# VERMONT TECHNICAL COLLEGE

# Bachelor of Science in Architectural Engineering Technology

# Capstone Senior Design Projects

# (2017)

## Heating, Ventilating, and Air-Conditioning Engineering Projects (2)

## Structural Engineering Project

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# Project Overview

Vermont Technical Consultants (VTC) is an environmental systems selection company. The proposal for this project came from ASHRAE student design challenge. The purpose of this project is to pick the best system for the Meteorological building in Diego Ramirez Islands. Our group is given fourteen weeks to come up with our solution to the owner's project requirements.

Introduction:

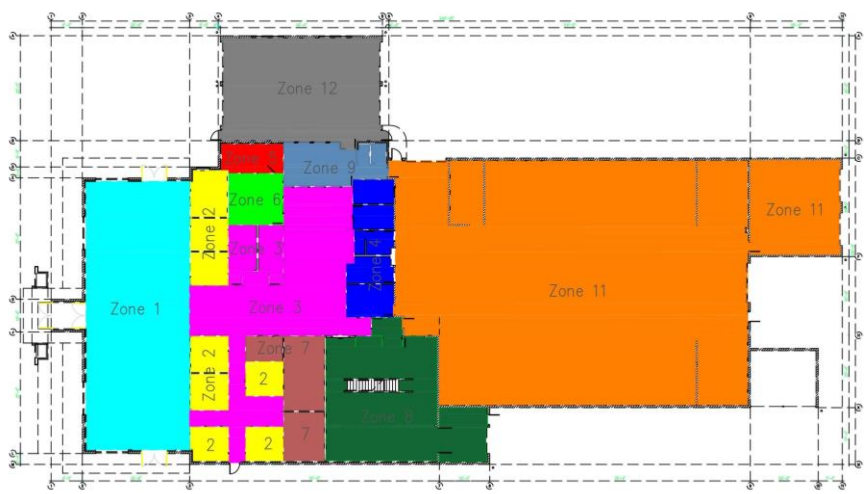
The building in question is a meteorological station located on the Diego Ramirez Islands, Chile. The facility is in operation for 24 hours a day, seven days a week and is “self- sustaining” in energy and design. It is a single- story with a mezzanine office and large repair workspace in the building. The project will be directed as a design/ bid/ build.

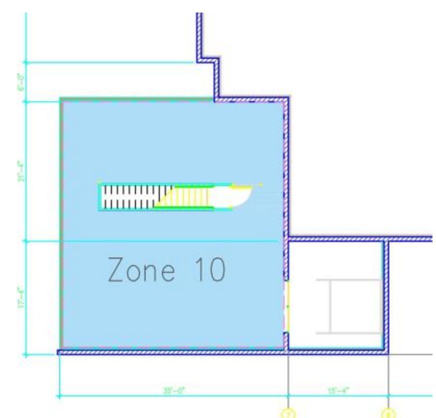
Owner project requirements have specific goals which are looking for all three systems to meet. All three systems must have a cost analysis for the initial, operations, and maintenance over a 50 year period. VTC must show a basic schematic layout of our three systems with zoning and energy saving strategies. Every effort should account for sustainable design, energy efficiency, health and safety, occupant comfort, functionality, longevity, flexibility, serviceability, and maintainability.

The building caters to meteorological operations that includes overnight stay. There will be eight private bedrooms, office cubicle area, meeting rooms, and shared spaces, involving a kitchen area, storage, copier areas, small meeting and break areas, larger meeting areas and a large repair facility for operation equipment. A small parking garage and a large service area for maintenance of any type. The building systems will have to take care of the occasional vehicle that will be idling inside the building.

Meteorological building will house eight people at most. There will be two people occupying the building at all times. The main goal is to pick out the best system based on the life cycle cost analysis and energy efficiency. VTC has picked out three systems that we will compare to our baseline system and all systems will comply with ASHRAE standards. The building will be comfortable, and properly vented with superior indoor air quality. This is accomplished by good ventilation and appropriate system sizing. The server room and data room will have their own zone and they will each have cooling with ventilation.

We identified from ASHRAE 90.1 the baseline system to compare to three other systems. The building was split into zones for individual climate control. Zoning will be consistent throughout all three systems. All occupancy schedules will be the same as well. This is in line of what the code specifies to equally compare all four systems to one another.



