2009 Senior Thesis Final Report

McKinstry Oregon Headquarters

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Prepared for

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mckinstry oregon hq
portland or

engr.psu.edu/ae/thesis/portfolios

project team
owner mckinstry
general contactor hoffman
construction manager ts
architect mildred design group
mechanical mckinstry
electrical mckinstry
structural tm rippey

architecture
simple rectangular grid. warehouse attaches at a rotated angle. flat, tilt-up concrete walls have vertical and horizontal lines to break the façade. 30% window area. built-up roof with 3” rigid insulation and 1.5” metal deck. anticipating a LEED Gold rating.

structure
6” reinforce concrete slab-on-grade on strip footing. 7” concrete walls and 8x8 concrete columns. w 12x19 joists spanning 25’ and w18x35 girders also spanning 25’ hold up the second floor. open web joists (32lh375/208) spanning 50’ and 48g6n18.8k girders spanning 50’ keep the roof up.

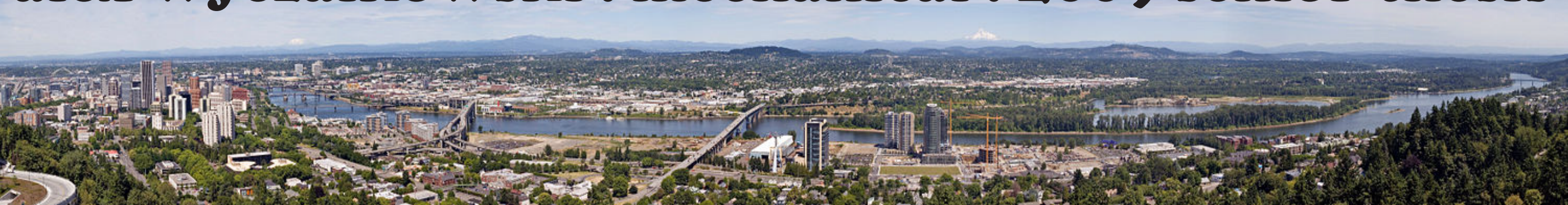
project information
size 50,590 sf
cost $15.5 million
construction mar 08 - mar 09
method design - build

mechanical
the central plant is a heat recovery chiller used for both heating and cooling. open loop ground source heat pump. single rooftop ahu (with vfd) distributes air via ducts to the office section of the building. series vav boxes with hot water reheats

electric
powered by 480/277 v 3 phase 4 wire stepped down to 208/120 v. lights are all fluorescent and there are 4 skylights above the second floor

construction
type iiib construction and design-build delivery. one interesting feature of construction is the tilt up walls. all the exterior walls will be poured on site and tilted up after curing.

alex wyczalkowski . mechanical . 2009 senior thesis



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1 Executive Summary

McKinstry Oregon Headquarters is a 50,590 square foot, 2 story office building. It began construction in March 2008 and is scheduled for completion in April 2009. It is located in Northeast Portland, overlooking the Columbia River. The building contains 2 floors of offices, as well as a full kitchen, showers, and a small weight room for employees. There is also a large warehouse at the west end of the building which is not ventilated. Existing conditions are described in sections 3-7.

The design of the Headquarters was dictated by three main factors: sustainability, comfort for tenants, and economy. Section 4 describes these design objectives.

A Dedicated Outdoor Air System (DOAS) is the basis of the mechanical redesign. Ventilation air provides latent cooling and Radiant Panels in the space address sensible loads. An overview of the DOAS system is located in section 8. Changing to DOAS effects many parts of the system specifically AHU, ductwork, piping, heat recovery, and the central plant. Sections 9-12 go over these changes.

The Construction breadth evaluates first cost, energy savings and payback. DOAS provided a yearly energy savings of 51,230 kWh/year or $4,100 (Section 13). Combined with a Tambient lighting system in the open office spaces (Section 15), yearly energy savings increased to 96,410 kWh/year or $7,715 (Section 16). The first cost went up $143,300 for the mechanical redesign, or $2.83/SF and $139,890 ($2.77/SF) for mechanical and Tambient, respectively. Payback was 35 years and 18 years respectively. Full cost analysis can be found in Sections 15 and 17.

Tambient lighting was implemented in the open office spaces of the building. This eliminated luminaires from the ceiling and placed them on the cubicles themselves. The redesign reduced lighting power density from 1.02W/SF to .50 W/SF. Full analysis is in Section 14.

2 Acknowledgements

2.1 Disclaimer

Changes and discrepancies in no way imply that the original design contained errors or was flawed. Differing assumptions, code references, requirements, and methodologies have been incorporated into this thesis project; therefore, investigation results may vary from the original design.

2.2. Credits

I would like to wholeheartedly thank everyone who helped me complete my senior thesis. It has been a lot of work, but in the end it was very satisfying.

First I would like to thank everyone at McKinstry Portland for giving me the opportunity to use the McKinstry Oregon Headquarters. Thank you Jon Eicher, Tom Konicke, Aaron Wozniak, Erik Teyema, Phil Ohnstad, Bev Patterson and everyone else at McKinstry.

Thank you to all of my professors and advisors who mentored me throughout the learning process, specifically Jelena Srebric, Jim Freihaut, and Moses Ling. Thank you to my classmates who gave me advice and help with thesis, especially Brad Sisenwain and Kanis Glaewketgarn for help with lighting redesign. Also thanks to everyone else who gave me advice during my research, specifically Mike O'Rourke and Jim Flores.

Most of all, I am grateful for my parents, Halina and Wojtek and my brothers, Matt and Chris for continued guidance. Thanks to all my friends and the Penn State Snowboard Club for keeping me sane through all of this!

3 Building and Mechanical System Overview

McKinstry Oregon Headquarters is a $15.5 million project which is scheduled for completion March 1, 2009. This includes two buildings. The only building of interest is the office building, as the other is simply a warehouse. Costs for the 50,590 square foot office building total $11.1 million dollars.

At the completion of construction, 67% of the office space will be in use. The rest of the space will be unfinished and available for expansion in the future

The headquarters is a 2 story office building. The office is laid out in a simple rectangular grid. At the West end of the building a full height 1 story warehouse attaches at a rotated angle.

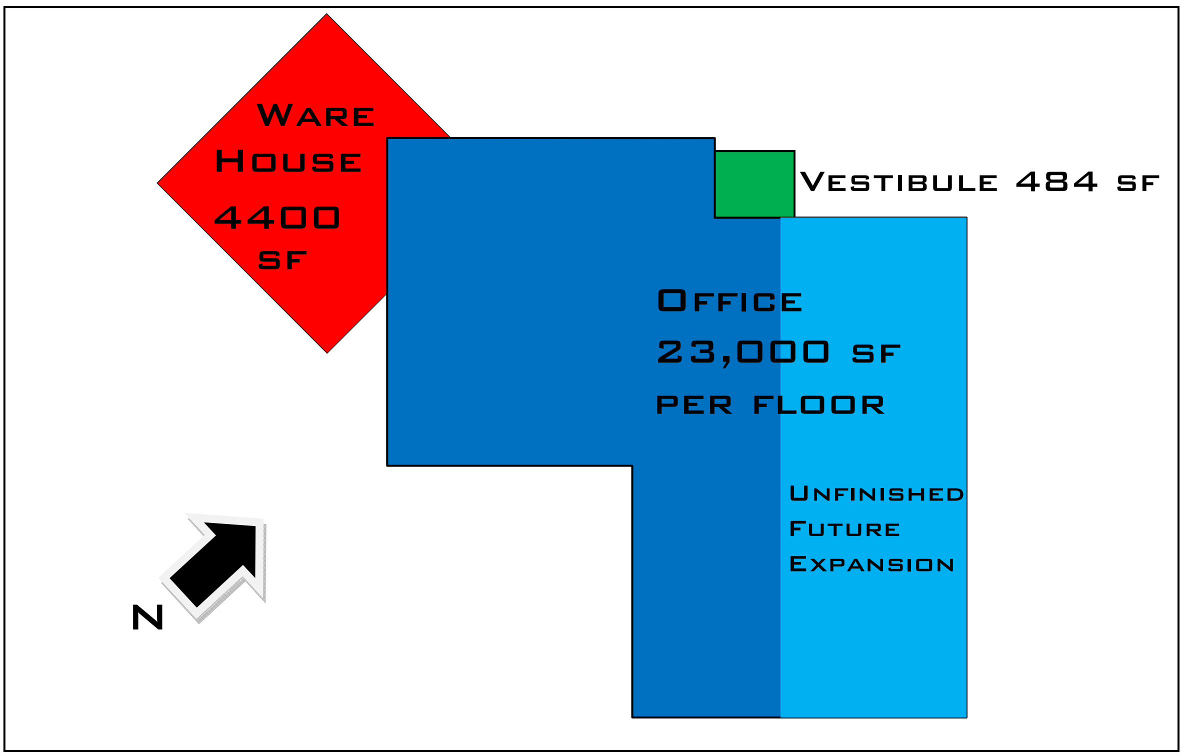


Figure 2.1. Building Footprint

The flat, tilt-up concrete walls have vertical and horizontal lines to break the long straight façade. Approximately 30% of the office façade is glazing and windows are double glazed. The base of the building is a reinforced concrete slab (there is no basement). The exterior walls are backed by 3-5/8" metal studs and 3.5" batt insulation. A built-up roof with 3" rigid insulation and 1.5" metal decking tops off the structure. The roof also has several translucent skylights for natural day lighting. The remaining lighting in the building is fairly standard with 100% fluorescent fixtures.

MECHANICAL SYSTEM

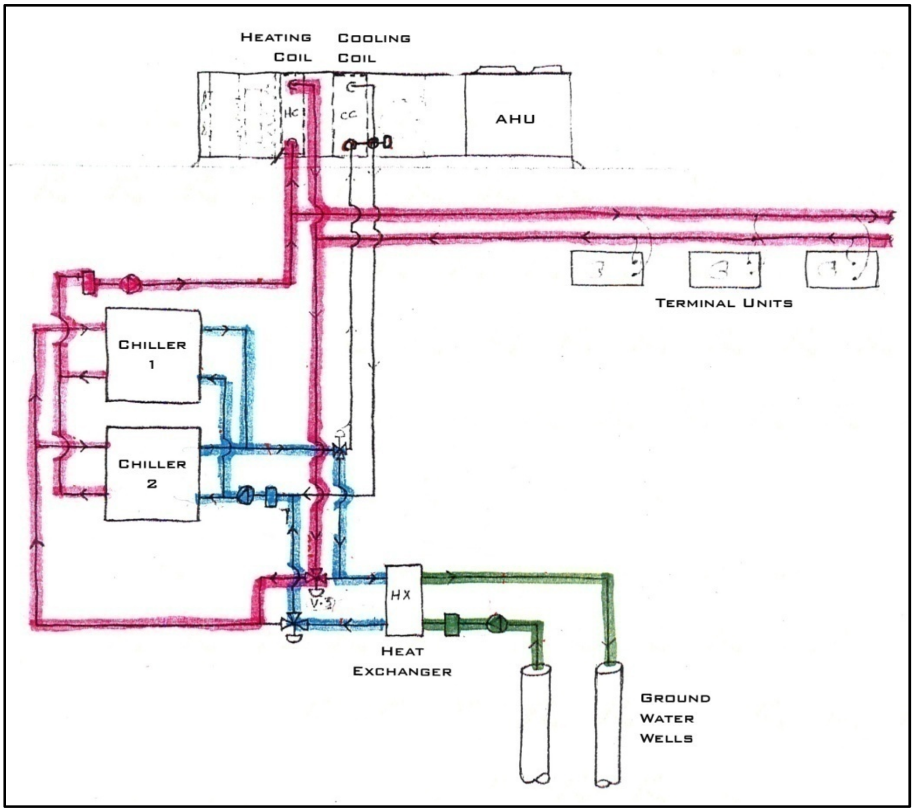


Figure 2.2. Waterside system, shown in heating mode. (McKinstry Design Documents)

The central plant of the building is a heat recovery chiller that is used for both heating and cooling. The mechanical system also includes an open loop ground source heat pump. Ground water accepts heat from the condensing water in cooling mode and provides heat to the evaporator water in heating mode. Recently designers added supplemental 1,000 kBTU/hr natural gas boiler to help meet peak loads. Evaporator side water and condenser side water are piped to the cooling and heating coils in the air handling unit, respectively. A single rooftop AHU (with VFD) distributes air via ducts to the office section of the building. Series VAV boxes with hot water reheats are located throughout the office. Also, an airside economizer can provide cooling on light load days. Two hot water unit heaters keep the warehouse warm in the winter. Heating is provided by the hot water loop and there is no cooling or ventilation. Linear diffusers condition the vestibule at the front of the building. Section 5 provides a detailed schematic of the waterside system.

4 Design Objectives and Requirements

Many factors go into the design of a mechanical system. Before choosing the correct system, a designer must first know what are the owner's and occupant's needs. In the McKinstry Oregon Headquarters, it is a combination of sustainability, comfort, and economy.

4.1 SUSTAINABILITY

First and foremost, McKinstry wanted to make sure their new building received LEED Certification. According to McKinstry designers, LEED has become the industry standard. Achieving certification is seen no longer as a perk, but a necessity. At the beginning of design, McKinstry looked into several sustainable solutions. One of which was on-site wind energy or solar energy. The designers also wanted to save water by harvesting rainwater. This grey water would supply all of the toilets and urinals in the building. The mechanical system is an open loop ground source heat pump. In a metaphorical way, the open loop system, like the roots of a tree, gets its energy from the earth. This can provide substantial savings on energy. Finally, being a mechanical company, they find an aesthetic to their work and chose to leave the ductwork exposed throughout the building.

4.2 COMFORT

Tenants' comfort was very important from the beginning of design. A comfortable employee is a more productive employee, so the designers wanted to make sure every effort was taken to maintain a comfortable environment inside the building. On the mechanical side, indoor temperatures were set to very comfortable temperatures (70ºF in the winter and 74ºF in the summer). Some buildings in the Portland area would actually raise their summer set point to as high as 80ºF to save energy.

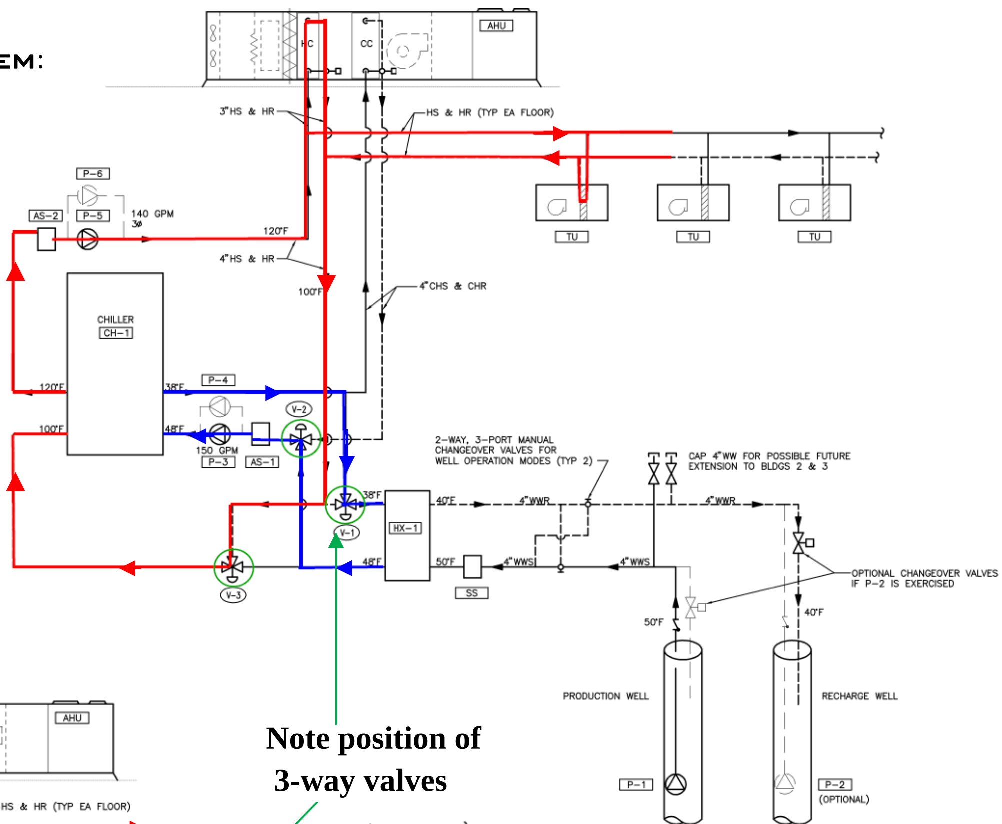
Windows in the room were placed higher on the walls to decrease direct sunlight onto the work plane. The building also includes a full kitchen with stove and hood system, showers for those who bike to work, and a weight room. All of this creates a welcome atmosphere to employees and encourages employees to spend time together on breaks.

4.3 ECONOMY

Finally, just as in virtually any project, hard dollars step in and dictate which ideas are feasible and which ideas are pipe dreams. Throughout the project, total costs dwindled from about $20 million to $15 million. Several ideas such as solar and wind power were scrapped (the wind power had a 30+ year payback). Rainwater harvesting was reduced from supplying all the toilet grey water to being a supplemental system. As with any building, the greatest challenge is to produce an aesthetic, functional building on a budget.

