12.0 Critical Industry Research – Chilled Beam HVAC Systems (MAE)

12.1 Background

Electricity prices over the past 5 years have increased by close to 75% at peak times in July 2008. As a result of this, the energy efficiency of buildings has become more scrutinized. Inefficient buildings result in not only costing the owner of the building more to operate, but also puts the owner more at risk to price fluctuations and increases, decreasing their bottom line profits. Energy efficiency was discussed at the 2008 PACE Roundtable during the Energy & Economy break-out session. One topic that was discussed in the break-out session was the potential for new types of technology to help lower the energy consumption of buildings. Specifically, chilled beam HVAC systems were mentioned as a potential new technology which can make drastic improvements to the energy consumption of a building.

Europe, which consistently has much higher energy costs than the United States, has been using chilled beam HVAC systems for several decades. Chilled beams use far less energy than the typical VAV systems that are commonly used in the United States. Chilled beams require less ductwork, and AHUs, but require more piping, pumps, and insulation.

12.2 Research Goal

The goal of this research is to gain an understanding of how chilled beams work, their uses, advantages, and disadvantages. Cost, schedule, and sustainability impacts associated with chilled beam systems will be compared to typical HVAC systems used in the United States. This research will develop a foundation that can be built upon by owners, designers, and constructors in the future as they explore alternative mechanical systems.

12.3 Research Steps

Research on chilled beams HVAC systems will begin with reviewing online articles, journals, case studies, and vendor publications. Once a thorough understanding of chilled beams is gained, interviews with industry members from across industry will be conducted. This will include owners, engineers, constructors, and suppliers to understand chilled beam applications and their advantages/disadvantages. Once the research has been completed, the information will be compiled to provide a source of information that industry members can use to help them explore alternative mechanical systems.

12.4 Introduction to Chilled Beams

Chilled beam HVAC systems use chilled water to cool building spaces. The chilled water is pumped to finned heat exchangers placed in the ceiling grid. Because water is a more efficient medium to transfer heat to and from the building spaces, air handlers and ductwork sizes can be reduced substantially. In fact, a 1" diameter water pipe can transport the same cooling energy as an 18" square air duct. This allows plenum space to be reduced which could result in higher ceiling heights or reduced structure height. There are two main types of chilled beams, passive and active. Passive beams are the simplest types of chilled beams and provide only sensible cooling and must be used in conjunction with another HVAC system to meet ventilation and latent load requirements. Active beams provide both sensible and latent cooling along with ventilation to the space.

12.5 Passive Chilled Beams

Passive chilled beams do not have any moving parts to move air, but relies on natural convection to raise the warm room air up to the chilled beam, where it passes through the heat exchanger coil and drops back down to cool the room. Figure 2 below shows how buoyancy makes a passive chilled beam work.

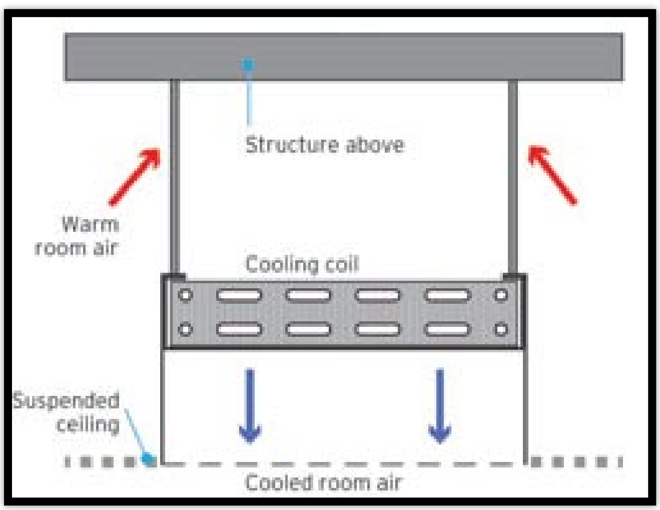


Figure 2 – Passive Beam Operation

As mentioned above, passive chilled beams only contribute to the sensible cooling of building spaces. A separate system must be used in conjunction to fulfill ventilation and latent load requirements. An under floor air distribution system is the most often used system used with passive beams, although many other systems would work as well. Because passive beams use natural convection to operate, they do not work for heating spaces, leading to the necessity of another system to heat the building.

Passive chilled beams typically are capable of removing 200 to 650 BTUH of sensible heat per linear foot of beam length. The output of passive beams depends on the beams width and the temperature differential between the entering air and circulated chilled water temperature. Output is typically limited by the convection air velocity. The velocity is controlled so that it does not create cold drafts for the building occupants.

Passive beams may be mounted above the ceiling or below the ceiling and exposed to view. This allows the designers to select a passive beam for each application. Figures 3 and 4 below shows examples of passive chilled beams.

Figure 3 – Exposed Passive Chilled Beams

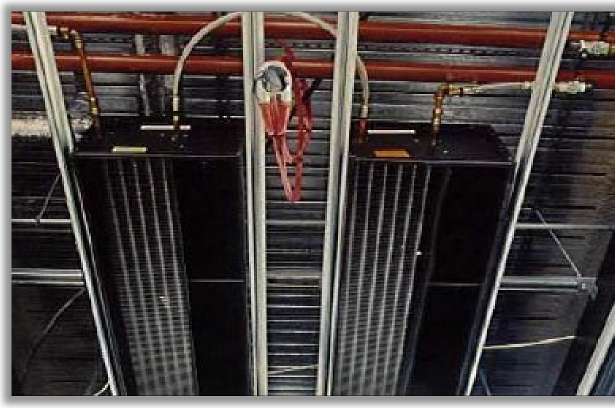


Figure 4 – Recessed Passive Chilled Beams

12.6 ACTIVE CHILLED BEAMS

Like passive chilled beams, active chilled beams have heat exchanger coils to cool passing air as it moves through the beam. Unlike a passive beam though, active beams also have conditioned air supplied to the beam. The conditioned air is called the primary cooling and the heat exchanger is called the secondary cooling. Active beams use forced air induction to lift the room air into the beam, mix the conditioned air and the room air, and then discharge the mixed air into the room through linear slots located along the outside edges of the beam. Due to the forced air induction, active beams are able to heat and cool a space. The latent load and ventilation air requirements are handled entirely by the primary air side of the chilled beam. The sensible load is split between the primary air and secondary cooling of the chilled beam. The secondary cooling of the chilled beam can typically extract 50-70% of the space sensible heat generated with the primary air extracting the remaining balance of the sensible load.

Figure 5 below shows the operation of an active chilled beam.

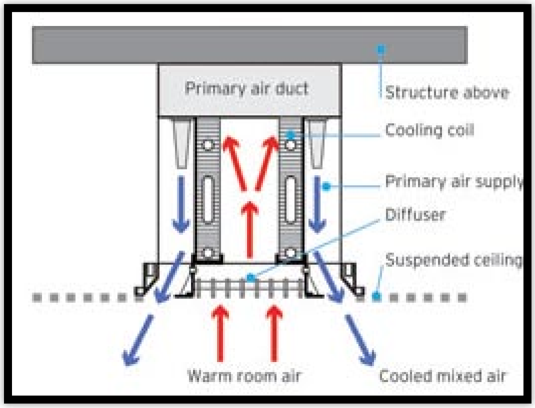


Figure 5 – Active Chilled Beam Operation

Active chilled beams can provide sensible cooling capacities as high as 1,100 BTUH per linear foot of beam. The specific performance capabilities depend on induction capabilities, coil circuitry, and chilled water supply temperature. Discharge air velocity needs to be analyzed to ensure occupant comfort.

Different types of active beams are even more numerous than with passive beams. They come in different lengths and widths, different nozzle types to affect the induction rate, and one, two or even four way discharge patterns.

Figures 6 and 7 below show different types of chilled beams.

