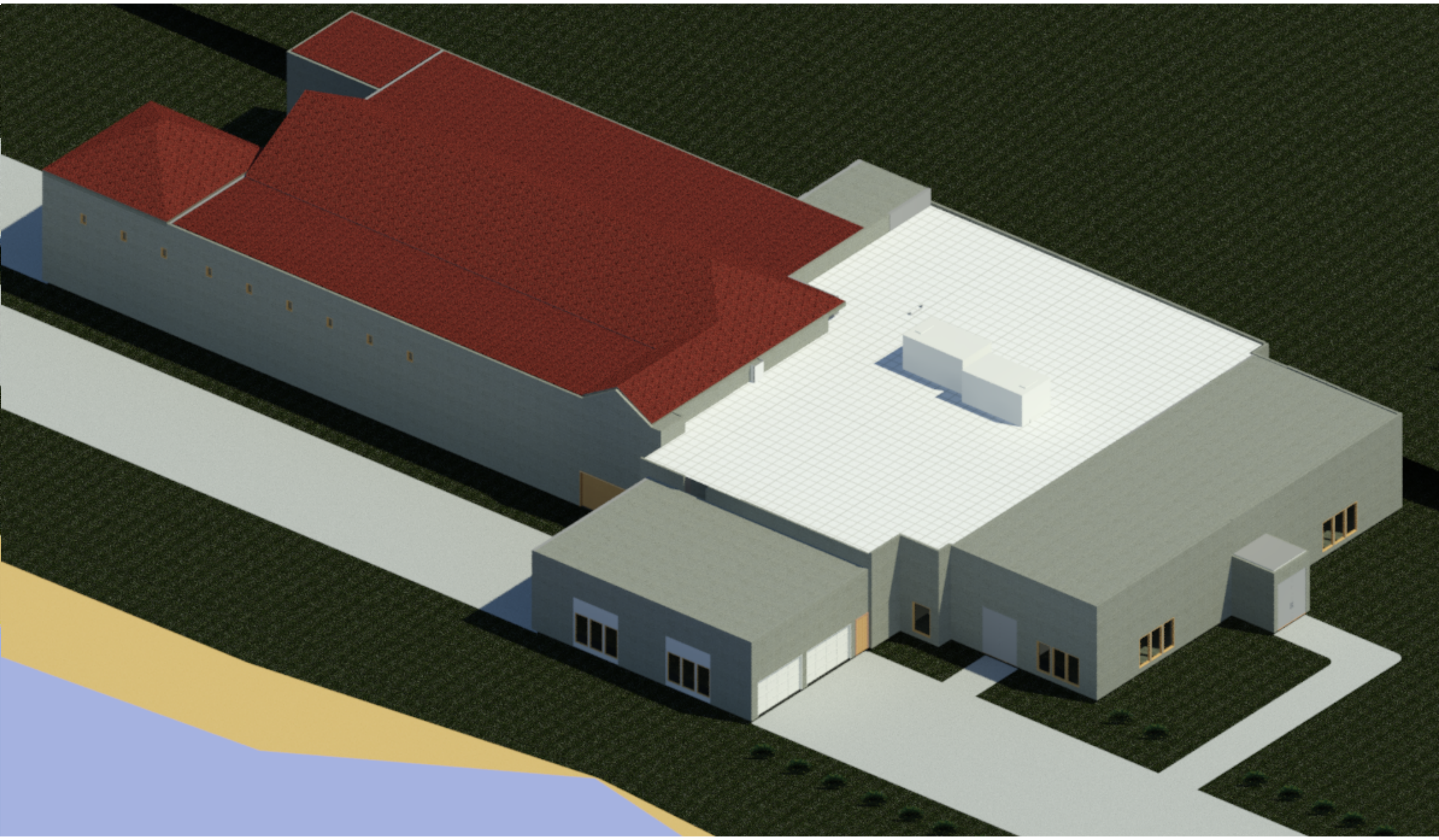
2017

HVAC DESIGN CALCULATIONS

ASHRAE Student Design Competition



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1 Executive Summary

This report is submitted by San Jose State University in San Jose, California for the HVAC Design Calculations ASHRAE Student Design Project Competition. The objective of the competition is to correctly size the variable air volume (VAV) air handling units (AHU) for the HVAC system of a meteorological research building on the Diego Ramírez Islands, Chile, while complying with the International Building Code latest ASHRAE Standards 55, 62.1, 90.1, and 189.1. The station is a single-story building with mezzanine office and repair building that will facilitate 24 hours a day, seven days a week, 365 days a year. Owner's Project Requirements (OPR), zoning, climate conditions, and building envelope were considered during the design calculation. TRACE 700 software by Trane Inc. was used to perform heating and cooling calculation. Exhaust, cooling and heating equipment was selected based off the load calculations and cost effectiveness analysis performed in Trace 700. This includes the VAV boxes (OPR requirement), AC unit and boiler in addition to the exhaust fan schedule. The selection of all the equipment is discussed in the System Selection section. The mechanical floor plan of the entire system is modeled in Revit.

The weather data was obtained from the ASHRAE website for performing load calculations. The Diego Ramírez Island has tundra climate and is classified by Climate Zone 8. The building envelope properties for Climate Zone 8 were defined using the OPR, ASHRAE Standards, and building drawings. The zoning was done based on the weather data, load calculation results, and ASHRAE standards.

The building has approximately 48 MBH of heating loads needs and 166 MBH of cooling loads needs per manual calculations. 12,975 cfm airflow from the VAV is required to support the building loads. The system selection was done based on these loads and the process is explained in the System Selection section of the report. Three rooftop air handing units were selected to serve the buildings. Exhaust fans were selected to serve the service stall area, bathrooms, locker rooms, and kitchen.

The initial cost for a 50-year life cycle cost from performed life cycle cost analysis was determined to be $61,611 for capital costs and approximately $3,415,193 at the end of 50 years. The cost is $194.24/ft^2. The allotted budget is $200/ft^2, which comes to a budget of $3,516,000 at the end of 50 years. Labor rates, utility and inflation rates were used for the cost analysis.

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3 Figures and Tables

4 Introduction

4.1 Owner Project Requirements

The Owner's Project Requirements (OPR) document outlines the details, requirements, and goals for the project. As stated in the OPR, the primary goals of the project are:

1. Design a variable air volume (VAV) heating, ventilation, and air conditioning (HVAC) system for a meteorological research center located on Diego Ramírez Islands, Chile.
2. The office, administrative, living, meeting, and information technology (IT) support spaces shall be maintained 24 hours per day, 7 days a week, 365 days a year.
3. Building is to be in accordance to:
    a. International Building Code
    b. ASHRAE Standard 15, current version
    c. ASHRAE Standard 55, current version
    d. ASHRAE Standard 62.1, current version
    e. ASHRAE Standard 90.1, current version
    f. ASHRAE Standard 154, if applicable current version
    g. ASHRAE Standard 189.1, current version
    h. ASHRAE Handbooks, current versions
    i. Industrial Ventilation, Manual of Recommended Practice

The OPR also notes the details that should be considered when designing the HVAC system for the building. Some of the important details include:

1. The building will be used as a meteorological research operation site
2. Operations will be conducted 24 hours a day
3. There will be, always, a minimum of 2 full time staff present in the facilities
4. The building consists of:
    a. Learning Center
    b. Conference & Training Room
    c. Parts Office
    d. Data Room
    e. Private Bedrooms
    f. Kitchen
    g. Community Room
    h. Exercise Room
    i. Storage Rooms
    j. Automobile Garage and Service Stalls
    k. Laundry Room

l. Locker Rooms
m. Quiet Room
n. Break/Lunch Rooms

5. The interior conditions of office, administrative, living, and meeting spaces will be designed per:

Summer	Winter	Sound
73°F (23°C) DB 55%RH	70°F (21°C) DB	NC 35

6. The interior conditions of meteorological center will be designed according to:

Summer	Winter	Sound
73°F (23°C) DB 55%RH	70°F (21°C) DB	NC 30

7. The interior conditions of IT support spaces will be designed per:

Criteria
65°F (15°C) DB 50%RH

4.2 Location

The Diego Ramírez Islands (56°29′S, 68°44′W) are cluster of small islands located approximately 60 miles below the southern coast of Chile. Of the small islands, Isla Gonzalo is the probable site of the building because it is the only inhabited island, even then only by an existing Chilean Navy weather station.

4.3 Environmental Effects

A few environmental effects on the HVAC systems include rain and atmospheric pollutants. These affect the corrosion rate of the materials that form the units and any exposed ducting. To calculate maintenance costs, these effects must be accounted for when designing a system.

4.3.1 Corrosion from Rain

The Diego Ramírez Islands located 65 miles' south-west of Cape Horn gets an average of 58 inches of rain annually. This rain is taken into consideration as it could contribute to rusting and corrosion of the commercially-used, galvanized sheet metal used for ducting placed on the roof of buildings. The rain also affects the system units on the rooftop as well. The relative humidity of the islands is around 80% daily, as shown in Figure 2 in Section 4.5. At or near

100% relative humidity at standard pressure, the air is saturated with water and fog is present[7]. Corrosion, an electrochemical process, occurs when steel or a metal that is ferrous, oxygen, and rainwater combine to form ferric oxide, otherwise known as rust[4]. Given this weather information, sheet metal ducts exposed to the outside was not cost-effective for this project, as the ducting would need to be replaced more frequently. Rooftop system units were chosen that did not require ducting to be exposed to weather conditions. The rooftop system units do get bombarded by the rain though, but other non-ferrous metals usually form the outer shell of the units, to withstand weather conditions. For any units that would be made with ferrous metals, the units could be painted to reduce the corrosion rate of the metal[4].

