter (inches)*

q = air volume flow - (cfm - cubic feet per minute)

To calculate duct diameter from this equation we rearranged the equation to be:

$$d_e = [(0.109136\ q^{1.9}) / \Delta p]^{(1/5.02)} \quad (2)$$

We then rounded to the nearest whole number to obtain the desired duct diameter. We then input the selected duct size into equation 1 to calculate the actual friction loss per 100 feet of duct. Lastly, we divided the duct length in feet by 100 feet to calculate the total friction loss for each length of duct. For the fittings we calculated loss coefficients for the fitting type using the tables in chapter 18 of the textbook, and an ASHRAE duct design manual for any fittings not shown in `the textbook. Velocity pressures were then calculated using the equation:

$$P_v = (q/4005)^2$$

where:

P_v *= velocity pressure (in. of water)* *q = air volume flow - (cfm –* ft^3 *per minute)*

The total friction loss through the fitting was then obtained by multiplying the loss coefficient by the velocity pressure. The total pressure loss was then calculated by summing the total pressure loss for each duct and fitting in a given direction of flow from the air handling unit to each diffuser. The largest pressure drop to any diffuser was used as a reference and the system was balanced by decreasing pressure with dampers at all other diffusers.

Results

Table 1: Flow Requirements For Each Diffuser by Zone

Zone	Cooling Load (kBTU)	Number of Diffusers	CFM/Diffuser
South, Level 1	52.934	4	605
West, Level 1	49.53	6	377
North, Level 1	30.149	4	344
East, Level 1	51.961	6	396
Core, Level 1	35.211	6	268
South, Level 2	59.213	4	676
West, Level 2	50.964	6	388
North, Level 2	32.103	4	367
East, Level 2	51.79	6	394
Core, Level 2	37.838	6	288

The number of diffusers per zone were decided based on which zones would experience the largest loads at a given time of day. Therefore, more diffusers were placed in the east and west zones than the north and south zones. Although technically the south has the highest loads, those are spread across the entire day whereas the east and west are predominately in the morning and afternoon, respectively.

Duct Sizing for Level 1

Table 2: Comparison of Duct Sizes for South Zone

Duct	Length				Type	Diameter (Revit)		Diameter (Textbook)	
12	6	ft	0	in	Flex	12	in	11	in
13	4	ft	7	in	Flex	12	in	11	in
14	4	ft	7	in	Flex	12	in	11	in
15	6	ft	1	in	Flex	12	in	11	in
42	19	ft	6	in	Round	12	in	11	in
43	18	ft	7	in	Round	15	in	15	in
44	15	ft	10	in	Round	16	in	15	in
45	4	ft	0	in	Round	16	in	11	in
46	1	ft	10	in	Round	16	in	15	in

The south zone on level one has 4 diffusers. These diffusers are connected to flex ducts, as can be seen in Table 2. Between Revit and the textbook values, they are both fairly logical. The largest difference is in duct 45, where Revit has placed a larger duct than is necessary for the flow requirements. Because duct 45 is only serving one diffuser, it appears there is no reason for making it so much larger than duct 42, which serves a comparable purpose. This inconsistency warrants further analysis.

Table 3: Comparison of Duct Sizes for West Zone

Duct	Length				Type	Diameter (Revit)		Diameter (Textbook)	
1	4	ft	7	in	Flex	12	in	10	in
16	4	ft	9	in	Flex	12	in	10	in
17	3	ft	1	in	Flex	12	in	10	in
18	3	ft	0	in	Flex	12	in	10	in
19	3	ft	1	in	Flex	12	in	10	in
20	3	ft	2	in	Flex	12	in	10	in
47	15	ft	2	in	Round	12	in	10	in
48	18	ft	9	in	Round	14	In	12	in
49	18	ft	5	in	Round	16	In	12	in
50	18	ft	11	in	Round	18	In	12	In
51	6	ft	0	in	Round	16	In	12	In
52	7	ft	8	in	Round	16	In	10	In
53	0	ft	11	in	Round	16	in	16	In

The flex ducts for the west zone, shown in Table 3, are approximately equal to the textbook values. Additionally, duct 53, which is the main supply for the west zone, is the same. However, the main branch, ducts 47 through 52, do not have similar duct diameters. Also, duct 50 in Revit is larger than duct 53 in Revit which is strange considering that duct 50 serves flow for 4 diffusers and duct 53 serves flow for 6 diffusers.