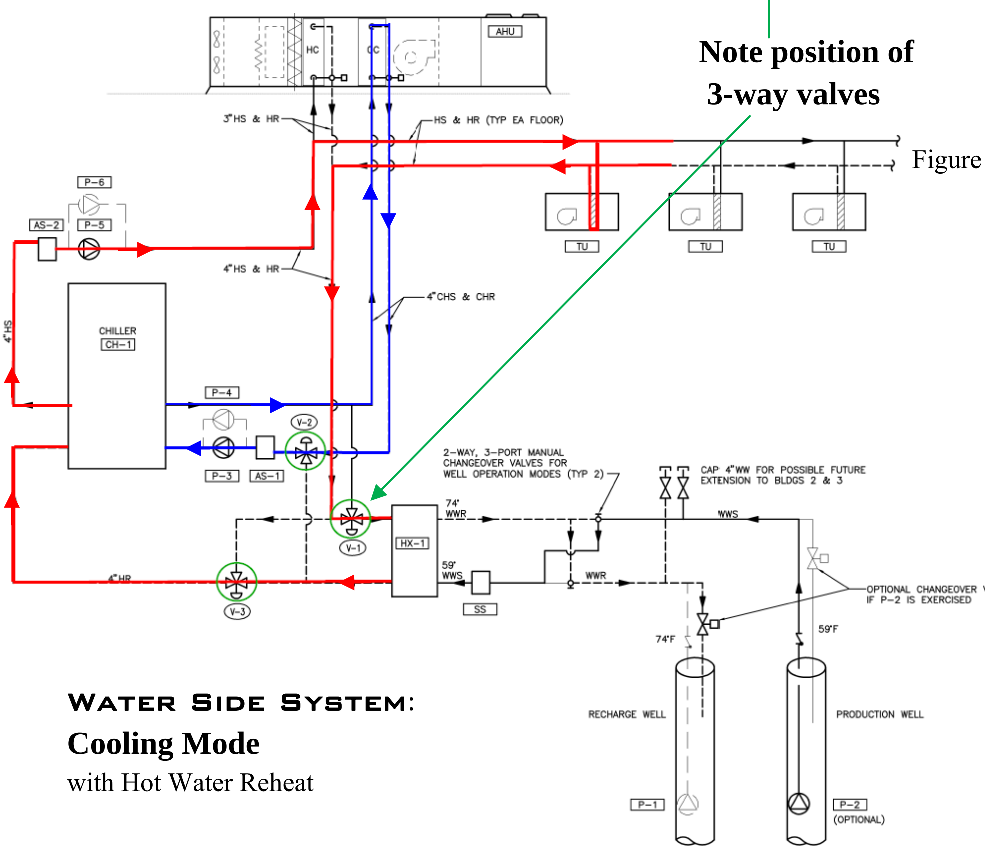
5 Mechanical System Schematic Drawings

Water Side System:
Heating Mode
with Airside Economizer



Note position of 3-way valves

Figure 9.1. Water Side System in Heating Mode



Air Side System:
A single rooftop AHU (with VFD) distributes air via a medium velocity duct system to the office section of the building. There are no drop ceilings in the offices, as to expose the duct work. Thus there is no plenum and square diffusers distribute air from the ceiling. Series VAV boxes with hot water reheats are located throughout the office. Return air is also ducted.

Water Side System:
Cooling Mode
with Hot Water Reheat

Figure 9.2. Water Side System in Cooling Mode

6 Design Conditions

The following table shows design conditions for McKinstry Oregon HQ. See Technical Report II[a] for full assumptions about indoor conditions and Appendix D of this report for full outdoor design conditions for Portland, OR.

Table 6.1. Indoor and Outdoor Design Conditions

Design Condition	Indoor (occupied)	Indoor (unoccupied)	Outdoor
Heating	70°F	65°F	21.9°F (DB, 99.6%)
Cooling	74°F, 50%RH	78°F	90.8° F (DB, .4%)

7 Ventilation Requirements

ASHRAE Standard 62.1 – 2007[b] sets forth guidelines "to provide indoor air quality that is acceptable to human occupants and that minimizes adverse health effects." Section 6 of the ASHRAE Standard provides the Ventilation Rate Calculation Procedure. Analysis of McKinstry Oregon Headquarters found a minimum outdoor air of **5,109 CFM**, or 14% outdoor air. This is less than the air handling unit's minimum outdoor air supply of 5,500 CFM. In summary, McKinstry Oregon Headquarters complies fully with ASHRAE Section 62.1 – 2007. Complete analysis and calculation can be found in Technical Report I[a].

8 Dedicated Outdoor Air System Overview

The mechanical redesign for the headquarters is based around a dedicated outdoor air system (DOAS). DOAS reduces airflow throughout the building by providing only ventilation air. This will provide yearly energy savings from reduced fan usage. Because of lowered CFM, the AHU and ductwork can also be downsized. For calculations, all loads, square footages, and other values include the area of future expansion.

Previously there were series VAV units throughout the building to control airflow and provide reheat. While there will still need to be a damper for balance, the units are much less complex with no need for fans or piping. This will save significantly on first cost. Details are shown in Section 14.

Several new elements must be added to the system with the DOAS redesign. An enthalpy wheel recovers energy from exhaust air, thus saving energy on ventilation load. Also, at the end of the ductwork, diffusers must be replaced with high induction diffusers. Since incoming air is much lower temperature, 42F, high induction diffusers ensure good air mixing and eliminate draft in the space.

A separate system must be introduced to meet demand loads. This thesis report employs radiant ceiling panels. Located at ceiling level, the panels cool/heat the space with chilled/hot water from the central plant. The panels require large water flow which will upsize piping throughout the building –previously piping was only for hot water reheat in the VAV units.

Radiant panels cannot handle latent loads. To avoid condensation on the panel's coils, latent load must be handled from the supply air. During high humidity and summer conditions, ventilation air is cooled and dried to 42F. With a low humidity ratio, the dry air keeps condensation from forming on the radiant panels. Calculations can be found in Section 11.1. In addition an enthalpy wheel recovers energy from return air.

The central plant now splits into two separate units, one in the previous location, and one on the rooftop with the AHU. The main chiller and boiler only provide chilled and hot water for the radiant panels. The chiller on the rooftop conditions outdoor air to 42F for dehumidification. In heating mode it can heat the air up to 95F. Section 12 goes over plant details.

SPACE COMFORT

By eliminating the VAV system and providing 100% outdoor air, the DOAS system ensures that all spaces receive adequate ventilation air. In a VAV system, outdoor air mixes with return air, and each space receives supply air based on load, not ventilation. With DOAS, the system is designed to specifically provide proper ventilation. Proper ventilation is a definite plus for occupant comfort. In addition, DOAS provides better control of air humidity. This is because the mechanism for sensible cooling is separate from latent cooling. If a VAV system has a small sensible load, there is no way to do a large amount of latent cooling. With DOAS, sensible and latent cooling are totally separate[c].

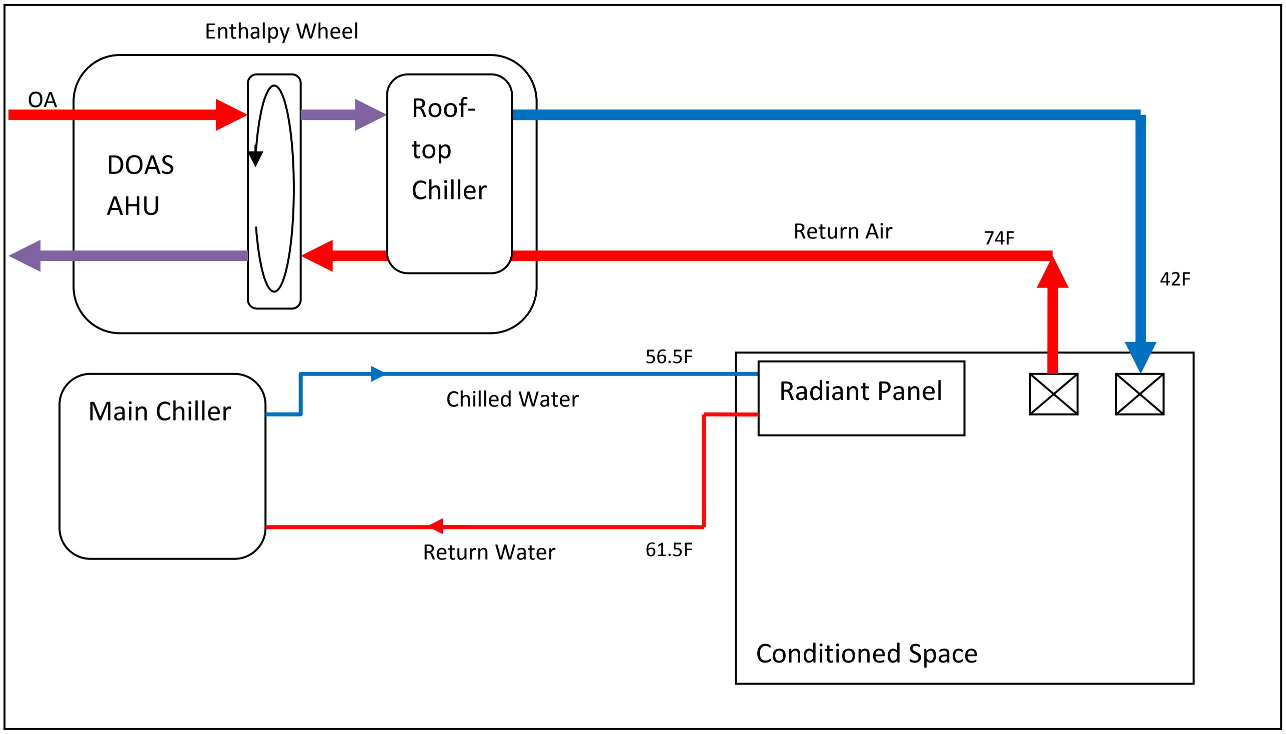


Figure 3.1. DOAS Schematic in Cooling Mode

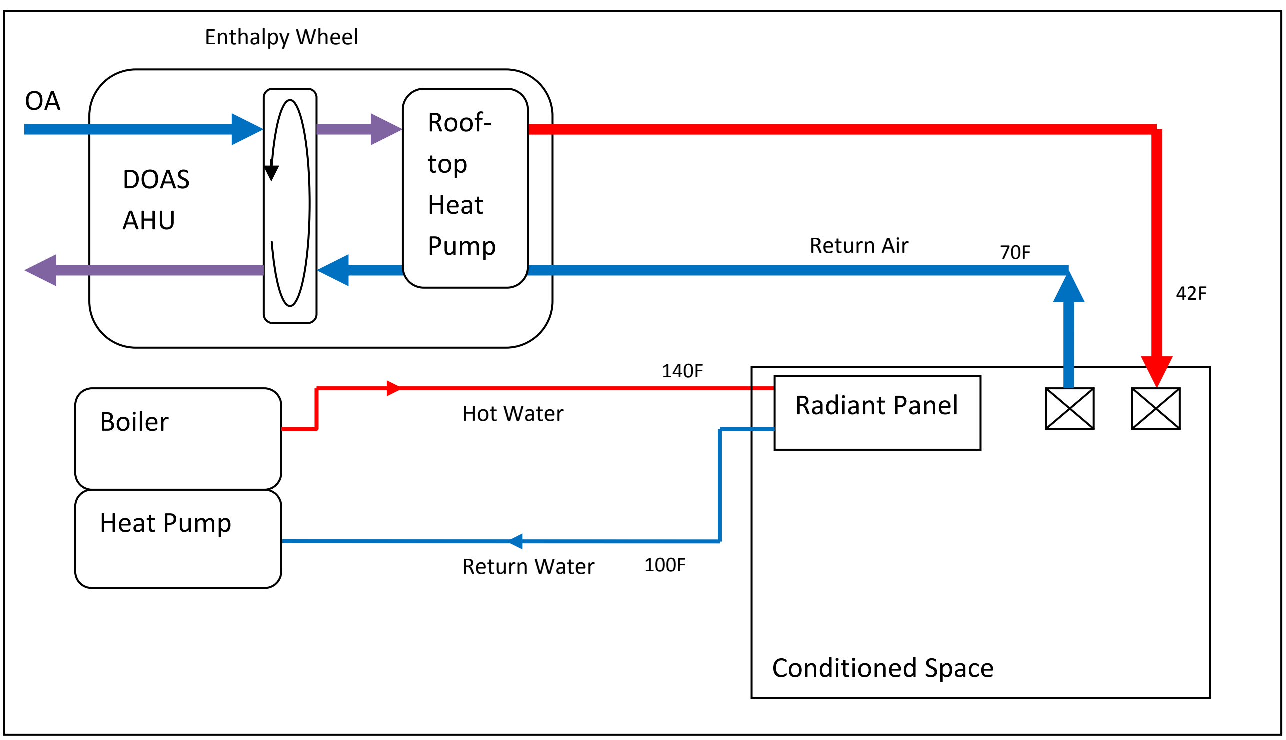


Figure 3.2. DOAS schematic in heating mode

9 Piping

Currently, because of hot water reheat, there is hot water supply (HWS) and return (HWR) to each VAV unit. After checking the HW piping in the original plans, the pipe size is adequate to accommodate the HW to the radiant panels[d]. For a DOAS system, we will have to add chilled water supply (CWS) and return (CWR) to each zone. These pipes will follow the same path as the HW, but will have to be larger as the CWS is much larger than HWS (225 GPM vs 45 GPM).

Table 9.1. Chilled water pipe sizing and head

Section	GPM	Pipe Size[d]	Head/100' (ft $H_2$0)[d]	Length (ft)	Fitting equiv Length (ft)	Total Length(ft)	Total Head (ft $H_2$0)
1	110.4	3.5"	1.6	71	19.25	90.25	1.44
2	90.7	3.5"	1.2	125	25.09	150.08	1.80
3	68.7	3"	1.2	35	15.0	50.00	0.60
4	25.2	2"	1.5	16	3.33	19.33	0.29
5	20	2"	1	39	6.67	45.67	0.46
6	14.4	1.5"	2	16	2.63	18.63	0.37
7	6.4	1.25"	1.3	22	0	22.00	0.29
					TOTAL	395.96	**5.25**
						x2 for return	5.25
						Panel Head[1]	3.00
						Chiller	18.2
						Authority Factor	x2
						Static Head	35
						TOTAL HEAD	**98.4**

[1]See Table 11.1.4 for panel head calculations

10 AHU and Ductwork

Since the total building CFM reduces to only ventilation air, the AHU and ductwork both can be downsized. Reduction in size produces a significant savings in first cost. Cost details are described in Section 14.

The size of an AHU is almost solely based on the CFM. Lowering CFM will also lower everything from fan HP to weight. Since supply air is constant, the fan does not need to be a variable speed drive. All of this will save on first cost. The following table compares the original air handler to the redesigned AHU. The difference in size is very noticeable.

Table 10.1. AHU comparison

	CFM	Fan Drive	Fan Power	Weight	Dimensions
Original	35,800	VFD	50 HP[e]	16,000 lbs[e]	414"x166"x120" [e]
Redesign	5110	Constant	7.5 HP[f]	1,180 lbs[f]	110"x52"x48" [f]

DUCTWORK

Next, the ductwork also can be downsized. Smaller duct diameter requires less sheet metal, which becomes another first cost savings (MPS pg 420). Once the ducts are sized, one must check pressure drop for the longest run. The total pressure drop through the system is very important for fan energy calculations. The table and figure below show a sample calculation of duct sizing.

Table 10.2. Duct sizes and pressure drops

CFM	Duct	FPM	ΔP/100'[d]	Length	ΔP"
3360	18"	1950	0.26	25	0.065
2150	14"	2000	0.37	20	0.074
1150	12"	1500	0.26	38	0.099
690	9"	1600	0.4	12	0.048
490	8"	1400	0.38	11	0.042
430	8"	1250	0.3	10	0.030
170	5"	1150	0.45	15.5	0.070
85	4"	950	0.44	15.5	0.068
30	4"	450	0.15	23	0.035
		FITTINGS			
Description			**C**	**FPM**	**ΔP"**
Tee			0.5	1950	0.119
Division tee			0.15	1500	0.021
Tee			0.13	1500	0.018
Tee			0.13	1500	0.018
elbow			0.26	1500	0.036
transition			0.12	1600	0.019
Div tee			0.13	1600	0.021
Div tee			0.13	1250	0.013
tee			0.52	1250	0.051
Div tee			1.8	950	0.101
				TOTAL FOR DUCTS	**0.947**
AHU					1.3
Terminal unit					0.05
Diffuser					0.1
				TOTAL PRESSURE DROP	**2.397**

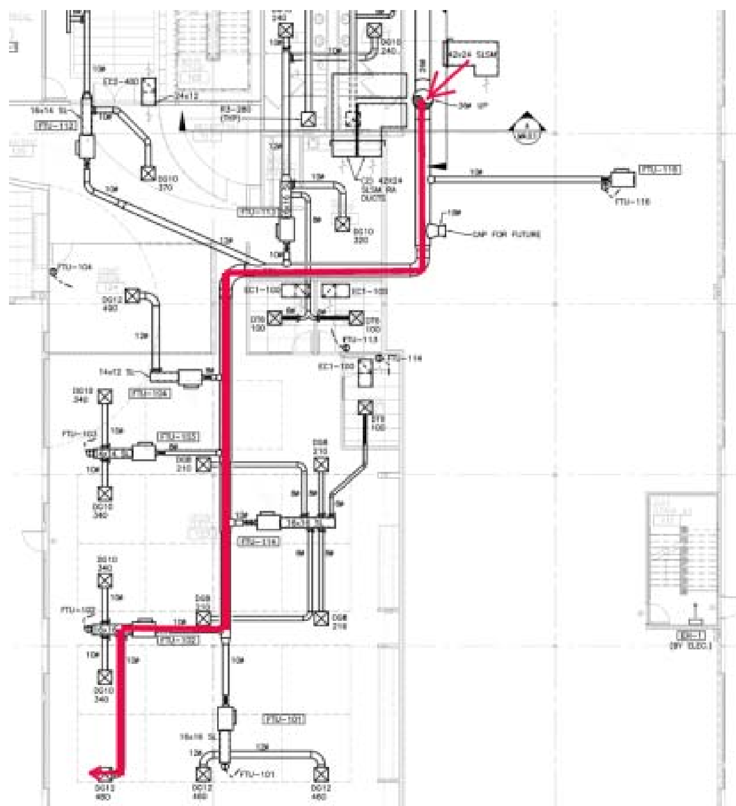


Figure 10.1. Design Duct Run

11 Radiant panels

Radiant panels now handle the majority of sensible loads in the building. As the name suggests, the panels use radiant heat transfer to condition the building. Water flows from the central plant to the radiant panel. Heat transfer occurs from copper piping inside of the panel, into the space as seen in the figure below.

