Martin Luther King, Jr. Human Services Center HVAC Analysis Report For Hamilton County Government

February 13, 2018

Written by Campbell & Associates, Inc.

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Purpose:

The purpose of this report is to provide the Owner of the Martin Luther King, Jr. Human Services Center Building (MLK) with as much information as possible in order for the Owner to make the best decision with regard to the design for upgrading the existing Heating, Ventilation, and Air Conditioning Systems (HVAC) of the respective building. As with any HVAC design, there are many options available to choose from that could meet the Owner's design criteria and intent. This report will limit the available options to those that provide the Owner with the best value while still meeting the Owner's requirements. HVAC systems that are excluded will be defined within the report along with the reasoning behind the exclusion. Since lowest first cost does not always indicate the best value for the Owner, this report will also analyze and compare the separate HVAC system options with respect to construction budget estimates, life cycle analysis, and energy costs in order for the Owner to best gage value. Wherever possible, real world utility and construction costs have been utilized in the analysis.

Existing Building Description:

The MLK building was originally built in 1928. It has 4 floors with a total approximate area of 20,310 ft^2 with approximately 16,455 ft^2 of conditioned space. The building is listed on the National Register of Historic Places as the First Baptist Church Education Building due to the building being designed in part by R.H. Hunt who is considered one of Chattanooga's most significant earliest architects[1].
The building is constructed of brick with the front façade of the building containing finished sandstone with decorations.
The first floor is the largest floor of the building with a total footprint that comprises approximately 5,912 ft^2. The second and third floors have a smaller footprint than the first at approximately 5,430 ft^2 each. The fourth floor has the smallest footprint at approximately 3,535 ft^2.
All but the second floor have roofs in some degree. The first and third floor roofs are where existing condensing units are installed.
Currently, there are no confirmed sources of asbestos located within the building. The age of the building means that the building was occupied during the period in which asbestos implementation was popular for fire protection. Therefore, it is recommended that asbestos testing be performed prior to any HVAC system renovations be performed in order to determine if abatement is necessary.

Existing Building HVAC Systems Description:

The existing HVAC systems within the building consist of 5 cooling only split direct expansion (DX) split systems for cooling with heating being performed by multiple electric reheat coils installed within the ductwork throughout the building. There are also multiple motorized dampers installed within the ductwork throughout the building that vary the amount of airflow to the respective zone it serves. The electric heating coils and motorized dampers are pneumatically controlled with a temperature sensor located within the respective zone. There is also a building automation system that is installed but no longer functioning. The existing DX cooling systems are controlled with a thermostat located within the area it is serving. Please see "*Existing HVAC Systems Schematic*" for further reference.
The HVAC systems currently are not functioning properly and occupants are cold. The indoor space temperatures cannot be maintained in several areas of the building. The existing HVAC issues causing the indoor temperature issues are described below.

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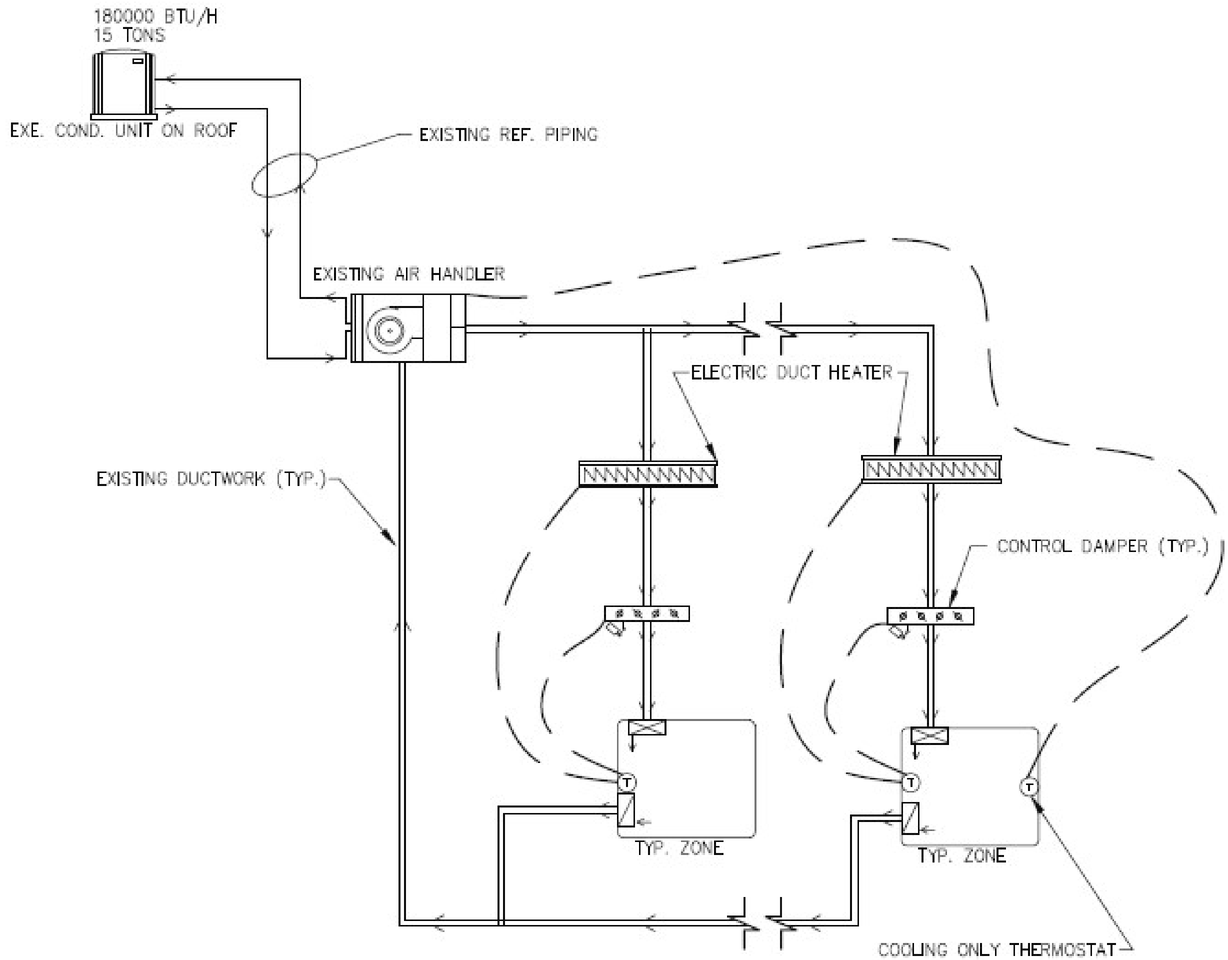
[1] https://npgallery.nps.gov/NRHP/AssetDetail?assetID=0563f321-8da9-4712-8ee5-b0b037500c84

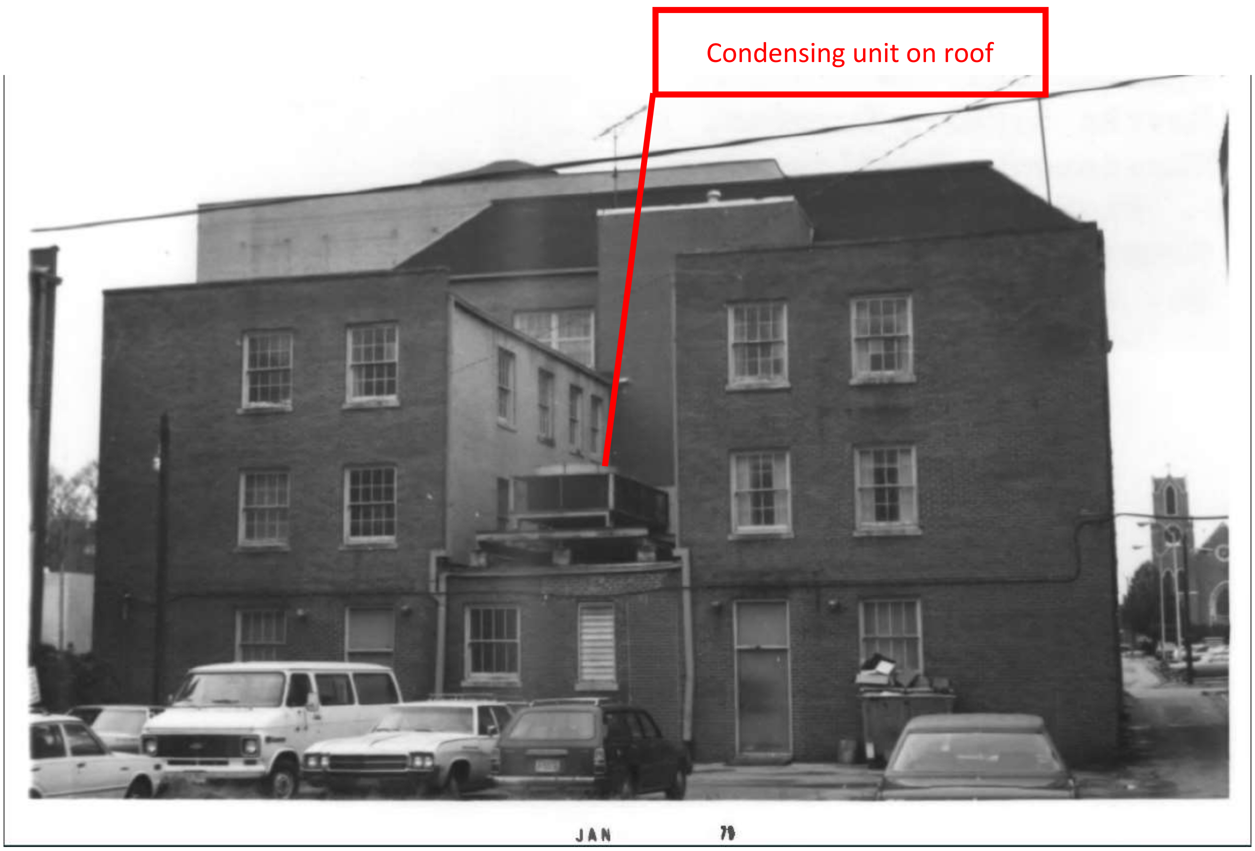


Existing HVAC Systems Schematic

Existing HVAC Systems Issues:

Issue 1: Relative Age Of Existing HVAC Components

Although the MLK building was originally built in 1928, there are no as-built documentation that states when the original HVAC systems were first installed. DX type cooling systems were not prolific during the 1920's when the building was first constructed and it is possible that the building was originally built with a heating only system. The digital archive for the National Register of Historic Places[1] does show the presence of a HVAC condensing unit installed on the first-floor roof (see "*1979 Photo of the Rear Side of Building*") so a pre-1979 install date for an HVAC system utilizing a large condensing unit can be assumed. Available documentation shows that new cooling only HVAC equipment was installed in existing ductwork near 2001. Field acquired data confirms this date as well. This indicates that the ductwork, ductwork lining, electric reheat, control dampers, and controls within the building was installed at least prior to 1979 which is a minimum of 39 years.



1979 Photo of the Rear Side of Building

With the existing DX equipment being installed around 2001, the DX equipment is the newest components of the existing systems at 17 years.

Although lifespans of building systems equipment can be extended through robust maintenance, building systems equipment with greatly extended lifespans can become difficult to maintain and can generate other problems such as operability and replacement part issues. Below is a table showing the estimated lifespan of the building's existing HVAC related equipment along with the age-related problems:

Table 1: Estimated Useful Life of Components Verses Estimated Installed Lifespan

HVAC Component or Equipment	BOMA[2] or SMACNA[3] Estimated Useful Life	Estimated Installed Lifespan	Current Related Issue
Existing Cooling Only DX Systems	15 years per SMACNA	17 years	Currently there are no issues with the operation or the maintenance of the installed DX units. However, these issues are expected to increase as the units age.
Pneumatic Controls of Electric Reheat Coils	18 years per BOMA	Greater than 39 Years	Age of these components are causing them to fail throughout the building. Replacement parts for pneumatic controls are hard to find due to more advance control systems making pneumatics obsolete. The components stage the heating within the respective zone served and their failure or inefficient operation causes occupant comfort issues.
Metal Ductwork	30 years per SMACNA	Greater than 39 Years	Structurally, the ductwork is most likely fine. Any sealants or gaskets initially installed with the ductwork have most likely deteriorated creating leakage.
Duct Lining	24 Years per SMACNA	Greater than 39 Years	Duct lining is exposed to the airstream that is circulated throughout the building. The age of the liner may be causing duct lining to deteriorate releasing products of the deterioration into the airstream. Although there are no known negative health effects related to duct lining deterioration, there could be a cleanliness issue that develops should the products be spread throughout the building and accumulate. Also, deteriorated lining loses its condensation control and energy loss effectiveness. The ductwork would require replacement in order to replace the duct lining.
Electric Reheat Coils	15 Years per SMACNA	Greater than 39 Years	Electric reheat coils are the primary source of heat for the building. Their age is causing them to fail throughout the building, creating occupant related comfort issues. Age related failures for electric coils may also result in increased fire or electrical hazards. Current energy codes do not allow for this type of system to be installed without the controls to prevent simultaneous cooling and heating.
Pneumatically Controlled Dampers and Controls	20 Years per SMACNA	Greater than 39 Years	The dampers are the primary source of zone control for the building and the age of these components are causing them to fail throughout. Failure could cause the dampers to be stuck wide open or to be fully closed creating comfort related issues. As stated above, replacement parts for pneumatic controls are difficult to find.

[2] *Preventative Maintenance Guidebook: Best Practices to Maintain Efficient and Sustainable Buildings* by the Building Owners and Managers Association (BOMA); 2010
[3] *HVAC Systems Duct Design* by the Sheet Metal and Air Conditioning Contractors' National Association, Inc. (SMACNA); 2006

The extended age of the equipment and components listed means that the best scenario for correcting their related issues is to replace entirely the existing system with a new system regardless of system type.

Issue 2: HVAC Zoning

Currently, the building's HVAC system consists of several large zones with single source of control for each zone. This is in itself is not an issue except for the following items:

- There are several offices with multiple occupants in a single zone. These zones comprise spaces located on the exterior of the building as well as interior spaces. Often, the temperature control for the zone is located in interior areas of the zone where the major cooling and/or heating loads are located at the exterior of the building.
    - Interior spaces are best controlled for comfort when in a zone separate from exterior spaces. Exterior spaces gain or lose heat more than respective interior spaces due to their exterior wall being in contact with the elements.
- The large conference room on the first floor is served by two separate DX systems as well as two separate duct heaters.
    - This space would be best served with one system since you would not have two separate sets of controls serving one large space. It is possible that the separate set of controls will conflict one another.
- Each zone has a respective zone damper and electric reheat coil. Should either of these fail, temperature control is compromised for the entire zone.

Issue 3: Corridor Returns

The existing HVAC systems have large corridor mounted return grilles in several areas of the building. Air is supplied into the individual spaces and returned into the corridor through door mounted return grilles or louvers. Originally, this was most likely done in order to minimize ductwork installation costs and minimize conflicts related to minimal space above the ceiling. Although the construction codes at the time of the installation allowed this, current construction codes do not. The reasoning is that corridors are considered a means of egress and should a fire be started in an area that returns air through a corridor, the returning air could carry smoke from the source of the fire through the egress corridor where people are attempting to leave the building.

Should any renovation cost reach approximately 35% or more of the value of the building, modification of the HVAC system in order to remove the corridor as a return path will be required in order to meet current codes. Should construction costs not reach the 35% threshold, the existing return issue could be "grandfathered in," meaning that code officials could overlook this or other code related issues due to their cost. Although there is potential for grandfathering the corridor returns, it is recommended that this issue be addressed in any HVAC renovation in order to prevent this from becoming an issue in the future.

HVAC Alternative System Selection Criteria:

Based upon the age of the HVAC components, poor zoning capability, as well as the corridor code issue described above, it is recommended that the HVAC systems be replaced in their entirety, including the ductwork. The reasoning for replacing the ductwork is that although the structural integrity of the existing ductwork is most likely intact, the interior insulation is most likely not and any attempt at cleaning the interior of the duct will most likely result in destroying the remaining insulation. This will affect every system on each floor. To replace the insulation will require disassembling the existing ductwork, replacing the insulation, and reassembling the duct. Since zoning rework is required, new ductwork is more feasible and less labor intensive. Minimizing the amount of ductwork would be preferable due to minimal ceiling space available.

Although the building is listed on the National Register of Historic Places, it is possible to replace the existing HVAC systems while still complying with the requirements of the listing providing that the exterior of the building remains as intact as possible. The HVAC systems as described in the following pages are possibilities that would be able to meet these requirements.

Selection criteria for selecting a replacement system is summarized below:

Table 2: HVAC Alternative System Selection Criteria and Reasoning

Criteria	Reasoning
Selected System must possess zoning capability greater than currently installed	Poor zoning is one of the building's current issues as described earlier.
The selected system must have minimal ductwork	Minimizing ductwork also minimizing ceiling space issues that are in the building as well as eliminating the existing need for corridor returns.
The selected system must minimize impact to the building's exterior.	The helps insure that the requirements of the National Register of Historic Places for the building are met.
The selected system must not require additional space out on the grounds of the building.	There is not much available due to the building being surrounded by parking and an alleyway.
The system must take advantage of the existing exterior equipment locations as best as possible.	Utilizing the existing structures supporting the existing condensing units is advantageous and helps ensure compliance with the requirements of the National Register of Historic Places.
The selected system must be more energy efficient than the currently installed system.	Saving energy would reduce current building related costs and help justify the expense of the existing system's replacement.
The selected system must meet current construction code requirements	Systems that do not meet current construction codes may not be approved by code authorities, may consume more energy, and are less safe than systems constructed to meet current codes.