Table 4: Comparison of Duct Sizes for North Zone

Duct	Length				Type	Diameter (Revit)		Diameter (Textbook)	
2	4	ft	3	in	Flex	12	in	9	in
3	4	ft	3	in	Flex	12	in	9	in
4	4	ft	9	in	Flex	12	in	9	in
5	6	ft	0	in	Flex	12	in	9	in
27	19	ft	9	in	Round	12	in	9	in
28	17	ft	6	in	Round	12	in	12	in
29	17	ft	6	in	Round	23	in	12	in
30	2	ft	8	in	Round	24	in	12	in
31	3	ft	8	in	Round	24	in	12	in

Ducts 29 through 31, as seen in Table 4, have significantly larger diameters than the textbook values. This over sizing seems unnecessary. However, it does follow the logic of ducts getting larger as the flow increases.

Table 5: Comparison of Duct Sizes for East Zone

Duct	Length				Type	Diameter (Revit)		Diameter (Textbook)	
1	4	ft	7	in	Flex	12	in	10	in
16	4	ft	9	in	Flex	12	in	10	in
17	3	ft	1	in	Flex	12	in	10	in
18	3	ft	0	in	Flex	12	in	10	in
19	3	ft	1	in	Flex	12	in	10	in
20	3	ft	2	in	Flex	12	in	10	in
47	15	ft	2	in	Round	12	in	10	in
48	18	ft	9	in	Round	14	in	12	in
49	18	ft	5	in	Round	16	in	12	in
50	18	ft	11	in	Round	18	in	12	in
51	6	ft	0	in	Round	16	in	12	in
52	7	ft	8	in	Round	16	in	10	in
53	0	ft	11	in	Round	16	in	16	in

The inconsistencies present in the east zone, Table 5, are almost identical to those in the west zone, Table 3. This consistency of inconsistency illustrates that the problem is systematic.

Table 6: Comparison of Duct Sizes for Core Zone

Duct	Length				Type	Diameter (Revit)		Diameter (Textbook)	
21	4	ft	6	in	Flex	12	in	8	in
22	2	ft	1	in	Flex	12	in	8	in
23	2	ft	10	in	Flex	12	in	8	in
24	2	ft	0	in	Flex	12	in	8	in
25	2	ft	0	in	Flex	12	in	8	in
26	5	ft	6	in	Flex	12	in	8	in
59	25	ft	10	in	Round	16	in	8	in
60	8	ft	10	in	Round	16	in	11	in
61	2	ft	4	in	Round	16	in	11	in
62	18	ft	4	in	Round	16	in	11	in
63	13	ft	0	in	Round	16	in	8	in
64	28	ft	8	in	Round	16	in	11	in
65	9	ft	10	in	Round	16	in	11	in

The flow requirements for the central zone, Table 6, are much smaller than those from all other zones on level 1. Therefore, the diameter of the ducts should also be smaller. The textbook diameter illustrates this logic. However, the Revit diameters are similar to those in the southern zone, a zone with twice the flow per diffuser. The Revit values need to be more fully analyzed.

