April 8, 2015

NEOMED RESEARCH AND GRADUATE EDUCATION + COMPARATIVE MEDICAL UNIT REPORT

PSUAE

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Executive Summary

This report is the culmination of a comprehensive analysis of the Research and Graduate Education building and Comparative Medical Unit expansion project. The goal of this analysis was to evaluate the merits and goals of the existing project and its systems, and then execute a proposal of alternatives intended to provide tangible benefits to the operators and occupants.

As a high-technology, medical research project the RGE and CMU proved to be a very interesting and technically challenging project to analyze. A high degree of system complexity resulted from the wide range of services needed and strict environmental requirements. The existing system showed itself to be well-designed with regard to programming requirements and in many ways the most appropriate solutions to the design challenges at hand. The goal of the project was very clear: provide the highest quality research and education facility possible to foster the growth and development of health care education within the university and the surrounding community.

Keeping in mind the project goals of quality, availability, independence, and flexibility, a modification to the existing building utilities was proposed in the form of a cogeneration plant to go alongside the existing plant in the RGE basement. Adding on-site generation capability would make the project completely independent of outside utility structures, and the myriad of thermal loads for both space conditioning and lab processes were potential uses for excess generation heat. A configuration was chosen that provided the ability to handle the full campus electrical load, with reasonable turndown for part load operation due to its modular nature. Excess heat was taken advantage of to cover both the low-pressure and high-pressure steam loads present throughout the year. Due to the low cost of electricity at the project location, electric on-site generation did not prove as big of a savings generator as is usually expected from cogeneration projects. However, the cogeneration plant still had a reasonable payback of roughly a decade due to very low gas prices and high equipment efficiencies. A number of the non-quantifiable benefits of cogeneration are directly applicable to this facility, including power reliability, conduciveness to facility expansion, and off-hour operation. In addition, the plant will decrease the campus energy use and environmental impact.

In conjunction with the proposed cogeneration or CHP plant, an interconnection scheme was devised so that the plant could operate in parallel with the electric grid safely and effectively. The ability to start up from a dead state without outside assistance, known as black start capability, was also designed into the cogeneration plant.

Another auxiliary component of the proposal was the implementation of a Design-Build project delivery method in place of the then-mandatory Multiple-Prime contract structure. Based on outside research findings and documented project management challenges, it is quite plausible that an alternative delivery method could have made project administration significantly smoother and quite possibly have saved schedule time and change order money.

Project Overview

The NEOMED Research and Graduate Education building and Comparative Medical Unit expansion project is the first phase of a multi-phase campus expansion plan at the Northeast Ohio Medical University. The project consists of the RGE, a four-story 63,000 SF biomedical research building. The first three floors are fully built out with laboratory and support spaces, offices, and small group instruction rooms. The fourth floor is shelled in and will be built out in the future as the research program grows. There is a half-basement of roughly 6,000 SF housing a stand-alone utility plant.

The CMU expansion (noted as V on the map below) consists of a 14,500 SF addition to an existing facility housing a multispecies vivarium and research spaces for animal models of human disease. This facility provides all animal care services for research and instruction at the university. Areas for behavioral analysis, cage washes, multispecies holding and processing, and storage for feed and bedding are all contained in the new addition.

As a minor component of the project, several existing wet laboratories in the existing Building D were renovated. These labs now constitute the REDI-Zone, an area dedicated to public-private partnership research and development with early-stage biomedical companies.

Several other projects have been constructed within the last five years at the NEOMED campus. NEOMED's first on-campus housing, named The Village, opened August 2013 along with the Phase 1 addition studied in this report. Phase 2 of expansion consisted of the NEOMED Education and Wellness Center, or NEW Building. Constructed in conjunction with Signet Development, this multi-use facility opened September 2014 and contains an auditorium, event spaces, a high school Bio-Med science academy, a wellness center, the Signet executive boardroom, and several amenities. Phase 3 was planned as a new office and teaching building; this project was dropped earlier during campus planning, but is now under development again.

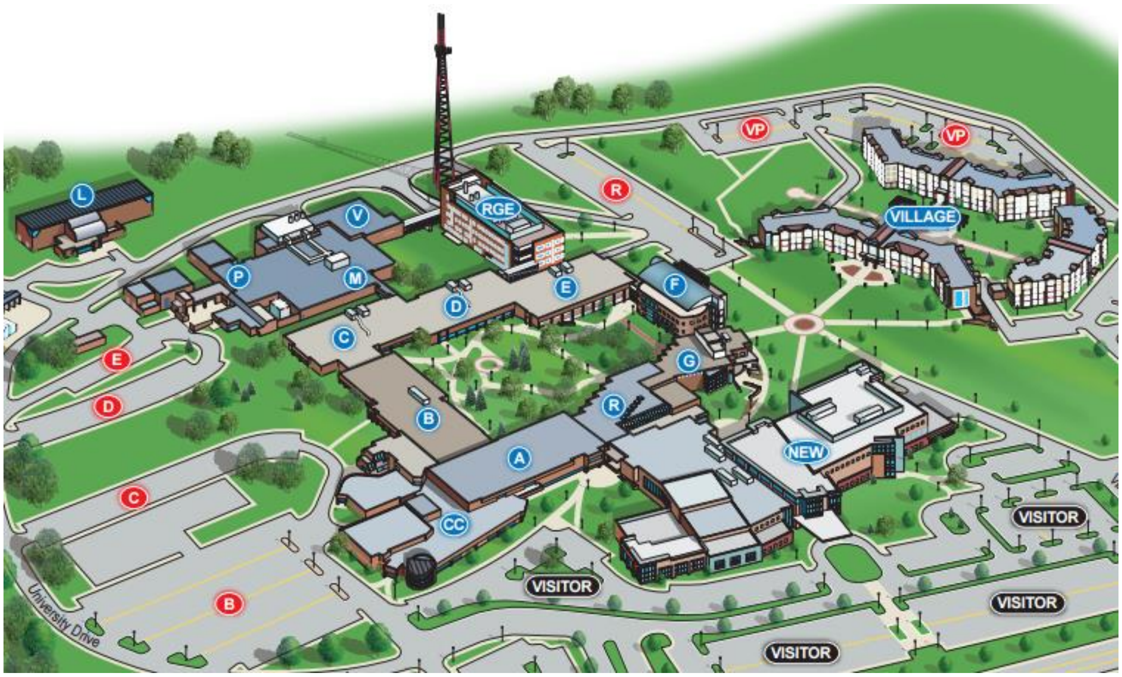


Figure 1: NEOMED Campus Map (Source: www.neomed.edu/map)

Existing Mechanical System

Design Criteria

Objectives and Requirements

The new Research and Graduate Education Building was built to help the university address the biomedical research and education needs of the region. It provides a working space for 30+ scientists focused on research involving better diagnosis and treatment of arthritis, cardiovascular disease, Alzheimer's disease, and innovative ways to design and deliver new medicines. The facility provides full support for teams with offices for faculty, write-up areas for researchers, small group teaching rooms, and open lab and support spaces. The top floor is shelled out for future program expansion.

The existing Comparative Medical Unit provides animal care services for research and teaching programs at the university. It is staffed by 8 personnel under a qualified vet specializing in lab animal medicine. The addition to the existing building was meant to expand animal care capabilities by adding to the vivarium and providing additional mechanical space.

Due to the sensitive nature of the activities in the lab and vivarium spaces, 100% outdoor air is required for these areas. As a result of this requirement, serious thought was given to the different energy recovery measures that could be taken to minimize the energy use of airside systems. HVAC System design was intended to have following characteristics: modular approach, energy responsiveness, flexibility for future changes, durability and ease of maintenance, reliability, and redundancy of critical components.

Code requirements that were followed include:

- Ohio State Building and Mechanical Codes.
- NEOUCOM Design and Engineering Guidelines
- Recommendations of the National Fire Protection Association (NFPA), in general, and, in particular:
    - HVAC: NFPA 90A, 90B, 96
    - HVAC: NFPA 45
- Recommendations of ASHRAE including ASHRAE 62-1999, Indoor Air Quality and ASHRAE/ANSI 15, Chiller Mechanical Rooms.
- National Electrical Code (NEC)
- Energy Conservation Act 222
- ANSI Z 9.5
- USGBC LEED Criteria
- NIH Design Requirements Manual
- Recommendations of AAALAC (animal areas)

Design Influences

Available utilities greatly affect building systems design. Existing campus utilities include electric, natural gas, cold water and sanitary/storm sewer. Electrical service consists of a high voltage loop stepped down to 480/277 and 208/120 at each building. Site natural gas piping is a mix of low pressure and medium pressure.

With regards to heating, roughly 6 or 8 boiler plants are located at various points on the existing campus. Typically one “heating” location is present for a heating water loop for each building project. The largest of these is the existing boiler and chiller plant in the M building, just to the east of existing CMU. This main plant feeds all of the original 1974 part of campus. The chillers at M Building feed nearly all of the entire campus as well. There are some smaller DX cooling units scattered throughout the campus, but they are not a significant percentage of the campus cooling capacity.

In addition to chillers and boilers, Building M also contains a high pressure steam boiler plant that makes 80 psig steam. Originally a coal fired plant in 1974 with two large coal boilers, it was switched to four natural-gas fired Ohio-Special steam boilers in 1991. The steam plant once served heat exchangers in the M building boiler room, AHU heating coils throughout campus, the DHW tank in the M building, numerous humidifiers throughout campus, and many lab steam outlets, plus steam sterilizers. The NEOMED campus has since downsized their use of steam, and now only hi-pressure steam is distributed to the CMU vivarium equipment, humidifiers in the CMU, and steam sterilizers.

Operability was a major influence in initial design, and is one of the factors that drove the decision to provide stand-alone utilities for the RGE Building. The RGE is intended to be available 24/7 to the scientists and their teams, and also the CMU must be able to provide 24/7 HVAC for the animals in the vivarium.

Distance to existing utilities also drove the decision to include stand-alone utilities. Originally, the design team considered extending the hi-pressure steam from the existing M building boiler room to the new RGE building, but that was cut due to budgetary concerns. Space was reserved in the RGE lab AHUs for humidifiers to be installed later, along with space for a medium pressure steam boiler in RGE basement. Also, the design team looked at extending piping from the central M building boiler and chiller plant; however, there was still going to be a need for additional chilled water and heating capacity so the cost to just include a new plant was very similar. Direct burial was considered as well as an indoor route, but that was complicated by the fact that the bridge connectors were alternate bids. The CMU addition is however connected to the M building boiler and chiller plant as well as the steam plant, seeing as the existing utilities were already located in the original building.

A variable air volume was deemed the safest and most obvious choice for airside systems. Due to the very stringent air change per hour requirements and variety of unique spaces, plus the need for 100% outdoor air, custom air handling units were created for the RGE labs and Vivarium expansion. The office side of the RGE does include a custom 30% outdoor air unit with a mixing plenum and economizer for some energy recovery.

Heat and energy recovery was a critical design point due to the large air turnover rate; a number of options were weighed. Desiccant dehumidification was ruled out, primarily due to the chemicals and contaminants that would be present. The design team did not know how those would have reacted with the desiccants, so they erred on the safer side. Also, the additional efficiency would primarily occur during cooling season and in a cool wet climate it was not “where the money was” with savings. Air-to-air, wheel, and heat-pipe systems were all eliminated as energy recovery systems due to their potential cross-over for contamination. A heat-pipe recovery was briefly considered, but would have needed to be a two coil design which is a more complex and expensive variety. The only options left were either simple run-around glycol coils or a heat pump between the outside air and exhaust air streams. The design team elected to use glycol coils in the end.

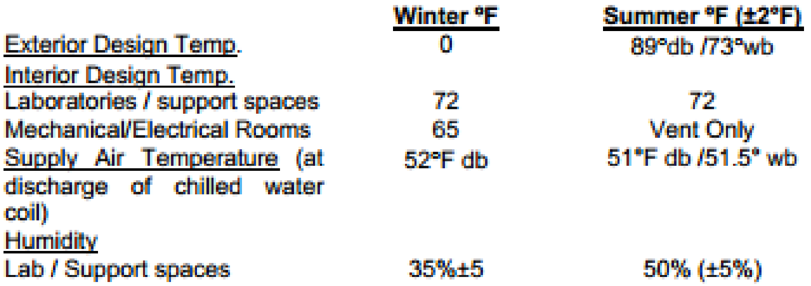
With concern to controls, the team did not consider CO2 monitoring since most spaces were going to have occupancy sensors; some of the sensors unfortunately did get value-engineered out. The new addition has an automatic temperature control system consisting of an independent direct digital control circuit. This circuit is connected and interfaced with the existing campus front ends to allow the campus-wide system to trend recording of the major equipment operation and alarms. This data is used to develop a point schedule for the RGE, as well as to trend recording of environmental conditions and lighting in the CMU to maintain AAALAC accreditation.

A RO/DI water system was provided for the labs and vivarium spaces, sized to supply the feed for the animal watering equipment. A separate laboratory waste collection system was provided to drain all laboratory fixtures. The waste is piped through a duplex limestone chip tank neutralization system.

With regards to fire protection, the new RGE includes a combination wet sprinkler and standpipe system with sprinkler drain risers extended to spill to the exterior. It was important to specify non-ferrous piping and components to be used in areas subject to magnetic fields or equipment. In addition, a new fire pump room was provided in the RGE basement. The existing CMU building was non fire suppressed, so the new addition was designed to remain non fire suppressed with the inclusion of fire separation walls between the existing building and new addition.

Design Conditions

The RGE Building has a variety of laboratory and office spaces, many of which had stringent space thermostat set points. All Occupied spaces were set according to the temperature and humidity settings in Figure 2, taken from Division 23 Section 3 of the BR+A Schematic Narrative.