4.3.2. Corrosion from Atmospheric Pollutants

Atmospheric pollutants, including chlorides, also have a hand in corroding steel and other ferrous metals. Since the Diego Ramírez Islands are surrounded by the Pacific and Atlantic Oceans, chlorides from the marine environment would reach the meteorological station, and thus, the rooftop of the low-lying buildings. Again, like rain, the chlorides corrode steel and other ferrous metals. With winds seen onshore at the Diego Ramírez Islands at 50-100 mph, the prevailing winds would be able to carry the chlorides easily from the surrounding oceans[7]. Chlorides, added into the electrochemical reaction mentioned earlier, increases the rate of corrosion of ferrous metals. This also warranted the team to decide not to choose rooftop system units that had ducting exposed to weather conditions. The rooftop system units would be exposed, and again, paint would be a good, temporary cover for units made with ferrous metals if necessary.

4.4 Climate and Climate Zone

The climate of Isla Gonzalo is a subarctic tundra climate where it is always very cold and humid. International climate zones are specified in Table B-4 of ASHRAE Standard 90.1 - Normative Appendix B. The climate of the island requires 12600 heating degree days; therefore, the building is in the climate zone defined as[1]:

Zone Number	Zone Name	Thermal Criteria (I-P Units)
8	Subarctic	12600 < HDD65°F

4.5 Weather

The weather of the island is typically windy, very cold, humid, and overcast. Figure 1 depicts the island's temperature averages. The annual average temperature of the islands is 41.4°F.

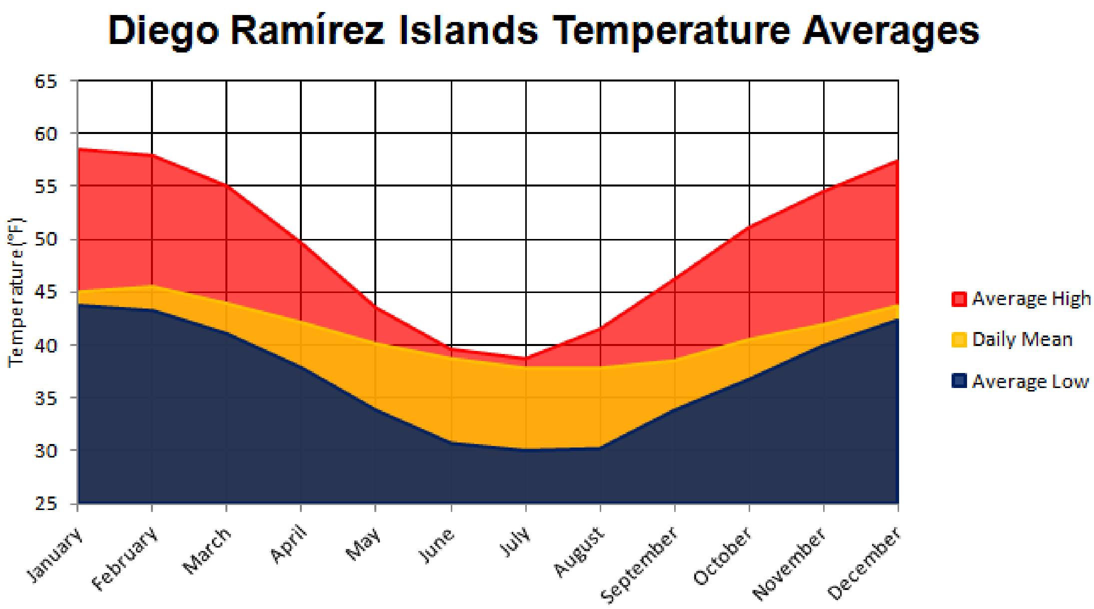

Figure 1. Diego Ramírez Islands average temperature graph[8].

Figure 2 depicts the relative humidity (RH) and precipitation of the islands. Due to the surrounding ocean and the islands' low temperatures, it is expected that the RH would be high.

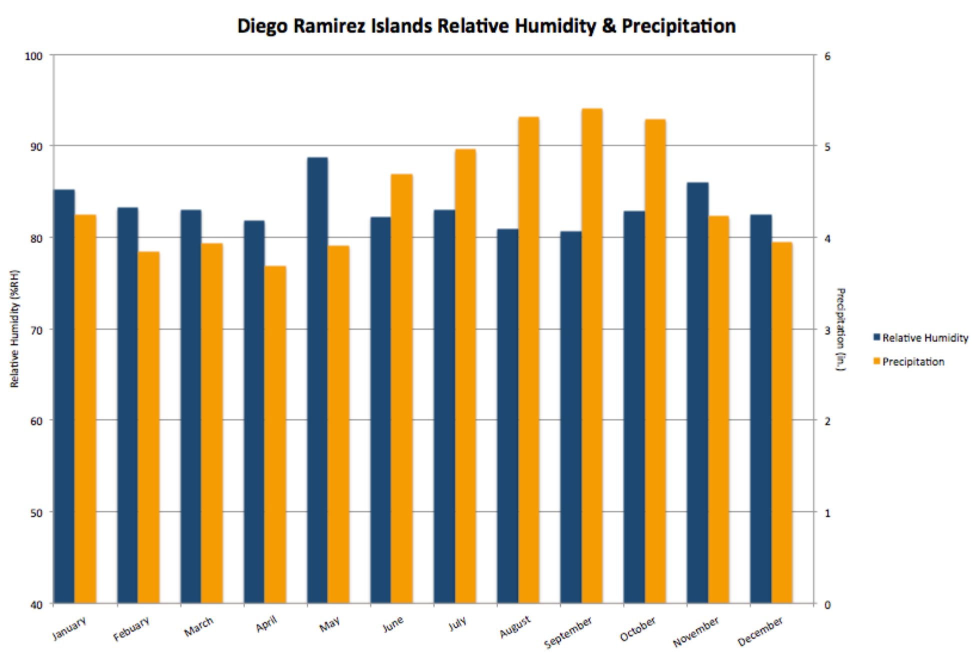

Figure 2. Diego Ramírez Islands relative humidity and precipitation graph[8].

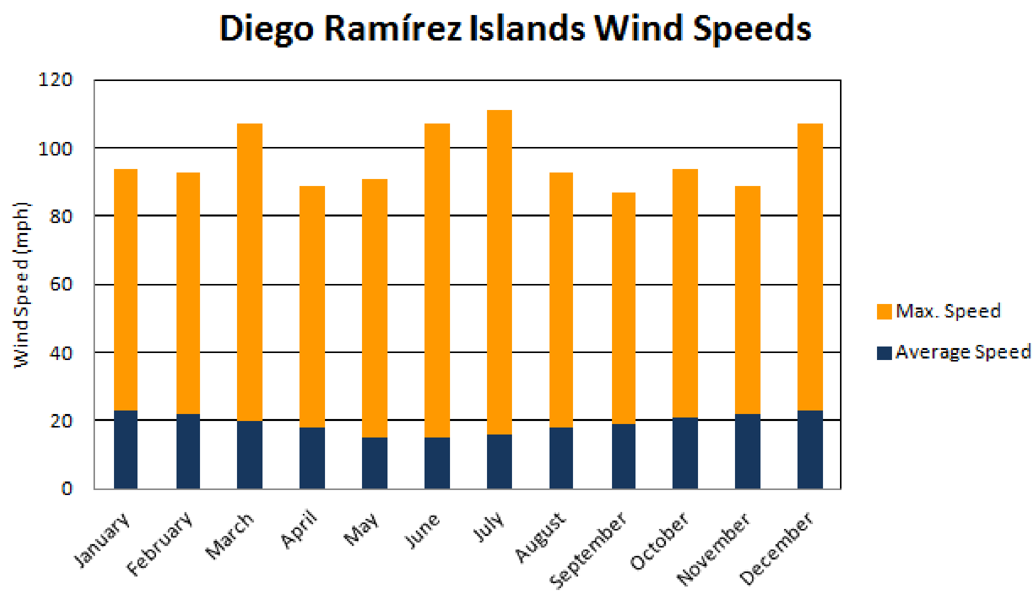

Figure 3. Diego Ramírez Islands average wind speeds graph[8].

4.6 Envelope

As stated in the OPR, all building envelope requirements specified in Table A-8 of ASHRAE Standard 189.1 are assumed to be met. The requirements based on Climate Zone 8 classification are summarized in Table 1.

Table 1. Building envelope details

Assembly	Details	Max. U	Max. SHGC
Walls	Light tan limestone, masonry mass wall construction	U-0.060	R-20 ci
Windows	Double glazed, bronze tint glass, ½" space	U-0.350	SHGC-0.45
Roof	Insulation over concrete deck	U-0.028	R-35.0 ci
Floor	Concrete poured over slab on grade	F-0.300	R-15 for 24in + R-5 ci below

5 Zoning Design

Appropriately zoning the building is imperative to the efficiency and cost effectiveness of the HVAC system. The zoning instructions detailed in the OPR state:

> "HVAC zones shall be selected based on the occupancy for each space. Where possible, spaces of similar occupancy shall be considered a single zone. Spaces with varying occupant loads (i.e. Classrooms, Break Rooms, Conference Rooms, and Assembly Areas) shall be provided with individual zone equipment."