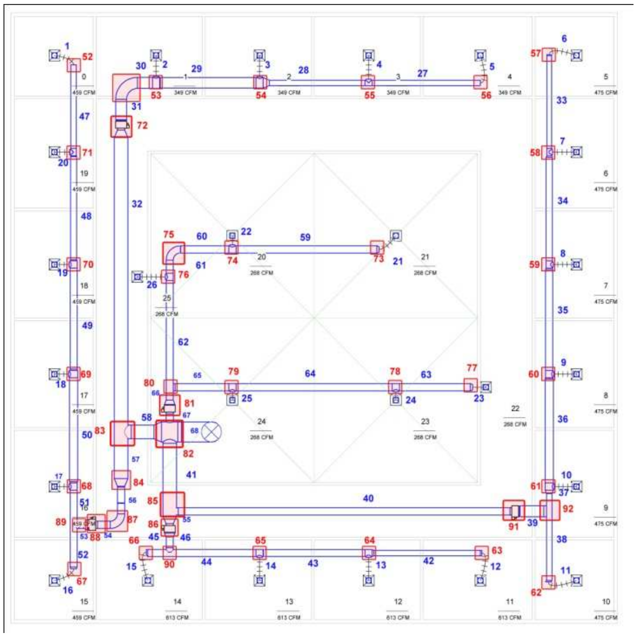

Figure 2: Duct Layout for Level 1

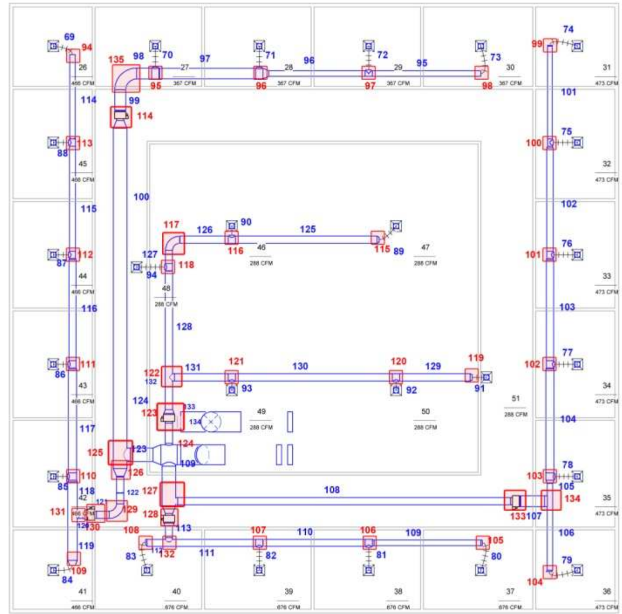

Figure 3: Duct Layout for Level 2

As can be seen in Figures 1 and 2, the duct layouts for the two levels are almost identical, with the only difference occurring at the main cross coming from the air handling unit. Therefore, the data generated for level 1 related to duct sizes are approximately equal to those on level 2.

Table 7: AHU Information

Unit	Level Serviced	CFM (Revit)	CFM (Textbook)	Pressure loss (in H20) (Revit)	Pressure loss (in H20) (Textbook)
AHU 1	1	20,000	9,200	2.89	8.67
AHU 2	2	20,000	9,364	2.89	8.33

As shown in table 7, the air handling units both supply over 9,000 CFM of air to their respective levels according to the textbook calculations. However, the Revit flow is 20,000 CFM, which is much greater than the textbook calculations. This difference can be explained, at least in part, by the difference in the pressure losses. The designed pressure loss in Revit is 1/3 of that used in the textbook. This difference in pressure loss can also explain the difference in the maximum duct diameter between Revit and the textbook calculations.

Conclusion

A comparison of textbook calculations and automatic duct sizing has revealed that Revit MEP takes a seemingly more conservative approach with both higher flow rates and smaller pressure losses than the numbers targeted as common practice in our calculations. A simple Δp V calculation shows that inputs assumed by Revit would require a fan energy of about 75% of what would be required by the textbook system and possibly cover a more extreme design condition by providing more air. However, the increase in ductwork and other possible changes to the system that accompany smaller fans in this scenario require that further life cycle analysis be undertaken to determine the cost-effectiveness of the two systems.

Furthermore, Revit made several errors in its design such as the contrast between ducts 50 and 53 where larger ductwork was given to a branch serving fewer diffusers of the same flow rate. A further understanding of why Revit sizes ducts in this way might elucidate how to make the process more transparent and easy to modify. Taking inconsistencies like this into account, it may be helpful in the future to use Revit as a tool for the initial sizing of ducts and then to go in and refine the sizes by hand; however, before this can really be a useful step we must figure out why the program locks in to an overblown flow rate so that we can either make adjustments to the system or scale the automatic sizing down to the flow rates we actually intend to have. In summary, the textbook duct design provided a more economical layout when only the ductwork is considered, but to make a final decision on whether the textbook or automated approach is more economical the complete system would need to be analyzed for each design and more research will need to go into straightening out the errors involved with Revit.