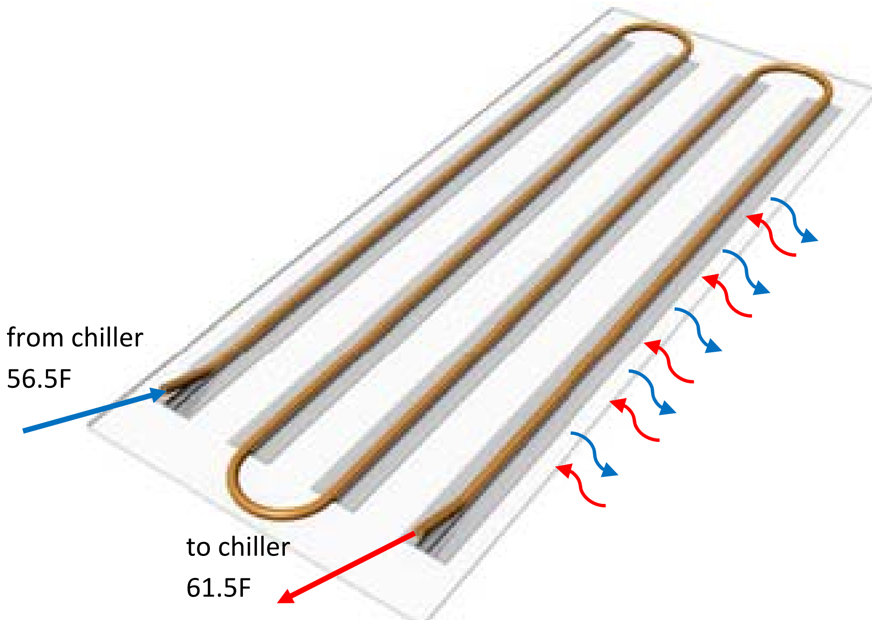


Figure 11.1. Radiant Panel shown in cooling mode[g]

11.1 Cooling Panel Design

SIZING

The following table shows calculations for a few sample spaces for sizing the radiant panels for cooling. Panel ΔT is 5F, with a 56.5F inlet temperature. Total load is estimated from equation 13.1, with CFM equal to supply air at the Fan Terminal Unit for each zone and supply air as 55F. This number is conservative, since designers estimated supply air before loads were known.

Table 11.1.1. Cooling Panel Sizing

Description	Area	Load	Vent Air	Air Sensible Capacity	Sensible Load	Area Panel[1]	Percent Ceiling
	SF	BTU/hr	CFM	BTU/Hr	BTU/Hr	SF	
Open Office[2]	593	18878	81.5	2817	16062	422	71.3%
Open Office[2]	608	23803	83.6	2889	20914	550	90.5%
Open Office[2]	400	13953	55.0	1901	12053	317	79.3%
Open Office[3]	1878	19288	258.2	8923	10365	398	21.2%

Conference[3]	400	10054	196.7	6798	3257	108	27.1%
Total For Building	42318	762900	5110	199000	563900	**17615**	41.6%

[1]Appendix E
[2]Perimeter Zone
[3]Interior Zone

With radiant ceiling panels, there is a risk of condensation forming on the coils. If the dew point of the space reaches above the temperature of the cooling coil at the inlet (coldest point), condensation will begin to form. This would eventually cause water to drip onto occupants and equipment. The room design conditions for cooling are as follows:

Figure 11.1.2. Radiant panel in an office[h]

Table 11.1.2. Room Conditions

Dry Bulb	Relative Humidity	Humidity Ratio	Dew Point	Chilled Water
74F[1]	50%[1]	.0089 lb/lb	**54.3F**	**56.5F**[2]

[1]Table 6.2.1
[2]Table 12.2.2

The dew point of the space is below the coldest temperature of the radiant panel. As long as design conditions are maintained, there will be no condensation. For design conditions to be met, any latent load must be handled. Below is a sample latent load calculation from a space with the highest latent load – a 400 square foot conference room. As shown, the latent capacity of the supply air is plenty to handle peak latent load.

Latent Load = 37 BTU/hr/person*occupancy (11.1.1)

Latent Load = 37*26.7 = **988 BTU/hr**

Latent Capacity = 4838 * CFM * (W_{room}-W_{supply}) (11.1.2)

Latent Capacity = 4838*81.5*(.0089-.0058) = **2950 BTU/hr**

CIRCUITS

Radiant panel circuitry must also be designed. The following equation is useful for finding flow rate.

$$GPM = BTUh/(500*\Delta T) \quad (11.1.3)$$

$$GPM_{total} = 563900/500/5 = 225.5\ GPM$$

One would like total pressure drop in the circuit to be in the vicinity of 5' of head. The following table shows calculations for panels and flow rate. Note that each panel is 2'x4'.

Table 11.1.3. Panel and Flow Rate calculations

Description	Sensible Load	Area Panel	Panels	Flow Rate
	BTU/Hr	SF		GPM
Open Office	16062	422	53	6.42
Open Office	20914	550	69	8.37
Open Office	12053	317	40	4.82
Open Office	10365	398	50	4.15
Conference	3257	108	14	1.30
Total	563900	17615	**2202**	**225.5**

If one assumes 8 panels per circuit we get a head of 3' per circuit.

Table 11.1.4. Circuit design

Panels/Circuit	Total Circuits	Flow Rate/Circuit	Head per panel[1]	Head per circuit
8	275	.820	.376'	3.01'

[1]Calculation Appendix

LAYOUT

Radiant panels should be spread out evenly over each zone. In perimeter zones, panels will cover most of the space, and will be much sparser in interior zones (see Table 11.1.1). Wherever radiant panels cover more than 70% of a zone, full ceiling systems will be used[i]. This is primarily at perimeter zones, and will also help coordinate with heating panels (see Section 11.2)

11.2 Heating Panel Design

SIZING

There are a few key differences when sizing heating panels. In the McKinstry Oregon Headquarters, all heating load is through the building envelope, and is equal across the entire perimeter. The eQUEST model from Technical Report 2 (Wyczalkowski) gives total heating load per floor. Panel ΔT is 40F, with an intlet of 100F. This is a large number however is acceptable providing expansion tanks are adequately sized.

Table 11.2.1. Heating Panel Sizing

Floor	Total Load	Perimeter	Load/ft	# Tubes[1]	Panel Width[1]	Area	Total Flow[2]
	BTU/hr	Ft	BTU/hr/ft	passes	ft	SF	GPM
1st	440000	625	704	10	5	3125	22
2nd	446000	625	714	10	5	3125	22.3

[1]See Appendix F
[2] Equation 11.1.3.

Heating load is slightly higher on the second floor. This is due to roof exposure, which is greater than heat loss through slab on grade at the first floor level.

CIRCUITS

Using equation 11.1.3 we can find total flow rate for each floor. For this calculation we will assume a circuit flow of 1 GPM, and then check if head loss is appropriate.

Table 11.2.2. Heating Panel Circuit Head Calculation

Floor	Total Load	Total Flow	Circuit GPM	#circuits	circuit length	Tube length[1]	Head/ 100ft[2]	Circuit Head
	BTU/hr	GPM	GPM		ft	ft	ft H_20	ft H_2O
1st	440000	22	1	22	28.41	284.1	2	**5.61**
2nd	446000	22.3	1	22.3	28.03	280.3	2	**5.68**

[1]Length = Perimeter/Circuits; 10 tubes/circuit
[2]See Appendix F

LAYOUT

Since all heat loads are on the perimeter, panel layout should be around the perimeter of the building, and work inside. The perimeter also needs to be cooled, so these panels would over lap. Here, a 4 pipe system will be used, so the panels can provide both heating and cooling.

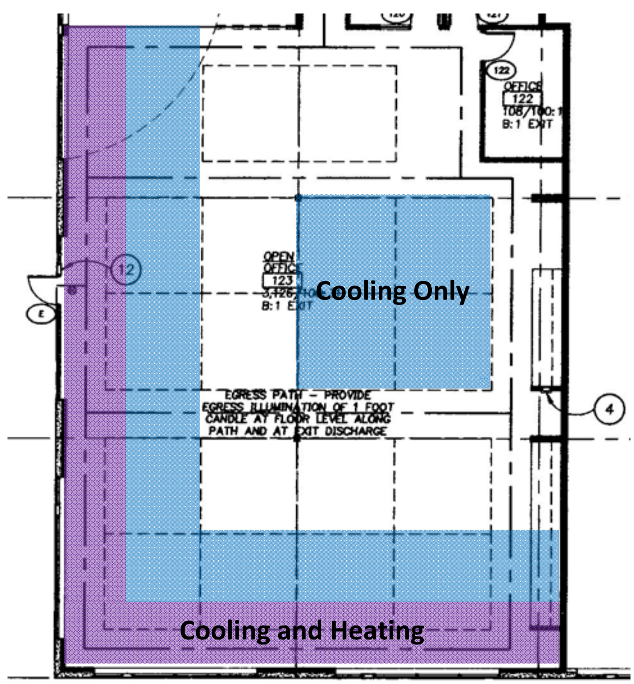


Figure 11.2.1. Radiant Ceiling Panel Layout

12 Chillers and Central Plant

In the redesign, there are two separate plants. One is located on the roof and conditions air in the AHU. The primary requirement of this plant is to handle latent load. The central plant produces hot and chilled water for the radiant panels. This plant accounts for the majority of sensible loads. Because of the enthalpy wheel, total plant size (cooling) can be reduced by **5.9 tons**. (see Section 13.1)

12.1 AHU Chiller

The AHU Chiller's main function is to handle latent loads. By cooling outdoor air to 42F, moisture is removed and the dry air ensures a dry conditioned space. Latent load calculations can be found in Section 11.1.

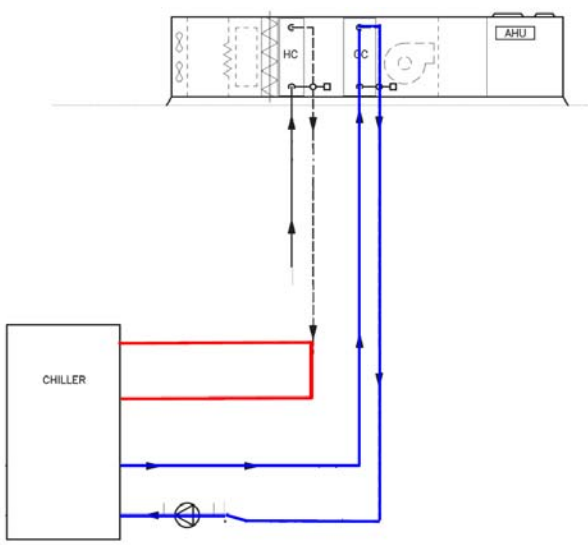


Figure 12.1.1.a. Chiller in heating mode

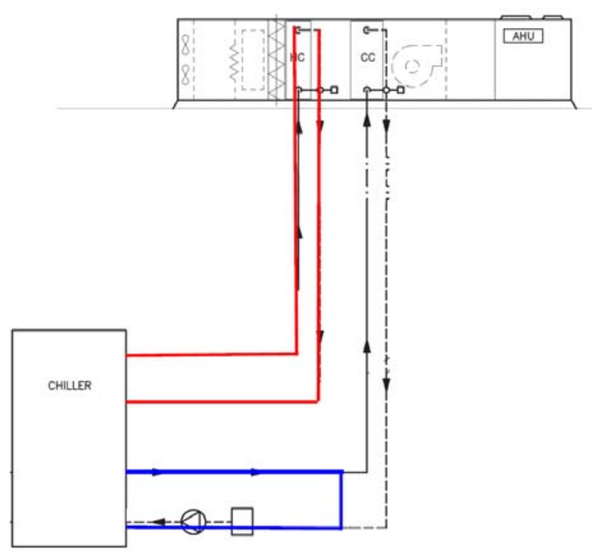


Figure 12.1.1.b. Chiller in cooling mode

As seen in the figure below, the chiller will heat or cool the space depending on outside air temperature. Heat rejection occurs into the atmosphere. To size the chiller, one can use the following equation:

$$Q=1.08*CFM*(T_{ew}-T_{supply}) \quad (12.1.1)$$

Q=1.08*5110*(77.2-42) = 194 kBTU/hr = **16.2 tons**

According to TMY data[j], the minimum temperature during occupancy hours is 20F. Assuming $COP_{heating} \approx COP_{cooling}$, the following equation shows supply air temperature at design heating condition:

$$T_{supply} = T_{ew} + Q/(1.08*CFM)$$

$$T_{supply} = (20+.8(70-20)) + 194000/(1.08*5110) = \mathbf{95F}$$

Since supply air temperature is not critical, any number above 70F is acceptable.

12.2 Central Plant

Changing to DOAS will make several key effects on the central plant. The heat recovery chiller now solely supplies water to the radiant panels. Also, operating temperatures change which affects both flow and efficiency.

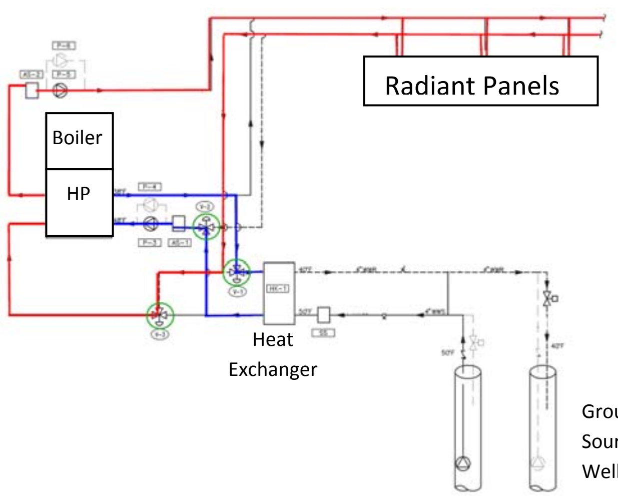


Figure 12.2.a. Central Plant During Heating

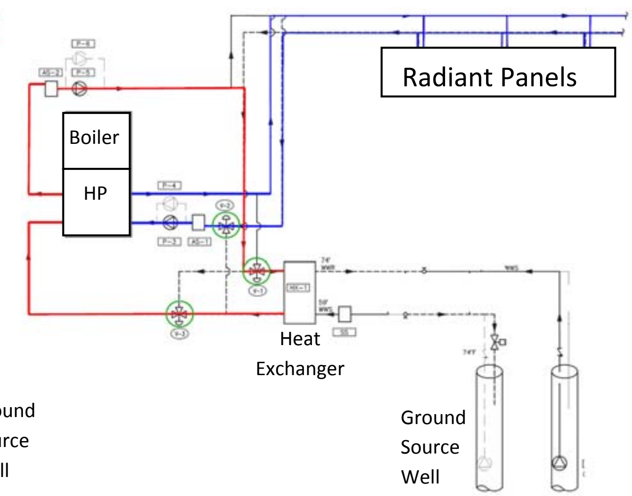


Figure12.2.b. Central Plant During Cooling

The chiller can be downsized by 16.2 tons because of the addition of the AHU chiller (in addition to reduction in energy from the Enthalpy Wheel, section 13.1)

Table 12.2.1. Chiller size

Original Size	AHU Chiller	Enthalpy Wheel	Redesign Size
123.5[1] tons	16.2 tons	5.9 tons	101.4 tons

[1]Appendix G

Because of the radiant panels, the chiller now operates at a higher temperature. This increases the efficiency of the chiller. In heating mode, the heat recovery chiller stages with the natural gas boiler to provide full heating capacity.

Using a heat pump with radiant panels poses a potential problem. Heat pumps like low condenser loop temperatures to keep efficiency high. Radiant ceiling panels work best at higher temperatures. At a high ΔT, heat transfer is primarily radiation and with a lower ΔT, heat transfer is dominated by convection. With radiant ceiling panels, one would like to keep heat transfer as primarily radiation, since convective transfer will stratify the air and keep hot air at the top of the space. To solve this, increase the ΔT of the hot water loop from 20F to 40F. By staging the heat pump and boiler, it allows the heat pump to work from 100F-120F, its optimal operating range. The boiler increases the hot water to 140F. This gives a Mean Water Temperature (MWT) of 120F. This is on the low side of radiant ceiling panel temperatures, but still acceptable (Appendix F). Increasing ΔT will also reduce GPM which reduces copper piping size. The only issue may be radiant asymmetry from the start to finish of the panel. However, since all heating is confined to less than 10' of the perimeter, this should not be a problem. The following table gives a list of operating temperatures and GPM flows for the central plant.

Table 12.2.2. Central Plant Operating Details

	Operating Temperature	ΔT	GPM
Original (Cooling)	52F-38F[1]	14F	140[1]
Redesign (Cooling)	56.5F-61.5F	5F	225
Original (Heating)	100F-120F[1]	20F	112[1]
Redesign (Heating)	100F-140F	40F	45

[1]Appendix G

Note that as ΔT varies, GPM changes inversely. Also, as GPM's go down, so do pumping costs. In the redesign, cooling GPM's go up, but heating GPM's go down. Once can assume that these values would be close to offsetting each other. Also, since pump energy is minimal compared to fan energy, the scope of this report does not include yearly pump energy differential.

13 Energy Analysis

13.1 Enthalpy Wheel

Using an enthalpy wheel greatly reduces the load on the building from ventilation air. This ventilation load is caused by the difference in temperature of the outside air and room air. By recovering heat and moisture from exhaust air, enthalpy wheels can reduce ventilation load by 80% (this report assumes an 80% efficient EW). Using TMY data from Portland, OR[j], the following charts show a typical heating and cooling day. The building is only ventilated during occupancy hours.

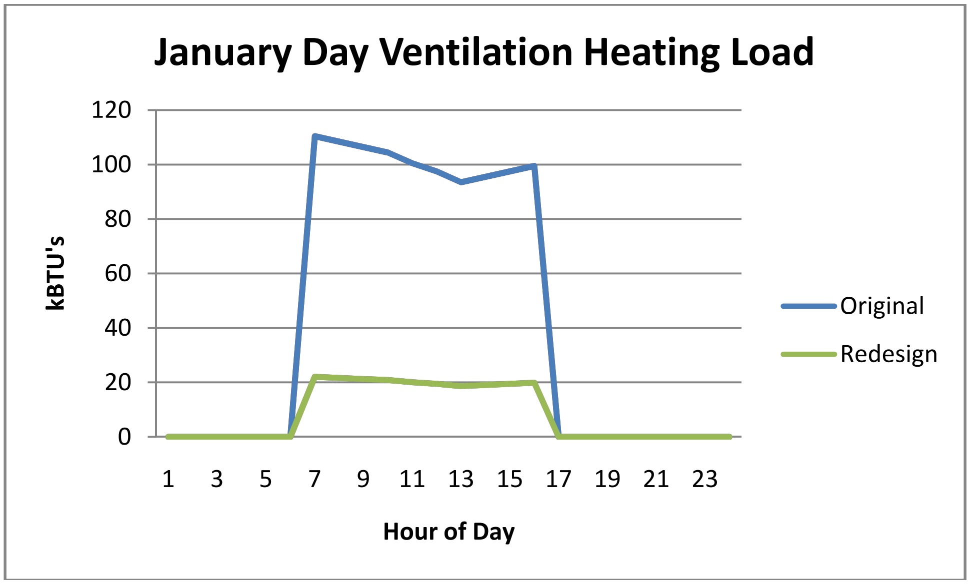


Figure 13.1.1. Ventilation heating load for January 19

Combining days over the entire year produces an annual energy saving as seen in the table below. Note most of the savings come in space heating. Assuming $.08/kWh utility rate (Appendix H), yearly cost savings from the enthalpy wheel total **$1,208**.