The application of the above selection criteria eliminated the following HVAC systems as alternatives to be considered:

Table 3: Rejected HVAC System Alternatives

HVAC System	Reasoning for Rejection
Pass Through Air Conditioning Systems (PTAC's)	Would require significant modification to the building's exterior which could create problems with the building's listing on the National Register of Historic Places. PTAC's are also one of the least energy efficient alternatives available.
Chilled and Heating Water System	There is not enough space for a chiller and boiler in the building's first floor mechanical room. There is not enough exterior space for a ground mounted air-cooled chiller. Mounting an air-cooled chiller on the first-floor roof would most likely require significant structural modifications. A chilled and heating water system is also considered less energy efficient than the systems proposed later in this report.
Split System Heat Pumps with Variable Volume and Temperature (VVT) Dampers	Although similar to what is currently installed but zoning is provided with variable dampers and without electric reheat. Heating is provided by the air to air heat pump. DX or Heat Pump systems 4.5 tons are larger require economizers which could potentially require significant modifications to the building exterior since the existing units are all larger than 4.5 tons. Large return ducts will be required and the available ceiling space is inadequate.
Split System DX with Electric Reheat	This system is essentially the type that is currently installed only assuming that the equipment is to be replaced. Current energy codes do not allow for reheating previously cooled air without reducing the supply air flow rate by at least half. Doing so would require additional controls (such as variable speed drives, variable volume dampers, etc.) and significant duct sizes as mentioned in the system described above.
Ground Source Heat Pump System	There is not enough available land area in order to apply this system type.

The elimination of the above systems left two viable alternatives. Each of these alternatives will be described below along with the reasoning for potentially utilizing the respective system.

Prior to analyzing the systems, HVAC load calculations were performed. These calculations utilized the floorplans that we were given and assumed minimal roof and exterior wall insulation. Ventilation utilized within the load calculations meet the requirements of current codes. The calculated HVAC loads totaled to 43.9 Tons which fell in line with sizing expectations and therefore was utilized in the following comparisons.

HVAC System Alternatives:

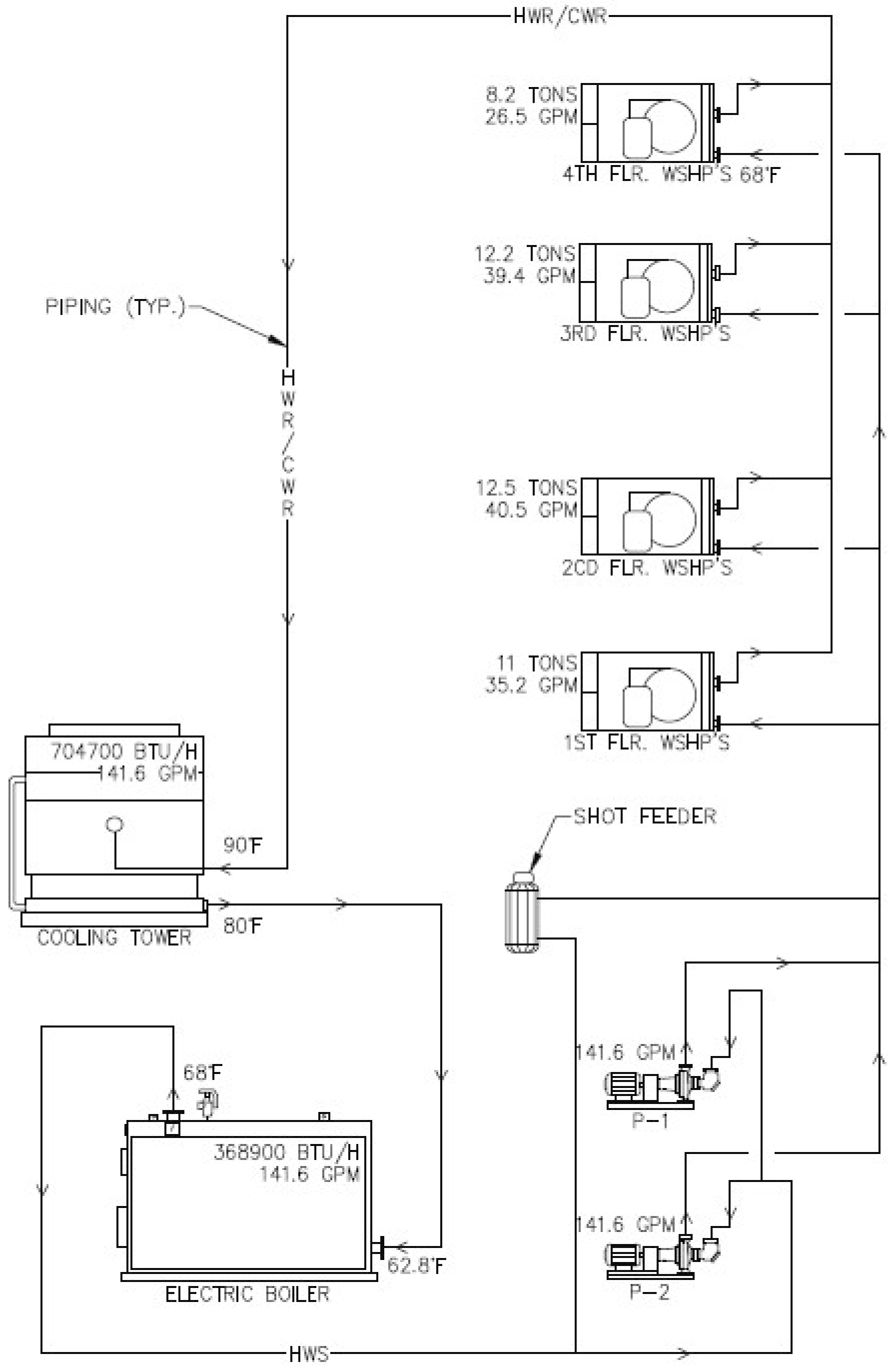
HVAC System Alternative 1: Water Source Heat Pumps

In order to best comply with the zoning requirements, to meet current codes, while modifying the building structure as little as possible, a water source heat pump (WSHP) system may be a viable solution. WSHP's are heat pumps that reject or take heat from water verses outside air. Water is circulated through piping from WSHP's to a boiler and/or cooling tower where heat is either added or taken. Please see the "*WSHP System Schematic*" for further components of the respective system.

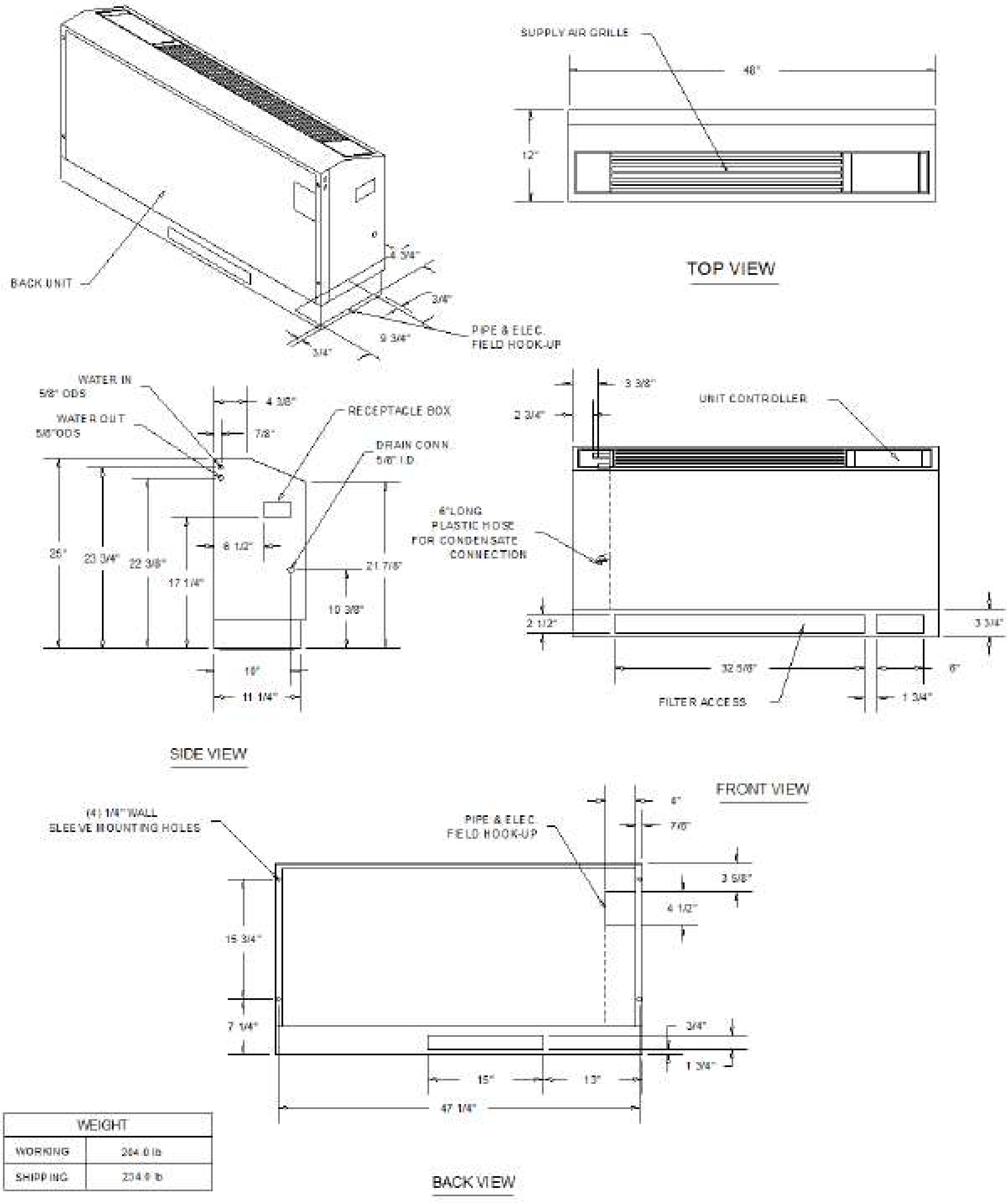
The reasons that the WSHP system could be a viable system type is based upon the following:

- Improved zoning, minimizing the impact of minimal above ceiling heights, as well as the elimination of corridor returns can be accomplished by utilizing Floor Mounted Console Units (*see "Floor Mounted Console Unit Example"*) or Vertical Stack Units (*See "WSHP Vertical Stack Unit Example (1 Ton")*) in respective spaces in order to provide individual occupants with their own temperature control. All of the return air would be retained within the individual space. Vertical Stack units would require the units to be aligned or stacked per floor since each share a common riser. Consoles or Stacked units would require minimal ductwork if any.
    - A stacked unit would also need to be built into a chase within the respective room it is installed and would require a special door for access (*See "WSHP Vertical Stack Unit Return Air Door Example (1 Ton)"*).
    - Above ceiling WSHP units are not as compact as the next system's available options. This is related to WSHP possession of a compressor and water to water heat exchanger.
- Water piping takes up much less room that ductwork and no modifications to ceiling heights would be required for distributing piping throughout the building.
    - Should console type units be utilized, fabricated chases may be required (*See "WSHP Floor Mounted Console Unit Installation Example"*) in order to cover and protect piping from the ceiling to the floor that would otherwise be routed exposed to view due to the presence of existing walls. The appearance of fabricated chases may seem unsightly to some, even though the chases can be painted to match the existing wall.
- The estimated service life of HVAC related piping is 30 years.
- WSHP's up to 25 tons are available to be utilized for larger areas but will require ductwork. WSHP units serving larger zones can utilize existing mechanical rooms.
- The estimated equipment service life for WSHP's is 19 years per SMACNA.
- Outside air would require new distribution ductwork but the ductwork sizes would be significantly smaller due to outdoor air moving less air than the original supply ductwork and there are no return ducts to be considered.
- A cooling tower (*please see "Cooling Tower Example (With Interior Cutaway)"*) could be located on the roof of the first floor (*please see "1979 Photo of the Rear Side of Building"*) where there are currently two existing condensing units. Cooling towers have an estimated service life of 20 years per SMACNA.
- An electric boiler as well as the necessary pumps, and water treatment can be placed within the first-floor mechanical room.
- The boiler would be required to be electric due to the absence of natural gas on the site. The heating requirement for the boiler would not be as great as that for a heating water system since air is not directly heated. The expected service life for electric boilers is 15 years per SMACNA.

- Hamilton County Government Maintenance personnel are familiar with maintaining this type of system since there are system types of this kind in use among their properties.
- WSHP systems are typically more efficient than other systems if interior zones are in cooling while exterior zones are in heating. When this occurs, the water transfers heat rejected by the interior zones to the exterior zones rather than rejecting heat to the outdoors.
- In order to best compare systems, the building characteristics and HVAC load requirements were inputted into an energy analysis program. The 2017 EIA average electrical cost of $0.1016/kWh for Tennessee was utilized in the calculations. The total results are included within the appendix. A summary of the estimated energy and first costs are listed below:
    - WSHP Estimated initial first cost: $210,371.00
    - WSHP Replacement Cost after 20 Years: $58,904.00
    - Estimated Annual Energy Cost: $18,055.00



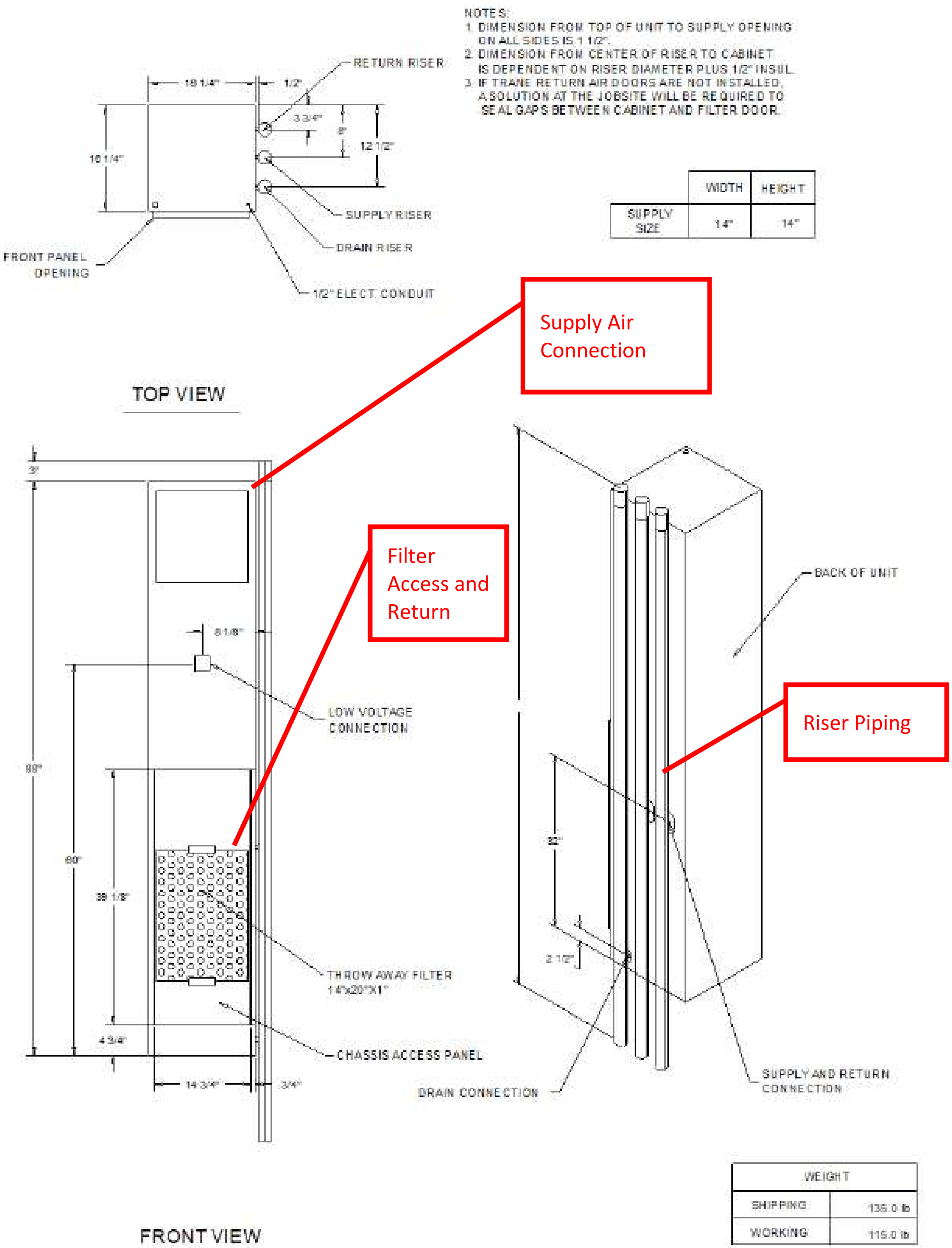
WSHP System Schematic



WEIGHT	
WORKING	204.0 lb
SHIPPING	234.0 lb

WSHP Floor Mounted Console Unit Example (1.25 Ton)

