Small Building HVAC Retrofit

Shant Douzdjian
Shane Cooney

June 11, 2019

ABT 212 - ZNE

Summary:

The goal of this project was to identify a small building on the University of California Davis campus, in collaboration with the Energy Conservation Office, most suitable for a state-of-the-art Heat Recovery Ventilator (HRV) unit. A full HVAC retrofit was assessed using the HRV unit for ventilation and a split heat pump system for heating and cooling. Initially, five buildings on campus were considered based on relevant criteria. After narrowing down to three candidates, a retrofit design was made for each building considering existing infrastructure, usage, and safety requirements. Finally cost, energy savings, and payback time were estimated. Ultimately, University House, located centrally on campus, was determined the best candidate for the HRV unit.

Background

Client & Context

The Energy Conservation Office (ECO) at the University of California Davis is a branch of the university's Facilities Management Department. ECO focuses on improving energy efficiency and mitigating energy use while maintaining the level of service provided by buildings. This is a much needed role as buildings account for about 40% of energy use nationwide (EIA, 2019).

One of ECO's ongoing initiatives is to improve small building Heating Ventilation and Air Conditioning (HVAC) energy use. While small buildings (which are usually less than 8,000 ft^2) make up about 15% of the total square footage on campus, they are often energy inefficient and present an opportunity for sizeable energy and dollar savings. There are several reasons why small buildings can be energy inefficient. They usually are older buildings and use a packaged heating and cooling unit for space conditioning as well as ventilation from outdoor air. Coupling ventilation and conditioning in a single unit results in inefficient power draw (Montgomery, Love, & Stephens, 2017). Additionally, these units are often oversized using more power than needed. Contractors often replace like for like units over the years and buildings continue to use oversized systems.

Because smaller buildings use packaged on-site HVAC units, ECO is unable to monitor usage remotely, unlike larger buildings on campus that use the central heating and cooling plant. Remote monitoring allows ECO to save energy use in areas of buildings when they are not in use.

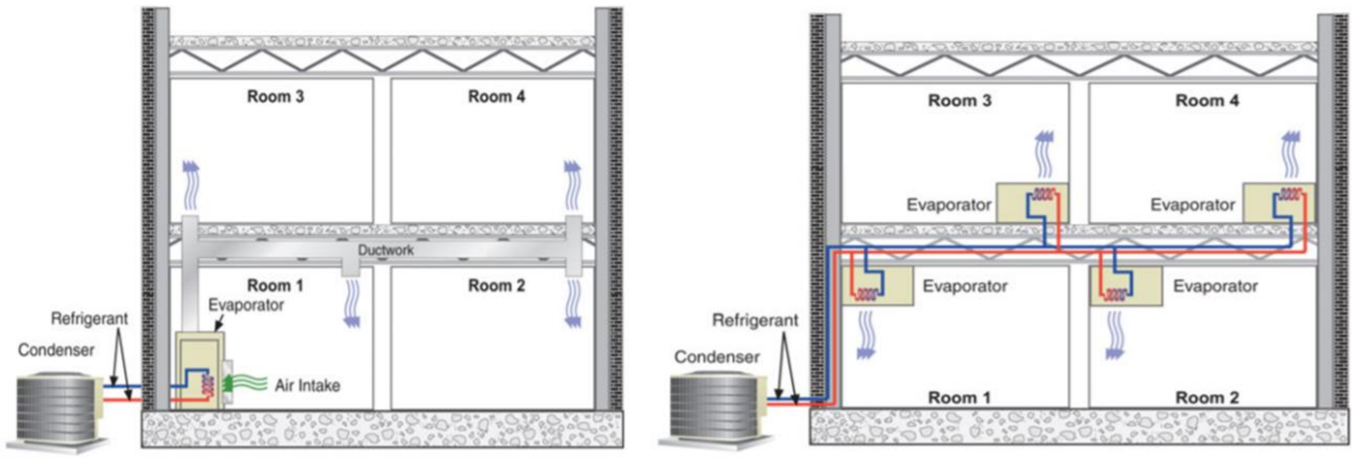
ECO's Retrofit

Between the outdated technology, lack of monitoring, and oversized units, small buildings have potential for significant energy savings. In an effort to improve small building energy use, ECO retrofitted its own office, a small building on campus. Rather than using a packaged HVAC unit, ECO decoupled ventilation and space conditioning using two separate units. For ventilation, they installed a Ventacity VS 1000 RT which is a Heat Recovery Ventilator (HRV). A HRV is able to recover and use heat that is normally exhausted at 83-93% efficiency (Ventacity, 2018). In the summer, heat from outdoor air is exchanged with the colder return air, while during the winter heat from the return air is exchanged with the fresh outdoor air. With the building's fresh supply air preconditioned, significantly less energy is required to condition that air easing the heating and cooling loads.