	Winter °F	Summer °F (±2°F)
Exterior Design Temp.	0	89°db /73°wb
Interior Design Temp.		
Laboratories / support spaces	72	72
Mechanical/Electrical Rooms	65	Vent Only
Supply Air Temperature (at discharge of chilled water coil)	52°F db	51°F db /51.5° wb
Humidity		
Lab / Support spaces	35%±5	50% (±5%)

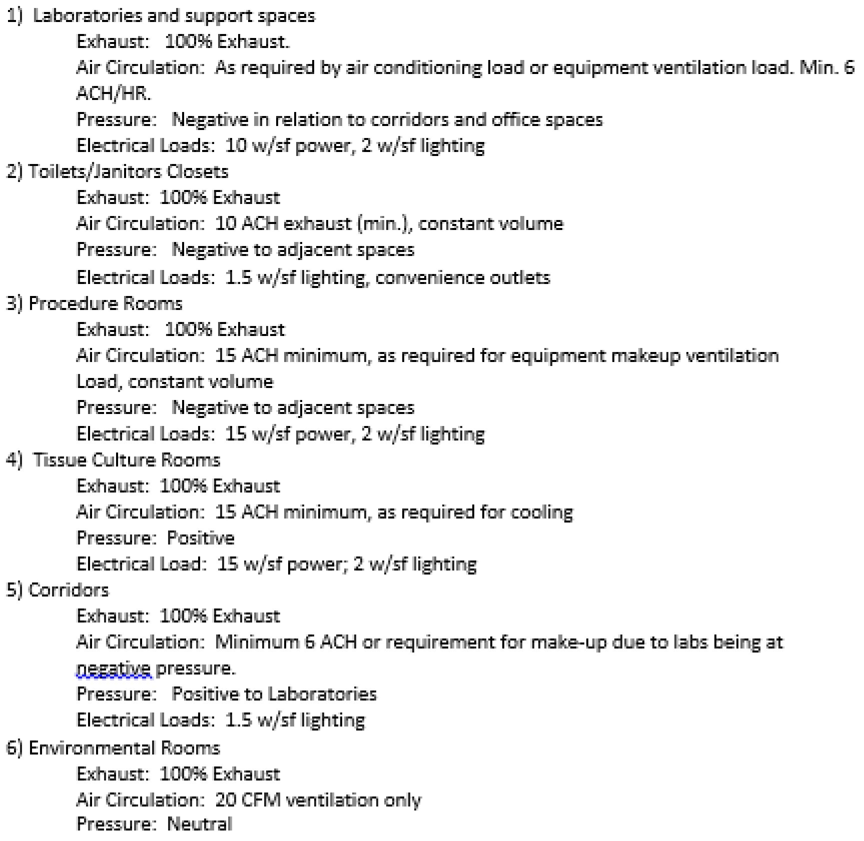
Figure 2: Design Temperatures and Humidity (Source: BR+A Schematic Design Narrative)

The project mechanical system was designed with a winter exterior design temperature of 0 degrees F and a summer exterior design temperature of 89 degrees dry bulb/73 degrees wet bulb +- 2 degrees.   Indoor design temperature and humidity varies based on space type. Labs and support spaces are set to 72 degrees F year-round. Mechanical and electrical rooms are conditioned to 65 degrees during the winter and ventilated with no conditioning in the summer. Animal holding rooms in the CMU have a selectable range from 68-85 degrees to provide species-appropriate conditioning, with the exception of rabbit holding areas set to exactly 65 degrees.

Humidity in the lab and associated support spaces is set to 35%(±5) in the winter and 50% (±5%) in the summer. Vivarium spaces in the CMU are set to 30-40%(±5) during winter and 50% (±5%) during summer.

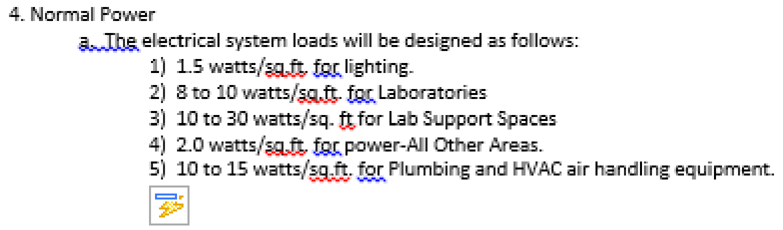
The majority of the RGE building is configured on a 100% OA system to control contaminants; labs, tissue culture rooms, operating rooms, etc. These rooms, however, have very stringent air circulation requirements. These requirements, given in minimum air changes per hour, ensure that enough uncontaminated fresh air is utilized and that delicate pressure relationships are maintained between rooms so as to avoid contaminant travel. These requirements are outlined below in Figure 3, from Division 23 Section 4a of the Schematic Narrative.

Very specific lighting and power loads are given by Figure 3 in addition to ventilation requirements. Additional values for electric loads are given in Division 26 Section 4a, listed below in Figure 4.



1) Laboratories and support spaces
    Exhaust: 100% Exhaust.
    Air Circulation: As required by air conditioning load or equipment ventilation load. Min. 6 ACH/HR.
    Pressure: Negative in relation to corridors and office spaces
    Electrical Loads: 10 w/sf power, 2 w/sf lighting
2) Toilets/Janitors Closets
    Exhaust: 100% Exhaust
    Air Circulation: 10 ACH exhaust (min.), constant volume
    Pressure: Negative to adjacent spaces
    Electrical Loads: 1.5 w/sf lighting, convenience outlets
3) Procedure Rooms
    Exhaust: 100% Exhaust
    Air Circulation: 15 ACH minimum, as required for equipment makeup ventilation Load, constant volume
    Pressure: Negative to adjacent spaces
    Electrical Loads: 15 w/sf power, 2 w/sf lighting
4) Tissue Culture Rooms
    Exhaust: 100% Exhaust
    Air Circulation: 15 ACH minimum, as required for cooling
    Pressure: Positive
    Electrical Load: 15 w/sf power; 2 w/sf lighting
5) Corridors
    Exhaust: 100% Exhaust
    Air Circulation: Minimum 6 ACH or requirement for make-up due to labs being at negative pressure.
    Pressure: Positive to Laboratories
    Electrical Loads: 1.5 w/sf lighting
6) Environmental Rooms
    Exhaust: 100% Exhaust
    Air Circulation: 20 CFM ventilation only
    Pressure: Neutral

Figure 3: Airflow requirements (Source: BR+A Schematic Design Narrative)



4. Normal Power
    a. The electrical system loads will be designed as follows:
        1) 1.5 watts/sq.ft. for lighting.
        2) 8 to 10 watts/sq.ft. for Laboratories
        3) 10 to 30 watts/sq. ft for Lab Support Spaces
        4) 2.0 watts/sq.ft. for power-All Other Areas.
        5) 10 to 15 watts/sq.ft. for Plumbing and HVAC air handling equipment.

Figure 4: Light and Power Design Loads (Source: BR+A Schematic Design Narrative)

System Breakdown

The project has utilities independent of the campus infrastructure. Contained within the RGE basement are four 3MMBTU natural gas-powered condensing boilers for heating, two 300-ton electric centrifugal chillers for cooling, and three 1000lb/hr. medium pressure vertical steam boilers for humidifiers and laboratory process equipment.

Most air handling units on the project were custom made by Air Enterprises. Two 100% Outdoor Air AHU's, sized at 37,500 CFM each, serve the lab areas to the west in the RGE. Serving the offices on the east is a smaller AHU at 25,000 CFM and 30% outdoor air. A small constant-volume 4,500 CFM air handler is located in the RGE basement to provide ventilation and space conditioning. The CMU expansion has a new 85,000 unit with 100% outdoor air similar to the two serving the RGE labs.

Running water for the project is provided by a new 6-inch water service. Domestic hot water is provided via duplex 250-gallon gas-fired condensing water heaters located in the RGE basement. The building is designed as a single zone with full recirculation back to the water heaters. A separate supply and return branch provides hot water for the lab equipment and is outfitted with local backflow preventers. The plumbing system is equipped with a duplex water booster to assist in serving the upper floors.

The RGE has a new main electrical service with a single-ended normal power switchboard rated at 480V 3000A. A pad-mounted distribution stepdown transformer takes the 480V down to 208/120V. This transformer is rated at 1500 kVA and is three-phase, four-wire. Power is then circuited throughout the building via double-throw branch automatic transfer switches. A 400kW/500kVA diesel emergency generator sits outside to provide power to the 225A emergency branch serving emergency light and power fixtures. The generator also is connected to a 300A circuit legally required for the fire pump, and an optional 800A standby circuit for HVAC components and select lab equipment.

Lighting in the RGE is mostly fluorescent. All lighting fixtures are suspended from the building structure rather than the ceiling system. Sensors and controls are provided to perform daylight dimming in perimeter areas and zero-occupancy shutoff. Existing Telecommunications system in the Comparative Medical Unit are extended to the expansion and the new RGE Building. 120V power sources, obtained from the emergency/standby system, provide power for alarms and access control system.

Airside

To achieve proper ventilation and space conditioning, there are five total air handling units for the project, broken down in the table below. AHU-1 and AHU-2 are located on the rooftop of the RGE and serve the Lab and Support areas, while AHU-3 is located on the roof as well and serves the RGE offices. AHU-4 is located in the Basement of the RGE and serves to simply provide constant volume ventilation and space conditioning to the mechanical plant. AHU-5 is located on the roof of the CMU addition.

Air Handling Units																
				Fans									Coils			
				Supply			Return			Exhaust			Heating		Cooling	
NO.	Type	Area	Min. OA. CFM	NO.	CFM/fan	ESP	NO.	CFM/fan	ESP	NO.	CFM/fan	ESP	GPM	Tot. MBH	GPM	Tot. MBH
AHU-1	Custom VAV	RGE Labs	50,000	4	12,500	4.0"	-	-	-	2	50,000	4.75"	140	2085	470	3584
AHU-2	Custom VAV	RGE Labs	50,000	4	12,500	4.0"	-	-	-	2	50,000	4.75"	140	2085	470	3584
AHU-3	Custom VAV	RGE Offices	8,400	2	14,000	3.0"	1	28,000	2.0"	-	-	-	51	820	150	1294
AHU-4	Constant	RGE Basm.	450	1	4,500	1.0"	-	-	-	-	-	-	13	194.4	47	187
AHU-5	Custom VAV	CMU exp.	85,000	4	21,250	4.0"	-	-	-	3	42,500	4.0"	270	3420	625	6135

Figure 5: AHU Schedule

Hot Water and Steam

Located in the RGE Basement plant are three 3MMBTU gas-powered condensing boilers providing preheat and reheat water for the airside equipment. A firetube steam boiler was added to the pre-existing CMU steam plant to handle the steam loads of the project. In addition,

Boilers							
NO.	Type	Medium	MBH In	MBH out	GPM	Steam PSIG	Min. Gas input pressure
B-1	Condensing	HW	3,000	2,883	225	-	3.5"
B-2	Condensing	HW	3,000	2,883	225	-	3.5"
B-3	Condensing	HW	3,000	2,883	225	-	3.5"
B-5	Firetube	Steam	1,969	1,697	-	80	9.5"
B-6	Modulating, Condensing	HW	3,000	2,664	133	-	3.5"
B-7	Modulating, Condensing	HW	3,000	2,664	133	-	3.5"

Figure 6: Boiler Schedule

Hydronic Pumps						
	NO.	Type	Service	GPM	Head Pressure (FT H20)	MHP
RGE	HWP-1	End Suction	Primary Heating Water	450	72	15
	HWP-2	End Suction	Primary Heating Water	450	72	15
	CWP-1	End Suction	Chilled Water Pump	680	65	20
	CWP-2	End Suction	Chilled Water Pump	680	65	20
	TWP-1	Horiz. Split Case	Tower Water Pump	1275	65	30
	TWP-2	Horiz. Split Case	Tower Water Pump	1275	65	30
	HGRP-1	End Suction	AHU-1 Heat Recovery Coil	480	65	15
	HGRP-2	End Suction	AHU-2 Heat Recovery Coil	480	65	15
	HCP-1	In-line	AHU-1 Heating Coil	140	15	1
	HCP-2	In-line	AHU-2 Heating Coil	140	15	1
	HCP-3	In-line	AHU-3 Heating Coil	50	12	0.5
	HCP-4	In-line	AHU-4 Heating Coil	12	12	0.125
	CWP-3	In-line	AHU-4 Cooling Coil	47	25	0.75
CMU	HWP-1	End Suction	Heating Water	500	50	15
	HWP-2	End Suction	Heating Water	500	50	15
	HCP-1	In-line	AHU-5 Heating Coil	270	12	1.5
	HGRP-1	End Suction	Heat Recovery	540	65	15

Figure 7: Pump Schedule

Chilled Water

Two 425-ton electric centrifugal chillers are located in the basement plant to provide chilled water for the HVAC equipment. Each Chiller is connected to a cooling tower on the roof of the RGE.

Chillers					
NO.	Type	Tons Output	Min. Turndown Tons	Evap. GPM	Cond. GPM
CH-1	Centrifugal	425	45	680	1275
CH-2	Centrifugal	425	45	680	1275

Figure 8: Chiller Schedule

Cooling Towers						
					Motors	
NO.	Type	Tons	No. Cells	Total GPM	HP	RPM
CT-1	Crossflow	425	1	1275	25	1800
CT-2	Crossflow	425	1	1275	25	1800

Figure 9: Cooling Tower Schedule

Energy Recovery

Within each of the three 100% outdoor air units is a run-around glycol loop for heat recovery.

Loads and Energy Use

During initial building analysis, an energy model/load calculation was constructed in Trane Trace 700 to compare to actual design documents. However, existing design documentation was limited. An Elite load calculation was utilized to quantify the envelope loads of the project, but no other documentation was available for load sizing. No yearly energy analysis had been performed for the project. The combination of existing calculation reports and specified design conditions were used to construct the Trace model, but some inputs were unspecified or unclear so assumptions needed to be made.

Assumptions

Documents provided did not specify any particular occupation densities. Therefore, when calculating internal loads and ventilation requirements, ASHRAE standard values for occupancy per 1000 square foot were internally referenced by the Trace model.

Given the research and laboratory programming of the building, the research function areas are required to maintain delicate pressure relationships. While perhaps not entirely realistic, all areas were modeled in the Trace file as having pressurized tight construction with 0 cooling and heating infiltration.

In the Trace model average values were used for the construction data for building elements. A library entry for the RGE wall was created, based off of section provided in construction drawings. The “RGE Wall” template consists of 5/8” gypsum board, followed by 6” insulation between metal studs, 2.73” hi-density stiff insulation, air space, and 4” face brick. Floor slabs were all entered as 4” heavyweight concrete and roof was calculated as 4” lightweight concrete. Interior partitions were all taken as .75” gypsum frame from the preloaded library. All glass was entered as a percentage of wall area, in most areas 38%. The default single clear ¼” window type was utilized.

Trane Trace has a preloaded library of several hundred American cities across the country. Weather data for Akron, Ohio was specified as this was the closest city to the project’s Rootstown, Ohio location.

At the time of model construction, no data for typical occupancy schedule was available. While not the most realistic measure, all schedules were specified as 100% available and will need to be modified as more information is obtained.

Heating and Cooling Loads

The first observation taken when the Trace model finished generating reports was that the calculated airflows for most of the air handlers were significantly larger than the design CFM respective to each AHU. The only value that was realistic was the 26,000 CFM cooling airflow calculated for AHU-3, which serves the office spaces. Each of the lab AHU’s were designed at 50,000 CFM; AHU-1 was twice that at

98,000 cooling CFM and AHU-2 was a whopping six times design value at 300,000 cooling CFM. The constant volume AHU-4 for the basement was twice design value at 19,000 cooling CFM.

The calculated plant capacities had corresponding overly-large loads. The total system cooling capacity of the RGE came out at 1958 tons, over twice the size of the existing chilled water plant. The system heating capacity came in at roughly 27MMBTU, three times the size of the existing hot water boiler arrangement. Further refinement of the Trace model modified schedule and material assumptions and put out closer, but still unrealistic values.