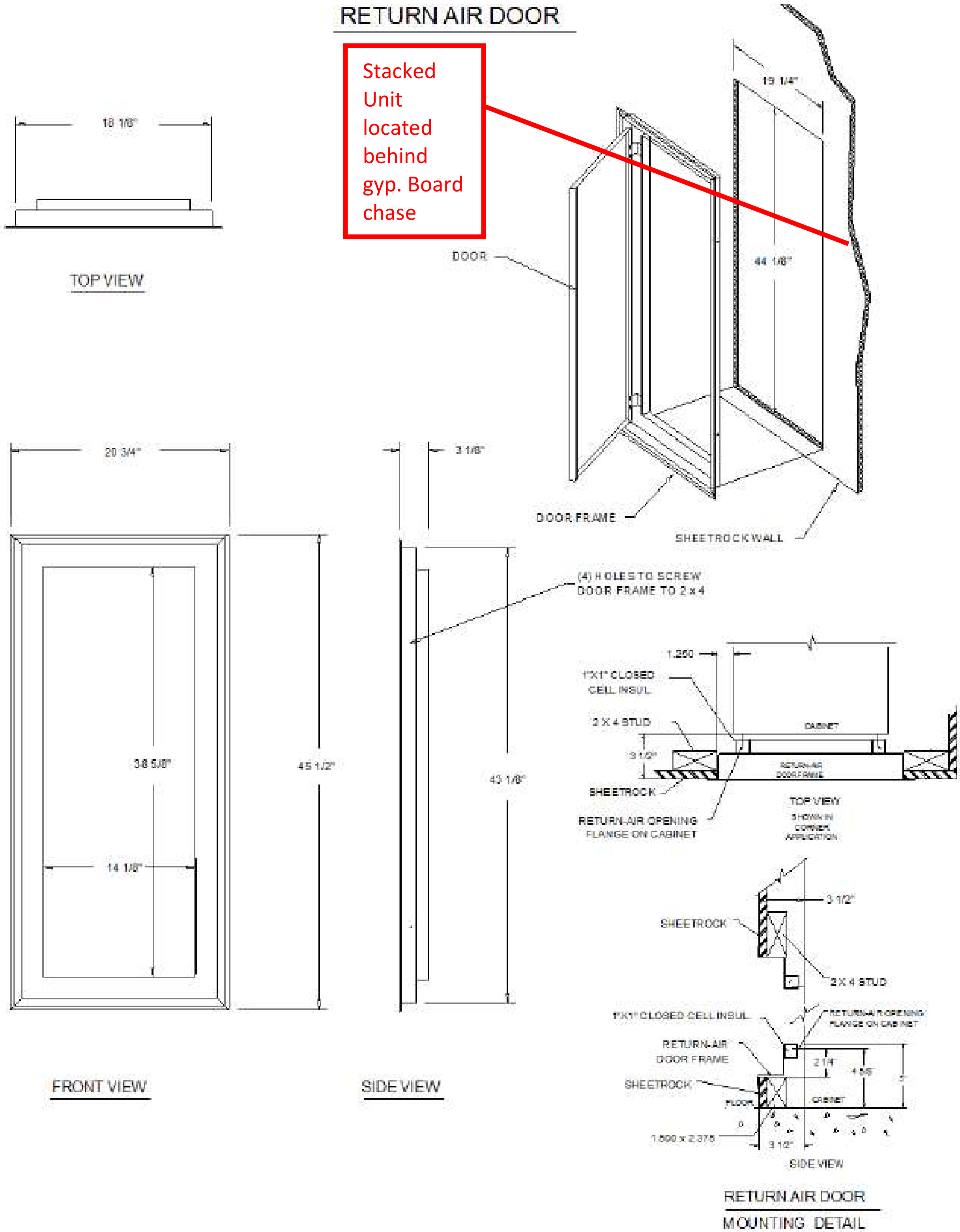
WSHP Floor Mounted Console Unit Installation Example



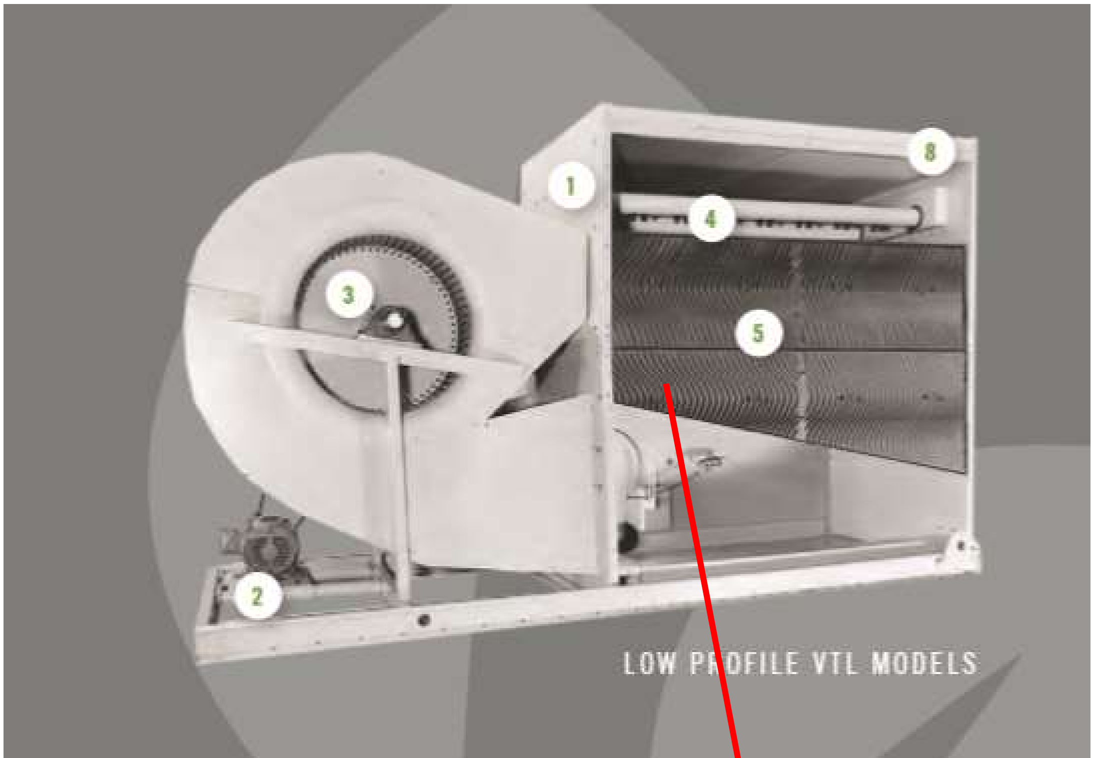
	WIDTH	HEIGHT
SUPPLY SIZE	14"	14"

WEIGHT	
SHIPPING	135.0 lb
WORKING	115.0 lb

WSHP Vertical Stack Unit Example (1 Ton)



WSHP Vertical Stack Unit Return Air Door Example (1 Ton)



<u>Cooling Tower Example (With Interior Cutaway)</u>

In order to best match the footprint and weight requirements of the structure supporting the existing condensing units, an open cooling tower will require utilization due to its smaller footprint and lower weight than closed cooling towers.

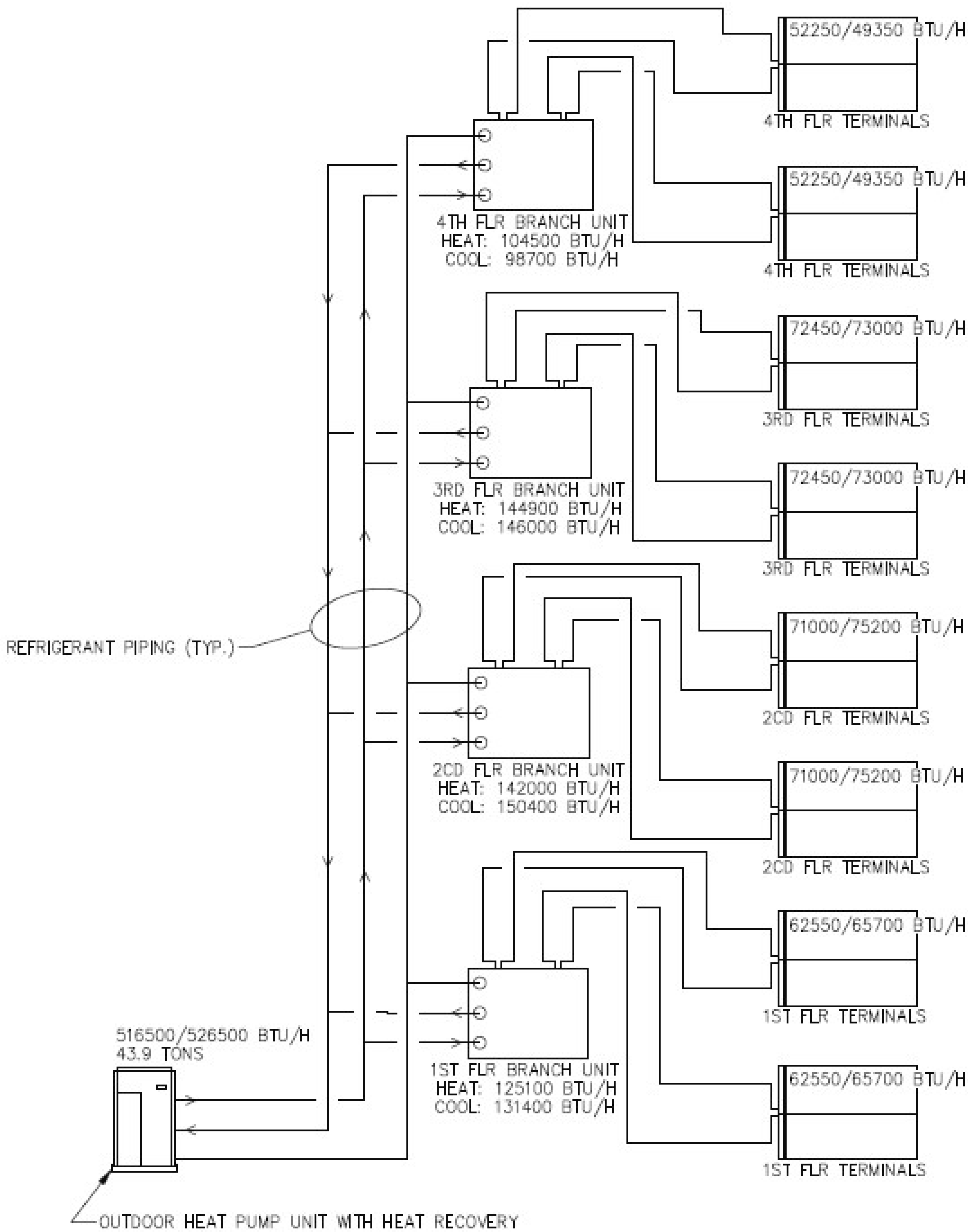
HVAC System Alternative 2: Variable Refrigerant Flow