For space conditioning, ECO replaced its air conditioner and natural gas furnace with a Variable Refrigerant Flow (VRF) system. VRF systems use a heat pump to heat and cool spaces in a building.

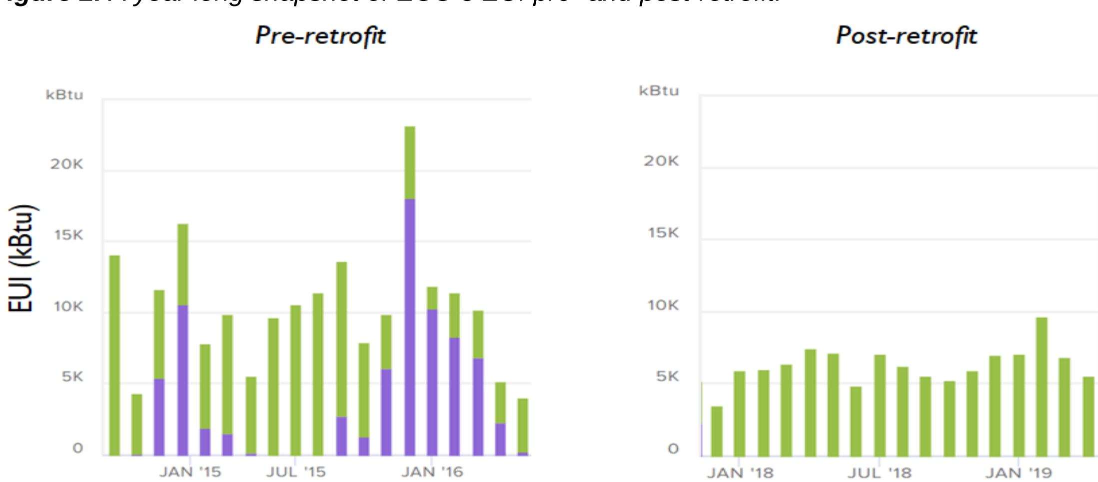
They are ductless systems where heat is transferred to or from indoor units via refrigerant from a larger outdoor unit. The indoor units act as an evaporator or condenser depending on if they are cooling or heating, respectively. “Variable refrigerant flow” refers to the ability to control the amount of refrigerant delivered to each of the indoor units, allowing the use of many indoor units at different configurations and individualized comfort. With a VRF system, indoor units can be configured so that unused spaces are not being conditioned, optimizing energy use. Such a system is fundamentally different from a ducted heating and cooling system, where the heat exchange takes place at the packaged unit, and the heated air is circulated to all spaces, whether or not they are in use. **Figure 1** shows a schematic for a traditional ducted and VRF system to illustrate the differences.

Figure 1. *A side by side comparison of a conventional packaged HVAC system (left) and a VRF system (right).*



To install a system where ventilation is handled by a HRV and heating and cooling by a VRF, ECO retrofitted its building such that the HRV unit utilizes the existing ductwork. Since 2016 when the retrofit occured, ECO has seen substantial energy savings. Their annual average Energy Use Intensity (EUI) dropped from 36 kBtu/ft^2 to 24 kBtu/ft^2. Monthly EUI pre- and post-retrofit are compared in **Figure 2.**

Figure 2. *A year long snapshot of ECO’s EUI pre- and post-retrofit.*



In addition to significant energy savings, a HRV + VRF system is fully electric. Without a gas powered furnace, on-site combustion ceases which is reflected in **Figure 2** where the purple bars represent energy from on-site natural gas combustion. As the University of California approaches its goal to be carbon neutral by 2025, electrifying end use that currently relies on natural gas is an important step (X). As of 2015, roughly half of UC Davis' on-site combustion was from buildings not connected to the Central Heating and Cooling Plant (Meier *et*. al, 2018). As an all electric system, a HRV + VRF retrofit is well suited for UC's long term sustainability goals.