Another important zoning circumstance that arose, especially when considering the subarctic climate of the island, is the potential for high amounts of loss in spaces adjacent to exterior walls such spaces also require their own zone. In addition, the Data Room must be zoned individually and requires its own separate VAV AHU system per the OPR. The room must comply with ASHRAE Class A1 & A2 recommended operating conditions for data centers per Table 2.

Table 2. Recommended and allowable ranges for various types of rooms.

Range	Class	Dry-Bulb Temperature	Humidity Range, Non-Condensing	Max. Dew Point
Recommended	All A	64.4°F to 80.6°F	41.9°F DP to 60%RH and 59°F DP	59°F
Allowable	A1	59°F to 89.6°F	20% to 80%RH	62.6°F
	A2	50°F to 95°F	20% to 80%RH	69.8°F

The finalized zoning plan is displayed below in Figure 4. The plan reflects the careful consideration all the instructions detailed in the OPR, general zoning principles, and building specific circumstances. The spaces that require individual zones include the Data Room, Conference Room, Electrical Room, Kitchen, and Shipping & Receiving Drop-Off. It is important to add that some sections of spaces that are adjacent to multiple exterior walls are, also, zoned individually i.e. the Exercise Room. In summary, the building contains 21 zones across its 17,582 ft^2 area.

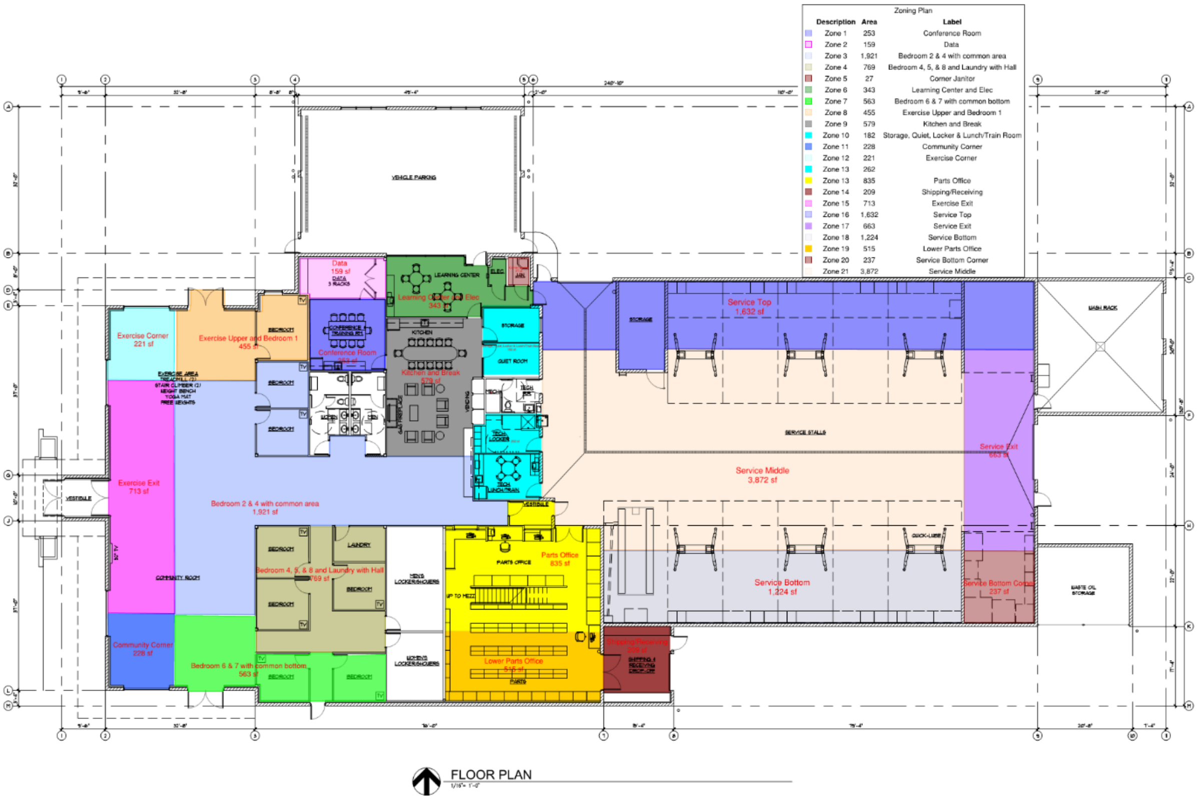

Figure 4. Zoned floor plan.

6 Load Calculations

Load calculations were performed in Trace 700 Load Design software. Trace 700 performs proficiently when analyzing user inputted data regarding details of the building such as weather data, minimum required ventilation, desired thermostat settings, internal loads, envelope details, number of zones and the system they occupy, and AHU type. After assuring that the inputted data follows ASHRAE Standards 55, 62.1, 90.1, 189.1 and ASHRAE Handbook - Fundamentals, results were generated in the form of System Checksums Reports found in Section 15.3.1.

To verify these results, calculations were performed outside of Trace 700 using Microsoft Excel. By retrieving space specific load (Btu/h) data from the "Peak Clg Ld" and "Peak Htg Ld" reports generated in Trace 700, inputting said data into Excel spreadsheets, and applying it to equations regarding airflow, energy loads, and air temperatures, load calculations were performed.

Below in Table 3, the results of both the Trace 700 and MS Excel calculations are displayed. On top in blue are results from the Trace 700 System Checksums Report, below it in green are the results from MS Excel. Displayed beneath both is the percentage difference between the two results.

Table 3. Trace 700 and MS Excel calculations for cooling and heating loads.

System	Load	Excel Calculations (Btu/h)	Trace 700 (Btu/h)	Percent Difference (%)
1	Cooling	80,000	83,167	-3.96%
	Heating	14,890	15,706	-5.48%
2	Cooling	12,199	12,312	+0.93%
	Heating	603	603	0.00%
3	Cooling	73,822	68,890	+6.68%
	Heating	32,307	31,741	+1.75%

7 System Selection

7.1 Sizing for Main System Cooling and Heating

System selection is the next procedure in completing the design process after evaluating the results of the load calculations. The OPR requires that a VAV system is servicing the building's HVAC requirements. Based on the circumstances regarding the various spaces, the building should require three different systems: one system specifically designated to the data room (System 2), one system designated to all other spaces (System 1), and an exhaust system designated to the Service Stalls and restrooms. System 2 will provide all heating, ventilation, air filtration, and dehumidification that the Data Room demands. Due to the circumstances, a VAV with water reheat system should provide the needed conditioning while reducing the amount of energy consumed by the system. The general schematic for the three VAV with reheat AHUs is shown in Figure 5 below.

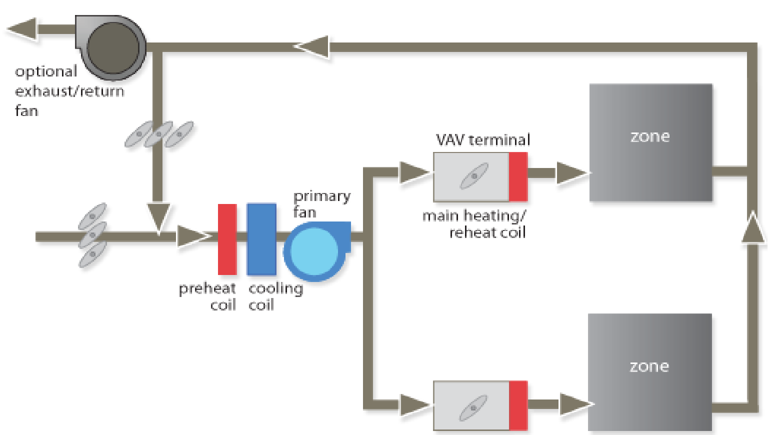

Figure 5. Schematic flow diagram of section of system[12].

7.2 Sizing for Server Room Cooling

By isolating the Data Room in Trace 700 it was easy to find a smaller package unit to serve this space. To protect the data servers from failing due to overheating the Data Room is also supplied by AHU-1 redundantly. There is a digitally controlled balance damper that will fully open if AHU-3 ever fails or if the station decides to put more than three data racks in the facility.

7.3 Outdoor-Air Energy Recovery, Filters, Economizers, and Noise Control

The systems use a return air plenums that go back into the unit to recover energy that would have been lost by just exhausting the entire building. This saves money by tempering air that is closer to the design requirements. Each room is equipped with a fire safety damper to ensure that no smoke will be transferred throughout the building in the event of a fire.

All package units supplied by Trane are designed with filters and economizers. The filters help to remove dust and other particles from the air to provide clean air to the system. The economizers are designed to bring more air in an efficient manner. All filters and economizers are provided with the units and are as stated in product manual.

The owner requested all noise to be reduced to under 30 dB for living spaces. This will be met by lining the main ducts as well as adding at minimum 6 feet of flex duct prior to each diffuser. The return units will not influence the noise because all the return air travels through a plenum space prior to entering the AHU on the roof of the building. The exhaust fans do not have noise attenuation because the service stalls were not considered livable space. The Air Handling Units chosen for the system are shown in Section 15.3.2.