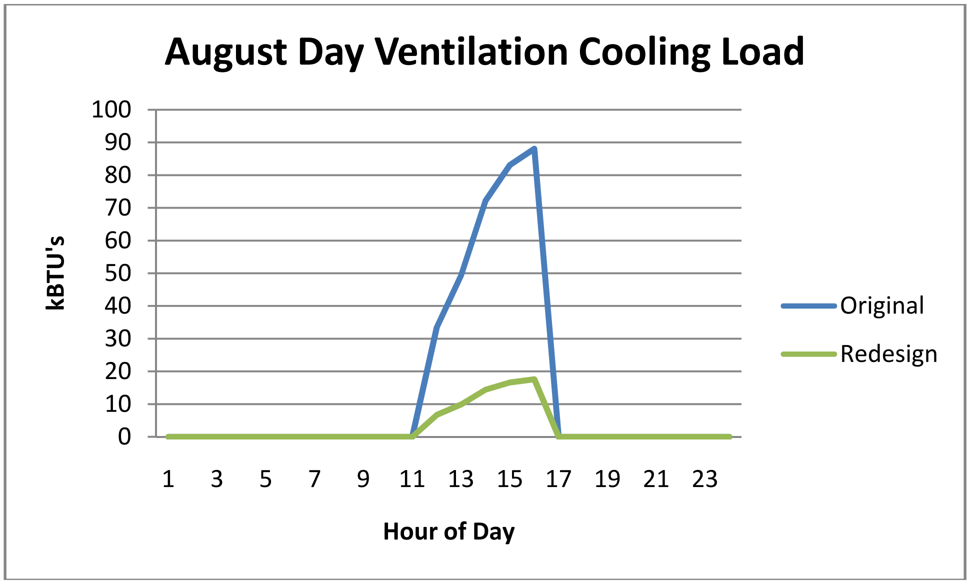


Figure 13.1.2. Ventilation cooling load for August 26

Table 13.1.1. Redesign Yearly Ventilation Savings

	Original	Redesign	Savings	Savings (per SF)
Total Heating Energy (kBTUx000)	252.8	50.6	202.21	4.35 kBTU/SF
Total Cooling Energy (kBTUx000)	11.1	2.2	8.9	.19 kBTU/SF
Energy to Heat Recovery Chiller[1] (kWhx000)	18.9	3.8	**15.1**	.32 kWh/SF
Heating Therms	2528	528	2000	.043 thms/SF

[1]Appendix G, COP = 4.1; also see equation 16.4

In addition to year round energy savings, the enthalpy wheel will also decrease the peak cooling load on the building. With a smaller load, chiller size can be reduced. Using the equation:

$$Q_{cooling}=1.08*CFM*(T_o-T_i) \quad (13.1)$$

One can see that a large change in ΔT will create a proportional change in load. With an 80% efficient enthalpy wheel, outdoor air temperature seen by the AHU reduces from 90F to 77.2F (assuming 74F indoor air, Section 6).

	Outdoor Air	Load (BTU/hr)	Savings
Original	90F	88300	
Enthalpy Wheel	77.2F	17660	**70640 BTU/hr = 5.89 Tons**

13.2 Fan Energy

The main advantage of DOAS is the reduction in fan energy. In the McKinstry Oregon Headquarters, supply air flow is as high as 36,000 CFM. By only supplying ventilation air, that can be reduced to a constant flow of 5,110 CFM. In addition, since the DOAS is a CAV system, there is no need for fans in the VAV units.

To calculate fan energy in for DOAS, one can assume constant volume for all occupied hours during the year. Using the following equation, one can calculate fan power, and from that yearly energy.

$$\text{Fan Power}_{kW} = P_{inwg}*Q_{CFM}/(8500*Eff_{fan}) \quad (13.2.1)$$

Efficiencies for supply and return fan are 63% and 42% respectively. (Jim Flores). Pressure drop is calculated from the longest duct run in the building. From Table 10.2 return and supply ΔP are 2.4" and .95" respectively. In addition, exhaust fans from the mechanical schedule also add to energy consumption (Appendix G).

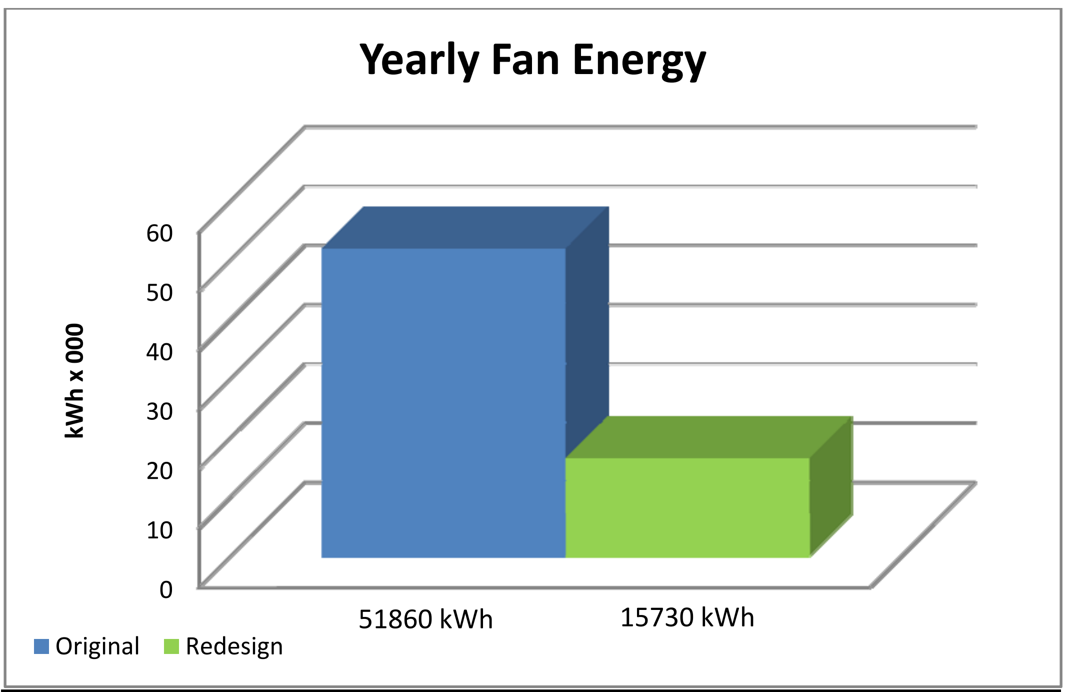


Figure 13.2.1. Yearly fan energy

Yearly savings comes to **36,130kWh**. The original fan energy value is based on the Energy Model built in Technical Assignment 2 (Wyczalkowski). Assuming $0.08/kWh utility rate (Appendix H), annual cost savings amount to **$2,890**.

14 Cost Analysis and Construction breadth

14.1 First cost analysis

All costs include area of future expansion.

DUCTWORK

With DOAS, the ductwork will be smaller because of reduced supply air. Appendix B shows detailed calculations and RS Means[k] costs for all of the ductwork in the main section of the first floor. By extrapolating SF costs over the entire building, one can find total savings.

Table 14.1.1. Original vs Redesign Ductwork Costs[1]

	Cost/SF	Total Cost	Savings
Original	$0.56	$26,042	
Redesign	$0.23	$10,426	**$15,615**

[1]Detailed Cost Breakdown in Appendix B

PIPING

Piping first costs will go up, because of the addition of chilled water pipes. Hot water pipes can be kept the same size as original, according to pressure drop tables[d]. In addition, the redesign includes steel[k] and PEX piping[L], where appropriate. With high copper prices, these alternatives provide additional cost savings to the owner.

Table 14.1.2. Original vs Redesign Piping Costs[1].

	Hot Water Piping	Chilled Water Piping	Total Cost	Savings
Original	$40,050	$0	$40,050	
Redesign	$30,990	$50,070	$81,060	**($41,010)**

[1]Detailed cost breakdown in Appendix C

RADIANT PANELS

Radiant panels are the most significant first cost for the mechanical system at $13/SF[c] and covering a large portion of the ceiling space. Cooling panels are concentrated along the perimeter of the building, as well as in the interior of the building, but in a smaller percentage of total ceiling space. As discussed in Section 11.2, heating panels overlap the cooling panels. These panels become 4-pipe and only add $2/SF to cooling panel cost[h]. The following table shows total prices for heating and cooling panels.

Table 14.1.4. Radiant panel cost

	Total Area (SF)[1]	Cost/SF	Price	Total Cost
Cooling Panels	17,615	$13	$228,990	
Heating Panels	6,316	$2	$12,630	**($241,620)**

[1]See Section 11 for calculation

CHILLER SIZE

As discussed in Section 12, chiller size can be reduced because of the enthalpy wheel. Total chiller reduction is 5.9 tons. Every ton in chiller size reduction reduces first cost by $1,000[c].

Savings = Size reduction * $1000 = 5.9*1000 = **$5,900**

MISCELLANEOUS

Table 14.1.3. Mechanical Equipment Cost Comparison

	AHU	Enthalpy Wheel	Diffusers[1]	Fan Terminal Units[1]	Total	Savings
Original	$105,000[e]	$0	$5,873	$52,450	$163,323	
Redesign	$20,000[f]	$10,600[k]	$7,342	$7,570	$45,512	**$117,811**

[1]See Calculation Appendix for calculations

FINAL FIRST COST

Total cost for the entire original mechanical system totals $1,394,511 (Appendix I). As seen in the figure below, first cost will increase with the DOAS system because of the large cost of radiant panels. The table below shows difference in total price and per SF.

Table 14.1.5. Total First Cost Comparison

	Total Mechanical Cost	Cost/SF	Redesign Savings	Savings/SF
Original	$1,394,511	$27.56		
Redesign	$1,537,814	$30.40	**($143,303)**	**($2.83)**

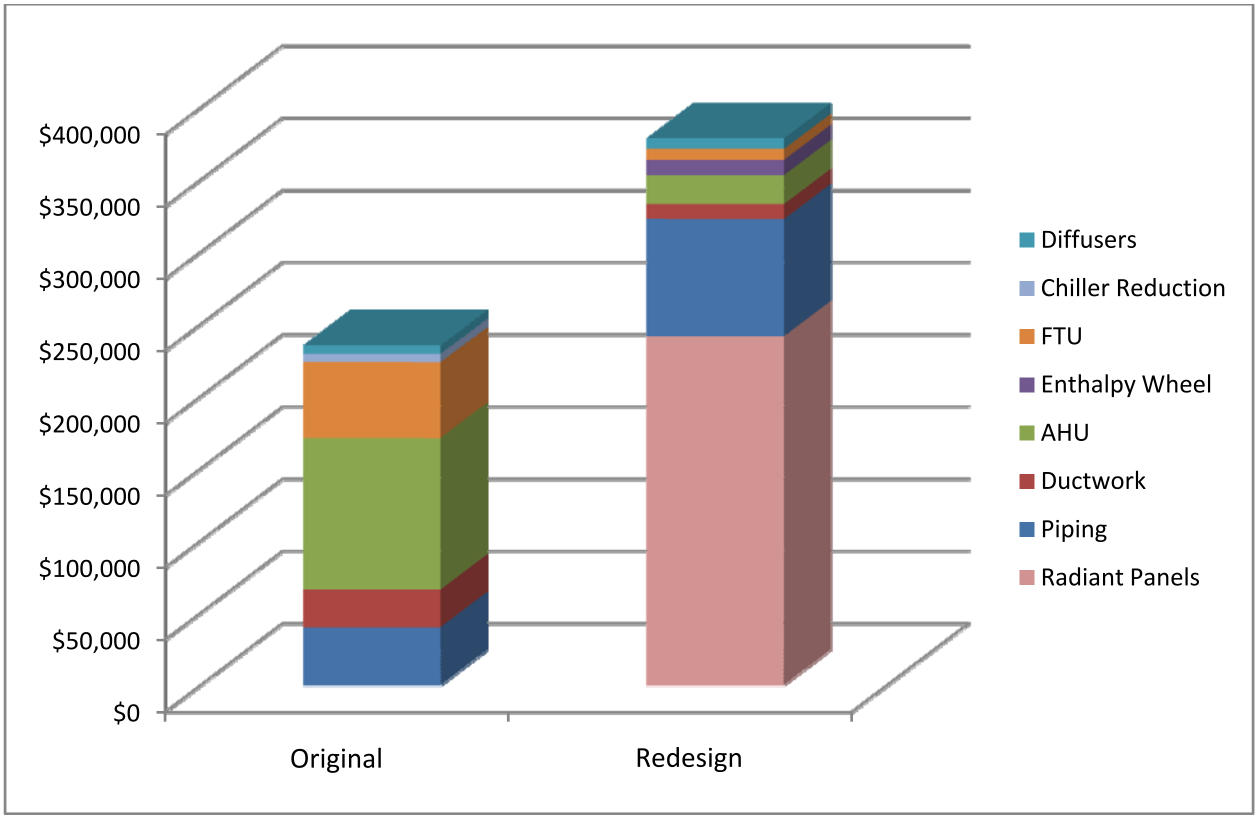


Figure 14.1.1. Mechanical First Costs

14.2 Yearly Savings and Payback Period

Although the first cost of the mechanical system will increase with the redesign, yearly energy consumption has been reduced. This comes from two different sources. Ventilation load is reduced from the enthalpy wheel (Table 13.1.1) and fan power is also reduced due to less supply air (Section 13.2). The following table shows yearly energy savings and payback period assuming a $0.08/kWh utility rate (Appendix H).

Ventilation	Fan Energy	Total Savings	Cost Savings	First Cost	Payback
15,100 kWh	36,130 kWh	51,230 kWh	$4,100	$143,303	**35.0 years**

CONSTRUCTION PHASING

A 35 year payback period is fairly high. However, current construction is scheduled to only finish 67% of the office spaces. The rest of the space will remain unfinished until McKinstry expands, or the space is leased to tenants. When considering this, much of the first cost savings will still be fully present, such as the AHU and Chiller reduction. However, some of the cost deficits such as piping and especially radiant ceiling panels will decrease by 33%. The following table shows first costs for all equipment with 67% office space completion.

Table 14.2.2. 67% Completion Costs

	Original	Redesign
Ductwork	$17,448	$6,985
Piping	$26,833	$54,310
AHU[1]	$105,000	$20,000
Enthalpy Wheel[1]	$0	$10,600
Diffusers	$3,935	$4,919
FTU	$35,142	$5,072
Radiant Panels	$0	$161,885
Chiller Reduction[1]	$0	($5900)
TOTAL	$188,358	$257,872
Savings		**($69,514)**

[1]Cost does not scale down

Even though first cost is still higher, initial added first cost has reduced by over 50% to $69,514. Payback period will also reduce, however not proportionally with first cost because not all of the building is in use. *It will reduce 33% because 1/3 of the building is not in use. Payback then reduces to 25 years.

Payback = First Cost / yearly savings

Payback = $69,514 / ($4,100*0.67) = **25 years***

15 Lighting Breadth

15.1 Design Criteria

After performing an energy model analysis on McKinstry Oregon Headquarters 9 (Appendix A), it was apparent that a large portion of building energy consumption comes from lighting. In fact, over 35% of yearly energy consumption is from area lighting. (Appendix A). That is more than cooling and heating combined. This provides a huge opportunity for energy savings. In addition, any lighting load eliminated from the space reduces the load on the cooling system, thus saving energy year round and reducing the chiller size.

The radiant panels create a coordination issue with ceiling space. Luminaires would either have to be coordinated with the panels or removed from the ceiling all together. Finally, the space should have an evenly and adequately illuminated work space. An AGI model provides lighting analysis.

15.2 Original Design

The figure to the right shows a typical open office space in the headquarters. The 50’x70’ space contains 18 cubicles, each 10’x10’. Over the entire building, there is 23,950 SF of similar open office space. This equates to 52% of the first and second floor (excluding the warehouse) that designated open office with cubicles. Placing an efficient lighting system, such as Tambient, could potentially save McKinstry a lot of energy. Currently, the space produces 1.02 W/SF of lighting load.

The table below shows a lighting schedule for the existing space.

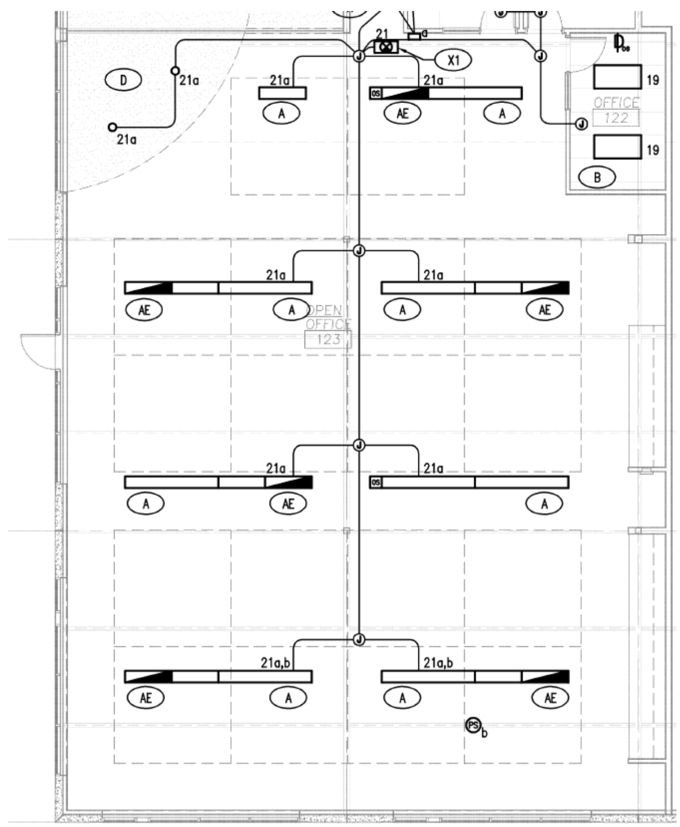


Figure 15.2.1. Lighting Plan for Open Office

Table 15.1. Original Lighting Schedule

Symbol	Description	Manufacturer[1]	Lamp	Total Fixtures
A	Suspended Pendant	Ledalite	2-T5HO	28
D	Downlight	Gotham	1-2/32TRT	2

[1]See Cutsheet Appendix

15.3 Tambient Redesign

Figure 15.3.1. Tambient Lighting[m]

Tambient is a new lighting system that places all of the lighting fixtures on the cubicles themselves. By combining intense downlighting for task lighting, floor illumination and diffused uplighting for space illumination, Tambient can provide substantial energy savings in office lighting. The radiant panels provide an opportunity for indirect lighting as the white ceiling panels are very reflective (see Figure 11.1.2). The AGI model assumes 0.8 reflectance.