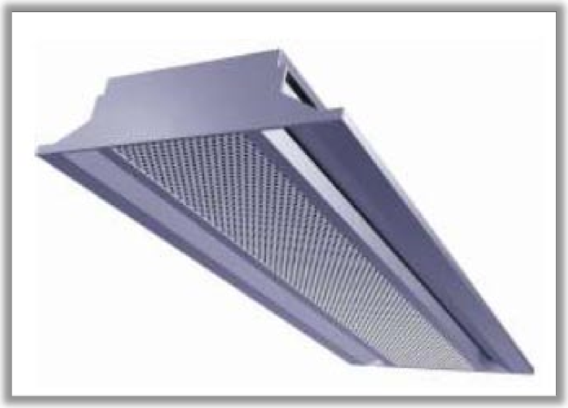


Figure 6 – 2-way Active Chilled Beams

Figure 7 – 4-way Active Chilled Beams

12.7 Multi-Service Chilled Beams

Multi-service chilled beams incorporate other building systems into the beam in a prefabricated unit. This prefabricated unit can be brought to the project site and drastically reduces the amount of time required to install all the building systems. Lighting fixtures and controls, speakers, occupancy sensors, smoke detectors, and even fire sprinklers can be incorporated into the beam. Mulit-service chilled beams come in both passive and active types.

Figure 8 below shows an example of a multi-service chilled beam.

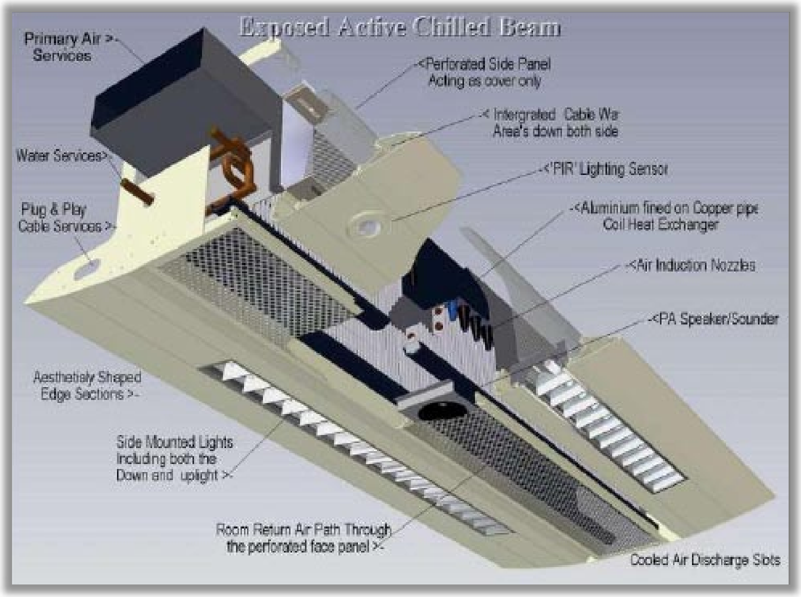


Figure 8 – Multi-service Chilled Beams

Figure 9 below shows passive multi-service beams and Figure 10 shows active multi-service beams.

Figure 9 – Passive Multi-service Beams

Figure 10 – Active Multi-service Beams

12.8 CHILLED BEAM ADVANTAGES

Chilled beam systems can drastically reduce the required primary air circulated throughout the building versus a conventional all air system. According to DADANCO, a chilled beam supplier, the required primary air is usually reduced by 75-85% when compared to an all air system. This reduction is made possible because water is much more efficient at moving energy than air.

In total, case studies have shown that chilled beam systems can save 20-40% in energy consumption when compared to an all air system. Albert Flaherty from WSP Flack + Kurtz said a recently built classroom building at The Massachusetts Institute of Technology with chilled beams has been using about 60% of the energy to operate the system when compared to a VAV system that would have typically been used. A laboratory building constructed at the University of North Carolina designed by Affiliated Engineers, Inc., cut energy consumption by 20%. Figure 11 below is a figure published by ASHRAE demonstrating typical power savings with chilled beam systems versus a conventional all air system.

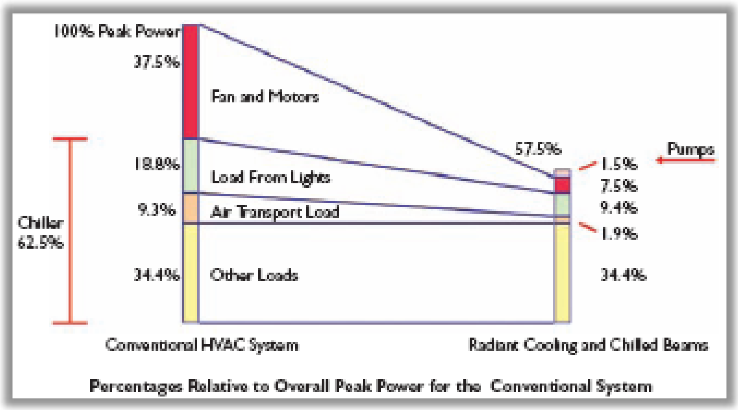


Figure 11 – Typical Power Savings for Chilled Beams; From ASHRAE

Chilled beams improve comfort within the building spaces. Increased comfort is achieved because the discharge air velocity of the chilled beam is slower than the all air system. Chilled beams are better at mixing the primary air and room air thoroughly (because of the induction principle), which results in uniform temperature throughout the room. With a chilled beam system, the ventilation air requirements are delivered to the building spaces at all times and at all loads, providing excellent indoor air quality and odor control.

Chilled beams reduce the ductwork system size in the plenums and vertical air shafts. In some cases, the building's floor-to-floor height can be reduced or more floors can be built within the same building height. Due to the reduced primary air requirement, air handling units (AHUs) and the respective rooms that house the AHUs can be reduced.

Lower energy consumption results in lower operation costs throughout the lifecycle of the building. Chilled beams usually have a higher first cost, but according to Alla Ketsnelson of Syska Hennessy Group, the payback period for chilled beams are within a few years of construction, typically no longer than 5 years.

There are no electrical line power connections to install in the field. This decreases the coordination between trades necessary to install the system.

Controls are simpler and cheaper for chilled beams than they are for VAV systems. A simple low cost zone valve is used to for temperature control as opposed to the complicated and expensive controls of a VAV system. Some chilled beams come from the supplier fitted with all the controls needed for operation.

Commissioning is easier with a chilled beam system. Commissioning only requires adjustments of the water balancing valves and primary air balancing dampers through simple static pressure readings.

Chilled beams have no regular maintenance costs because there are no moving parts inside the chilled beam. Chilled beams need infrequent vacuuming of the unit's coil as required. Cleanings are usually required only every 4-5 years unless the beams are used in an especially dirty environment.

Because chilled beams have no moving parts and no fans in the building spaces, they operate very quietly. Chilled beams are typically are designed so the typical inlet static pressure is 0.5" w.c. or less. According to DADANCO, chilled beams, when designed in this manner, can achieve a background noise of less the 35dB.

12.9 Chilled Beam Disadvantages

First cost of chilled beams is typically higher than when compared to other all air systems. Chilled beam systems save money on VAVs, ductwork, AHUs and fans, and controls but add money for the chilled beams themselves, water piping, pipe insulation, and pumps.

Chilled beams are relatively unknown in the United States. They have been used in Europe for several decades, but the building industry in the US is just starting to receive data on cost, schedule, and efficiency impacts of chilled beams. There are not many case studies with data solidifying the benefits of chilled beams. Due to the lack of knowledge in the building industry about chilled beams, design and construction professionals are adding contingencies to chilled beams systems in order to protect themselves from the risk of unfamiliarity. Albert Flaherty of WSP Flack + Kurtz speculated that chilled beam systems should cost, on average, only 5-15% more to install. However, on the projects that he has worked on, he has seen a 30% premium for chilled beams.

Some types of building owners may not find the payback of the higher first cost from the reduced energy consumption attractive. Developers are usually not willing to pay a higher first cost. This is because tenants that lease out building space from them are unlikely to pay more for reduced utility bills. A college campus or government buildings would be a likely candidate to use chilled beams. In these cases, they own and operate the buildings and would benefit from a short payback period and lower utility bills.

Chilled beams cannot be used in areas where space humidity levels cannot be consistently maintained. The dew point temperature of the space air must remain below the temperature of the chilled water supply. Areas that would not be suitable would be lobby entrances, kitchens, exercise rooms, and pool areas.

The building envelope tightness must be adequate to prevent excessive moisture transfer into the building. Increased moisture in the building air has the potential to condense on the chilled beam coil and create moisture in the building spaces.

Chilled beams cannot be mounted on ceilings higher than 20 feet. This is due to the induction of the air brought into the beam must be from around the building occupants to properly condition the building spaces.