7.4 Boiler

The boiler system serves the Titus VAV reheat units. The boiler was sized not off square footage of the building because it was decided not to heat the service stalls. The boiler was sized off total heat required in BTU/h from the Trace results. The boiler was oversized due so that the system by be expanded as well as there were no commercial units smaller than the one chosen. The boiler that was chosen for the system is shown in Appendix

7.5 Exhaust System

The Exhaust system for the bathrooms are sized by the number of air changes per hour. It was decided since there will not be a large population manning the building at a time that there will be 10 air changes per hour. This means that there will be an air change every 6 minutes. The size of the exhaust fan in CFM is found by using Equation 1:

$$CFM = \frac{Volume\ of\ Space * Number\ of\ Air\ Changes\ per\ Hour}{60\ minutes\ per\ hour} \qquad \text{(Equation 1)}$$

The exhaust system for the service stall areas were calculated via the areas. It was found that the minimum exhaust rate was 1.5 CFM/ft^2. The exhaust fans that were chosen for the system are found in Section 15.3.2.

8 Duct Design

The duct design is designed in Revit and located in Appendix 15.2.1. The design took into consideration the cost of duct per foot and was reduced to the minimum amount of duct needed using the CFM of each zone and a ductulator. The return system of the duct is a plenum system where the fan on the package unit will pull the air up from the space after it is done cooling the zones. The service stall area was assumed to have outside air louvers built into the design of the building to prevent negative pressure in the work area.

9 ASHRAE Standards

9.1 ASHRAE Standard 55

The purpose of ASHRAE Standard 55 is to set guidelines for acceptable thermal environmental conditions for human occupancy by specifying the required combinations of indoor thermal environmental factors and personal factors. There are six primary factors contributing to the thermal environment of an occupied space: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. Section 5 details the requirements, which include operative temperature, humidity limits, elevated air speeds, local thermal discomforts, and temperature variations with time, that must be met to provide an acceptable thermal environment for occupied spaces.

Determining Acceptable Thermal Environmental Conditions

To determine an acceptable operative temperature for the meteorological research building located in the subarctic Diego Ramirez Islands some assumptions regarding environment conditions must be made:

1. The Learning Center is the space in which the thermal environmental conditions will be determined for
2. General occupant activity is regarded as office type work
3. Occupants are wearing trousers, long-sleeve shirts and sweaters, and T-shirts
4. The HVAC system will maintain design air temperature and humidity
5. Occupants have no control over local air speed
6. Room walls are assumed to have high emissivity

7. The temperature differences of the surfaces of the space are relatively small
8. Conditions for most practical cases are not met

Table 4. Environment assumptions

Assumptions	
Metabolic Rate	1.1 met
Clothing Insulation	1.01 clo
Summer Design Air Temperature	73°F
Winter Design Air Temperature	70°F
Operative Temperature Range	73.4°F – 77.9°F
Relative Humidity	55%RH
Emissivity, ε	1
Temperature of surface 1, t_1	58°F
Temperature of surface 2, t_2	67°F
Temperature of surface 3, t_3	67°F
Temperature of surface 4, t_4	69°F

Calculating Parameters

When finding the mean radiant temperature, $\bar{t}_r$, which is the uniform temperature of an imaginary enclosure in which radiant heat transfer from the human body equals the radiant heat transfer in the actual nonuniform enclosure, Equation 2 was used with regards to the surface temperature of surface N, t_N, and the angle factor between an occupant and surface N, $F_{p\text{-}N}$.

$$\bar{t}_r = t_1 F_{p-1} + t_2 F_{p-2} + .. + t_N F_{p-N} \qquad \text{(Equation 2)}$$

$\bar{t}_r$ = mean radiant temperature (°F)
t_N = surface temperature of surface N (°F)
$F_{p\text{-}N}$ = angle factor between an occupant and surface N

In situations where conditions for most practical cases are not met and high precision approximation of the operative temperature is needed Equation 3 can be used to accurately approximate the operative temperature, t_{op}, with regards to coefficient representing the ratio of heat transfer due to convection/radiation, A, mean air temperature, t_a, and mean radiant temperature, t_r,

$$t_o = A t_a + (1 - A)\bar{t}_r \qquad \text{(Equation 3)}$$

t_o = operative temperature (°F)
t_a = design air temperature (°F)
A = coefficient representing the ratio of heat transfer due to convection/radiation

Since the operative temperature, t_o, is in the assumed temperature range, Equation 4 was be used to find the acceptable air speed, V, for an occupied space with a design air temperature, t_a.

$$V = 31375.7 - 857.295 t_a + 5.86288\, t_a{}^2 \qquad \text{(Equation 4)}$$

V = air speed (fpm)

Results

The results are showing in Table 5 below. It is important to note that the calculated value for the upper limit to average air speed, V, is contingent on the fact that the assumed operative temperature range of 73.4°F – 77.9°F is met; however, the calculated results show that the operative temperature range is 69.125°F – 69.9°F.

Table 5. Calculated thermal environmental conditions

Winter Design Criteria	Summer Design Criteria
$V = 93.162\ fpm$	$V = 36.453\ fpm$
$\bar{t}_r = 65.25°\mathrm{F}$	$\bar{t}_r = 65.25°\mathrm{F}$
A = 0.6	A = 0.5
$t_o = 69.125°F$	$t_o = 69.9°F$

9.2 ASHRAE Standard 62.1

Outdoor Air Quality

The focus of this project is to condition and maintain the indoor air quality such that it is acceptable to the human occupants and minimizes adverse health effects; however, the investigation and assessment of the quality of the outdoor air cannot be neglected. In accordance with Section 4.1-4.2 of ASHRAE Standard 62.1-2010, the outdoor air quality is to be investigated prior to the completion of the building's ventilation system. Section 4.1 addresses the air quality of the region and whether it follows ambient air quality standards. In the US, outdoor air quality is to be assessed by the Environmental Protection Agency (EPA) via the National Ambient Air Quality Standards (NAAQS); however, in Chile, the standards of air quality have been set by the Chilean equivalent to the EPA, CONAMA[5]. In the Chilean standards, a region is denoted as a "latent non-attainment" region if the air pollution concentration levels (CO, Pb, NO_2, PM_{10}, $PM_{2.5}$, O_3, SO_2) are within 80%-100% of the standard and labeled as "saturated non-attainment" regions when the standard is exceeded.

Table 6. Chilean air quality standards[5]

Pollutant	80%-100% Standard (µg/m^3)
$PM_{2.5}$	40 - 50
PM_{10}	120 - 150
CO	8,000 - 10,000 (8 hr. avg.)
Pb	0.40 - 0.50
NO_2	79.7 - 99.6
O_3	0.976 - 1.22 x 10^{-4} (8 hr. avg.)
SO_2	2.01 - 2.52 x 10^{-3}

Section 4.2 addresses the local air quality and the possibility of contaminants from surrounding facilities to enter the building; however, since the Islands are mostly uninhabited, this should not be a concern.

The air pollution levels of the Diego Ramirez Islands are under researched due to the lack of inhabitants and remote location. These facts should give reason to believe that the Islands' air quality is excellent. The nearest studied region to the Islands is Punta Arenas, which is small city located in the southern coast of Chile 250 miles away, its air quality is regarded as "Good" by scoring an average of 36 over a 5-day period in the Air Quality Index (AQI)[13]. The AQI ranges from 0 to 500, where 0-50 is "Good - Air quality is considered satisfactory, and air pollution poses little or no risk." This AQI score converts to a $PM_{2.5}$ concentration of 7.2 µg/m^3, well below the standard. Per ASHRAE Standard 52.2-2012, the minimum efficiency reporting value (MERV) for the required corresponding particulate air filters or air cleaners falls must be within 9 to 12 and shall be provided upstream of all cooling coils or other devices with wetted surfaces through which air is supplied to a livable space.

Solution to Acceptable Indoor Air Quality - Ventilation

The building's minimum ventilation and exhaust requirements detailed in ASHRAE Standard 62.1-2010 Table 6-1 and Table 6-4, respectively, requires compliance to create an acceptable solution to indoor air quality. Table 6-1 "Minimum Ventilation Rates In Breathing Zone" displays space specified ventilation rates in order to, ultimately, calculate the outside air intake flow value for the ventilation system, V_{ot}. In the table, the criteria for default occupancies are also described; the OPR states that all spaces should be conditioned for default occupancies detailed in ASHRAE Standard 62.1.