The redesign includes standard Tambient lights (Figure 15.3.1.) and Tambient uplights (called batwings) which are placed strategically to properly illuminate the rest of the space.

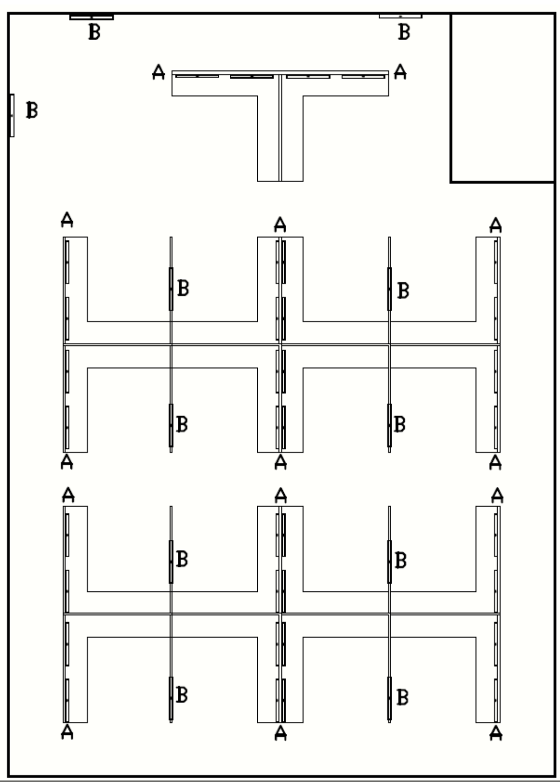


Figure 15.3.2. Redesign open office lighting plan

Table 15.3.1. Redesign Lighting Schedule

Symbol	Description	Manufacturer[1]	Lamp	Total Fixtures
A	Desk/Uplight	Tambient	1 – T5	36
B	Batwing Uplight	Tambient	1 – T5	11

[1]See Cutsheet Appendix

Office spaces have several requirements for illuminance. First, task spaces must be illuminated to an average of 30 footcandles (±10%)[n]. Egress areas must be an average of 5 footcandles[n]. The following figures are from AGI analysis of the space.

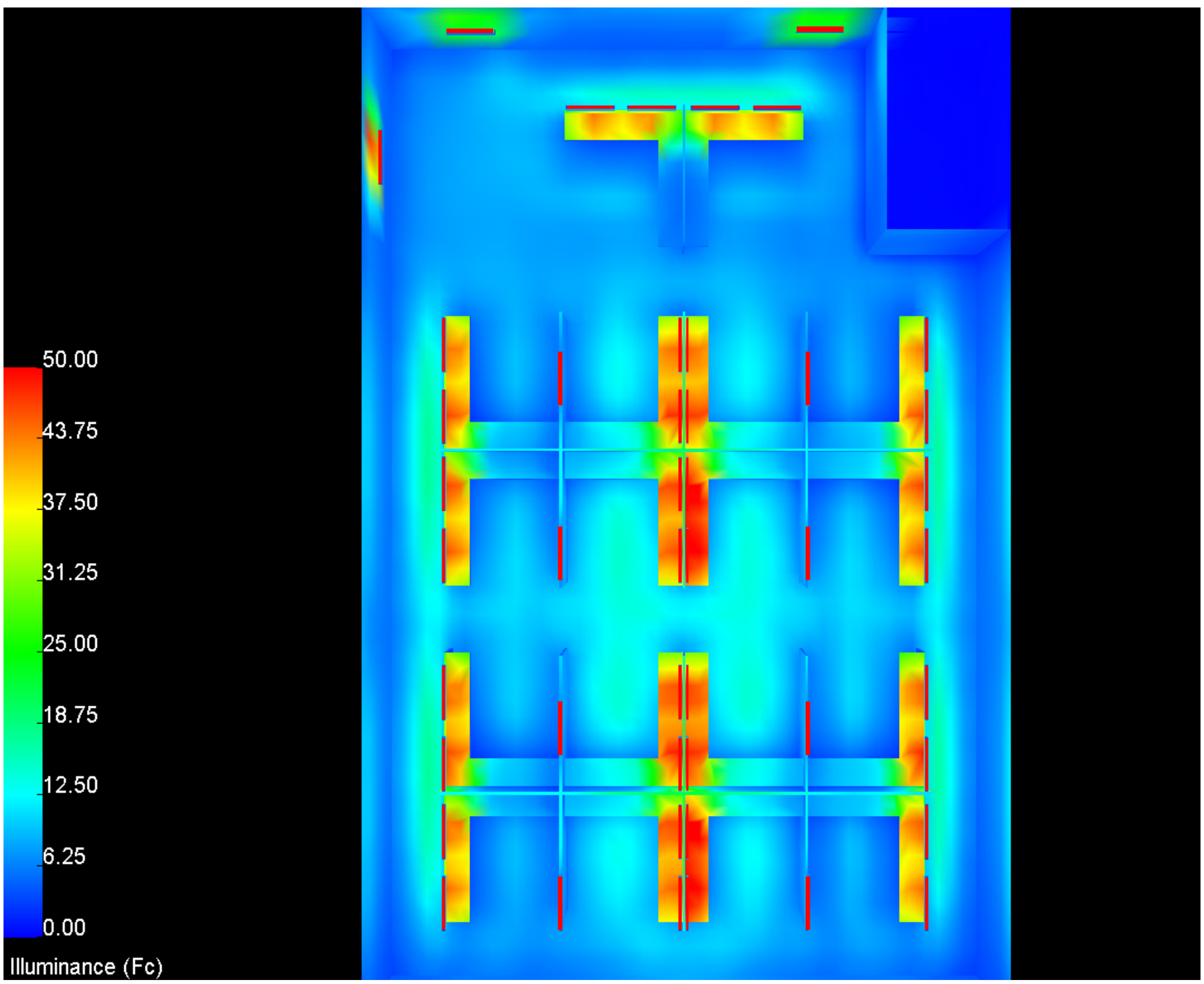


Figure 15.3.3. Pseudocolor illuminance rendering

Table 15.3.2. Floor Calculation summary

FLOOR ILLUMINANCE (fc)			
Average	Maximum	Minimum	Max/Min
9.43	15.7	4.5	3.49

Table 15.3.3. Work Plane Calculation Summary

WORK PLANE ILLUMINANCE (fc)			
Average	Maximum	Minimum	Max/Min
29.19	48.7	7.6	**6.41**

Table 15.3.2 shows that floor illuminance is easily above the required average of 5 fc. Work plane illuminance is within 10% of the required average of 30fc. However, the Max/Min value is very large. This is obvious in the pseudocolor rendering as well. An easy solution to this is to provide task lighting. Finelite produces an LED desk lamp that runs on 3W and can produce 20+ foot candles on an 11"x17" surface (Cutsheet Appendix). At a mere 3W, 18 of these (one for each cubicle) will use only 54 extra watts. The table below shows energy usage for the original design and redesign in the open office.

Table 15.3.4. Open Office Lighting Power Density

	Area	Total Watts	Lighting Power Density
Original	3353 SF	3424	1.02 W/SF
Redesign	3353 SF	1678	**.50 W/SF**

The Tambient lighting system provided a very significant savings in lighting power, over 50% reduction. This is great for the building, as over 35% of its total load is lighting. In addition, by locating lighting on the cubicles rather than the ceiling, it eliminates all of the coordination issue. Finally, as seen in the rendering below, the Tambient lighting system produces an even light distribution across the ceiling. It also gives a better aesthetic to the office space by eliminating clutter from the ceiling space and making the office look more open.

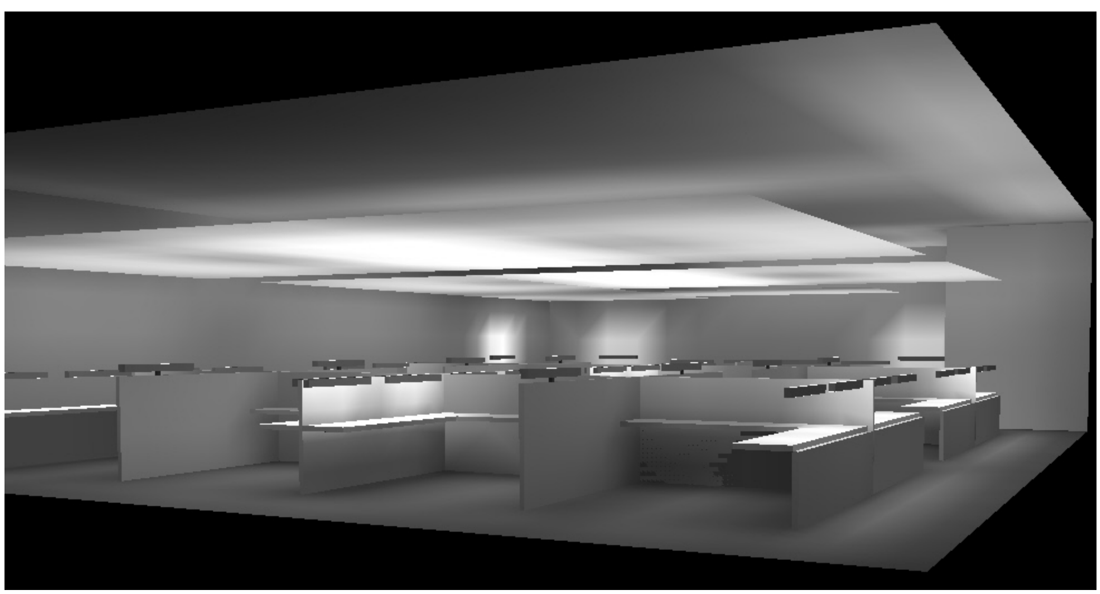


Figure 15.3.4. Perspective Greyscale illuminance rendering

16 Payback With Lighting

Reducing lighting load pays back twofold. Not only is there less energy required for lighting, but it also reduces demand on the chiller due to reduced load. Table 15.3.4 shows that lighting power density reduces to .5W/sf. With 24,000 SF of open office in the building, the following table projects yearly energy savings.

Table 16.1. Yearly Lighting Energy and Cost Savings

	Density	Power	Energy Use	Energy Savings	Cost Savings
	W/SF	kW	kWh/yr	kWh	
Original	1.02	24.43	76,232		
Redesign	0.5	**11.98**	37,369	**38,863**	**$3,109.08**

Energy and power savings provide two more opportunities to lower payback. First, 12 kW reduced lighting power is 12 kW of demand load the chiller does not need to cool. To convert kW to tons:

1 kW = 3413 BTU/hr (16.1)

1 ton = 12,000 BTU/hr (16.2)

1 kW = 0.2844 tons

11.98 kW = **3.41 tons**

This 3.41 tons is a direct reduction of chiller demand load. As previously stated in Section 14.1, each ton of load reduction reduces chiller cost by $1000[c]. Tambient lighting saves **$3410** in reduced chiller size.

Finally, 38,860kWh saves in yearly operating costs for the chiller. However, to calculate electrical usage, one must account for COP of the chiller. COP is a ratio of cooling energy/electrical energy input. This means the higher a chiller's COP, the less electrical energy needed to produce the desired cooling. From Appendix G, the chiller's EER (energy efficiency ratio) is 21.

COP = EER/3.412 (16.3)

COP = 21/3.412 = 6.15

So, electrical energy needed to produce required cooling:

$Q_{electric} = Q_{load}/COP$ (16.4)

$Q_{electric} = 38863kWh/6.15 = 6319kWh$

At a utility rate of $0.08/kWh:

Savings = 6319*.08 = **$506/year**

All together, Tambient lighting saves $3410 in first cost and $3615 in yearly savings.

The following table shows the new payback, with Tambient lighting included. The new lighting system reduces payback period to only 18 years, making the redesign much more promising.

Table 16.2. Overall Redesign Payback

	Yearly Energy Savings	Yearly Cost Savings	First Cost Deficit	Payback
Mechanical Redesign	51,230 kWh	$4,100	$143,300	35.0 years
Redesign with Tambient	96,410 kWh	$7,715	$139,890	**18.1 years**
***67% Finished**	64,595 kWh	$5,170	$66,104	**12.8 years**

67% finished assumes that 1/3 of the office space in the building will not be in use. This reduces yearly energy usage, and thus savings, by 33%.*

17 Conclusion

Designers at McKinstry had three main objectives: sustainability, comfort and economy. The redesign presented in this thesis provides all three. By saving energy every year for the lifespan of the building, any reduction in energy helps the building become more sustainable. Also, the sustainable elements of the original design were all kept in place. The ground source water loop, as well as the rainwater harvesting, were undisturbed by the redesign. In addition DOAS provides a more comfortable environment.

The large first cost increase for the redesign may not seem very economical. However, as stated in Section 14.2, current construction leaves 1/3rd of the office space unfinished. This reduces initial added first cost from $143,000 down to $69,500. Also with Tambient lighting providing a reasonable payback at 18 years (with 100% construction), the redesign is economical for McKinstry.

The redesign ensures occupant comfort. By eliminating the VAV system and providing 100% outdoor air, the DOAS system ensures that all spaces receive adequate ventilation air. In addition, DOAS provides better control of air humidity. Proper ventilation is a definite plus for occupant comfort. Radiant panels provide a draft free source of heating and cooling. DOAS does not recirculate any air. If any contaminant is present in any area of the space, it will not redistribute throughout the building.

Finally, Tambient lighting gives a better aesthetic to the office space by eliminating clutter from the ceiling space and making the office look more open. An appealing looking space is comforting to occupants.

18 References

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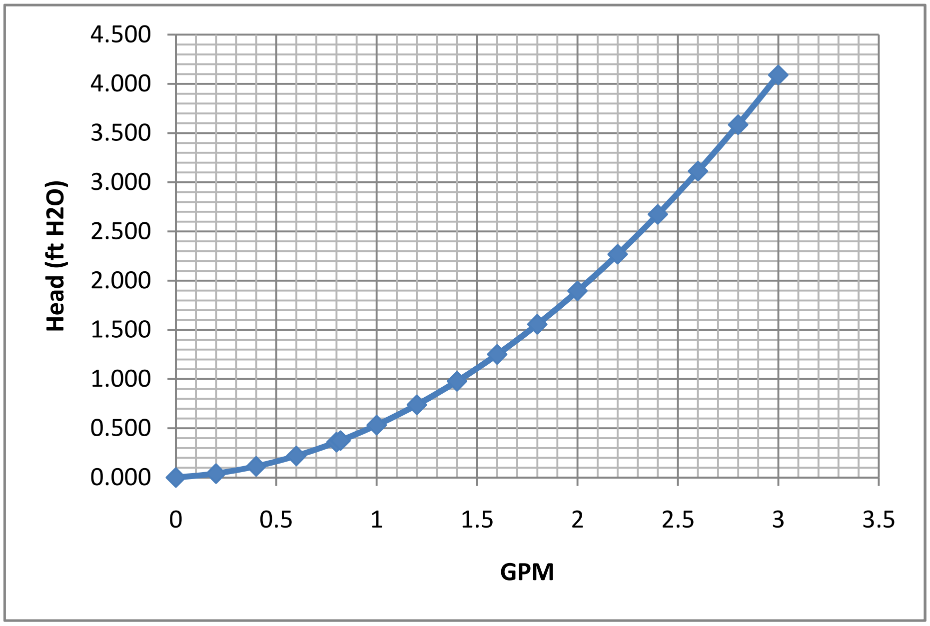
Calculation Appendix

A. Cooling Panel Head

Radiant panel pressure drop	
GPM	Head
0	0.000
0.2	0.040
0.4	0.113
0.6	0.220
0.8	0.360
0.82	**0.376**
1	0.533
1.2	0.739
1.4	0.978
1.6	1.251
1.8	1.557
2	1.896
2.2	2.268
2.4	2.674
2.6	3.113
2.8	3.584
3	4.090

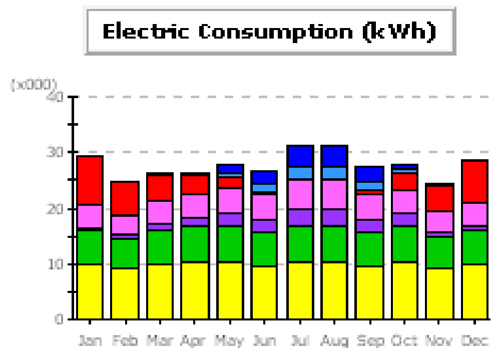


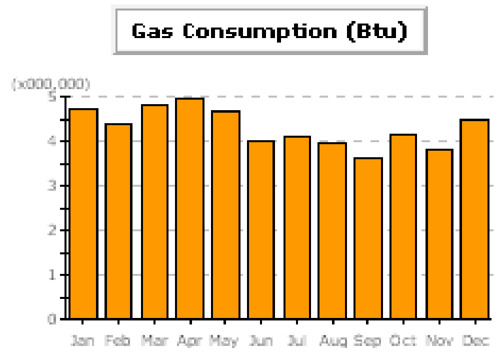
B. Diffuser and FTU Calculations

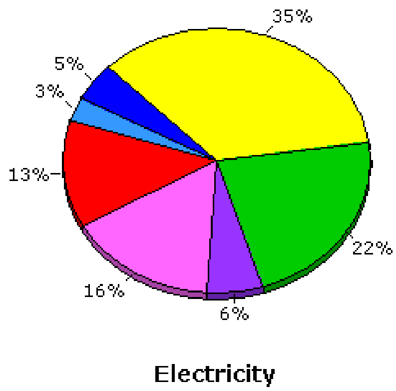
FTU'S	Current SF	FTU's	SF/FTU	Total SF	Total FTU	Cost/FTU	Total Cost	Savings
Original	31160	33	944	46215	49	$1,071.63	$52,449.79	
Redesign	31160	33	944	46215	49	$150.00	$7,341.60	**$45,108.19**

DIFFUSER	Current SF	Count	SF/FTU	Total SF	Total FTU	Cost/FTU	Total Cost	Savings
Original	15580	44	354	46215	131	$45.00	$5,873.28	
Redesign	15580	44	354	46215	131	$58.00	$7,570.01	**($1,696.73)**