Another viable HVAC system that can comply with the building's zoning requirements, meet current codes, and while modifying the building's structure as little as possible is a Variable Refrigerant Flow (VRF) system. Instead of circulating water to WSHP's, a boiler, and a cooling tower, a VRF system circulates refrigerant to and from terminals to an outdoor mounted heat pump (*please see the "VRF System Schematic"*). A branch unit (*See" Branch Unit Example"*) distributes the refrigerant to the terminals based upon need and heating or cooling requirement. A VRF system is essentially a heat pump type system that can heat and cool different zones simultaneously.

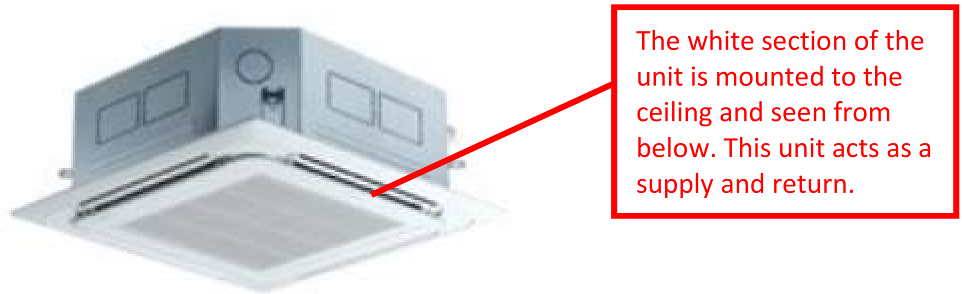
The reasons that the VRF system could be a viable system type is based upon the following:

- As with WSHP's, improved zoning as well as the elimination of corridor returns can be accomplished by the VRF system through the use of either Floor Mounted Terminal Units (*see "Floor Mounted Terminal Unit Example"*), Ceiling Mounted Terminal Units (*see" Ceiling Mounted Terminal Unit Example"*), or Ducted Terminal Units (*see "Ducted Terminal Unit Example"*) in respective spaces in order to provide individual occupants with their own temperature control. Even with the ducted terminal units, all of the return air would be retained within the individual space. VRF ducted terminal units are not very large (a 1 ton ducted terminal unit has a height of 10-¼") and are designed to be installed in areas with minimal ceiling space.
- Refrigerant piping takes up much less room that ductwork or water piping and no modifications to ceiling heights would be required for distributing refrigerant piping throughout the building.
    - As with WSHP Console units, Floor Mounted Terminal type units may require fabricated chases (*See "WSHP Floor Mounted Console Unit Installation Example"*) in order to cover and protect piping from the ceiling to the floor that would otherwise be routed exposed to view due to the presence of existing walls. These chases would be smaller for VRF systems since refrigerant piping is smaller than water piping. The appearance of fabricated chases may seem unsightly to some even though the chases can be painted to match the wall they are in front of.
- The estimated service life of a heat pump system (such as VRF) is 15 years per SMACNA. This includes the terminal units, branch units, outdoor condensing units, and piping.
- Vertical Ducted Terminal Units are available to be utilized for larger areas but will require ductwork. These units have typical capacities of 5 tons or less so care must be taken in their application.
- As with WSHP's, outside air would require new distribution ductwork but the ductwork sizes would be significantly smaller that the currently installed supply air ducts due to moving less air and no return air ductwork is needed.
- The outdoor mounted heat pump could be located on the roof of the first floor (*please see "1979 Photo of the Rear Side of Building"*) where there are currently two existing condensing units.
- VRF systems are typically more efficient than other systems (including WSHP) if interior zones are in cooling while exterior zones are in heating. When this occurs, the refrigerant transfers heat rejected by the interior zones to the exterior zones rather than rejecting heat to the outdoors through the heat pump.
- In order to best compare system choices, the building characteristics and HVAC load requirements were inputted into a system analysis tool as mentioned in Choice # 1. As with the WSHP calculations, the 2017 EIA average electrical cost of $0.1016/kWh for Tennessee was utilized in the calculations. The total results are included within the appendix. A summary of the estimated energy, maintenance, and first costs are listed below:

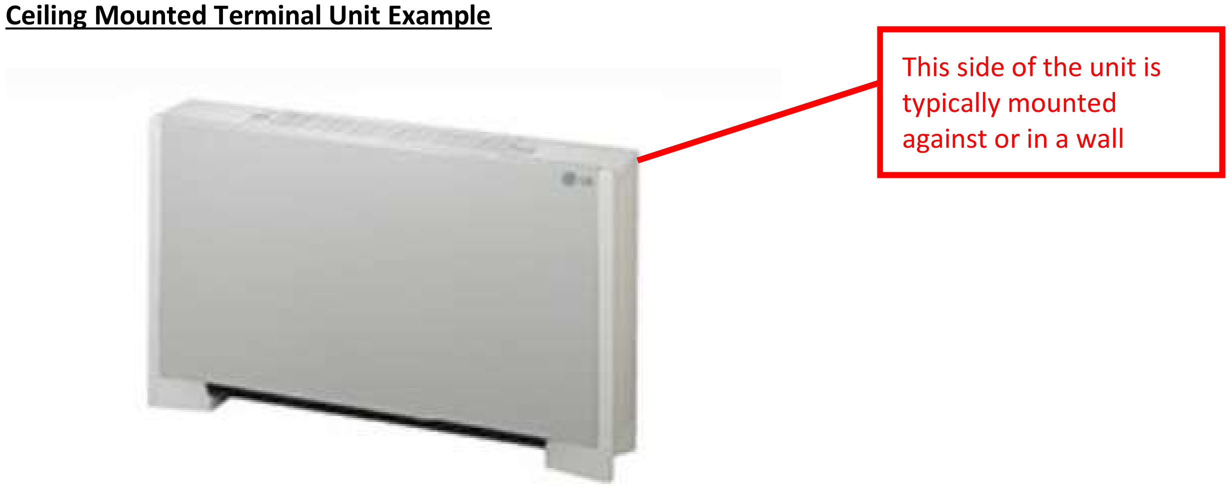
- Estimated VRF initial first cost: $273,482.00
- VRF Replacement Cost after 15 Years: $109,393.00
- Estimated VRF Annual Energy Cost: $9,543.00