Objective

ECO is currently in possession of an extra Ventacity VS 1000 RT. ECO recruited our help to identify a small building on campus to use this state-of-the-art HRV unit. Considering the energy savings and long-term carbon goals of the campus, installing this unit with a VRF system makes the most logical sense.

Methodology

Preliminary Building Candidates

The first step was to identify a series of small buildings to evaluate for retrofit. Our team began with a list of five small buildings throughout the UC Davis campus, with an area square footage (ASF) ranging from 1250-4500. Succeeding this initial selection, we collaborated with ECO to develop a list of significant, interrelated selection criteria to assess which buildings would be most suitable for a retrofit. These qualities and their respective significance resulted in an evaluative matrix.

Figure 3. *Evaluative criteria used in building selection process.*

				Weight
Criteria:				
Existing Infrastructure				3
Potential Energy Savings				3
Cost of Install				2
Impact of Retrofit				1
Size of Unit Required (Energy)				1
Learning Outcomes/Scalability				2
Building Usage				1
Building Life Expectancy				2
Showcase Ability				1
Existing Equipment Life Expec.				1
Totals:	**0**	**0**	**0**	

Figure 3 shows the evaluative criteria determined and corresponding weights, ranging from 1-3, indicating relative importance. Immediately after producing the matrix, we narrowed down the group of five small buildings to three based on preliminary research. The following five buildings were considered during the preliminary review:

- Bee Biology
- Utilities Headquarters
- Ag Field Station
- Music Annex
- University House

Within this preliminary stage of analysis, we determined with ECO that building usage and existing infrastructure were the primary indicators for narrowing the candidate list. Accordingly, Utilities Headquarters was dismissed due to low-usage and lack of retrofit impact. Although Bee Biology is a highly used building and an adequate size for the HRV unit, it was ruled out due to specialized ventilation code requirements for laboratories. This left Ag Field Station, Music Annex, and University House as candidates for the retrofit.

Retrofit Design

Each building was toured to determine current operation status and to gather specific information instrumental in proposing a retrofit. We analyzed the size and technology of the existing HVAC systems; considering the condition of the equipment and infrastructure, the physical layout of the space, and the accessibility of the ductwork. These characteristics have significant effect on cost, as the existing infrastructure determines both the scope of alterations required for HRV unit, as well as the potential energy savings amounted to a VRF and HRV split-system. **Table 1** shows relevant information for each building. Existing duct plans can be found in the Appendix along with schematics showing existing heating and cooling configurations.

Table 1. *Relevant parameters for three candidate buildings.*

Building	Year Built	ASF	Usage	Heating	Cooling
Ag Field Station	1973	2,200	Office/Admin	Furnace	2 packaged AC units
Music Annex	1950	1,244	Office/Admin	Ducted Heat pump	Ducted Heat pump
University House	1908	2,396	Office/Student Space	Furnace	2 packaged AC units

Considering the data acquired above and on-site visits, we designed each building's retrofit determining:

- Placement of the HRV unit outside
- Required configuration to the ductwork
- Placement of the outdoor and indoor VRF units

Noise level, visibility, and exposure to sunlight were the main considerations for placement of the outdoor VRF unit. Accordingly, the VRF for each of the three designs was placed where the existing compressor was. **Figure 4** shows the proposed design for each building. The red lines highlight the ductwork configuration connecting to a large red box which is the HRV unit.

Figure 4. *Proposed HRV + VRF design for a) Ag Field Station b) Music Annex and c) University House*

Ag Field Station and University House require minimal rearrangement of ductwork for the HRV unit. Ag Field station would require the ducts from the two different AC units connected as indicated in **Figure 4a**. For University House, the ductwork between the two packaged AC units is currently blocked off via a barrier (see figures in Appendix). This would simply require the barrier to be removed. The HRV would be ground-mounted on the side of the building where the current Coolerado unit is; out of plain sight and in the shade.