Appendix A Original Annual Energy Use







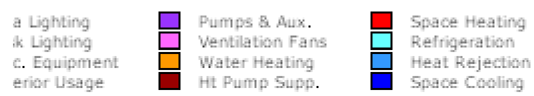


Figure A. Electric consumption, gas consumption, and electricity breakdown

Table A Electric and gas consumption

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.02	0.05	0.23	0.23	1.33	2.26	3.90	3.73	2.58	0.69	0.11	0.09	15.21
Heat Reject.	0.01	0.03	0.16	0.16	0.92	1.40	2.16	2.19	1.71	0.68	0.08	0.09	9.60
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	8.66	5.88	4.65	3.60	1.76	0.57	0.19	0.18	0.73	3.06	4.88	7.64	41.79
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	4.03	3.64	4.04	4.24	4.57	4.43	5.33	5.24	4.40	4.28	3.64	4.02	51.86
Pumps & Aux.	0.29	0.47	1.10	1.29	2.22	2.50	2.85	2.87	2.57	2.03	0.94	0.68	19.82
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	6.24	5.65	6.24	6.48	6.50	5.96	6.51	6.50	5.96	6.51	5.69	6.24	74.47
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	9.94	9.00	9.95	10.38	10.40	9.48	10.40	10.40	9.48	10.40	9.02	9.94	118.78
Total	29.19	24.72	26.36	26.38	27.69	26.60	31.33	31.11	27.42	27.65	24.37	28.72	331.54

Gas Consumption (Btu x000,000) =(Therms x10)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	4.70	4.37	4.83	4.93	4.65	3.99	4.11	3.96	3.63	4.12	3.82	4.46	51.59
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	4.70	4.37	4.83	4.93	4.65	3.99	4.11	3.96	3.63	4.12	3.82	4.46	51.59

Original

	DUCTWORK			ELBOWS			CONNECTORS			TEES		
Size	Length (ft)	Cost/ft	Price	Count	Cost ea.	Price	Count	Cost ea.	Price	Count	Cost ea.	Price
36	15	$29.50	*$442.50*							1	$160.00	*$160.00*
26	48	$14.00	*$672.00*				2	$14.00	*$28.00*			
22	96.5	$11.50	*$1,109.75*	7	$115.00	*$805.00*	2	$11.90	*$23.80*			
20	49.5	$10.50	*$519.75*	4	$74.00	*$296.00*	2	$10.90	*$21.80*			
18	22	$9.50	*$209.00*	1	$55.50	*$55.50*	1	$10.05	*$10.05*	1	$78.00	*$78.00*
16	18.5	$6.95	*$128.58*	2	$42.50	*$85.00*	2	$9.00	*$18.00*			
12	134	$5.20	*$696.80*	9	$14.35	*$129.15*	2	$6.90	*$13.80*	3	$21.00	*$63.00*
10	513	$4.30	*$2,205.90*	38	$10.85	*$412.30*				6	$16.45	*$98.70*
8	131	$2.66	*$348.46*	18	$7.60	*$136.80*				1	$11.55	*$11.55*
			$6,332.74			**$1,919.75**			**$115.45**			**$411.25**
											TOTAL	$8,779.19
											per SF	***$0.56***
											BUILDING TOTAL	**$26,041.72**

Redesign

	DUCTWORK			ELBOWS			CONNECTORS			TEES		
Size	Length (ft)	Cost/ft	Price	Count	Cost ea.	Price	Count	Cost ea.	Price	Count	Cost ea.	Price
18	15	$9.50	*$142.50*							1	$78.00	*$78.00*
14	48	$6.05	*$290.40*				2	$8.00	*$16.00*			
12	110	$5.20	*$572.00*	9	$14.35	*$129.15*	2	$6.90	*$13.80*			
10	12	$4.30	*$51.60*	1	$10.85	*$10.85*	1	$5.70	*$5.70*			
9	24	$3.50	*$84.00*	2	$9.00	*$18.00*	1	$4.20	*$4.20*			
8	86	$2.66	*$228.76*	6	$7.60	*$45.60*				2	$11.55	*$23.10*
7	175	$2.40	*$420.00*	12	$6.55	*$78.60*				1	$10.20	*$10.20*
6	219	$2.02	*$442.38*	20	$6.20	*$124.00*	1	$2.81	*$2.81*	1	$8.85	*$8.85*
5	139	$1.77	*$246.03*	10	$5.40	*$54.00*	1	$2.61	*$2.61*	1	$8.20	*$8.20*
4	199.5	$1.39	*$277.31*	19	$4.71	*$89.49*				6	$6.15	*$36.90*
			$2,754.98			**$549.69**			**$45.12**			**$165.25**
											TOTAL	$3,515.04
											per SF	***$0.23***
											BUILDING TOTAL	**$10,426.66**

Table C.1. Original Piping Costs, Hot Water ONLY

	PIPE			ELBOWS			TEES		
Size	Length (ft)	Cost/ft	Price	Count	Cost ea.	Price	Count	Cost ea.	Price
2	125	$25.00	*$3,125.00*	2	$29.00	*$58.00*	5	$44.50	*$222.50*
1.5	31	$16.10	*$499.10*	3	$16.10	*$48.30*	0	$31.50	*$0.00*
1.25	70	$12.50	*$875.00*	1	$10.25	*$10.25*	5	$29.50	*$147.50*
1	59	$9.05	*$533.95*	1	$6.80	*$6.80*	4	$15.75	*$63.00*
0.75	165	$6.00	*$990.00*	11	$2.76	*$30.36*	1	$7.00	*$7.00*
0.5	34	$3.83	*$130.22*	3	$1.23	*$3.69*	0	$10.85	*$0.00*
			$6,153.27			**$157.40**			**$440.00**
								TOTAL	$6,750.67
								with Return	$13,501.34
								per SF	***$0.87***
								BUILDING TOTAL	**$40,049.06**

Table C.2. Redesign Piping Costs, Hot Water ONLY

	PIPE			ELBOWS			TEES		
Size	Length (ft)	Cost/ft	Price	Count	Cost ea.	Price	Count	Cost ea.	Price
2	125	$25.00	*$3,125.00*	2	$29.00	*$58.00*	5	$44.50	*$222.50*
1.5	31	$16.10	*$499.10*	3	$16.10	*$48.30*	0	$31.50	*$0.00*
1.25	70	$12.50	*$875.00*	1	$10.25	*$10.25*	5	$29.50	*$147.50*
1[1]	59	$1.26	74.34	1	$1.26	*$1.26*	4	$1.26	*$5.04*
0.75[1]	165	$0.76	125.4	11	$0.76	*$8.36*	1	$0.76	*$0.76*
0.5[1]	34	$0.62	21.08	3	$0.62	*$1.86*	0	$0.62	*$0.00*
			$4,719.92			**$128.03**			**$375.80**
								TOTAL	$5,223.75
								with Return	$10,447.50
								per SF	***$0.67***
								BUILDING TOTAL	**$30,990.45**

Table C.3. Redesign Piping Costs, Chilled Water ONLY

	PIPE			ELBOWS			TEES		
Size	Length (ft)	Cost/ft	Price	Count	Cost ea.	Price	Count	Cost ea.	Price
3.5[2]	88	$17.45	*$1,535.60*	2	$200.00	*$400.00*	4	$245.00	*$980.00*
3[2]	31	$15.55	*$482.05*	0	$78.00	*$0.00*	1	$133.00	*$133.00*
2.5	32	$38.00	*$1,216.00*	3	$58.50	*$175.50*	0	$119.00	*$0.00*
2	64	$25.00	*$1,600.00*	2	$25.00	*$50.00*	4	$44.50	*$178.00*
1.5	14	$16.10	*$225.40*	1	$16.10	*$16.10*	0	$31.50	*$0.00*
1.25	88	$12.50	*$1,100.00*	4	$12.50	*$50.00*	3	$29.50	*$88.50*
1[1]	122	$1.26	*$153.72*	9	$1.26	*$11.34*	0	$15.75	*$0.00*
0.75[1]	27	$0.76	*$20.52*	2	$0.76	*$1.52*	0	$7.00	*$0.00*
0.5[1]	18	$0.62	*$11.16*	1	$0.62	*$0.62*	1	$10.85	*$10.85*
			$6,344.45			**$705.08**			**$1,390.35**
								TOTAL	$8,439.88
								With Return	$16,879.76
								per SF	***$1.08***
								BUILDING TOTAL	**$50,070.48**

[1] PEX Piping
[2] Steel Pipe

Appendix D Portland Design Conditions

2005 ASHRAE Handbook - Fundamentals (IP)

Design conditions for PORTLAND, OR, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
PORTLAND	**726980**	**45.58N**	**122.58W**	**39**	**14.675**	**-8.00**	**NAP**	**7201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
1	**21.9**	**27.0**	**7.1**	**7.9**	**24.7**	**14.0**	**11.2**	**31.2**	**31.1**	**32.5**	**28.1**	**35.6**	**13.3**	**120**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
8	**21.5**	**90.8**	**67.5**	**86.6**	**66.2**	**83.1**	**65.0**	**69.2**	**87.2**	**67.6**	**84.2**	**65.9**	**80.7**	**10.8**	**310**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
62.5	**84.7**	**75.0**	**61.1**	**80.5**	**73.0**	**59.7**	**76.7**	**71.2**	**25.5**	**87.7**	**24.1**	**84.0**	**22.8**	**80.7**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
24.2	**20.0**	**17.9**	**77.2**	**98.8**	**19.2**	**3.9**	**5.8**	**101.6**	**15.0**	**103.9**	**11.6**	**106.1**	**8.4**	**108.9**	**4.2**

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	*18b*	*18c*	*18d*	*18e*	*18f*	*18g*	*18h*	*18i*	*18j*	*18k*	*18l*
0.4%	**58.4**	**54.1**	**62.3**	**52.4**	**68.9**	**53.9**	**77.5**	**60.8**	**87.0**	**65.6**	**91.3**	**67.7**
1%	**56.3**	**52.0**	**60.1**	**52.2**	**66.6**	**53.3**	**74.7**	**59.0**	**84.0**	**64.5**	**87.3**	**66.1**
2%	**54.6**	**50.4**	**58.2**	**51.6**	**64.3**	**52.5**	**71.8**	**57.4**	**80.6**	**62.7**	**84.7**	**65.2**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	*18n*	*18o*	*18p*	*18q*	*18r*	*18s*	*18t*	*18u*	*18v*	*18w*	*18x*
0.4%	**96.8**	**69.9**	**97.5**	**69.4**	**91.6**	**65.1**	**80.2**	**60.1**	**63.6**	**56.5**	**58.7**	**54.8**
1%	**93.4**	**69.3**	**93.5**	**68.6**	**89.1**	**65.0**	**76.3**	**59.1**	**61.4**	**55.7**	**56.5**	**53.0**
2%	**90.2**	**68.4**	**90.3**	**67.7**	**86.4**	**64.2**	**73.3**	**58.1**	**59.7**	**54.3**	**54.8**	**51.9**

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	*19b*	*19c*	*19d*	*19e*	*19f*	*19g*	*19h*	*19i*	*19j*	*19k*	*19l*
0.4%	**54.7**	**57.6**	**56.2**	**59.2**	**56.5**	**64.7**	**62.8**	**74.1**	**67.7**	**85.4**	**69.1**	**87.5**
1%	**52.7**	**55.4**	**54.7**	**58.2**	**55.2**	**63.0**	**60.4**	**71.5**	**65.5**	**79.7**	**67.7**	**85.0**
2%	**51.1**	**54.0**	**52.9**	**56.5**	**54.1**	**61.1**	**58.9**	**69.4**	**64.0**	**77.4**	**66.3**	**82.4**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	*19n*	*19o*	*19p*	*19q*	*19r*	*19s*	*19t*	*19u*	*19v*	*19w*	*19x*
0.4%	**72.1**	**91.1**	**71.4**	**91.8**	**68.4**	**85.6**	**63.0**	**75.6**	**58.7**	**62.4**	**55.3**	**57.6**
1%	**70.7**	**89.5**	**70.2**	**89.2**	**67.3**	**84.1**	**61.8**	**72.3**	**57.0**	**60.1**	**53.6**	**56.1**
2%	**69.3**	**87.4**	**69.1**	**87.0**	**66.3**	**81.6**	**60.4**	**69.1**	**55.6**	**58.4**	**52.1**	**54.4**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
10.2	**13.1**	**15.6**	**17.1**	**18.2**	**18.9**	**21.2**	**21.5**	**21.3**	**17.2**	**11.1**	**9.4**

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

Appendix E Cooling Panel Sizing

Radiant Cooling Panel

Cooling Performance

Room Air Temperature minus MWT °F (°C)	Absorbed Energy per Room Designation* BTUH/Ft.² (Watts/m²)					
	A	B	C	D	E	F
10 (5.5)	17 (54)	21 (66)	28 (88)	35 (110)	38 (120)	40 (126)
11 (6.1)	19 (60)	23 (73)	30 (95)	37 (117)	40 (126)	42 (132)
12 (6.7)	21 (60)	25 (73)	31 (95)	38 (117)	41 (126)	43 (132)
13 (7.2)	22 (69)	27 (85)	33 (104)	40 (126)	43 (136)	45 (142)
14 (7.8)	24 (76)	28 (88)	35 (110)	42 (132)	45 (142)	47 (148)
15 (8.3)	26 (82)	30 (95)	38 (120)	44 (139)	47 (148)	48 (151)
16 (8.9)	28 (88)	32 (101)	39 (123)	45 (142)	48 (151)	50 (158)
17 (9.4)	30 (95)	34 (107)	41 (129)	47 (148)	50 (158)	52 (164)
18 (10.0)	31 (98)	36 (114)	43 (136)	49 (155)	52 (164)	53 (167)
19 (10.6)	33 (104)	38 (120)	45 (142)	50 (158)	54 (170)	55 (173)
20 (11.1)	35 (110)	40 (126)	46 (145)	52 (164)	55 (173)	57 (180)
21 (11.7)	37 (117)	42 (132)	48 (151)	54 (170)	57 (180)	58 (183)
22 (12.2)	39 (123)	43 (136)	50 (158)	56 (177)	59 (186)	60 (189)
23 (12.8)	40 (126)	45 (142)	52 (164)	58 (183)	61 (192)	62 (196)
24 (13.3)	42 (132)	47 (148)	53 (167)	59 (186)	62 (196)	63 (199)
25 (13.9)	44 (139)	49 (154)	55 (174)	61 (192)	64 (202)	65 (205)
26 (14.4)	46 (145)	51 (161)	56 (177)	63 (199)	66 (208)	67 (211)
27 (15.0)	48 (151)	53 (167)	58 (183)	64 (202)	67 (205)	68 (214)
28 (15.6)	49 (155)	55 (174)	60 (189)	65 (205)	69 (218)	72 (227)

*** Room Designations:**

A: Interior Room
B: No Glass, Exterior Wall
C: 25% Clear Glass, Exterior Wall
D: 50% Clear Glass, Exterior Wall
E: 75% Clear Glass, Exterior Wall
F: 100% Clear Glass, Exterior Wall

C7

Appendix F Heating Panel Sizing

Table assumes 20F ΔT. Redesign uses 40F ΔT. Multiply all values 2x for actual output

Linear Radiant Panel STERLING

LINEAR PANEL IMPERIAL OUTPUTS

# OF TUBES		1	2	2	2	4	3	4	4	5	6
NOMINAL PANEL WIDTHS * (INCHES)		6	8	10	12	16	18	20	24	30	36
MEAN WATER TEMPERATURE (°F)	120	54	63	-	78	94	109	-	163	196	224
	125	62	73	-	93	111	128	-	188	226	258
	130	71	85	-	106	129	148	-	213	256	292
	135	79	94	-	121	147	166	-	238	285	327
	140	87	104	125	134	165	186	227	263	315	361
	145	96	114	137	149	185	205	245	288	345	394
	150	104	124	151	162	202	225	264	313	375	428
	155	112	134	163	177	219	246	282	338	406	463
	160	121	145	177	190	238	263	301	363	436	497
	165	129	154	189	205	255	282	320	389	466	531
	170	137	164	203	218	276	302	340	413	495	565
	175	146	175	215	233	292	320	360	438	525	599
	180	154	186	229	246	312	340	380	463	555	633
	185	162	197	241	261	329	359	404	488	586	668
	190	171	207	255	275	348	379	427	513	615	702
	195	179	216	267	289	365	397	452	538	645	736
	200	187	226	281	303	384	417	471	563	675	771
	205	195	236	293	317	401	436	490	588	705	805
	210	204	248	307	330	420	456	509	613	735	839
	215	212	258	319	345	439	474	527	638	764	874

OUTPUTS EXPRESSED IN BTUH/LINEAL FOOT OF PANEL AND ARE BASED ON 70°F ROOM TEMPERATURE. FOR EVERY 1°F DECREASE IN ROOM TEMPERATURE BELOW 70°F, THE OUTPUT INCREASES BY 0.9%. FOR EVERY 1°F INCREASE IN ROOM TEMPERATURE ABOVE 70°F, THE OUTPUT DECREASES BY 0.9%.

ANY PANEL WIDTH CAN BE CONSTRUCTED BY COMBINING 4" AND 6" EXTRUSIONS AND INTERPOLATING THE APPROPRIATE OUTPUTS.

***REFER TO PAGE L-7 FOR ACTUAL PANEL WIDTHS & FINISHED OPENINGS**

Note: Table for ethylene and propylene 50/50 glycol also available upon request.