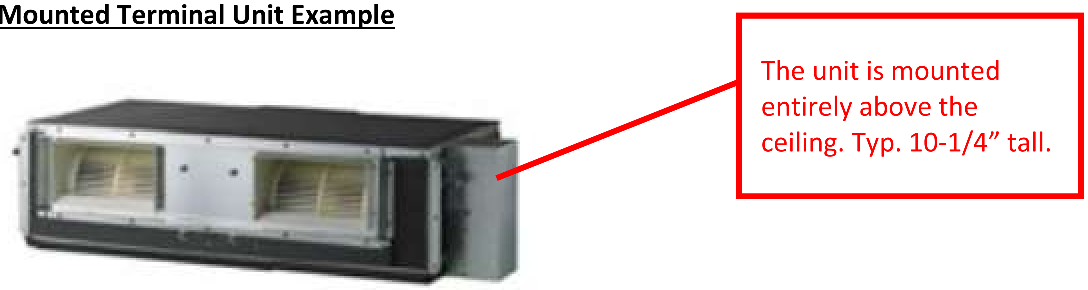
<u>VRF System Schematic</u>



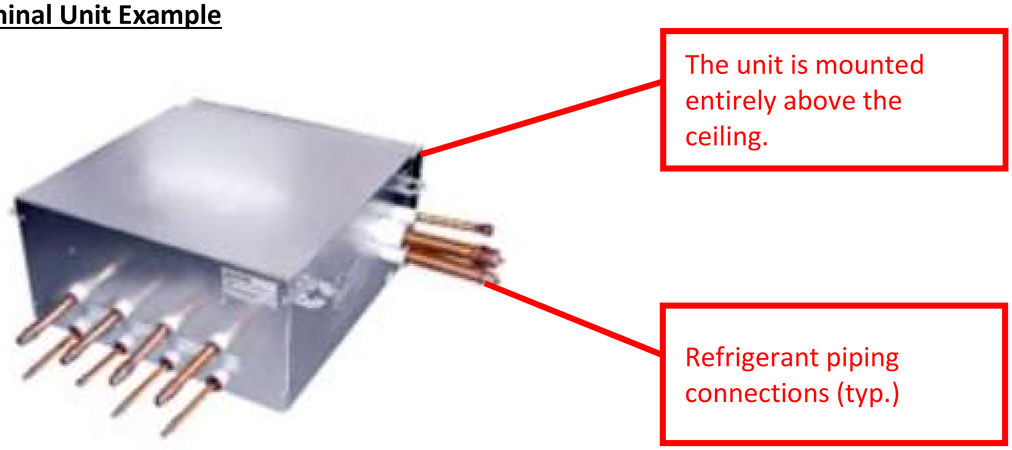
Ceiling Mounted Terminal Unit Example



Floor Mounted Terminal Unit Example



Ducted Terminal Unit Example



Branch Unit Example

Recommendation

For further analysis, the estimated first costs, calculated HVAC related utility costs, and replacement costs were inputted into an economic analysis program and analyzed over a 50-year period in order to accommodate estimated service life differences, the output of which is located in the appendix. An escalation rate of 1% for electrical costs and 3% for equipment costs were utilized in the calculations. Maintenance costs were excluded in the analysis due to the Owner providing their own maintenance and not through a separate contractor. The economic differences between the two systems are summarized in the table below:

Table 4: Economic Differences between WSHP and VRF

Item	WSHP Result ($)	VRF Result ($)	Difference ($) [Lowest]
Estimated Initial First Cost	$210,371.00	$273,482.00	$63,111.00 [WSHP]
Estimated Equipment Replacement Costs	$58,904.00 after 20 Years	$109,393.00 after 15 Years	$50,489.00 [WSHP]
Estimated Annual HVAC Related Energy Costs	$18,055.00	$9,543.00	$8,512.00 [VRF]
Total Present Worth over a 50-year period	$1,684,427.00	$1,744,442.00	$60,015.00 [WSHP]

Although the VRF had the highest energy savings, the WSHP system has the lowest Estimated Initial First cost, lowest Estimated Equipment Replacement Costs over the longest period, which resulted in the WSHP having the lowest Total Present Worth between the two systems. When considering how long it would take for the difference in HVAC Related Energy Costs between the two systems to pay for the difference in initial first cost of the VRF system, the period of time it takes to pay the amount back is 7.1 years when a 1% escalation cost for energy is applied.

The pro's and con's for selecting each system are summarized on the next page.

Table 5: Pro's and Con's between WSHP and VRF

System	Pro's For Selection	Con's Against Selection
WSHP	Lowest Estimated Initial First Cost, Estimated Equipment Replacement Costs, and Total Present Worth; A lower Total Present Worth means that less "future" money will be spent on the WSHP system vs. VRF; WSHP meets all of the selection criteria requirements	Not as much energy savings as the VRF system; applying above ceiling options are not as feasible as the VRF system for this building which could mean that chases require fabrication; Water piping takes up more space than refrigerant piping which means that the installation/routing of piping may not be as easy with WSHP as with VRF; WSHP requires a boiler that must be electric unless natural gas is routed to the site.
VRF	Highest Estimated HVAC Related Energy Savings; The system has more above ceiling options available than WSHP meaning; VRF meets all of the selection criteria requirements; Refrigerant piping takes up less space than water piping which could make the installation and/or routing of piping easier than WSHP piping.	Highest Estimated Initial First Cost, Estimated Equipment Replacement Costs, and Total Present Worth; A higher Total Present Worth means that more "future" money will be spent on the VRF system vs. WSHP; Hamilton County Maintenance Personnel may be unfamiliar with this type of system.

Based upon the above pro's and con's, it is recommended that the Owner utilize a WSHP system for replacing the existing HVAC system of the building providing that the Owner believes that the con's of the WSHP system do not outweigh the pro's. Both systems will meet the criteria for equipment selection and will perform well, but should the Owner want to emphasize energy savings and the lack of fabricated chases over the other factors listed in this report, a VRF system would be the better choice.

Please note that the above initial first costs listed in this report were based upon preliminary budget estimates. Should the Owner agree with the premise of this report and accept its findings, a more detailed budget estimated based upon equipment selection and layout can be performed.

End of Report

Appendix

Energy Analysis Program Output

Annual Cost Summary

18-002 MLK BLDG
Campbell & Associates, Inc.

02/12/2018
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Table 1. Annual Costs

Component	MLK VRF ($)	MLK WSHP ($)
Air System Fans	3,663	3,133
Cooling	4,034	5,525
Heating	1,846	7,292
Pumps	0	1,960
Heat Rejection Fans	0	146
HVAC Sub-Total	**9,543**	**18,055**
Lights	6,094	6,094
Electric Equipment	0	0
Misc. Electric	0	0
Misc. Fuel Use	0	0
Non-HVAC Sub-Total	**6,094**	**6,094**
Grand Total	**15,637**	**24,149**

Only HVAC related energy costs were considered in the economic analysis. Lighting energy direct costs were excluded.

Table 2. Annual Cost per Unit Floor Area

Component	MLK VRF ($/ft²)	MLK WSHP ($/ft²)
Air System Fans	0.214	0.183
Cooling	0.236	0.323
Heating	0.108	0.426
Pumps	0.000	0.115
Heat Rejection Fans	0.000	0.009
HVAC Sub-Total	**0.558**	**1.056**
Lights	0.356	0.356
Electric Equipment	0.000	0.000
Misc. Electric	0.000	0.000
Misc. Fuel Use	0.000	0.000
Non-HVAC Sub-Total	**0.356**	**0.356**
Grand Total	**0.914**	**1.412**
Gross Floor Area (ft²)	17103.6	17103.6
Conditioned Floor Area (ft²)	17103.6	17103.6

Note: Values in this table are calculated using the Gross Floor Area.

Table 3. Component Cost as a Percentage of Total Cost

Component	MLK VRF (%)	MLK WSHP (%)
Air System Fans	23.4	13.0
Cooling	25.8	22.9
Heating	11.8	30.2
Pumps	0.0	8.1
Heat Rejection Fans	0.0	0.6
HVAC Sub-Total	**61.0**	**74.8**
Lights	39.0	25.2
Electric Equipment	0.0	0.0
Misc. Electric	0.0	0.0
Misc. Fuel Use	0.0	0.0
Non-HVAC Sub-Total	**39.0**	**25.2**
Grand Total	**100.0**	**100.0**

Engineering Economic Analysis Program Outputs and Inputs

Lifecycle Summary

Project: 18-002 MLK Bldg HVAC Analysis — 2/12/2018
Prepared By: Campbell & Associates, Inc. — 2:19:29 PM

MLK Building HVAC Analysis

Comparison between WSHP and VRF

Type of Analysis........ Public Sector Lifecycle Analysis
Type of Design Alternatives........ Mutually Exclusive
Length of Analysis........ 50 yrs
Discount Rate........ 0.00 %

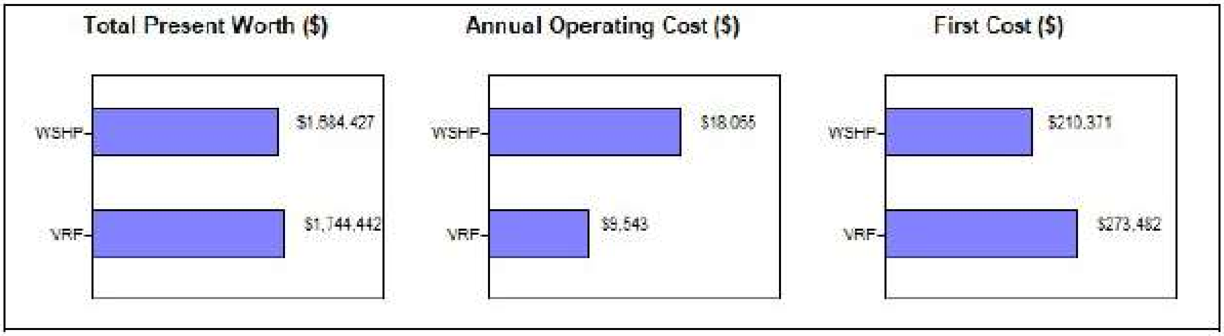

Table 1. Executive Summary

Economic Criteria	Best Design Case for Each Criteria	Value ($)
Incremental SIR Analysis	Water Source Heat Pump	-
Lowest Total Present Worth	Water Source Heat Pump	$1,684,427
Lowest Annual Operating Cost	Variable Refrigerant Flow	$9,543
Lowest First Cost	Water Source Heat Pump	$210,371

Table 2. Design Cases Ranked by First Cost

Design Case Name	Design Case Short Name	Total Present Worth ($)	Annual Operating Cost ($/yr)	First Cost ($)
Water Source Heat Pump	WSHP	$1,684,427	$18,055	$210,371
Variable Refrigerant Flow	VRF	$1,744,442	$9,543	$273,482

Table 3. Incremental Analysis Data

Challenger	Base Case	Additional First Cost ($)	NPW Savings ($)	SIR	Payback Period (yrs)
VRF	WSHP [Winner]	$63,111	$-60,015	0.049	7.1

Analysis Details

Project: 18-002 MLK Bldg HVAC Analysis
Prepared By: Campbell & Associates, Inc.