Trace outputs are summarized in Appendix A. Designer reports from the Elite model are located in Appendix B.

Energy Use

According to the Trace 700 model, yearly electric consumption is on the order of 4,200,000 kWh. Yearly gas consumption is on the order of 200,000 therms and yearly water consumption is 7 million gallons. Building energy consumption comes in at roughly 350 kBtu/SF-year. Source energy consumption comes in at about 655 kBtu/SF-year. Based on Trace default financial values, total annual utility cost is $221,799 per year. Based on Trane Trace calculations, 7.7 million lbm/year of CO2 is emitted. 53,200 gm/year of SO2 is emitted and 13,300 gm/year of NOX is emitted. Given the error in heating and cooling loads, these numbers are not to be trusted; accurate utility data from the NEOMED campus plant was later gathered during proposal execution and provides a much better assessment of energy use.

ASHRAE Standard Evaluations

ASHRAE 62.1.5-2013: Systems and Equipment

5.1 Ventilation Air Distribution

The RGE, CMU and Building D are all in compliance with Section 5.1. The laboratories, support rooms, vivarium, and other such rooms are supplied with 100% outdoor air, therefore the airflow needed for proper conditioning easily exceeds ventilation requirements. The design documents all have appropriate information for balancing and minimum airflow allowed.

5.2 Exhaust Duct Location

Documents indicate that all exhaust duct runs are negatively pressurized relative to the supply duct runs in each room. The lab exhaust runs through two custom air handling units each at 50,000 CFM. Smaller exhaust fans are located above the office wings, and space is allotted for exhaust fans to be placed for future expansion.

5.3 Ventilation System Controls

The RGE building and the CMU addition each have an independent direct digital control systems interfaced with existing campus network. The system accomplishes all sensing and controlling via electronic actuation of all valves and dampers.

5.4 Air Stream Surfaces

All airstream surfaces are comprised of sheet metal ductwork with metal fasteners to comply with requirements for resistance to mold growth and erosion.

5.5 Outdoor Air Intakes

Outdoor air intake for office end of the RGE building is located on the east face of AHU-3. The outdoor air intake of the laboratory air handlers is located on the north face of the supply air tunnel. All outdoor air intakes are well outside of the required distances; the exhaust stacks for the lab exhaust are 25 feet high per 62.1 Table 5.5.1, giving plenty of distance for the class 4 air to discharge. In addition, each inlet is protected by a mesh screen and louvers to protect from rain, snow, and birds. All AHU's on the project are equipped with access doors for maintenance purposes.

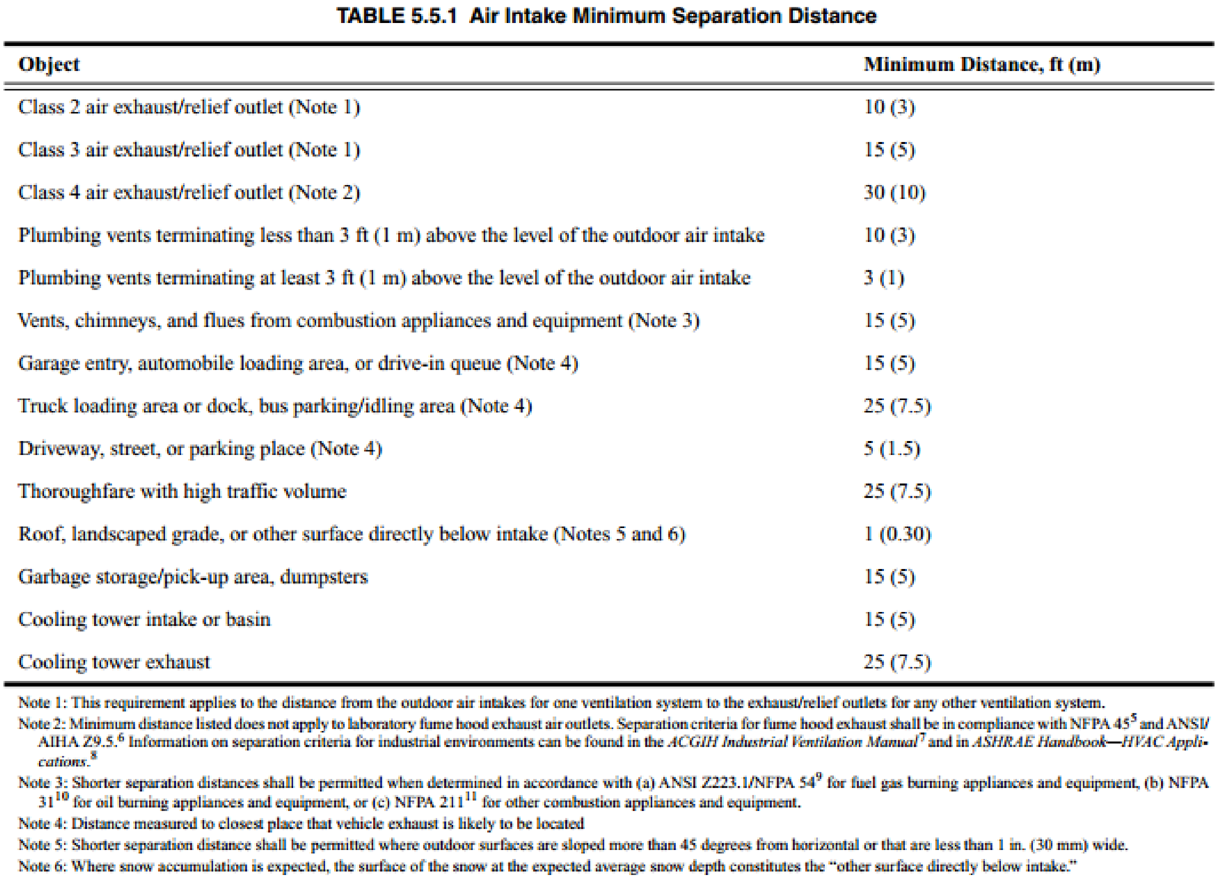


TABLE 5.5.1 Air Intake Minimum Separation Distance

Object	Minimum Distance, ft (m)
Class 2 air exhaust/relief outlet (Note 1)	10 (3)
Class 3 air exhaust/relief outlet (Note 1)	15 (5)
Class 4 air exhaust/relief outlet (Note 2)	30 (10)
Plumbing vents terminating less than 3 ft (1 m) above the level of the outdoor air intake	10 (3)
Plumbing vents terminating at least 3 ft (1 m) above the level of the outdoor air intake	3 (1)
Vents, chimneys, and flues from combustion appliances and equipment (Note 3)	15 (5)
Garage entry, automobile loading area, or drive-in queue (Note 4)	15 (5)
Truck loading area or dock, bus parking/idling area (Note 4)	25 (7.5)
Driveway, street, or parking place (Note 4)	5 (1.5)
Thoroughfare with high traffic volume	25 (7.5)
Roof, landscaped grade, or other surface directly below intake (Notes 5 and 6)	1 (0.30)
Garbage storage/pick-up area, dumpsters	15 (5)
Cooling tower intake or basin	15 (5)
Cooling tower exhaust	25 (7.5)

Note 1: This requirement applies to the distance from the outdoor air intakes for one ventilation system to the exhaust/relief outlets for any other ventilation system.

Note 2: Minimum distance listed does not apply to laboratory fume hood exhaust air outlets. Separation criteria for fume hood exhaust shall be in compliance with NFPA 45[5] and ANSI/AIHA Z9.5.[6] Information on separation criteria for industrial environments can be found in the *ACGIH Industrial Ventilation Manual*[7] and in *ASHRAE Handbook—HVAC Applications*.[8]

Note 3: Shorter separation distances shall be permitted when determined in accordance with (a) ANSI Z223.1/NFPA 54[9] for fuel gas burning appliances and equipment, (b) NFPA 31[10] for oil burning appliances and equipment, or (c) NFPA 211[11] for other combustion appliances and equipment.

Note 4: Distance measured to closest place that vehicle exhaust is likely to be located

Note 5: Shorter separation distance shall be permitted where outdoor surfaces are sloped more than 45 degrees from horizontal or that are less than 1 in. (30 mm) wide.

Note 6: Where snow accumulation is expected, the surface of the snow at the expected average snow depth constitutes the "other surface directly below intake."

Figure 10: ASHRAE Std. 62.1 Table 5.5.1

5.6 Local Capture of Contaminants

All areas with equipment that generate contaminates, such as labs and restrooms, have exhaust to capture contaminates and direct outdoors away from any intake openings.

5.7 Combustion Air

All laboratory spaces are equipped with fume hoods for removal of any potential combustion products.

5.8 Particulate Matter Removal

Supply air tunnels have a MERV-9 pre-filter and a MERV-14 after-filter within each air handler. Heat recovery coils within exhaust tunnels have MERV-9 pre-filters. Also, room-side replaceable “filter grilles” are used for exhaust of the animal holding room in the CMU. All of these meet the minimum ASHRAE standard of MERV-8 filtration.

5.9 Dehumidification Systems

Lab and support spaces are designed at 35% humidity in winter and 50% humidity in summer. The vivarium is designed at 30-40% winter humidity and 50% summer humidity. These are all less than the required 65% maximum. Regarding section 5.9.2, the RGE has two custom air handling units, with both supply and exhaust at 37,500 CFM for 100% outdoor air intake. The CMU addition has an 85,000 CFM supply and exhaust in a similar fashion.

5.10 Drain Pans

No mention of drain pans is given in the specifications

5.11 Finned-Tube Coils and Heat Exchangers

Plate and frame heat exchangers are utilized on this project rather than finned-tube heat exchangers

5.12 Humidifiers and Water-Spray Systems

The project utilizes Nortec NH series electrode steam humidifiers which are specified to use potable water and drain pans per ASHRAE standard.

5.13 Access for Inspection, Cleaning, and Maintenance

Sufficient access to HVAC equipment has been designed.

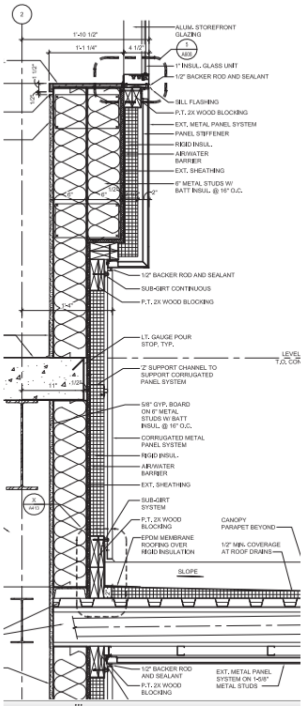


Figure 11: Typ. Architectural Wall Section (Source: TC Architects Construction Documents)

5.14 Building Envelope and Interior Surfaces

Architectural wall sections such as Figure 6 indicate a building envelope with rigid insulation, moisture barriers, and batt insulation between studs.

5.15 Buildings with Attached Parking Garages

Building has no attached parking garages, therefore section 5.15 does not apply.

5.16 Air Classification and Recirculation

The laboratories, animal operating rooms, and various technical support spaces are all Class 2 air per Table 6.2.2.1. However, it is important to note that the airstreams from any of the fume hoods is Class 4 as stated by Table 5.16.1. All other areas such as conference rooms and offices are Class 1 air. As stated before, the laboratory and animal care areas are operating on 100% outdoor air with no recirculation. The Class 1 rooms all recirculate air via return ducts. It is also important to note that the biosafety cabinet fume hoods shall recirculate 100% back into the procedure rooms.

5.17 ETS Air

Smoking is not allowed in any part of the building; 5.17 does not apply.

ASHRAE 62.1.6-2013: Procedures

6.1 General

The site's outdoor air has no contamination issues and is deemed acceptable for ventilation purposes. Proper ventilation rates are hereby calculated via the prescriptive Ventilation Rate Procedure and the Exhaust Rate Procedure and compared to the existing design specifications. No natural ventilation strategies are used in the design.

6.2 Ventilation Rate Procedure

A preconfigured excel spreadsheet was used to calculate ventilation needed for the offices and conference rooms to the east end of the RGE building, covered by AHU-3. In this project, this was the only air handler configuration that was not configured for 100% outdoor air intake. The breakdown from the spreadsheet calculations is located in Appendix A.

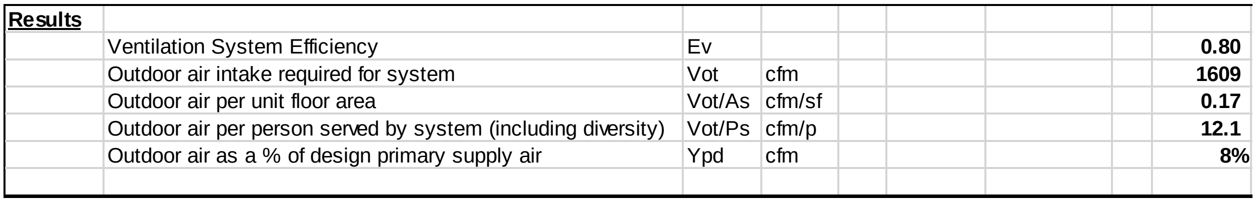
First, breathing zone outdoor air flow rates are calculated with Equation 6-1 from ASHRA 62.1-2013 for each room

$$V_{bz} = R_p{*}P_z + R_a{*}A_z$$

Where R_p is outdoor airflow rate per person, P_z is zone population by occupancy class, R_a is outdoor airflow rater per area, and A_z is the area covered by the zone. Table 6-1 of ASHRAE Standard 62.1-2013 contains values for both R_p and R_a, and is referenced by the spreadsheet.

The next step is to find and factor in the zone air distribution effectiveness E_z, found in Table 6-2. In all instances examined, supply air was delivered via ceiling diffusers at cooling temperature, so E_z was 1.0 all around. These values are also referenced in the spreadsheet in Appendix A.

After entering area and airflow data from the drawings, the total supply airflow amounted to roughly 19,600 CFM. This is slightly less than the design value for AHU-3 of 28,000 CFM. Figure 7 below gives a breakdown of total system ventilation.



Results								
	Ventilation System Efficiency	Ev						**0.80**
	Outdoor air intake required for system	Vot	cfm					**1609**
	Outdoor air per unit floor area	Vot/As	cfm/sf					**0.17**
	Outdoor air per person served by system (including diversity)	Vot/Ps	cfm/p					**12.1**
	Outdoor air as a % of design primary supply air	Ypd	cfm					**8%**

Figure 12: AHU-3 Ventilation Breakdown

Also, tallying up the individual zones indicates a surplus of 1294 CFM of unneeded outdoor air and a maximum Z_p value of .26. This could present an opportunity for energy savings.

ASHRAE 90.1.5-2013: Building Envelope

5.1 General

As shown by Figure B1-1 in ASHRAE Standard 90.1-2013 Section 5.1.4, the project's location in Rootstown, Ohio places it in the 5A Climate Zone, a relatively cool, moist region.