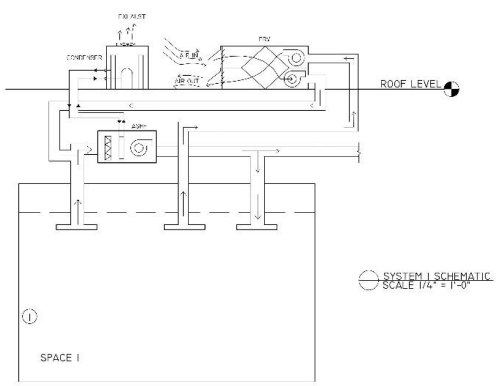

Baseline System:

The baseline system is a package rooftop air conditioner. ASHRAE 90.1 guide outlines a system based on your climate zone and square footage. The system will be constant volume fan controlled and will have direct expansion (DX) cooling system. For heating it has a vented gas fired furnace. The rooftop system will come with standard pleated filter racks and basic fresh outdoor air intake. The baseline rooftop unit was chosen because of simplicity and due to the frequent use in commercial spaces, especially with one story buildings.

System 1:

The first system is using air source heat pumps (ASHP) that will be ceiling hung air handlers with short duct runs to supply to multiple areas from one unit. By having multiple units it will allow for good zone control and much less reliance on a single large system to take care of the building. These ASHP units are powered by electricity. Each zone will have a separate thermostat for individual climate control. These ducted heat pumps will be coupled with a separate Energy Recovery Ventilator (ERV) system. This will provide fresh outdoor air while recovering sensible and latent energy from the air as it goes through the unit. Having a unit like this will increase the building's efficiency and help to meet the building's heating and cooling requirements. For the parking and garage space there will be separate ceiling hung gas fired unit heaters with no cooling for the space and separate exhaust fans.

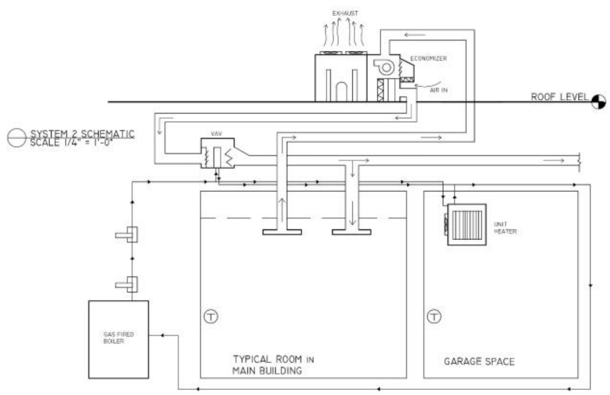
The big energy savings with system 1 comes from the ERV. When air gets removed from the building, energy was used to warm that air, but it needs to be exhausted. The ERV uses the warm air to precondition the outdoor air coming into our system. By using an ASHP it is inherently efficient with the system having a high COP. The hallways were the main spot for our systems. The systems are placed in the building where operation and maintenance can be performed. If maintenance needs to happen, it would not shut down the use of the individual rooms.




System 2:

The second system will have a gas fired boiler with VAV reheat boxes for heating. Cooling will be handled by rooftop units with DX cooling and will also be equipped with economizers. The economizers will take advantage of free cooling due to the already cool climate and pull fresh outdoor air. This will lower power consumption through much of the cooling season and provide cool, fresh, outdoor air to cool the indoor spaces. With the placement of VAV boxes and reheat coils in each room it will allow precise control the individual rooms. It will also introduce fresh outdoor air to meet minimum ventilation requirements. For the garage spaces, heating will be handled by ceiling hung hot water fan coil units fed by the hot water loop form the boiler.

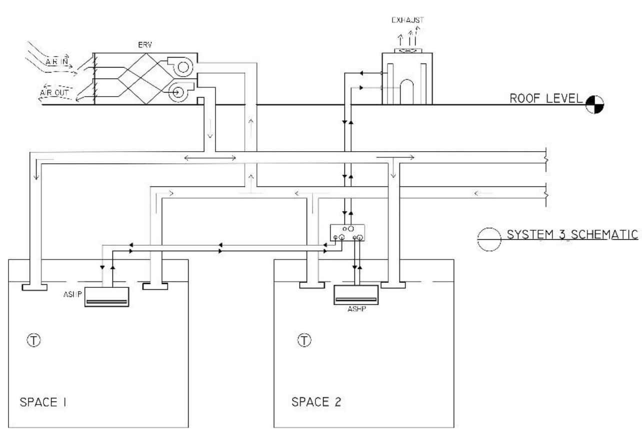
System 2 economizer will bring major cost savings for cooling. The economizer is correlated with "free cooling". When temperatures and condition are right outside we can use that air and bring it into our building to condition the spaces. What little heating the building has, will be heated efficiently by the VAV reheat system. The economizer is located on the roof with the condenser. The VAV boxes are located in the drop down ceiling. The garage space will be heated off the boiler loop that also goes to our VAV reheat boxes. The water loop is attached to the fan coil units that will heat our garage spaces.