Appendix G Mechanical Equipment

PUMPS	Well Water Supply (P-1, P-2 Alternate)	Chilled Water (P-3, P-4 Alternate)	Condenser Water (P-5, P-6 Alternate)
Location	Well	Mechanical Room	Mechanical Room
GPM	200-300	140	130
Total Head (ft)	128-153	81	90
VFD	Yes	No	No
Motor HP	25	7.5	7.5
Efficiency	ASHRAE Table 10.8	ASHRAE Table 10.8	ASHRAE Table 10.8

EXHAUST FANS	EF-1	EF-2	EF-3	EF-4
Location	Toilet Room	Data Room	Locker Room	Elevator Room
Fan Type	Centrifugal	Centrifugal	Centrifugal	Centrifugal
CFM	1200	400	1080	400
HP	.33	.125	.33	.125
Efficiency	Code minimum	Code minimum	Code minimum	Code minimum

CHILLER – CH-1	
Multi-stage, water cooled	
Location	Mechanical Room
Operating Weight	4100 lbs
Compressor	Rotary Scroll
HEATING	
kBTUh	1,303
COP	4.1
Power Input	94.3 kW
CHW EWT/LWT	52/38
CDW EWT/LWT	100/120
COOLING	
kBTUh	1,722
Capacity	123.5 tons
EER	21
Power Input	70.6 kW
CHW EWT/LWT	69.2/48
CDW EWT/LWT	60/86.8

AIR HANDLING UNIT – AHU-1	
Location	Rooftop
Supply Fan	Plug, Blow Through
Supply CFM	35,800
Supply BHP/HP	44.7/50
Supply Motor Eff	Premium
Supply VAV Control	VFD
Minimum OA	5,500 CFM
Exhaust CFM	35,800
Exhaust BHP/HP	12.75/15
Exhaust Motor Eff	Premium
Exhaust VAV Control	VFD
Cooling MBH	970 Sens/1065 Total
Chilled Water EWT/LWT	44/59.2
Cooling Coil EAT/LAT	79DB,62WB/ 52.3
CW GPM	140
Heating MBH	1122
Heating Coil EWT/LWT	120/100
Heating Coil EAT/LAT	69/98
HW GPM	112
Unit Size	16,000 lbs

Appendix H Energy Sources and Rates

Electricity is provided to the building by Portland General Electric (PGE). The rate code is "PGE 83S 3P N-TOU Lrg N-Res Elec". Essentially this means it is large non-residential electric. The following is a general formula for charges:

Monthly Charge = [$25 + $.05298*(kWh usage) + $2.27*(kW demand)]/.8

Where 0.8 is the Power Factor adjustment. Average cost comes to about **$.08/kWh**

Natural Gas is provided by Northwest Natural. The code is "NW Natural-OR 3-Comm Uniform". The following is a general formula for charges:

Monthly Charge = $8 + $1.198/therm. Average cost comes to about **$1.23/therm**

Appendix I System Costs Breakdown

McKinstry For The Life Of Your Building

McK - Oregon HQ Building #1 Permit Pricing

updated: 08/06/08

Trade	Shell & Core Market Base	Shell & Core Premium	Shell & Core Sub Total	Tenant* Market Base	Tenant* Premium	Tenant* Sub Total	Total Market Base	Total Project
HVAC	$ 276,013	$ 581,369	$ 857,382	$ 368,829	$ 168,300	$ 537,129	$ 644,842	$ 1,394,511
Plumbing	$ 204,713	$ 26,400	$ 231,113	$ 87,517	$ 13,800	$ 101,317	$ 292,230	$ 332,430
Electrical	$ 246,000	$ 154,600	$ 400,600	$ 649,988	$ 116,300	$ 766,288	$ 895,988	$ 1,166,888
Fire Protection	$ 108,706		$ 108,706	$ 28,389		$ 28,389	$ 137,095	$ 137,095
Data			$ -	$ 83,382	$ 69,302	$ 152,684	$ 83,382	$ 152,684
Energy - ITS		$ 43,390	$ 43,390	$ -	$ -	$ -	$ -	$ 43,390
Energy - Cx			$ -	$ -	$ -	$ -	$ -	$ -
Energy - Model			$ -	$ -	$ -	$ -	$ -	$ -
Energy - LEED			$ -	$ -	$ -	$ -	$ -	$ -
Total	$ 835,432	$ 805,759	$ 1,641,191	$ 1,218,105	$ 367,702	$ 1,585,807	$ 2,053,537	$ 3,226,998

* Based on McK Tenant Buildout Only

Premium Breakdown

General		
	1) Additional trailer/office set-up for additional office staff	Not in Budget
HVAC - Shell and Core		
	1) Well Drilling/Permits	$ 180,000
	2) Heat Pump System	$ 401,369
Plumbing - Shell and Core		
	1) Rain Water Harvesting	$ 21,000
	2) Overflow Drains	$ 5,400
HVAC - Tenant		
	1) Hot Water to FPB	$ 125,000
	2) ITS	$ 43,300
Plumbing -Tenant		
	1) Rain Water Harvesting	$ 5,800
	2) Gas Piping	$ 8,000
Elec Shell and Core		
	1) Well	
	2) Building Communications conduit between B1 and B2	
	3) Power distribution and Electrical room location	
	4) Future underslab conduit provisions	
	5) CCTV and DSL at site trailers	
	6) Upgrades to mechanical equipment	
		$ 154,600
Elec Tenant		
	1) Lighting Control Panel coordinated w/ ITS	
	2) Light fixtures and interior controls	
	3) IT infrastructure	
	4) Security and CCTV	
		$ 116,300
Data Tenant		
	1) Paging System	$ 8,942
	2) Audio Visual	$ 60,360

Centris®

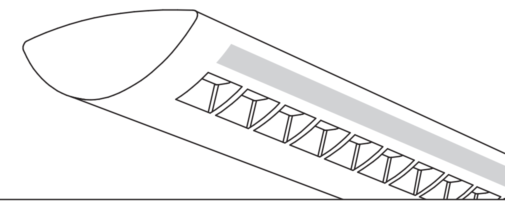
Suspended

Direct/Indirect

2 T5HO - Perf Housing

RESPONSE READY

QuickShip



Project Name

Spec Type

Notes

Order Guide

Some combinations of product options may not be available. Consult factory for assistance with your specification.

Product Series & Type	Lamping	Lower Optics	Upper Optics	Run Length	Wiring	Voltage	Ballast	Color & Finish
9506	**H02**			–	–	–	–	–
Centris Direct/Indirect	2 T5HO	**M** Round Perf Housing / Solid Baffle **T** Round Perf Housing / Round Perf Baffle **U** Slot Perf Housing / Solid Baffle **Z** Slot Perf Housing / Round Perf Baffle See details on reverse	**N** None **D** Down Kit **Y** Lamp Separator See details on reverse	*Enter the total run length in feet (4ft increments)* See details on reverse	**1** 1 cct **2** 2 cct **3** 1 cct w/ Emergency cct **4** 2 cct w/ Emergency cct **5** 1 cct w/ Battery Pack **6** 2 cct w/ Battery Pack **7** 1 cct Dimming Consult website for complete list of standard wiring options	**1** 120V **2** 277V **3** 347V	**E** Standard Ballast Consult website for ballast manufacturer information	**W** Standard White **C** Factory Color **X** Custom Color Consult website for color and finish options

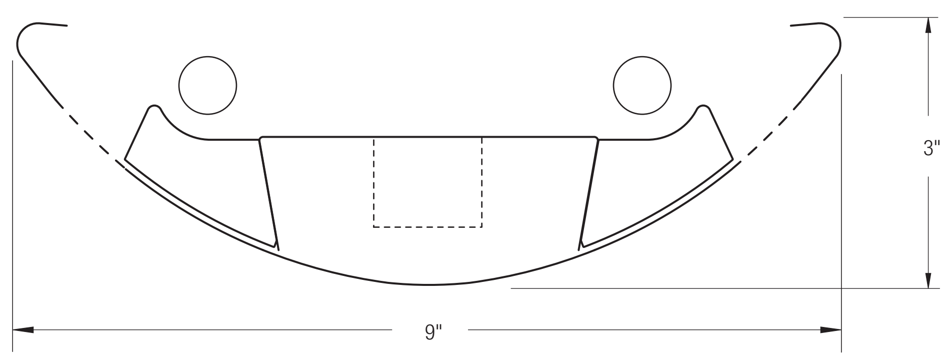
Mounting Hardware

Mount Type	Suspension Length
Consult separate mounting spec sheet for mount type options	*Enter distance from ceiling to top of fixture in inches*

Upgrades & Accessories

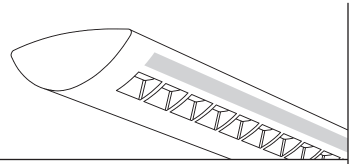
Please indicate with check mark.

- ☐ Lamps Included
- ☐ Lamps Included and Installed
- ☐ Sculptured Endcap
  See details on reverse
- ☐ Response Daylight (Integrated Controls)
  For details visit www.ledalite.com/response



Centris®

Suspended
Direct/Indirect
2 T5HO - Perf Housing



Photometry Optics ZN Slot Perf Housing / Round Perf Baffle

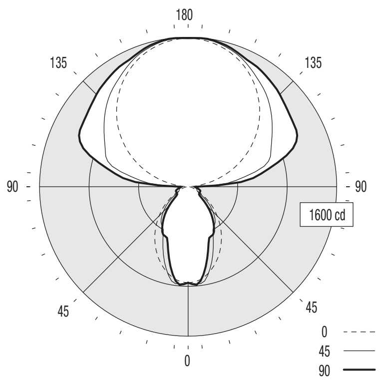
Report Summary

Report # 2101667
Filename 9506H02UN-ZN.ies
Efficiency 84.8%

Peak Candela Value* 1597 @ 173°
Peak to Zenith Ratio* 1 : 1
* Between 90-180° vertical angle

Candela Distribution

Vertical Angle	Horizontal Angle 0	22.5	45	67.5	90	Zonal Lumens
0	1028	1028	1028	1028	1028	
5	1017	1029	1044	1045	1054	100
15	931	963	911	797	794	247
25	792	764	643	569	585	308
35	625	545	498	482	478	323
45	442	363	378	303	290	271
55	264	270	216	142	143	189
65	116	146	108	129	140	129
75	56	62	95	115	127	96
85	15	35	65	78	87	66
90	4	34	64	80	93	
95	75	226	424	436	570	359
105	337	520	848	925	998	776
115	612	716	986	1223	1296	958
125	866	924	1106	1273	1336	987
135	1090	1123	1241	1355	1396	957
145	1277	1307	1355	1432	1455	855
155	1426	1448	1467	1489	1500	677
165	1528	1544	1552	1565	1569	439
175	1582	1585	1590	1596	1597	154
180	1591	1591	1591	1591	1591	



Coefficients of Utilization (%)

Ceiling:	80				70			50			0
Wall:	**70**	**50**	**30**	**10**	**70**	**50**	**30**	**50**	**30**	**10**	**0**
0 RCR	85	85	85	85	75	75	75	57	57	57	18
1	78	74	71	68	69	66	63	50	48	47	15
2	71	65	60	56	62	58	54	44	41	39	13
3	65	57	51	47	57	51	46	39	36	33	11
4	59	51	44	39	52	45	40	35	31	28	10
5	54	45	39	34	48	40	35	31	27	24	9
6	50	40	34	29	44	36	31	28	24	21	8
7	46	36	30	26	41	33	27	25	21	19	7
8	43	33	27	22	38	29	24	23	19	16	6
9	40	30	24	20	35	27	22	21	17	15	6
10	37	27	22	18	33	25	20	19	16	13	5

Based on a floor reflectance of 0.2

Avg. Luminance (cd/m²)

Vertical Angle	Horizontal Angle 0	45	90
55	1876	1123	669
65	1119	671	759
75	882	763	848
85	701	772	789

IES files for this and other photometric options can be downloaded online at www.ledalite.com

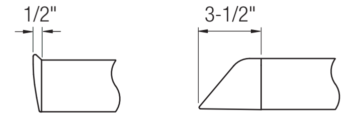
Additional Information

Modules

Module length excludes endcaps. Nominal mount spacing for individually mounted modules.

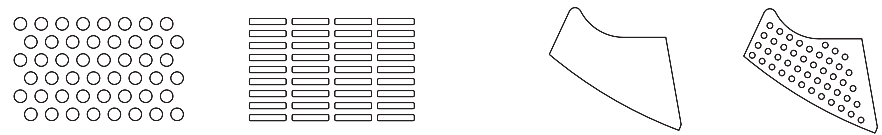
Module	Mount Spacing
4ft	4' 0"
8ft	8' 0"
12ft	12' 0"

Endcap



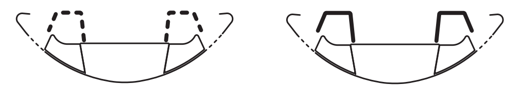
Flat (Standard) Sculptured

Lower Optics



Round Perf Housing Slot Perf Housing Solid Baffle Round Perf Baffle

Upper Optics



D Down Kit **Y** Lamp Separator

Specifications

Due to continuing product improvements, Ledalite reserves the right to change specifications without notice.

Housing
Die-formed 20 gauge cold-rolled steel.

Weight
3.0 lb/ft.

Optical System
Direct/Indirect: Constructed of 96% reflective white steel to produce a direct/indirect distribution. Baffles are white blades spaced 2-7/16" apart and are 3/4" deep (18 cells per 4ft section). Perforation of baffles and housing is optional. Perforated housing options include acrylic overlay. Optional field-installable Variable Optics kits provide additional downlight as required.

Semi-Indirect: Constructed of 96% reflective white steel with perforated housing and acrylic overlay to produce a semi-indirect distribution. Perforated housing available in round or slot perforation patterns.

Indirect: Constructed of 96% reflective white steel to produce an indirect distribution.

High performance options use additional highly-specular aluminum reflectors.

Endcaps
Die-cast endcap or optional die-cast sculptured endcap.

Joints
Self-aligning joining system with hands-free pre-joining wire access.

Mounting
Aircraft cable gripper is tamper-resistant and provides infinite vertical adjustment capability. Aircraft cable, crimp and cable gripper independently tested to meet stringent safety requirements.

Electrical
Factory pre-wired to section ends with quick-wire connectors.

Ballast
Electronic.

Approvals
Certified to UL and CSA standards.

Finish
High-quality powder coat. Available in Ledalite Standard White (textured matte finish), and a selection of other factory and customer-specified colors. Consult factory for details.

FEATURES

OPTICAL SYSTEM

- Reflector - Self-flanged, matte-finished clear reflector. Fluted vertical upper section works in conjunction with Bounding Ray Optical Principle™ to provide optimal fixture performance. Minimum flange matches reflector finish. White painted flange optional.
- Cross Baffle - Clear acrylic cross baffle with surface that provides a decorative edge-glow appearance.
- Hinged lampdoor seals upper trim for optimal fixture efficiency and the reduction of stray light in the plenum.

MECHANICAL

- 16-gauge galvanized steel mounting/plaster frame with integral yoke to retain optical system. Maximum 1-1/2" ceiling thickness.
- 16-gauge galvanized steel mounting bars with continuous 4" vertical adjustment. Tool-less, cam-action locking system allows for adjustment from above or below the ceiling. Shipped pre-installed.
- Galvanized steel junction box with bottom-hinged access covers and spring latches. Two combination 1/2"-3/4" and three 1/2" knockouts for straight-through conduit runs. Capacity: 8 (4 in, 4 out) No. 12 AWG conductors rated for 90°C.

ELECTRICAL SYSTEM

- Horizontally-mounted, positive-latch, thermoplastic socket(s).
- Class P, thermally protected, high power factor electronic ballast(s) mounted to the junction box.

LISTING

- Fixtures are UL listed for thru-branch wiring, recessed mounting and damp locations. Listed and labeled to comply with Canadian Standards (see Options).

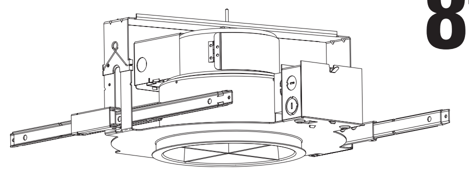
Type .... Catalog number ....

Decorative Compact Fluorescent Downlights

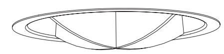
8" PDXF

Ice Blade™

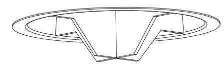
Horizontal Lamp
Triple-Tube



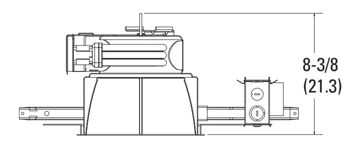
CLRF



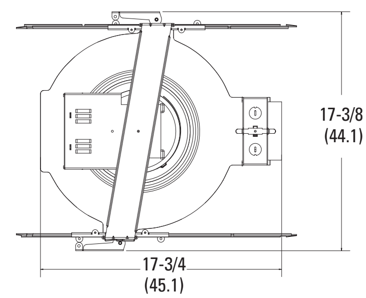
CLRR



CLRA



Aperture: 7-7/8 (20.0)
Ceiling Opening: 8-7/8 (22.5)
Overlap Trim: 9-1/4 (23.5)



All dimensions are inches (centimeters).

ORDERING INFORMATION

Example: **PDXF 1/32TRT 8AR CLRF MVOLT**

Choose the boldface catalog nomenclature that best suits your needs and write it on the appropriate line. Order accessories as separate catalog number (shipped separately).

PDXF ______ **8AR** ______ ______ ______ ______

Series	Lamp/ Wattage	Trim Color	Baffle Type	Voltage	Ballast[2]	Options
PDXF	**1/18TRT**	**8AR** Clear	**CLRF** Clear Flush	**MVOLT**[1]	(blank) GEB10 standard. Electronic ballast.	**TRW** White painted flange
	1/26TRT		**CLRR** Clear Round	**120**	**DMHL**[3] Lutron Hi-Lume electronic dimming ballast.	**WLP** With 35°K lamp (shipped separately).
	1/32TRT		**CLRA** Clear Angular	**277**	**ADEZ**[3] Advance Mark X electronic dimming ballast.	**LRC**[4] Provides compatibility with Lithonia Reloc System.
	1/42TRT			**347**		**GMF**[5] Single, slow-blow fuse.
	1/57TRT					**GLR**[5] Single, fast-blow fuse.
	2/18TRT					**RIF** Radio Interference Filter.
	2/26TRT					**ELR**[6] Emergency battery pack. Remote test switch provided.
	2/32TRT					**QDS** Quick Disconnect for easy ballast replacement.
	2/42TRT					**GSKT** Gasketing.
						DS Dual switching.
						CSA Listed and labeled to comply with Canadian Standards.
						CP Chicago Plenum.
						CAL Clear acrylic lens. For use where enclosed fixture is required.

Accessories

Order as separate catalog number.

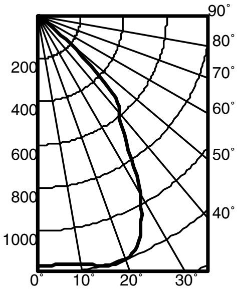
SC8FL Sloped ceiling adaptor. Degree of slope must be specified (10D, 15D, 20D, 25D, 30D). Ex: SC8FL **10D**

NOTES:
1 Multi-volt electronic ballast capable of operating on any line voltage from 120V through 277V, 50 or 60 HZ.
2 For additional ballast types, refer to Technical Bulletins tab.
3 Available in 120V or 277V only.
4 For compatible Reloc systems, refer to Technical Bulletins tab.
5 Not available with MVOLT.
6 For dimensional changes, refer to Technical Bulletins tab. Not available with QDS or CP options.