To calculate V_{ot}, the breathing zone outdoor airflow, V_{bz}, must be determined first by finding the sum of the product of the zone area, A_z, and the outdoor airflow rate required per unit area, R_a, and the product of the zone population, P_z, and the outdoor airflow rate required per person, R_p (Equation 5).

$$V_{bz} = R_a A_z + R_p P_z \quad \text{(Equation 5)}$$

Once V_{bz} is calculated for, the zone outdoor airflow, V_{oz}, is determined by finding the quotient of V_{bz} and the zone distribution effectiveness, E_z, which is displayed in Table 6-2 (Equation 6).

$$V_{oz} = V_{bz}/E_z \quad \text{(Equation 6)}$$

For multiple-zone recalculating air systems, which is what should be selected as the ventilation system type due to the intense requirements of conditioning the South Pacific subarctic ocean air, the primary outdoor air fraction, Z_{pz}, must be determined by finding the quotient of the zone outside airflow and the zone primary airflow, V_{pz} (Equation 7).

$$Z_{pz} = V_{oz}/V_{pz} \quad \text{(Equation 7)}$$

Then, the uncorrected outdoor air intake, V_{ou}, is calculated by finding the product of the occupant diversity, D, and the sum of all breathing zone outside airflows (Equation 8).

$$V_{ou} = \sum R_a A_z + D \sum R_p P_z \quad \text{(Equation 8)}$$

The occupant diversity is found by finding the quotient of the system population, P_s, and the sum of all zone populations (Equation 9).

$$D = P_s/\Sigma_{all\ zones} P_z \quad \text{(Equation 9)}$$

The outdoor air intake flow is then found by finding the quotient of the uncorrected air intake and the system ventilation efficiency, E_v, which is displayed in Table 6-3 (Equation 10).

$$V_{ot} = V_{ou}/E_v \quad \text{(Equation 10)}$$

Solution to Acceptable Indoor Air Quality - Exhaust

Correctly sizing the exhaust system is key to ensuring that the building's safety requirements are, at the very least, met. Exhaust makeup air can be any combination of recirculated air, transfer air, or outdoor air. Minimum exhaust rates are displayed in ASHRAE 62.1-2010 Table 6-4 and denoted in terms of either cfm per unit or cfm per ft^2. The exhaust system of the building should service the restrooms, locker rooms, kitchen, janitor closets, and service stalls at a rate at which is detailed below:

1. Restrooms are to be exhausted at a rate of 50 cfm per unit (toilet)
2. Locker rooms are to be exhausted at a rate of 0.50 cfm per ft^2
3. The service stalls area is to be exhausted at a rate of 1.5 cfm per ft^2
4. The kitchen is to be exhausted at a rate of 0.70 cfm per ft^2
5. The janitor closet is to be exhausted at a rate of 1.00 cfm per ft^2

The large service stall area will accommodate all general maintenance and repair needs. A parking garage will occupy a section of the stalls and there will be two instances a week where a V8 diesel engine vehicle is kept running for 45 minutes at a time. This classifies the service stall area as a room of auto repair that requires:

> "Stands where engines are run shall have exhaust systems that directly connect to the engine exhaust and prevent escape of fumes" (ASHRAE 62.1-2010 Table 6-4 Note A)

This special circumstance requires a vehicle exhaust extraction system that will utilize elongated hoses with one end attached to the vehicle's muffler and the other end is attached to an exit vent directly connected to the outdoors. An example of this system is shown below in Figure 6.

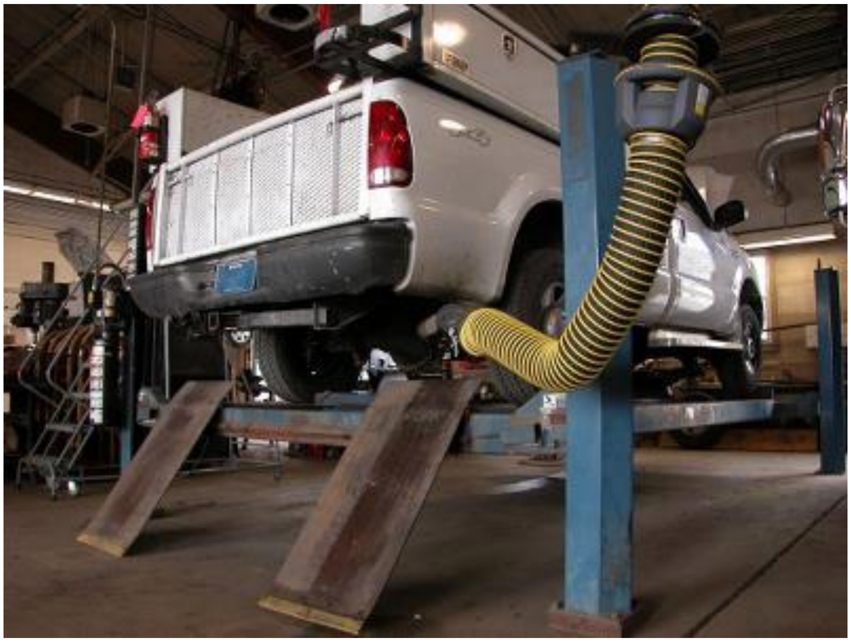

Figure 6. Vehicle exhaust extraction system[11]

The V8 diesel engine vehicle is assumed to be a light duty truck capable of performing any tasks the crew requires. Nissan is a popular brand of vehicle in Chile and their line of Titan trucks use Cummins ISB 6.7L V8 engines. From Donaldson Horsepower and Exhaust Flow Guide[6] the exhaust flow rate of this engine running at 2500 RPM is shown in Table 7. While left running, the expected RPM of a V8 engine should be around 1200 RPM; therefore, sizing this exhaust system at 2500 RPM is an extremely conservative approach.

Table 7. V8 Diesel engine exhaust rates

HP	Exhaust Rate (cfm)
185	1257
205	1246
225	1311
245	1456
275	1673

10 Energy Analysis

10.1 Energy Conservation Methods

Energy analysis, using a calculation software called eQuest, was performed for the HVAC system to obtain the annual energy consumption of the building. The annual energy consumption of the building came to be 250,330 kWh as shown graphically in Figure 7 and textually in Table 8.

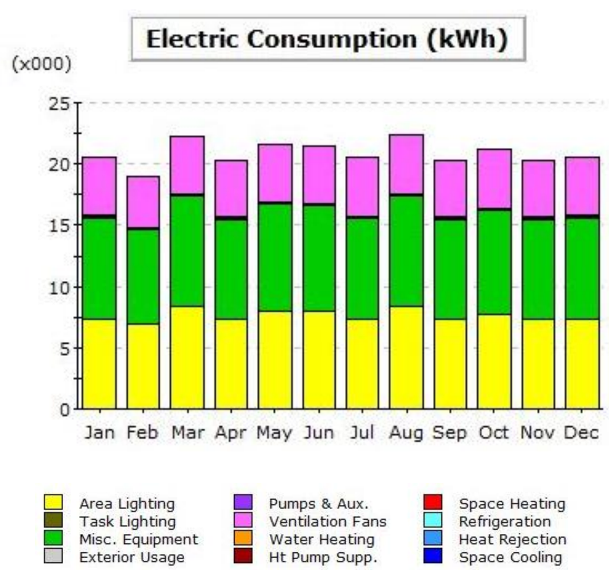

Figure 7. eQuest calculated electric consumption graph for building.

Table 8. eQuest calculated electric consumption table for building with all values in kWh.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Vent. Fans	4.69	4.23	4.69	4.57	4.74	4.75	4.82	4.81	4.63	4.75	4.60	4.70	56.00
Pumps	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.46
Ext. Usage	0.17	0.13	0.14	0.14	0.10	0.09	0.10	0.16	0.15	0.16	0.16	0.17	1.67
Misc. Equip.	8.25	7.69	9.01	8.16	8.76	8.65	8.26	9.01	8.14	8.51	8.14	8.25	100.84
Area Lights	7.35	6.95	8.35	7.34	8.02	7.99	7.36	8.35	7.32	7.69	7.32	7.35	91.37
Total	20.49	19.04	22.24	20.24	21.65	21.52	20.58	22.37	20.28	21.16	20.25	20.51	250.33

Since the islands are remote, having to supply energy to the meteorological station comes at a higher cost. To offset some of the costs and to conserve non-renewable energy, two methods of energy conservation are discussed below.

The use of either photovoltaics or wind are two methods of clean energy conservation that are considered for the station, at the request that the Owner recommends research into offsetting 5% of the annual energy consumption, or approximately 12,500 kWh/yr.

10.1.1 PV Array Sizing and Cost Analysis

The OPR recommends doing research for PV array sizing and cost analysis, though there is quite a bit of precipitation on the island, as shown in Section 4.5. The PV array was considered to offset 5% of the annual electricity needs. 17 Solar World SW-250-Poly modules rated at 225W were selected to cover that need, which would cover 307 ft^2 of the station's rooftop. The array will be facing south at an angle of 56^o and an azimuth angle of 0^o. The module was selected based on its efficiency of 14.91%[3]. Each module costs 250 USD, which comes to a total of 4,250 USD for the all the modules. Calculations for the sizing and cost analysis for the PV array can be found in Section 15.1.1.

10.1.2 Wind Turbine Sizing and Cost Analysis

Though the OPR does not recommend doing research for wind turbine sizing and cost analysis, given that the islands provide Class III wind power daily, as shown in Section 4.5, wind turbines were considered to offset 5% of the annual electricity needs of the meteorological station. The Bergey Excel 6 Wind Turbine rated at 5.5kW was selected due to its durability, ability to continue producing energy in winds up to 45mph and survive winds up to 134 mph. One of these turbines with a hub height of 49m would be able to provide 18,600 kWh/year, over

6000 more kWh/year than necessary, as shown per calculations in Section 15.1.2. This discrepancy accounts for the frequent winds seen by the turbine that are above 45 mph, which sometimes reach 100 mph. The total cost for one wind turbine is 21,995 USD since tax credits from the U.S. Federal Government do not apply in Chile.