System 3:

The last system it will utilize multiple ductless split ASHP also known as a variable refrigerant flow (VRF) system. The VRF will be located within each of the spaces. There will be wall and ceiling mounted evaporator coils throughout the building to handle each zone. The split units have constant volume air making for good climate control. This system will also utilize a roof mounted DOAS to handle energy recovery and ventilation requirements. For the garage spaces they will be heated with ceiling hung gas fired unit heaters same as system 1.

The space is heated and cooled by the ASHP, and ventilated by the ERV. The ERV in this system will be where we find significant energy savings within our building. This system will exchange indoor exhaust air with fresh outdoor air. The air source heat pump configuration allows for individual climate control.



Overall:

All three systems work well for the building and have pros and cons and would help to achieve the buildings goals. The initial cost and life cycle cost helped to differentiate which of the three systems are the most viable. The life cycle cost (LCC) is over a 50 year study period. This was important to figure over time because of inflation and owners rate of return. Our baseline system consists of only rooftop units came to a total price of $274,594. This is includes labor and materials for all of the aspects of installing a rooftop. System 1 has the highest cost of all of the systems. The initial cost and the total LCC analysis is respectively $372,285 initial cost, and $1,026,362 for the LCC. This is because of the large amount of individual condensers instead of having a single centralized unit to handle the whole building. System 2 was the second most expensive for initial cost at $339,034, but was by far the lowest for the LCC cost at $655,263. Due to the small amount of equipment that has relatively low amounts of maintenance which keeps the overall cost down. This system also uses more propane than electricity, due to propane's lower cost this saved money overall for the system.  System 3 was the middle of the road with an initial cost of $293,661 and an LCA cost of $818,100, due to the use of one centralized condenser with many evaporators which was able to keep the cost down.

VTC result is that system 2 would be the best choice for the building for a number of different reasons. First, the initial price, even though it's not the lowest, is a reasonable cost for a system like this. What stands out is the low LCC cost, making this system a very good long term investment. This system is also highly efficient with its use of a rooftop paired with an economizer which takes advantage of lots of free cooling for an environment like this. What the system also does well is keep the electricity cost down by using a gas fired boiler for its heat instead of using heat pumps which rely only on electricity to heat and cool the spaces. By having many decentralized components the system it makes system 2 highly reliable. The VAV boxes will be less prone to issues or regular breakdowns, and even if there are problems, they can be relatively simple to fix. Overall we think system 2 is the one we would install for this building.

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# Meteorological Station

SRS Engineering is designing the structural system for the 2017 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Student Design Competition building. A new meteorological station is to be built on Isla Bartolomé, the largest of the Diego Ramirez Islands off the southern coast of Chile. This location is extremely remote and is in a highly seismic zone. The 22 foot high one-story building consists of an approximately 8,100 sq. ft. living/housing and training area, a 1600 sq. ft. mezzanine weather monitoring office space, as well as an 8600 sq. ft. vehicle service/repair area.

Our design objective is to provide an efficient and economical structural system that also takes into account long-term performance, longevity and sustainability issues.