Music Annex's design would require significant modifications to the ductwork. The evaporator for the current system is currently in the attic where it is connected to the ductwork. For ventilation purposes the HRV unit is restricted from being placed in the attic. Therefore, the ducting would need to be rerouted outside where the compressor currently sits.

With these designs, the remaining considerations for each retrofit is ventilation code compliance, and heating and cooling load estimates to determine the VRF size required. Heating and cooling load calculations can be very in-depth and often require expertise around certain programs. Therefore, one building design was chosen and used in a crude heating and cooling load model. More importantly, relevant heating and cooling load parameters were collected for the building which can be used by ECO in the future. Due to the feasibility and ease of design, University House was chosen for the ventilation and heating and cooling load calculations covered in the next sections.

University House Heating and Cooling Load Estimates

To properly size the heat pump, heating and cooling load calculations were required for each building. Models for heating and cooling loads can be very complicated. Several computer programs exist including Trace 700, Elite CHVAC, and EnergyPlus. For a more in depth understanding of heating and cooling load calculations, Chapter 28 of ASHRAE Fundamentals is an industry-wide reference (ASHRAE Fundamentals, 2001).

For the purpose of this report, cooling and heating load calculations were drastically simplified. For a more accurate estimate, and therefore accurate heat pump size, it is suggested that ECO utilize one of the above programs or reach out to UC Davis' Wester Cooling Efficiency Center (WCEC).

The cooling load was broken into four parts:

- Conductive heat gain through walls and windows
- Sensible heat gain from people
- Instantaneous heat gain from lights
- Radiative heat gain through windows

Equations 1-4 were used to calculate each part, respectively.

$$Q_{Conductance} = U * A * TD \qquad \textbf{Eq. 1}$$

Where U is the coefficient of heat transfer specific to material, A is the square footage of the material, and TD is the indoor and outdoor temperature difference

$$Q_{People} = n * 380 \frac{Btu}{hr*person} \qquad \textbf{Eq. 2}$$

Where n is the peak number of people in the building during an average day

$$Q_{Lights} = l * 3.41 \frac{Btu}{hr*W} \qquad \textbf{Eq. 3}$$

Where l is the number of lights in the building

$$Q_{Radiative} = A * SC * SCL \qquad \textbf{Eq. 4}$$

Where SC is the shading coefficient and SCL is the solar cooling load specific to the geographic locations and orientation of the building

Relevant building, material, lighting, and occupant parameters were collected on site and reported in the Technical section of the Appendix. These parameters may be of use for any future cooling and heating load estimates.

University House was built in 1908 when insulation was not used in buildings. Accordingly, U values for uninsulated dry wall (U=0.3) and single pane window (U=0.8) were used (ASHRAE Fundamentals, 2001). Using 75^{o} as the design temperature and 100^{o} as peak temperature for Davis, a temperature difference of 25^{o} F was used. This value can be slightly modified but for this model it is appropriate.

An estimate for the number of people in University House taken from full time employees on site who reported peak usage during the day is usually around 27 people. Accordingly, using ASHRAE's values for sensible heat gain for "seated at rest" work (380 Btu/hr *person), the peak number of occupants was scaled to estimate sensible heat gain.

For lighting, University House is fitted with Ecolux 32W 4100K lights. 3.41 Btu/W was used to estimate head load per wattage of light (ASHRAE Fundamentals, 2001).

Ventilation Requirements

California Code requires outdoor air ventilate buildings at a rate of 0.06 cfm/ft^2 ("California Mechanical Code 2016 402.1," 2019). Accordingly, the HRV must have the appropriate static pressure to ventilate the building according to code. Since the building will be retrofitted, rather than designing the duct sizes based on ventilator parameters, pressure loss was calculated based on existing configurations including frictional and fitting losses.

Using University House to estimate pressure losses, the necessary flow rate for each room was calculated in cfm. Working from the room farthest away from the HRV unit to the closest, required flow rates in each duct branch were summed to determine the total cfm required. With duct sizing, air flow, area, and velocity known, frictional losses were calculated based on a friction loss diagram ("Friction Loss Diagram," 2019). Fitting losses were determined using C values for duct expansions (C=0.84) and 90^o bends (C=0.33).