11 Life Cycle Cost Analysis

11.1 Labor Costs

We used FastEST, FastDUCT software to compute our materials cost and provide us with an estimate for labor hours. Labor costs have been calculated per average Chilean wages of $3.75 per hour[10]. Assumptions suggested by industry advisors were made regarding the amount of man hours required to install all HVAC related components. The entire estimated labor costs total $9,840. The wage rate of Chile serves as a huge economical advantage to the owner when compared to a similar project cost in the United states, where labor is approximately fifty times more expensive.

11.2 Capital Costs

The total HVAC system, which includes AHUs, VAVs, and an extensive amount of ducting, capital costs total an estimated $61,611 per figures provided by industry advisors.

11.3 Energy Payback

Energy payback from the PV Array or Wind Turbine is dependent on the capital and maintenance costs for each set-up, how much electricity is generated by the set-up each year, and the cost of electricity each year account for inflation at a rate of 3% per year.

11.3.1 PV Array vs. Wind Turbines

Initially the costs of the PV array will be substantially lower: $4,250 compared to $21,995 of the wind turbine. The lifecycle of the PV array and the wind turbine are fairly close: around 25-30 years. The efficiency of both systems break down about the same which is about 1-2% a year depending on the amount of maintenance done in those years. The wind turbine, although more expensive, produces 6000 more kWh/year than the PV array. Due to degradation the wind turbine decreases its efficiency by 1.5 percent per year for 25 years along with the cost of electricity continuing to increase the amount of money saved over the 5% of the total energy load of the building would be $22,397. This is $441.99 more than the cost of the wind turbine. Over 50 year the PV system, after being replaced once as well as accounting for degrading equipment, will save the station just over $150,000. While the wind turbine, after being replaced once as well as accounting for degrading equipment, will save the station just over $210,000.

11.4 Total Costs

The total cost for electricity and natural gas over a 50-year period while considering an inflation rate of 3% per year is $5,158,619; however, after considering the return on investment at 7%, the total cost over the 50-year period totals $3,343,742. By adding the labor costs, capital costs, and electricity and gas costs. The total costs equal $3,415,193. This value equates to $194.24/ft^2, which is below the $200/ft^2 budget detailed by the owner.

12 Conclusions

The proposed 17,582 ft^2 Diego Ramirez Islands meteorological research center is required to be in accordance to the International Building Code, ASHRAE Handbook - Fundamentals, and ASHRAE Standards 15, 55, 62.1, 90.1, and 189.1, which include standards in regards to load criteria, safety, thermal environmental conditions, ventilation for acceptable air quality, energy, and designs for high-performance green buildings.

Based on the data from Trace 700 the building would require 48 MBH of heating, 166 MBH of cooling, and 10,065 cfm to be adequately conditioned. The building is divided into a total of 21 zones, which are serviced by VAV boxes with hot water reheat. The Data Room requires an unshared AHU and requires to be maintained at ASHRAE Recommended Class 1 & 2 operating conditions for servers. In addition, there will be two more AHUs servicing the remaining spaces of the building. A boiler will be supporting the three AHU systems.

The LCCA over a 50-year period revealed that the total costs of the project would amount to $3,415,193, equating to $194.24/ft^2. This value is below the owner's detailed budget of $200/ft^2.

13 Acknowledgements

The team would like to thank Dr. Nicole Okamoto (ME Department Chair – SJSU) and Dr. Raghu Agarwal (Professor – SJSU) for their support, guidance, and reviews throughout the project. The design team would also like to extend thanks to Sargon Ishaya (Principal – Pragmatic Professional Engineers) for providing industry knowledge, concepts, and feedback.

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15 Appendix

15.1 Calculations

Calculations performed to size analyze cost for the PV array and wind turbines are shown below. Annual electricity consumption for the meteorological station is 250,330 kWh/year. The PV array and wind turbines were sized to alleviate 5% of the need, equivalent to 12,500 kWh/year.

15.1.1 PV Array

Annual electricity consumption = 250,330 kWh/year
5% of annual electricity consumption = ~12,500 kWh/year
Electrical consumption in a day = 34.25 kWh/day
Average daylight hours on the island = 12 hours
PV electrical energy every hour = 2.85 kW
Overall DC to AC derate factor = 0.77

$$\frac{2.85\ kW * \frac{1000\ W}{1\ kW}}{0.77} = 3706\ W$$

Assume module is rated at 225 W.

$$\frac{3706\ W}{225\ W} = 17\ modules$$

PV Array Selection: 17 Solar World SW-250-Poly modules with 225W rated power.
Cost per module: $250
Total cost: $4,250

15.1.2 Wind Turbines

Annual electricity consumption = 250,330 kWh/year
5% of annual electricity consumption = ~12,500 kWh/year
Average wind speeds at Diego Ramírez Islands = 11.92 mph or 5.33 m/s at a height of 10m[8]
Wind shear equation is $v(z) = v(z_0) * \left(\frac{z}{z_0}\right)^n$, where n is 0.14 which is the wind shear exponent that represents low grass and fallow lands in Diego Ramírez Islands:

$$v(80m) = v(10m) * \left(\frac{80m}{10m}\right)^{0.14}$$
$$v(80m) = 5.33\frac{m}{s} * (8)^{0.14} = 7.43\frac{m}{s}\ or\ 16.62\ mph$$

Per the Wind Power Class Table at 80m[9], the Wind Power Class of the Diego Ramírez Islands is at the high end of Class III. Diego Ramírez Island average wind speeds at 49m, the height that Bergey sets up wind turbines, are seen at 15.37 mph using the same wind shear equation, this wind turbine would be able to cover 18,600 kWh/year, over 6,000 more kWh/year than necessary. Figure A1 shows the graph used to interpolate this information. Table A1 shows the yearly energy production for average wind speeds in increments of 2 mph.

$$Yearly\ Energy\ Production = -8.9583x^3 + 352.68x^2 - 2451x + 5482.3$$

$$Yearly\ Energy\ Production =$$

$$-8.9583(15.37mph)^3 + 352.68(15.37mph)^2 - 2451(15.37mph) + 5482.3$$

$$Yearly\ Energy\ Production = 18{,}600\ kWh/year$$

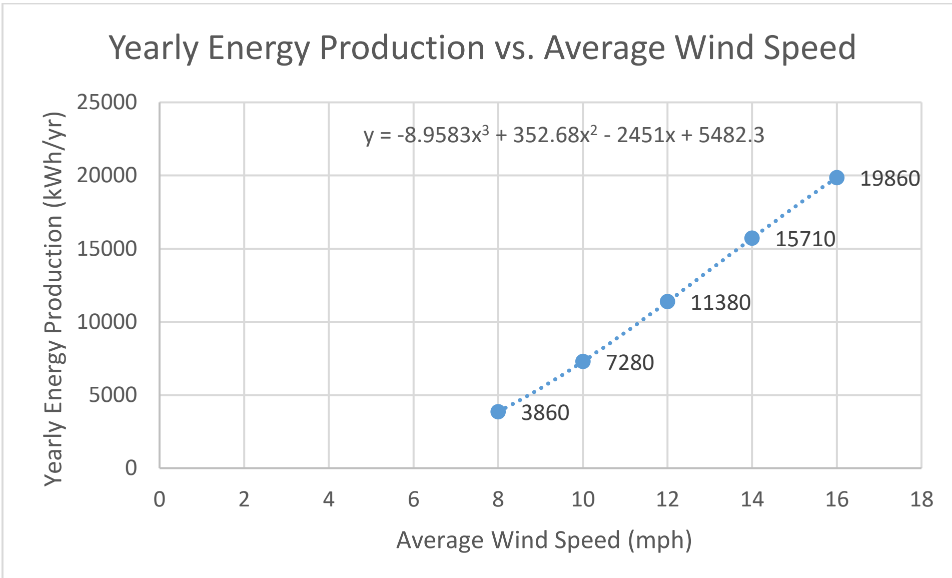

Figure A1. Yearly energy production vs. average wind speed graph.

Table A1. Annual energy production of Bergey Excel 6 Turbine based on average wind speed.[2]

Average Wind Speed (mph)	Annual Energy Production (kWh/yr)
8	3,860
10	7,280
12	11,380
14	15,710
16	19,860

Wind Turbine Selection: One Bergey Excel 6 Wind Turbine with 5.5kW rated power

Price: $21,995

15.2. Duct Design

Duct design can be found on the next few pages. Figure A2 includes an un-annotated duct layout, Figure A3 includes an annotated duct layout with VAV tags, Figure A4 includes an AHU layout only, and Figure A5 includes a profile view of the air handling units from the roof intruding into the building.