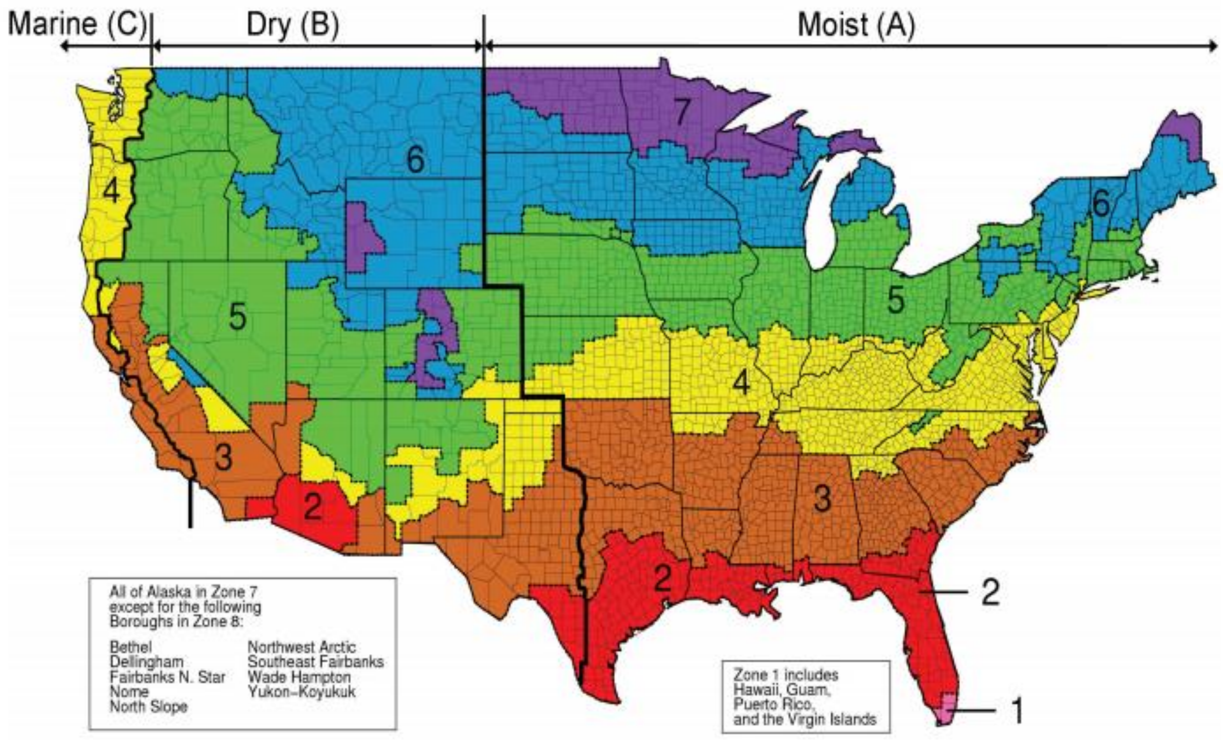


Figure B1-1 U.S. climate zone map (*ASHRAE Transactions*, Briggs et al., 2003).

Figure 13: ASHRAE Std. 90.1.5.1.4 Figure B1-1

5.2 Compliance Paths

Here we will elect to use the prescriptive evaluation for the building envelope outline in Section 5.5 of the code.

5.4 Mandatory Provisions

The building is constructed with a continuous air and water membrane throughout the entirety of the envelope. In addition, the entrances to the RGE and CMU have vestibules per section 5.4.3.4 of the code.

5.5 Prescriptive Building Envelope Option

Insulation values for the envelope are not available, making the envelope difficult to access. More information finding will be required.

ASHRAE 90.1.6-2013: Heating, Ventilation, and Air Conditioning

6.4 Mandatory Provisions

The prescriptive path outlined in Section 6.4 of Standard 90.1-2013 shall be followed as the building project does not meet the size criteria for the simplified approach outlined in Section 6.3. All equipment meets efficiency standards outlined in the tables of Section 6.8 and load calculations were conducted in the program Chvac 7 in accordance with ASHRAE Standards. The DDC system mentioned in the Standard 62.1.5.3-2013 controls all equipment in accordance with Standard 6.4.3.

6.5 Prescriptive Path

AHU-3 is outfitted with an economizer in accordance with code Section 6.5.1. The automatic temperature control system governs the zone controls via digital sensors and actuators. Also, given the data presented in the analysis of Standard 62.1.6.2 the amount of outdoor air utilized by the office air handler is less than the amount needed to require energy recovery equipment. However, the two AHU's feeding the labs of the RGE and the AHU feeding the CMU expansion use heat pipes with refrigerant to transfer heat from the exhaust stream to the supply stream during heating season, and vice versa during the cooling season.

ASHRAE 90.1.7-2013: Service Water Heating

Domestic water service is piped through water softeners with a duplex water system to provide adequate pressure for lab fixtures. Hot water will be provided via duplex 250 gallon condensing water heaters. This equipment is of proper efficiency per standard 7.8.

ASHRAE 90.1.8-2013: Building Power

This project has a new main electrical service made up of a single ended normal power switchboard, diesel emergency generator, branch automatic transfers and an optional standby distribution system. Feeders are sized within the required voltage drop of 2% and branch circuits are sized to no more that 3% voltage drop.

ASHRAE 90.1.9-2013: Building Lighting

All lighting on the project is automatically switched off via low voltage relays or occupancy sensors. Multi-level switch control is provided in perimeter areas to reduce intensity of light during daylight hours.

ASHRAE 90.1.10-2013: Other Equipment

None of the equipment mentioned in Section 10 applies to the project.

LEED Analysis

The project schematic design outline states that the team sought for a basic LEED Certification level. What follows is a quick breakdown of the RGE and CMU's adherence to the Energy and Atmosphere and Indoor Environmental Air Quality sections of the USGBC LEED 2013 Standard for New Construction.

Energy and Atmosphere Credits

EA Prerequisite 1: Fundamental Commissioning and verification- pass

Commissioning performed by PSI, INC

EA Prerequisite 2: Minimum Energy Performance- pass

Option 2- follows ASHRAE Standard 90.1

EA PREREQUISITE: BUILDING-LEVEL ENERGY METERING-pass

New meters installed for natural gas, HW, DCW, CW, Electric at CMU; meters for NG, Electric, and DCW at RGE

EA PREREQUISITE: FUNDAMENTAL REFRIGERANT MANAGEMENT-pass

No CFC's in any of new construction

EA CREDIT: ENHANCED COMMISSIONING-0 pts

No follow-up commissioning after building opened

EA CREDIT: OPTIMIZE ENERGY PERFORMANCE-0 pts

No energy modeling/simulation performed

EA CREDIT: ADVANCED ENERGY METERING-1 pt

Meters are interfaced with campus network. ATC stores data and trends and develops point schedule

EA CREDIT: DEMAND RESPONSE-0 pts

No demand response program used

EA CREDIT: RENEWABLE ENERGY PRODUCTION-0 pts

No renewable energy sources on campus utilized

EA CREDIT: ENHANCED REFRIGERANT MANAGEMENT- 0 pts

No analysis performed on refrigerants used

EA CREDIT: GREEN POWER AND CARBON OFFSETS-0 pts

No contract engaged

Indoor Environmental Quality Credits

EQ PREREQUISITE: MINIMUM INDOOR AIR QUALITY PERFORMANCE-pass

Project meets ASHRAE STD 62.1

EQ PREREQUISITE: ENVIRONMENTAL TOBACCO SMOKE CONTROL-pass

Due to the nature of the activities inside of both the RGE and CMU, smoking is prohibited in or around

EQ CREDIT: ENHANCED INDOOR AIR QUALITY STRATEGIES- 1 pt

Pressurized Vestibules are used at all entryways, areas with potentially hazardous chemicals are kept at negative pressure and sufficiently exhausted, and all AHU's have MERV-14 after filters

EQ CREDIT: LOW-EMITTING MATERIALS- 0pts

EQ CREDIT: CONSTRUCTION INDOOR AIR QUALITY MANAGEMENT PLAN- 0 pts

EQ CREDIT: INDOOR AIR QUALITY ASSESSMENT- 0 pts

EQ CREDIT: THERMAL COMFORT- 0 pts

All temperature and humidity controlled by ddc system to exact design specifications

EQ CREDIT: INTERIOR LIGHTING- 0 pts

Mostly fluorescents used, mostly automatic controls

EQ CREDIT: DAYLIGHT- 0 pts

No daylighting analyses performed

EQ CREDIT: QUALITY VIEWS- 1 pt

Layout and glazing is such that at least 75% of all regularly occupied spaces in RGE have unobstructed outdoor visibility.

EQ CREDIT: ACOUSTIC PERFORMANCE- 0 pts

No acoustical analysis performed

As evidenced by this analysis, the design did not truly aim for any sort of serious LEED certification, despite what the schematic outline states or what the original intent may have been.

Overall System Evaluation

Overall, the system functions very well towards meeting the priorities of the owner, which are running an excellent facility conducive to top-notch biomedical research, while maintaining some level of efficiency and affordability. Given the stringent design conditions, viable system options, and existing conditions, the mechanical design is very reasonable and functions well.

Proposed Redesign

Considerations

When evaluating potential alternatives to the systems already in place on the RGE + CMU project, there were a number of considerations to be made. During conversation with facility administration, it was made very clear that the top priorities of this project during its design and construction were:

1) Quality of facility
2) 24/7 availability for researchers and staff
3) Independence and reliability of systems
4) Flexibility for future changes

Cost and energy savings were absolutely important, but the established programming took precedence. Alternate systems and methods were evaluated in the context of these priorities.

Due to the required high air changeovers in many areas, energy recovery was a major consideration during design. While evaluating the existing energy recovery methods, no real practical alternative for air-side energy recovery presented itself. The idea of using active chilled beams in place of VAV was considered as a way of reducing the amount of wasted energy in the HVAC system. While they have been successfully utilized in lab applications, there are a litany of precautions to be taken. Normally chilled beams are only beneficial in labs where the HVAC system is sized largely based on equipment loads and less making up exhaust from fume hoods. The use of chilled beams in a vivarium may not even be allowed via code. While there is some potential for the implementation of chilled beams to result in less energy waste and smaller airside equipment, there is too much risk associated on this particular project due to stringent ACH, humidity, and pressure relationships required.

One major area with potential for alternate methods was within the construction management and delivery of the project. As a very technically challenging project, the RGE + CMU had a high expense relative to size and scope, and a premium on quality. The project was also on a very strict schedule; the new facilities were to be ready for use in time for the start of the 2013 fall semester. However, due to NEOMED being a public university and therefore a public, state-funded building project, the owner was legally required to use a competitively bid multiple-prime contract structure. The project experienced notable schedule over-runs due to weather and delays, and conflicts occurred as a result.

Proposed Alternatives

In light of the stated design priorities and importance of energy conservation, the implementation of cogeneration presented itself as a viable and attractive alternative to the existing system. On-site electricity generation would allow more independence for the facility as well as another layer of reliability. In addition, the excess heat generated is excellent for steam processes, and the project has a sizable, consistent steam requirement. Provisions could be made to accommodate the planned expansion of the shelled-out areas and future humidifiers in the RGE building, or even the other campus projects.

One breadth study consists of electrical work coinciding with CHP application. Interconnection with the existing utility and the implementation of black start capability will both be addressed. The ability to still utilize the electric grid in addition to on-site generation will be very important, but precautions must be taken with interconnection design to prevent accidents and malfunctions. Being able to restart on-site generation in case of a blackout, without outside assistance, is also another crucial consideration.

The other breadth study consists of the evaluation of the multiple-prime project delivery structure implemented on the project. A comparison to other alternate systems, such as single-prime, design-build, and CM-at-risk will be made by use of real research on different projects. The research will be used to support potential benefits from an alternate delivery system within the context of this particular project.

Proposed Redesign Analysis

Mechanical Depth: CHP Implementation

Research

Research was conducted to learn about the different cogeneration strategies and their benefits and drawbacks. There are currently three main methods used for electrical generation in a CHP system. These are known as prime movers, and can be steam or gas turbines, reciprocating engines, or fuel cells. Fuel cells are a relatively new and underdeveloped technology, and were deemed impractical and inefficient for this project so they were never considered.

Reciprocating engines used for cogeneration are essentially like larger versions of an automobile engine. They tend to have smaller electrical capacities, and so are more suited for smaller plants. They tend to have a higher electrical efficiency than turbines, which results in less heat available for recovery. This heat is usually lower grade, and in the form of hot water. This means that when configured to provide absorption cooling, only a single-effect chiller can be used.

In comparison to turbines, engines have much quicker start times- a typical internal combustion engine can start up within five to ten minutes, whereas steam turbines often need a half hour and assistance from another power source to start up. Engines are much less sensitive to partial loads, and can even be configured in blocks to allow for a wider range in load turndown and better part-load power efficiency.

Turbines used for cogeneration are similar in operation to the turbines used for aircraft. They tend to run larger than reciprocating engines, and due to their lower efficiency they give off more heat for recovery. This heat is of higher-quality steam, which is much more conducive for process steam generation. Also, this high quality heat allows for double effect absorption cooling, which has a higher coefficient of performance than single effect. Steam and gas turbines do not typically respond well to fluctuations in load, and are better used in constant operation applications.

There are advantages and disadvantages to each prime mover available for cogeneration. The most suitable prime mover will depend on factors such as plant size, Thermal-to-Electric Ratio, and the fraction of time the plant is operating known as the Load Factor.

Utility Data Collection and Analysis

The first step toward designing a cogeneration plant for the project was to gather real utility data. Early in the proposal execution, utility data was gathered covering years 2003 through 2014. Each month, Kilowatt-hours, MCF's of gas, average temperature, and dollars spent on electric and gas were tabulated. This raw data is formatted in spreadsheets located in Appendix C.

In another spreadsheet, several calculations were performed to derive utility trends. First, the monthly electric prices were calculated by dividing dollars spent by Kilowatt-hours of consumption. Natural gas prices were calculated in the same manner. Then, using a conversion factor of 293 kWh per MMBTU, the unit prices were converted to identical units and the difference between them was calculated. This difference in price between electric and natural gas is known as the Spark Gap or Spark Spread; it is a good metric for gauging the payback period of on-site generation. Then, in separate cells, Kilowatt-hours values were converted to Kilowatts and MMBTU's converted to MBH. Using the same conversion factor as before, these units were made identical and the Thermal-to-Electric Ratio (λD) was calculated.

The full spreadsheet is located in Appendix C; the ten-year average of all of these calculations is shown below:

$/kwh	$0.077
$/MMBTU	$7.85
Spark Gap	**$14.60**
kW	1084
MBH	6010
λD	**1.63**

From this data, we can see that we have an average spark gap of $14.60, which is not a bad number but not as great as it could be. The average Thermal-to-Electric ratio is 1.63, which is close to the "sweet spot" for CHP of 1.5.