The worksheet used to calculate pressure losses for University House is in the Technical section of the Appendix. Duct branches and fittings were labeled based on the duct plan retrieved from FacilitiesMap in the Appendix. Ultimately, static pressure los was calculated to be about 0.011 in Water Column (WC). Considering the HRV unit can supply 0.8 in WC (Ventacity, 2018), this is a negligible amount and is not a concern for the retrofit design.

Energy Savings, Cost, and Payback Time

EUI savings were estimated based on energy savings from ECO's retrofit. As a building with empirical evidence of savings, this provides a rough estimate of energy savings for each building. A more accurate heating and cooling load model will give more accurate energy saving estimates.

$$\Delta EUI = A\left[\frac{36kBtu/ft^2\,yr}{3100\,ft^2} - \frac{24\,kBtu/ft^2\,yr}{3100\,ft^2}\right] \qquad \textbf{Eq. 5}$$

Cost for the VRF system was broken into three parts: labor, material, and outdoor and indoor unit. Labor costs were similarly scaled using **Eq. 6** based on labor costs for ECO's retrofit which totaled $88,830 (Morejohn, 2019).

$$Labor\ Cost = A\left[\frac{\$88{,}830}{3100\,ft^2}\right] \qquad \textbf{Eq. 6}$$

Material costs accounted for piping, insulation and electrical materials for equipment, concrete pad, lumber, hangers, hardware, etc. Again, those costs were scaled based on square footage per **Eq. 7** and taken from ECO's retrofit records (Morejohn, 2019).

$$Material\ Cost = A\left[\frac{\$12{,}735}{3100\,ft^2}\right] \qquad \textbf{Eq. 7}$$

The cost of the outdoor and indoor units was retrieved from a HVAC engineer at Norman-Wright who provided a quote of $16,000 for an 8 ton outdoor unit, and 9 indoor units. Ag Field Station and University House both require an 8 ton unit and 9 indoor units so that price was used for those buildings, while Music Annex was scaled down accordingly.

Payback time (**Eq. 8**) was simply computed based on estimated EUI savings and an assumed electricity cost of $0.15/kwh, which is the average for California. UC Davis does purchase its electricity at a discounted rate so a more accurate payback time should utilize that.

$$\frac{1}{Payback\ Time\ (yr)} = \Delta EUI\ (\frac{kBtu}{ft^2 yr}) * ASF\ (ft^2) * \frac{1\ kwh}{3.14\ kBtu} * \frac{\$0.15}{kwh} * \frac{1}{\$Capital} \quad \textbf{Eq. 8}$$

Results

Energy Savings, Cost, & Payback Time

Table 2 shows the results for the energy savings, cost, and payback time calculations for each building. Payback time estimates were based on just capital investment due to the unrealistically high payback time for the total cost (ranging from 100 - 200 years).

University House and Ag Field Station were comparable in energy savings, however, the University House payback time is faster by about 2 years. Music Annex, while the cheapest option, results in the most limited energy savings and has a significantly longer payback time than the alternative options. In addition to these considerations, Ag Field Station is currently under construction and the future usage of the space is unknown, while Music Annex has low usage and limited sun exposure, in comparison to the other two buildings surveyed.

Table 2. *Energy savings, Costs, and Payback Times for each building.*

Building	**Energy Savings ($kBtu/ft^2$ yr)**	**Capital Cost ($)**	**Total Cost ($)**	**Payback Time (yrs)**
Ag Field Station	10.3	16,000	81,000	16
Music Annex	5	12,000	48,000	43
University House	11	16,000	96,000	14

Evaluative Matrix

Table 3. *Finalized evaluative criteria for each building.*

	Ag Field Station	**University House**	**Music Annex**	**Weight**
Criteria:				
Existing Infrastructure	2	3	1	3
Potential Energy Savings	2	2	1	3
Cost of Install	2	2	1	2
Impact of Retrofit	2	3	2	1
Size of Unit Required (Energy)	2	2	3	1
Learning Outcomes/Scalability	2	3	1	2
Building Usage	n/a	3	2	1
Building Life Expectancy	1	3	2	2
Showcase Ability	2	3	1	1
Existing Equipment Life Expec.	2	2	2	1
Totals:	**30**	**44**	**24**	

After quantifying our selection criteria, our results indicate that University House is the most attractive building for an HVAC retrofit for a variety of reasons: University House's straightforward ductwork and existing HVAC layout provides a simple, scalable, cost and energy effective solution to reducing EUI and improving occupant comfort. Furthermore, the building's historic status means that it will not be demolished or abandoned in the foreseeable future, which rationalize a long term investment. Lastly, the location and use of the building make it an excellent candidate for showcasing UC Davis' sustainability efforts, as well as ECO's involvement in improving energy use throughout campus.