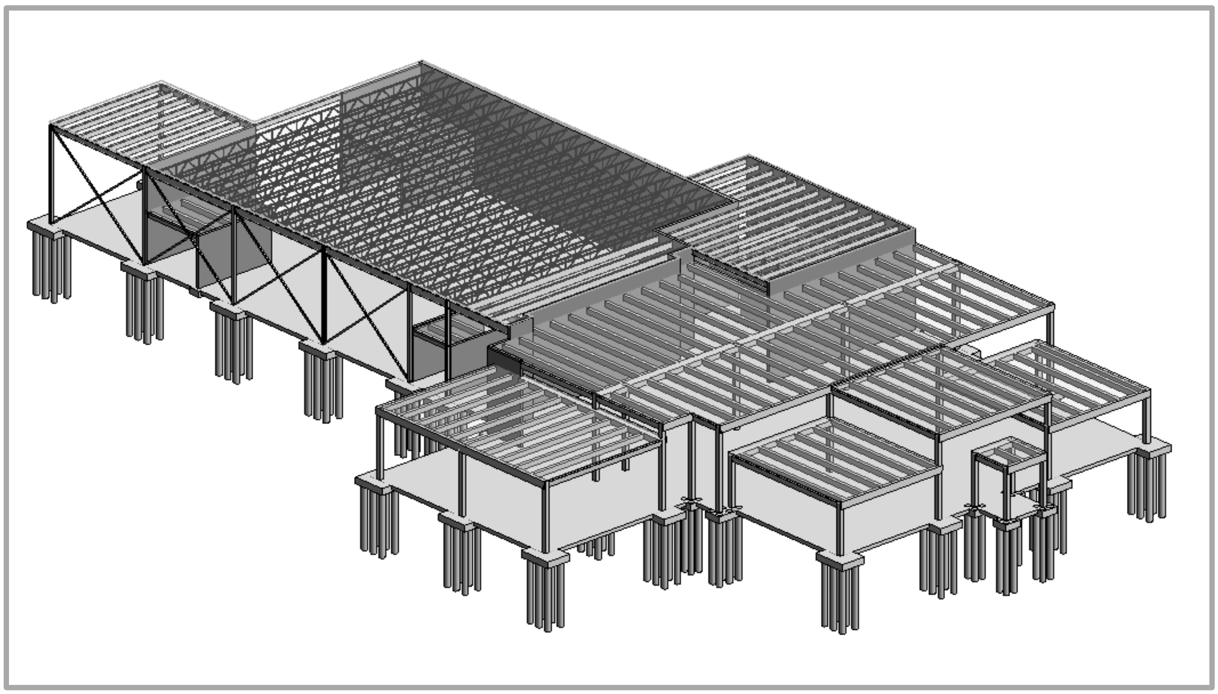
*Above*: An architectural rendering of the proposed meteorological station.

## Hybrid Structural System

A mixed system of structural steel and reinforced concrete is used in order to best meet the owner's needs and the design challenges, which include a long span in the vehicle service area and a considerable seismic lateral load, as well as to make use of the availability of materials found in this location, and the sustainability benefits that both materials can provide to the structure.

The vehicle service area is framed using structural steel. Open web joists (OWJ) are used for the roof system in order to accommodate the 76 foot span and eliminate the need for interior columns in this part of the building. The 40LH10 joists will allow for HVAC ductwork to be easily installed and still allow enough clear space for the vehicle lifts. Large spans are better achieved with these joists, which are stiff and lightweight. On one end the joist system will be supported by an 8 inch bearing/shear wall. On the other end they will be supported by W-shape girders supported by W-shape steel columns. All steel members will be simply connected. The roof for shorter spans and smaller areas in this section of the building, including over the office space and the vehicle wash area, will be supported by W-shape joists to minimize the number of different types of OWJ. A typical metal decking system will be used for the roof.

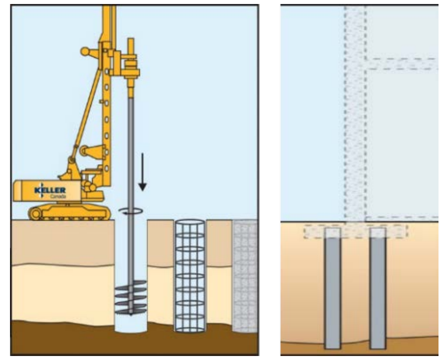
On the other hand, the living/housing and training area of the building will be framed using reinforced concrete because of the local availability of the material and experienced labor. Because of the difference in space usage in this building, reinforced concrete is also the best choice for this area because it will provide sound attenuation from the vehicle service area. Its rigidity and durability will contribute to providing a 50-year life span in this highly adverse weather-prone environment. The roof system comprises the continuous construction of a cast-in place (CIP) wide-module ribbed slab (slab-joists) system fixedly supported by 26” x 20” and 18” x 20” reinforced concrete beams and 12” x 12” columns. Members landing on 8 inch bearing or shear walls are simply supported.



*Above*: A model of the hybrid framing system used in the building.