Graphs were constructed with the calculation spreadsheet to identify consistent trends. Plots of electric demand, thermal demand, and Thermal-to-Electric Demand Ratio were created to illustrate monthly trends:

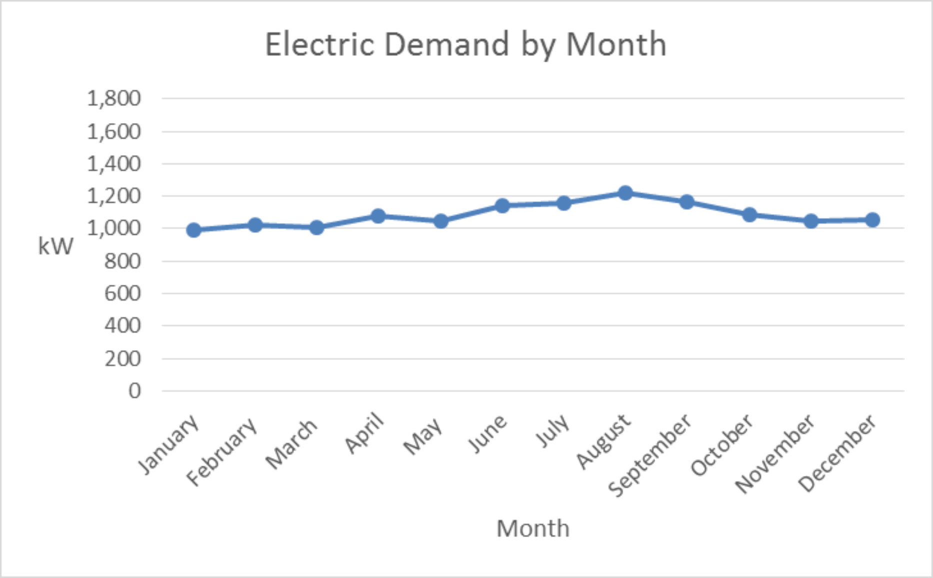


Figure 14: 10-Year Average Electric Load Profile

The electric load profile is relatively stable, with a slight peak during the summer months. This is due to electric chillers on campus operating during the cooling season. Discounting the power used by chillers, the campus has a fairly stable month-to-month demand of around 1000kW.

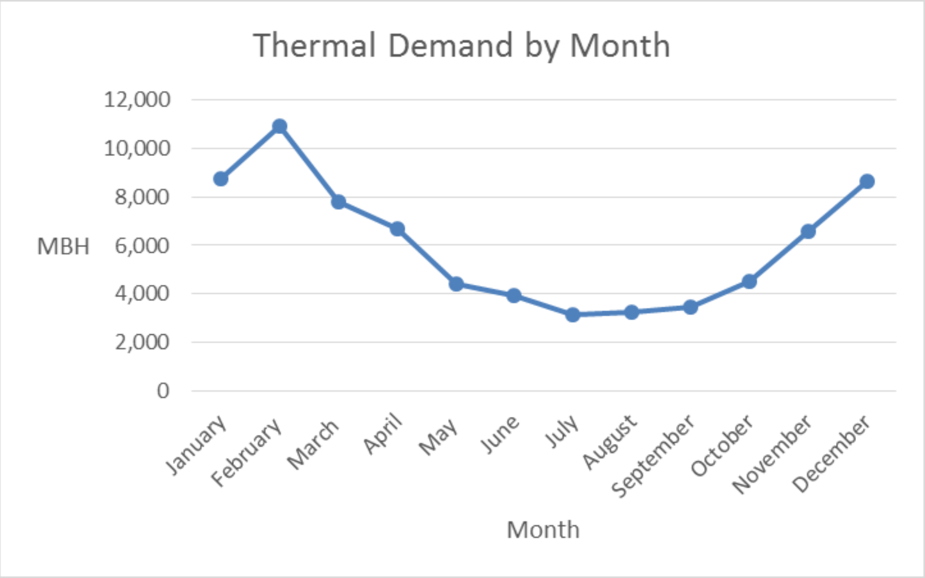


Figure 15: 10-Year Average Thermal Load Profile

Thermal demand varies much more by season than electric, as expected in a temperate area such as northeast Ohio. A peak of about 1100 MBH occurs in February, and a low of around 3500 MBH occurs in the middle of the summer. Given that there are no heating operations during the summer months, we can deduce that this low is the base steam load for the process and humidification needs of the campus.

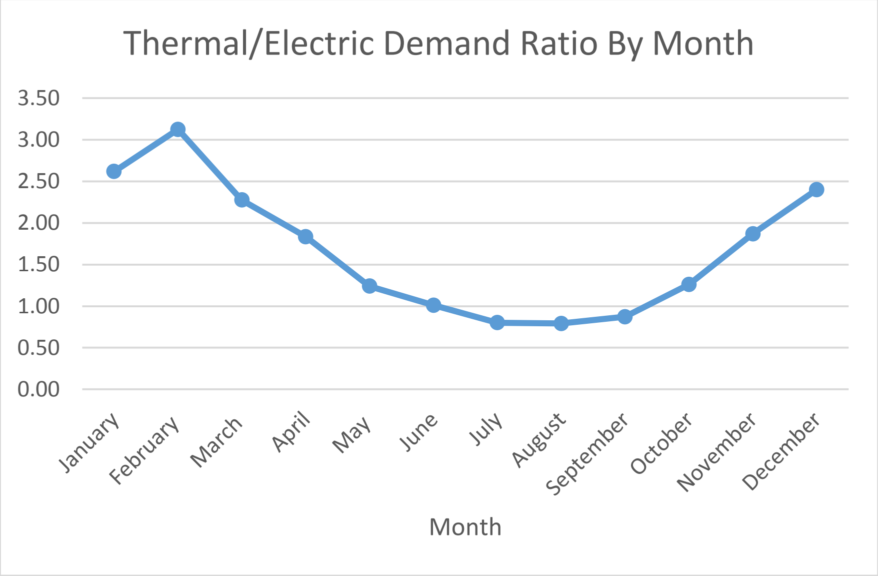


Figure 16: 10-Year Average Thermal-to-Electric Ratio

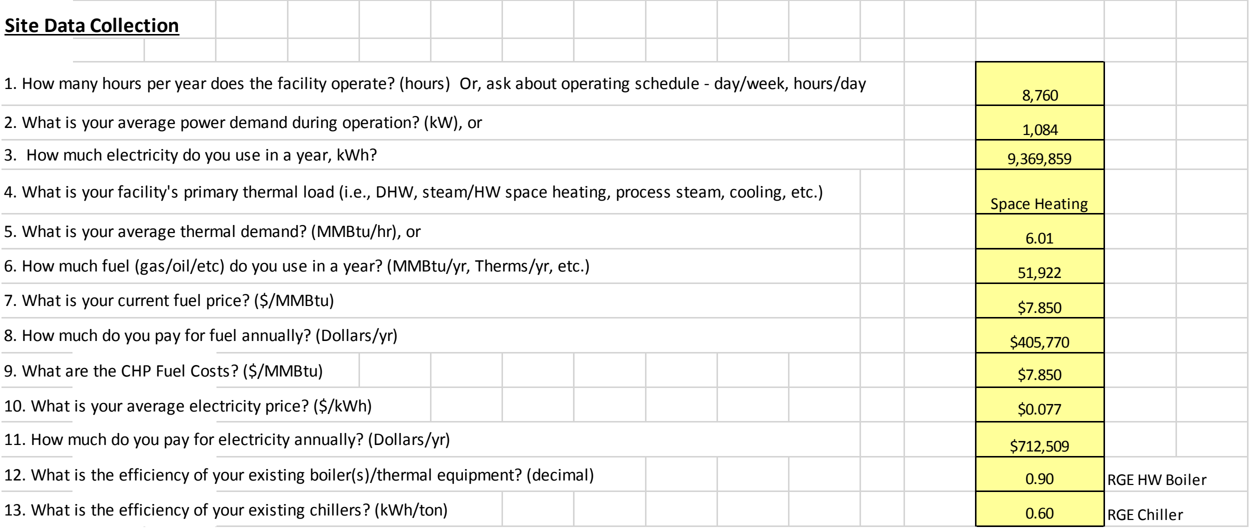
System Selection Process

A number of existing conditions were evaluated for their conduciveness to cogeneration. One consideration discussed early on was whether to use the cogeneration plant to provide for the RGE and CMU project alone, or to provide for the whole campus. A district system was deemed much more practical, as it would provide much more leeway than a stand-alone system for just one building. A district system could also provide utilities for the later campus expansions, such as the year-round heating required for the lap pool and hydrotherapy pool located in the NEW building. The heating and chilled water plant in the M building adjacent to the project already provides for most of the campus, so it is not unrealistic to expect a cogeneration plant located in the RGE to serve as a district system.

Out of all of the potential uses for recovered heat, the summer steam load identified in early utility analysis seemed like the most logical choice. As a steady load with good relative size to electric demand, this load is conducive to the proposed plant. Other uses for recovered engine heat will still be considered, namely space heating and cooling via absorption chillers.

Other considerations included the need for a dual-fuel prime mover. The natural gas available on site is an excellent fuel with good thermal properties and low emissions, but can become hard to transport in bitter cold weather. A cogeneration system capable of running on other fuels will be very important on this project. In addition, the current RGE basement would not have any room for the new plant; the area would need to be expanded from a half basement to the full building footprint. There is no reason why this could not have been done if it was requested during design; however it must be kept in mind that this would add some cost to the project.

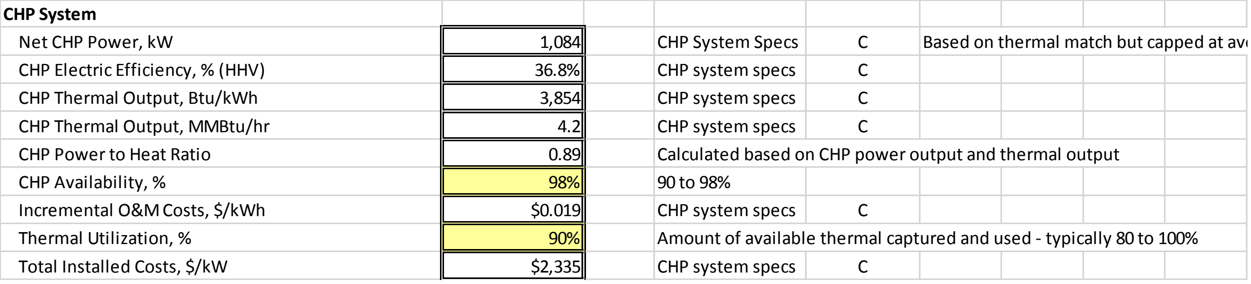
Most of the project conditions and priorities pointed to reciprocating engines as the best prime mover for a CHP plant. However, it is important to have some type of objective analysis to confirm or refute this opinion. An initial screening was performed using a DOE CHP Qualification Tool spreadsheet, with utility data taken from the 10-year average values previously calculated and equipment data taken from design documents and product literature. The full calculation is located in Appendix D.



Site Data Collection		
1. How many hours per year does the facility operate? (hours) Or, ask about operating schedule - day/week, hours/day	8,760	
2. What is your average power demand during operation? (kW), or	1,084	
3. How much electricity do you use in a year, kWh?	9,369,859	
4. What is your facility's primary thermal load (i.e., DHW, steam/HW space heating, process steam, cooling, etc.)	Space Heating	
5. What is your average thermal demand? (MMBtu/hr), or	6.01	
6. How much fuel (gas/oil/etc) do you use in a year? (MMBtu/yr, Therms/yr, etc.)	51,922	
7. What is your current fuel price? ($/MMBtu)	$7.850	
8. How much do you pay for fuel annually? (Dollars/yr)	$405,770	
9. What are the CHP Fuel Costs? ($/MMBtu)	$7.850	
10. What is your average electricity price? ($/kWh)	$0.077	
11. How much do you pay for electricity annually? (Dollars/yr)	$712,509	
12. What is the efficiency of your existing boiler(s)/thermal equipment? (decimal)	0.90	RGE HW Boiler
13. What is the efficiency of your existing chillers? (kWh/ton)	0.60	RGE Chiller

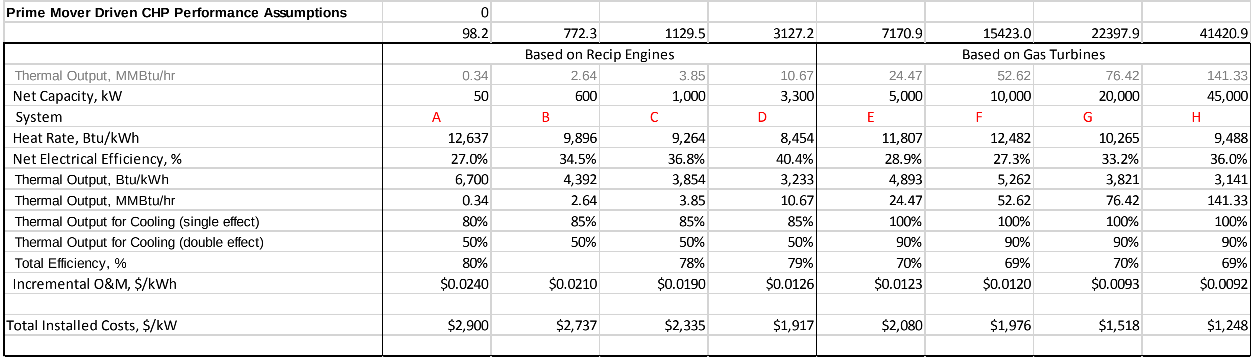
Figure 17: Initial System Screening Site Data Input

Based on the site data, the spreadsheet logic selected Example System C as the ideal configuration for this project. This configuration consists of a 1000 kW reciprocating engine as the prime mover, with a generating efficiency of 36.8 percent, 3.8 percent higher than typical grid efficiency. This engine gives off roughly 3800 MBH in waste heat, perfect for the base steam load calculated previously.