12.10 Chilled Beam Applications

Chilled beams are ideal for applications with high space sensible cooling loads such as office space, computer labs, and laboratories.

Retrofits of existing building are excellent candidates for chilled beam system. The Constitution Center in Washington D.C. is the largest chilled beam system in the United States. This particular building was demolished to just the structure and replaced with modern building systems and façade. The building's floor-to-floor height did not provide enough space to use a VAV system and the engineers decided to use a chilled beam system to condition the building.

Building codes may restrict the height of buildings and reduce the valuable floor space. It is possible to use lower floor-to-floor heights with chilled beams and potentially add another floor in the same height as a building with an all air system. This would add a lot of value to the owner and make the project more profitable. Chilled beams, especially when multi-service beams are used, can save 2-3' in plenum space per floor.

12.13 Conclusion and Recommendation

Results of the research conducted on chilled beam HVAC systems have returned some impressive findings. Chilled beams are able to extract 50-70% of the sensible load through the heat exchanger coil in each beam, which allows the designer to reduce the size of the primary air supplied to the building. Typically, chilled beams are able to reduce the primary air supplied to building spaces by 75-85%. Water is much more efficient at moving energy throughout the building, and therefore will reduce the buildings energy consumption by 20-40%.

Chilled beams have an initial first cost higher than all air systems. Typically, chilled beams will cost between 10-30% more than an all air system. However, the reduced operating cost of chilled beams results in a payback period typically less than 5 years.

Chilled beams are especially beneficial on projects that have height restriction issues or for existing building retrofits and renovations. Chilled beams are able to reduce the necessary plenum space required to run all the building systems.

Chilled beams may not be a viable solution for the mechanical system of buildings or areas of buildings that have high latent loads and variable humidity loads. The dew point of the room must be below the temperature of the chilled water running through the beam in order to avoid condensation throughout the building spaces.

13.0 Chilled Beam Cost and Schedule Impact (Mechanical Breadth)

13.1 Background Information

This analysis will use the lessons learned in the Critical Industry Research on chilled beam HVAC systems and apply it to the Redland Tech Center project, specifically Building II. The mechanical system of Building II is a VAV system and should be an excellent candidate for a chilled beam system.

13.2 Goal

The goal for this analysis is determine the HVAC loads of Building II, size and specify the new chilled beam system, and then determine the cost and schedule impact of changing the system. Whenever the costs have been calculated, if there is a higher first cost for the chilled beam system, the payback period for the alternate HVAC system will be calculated.

13.3 Method

- Establish the design loads and required outdoor air ventilation rate
- Size the chilled beams and calculate number of beams required per floor
- Analyze the cost impacts incurred by switching the HVAC system to chilled beams
- Develop schedule for installing the chilled beam system
- Conduct payback period for installing chilled beam system

13.4 Resources

- Alla Ketsnelson at Syska Hennessy Group
- META Engineers
- John Hoke and Steve Mills at L.H. Cranston
- Ken Laudermilk at TROX USA
- Jim Martinoski and Erin Gardner of Clark Construction
- R.S. Means

13.5 Expected Outcome

The feasibility of using chilled beams at the Redland Tech Center project will be determined. Cost, schedule, and energy efficiency impacts will be determined. The discounted payback period for the alternate HVAC system will be determined.

13.6 Sizing the Chilled Beams

For this analysis, active chilled beams will be used as the replacement HVAC system for the Redland Tech Center. Active beams were decided upon because they do not require an alternate air source for ventilation and latent loads whereas passive beams would need one. Multi-service beams would add another level of complexity to the analysis that is unnecessary to determine the feasibility of chilled beams as an alternate HVAC system.

Only the open office space on each floor will be included in this analysis of changing the mechanical system. The HVAC systems for the lobby, exercise room, café, corridors, and bathrooms will be not be changed for this analysis. Both the exercise room and café have their own separate systems and will not have to be considered in any part of this analysis. The lobby, corridors, and bathrooms are part of the whole buildings HVAC system and will need to be considered whenever sizing equipment.

To maximize the potential energy savings of this design, the primary air supply flow rate (CFM) will be calculated using ASHRAE 62.1-2007 for minimum outdoor air rates. This will provide the minimum amount of air flow to the building spaces. Whenever the flow rate for the primary air is established, the required humidity ratio will be calculated to determine the maximum humidity ratio which will control the latent loads of the building spaces.

The first step in sizing the chilled beams for Building II is to determine the design conditions and loads that the system will need to control. The following assumptions will govern the calculation of design loads:

- CFM provided to the office space through the VAV represents the design sensible load
- 100 ft^2/person
- 72^{o}F room air, 55^{o}F supply air for current design
- Latent load = 200BTUH/person for latent load

By using the CFM provided with the VAV system, it is possible to calculate the design loads the original mechanical engineers used for their design. Table 1 below shows the calculated design loads and outdoor air requirements for each floor. These values will be used to size the chilled beam system.

Floor	Description	Area (SF)	Population	VAV CFM	Sensible Load (BTUH)	Latent Load (BTUH)	Outdoor Air Requirement (CFM)
1	Open Office	11,380	114	9,500	174,420	22,760	1,565
2	Open Office	19,862	199	12,000	220,320	39,724	2,731
3	Open Office	20,534	205	12,000	220,320	41,068	2,823
4	Open Office	20,534	205	12,000	220,320	41,068	2,823
5	Open Office	20,534	205	12,000	220,320	41,068	2,823
6	Open Office	20,534	205	12,000	220,320	41,068	2,823
7	Open Office	20,534	205	12,000	220,320	41,068	2,823
8	Open Office	20,534	205	12,000	220,320	41,068	2,823
9	Open Office	20,534	205	12,000	220,320	41,068	2,823

Table 1 – Design Conditions and Loads for Building II

Below are the sample calculations to calculate the design loads for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Population = \frac{Floor\ Area}{100\frac{ft^2}{person}} = \frac{11{,}380}{100} = 114\ people$$

$$Sensible\ Load = 1.08 \times CFM \times (T_R - T_S) = 1.08 \times 9{,}500 \times (72 - 55) = 174{,}420 BTUH$$

$$Latent\ Load = 200\frac{BTUH}{Population} \times Population = 200 \times 114 = 22{,}760 BTUH$$

The outdoor air requirements were calculated according to ASHRAE 62.1-2007. All values used to calculate the necessary CFM were from Table 6-1 and Table 6-2 of ASHRAE 62.1-2007. The required outdoor air has two parameters that determine the amount needed: people outdoor air rate and area outdoor air rate. Table 2 below shows the required outdoor air rate (V_{OZ}) for each floor.

Floor	Description	Area (A_z)	Population (P_z)	R_axA_z (CFM)	R_pxP_z (CFM)	V_{bz} (CFM)	V_{oz} (CFM)
1	Open Office	11,380	114	683	569	1252	1565
2	Open Office	19,862	199	1192	993	2185	2731
3	Open Office	20,534	205	1232	1027	2259	2823
4	Open Office	20,534	205	1232	1027	2259	2823
5	Open Office	20,534	205	1232	1027	2259	2823
6	Open Office	20,534	205	1232	1027	2259	2823
7	Open Office	20,534	205	1232	1027	2259	2823
8	Open Office	20,534	205	1232	1027	2259	2823
9	Open Office	20,534	205	1232	1027	2259	2823

Table 2 – Required Outdoor Air Flow Rates

Below are the sample calculations to calculate the outdoor air requirements for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Area\ Outdoor\ Air\ Rate = R_a \times A_z = 0.06\frac{CFM}{ft^2} \times 11{,}380ft^2 = 683CFM$$

R_a = Outdoor Airflow Rate per Person from ASHRAE 62.1-2007 Table 6-1

$$People\ Outdoor\ Air\ Rate = R_p \times P_z = 5\frac{CFM}{person} \times 114people = 569CFM$$

R_p = Outdoor Airflow Rate per Unit Area from ASHRAE 62.1-2007 Table 6-1

$$Breathing\ Zone\ Outdoor\ Airflow(V_{bz}) = R_a \times A_z + R_p \times P_z = 683CFM + 569CFM = 1{,}252CFM$$

$$Outdoor\ Airflow(V_{oz}) = \frac{V_{oz}}{E_z} = \frac{1{,}252CFM}{0.8} = 1{,}564CFM$$

E_z = Air Distribution Effectiveness from ASHRAE 62.1-2007 Table 6-2

For comparison sake, the below Table 3 shows the original design air flow rate to the space and the outdoor air flow rate used for this analysis.