## Foundation System

The soil conditions of the site consist of a shallow soil layer turning immediately into phyllite meta-basalt rock and then to bedrock. For these conditions, a straight drilled shaft foundation system has been designed. The construction of this foundation includes auguring a hole, filling it with cage steel reinforcement and 4000 psi concrete. To make drilling construction faster and easier, the axial load from each column is distributed among multiple 16” diameter shafts.



## Lateral Resistance

To combat the controlling seismic lateral load of 575 kips in this location, shear walls combined with cross bracing have been designed to distribute this load along several lines of framing. For areas where cross bracing is needed, an X type bracing system is used. Based on the controlling earthquake load, 8 inch shear walls will be used to provide lateral resistance in both directions where needed.

## Sustainability Concepts

One of the benefits of our design is that most of the building is reinforced concrete. The use of concrete provides the building with a high level of sustainability through durability, resiliency, heat island mitigation, storm water management, thermal mass, low or no volatile organic compounds, recyclable opportunities, local availability, and sound attenuation. Other ways we improve the sustainability of reinforced concrete for our building is to reduce the use of Portland cement by using other greener materials in the mix such as fly ash, a material that could contribute to greener concrete, and cement with photocatalytic qualities that remove carbon monoxide and other pollutants from the atmosphere.

As for the steel frame system, the use of steel means that the material can be recycled after its lifetime if need be. By having a plan to protect the steel during construction, we can improve the performance and longevity of the steel being used for the structure as well. With steel, we reduce the amount of natural resource usage, fewer transport trips, faster construction, less emission and energy usage, all which contribute to a more sustainable building.

## Conclusion

SRS Engineering has provided a design that meets and exceeds our client’s needs, improves constructability issues and lifecycle performance, minimized the cost of construction, and contributes to sustainability for a more comfortable and friendly construction environment and building performance.

# Variable Air Volume System Design for a Meteorological Center

A Design Process Overview

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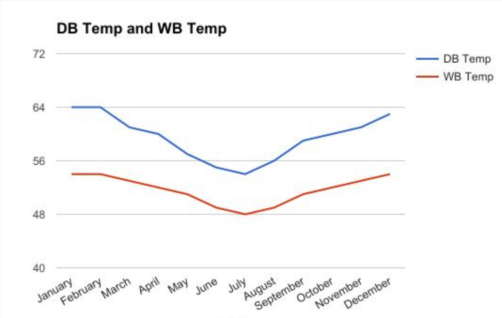
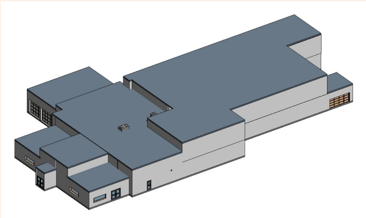



Scope:

International Mechanical Solutions (IMS) has been hired to design a variable air volume (VAV) system for a new meteorological center on Diego Ramirez Island, south of Chile. Along with the research station, the structure will include living, eating, and recreation areas, offices, and areas to park and maintain vehicles.

The structure is almost entirely a single story, with the exception of the station itself which sits above the office, and has a fairly uniform flat roof height of 19' and 22'. While the total area is about 20,000 square feet, half of that is taken up by vehicle spaces which are only planned to be in use for a few hours a week. This area will require significant design specifications such as pressurizing the living space with respect to the garage, proper ventilation to protect human safety from exhaust fumes, and consideration of a different mechanical system due to the space's extremely low demand. Other design considerations include a data center that requires its own separate and complete HVAC system, fluctuating occupancies, and energy conservation measures.



The building owners have requested that IMS pay particular attention to following the standards ASHRAE 55, 62.1, 90.1, and 189.1. These standards, developed by the international organization for the HVAC industry, address indoor comfort, ventilation, and minimum and advanced energy specifications for achieving optimal comfort, safety, and sustainability in the industry.

Methodology:

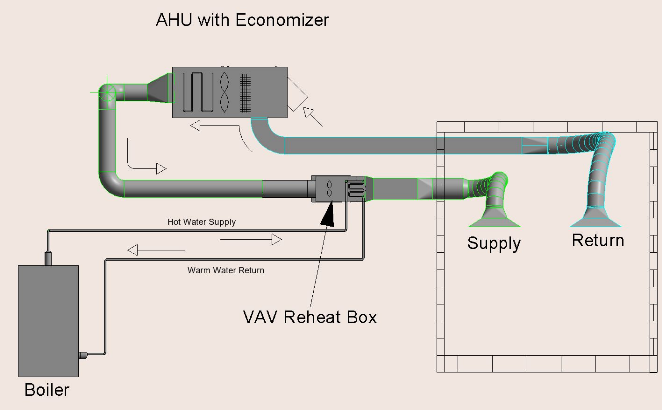
The team used Carrier's Hourly Analysis Program (HAP) to perform the calculations. HAP allows for the input of almost any piece of data, but most notably climate data, insulation and mass data, information about the spaces, lighting, equipment, occupancy, and thermostat scheduling, and types of mechanical equipment and systems.