CHP System					
Net CHP Power, kW	1,084		CHP System Specs	C	Based on thermal match but capped at av
CHP Electric Efficiency, % (HHV)	36.8%		CHP system specs	C	
CHP Thermal Output, Btu/kWh	3,854		CHP system specs	C	
CHP Thermal Output, MMBtu/hr	4.2		CHP system specs	C	
CHP Power to Heat Ratio	0.89		Calculated based on CHP power output and thermal output		
CHP Availability, %	98%		90 to 98%		
Incremental O&M Costs, $/kWh	$0.019		CHP system specs	C	
Thermal Utilization, %	90%		Amount of available thermal captured and used - typically 80 to 100%		
Total Installed Costs, $/kW	$2,335		CHP system specs	C	

Figure 18: Screening System Selection



Prime Mover Driven CHP Performance Assumptions	0							
	98.2	772.3	1129.5	3127.2	7170.9	15423.0	22397.9	41420.9
	Based on Recip Engines				Based on Gas Turbines			
Thermal Output, MMBtu/hr	0.34	2.64	3.85	10.67	24.47	52.62	76.42	141.33
Net Capacity, kW	50	600	1,000	3,300	5,000	10,000	20,000	45,000
System	A	B	C	D	E	F	G	H
Heat Rate, Btu/kWh	12,637	9,896	9,264	8,454	11,807	12,482	10,265	9,488
Net Electrical Efficiency, %	27.0%	34.5%	36.8%	40.4%	28.9%	27.3%	33.2%	36.0%
Thermal Output, Btu/kWh	6,700	4,392	3,854	3,233	4,893	5,262	3,821	3,141
Thermal Output, MMBtu/hr	0.34	2.64	3.85	10.67	24.47	52.62	76.42	141.33
Thermal Output for Cooling (single effect)	80%	85%	85%	85%	100%	100%	100%	100%
Thermal Output for Cooling (double effect)	50%	50%	50%	50%	90%	90%	90%	90%
Total Efficiency, %	80%		78%	79%	70%	69%	70%	69%
Incremental O&M, $/kWh	$0.0240	$0.0210	$0.0190	$0.0126	$0.0123	$0.0120	$0.0093	$0.0092
Total Installed Costs, $/kW	$2,900	$2,737	$2,335	$1,917	$2,080	$1,976	$1,518	$1,248

Figure 19: Screening Tool Configuration Specs

This initial screening confirmed that a mid-sized reciprocating engine would be the ideal prime mover for the cogeneration plant. For the next step in analysis, several sizes of GE Jenbacher Model 3 and Model 4 Series engines were used. The Jenbacher is specifically designed for CHP use; it has features including lean burn controls, multiple fuels, and high generating efficiencies.

Configuration Feasibility analysis

In order to properly size the CHP system, it was necessary to use utility data gathered after completion of the project. Using the same method that was used to plot 10-year average trends, plots were made of 2014 (data taken after project completion). On these same plots, 2013 data was plotted as a comparison and to determine if the 2014 data was valid or too different for use.

Based on the plots, it would be reasonable to use the 2014 data as the basis for sizing the CHP plant. The 2014 electrical load profile follows roughly the same pattern as the previous year; it is simply increased in accordance with the RGE and CMU electrical loads. The 2014 thermal profile essentially follows the same pattern as the previous year, with any variability likely due to temperature differences between years. The 2014 profile shows a base thermal load of roughly 4800 MBH, up from a 2900 MBH base load from 2013; the difference is roughly equivalent to the capacity of the steam boiler installed in the project.

From these plots, a thermal load of 4.82 MMBTU will be used for configurations designed to handle the process steam load and the average thermal load of 8.42 MMBtu was used in configurations designed for trigeneration. The average 2014 electric load of 1565 kW was used in all configurations. 2014 prices were also used to best reflect current conditions.

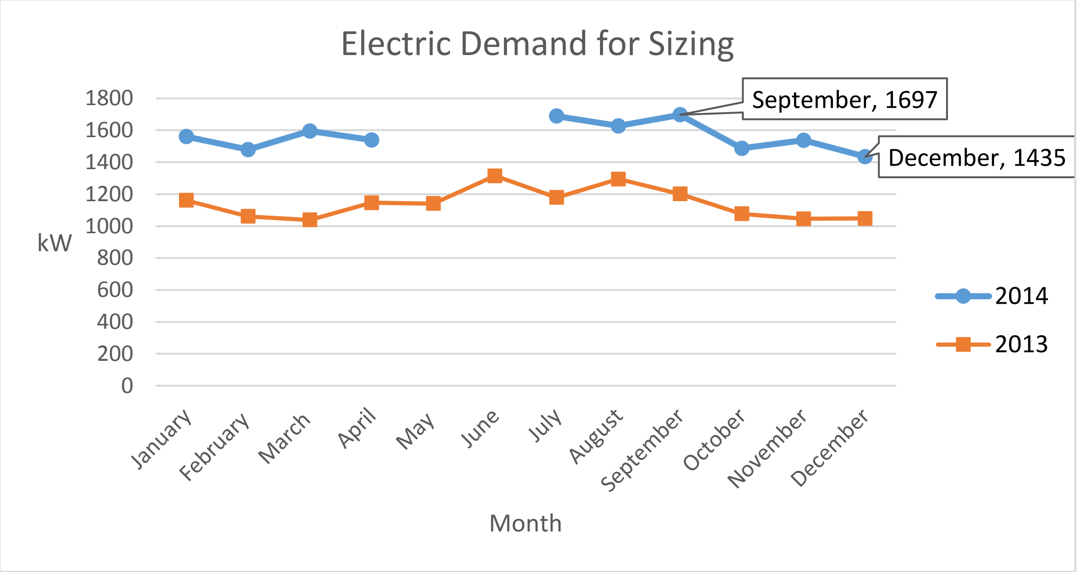


Figure 20:2013/2014 Electric Load Profile

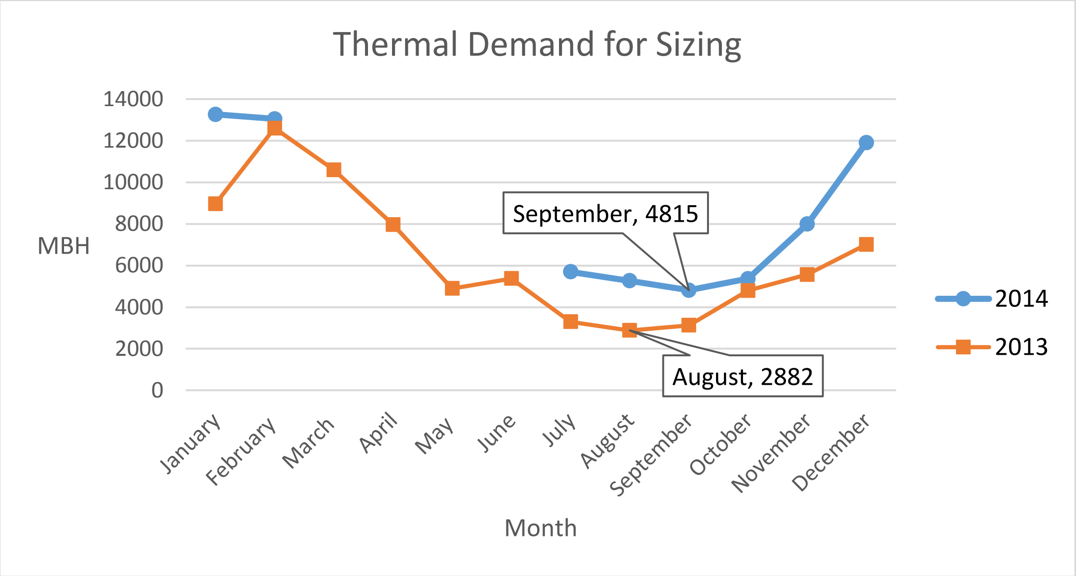


Figure 21: 2013/2014 Thermal Load Profile

Nine configuration were chosen for analysis, based on two variables each with three options:

Generator Configuration: Single vs. Two-Gen. Block vs. Three-Gen. Block (3)

Waste Heat Application: Steam vs. Heating/Cooling sized to waste heat vs.
Heating/Cooling sized to cooling load w/ boiler makeup X (3)

= 9 configs

Each option is listed with corresponding payback period and emissions. Full calculation spreadsheets for payback and emissions are detailed in Appendix E.

			Emissions	
Configuration	**Equipment Setup**	**Payback Period**	**Vehicles**	**Houses**
A	1 GE Jenbacher J420 with process steam load	8.4	2,201	1,439
B	2 GE Jenbacher J316 with process steam load	10.5	2,630	1,720
C	3 GE Jenbacher J312 with process steam load	14.4	2,945	1,926
D	1 GE Jenbacher J420 with trigeneration, absorption cooling sized to thermal output	11.1	2,076	1,358
E	2 GE Jenbacher J316 with trigeneration, absorption cooling sized to thermal output	11.4	2,461	1,610
F	3 GE Jenbacher J312 with trigeneration, absorption cooling sized to thermal output	14.5	2,756	1,802
G	1 GE Jenbacher J420 with trigeneration, full load absorption cooling with boiler makeup	11.4	2,076	1,358
H	2 GE Jenbacher J316 with trigeneration, full load absorption cooling with boiler makeup	11.5	2,461	1,610
I	3 GE Jenbacher J312 with trigeneration, full load absorption cooling with boiler makeup	14.5	2,756	1,802

Figure 22: Potential Cogeneration Configurations

Based on these results and good engineering judgement, configurations A and B appear to be the most worthy options. A has a single generator sized to the base electric load of 1435 kW, and has just enough waste heat to handle the full process steam load. B has two generators that together can handle the peak 1697 kW electric load, and gives off more than enough heat to feed process steam loads. Out of all the iterations, the ones with steam loads had better emissions scores than ones configured for trigeneration. In addition, options A and B had the best payback periods of 8.4 and 10.5 years, respectively.

Sensitivity Study

A sensitivity analysis was conducted on the top two configurations to gauge the effect of fluctuations in utility rates. While the most current utility rates were used in the configuration screenings, in reality these rates will change over the course of the plant's life. In all likelihood, electricity will increase in cost due to construction and development, and natural gas will continue to drop due to the growing production of the Utica shale region encompassing northeast Ohio. Reduced gas rates, increased electric rates, and a combination of both were plugged into the screening tool spreadsheets of A and B to predict the effect on payback period.

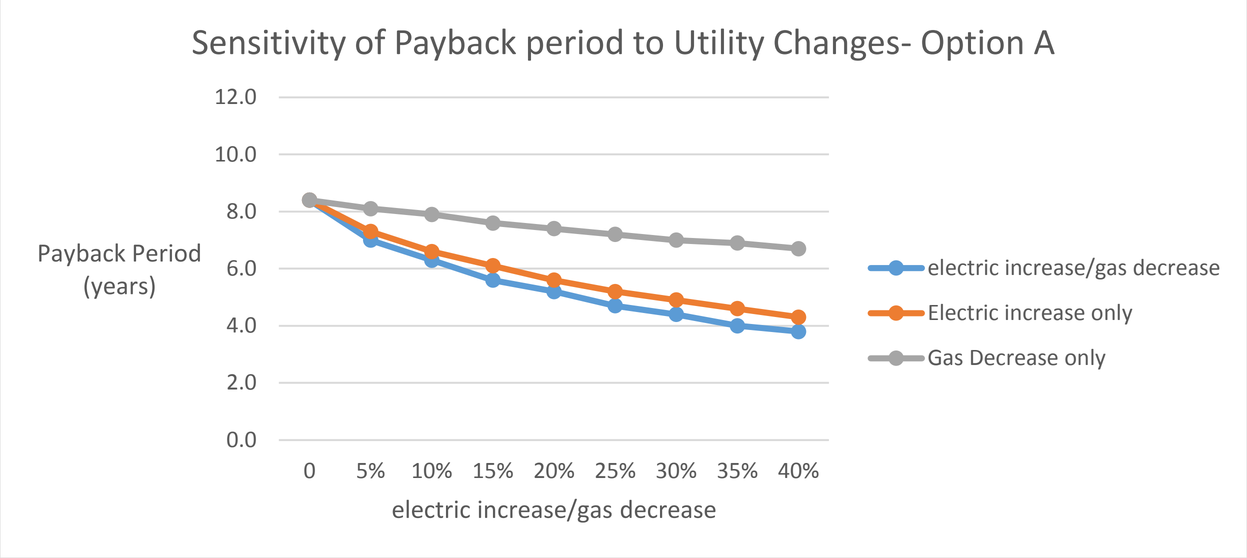


Figure 23: Utility sensitivity-Option A

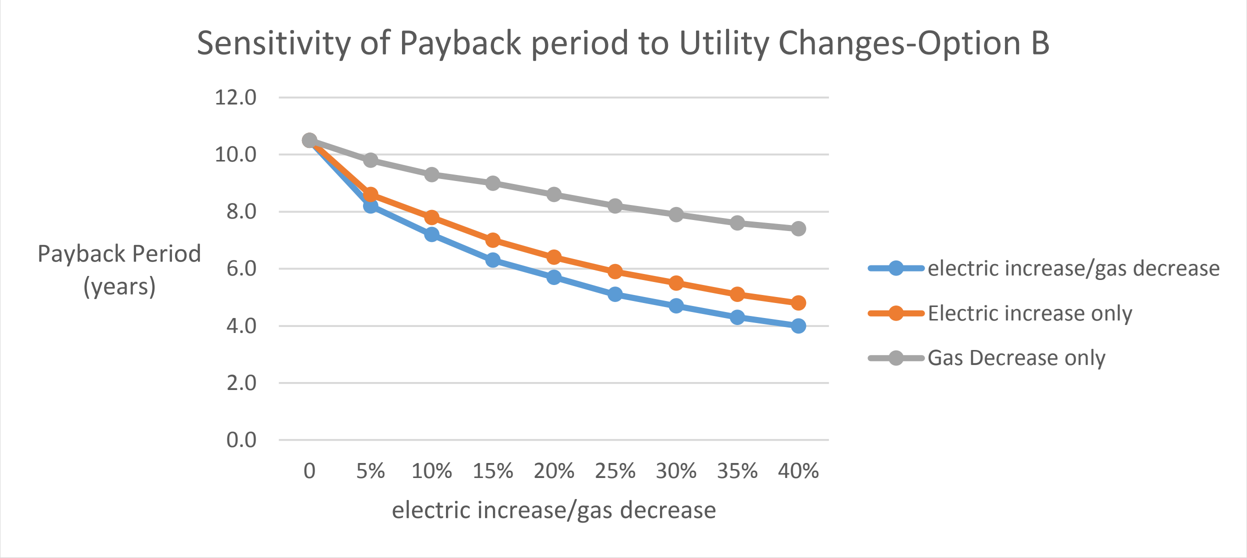


Figure 24: Utility Sensitivity-Option B

The sensitivity analysis shows that while a decrease in gas price will have some positive effect on payback period, increase in electricity cost will have the greatest financial effect. Just a five or ten percent increase in electric rates can shave several years off of payback.

System Configuration and Operation

While the chosen configurations appear conducive to handling steam loads, there is one caveat. In a reciprocating engine cogeneration setup, waste heat is derived from two separate sources: exhaust gas and engine jacket water. The coolant water can be used to produce low-pressure steam via forced circulation; however, only the engine exhaust can be used to generate high-pressure steam. Roughly half of the Jenbacher engine's waste heat is dissipated in exhaust gas, so there is a limit on how much high pressure steam the cogeneration plant can produce.