Floor	Original CFM	Analysis Outdoor Air CFM	% of Original
1	9,500	1565	16.5
2	12,000	2731	22.8
3	12,000	2823	23.5
4	12,000	2823	23.5
5	12,000	2823	23.5
6	12,000	2823	23.5
7	12,000	2823	23.5
8	12,000	2823	23.5
9	12,000	2823	23.5

Table 3 – Comparison of Original Design and Analysis Air Flow Rates

The above table shows the air supply flow rate to the building spaces will be reduced by almost 77% when a chilled beam system is used. This reduction in air flow will save money in ductwork, AHUs, fans, and operating costs.

Now that the required outdoor air flow rate has been determined, the next step is to determine the required humidity ratio of the supply air which will provide enough capacity to handle the latent load of the building occupants. In this calculation, we will assume the room is to be maintained at 72^{o}F and 50% relative humidity. This condition corresponds to a humidity ratio (w_{ra}) of 0.00836 lb_w/lb_{da}, found from the psychometric chart in Appendix A. Table 4 below shows the supply air humidity ratio required for each floor.

Floor	Supply Air Humidity Ratio (w_{sa})
1	0.00535
2	0.00535
3	0.00535
4	0.00535
5	0.00535
6	0.00535
7	0.00535
8	0.00535
9	0.00535

Table 4 – Required Supply Air Humidity Ratio

Below are the sample calculations to calculate the outdoor air requirements for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Humidity\ Ratio(w_{sa}) = w_{ra} - \frac{BTUH_{Latent}}{CFM \times 4{,}840} = 0.00836 - \frac{41{,}068}{2{,}823 \times 4840} = 0.00535 \frac{lb_w}{lb_{da}}$$

The above humidity ratio corresponds to supply air of 55°F and 58% relative humidity, found from the chart in Appendix A.

The primary air will handle all of the latent loads and outdoor air supply. The sensible load will partly be handled by the primary air supply with the balance of the sensible load being handled by the secondary cooling of the chilled beam. Table 5 below shows the amount of sensible load controlled by the primary and secondary side of the chilled beam.

Floor	Total Sensible Load (BTUH)	Primary Air Sensible Capacity (BTUH)	Primary Air Sensible % of Total	Secondary Sensible Capacity (BTUH)	Secondary Sensible % of Total
1	174,420	28,729	16.5%	145,691	83.5%
2	220,320	50,142	22.8%	170,178	77.2%
3	220,320	51,838	23.5%	168,482	76.5%
4	220,320	51,838	23.5%	168,482	76.5%
5	220,320	51,838	23.5%	168,482	76.5%
6	220,320	51,838	23.5%	168,482	76.5%
7	220,320	51,838	23.5%	168,482	76.5%
8	220,320	51,838	23.5%	168,482	76.5%
9	220,320	51,838	23.5%	168,482	76.5%

Table 5 – Required Sensible Load Capacities of Chilled Beam

Below are the sample calculations to calculate the required sensible load capacities of the chilled beams for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Primary\ Air\ Sensible\ Capacity = 1.08 \times CFM \times (T_R - T_S) = 1.08 \times 1{,}565(72 - 55) = 28{,}729 BTUH$$

$$Secondary\ Sensible\ Capacity = Total\ Sensilbe\ Load - \ Primary\ Air\ Sensible\ Capacity$$
$$= 174{,}420 BUTH - 28{,}729 BTUH = 145{,}691 BUTH$$

For this analysis, an assumption of 1,000 BTUH of sensible cooling per linear foot of chilled beam and 6’ chilled beams will be used. Table 6 below shows the number of chilled beams that will be required per floor.

Floor	Secondary Sensible Capacity (BTUH)	Linear Feet of Chilled Beam Required	Number of 6' Chilled Beams
1	145,691	146	25
2	170,178	170	29
3	168,482	168	29
4	168,482	168	29
5	168,482	168	29
6	168,482	168	29
7	168,482	168	29
8	168,482	168	29
9	168,482	168	29
		Total Number of 6’ Beams	**257**

Table 6 – Number of Chilled Beams Required per Floor

Below are the sample calculations to calculate the number of 6’ chilled beams required for Floor 1. Similar calculations were used to calculate the values for the other floors.

$$Feet\ of\ Beam\ Required = \frac{Sensilbe\ Load}{1{,}000\frac{BTUH}{ft\ of\ beam}} = \frac{145{,}691 BTUH}{1{,}000\frac{BTUH}{ft\ of\ beam}} = 146'$$

$$Number\ of\ 6'Chilled\ Beams = \frac{Feet\ of\ Beam\ Required}{6\frac{ft}{beam}} = 24\ beams$$

13.7 Cost Impacts of Chilled Beams

According to TROX USA, Inc., active chilled beams cost $140 per linear foot to purchase the beam and $140 per linear foot for the labor to install the beam. Using $280 per linear foot cost, the 6' beams used on this project will cost $1,680 per beam. Table 7 below shows the material, labor, and total cost of the active chilled beams for each floor of Building II.

Floor	Number of 6' Chilled Beams	Material Cost	Labor Cost	Total Cost
1	25	$21,000	$21,000	$42,000
2	29	$24,360	$24,360	$48,720
3	29	$24,360	$24,360	$48,720
4	29	$24,360	$24,360	$48,720
5	29	$24,360	$24,360	$48,720
6	29	$24,360	$24,360	$48,720
7	29	$24,360	$24,360	$48,720
8	29	$24,360	$24,360	$48,720
9	29	$24,360	$24,360	$48,720
		Total Chilled Beam Cost		**$431,760**
		Chilled Beam Cost per SF		**$2.47**

Table 7 – Chilled Beam Costs per Floor

Material and labor costs for the different components of the VAV mechanical system of Building II are seen in Table 8 below.

Description	Material	Labor	Total	% of Total
Chilled Water Piping	$116,601	$66,159	$182,760	7.6%
Mechanical Insulation	$58,998	$76,002	$135,000	5.6%
Pumps	$20,004	$3,558	$23,562	1.0%
Cooling Towers	$205,775	$16,325	$222,100	9.2%
VAVs	$37,088	$8,212	$45,300	1.9%
Fans	$79,100	$7,413	$86,513	3.6%
Self Contained AHUs	$790,242	$38,183	$828,425	34.5%
Ductwork	$97,290	$607,710	$705,000	29.3%
Controls	$86,670	$48,330	$135,000	5.6%
Condensate Piping	$9,412	$13,488	$22,900	1.0%
Testing and Balancing	$0	$18,000	$18,000	0.7%
Totals	**$1,501,178**	**$903,382**	**$2,404,560**	**100.0%**
VAV Mechanical System Cost per SF = $11.44				

Table 8 – VAV Mechanical System Cost Breakdown

The cost impact for this analysis will use an add-deduct cost method. Each line item of the above cost summary will be analyzed for cost changes due to the chilled beam mechanical system.

The total CFM of the original VAV mechanical system is 112,900 CFM. Whenever the chilled beam system is implemented, only part of the original system will be converted to chilled beams. The spaces that remain supplied with air through the remaining VAVs account for 5,000 CFM on the first floor and another 300 CFM for each typical office floor adding up to 8,600 CFM. In areas where components are shared between the chilled beams and the remaining VAVs, a factor of 92% (chilled beam reduction portion of original airflow=(112,900-8,600)/112,900)will be used to calculate the savings by switching to the chilled beams. An area where this pertains is for ductwork, fans, and controls.

The primary air side of the chilled beam system is 24,060 CFM. With another 8,600 CFM for the remaining VAVs, the chilled beam mechanical system will need AHUs with a total CFM capacity of 32,660 CFM.

Chilled Water Piping

The chilled water piping that is already in the cost summary for the original system will remain (mostly for risers). The chilled beam system will need an additional 1,300 linear feet of 1-1/2" chilled water piping per floor to provide the chilled water to the chilled beams. 1,300 linear feet was estimated by running a two pipe loop system through the center of the open office space with an additional 20% for the branches off to the chilled beams. According to L.H. Cranston, 1-1/2" hydronic piping would cost $14 per linear foot of pipe.