Living Spaces

| | |
|---|---|
| Area | 10,260 SF |
| Cooling Load | 6.2 tons |
| Heating Load | 74.5 MBH |
| Ventilation Load | 7277 CFM |
| Outdoor Ventilation | 3827 |
| CFM/person | 27.3 |

<u>Design:</u>

VAV systems are composed of several mechanical functions working together. A central ventilation unit mixes air returning from the conditioned space with cool fresh outdoor air, performs any necessary additional cooling with a built in air-to-air heat exchanger, and sends it back. Before diffusing into the room, the air passes through the VAV reheat box which both modulates the air supply with a damper and, if called for by the zone thermostat, heats the air by blowing it over a hot water coil. This hot water is supplied by a water boiler, or, in this case, two cycled boilers to share the load and provide ongoing service if one requires repairs.




The garage and vehicle repair space will utilize on-demand unit heaters which will drastically cut on down energy use. These will use hot water from the boilers and a fan to deliver heat. Garage cooling will be provided with natural ventilation. Incidentally, the same boilers being used for heat may also supply domestic hot water, though a dedicated unit could as well.

Several other design improvements were included in this project. Exterior spaces which actively lose conditioned air to the outdoors through exfiltration were zoned off from the interior spaces which maintain a much more constant temperature. The air handling unit (AHU) is programed to mix and cool air to 55°F before sending it into the building to generate the necessary 50% relative humidity conditions as required by the owner. While this air will then be warmed to 72°F by being passed over the VAV's reheat coil, it won't pick up from or lose humidity to the coil itself. Energy recovery ventilators have also been added to the Center to provide ventilation when the space is not calling for heating or cooling.

VAV is one of the most adaptable mechanical systems available and is easy for engineers to size due to the volume dampers. It provides great local temperature control at an economical price.

Energy Conservation:

*Occupancy sensors*

CO2 sensors help determine occupancy levels and optimize equipment usage. This not only saves energy immediately, but delays maintenance needs and costs. Sensors are a relatively cheap option, especially during new construction.

*Carbon Monoxide Sensors*

Minimum ventilation rates are required in garages at all times. The rate may be reduced if carbon monoxide (CO) sensors are installed, particularly near the ground to where the pollutant sinks. This save energy and allows for a smaller fan. In fact, the garage will feature two exhaust fans: one for background ventilation and one specifically for when the vehicles are running.

*Long term building feedback*

This meteorological center is quite remote and has a total stated occupancy per the OPR of eight people. Along with a fluctuating number of people, several things in the building have variable energy intensities, including vehicle maintenance, cooking, using certain rooms, and weather monitoring. By keeping good long term data on occupancy, equipment using, daylighting, and general requirements of the HVAC system, including fan usage, humidity levels, heating and cooling requirements, balancing zones, the building can be tuned to exact needs.

*Solar thermal and electric*

Solar pv and and an analysis of solar thermal hot water potential are required by the owner. The heating system is too hot (160°F) and the domestic hot water demand too small to justify the installation of a solar thermal system but solar panels will indeed cut down on electrical usage. PV is meant to provide 5% of the building's usage (9kW in this case), so although the location of the station receives relatively poor isolation for at least a quarter of the year, the panels will still be fully utilized.

*Thermal Mass*

Thermal mass, such as concrete, acts as a heat battery by slowing the fluctuations in temperature. During the day, extra heat that enters the building is stored in the concrete instead of causing air temperature to rise too drastically, while the cool night air draws the heat out. This has a dramatic effect on demand and will change the system design by incorporating greater ventilation capacity while shrinking other mechanical equipment.

Cost:

At an owner requested rate of $200/SF and RMS Means Data indicating that mechanical engineering and installation costs usually average 7% and 20% of total costs respectively, the team at IMS expects the owner to spend some $1.075 million on upfront mechanical costs. HAP further estimates that between propane and electrical costs, the mechanical system will ultimately costing close to $80,000 per year.