The diagram on the following page illustrates the setup of a combination system with two Jenbacher 316 engines producing both high and low pressure steam. Circulation pumps force jacket water to a steam separator, where some of the water flashes to steam at about 10 psig. The remaining water is recirculated to the engine. Attached to each exhaust outlet is a once-through heat recovery steam generator for production of high pressure steam at 60 psig. An OTSG is different from a regular HRSG in that it consists of a simple tube circuit in place of the typical economizer, boiler, superheater arrangement. This eliminates the need for steam drums, blowdown systems, and recirculation systems, making the OTSG much more straightforward and smaller than typical HRSG arrangements. An additional benefit is that an OTSG can run dry, meaning that the engine can still run even when steam is not needed. This arrangement can effectively utilize heat recovery to generate both high pressure steam for process and low pressure steam for humidification in the RGE and CMU

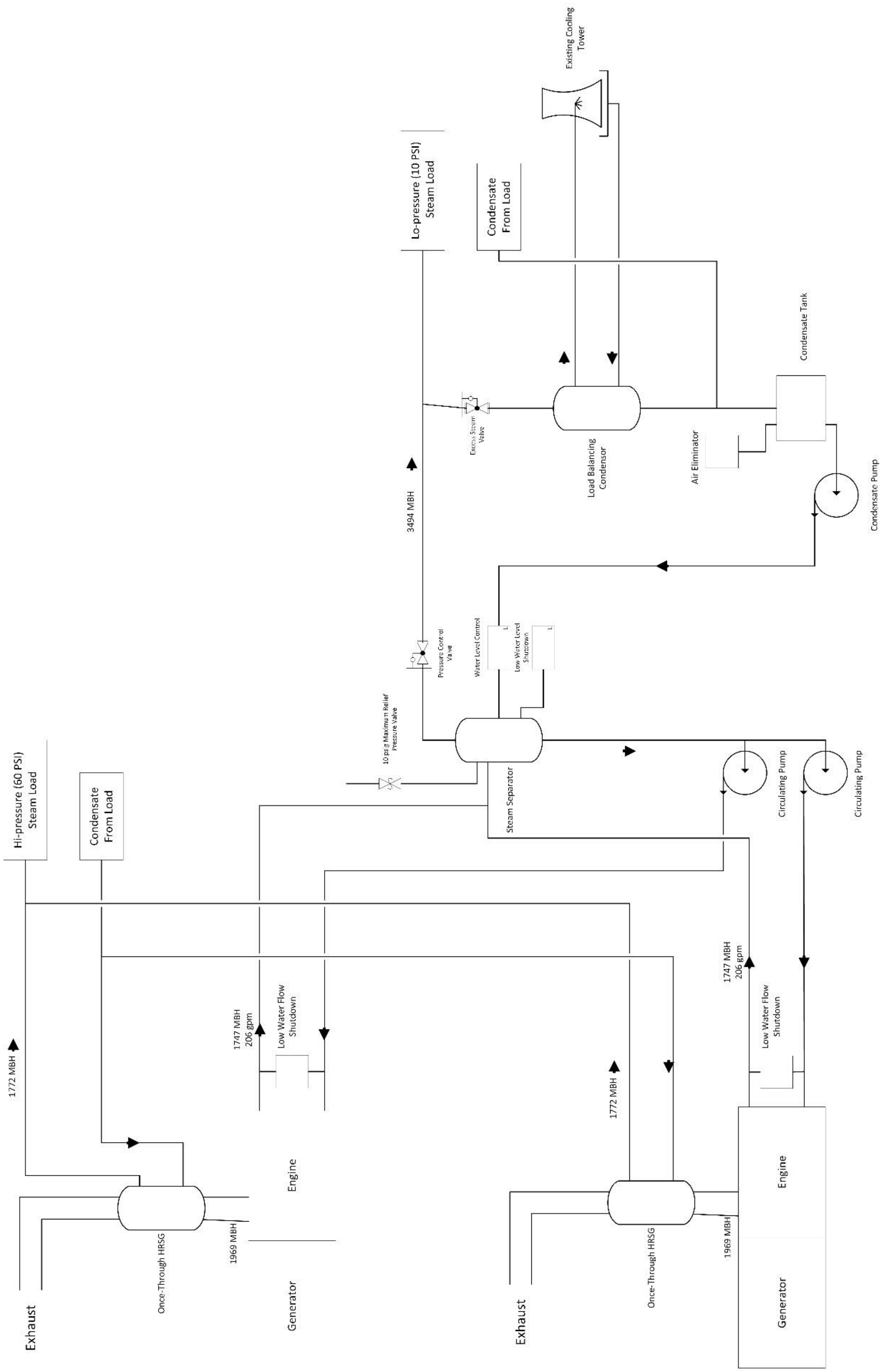


Figure 25: Cogeneration Plant Configuration

Recommendations and Further Expansion

Based upon the analyses conducted, Option B is recommended for implementation. This Cogeneration system consists of two Jenbacher 316 engines each with a generating capacity of 848 kW, combined for almost 1700 kW of generating power for the entire campus. The engine block produces roughly 6700 MBH of useful heat in both liquid and gaseous form. This heat will be used to take care of the campus steam loads.

The configuration was chosen because it is capable of meeting campus peak loads with no outside assistance. As a reciprocating engine block, there is also good turndown capability for meeting part loads during off-hours and base electrical loads during non-cooling periods. In addition, an engine block adds a layer of redundancy; it is unlikely that both engines will go out at the same time. In addition, the extra heat adds a safety factor and also makes further steam load expansion permissible, such as the eventual fitout of the RGE top floor and humidifiers for the RGE rooftop units.

Despite not having the lowest payback period, option B is still reasonable at ten years. Expected fluctuations in utility rates could result in an even shorter period. Bearing in mind, however, this analysis does not factor in other required work such as the need for a full basement and utility tie-in.

Further expansion of the cogeneration system coinciding with later phases of campus expansion could be placed in the full RGE basement; however, it is best practice to place the equipment as close to thermal loads as possible. Therefore, the best option for such expansion would be to locate new equipment somewhere near or inside the NEW Center building.

Electrical Breadth: Power Interconnect and Black Start Capability

Interconnection Laws and Standards

Safe interconnection is a major consideration for any cogeneration system that wants to operate in parallel with the electric grid. Many state authorities have laws and standards governing interconnection to ensure safety and help expedite the application process. However, not all states have these policies, and policy can vary wildly state to state.

The EPA's documentation on state interconnection standards shows that Ohio does in fact have a set of interconnection standards, and that these standards are considered more "district-generation friendly" than those of many other states. For one, Ohio is one of only three states that have no system size limit for interconnection; other policies have limits ranging from 25 MW to 10 kW. Ohio also leaves the decision to provide a disconnect switch at the utility's discretion. In addition, Ohio mandates the practice of net metering for all investor-owned utilities (i.e. on-site generation) regardless of size. Net metering is a practice in which excess electricity generated on-site and distributed elsewhere is used to offset electricity provided by the grid. Several expedited permitting methods exist, depending on system size and type.

Research has shown that Ohio has fairly relaxed rules for grid interconnection, and that there will be no issue with interconnecting the proposed cogeneration system.

Utility Interconnect Design

The best option for a facility that wants both on-site generation and grid connectivity is a parallel operation where the electric loads of a campus or facility are actively tracked, then adjust the generator output to match the load with any excess load coming from the grid. Another option would be to operate generators at full load and sell excess electricity back to the utility or receive net metering credits. While Ohio does have a net metering policy, it was deemed wiser to operate with the first option. The proposed cogeneration setup can be operated at part-load when needed, which use less gas than constant full load operation, plus it is unknown if the local grid is adequately sized to handle extra load.

Interconnection is often a difficult issue. Utilities and/or state regulations often require considerable protective relays and special fuses or breakers. The standard approach taken by a utility is usually to drop a generator off-line anytime a fault occurs anywhere in the system, which is less than ideal for the facility operator. In fact, due to all the protective measures required, it is not uncommon for facility breakers to trip and kick a generator off-line for unwarranted reasons such as a voltage surge on the utility line. And above all, safety is paramount in design to ensure the protection of facility staff and maintenance personnel.

While voltage regulation is the responsibility of the electric utility, control of current and power factor is the domain of the facility. Generator excitation must be controlled via a power factor controller; over-excitement produces excessive reactive power which reduces the reactive power drawn from the grid and adversely affects current. Communication must be established with the utility to vary excitation with respect to utility network load fluctuations. The practice of controlling power factor acts to incentivize the utility to cooperate with onsite generators.

Another important aspect of interconnection is phase synchronization. A generator that is out-of-synch with the utility can cause large transient faults within the system. During a utility blackout event, it is important to make sure the generator remains isolated when utility service is restored, as it may or may not be in phase with the grid. In addition, problems can occur when a breaker opens on a generator. If the generator is undersized compared to the load present in the system, the generator overloads and begins to drop voltage and frequency. If oversized, the generator may be subject to overspeeding.

Several pieces of equipment are very important for grid interconnect design. Reclosing breakers are a popular alternative to regular circuit breakers; they may be set to interrupt a circuit and then re-energize a line after a certain time. Sectionalizers are more permanent breakers used in conjunction with reclosing breakers to isolate a fault and allow normal power to be restored elsewhere. This system is helpful for mitigating the adverse effects that can result from robust protection relaying, because the generator can quickly be put back online and a circuit breaker doesn't need to be reset every time some small fault occurs. Automatic synchronizers are also frequently employed to ensure that a generator is not brought back online without first being in phase with the utility. A variety of relays are employed for measurement of current, voltage, frequency, and excitation. Another important consideration is the utility transformer; depending on the primary-secondary connection scheme, it may be necessary to replace or modify the transformer to include a grounded leg on the facility side.

The figure on the following pages illustrates a proposed interconnection scheme for the 1696 kW cogeneration plant. It includes a number of the items mentioned in a configuration meant to ensure safe and effective plant operation in parallel with the existing local utility grid.

Black Start Capability

Most reciprocating engines either are self-starting or need the assistance of a battery pack. As a smaller, inverter-based engine, the Jenbacher 316 is capable of self-starting in the event of an outage.