Material Cost for Additional Chilled Water Piping = $8.94/lf *1,300lf/floor*9floors = $104,598
Labor Cost for Additional Chilled Water Piping = $5.06/lf *1,300lf/floor*9floors = $59,202
Total Cost for Additional Chilled Water Piping = $163,800

Mechanical Insulation

All of the supply piping for the chilled beam system will needed to be insulated in order to prevent condensation on the pipes. However, the cost of this added insulation will be offset by the cost reduction for the insulation used on the VAV system. L.H. Cranston estimated that the cost change would be negligible for the mechanical insulation.

Pumps

Water pumping capacity will need to be increased with the chilled beam system. META Engineers estimated that the additional pump capacity needed would double from the original amount of pump capacity provided by the original VAV system. The original system cost $23,562.

Material Cost for Additional Pump Capacity = $20,004*2 = $40,008
Labor Cost for Additional Pump Capacity = $3,558*2 = $7,116
Total Cost for Additional Pump Capacity = $47,124

Cooling Tower

The HVAC loads of the building are the same with both systems. Therefore, the capacity required of the cooling towers will remain the same.

VAVs

72 of the 84 VAVs in Building II will be deleted with the chilled beam system. Each VAV has a total cost of $539.

Material Savings for Reduced Number of VAVs = 72VAVs*$442/VAV = $31,824
Labor Savings for Reduced Number of VAVs = 72VAVs*$97/VAV = $6,984
Total Savings for Reduced Number of VAVs = $38,808

Fans

Total air flow rates for the chilled beam part of the building will be reduced by 77% with the chilled beam system. To be conservative, a 70% reduction will be used for this analysis. The original cost of the fans for Building 2 is $86,513. A 92% factor will be used to eliminate the remaining VAVs share of fan costs.

Material Savings for Reduced Fan Airflow = 0.7*0.92*$79,100 = $50,940
Labor Savings for Reduced Fan Airflow = 0.7*0.92*$7,413 = $4,774
Total Savings for Reduced Number of VAVs = $55,714

Self Contained AHUs (SCUs)

All of the self contained AHUs (one on each floor) will be deleted with the chilled beam system. This is due to the fact that the SCUs house everything needed for heating and cooling the building, including the heating coil and compressor for cooling. With the chilled beam system, electric heating coils will need to be added to the chilled beams to heat the building, a centrifugal chiller will be added in the mechanical penthouse to provide the chilled water, and AHUs will be added to provide the required primary outdoor air. See the cost estimate below for the added heating coils, centrifugal chiller, and AHUs.

Material Savings for Deleting SCUs = $790,242
Labor Savings for Deleting SCUs = $38,183
Total Savings for Reduced Number of VAVs = $828,425

Electric Heating Coils

In the original system, each SCU had 67KW heating coil built into it for a total heating capacity of 603KW. In order to achieve same amount of heat capacity with the heating coils on each chilled beam, a 3KW heating coil will be used for each beam. There are a total of 248 beams requiring the 3KW heating coil. With the additional heating coils throughout the building spaces, wiring will need to be added to power the heating coils. See below cost estimate for added wiring. Cost data for the heating coils was gathered from R.S. Means.

Material Cost for Heating Coils = 257coils*$620/coil = $159,340
Labor Cost for Heating Coils = 257coils*$59/coil = $15,163
Total Cost for Heating Coils = $174,503

Wiring and Conduit for Heating Coils

The 28 heating coils per floor will require 650 ft per floor of 3-wire #12 AWG to power the heating coils. EMT conduit will also need to be installed to house the wire. Cost data for the wiring and conduit was gathered from R.S. Means.

Material Cost for Wiring and Conduit = 3-wires*$0.81/LF*650LF/floor*9floors = $14,217
Labor Cost for Wiring and Conduit = $2.47/LF*650LF/floor*9floors = $14,450
Total Cost for Wiring and Conduit = $28,667

Centrifugal Chillers

A centrifugal chiller must be provided to cool the chilled water system. For Building II, all loads including the office areas, corridors, and lobby have a total load of 870-tons of cooling required. For this analysis, a 900-ton centrifugal chiller will be added to cost of the chilled beam system. Cost data for the centrifugal chiller was gathered from R.S. Means.

Material Cost for Centrifugal Chiller = $384,160
Labor Cost for Centrifugal Chiller = $18,032

Total Cost for Centrifugal Chiller = $402,192

Air Handling Units (AHUs)

The chilled beam system needs AHUs with a total CFM capacity of 32,660 CFM. To maximize efficiency and minimize mechanical room area, the chilled beam system will use two AHUs, one 15,000 CFM AHU on the first floor and one 20,000 CFM AHU in the mechanical penthouse at the roof level. Cost data for the AHUs was gathered from R.S. Means.

Material Cost for 15,000 CFM AHU = $20,272
Labor Cost for 15,000 CFM AHU = $2,968
Total Cost for 15,000 CFM AHU = $23,240

Material Cost for 20,000 CFM AHU = $26,320
Labor Cost for 20,000 CFM AHU = $4,088
Total Cost for 20,000 CFM AHU = $30,408

Material Cost for AHUs = $46,592
Labor Cost for AHUs = $7,056
Total Cost for AHUs = $53,648

Ductwork

Total air flow rate for the building is reduced by 77% with the chilled beam mechanical system. To be conservative, a 70% reduction in CFM will be used for this analysis. Ductwork cost is based on the weight of the duct installed. A 70% reduction in will not reduce the weight of the ductwork by 70%. A reasonably accurate method to determine reduction in ductwork weight is to reduce the cross-sectional area of a square duct and calculate the reduction in surface area of the reduced duct. Figure 12 below is a visual representation of how much the duct sizes will be reduced by using the chilled beam system.

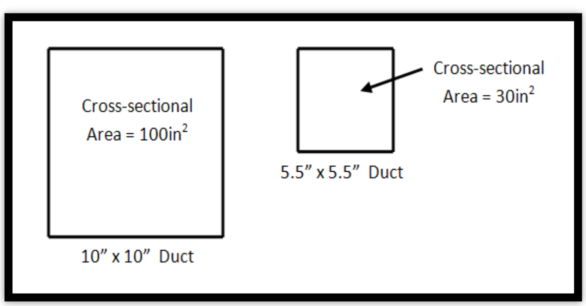


Figure 12 – Representation of the Reduction in Duct Size

1 linear foot of the original 10”x10” duct will have 3.33ft^2 of sheet metal. 1 linear foot of the reduced 5.5”x5.5” duct will have 1.83ft^2 of sheet metal. Therefore, a reduction of a duct’s flow rate by 70% will correspond to a reduction of 45% to the amount of sheet metal needed to fabricate the duct.

The duct work for the chilled beam system will follow the same approximate loop as the original system. It does not seem reasonable to reduce the labor cost by 45% because, while there will be less labor involved, the same basic steps will need to be taken to install the duct. L.H. Cranston estimated that the reduction of labor to install the ductwork for the chilled beam system would be around 25%. A 92% factor will be used to eliminate the remaining VAVs share of ductwork cost.

Material Savings for Ductwork = 0.45*0.92*$97,290 = $40,278
Labor Savings for Ductwork = 0.25*0.92*$607,710 = $137,773
Total Savings for Ductwork = $178,051

Controls

The controls used with the VAV system are much more complex than the controls used with the chilled beam system. The VAV system has thermostats for each zone of the building that must be individually wired, adding cost. The control system for the chilled beams is an automatic valve that adjusts the operation of the chilled beam according to the design. This valve is included in the cost of the chilled beam. Therefore, all the cost for control systems with the VAV system can be deleted from the cost forthe chilled beam estimate.

Material Savings for Deleted Control Systems = 0.92*$86,670 = $79,736
Labor Savings for Deleted Control Systems = 0.92*$48,330 = $44,464
Total Savings for Deleted Control Systems = $124,200

Condensate Piping

Because the cooling capacities of the Building II’s HVAC system did not change, the cost of the condensate piping will not change.

Testing and Balancing

The testing and balancing of the chilled beam system will cost less than the original VAV system. The VAV system had a substantial amount more ductwork that would take longer to commission. Paul Tseng of Advanced Building Performance, the third party testing and balancing agency, estimates the reduction in labor cost for the chilled beam part of the HVAC system will be reduced by switching to the chilled beam system would be 50%.