Recommendations & Conclusions

We conclude that University House is the best option for an HRV / VRF retrofit as it strongly satisfies nearly all of the selection criteria in the evaluative matrix. Ultimately, University House maximizes potential energy savings and minimizes payback time. Additionally, the impact of retrofitting is by far the most compelling: upon one of our visits to University House to take measurements, we were struck to hear the excitement of the occupants when we mentioned the potential of an improved HVAC system; they complained about uncomfortable temperatures in the winter and summer.

Given the rough figures we estimated for heating and cooling loads, we suggest that ECO perform a comprehensive review of the building's solar radiance and heat conductivity through both walls and windows to insure accurate system sizing. However, our calculations lead us to discover that due to the age of the building, there is zero wall insulation. A lack of insulation greatly reduces a building's ability to maintain hot and cold air, which creates additional heating and cooling loads and mitigates potential energy savings. While installing insulation is labor intensive and may be difficult due to the building's historic status, the yield in potential energy savings and increased occupant comfort could be worth the investment. We suggest that ECO consider these potential improvements.

Bibliography

ASHRAE Fundamentals. (2001). *American Society of Heating, Refrigerating and Air-Conditioning Engineers*. Atlanta, GA.

California Mechanical Code 2016 402.1. (2019).

EIA. (2019). Frequently Asked Questions. Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=86&t=1

Friction Loss Diagram. (2019). Retrieved from https://www.engineeringtoolbox.com/ductwork-friction-loss-d_1122.html

Meier, A., Davis, S., Victor, D., Brown, K., & McNeilly, L. (2018). *University of California Strategies for Decarbonization: Replacing Natural Gas*.

Montgomery, J., Love, C., & Stephens, C. (2017). *Energy and Indoor Air Quality Impacts of DOAS Retrofits in Small Commercial Buildings*. Retrieved from https://buildingsciencelabs.com/wp-content/uploads/2017/11/CCBST-2017-Energy-and-Indoor-IAQ-Impacts-DOAS-Retrofits.pdf

Morejohn, J. (2019). Email with Josh Morejohn on May 16, 2019. Energy Conservation Office.

Ventacity. (2018). VS 1000 RT Product Sheet.

Appendix

Tables of relevant parameters used for heating and cooling load calculations for University House. The first table includes values for dry wall and window square footage for each room.

The second table includes information on daily usage.

Room, Lighting, & Material Specs

Room	# of Lights	Window sqft (in^2)	Wall Height (in)	Wall Width (in)	Wall Area (in^2)	Plugload Items
115	6	2442	90	244	21960	
Lobby	30	3918.75	90	205.5	18495	
114	18	7006.25	98	71	6958	3 computers + 1 large printer
102	4	4488.75	90	2	180	
Hall	14		90	1	90	
105	12	5325.75	90	253	22770	
106	8	10473.75	98	31	3038	Fridge + Microwave + coffee pot
101	6	6048.75	98	179	17542	
103	4	2992.5	90	67	6030	
104	4	2992.5	90	69	6210	
	106	45689			103273	