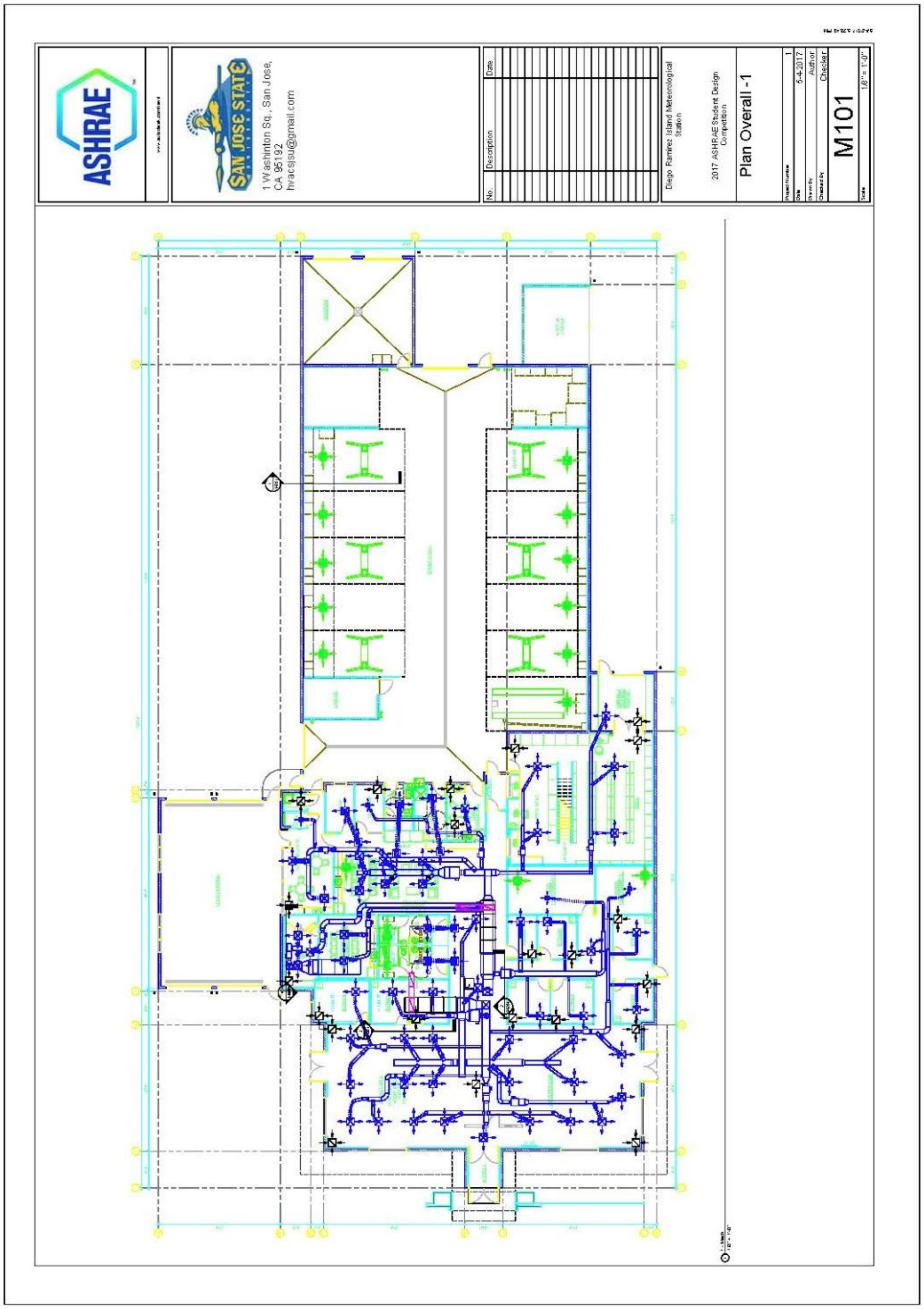

Figure A2. Duct design layout of building.

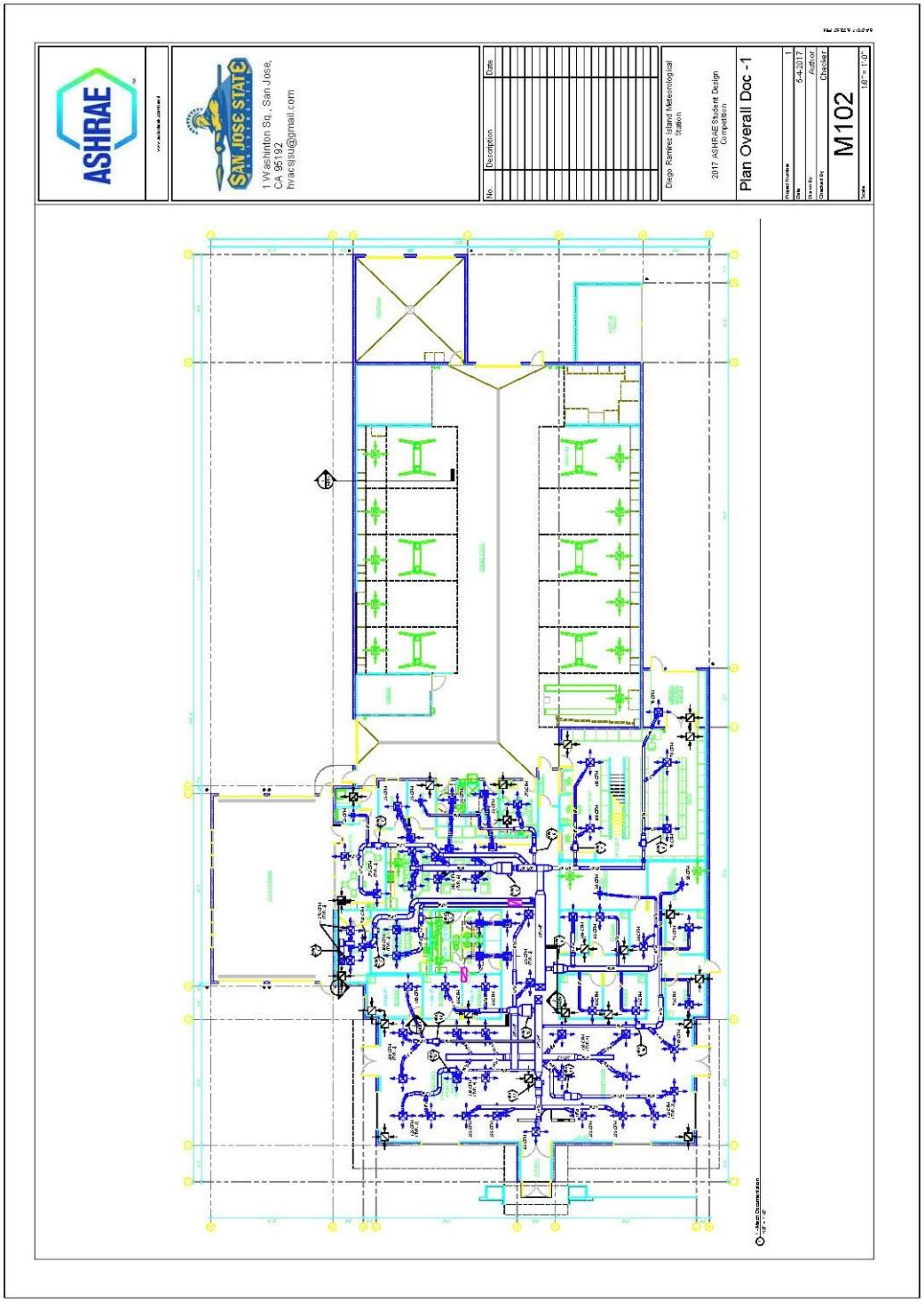

Figure A3. Duct design layout of building with VAV tags.

Figure A4. Layout of AHUs.