Material Savings for Testing and Balancing = $0
Labor Savings for Testing and Balancing = 0.5*0.92*$18,000 = $16,560
Total Savings for Testing and Balancing = $16,560

Material and labor costs for the different components of the chilled beam mechanical system of Building II are seen in Table 9 below.

Description	Material	Labor	Total	% of Total
Chilled Beams	$215,880	$215,880	$431,760	17.4%
Chilled Water Piping	$221,199	$125,361	$346,560	14.0%
Mechanical Insulation	$58,998	$76,002	$135,000	5.4%
Pumps	$60,012	$10,674	$70,686	2.9%
Cooling Towers	$205,775	$16,325	$222,100	9.0%
VAVs	$5,264	$1,228	$6,492	0.3%
Fans	$28,160	$2,639	$30,799	1.2%
Self Contained AHUs	$0	$0	$0	0.0%
Electric Heating Coils	$159,340	$15,163	$174,503	7.0%
Wiring and Conduit for Heating Coils	$14,217	$14,450	$28,667	1.2%
Centrifugal Chiller	$384,160	$18,032	$402,192	16.2%
AHUs	$46,592	$7,056	$53,648	2.2%
Ductwork	$57,012	$469,937	$526,949	21.3%
Controls	$6,934	$3,866	$10,800	0.4%
Condensate Piping	$9,412	$13,488	$22,900	0.9%
Testing and Balancing	$0	$16,560	$16,560	0.7%
Totals	**$1,472,954**	**$1,006,662**	**$2,479,616**	**100%**
Chilled Beam Mechanical System Cost per SF = $11.79				

Table 9 – Chilled Beam Mechanical System Cost Breakdown

Table 10 below shows the percent increase for the chilled beam mechanical system versus the original VAV system.

VAV Cost	Chilled Beam Cost	% Increase
$2,404,560	$2,479,616	1.03

Table 10 – Chilled Beam % Increase

Additional Office Leasing Space

Removing the 6 SCUs from floors 2-7 will provide an additional 2,160 SF of office space for the project. This amount of area will lease out for approximately $12/SF per month, resulting in an additional leasing income of $25,920/month.

13.7 Schedule Impacts of Chilled Beams

The original schedule for the VAV mechanical system was obtained from the mechanical subcontractor and can be viewed on the following page. This schedule was analyzed for similarities and differences to build the chilled beam system schedule off of. The following activities have been added, deleted, or changed in duration for the chilled beam schedule. The chilled beam schedule is after the original VAV schedule.

- Pump installation time was doubled to account for the additional pumps in the chilled beam design.
- Centrifugal chiller installation time was estimated to take 10 days for the chilled beams.
- The outdoor air riser duration has been changed from 9 days to 6 days in order to account for the smaller size duct used.
- The chilled beam system deleted all the SCUs from the system and added chilled beams, a chilled water loop for each floor, and heating coils and wiring for each chilled beam.
- Control installation is now not needed for each floor; it only needs to be added into the schedule when that floor has an AHU.

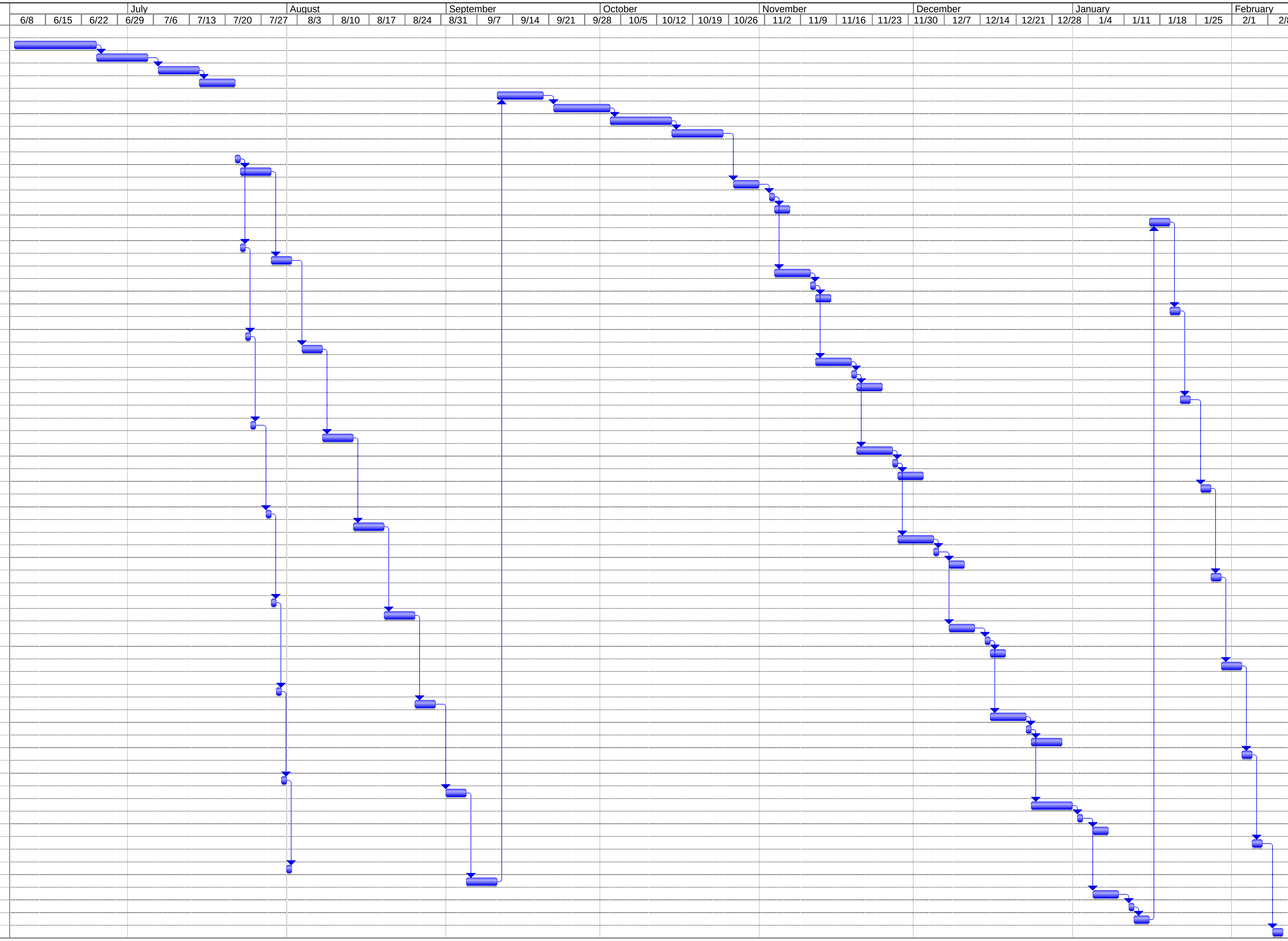
TROX USA, Inc., estimated that a contractor would be able to install 6 linear feet of beam per day with a standard crew. This duration was used for the calculations of the chilled beam schedule. The remaining durations used for the schedule were obtain from L.H. Cranston or R.S. Means.

The original schedule for the VAV system started on June 9, 2009, and finished on February 10, 2009, a total duration of 246 days. The schedule developed for the chilled beam system (on the following page) has construction starting on June 9, 2009, and finishing on March 19, 2009, a total duration of 283 days.

It is not surprising that the chilled beam system increased the duration of the construction schedule. The chilled beam system has more components to install in the building, from the actual chilled beams, 29 beams per floor versus 8 VAVs per floor, to the heating coil and electric wire to power the coil, and also the increased amount of chilled water piping.

The increased schedule duration for the chilled beam system will not affect the completion date of the overall project. The area where the chilled beam schedule is further behind the original VAV schedule is in the open office space area where the chilled beams, ductwork, and chilled water piping are being installed. Because the building is a core and shell project, the project team doesn’t have to work around finishes in the open office space.