8" PDXF

Distribution curve | **Distribution data** | **Output data** | **Coefficient of utilization** | **Illuminance Data at 30" Above Floor for a Single Luminaire**

PDXF 1/42TRT 8AR CLRF, (1) CF42DT/E/IN/835, 3200 lumens per lamp, test no. LTL11023



From 0˚	Ave	Lumens
0	1164	
5	1160	111
15	1202	340
25	1124	508
35	719	459
45	443	316
55	56	64
65	19	19
75	8	8
85	1	2
90	0	

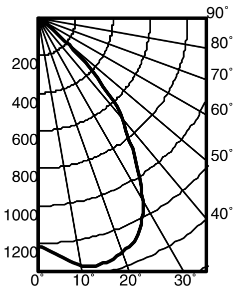
Zone	Lumens	% Lamp
0˚ - 30˚	959.2	30.0
0˚ - 40˚	1418.4	44.3
0˚ - 60˚	1797.8	56.2
0˚ - 90˚	1827.1	57.1
90˚ - 180˚	0.0	0.0
0˚ - 180˚	1827.1	*57.1

*Efficiency

pf	20%					
pc	80%		70%		50%	
pw	50%	30%	50%	30%	50%	30%
1	.62	.61	.61	.60	.59	.58
2	.57	.55	.56	.54	.54	.52
3	.52	.49	.52	.49	.50	.48
4	.48	.45	.48	.44	.46	.43
5	.44	.41	.44	.40	.43	.40
6	.41	.37	.41	.37	.40	.36
7	.38	.34	.38	.34	.37	.33
8	.35	.31	.35	.31	.34	.31
9	.33	.29	.32	.29	.32	.29
10	.31	.27	.30	.27	.30	.26

		50% beam angle 61.4˚		10% beam angle 92.8˚	
Mount height	Inital fc at beam center	Beam diameter	fc at beam edge	Beam diameter	fc at beam edge
8	38.5	6.5	19.2	11.5	3.9
10	20.7	8.9	10.3	15.7	2.1
12	12.9	11.3	6.4	19.9	1.3
14	8.8	13.7	4.4	24.1	0.9
16	6.4	16.0	3.2	28.3	0.6

PDXF 2/32TRT 8AR CLRF, (2) CF32DT/E/IN/835, 2400 lumens per lamp, test no. LTL11025



From 0˚	Ave	Lumens
0	1218	
5	1270	124
15	1352	381
25	1266	575
35	895	561
45	455	340
55	64	72
65	22	22
75	8	9
85	2	2
90	0	

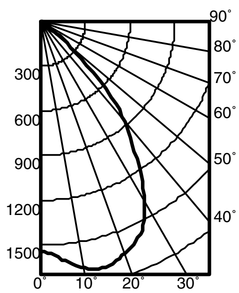
Zone	Lumens	% Lamp
0˚ - 30˚	1078.8	22.5
0˚ - 40˚	1639.4	34.2
0˚ - 60˚	2050.8	42.7
0˚ - 90˚	2083.8	43.4
90˚ - 180˚	0.0	0.0
0˚ - 180˚	2083.8	*43.4

*Efficiency

pf	20%					
pc	80%		70%		50%	
pw	50%	30%	50%	30%	50%	30%
1	.48	.46	.47	.45	.45	.44
2	.44	.41	.43	.41	.41	.40
3	.40	.37	.39	.37	.38	.36
4	.37	.34	.36	.34	.35	.33
5	.34	.31	.33	.31	.32	.30
6	.31	.28	.31	.28	.30	.28
7	.29	.26	.29	.26	.28	.25
8	.27	.24	.26	.24	.26	.23
9	.25	.22	.25	.22	.24	.22
10	.23	.20	.23	.20	.23	.20

		50% beam angle 65.0˚		10% beam angle 92.7˚	
Mount height	Inital fc at beam center	Beam diameter	fc at beam edge	Beam diameter	fc at beam edge
8	40.3	7.0	20.1	11.5	4.0
10	21.7	9.5	10.8	15.7	2.2
12	13.5	12.1	6.7	19.9	1.3
14	9.2	14.6	4.6	24.1	0.9
16	6.7	17.2	3.3	28.3	0.7

PDXF 2/42TRT 8AR CLRF, (2) CF42DT/E/IN/835, 3200 lumens per lamp, test no. LTL11024



From 0˚	Ave	Lumens
0	1539	
5	1603	155
15	1705	478
25	1577	716
35	1121	701
45	565	423
55	75	86
65	27	27
75	10	11
85	2	2
90	0	

Zone	Lumens	% Lamp
0˚ - 30˚	1350.0	21.1
0˚ - 40˚	2050.7	32.0
0˚ - 60˚	2560.1	40.0
0˚ - 90˚	2599.9	40.6
90˚ - 180˚	0.0	0.0
0˚ - 180˚	2599.9	*40.6

*Efficiency

pf	20%					
pc	80%		70%		50%	
pw	50%	30%	50%	30%	50%	30%
1	.44	.43	.44	.43	.42	.41
2	.41	.39	.40	.38	.39	.37
3	.37	.35	.37	.35	.36	.34
4	.34	.32	.34	.31	.33	.31
5	.32	.29	.31	.29	.30	.28
6	.29	.26	.29	.26	.28	.26
7	.27	.24	.27	.24	.26	.24
8	.25	.22	.25	.22	.24	.22
9	.23	.21	.23	.20	.23	.20
10	.22	.19	.22	.19	.21	.19

		50% beam angle 64.7˚		10% beam angle 92.5˚	
Mount height	Inital fc at beam center	Beam diameter	fc at beam edge	Beam diameter	fc at beam edge
8	50.9	7.0	25.4	11.5	5.1
10	27.4	9.5	13.7	15.7	2.7
12	17.1	12.0	8.5	19.8	1.7
14	11.6	14.6	5.8	24.0	1.2
16	8.4	17.1	4.2	28.2	0.8

NOTES:

1 For electrical characteristics, refer to Technical Bulletins tab.

2 Tested to current IES and NEMA standards under stabilized laboratory conditions. Various operating factors can cause differences between laboratory data and actual field measurements. Dimensions and specifications are based on the most current available data and are subject to change without notice.

3 Consult factory or IES file for other photometric reports.

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A DIVISION OF ACUITY LIGHTING GROUP, INC.
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P 800 315 4982 F 770 860 3129
www.gothamlighting.com

Task Ambient Lighting - Style L202M

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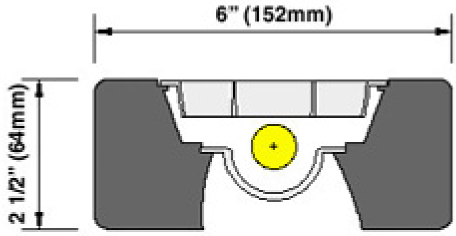
General Information



Length: 70-3/4" (1797mm)

Lamp type: (2) F21T5 Standard output

Optics: Mid-mount

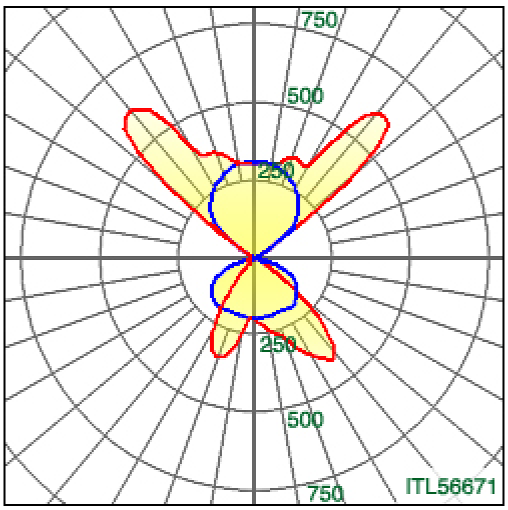
% Light Direct: 47%

% Light Indirect: 53%

Total Efficiency: 61.6%
(28.9% dn, 32.6% up)

Total Lamp Lumens: 4200

Light Levels and Power



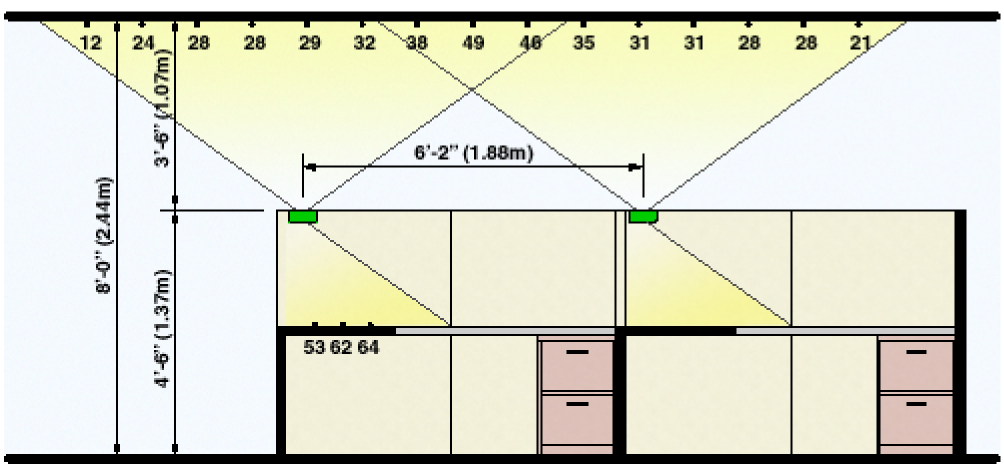
180-0 Degrees, 90-270 Degrees

W/SF	Average Room Illuminance at 30" A.F.F.
0.6	18 FC
0.8	25 FC

Note:
Illuminance is based on a minimum of 10 workstations.
Light levels will be 5-10% greater in large rooms with more workstations.
Ballast Factor: .98
Input Watts: 34
Maximum Candlepower at 140 deg = 629 cd

Download IES file

Illuminance Levels



Illuminance calculations based on the Reflectance's: Room 80/50/20, Desktop 60, Partitions 45.
Ceiling height: 8'-0" Work Surface Height: 29" Mounting height: 54 " LLF= 1
Tambient Luminaire length: 6'-0" All Illuminance values are in Footcandles

Ambient Lighting - Style A102

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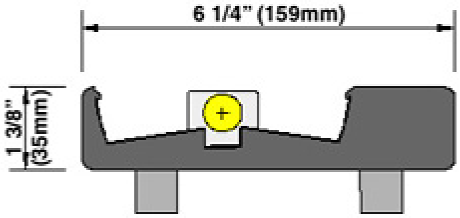
General Information



Length: 47-1/2" (1206mm)

Lamp type: F28T5 Standard output

Optics: Std.

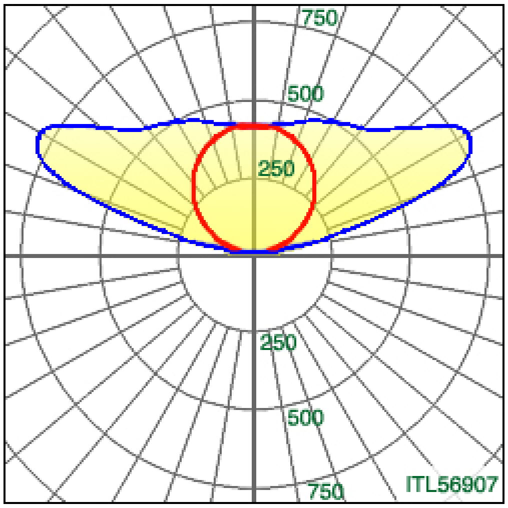
% Light Direct: 0%

% Light Indirect: 100%

Total Efficiency: 78.8%

Total Lamp Lumens: 2900

Light Levels and Power



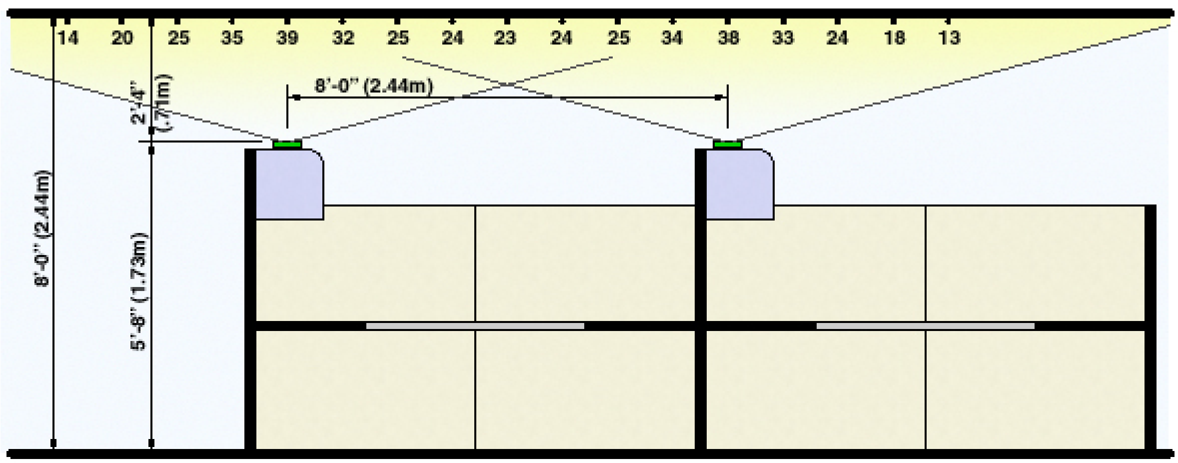
180-0 Degrees, 90-270 Degrees

W/SF	Average Room Illuminance at 30" A.F.F.
0.6	16 FC
0.8	21 FC

Note:
Illuminance is based on a minimum of 10 workstations.
Light levels will be 10-15% greater in large rooms with more workstations.
Ballast Factor: .98
Input Watts: 34
Maximum Candlepower at 117 deg = 789 cd

Download IES file

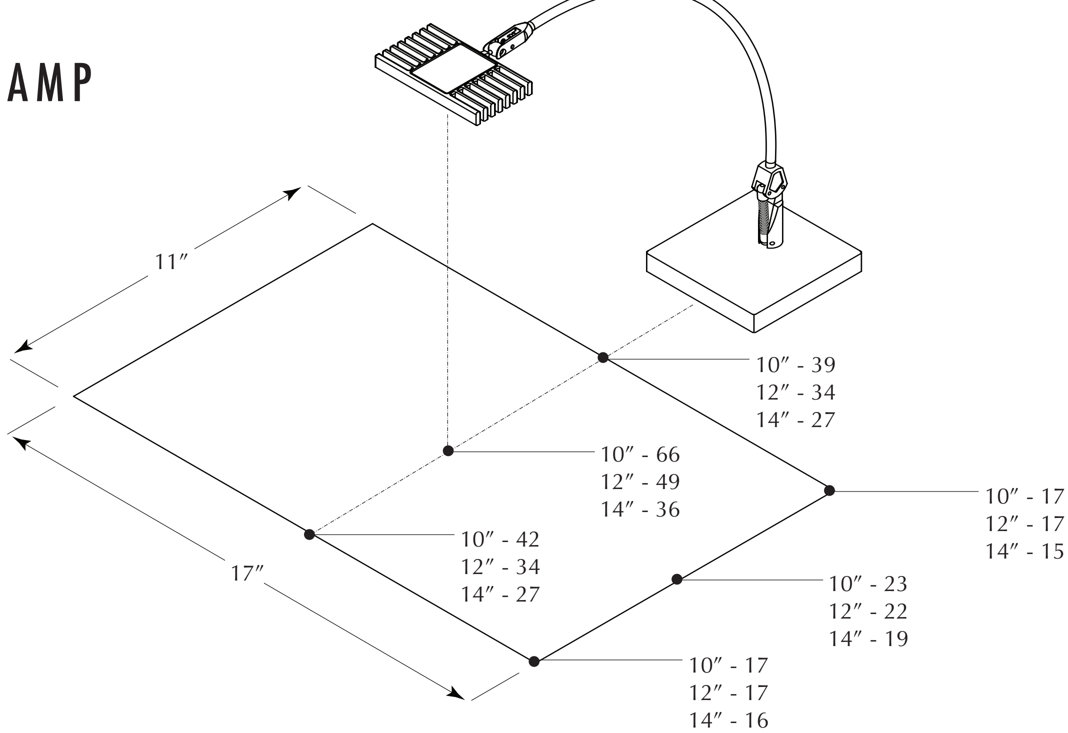
Illuminance Levels

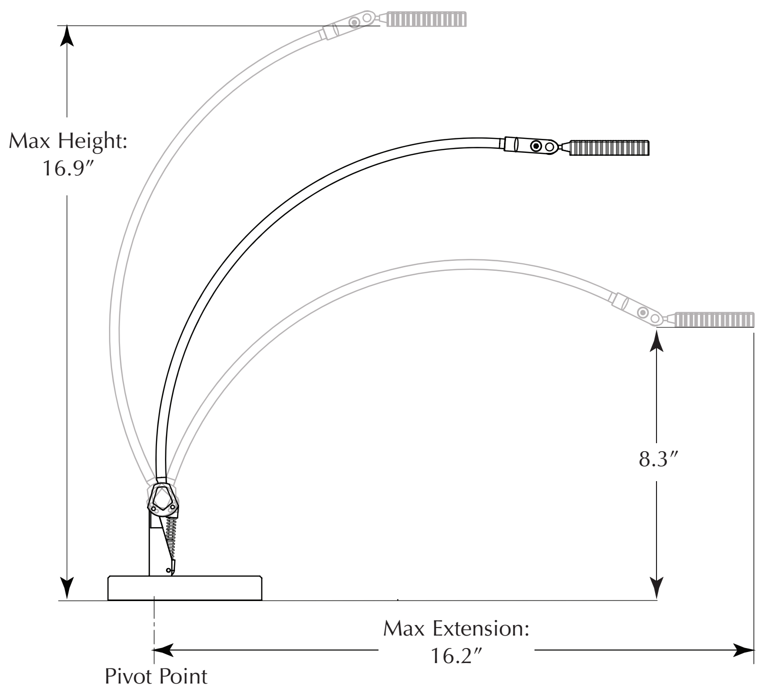


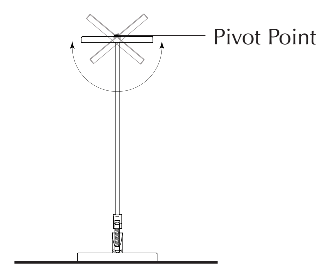
Illuminance calculations based on the Reflectance's: Room 80/50/20, Desktop 60, Partitions 45.
Ceiling height: 8'-0" Work Surface Height: 29" Mounting height: 68" LLF= 1
Tambient Luminaire length: 4'-0" All Illuminance values are in Footcandles
For high output lamp, multiply values by 1.72

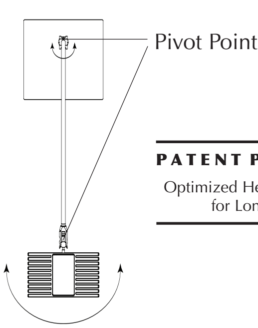
3W DESK LAMP

All measurements in footcandles based on the distance between the lamp head to the desk surface at 10″, 12″ and 14″.









PATENT PENDING

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