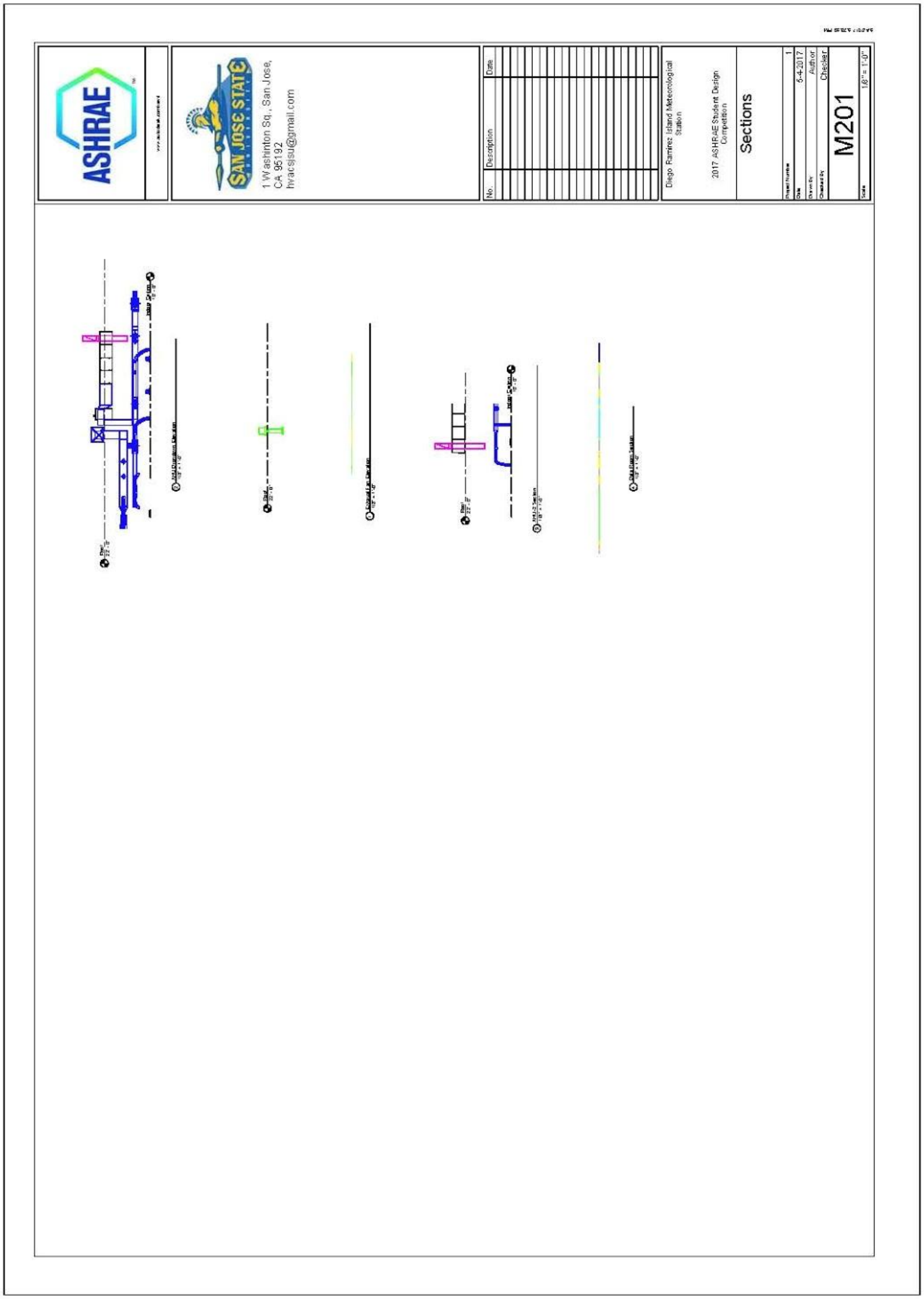

Figure A5. Profile view of AHUs.

15.3 Load Calculations Reports and Schedules

15.3.1 Trace 700 Checksums Reports

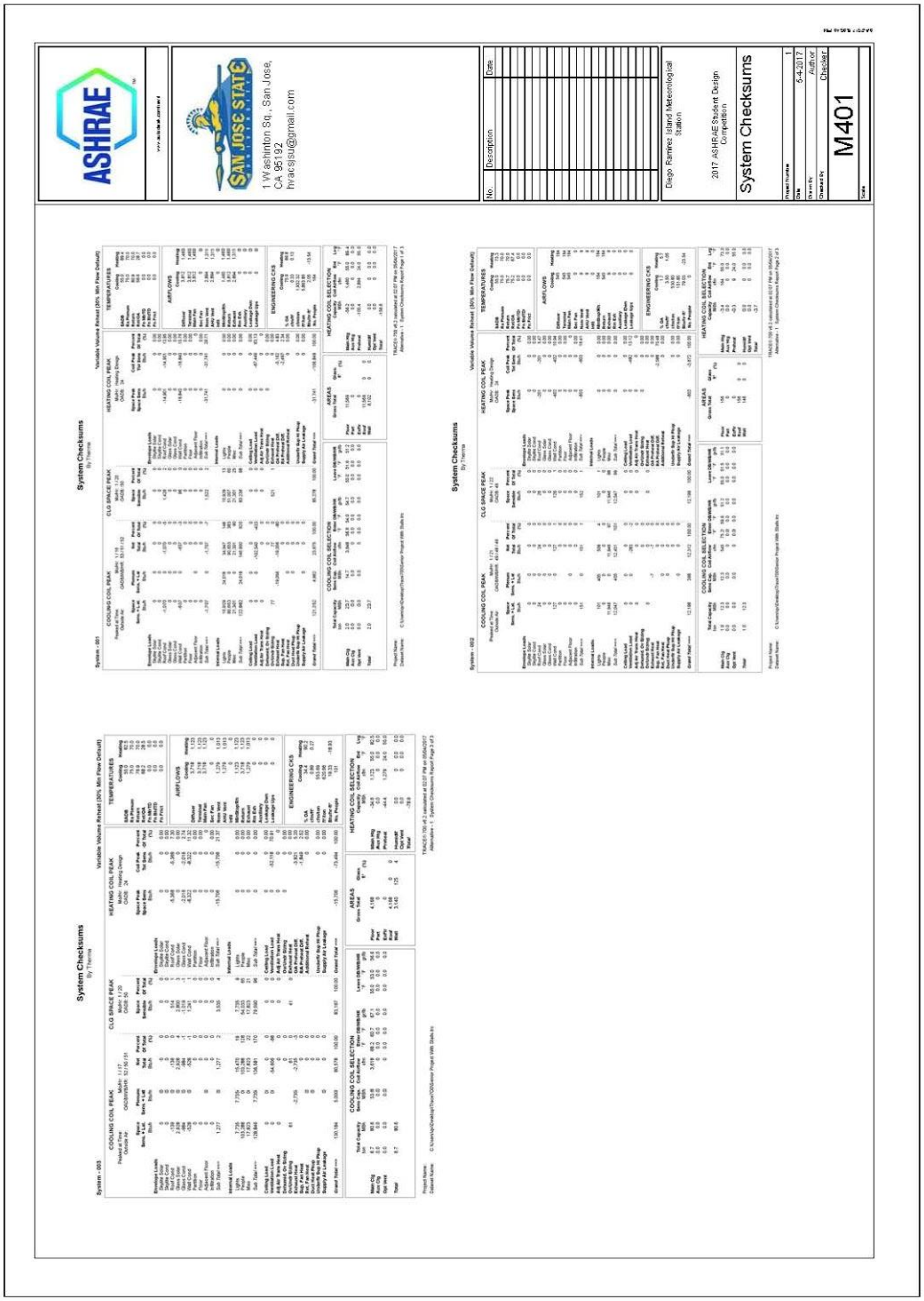

Figure A6. Trace 700 Checksums Reports.

15.3.2 Schedules

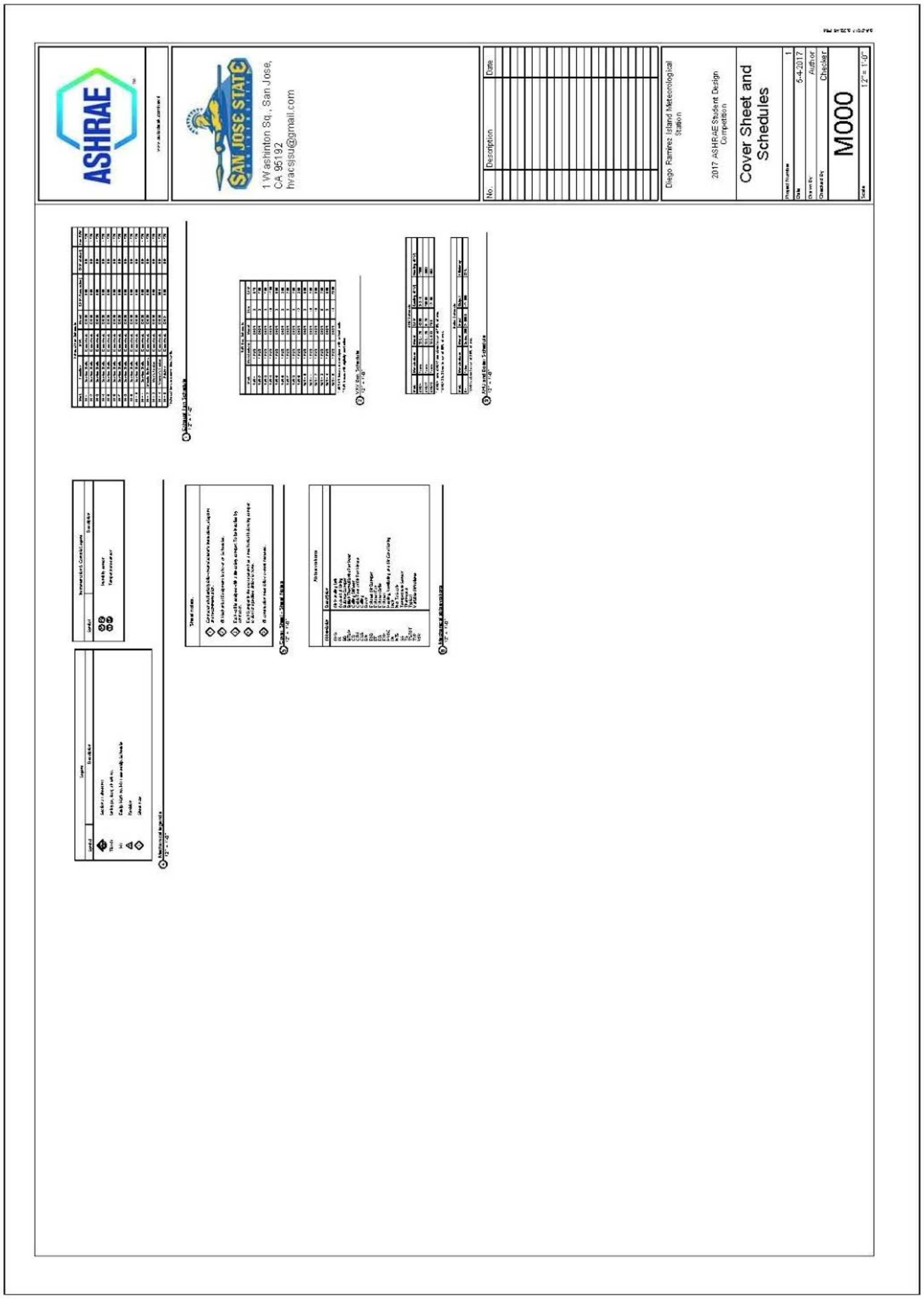

Figure A7. Schedules for AHUs, VAV boxes, and boiler.