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Original VAV Schedule**	**175 days**	**Mon 6/9/08**	**Tue 2/10/09**	
2	Install Pipe CWS&R	12 days	Mon 6/9/08	Tue 6/24/08	
3	Install Pipe 2" Make-up CT-1	8 days	Wed 6/25/08	Fri 7/4/08	2
4	Install Cooling Towers	6 days	Mon 7/7/08	Mon 7/14/08	3
5	Install Chilled Water Pumps	5 days	Tue 7/15/08	Mon 7/21/08	4
6	Install Toilet Exhaust Duct Riser	7 days	Thu 9/11/08	Fri 9/19/08	68
7	Install OAI Riser Ductwork	9 days	Mon 9/22/08	Thu 10/2/08	6
8	Install Duct Riser SP-1	8 days	Fri 10/3/08	Tue 10/14/08	7
9	Install Duct Riser SP-2	8 days	Wed 10/15/08	Fri 10/24/08	8
10	**1st Floor**	**128 days**	**Tue 7/22/08**	**Mon 1/19/09**	
11	Set SCU-1	1 day	Tue 7/22/08	Tue 7/22/08	
12	Pipe SCU-1	4 days	Wed 7/23/08	Mon 7/28/08	11
13	Install Duct Loop	5 days	Mon 10/27/08	Fri 10/31/08	9
14	Install VAVs	1 day	Mon 11/3/08	Mon 11/3/08	13
15	Install Controls	3 days	Tue 11/4/08	Thu 11/6/08	14
16	Testing and Balancing	2 days	Fri 1/16/09	Mon 1/19/09	71
17	**2nd Floor**	**129 days**	**Wed 7/23/08**	**Wed 1/21/09**	
18	Set SCU-2	1 day	Wed 7/23/08	Wed 7/23/08	11
19	Pipe SCU-2	4 days	Tue 7/29/08	Fri 8/1/08	12
20	Install Duct Loop	5 days	Tue 11/4/08	Mon 11/10/08	14
21	Install VAVs	1 day	Tue 11/11/08	Tue 11/11/08	20
22	Install Controls	3 days	Wed 11/12/08	Fri 11/14/08	21
23	Testing and Balancing	2 days	Tue 1/20/09	Wed 1/21/09	16
24	**3rd Floor**	**130 days**	**Thu 7/24/08**	**Fri 1/23/09**	
25	Set SCU-3	1 day	Thu 7/24/08	Thu 7/24/08	18
26	Pipe SCU-3	4 days	Mon 8/4/08	Thu 8/7/08	19
27	Install Duct Loop	5 days	Wed 11/12/08	Tue 11/18/08	21
28	Install VAVs	1 day	Wed 11/19/08	Wed 11/19/08	27
29	Install Controls	3 days	Thu 11/20/08	Mon 11/24/08	28
30	Testing and Balancing	2 days	Thu 1/22/09	Fri 1/23/09	23
31	**4th Floor**	**131 days**	**Fri 7/25/08**	**Tue 1/27/09**	
32	Set SCU-4	1 day	Fri 7/25/08	Fri 7/25/08	25
33	Pipe SCU-4	4 days	Fri 8/8/08	Wed 8/13/08	26
34	Install Duct Loop	5 days	Thu 11/20/08	Wed 11/26/08	28
35	Install VAVs	1 day	Thu 11/27/08	Thu 11/27/08	34
36	Install Controls	3 days	Fri 11/28/08	Tue 12/2/08	35
37	Testing and Balancing	2 days	Mon 1/26/09	Tue 1/27/09	30
38	**5th Floor**	**132 days**	**Mon 7/28/08**	**Thu 1/29/09**	
39	Set SCU-4	1 day	Mon 7/28/08	Mon 7/28/08	32
40	Pipe SCU-4	4 days	Thu 8/14/08	Tue 8/19/08	33
41	Install Duct Loop	5 days	Fri 11/28/08	Thu 12/4/08	35
42	Install VAVs	1 day	Fri 12/5/08	Fri 12/5/08	41
43	Install Controls	3 days	Mon 12/8/08	Wed 12/10/08	42
44	Testing and Balancing	2 days	Wed 1/28/09	Thu 1/29/09	37
45	**6th Floor**	**133 days**	**Tue 7/29/08**	**Mon 2/2/09**	
46	Set SCU-6	1 day	Tue 7/29/08	Tue 7/29/08	39
47	Pipe SCU-6	4 days	Wed 8/20/08	Mon 8/25/08	40
48	Install Duct Loop	5 days	Mon 12/8/08	Fri 12/12/08	42
49	Install VAVs	1 day	Mon 12/15/08	Mon 12/15/08	48
50	Install Controls	3 days	Tue 12/16/08	Thu 12/18/08	49
51	Testing and Balancing	2 days	Fri 1/30/09	Mon 2/2/09	44
52	**7th Floor**	**134 days**	**Wed 7/30/08**	**Wed 2/4/09**	
53	Set SCU-7	1 day	Wed 7/30/08	Wed 7/30/08	46
54	Pipe SCU-7	4 days	Tue 8/26/08	Fri 8/29/08	47
55	Install Duct Loop	5 days	Tue 12/16/08	Mon 12/22/08	49
56	Install VAVs	1 day	Tue 12/23/08	Tue 12/23/08	55
57	Install Controls	3 days	Wed 12/24/08	Mon 12/29/08	56
58	Testing and Balancing	2 days	Tue 2/3/09	Wed 2/4/09	51
59	**8th Floor**	**135 days**	**Thu 7/31/08**	**Fri 2/6/09**	
60	Set SCU-8 (in Penthouse)	1 day	Thu 7/31/08	Thu 7/31/08	53
61	Pipe SCU-8	4 days	Mon 9/1/08	Thu 9/4/08	54
62	Install Duct Loop	5 days	Wed 12/24/08	Wed 12/31/08	56
63	Install VAVs	1 day	Fri 1/2/09	Fri 1/2/09	62
64	Install Controls	3 days	Mon 1/5/09	Wed 1/7/09	63
65	Testing and Balancing	2 days	Thu 2/5/09	Fri 2/6/09	58
66	**9th Floor**	**136 days**	**Fri 8/1/08**	**Tue 2/10/09**	
67	Set SCU-9 (in Penthouse)	1 day	Fri 8/1/08	Fri 8/1/08	60
68	Pipe SCU-9	4 days	Fri 9/5/08	Wed 9/10/08	61
69	Install Duct Loop	5 days	Mon 1/5/09	Fri 1/9/09	63
70	Install VAVs	1 day	Mon 1/12/09	Mon 1/12/09	69
71	Install Controls	3 days	Tue 1/13/09	Thu 1/15/09	70
72	Testing and Balancing	2 days	Mon 2/9/09	Tue 2/10/09	65



Project: Original VAV Schedule
Date: Mon 4/6/09

Task | Split | Progress | Milestone | Project Summary | External Tasks | External Milestone | Deadline