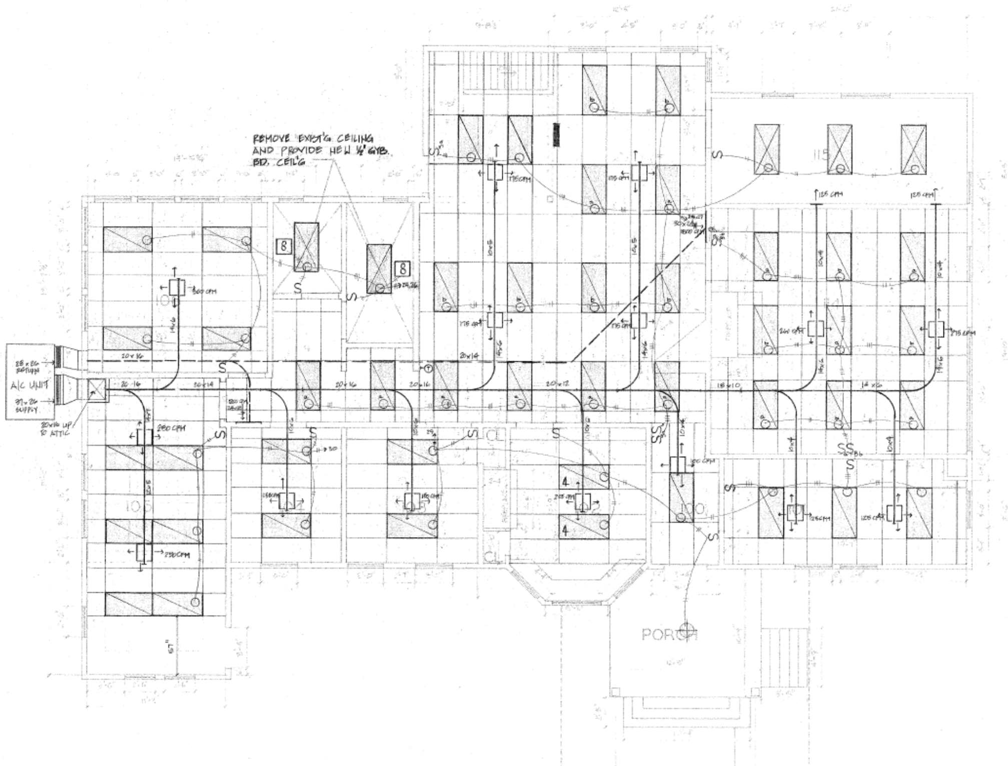
Cooling Load

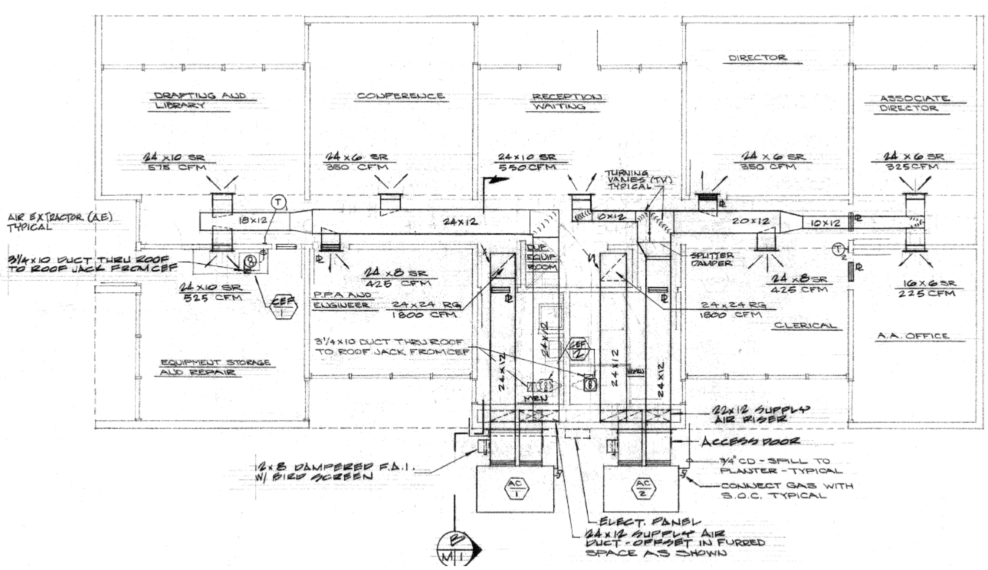
Conductive Heat		People		Lights		Radiative Heat from Windows		Total Cooling Load (Btu/h)
Dry Wall				Wattage/lights	32	Area	317.2847	**96903**
U	0.294117647	Total Usage/day	60	# of lights	106	SC	0.8	
Area	717.1736111	Peak Usage/day	27	Btu/Watt	3.41	SCL	250	
TD	25	Q	10260	Q	11566.72	Q	63456.94	
Q	5273.335376							
Windows								
U	0.8							
Area	317.2847222							
TD	25							
Q	6345.694444							

Heating Load

Btu/sqft	Total sqft	Heat Load (Btu/h)
36	2396	**86256**

Ductwork for Candidate Buildings





Pressure Calculations

Pressure calculations for University House. The first table gives the cfm required per space based on California Mechanical Code. The second table shows the calculations for ducts and fittings using ambiguous ID’s for different areas of ducting (not shown in duct image).