2/13/2018
10:47:32 AM

MLK Building HVAC Analysis

Comparison between WSHP and VRF

Type of Analysis .... Public Sector Lifecycle Analysis
Type of Design Alternatives .... Mutually Exclusive
Length of Analysis .... 50 yrs
Discount Rate .... 0.00 %

1A. Summary of Results

Base Case [Winner]	Water Source Heat Pump [WSHP]
Challenger	Variable Refrigerant Flow [VRF]
[WSHP] Total Present Worth ($)	$1,684,427
[VRF] Total Present Worth ($)	$1,744,442
Net Present Worth Savings ($)	$-60,015
Savings-To-Investment Ratio (SIR)	0.049
Payback Period (yrs)	7.1 years

1B. Comparative Analysis Details

		Cash Flow (Present Worth $)			SIR and Payback Calculation (Present Worth $)				
Year	Date	[WSHP] Cash Flow ($)	[VRF] Cash Flow ($)	Net Present Worth Savings ($)	Operating Cost Savings ($)	Cumulative Operating Cost Savings ($)	Additional Investment Cost ($)	Cumulative Additional Investment Cost ($)	Year-End SIR
0	Initial	210,371	273,482	-63,111	0	0	63,111	63,111	0.000
1	1	18,236	9,638	8,597	8,597	8,597	0	63,111	0.136
2	2	18,418	9,735	8,683	8,683	17,280	0	63,111	0.274
3	3	18,602	9,832	8,770	8,770	26,050	0	63,111	0.413
4	4	18,788	9,930	8,858	8,858	34,908	0	63,111	0.553
5	5	18,976	10,030	8,946	8,946	43,854	0	63,111	0.695
6	6	19,166	10,130	9,036	9,036	52,890	0	63,111	0.838
7	7	19,357	10,231	9,126	9,126	62,016	0	63,111	0.983
8	8	19,551	10,334	9,217	9,217	71,233	0	63,111	1.129
9	9	19,746	10,437	9,309	9,309	80,542	0	63,111	1.276
10	10	19,944	10,541	9,403	9,403	89,945	0	63,111	1.425
11	11	20,143	10,647	9,497	9,497	99,441	0	63,111	1.576
12	12	20,345	10,753	9,592	9,592	109,033	0	63,111	1.728
13	13	20,548	10,861	9,687	9,687	118,720	0	63,111	1.881
14	14	20,754	10,969	9,784	9,784	128,505	0	63,111	2.036
15	15	20,961	181,510	-160,549	-160,549	-32,044	0	63,111	-0.508
16	16	21,171	11,190	9,981	9,981	-22,063	0	63,111	-0.350
17	17	21,383	11,302	10,081	10,081	-11,982	0	63,111	-0.190
18	18	21,596	11,415	10,182	10,182	-1,800	0	63,111	-0.029
19	19	21,812	11,529	10,283	10,283	8,483	0	63,111	0.134
20	20	128,418	11,644	116,773	116,773	125,256	0	63,111	1.985
21	21	22,251	11,761	10,490	10,490	135,747	0	63,111	2.151
22	22	22,473	11,878	10,595	10,595	146,342	0	63,111	2.319
23	23	22,698	11,997	10,701	10,701	157,043	0	63,111	2.488
24	24	22,925	12,117	10,808	10,808	167,851	0	63,111	2.660
25	25	23,154	12,238	10,916	10,916	178,767	0	63,111	2.833
26	26	23,386	12,361	11,025	11,025	189,792	0	63,111	3.007
27	27	23,620	12,484	11,135	11,135	200,927	0	63,111	3.184
28	28	23,856	12,609	11,247	11,247	212,174	0	63,111	3.362
29	29	24,094	12,735	11,359	11,359	223,533	0	63,111	3.542
30	30	24,335	278,388	-254,053	-254,053	-30,519	0	63,111	-0.484
31	31	24,579	12,991	11,588	11,588	-18,932	0	63,111	-0.300

Analysis Details

Project: 18-002 MLK Bldg HVAC Analysis
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		Cash Flow (Present Worth $)			SIR and Payback Calculation (Present Worth $)				
Year	Date	[WSHP] Cash Flow ($)	[VRF] Cash Flow ($)	Net Present Worth Savings ($)	Operating Cost Savings ($)	Cumulative Operating Cost Savings ($)	Additional Investment Cost ($)	Cumulative Additional Investment Cost ($)	Year-End SIR
32	32	24,825	13,121	11,703	11,703	-7,228	0	63,111	-0.115
33	33	25,073	13,252	11,821	11,821	4,592	0	63,111	0.073
34	34	25,324	13,385	11,939	11,939	16,531	0	63,111	0.262
35	35	25,577	13,519	12,058	12,058	28,589	0	63,111	0.453
36	36	25,833	13,654	12,179	12,179	40,768	0	63,111	0.646
37	37	26,091	13,790	12,300	12,300	53,069	0	63,111	0.841
38	38	26,352	13,928	12,423	12,423	65,492	0	63,111	1.038
39	39	26,615	14,068	12,548	12,548	78,040	0	63,111	1.237
40	40	219,029	14,208	204,820	204,820	282,860	0	63,111	4.482
41	41	27,150	14,350	12,800	12,800	295,660	0	63,111	4.685
42	42	27,422	14,494	12,928	12,928	308,588	0	63,111	4.890
43	43	27,696	14,639	13,057	13,057	321,645	0	63,111	5.096
44	44	27,973	14,785	13,188	13,188	334,833	0	63,111	5.305
45	45	28,253	428,613	-400,360	-400,360	-65,528	0	63,111	-1.038
46	46	28,535	15,082	13,453	13,453	-52,075	0	63,111	-0.825
47	47	28,821	15,233	13,587	13,587	-38,487	0	63,111	-0.610
48	48	29,109	15,385	13,723	13,723	-24,764	0	63,111	-0.392
49	49	29,400	15,539	13,861	13,861	-10,904	0	63,111	-0.173
50	50	29,694	15,695	13,999	13,999	3,096	0	63,111	0.049
Totals		1,684,427	1,744,442	-60,015	3,096		63,111		

Study Inputs

Study Title	MLK Building HVAC Analysis	
Study Description :		
	Comparison between WSHP and VRF	
Type of Analysis	Public Sector Lifecycle Analysis	
Type of Design Alternatives	Mutually Exclusive	
Base Year	1	
Currency Symbol	$	
Length of Analysis	50	yrs
Discount Rate	0.00	%

Design Case Inputs

Type of Analysis........ Public Sector Lifecycle Analysis
Length of Analysis........ 50 yrs
Income Taxes........ Not Considered

General Information :

Design Case Name .... Water Source Heat Pump
Design Case Short Name ... WSHP
Description :

Investment Costs :

Cost Item	Cost ($)	Year Incurred	Esc Rate (%/yr)	Salvage Value ($)	Useful Life (yrs)
Installation	$ 210,371	0	0.00	$ 0	20

There are no loan inputs

Annual Operating Costs :

Cost Item	Cost ($)	Start Year	Number Of Years	Esc Rate (%/yr)
Maintenance	$ 0	1	50	0.00
Utility Costs	$ 18,055	1	50	1.00

Non-Annual Operating Costs :

Cost Item	Cost ($)	Year First Incurred	Times Cost Occurs	Years Between Costs	Esc Rate (%/yr)
Replacement Costs	$ 58,904	20	2	20	3.00

Design Case Inputs

Project: 18-002 MLK Bldg HVAC Analysis 2/13/2018
Prepared By: Campbell & Associates, Inc. 11:45:46 AM

Type of Analysis .... Public Sector Lifecycle Analysis
Length of Analysis .... 50 yrs
Income Taxes .... Not Considered

General Information :

Design Case Name .... Variable Refrigerant Flow
Design Case Short Name ... VRF
Description :

Investment Costs :

Cost Item	Cost ($)	Year Incurred	Esc Rate (%/yr)	Salvage Value ($)	Useful Life (yrs)
First Cost	$ 273,482	0	0.00	$ 0	15

There are no loan inputs

Annual Operating Costs :

Cost Item	Cost ($)	Start Year	Number Of Years	Esc Rate (%/yr)
Maintenance	$ 0	1	50	0.00
Energy	$ 9,543	1	50	1.00

Non-Annual Operating Costs :

Cost Item	Cost ($)	Year First Incurred	Times Cost Occurs	Years Between Costs	Esc Rate (%/yr)
Replacement	$ 109,393	15	3	15	3.00