ID	Task Name	Duration	Start	Finish	Predecessors
1	**Chilled Beam Schedule**	**202 days**	**Mon 6/9/08**	**Thu 3/19/09**	
2	Install Pipe CWS&R	12 days	Mon 6/9/08	Tue 6/24/08	
3	Install Pipe 2" Make-up CT-1	8 days	Wed 6/25/08	Fri 7/4/08	2
4	Install Cooling Towers	6 days	Mon 7/7/08	Mon 7/14/08	3
5	Install Chilled Water Pumps	10 days	Tue 7/15/08	Mon 7/28/08	4
6	Install Centrifugal Chiller	10 days	Tue 7/29/08	Mon 8/11/08	5
7	Install Toilet Exhaust Duct Riser	7 days	Tue 8/12/08	Wed 8/20/08	6
8	Install OAI Riser Ductwork	6 days	Thu 8/21/08	Thu 8/28/08	7
9	Install Duct Riser SP-1	8 days	Fri 8/29/08	Tue 9/9/08	8
10	Install Duct Riser SP-2	8 days	Wed 9/10/08	Fri 9/19/08	9
11	**1st Floor**	**118 days**	**Mon 9/22/08**	**Fri 3/6/09**	
12	Set AHU-1	1 day	Mon 9/22/08	Mon 9/22/08	10
13	Pipe AHU-1	4 days	Tue 9/23/08	Fri 9/26/08	12
14	Install Chilled Beams	5 days	Mon 10/6/08	Fri 10/10/08	80
15	Install Duct Loop	5 days	Mon 10/13/08	Fri 10/17/08	14
16	Install Chilled Water Loop	3 days	Mon 10/20/08	Wed 10/22/08	15
17	Install Heating Coils	2 days	Thu 10/23/08	Fri 10/24/08	16
18	Wire Heating Coils	2 days	Mon 10/27/08	Tue 10/28/08	17
19	Install VAVs	3 days	Wed 10/29/08	Fri 10/31/08	18
20	Install Controls	3 days	Mon 11/3/08	Wed 11/5/08	19
21	Testing and Balancing	2 days	Thu 3/5/09	Fri 3/6/09	74
22	**2nd Floor**	**96 days**	**Thu 10/23/08**	**Mon 3/9/09**	
23	Install Chilled Beams	5 days	Thu 10/23/08	Wed 10/29/08	16
24	Install Duct Loop	4 days	Thu 10/30/08	Tue 11/4/08	23
25	Install Chilled Water Loop	3 days	Wed 11/5/08	Fri 11/7/08	24
26	Install Heating Coils	2 days	Mon 11/10/08	Tue 11/11/08	25
27	Wire Heating Coils	2 days	Wed 11/12/08	Thu 11/13/08	26
28	Testing and Balancing	1 day	Mon 3/9/09	Mon 3/9/09	21
29	**3rd Floor**	**85 days**	**Mon 11/10/08**	**Tue 3/10/09**	
30	Install Chilled Beams	5 days	Mon 11/10/08	Fri 11/14/08	25
31	Install Duct Loop	4 days	Mon 11/17/08	Thu 11/20/08	30
32	Install Chilled Water Loop	3 days	Fri 11/21/08	Tue 11/25/08	31
33	Install Heating Coils	2 days	Wed 11/26/08	Thu 11/27/08	32
34	Wire Heating Coils	2 days	Fri 11/28/08	Mon 12/1/08	33
35	Testing and Balancing	1 day	Tue 3/10/09	Tue 3/10/09	28
36	**4th Floor**	**77 days**	**Fri 11/21/08**	**Wed 3/11/09**	
37	Install Chilled Beams	5 days	Fri 11/21/08	Thu 11/27/08	31
38	Install Duct Loop	4 days	Fri 11/28/08	Wed 12/3/08	37
39	Install Chilled Water Loop	3 days	Thu 12/4/08	Mon 12/8/08	38
40	Install Heating Coils	2 days	Tue 12/9/08	Wed 12/10/08	39
41	Wire Heating Coils	2 days	Thu 12/11/08	Fri 12/12/08	40
42	Testing and Balancing	1 day	Wed 3/11/09	Wed 3/11/09	35
43	**5th Floor**	**66 days**	**Tue 12/9/08**	**Thu 3/12/09**	
44	Install Chilled Beams	5 days	Tue 12/9/08	Mon 12/15/08	39
45	Install Duct Loop	4 days	Tue 12/16/08	Fri 12/19/08	44
46	Install Chilled Water Loop	3 days	Mon 12/22/08	Wed 12/24/08	45
47	Install Heating Coils	2 days	Fri 12/26/08	Mon 12/29/08	46
48	Wire Heating Coils	2 days	Tue 12/30/08	Wed 12/31/08	47
49	Testing and Balancing	1 day	Thu 3/12/09	Thu 3/12/09	42
50	**6th Floor**	**55 days**	**Fri 12/26/08**	**Fri 3/13/09**	
51	Install Chilled Beams	5 days	Fri 12/26/08	Fri 1/2/09	46
52	Install Duct Loop	4 days	Mon 1/5/09	Thu 1/8/09	51
53	Install Chilled Water Loop	3 days	Fri 1/9/09	Tue 1/13/09	52
54	Install Heating Coils	2 days	Wed 1/14/09	Thu 1/15/09	53
55	Wire Heating Coils	2 days	Fri 1/16/09	Mon 1/19/09	54
56	Testing and Balancing	1 day	Fri 3/13/09	Fri 3/13/09	49
57	**7th Floor**	**44 days**	**Wed 1/14/09**	**Mon 3/16/09**	
58	Install Chilled Beams	5 days	Wed 1/14/09	Tue 1/20/09	53
59	Install Duct Loop	4 days	Wed 1/21/09	Mon 1/26/09	58
60	Install Chilled Water Loop	3 days	Tue 1/27/09	Thu 1/29/09	59
61	Install Heating Coils	2 days	Fri 1/30/09	Mon 2/2/09	60
62	Wire Heating Coils	2 days	Tue 2/3/09	Wed 2/4/09	61
63	Testing and Balancing	1 day	Mon 3/16/09	Mon 3/16/09	56
64	**8th Floor**	**33 days**	**Fri 1/30/09**	**Tue 3/17/09**	
65	Install Chilled Beams	5 days	Fri 1/30/09	Thu 2/5/09	60
66	Install Duct Loop	4 days	Fri 2/6/09	Wed 2/11/09	65
67	Install Chilled Water Loop	3 days	Thu 2/12/09	Mon 2/16/09	66
68	Install Heating Coils	2 days	Tue 2/17/09	Wed 2/18/09	67
69	Wire Heating Coils	2 days	Thu 2/19/09	Fri 2/20/09	68
70	Testing and Balancing	1 day	Tue 3/17/09	Tue 3/17/09	63
71	**9th Floor**	**22 days**	**Tue 2/17/09**	**Wed 3/18/09**	
72	Install Chilled Beams	5 days	Tue 2/17/09	Mon 2/23/09	67
73	Install Duct Loop	4 days	Tue 2/24/09	Fri 2/27/09	72
74	Install Chilled Water Loop	3 days	Mon 3/2/09	Wed 3/4/09	73
75	Install Heating Coils	2 days	Thu 3/5/09	Fri 3/6/09	74
76	Wire Heating Coils	2 days	Mon 3/9/09	Tue 3/10/09	75
77	Testing and Balancing	1 day	Wed 3/18/09	Wed 3/18/09	70
78	**Penthouse**	**122 days**	**Mon 9/29/08**	**Thu 3/19/09**	
79	Set AHU-2	1 day	Mon 9/29/08	Mon 9/29/08	13
80	Pipe AHU-2	4 days	Tue 9/30/08	Fri 10/3/08	79
81	Testing and Balancing	1 day	Thu 3/19/09	Thu 3/19/09	77

Project: Chilled Beam Schedule
Date: Mon 4/6/09

Task | Split | Progress | Milestone | Project Summary | External Tasks | External Milestone | Deadline

13.8 Energy Savings

The Environmental Protection Agency (EPA) has a calculator to determine the average energy costs throughout the United States. For this analysis, we will use this estimated average use as our baseline energy consumption for the original VAV system.

Average Annual Energy Cost/SF for Mid-Atlantic Area Office Building = $1.59/SF
= $1.59/SF*210,240SF = $334,282 per year

Without designing the chilled beam system using sophisticated design software, it is not possible to accurately predict the energy savings of the chilled beam system versus the VAV system. Therefore, for this analysis, a range of possible savings in energy will be used. Table 11 below shows the energy cost savings for 20%, 30%, and 40% reductions in HVAC system energy consumption for chilled beams.

Energy Reduction	Energy Costs per Year
20%	$267,426
30%	$233,997
40%	$200,569

Table 11 – Energy Costs per Year for Various Possible Energy Reductions

13.9 Payback Period

The payback period for switching the HVAC system to chilled beams will be less than one year. The initial cost of the chilled beams is higher by $75,056, or an increase of 1.03%. Operating costs are much more in favor of the chilled beams than the VAV system. The chilled beam system will save between $66,856 and $133,713 versus the VAV system. In addition to lower operating costs, the chilled beam system will have increased revenue of $25,920/month or $311,040/year for the additional office area available for leasing.

13.10 Conclusion and Recommendation

Chilled beams were shown to have many advantages over VAV systems in this analysis. The chilled beam system equivalent to the original VAV system designed for the Redland Tech Center had an increased initial cost by $75,056. Even though the chilled beam system was more expensive initially, the operating costs are much lower and then revenues are higher whenever the chilled beam system is used.

The construction schedule increased in duration for the chilled beam system when compared to the original VAV system. This increase is mainly due to the additional number of components that a chilled beam system uses to control the building spaces.

Chilled beams have shown promise that they are capable of exceeding the best all air HVAC systems. Industry professionals in the United Stated need to continue working with chilled beams to expand their knowledge of these HVAC systems. Only then will the true costs, schedule, and energy savings be known.