Room Number	Room Area	Type	Required CFM	Required Ventilation (0.6cfm/ft2)
0100	190	Office/Lobby	0.06	11.4
0101	163	Office/Lobby	0.06	9.78
0102	152	Office/Lobby	0.06	9.12
0103	118	Office/Lobby	0.06	7.08
0104	100	Office/Lobby	0.06	6
0105	264	Office/Lobby	0.06	15.84
0106	198	Office/Lobby	0.06	11.88
0112	569	Office/Lobby	0.06	34.14
0114	417	Office/Lobby	0.06	25.02
0115	177	Office/Lobby	0.06	10.62

ID	Type	Volume Flow (cfm)	Diameter (in)	Width (in)	Area (in^2)	Area (ft^2)	Equivalent Round Diameter (in)	Length (ft)	Velocity (ft/m)	Delta P (in WC)	Fitting Losses (in WC)
A	Duct	129.48	20	16	256	21.33	19.52	0.62	0.16	0.00	NA
B	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
C1	Branch	15.84	14	7	49	4.08	10.66	2.40	0.26	0.00	NA
C2	Branch	7.92	12	5	25	2.08	8.27	3.30	0.26	0.00	NA
D	Duct	113.64	20	14	196	16.33	18.22	1.12	0.14	0.00	NA
E	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
F	Branch	11.88	14	6	36	3.00	9.80	3.24	0.25	0.00	NA
G	Duct	101.76	20	14	196	16.33	18.22	4.00	0.16	0.00	NA
H	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
I	Branch	6	10	6	36	3.00	8.40	3.30	0.50	0.00	NA
J	Duct	95.76	20	16	256	21.33	19.52	4.00	0.22	0.00	NA
K	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
L	Branch	7.08	10	6	36	3.00	8.40	3.30	0.42	0.00	NA
M	Duct	88.68	20	16	256	21.33	19.52	3.00	0.24	0.00	NA
N	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
O	Branch	14.93625	14	6	36	3.00	9.80	2.12	0.20	0.00	NA
P	Branch	7.468125	10	5	25	2.08	7.62	5.12	0.28	0.00	NA
Q	Duct	73.74375	20	12	144	12.00	16.80	3.00	0.16	0.00	NA
R	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
S	Branch	9.12	10	6	36	3.00	8.40	3.30	0.33	0.00	NA
T	Duct	64.62375	20	12	144	12.00	16.80	2.20	0.19	0.00	NA
U	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
V	Branch	14.93625	14	6	36	3.00	9.80	2.12	0.20	0.00	NA
W	Branch	7.468125	10	5	25	2.08	7.62	5.12	0.28	0.00	NA
X	Duct	49.6875	20	12	144	12.00	16.80	1.12	0.24	0.00	NA
Y	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
Z	Branch	4.2675	10	4	16	1.33	6.74	2.40	0.31	0.00	NA
AA	Duct	45.42	18	10	100	8.33	14.51	6.40	0.18	0.00	NA
AB	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
AC	Branch	4.89	10	4	16	1.33	6.74	4.00	0.27	0.00	NA
AD	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
AE	Branch	17.82	14	6	36	3.00	9.80	2.00	0.17	0.00	NA
AF	Branch	5.31	10	4	16	1.33	6.74	4.80	0.25	0.00	NA
AG	Duct	22.71	14	6	36	3.00	9.80	3.00	0.13	0.00	NA
AH	Tee	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
AI	Branch	4.89	10	4	16	1.33	6.74	4.00	0.27	0.00	NA
AJ	Duct	17.82	14	6	36	3.00	9.80	1.50	0.17	0.00	NA
AK	Bend	NA	NA	NA	NA	NA	NA	0.00	NA	NA	0.00
AL	Branch	17.82	14	6	36	3.00	9.80	2.00	0.17	0.00	NA
AM	Branch	5.31	10	4	16	1.33	6.74	4.80	0.25	0.00	NA
										0.0112	**0**