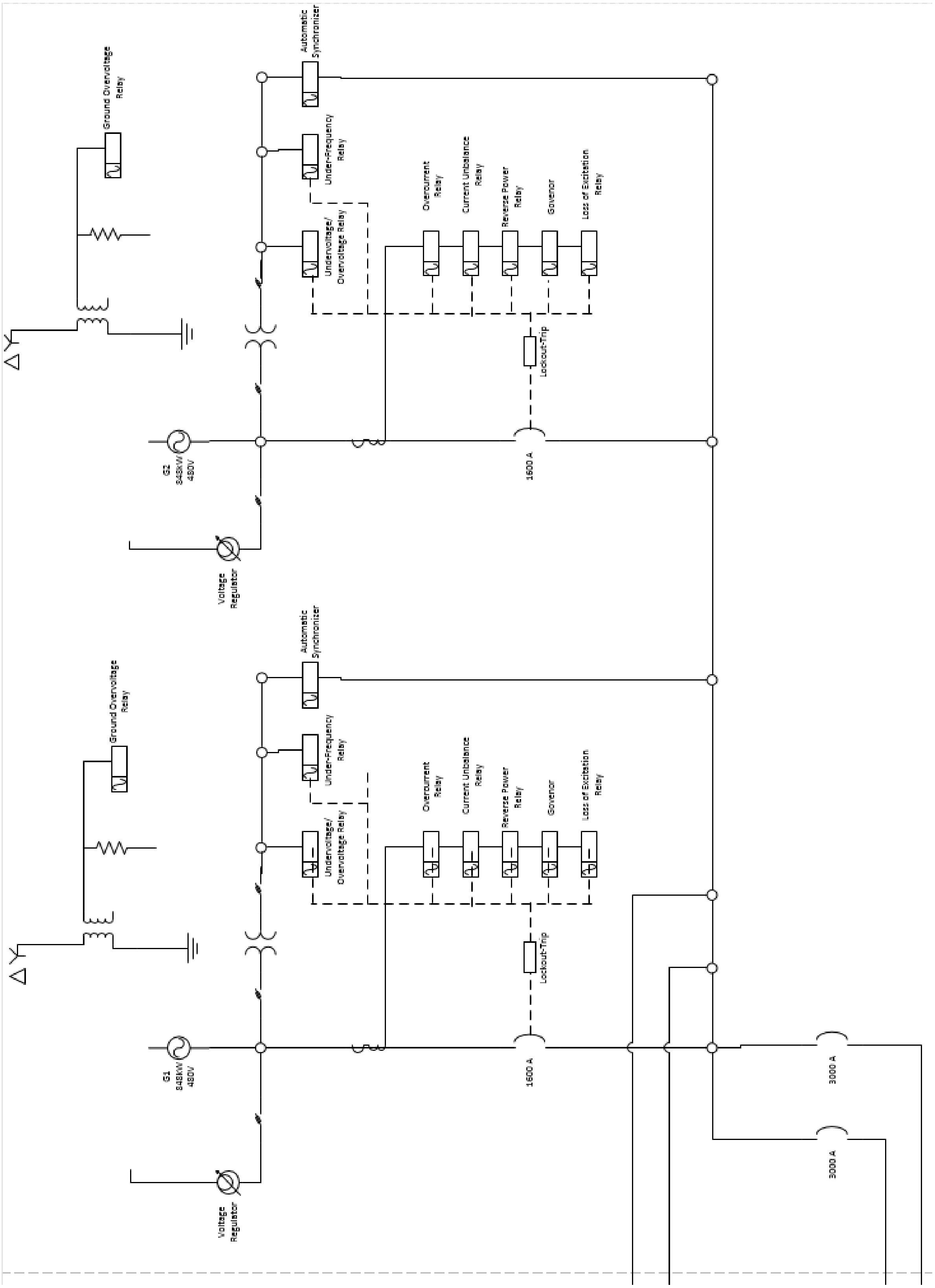


Figure 26: Electric Grid Interconnect Diagram-Part 1

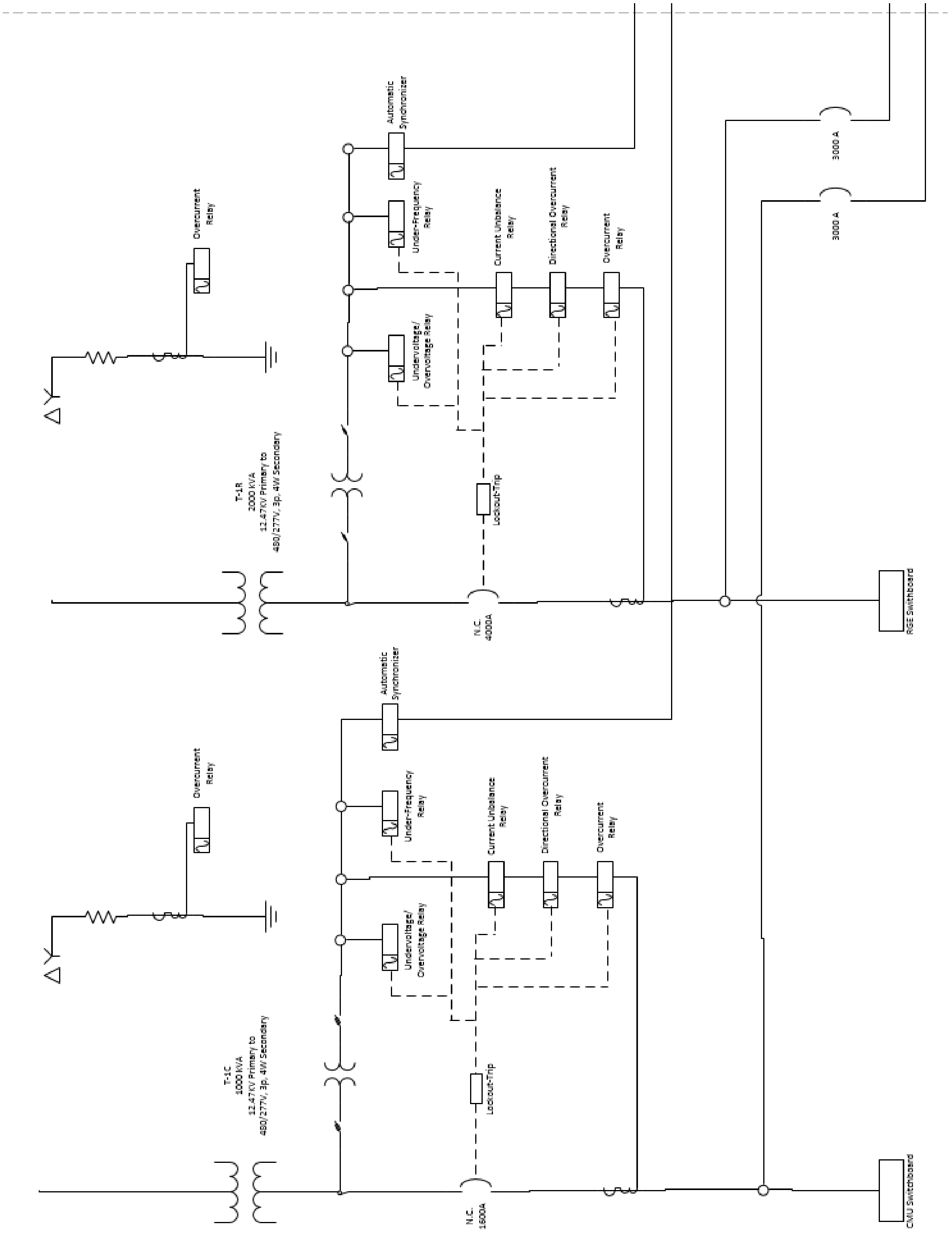


Figure 27: Electric Grid Interconnect Diagram-Part 2

Construction Management Breadth: Alternative Project Delivery

Background

At the time of bidding in 2011, the state of Ohio mandated that all building projects funded with state money were to be awarded as competitive multiple-prime contracts. As a project on a public university, the NEOMED RGE + CMU fell under this ruling and was multiple prime. Early in 2012 the Ohio AIA changed its stance and now allows other delivery methods for state funded building.

While the owner did hire a construction management firm to help manage the project, the firm was only an agent of the owner within the project structure. The CM did not hold any of the contracts for work; as a result the contractors were not beholden to the CM and their advice. The project experienced notable over-runs due to weather and contractor delays, and there were several instances during and after project delivery when conflict arose among the different parties involved on the project. It is quite plausible that had an alternative delivery method been an option at the time, the project could have avoided several obstacles on the way to completion.

Research

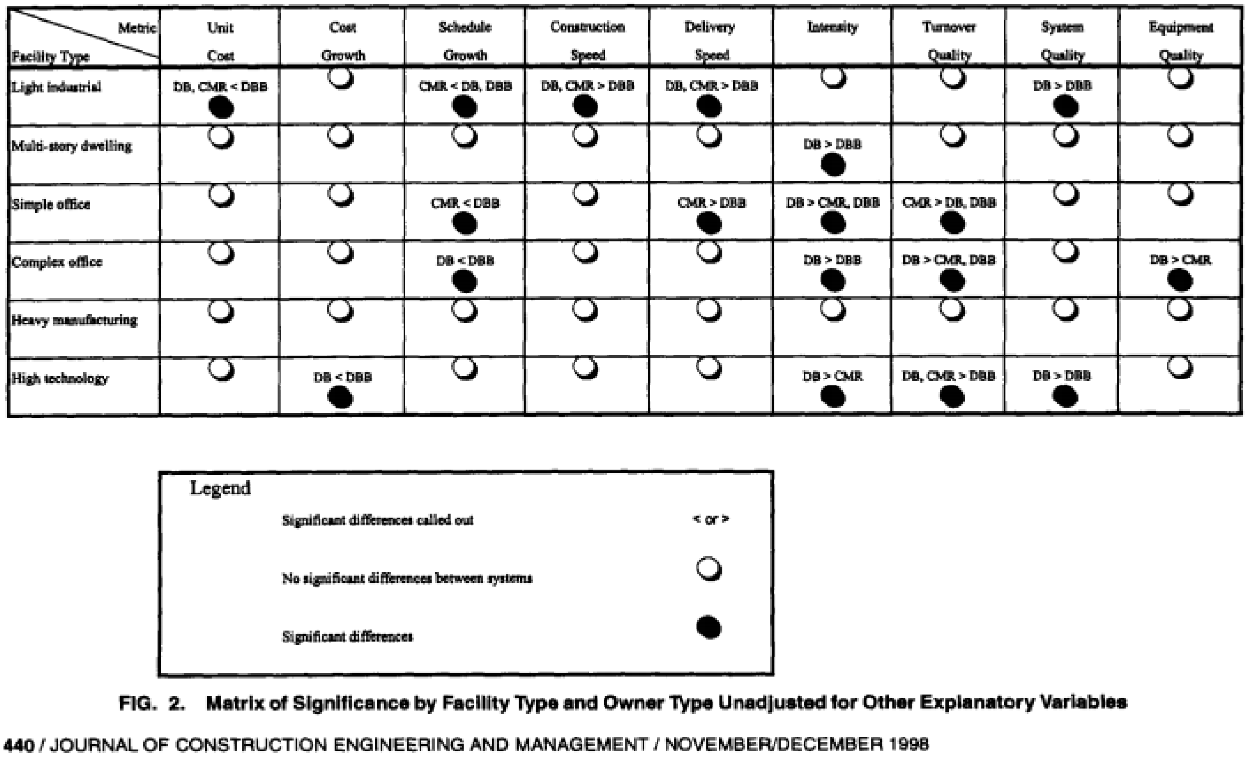
To better gain an understanding of real implications of different project delivery methods, established research on the subject was studied. The main source of this data was a study published in a 1998 issue of the Journal of Construction Engineering and Management titled “Comparison of U.S. Project Delivery Systems”. This paper presents data collected from 351 U.S. building projects regarding cost, schedule, and quality in relation to project delivery method. Three methods were chosen for analysis: Design-Bid-Build, Design-Build, and Construction Management at Risk.

The paper used several data sets to further categorize projects. Six different facility types were identified: the RGE + CMU would fall into the “high technology” category, which made up 17% of project surveyed or roughly 60 different projects. The project belongs to the 5,000-15,000 m^2 range, which encompassed one-third of projects in the study and constituted a small-mid size project bracket. RGE unit cost was calculated with project statistics, and numbers for location index and inflation taken from the RS Means Building Construction 2013 edition:

($38 million/80,000 SF)(100/96 location index)*(.558 inflation 1998-2013) = $274/SF or $2950/m*^{2}

This places the RGE in the top unit cost bracket of projects over $1800/m^2. It is noted that the majority of these projects also fell into the high technology facility type.

Univariate results showed that ½ of CM-at-Risk and Design-Build projects studied were delivered on time or ahead of schedule. By contrast, ½ of the Design-Bid-Build projects were more than 4% late. In addition, a moderate improvement in quality in both CM-at-Risk and Design-Build was observed relative to Design-Bid-Build quality.



Metric / Facility Type	Unit Cost	Cost Growth	Schedule Growth	Construction Speed	Delivery Speed	Intensity	Turnover Quality	System Quality	Equipment Quality
Light industrial	DB, CMR < DBB ●	○	CMR < DB, DBB ●	DB, CMR > DBB ●	DB, CMR > DBB ●	○	○	DB > DBB ●	○
Multi-story dwelling	○	○	○	○	○	DB > DBB ●	○	○	○
Simple office	○	○	CMR < DBB ●	○	CMR > DBB ●	DB > CMR, DBB ●	CMR > DB, DBB ●	○	○
Complex office	○	○	DB < DBB ●	○	○	DB > DBB ●	DB > CMR, DBB ●	○	DB > CMR ●
Heavy manufacturing	○	○	○	○	○	○	○	○	○
High technology	○	DB < DBB ●	○	○	○	DB > CMR ●	DB, CMR > DBB ●	DB > DBB ●	○

Legend

Significant differences called out	< or >
No significant differences between systems	○
Significant differences	●

FIG. 2. Matrix of Significance by Facility Type and Owner Type Unadjusted for Other Explanatory Variables

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Figure 28: Univariate Results by Facility Type (Source: J. Constr. Eng. Manage. 1998.124:435-444.)

Univariate results were further broken down by facility type, detailed in the figure above taken from the research paper. High technology projects in the study showed several areas where a Design-Build delivery performed significantly better than Design-Bid-Build, namely cost growth (defined as a percent difference between final cost and contract cost) and system quality. Design-Build showed a significant advantage over CM-at-Risk in intensity, which the report defined as unit cost divided by total project time. Both DB and CM-at-Risk showed significant advantage over DBB in turnover quality, which was measured in three areas: difficulty of facility start-up, number and magnitude of call-backs, and operation and maintenance cost.

When the results were segregated by public vs. private ownership, DB was shown to significantly outperform DBB in all nine categories measured. Publicly-owned CM-at-Risk projects significantly outperformed DBB in schedule growth (percent difference between real time and planned time) and turnover quality specifically. There were no appreciable differences between DB and CMR found for the public projects studied.

In addition to the univariate analysis, a multivariate analysis was conducted in an attempt to explain the variability in unit cost and delivery speed. Overall, a trend was established for both metrics across all projects that had DB performing best, CMR in the middle, and DBB least favorable. Several interesting findings were discussed that pertain to the RGE + CMU project. First, the unit cost of a high technology project was largely determined by physical building size. Interestingly enough, DBB projects were shown to have on average a slight decrease in construction speed with increasing size, which runs opposite of the overall positive correlation found when looking at all studied projects.

The multivariate analysis demonstrated that project delivery played a major role in the success of a project. Delivery method was found to have a significant influence on construction speed specifically, but less so on total delivery speed. Delivery was also the single biggest influence on schedule growth. In fact, it was concluded that project delivery method was the biggest influence across every metric, matched only by facility type.

While many industry professionals hold their own views on different project delivery methods and anecdotes abound, this research provides objective evidence that delivery methods such as Design-Build and CM-at-Risk provide advantages over more traditional methods that would have benefitted this particular project.

Potential Project Benefits

In light of the research conducted an alternate Design-Build delivery system will be proposed for the RGE + CMU project. There are several areas in which this project could have potentially benefitted from a DB approach.

After months of design work, the project began bidding in the fall of 2011. The project was split into three phases of bidding, spaced out over the course of about a year. The project broke ground December 2011 and construction began; owner move-in was originally scheduled for the end of May 2013. Construction had no major delay issues during the early phases of the project. However, around February-March 2013 the schedule started slipping. Following through that spring and summer the project experienced an exponentially-growing schedule slippage. Disputes ensued among the contractors and with the project team on who was to blame. Project completion got pushed back to July and then to August. The owner stated that move-in of faculty and researchers could start no later than July 15 in order to be ready for the coming semester; if move-in was not complete by fall, they would lose hundreds of thousands of dollars in grant money.

Much deliberation ensued and a schedule was eventually devised that summer with sequencing that allowed the owner to move in during July and August while some construction activities were still happening. The RGE and CMU expansion were finally completed late August 2013 and the building was opened for use in time for the fall semester. For more detail, several real project schedules prepared by the construction manager can be found in Appendix H.

However, the electrical contractor made a claim in May 2013 for $777,000 due to loss of productivity, extension of supervision and general conditions, and other factors resulting from delays as well as a request for more time. This claim was followed by several notices during the summer and fall, and a damage report compiled by an independent consultant submitted November 2013. Following the report, the Architect denied the claim and that winter the parties made several attempts to resolve the dispute at the project level. After these efforts failed, the State Architect’s Office threatened to get involved and in response an official mediation was held May 2014 in an attempt to formally settle the dispute.

Based on mediation statements, the contractor’s damages report, and correspondence, an idea of how the ordeal ended up could be deduced. The electrical contractor’s delay and damages claims were eventually rejected by the state, but it acted as a bargaining chip to gain $300,000 of smaller claims they wanted and receive their last contract payment of $279,095. This dispute was simply the largest of a small number of conflicts that arose on the project as a result of project delivery structure.

In conclusion, the project could have benefitted greatly from the implementation of a Design-Build delivery system. The CM agency has experience working on design-build teams, and essentially could have done the same job except with contractual authority to back it up. The management and timely execution of the project could have occurred much more smoothly had an alternative delivery method been available at the time of bidding.

Summary of Work and Conclusions

Based upon the analyses contained within this report, it is plausible that the proposed alternates could have had a positive effect on the design, construction and operation of the Research and Graduate Education and Comparative Medical Unit project. Option B evaluated in the mechanical depth appears to be the most attractive alternate when weighing the different needs and desires of the project according to their priority. Generating on-site electricity to campus full load with waste heat used for steam needs is considerably more feasible than aiming for space heating or trigeneration, or running a generation scheme for a base load or grid buyback.

Research on grid connection requirements and responsibilities for this particular project show that it is quite feasible to implement a parallel operation of on-site generation and local electric grid. In addition, had an alternative project delivery method been possible it could have had a positive effect on project management.

The existing project and the work performed was of excellent quality; the conclusions of this report are in no way meant to imply any flaws. This analysis was conducted in an academic context in which there was much more freedom and flexibility for exploration than in the real world. The opinions expressed within this report are the sole interpretation of the author and reflect the results of a comprehensive educational exercise.

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Rob Leicht	*Asst. Professor of Architectural Engineering – Penn State*
Tim Warren	*President - JDB Engineering, Inc.*
Tom Leary	*Executive VP/DOP - JDB Engineering, Inc.*
Ari Tinkoff	*Managing Director/Principal - BR+A Consulting Engineers*
Scott Walthour	*Managing Principal – Arium AE*
Chris Elgin	*Structural Engineer - GPD Group*
Diet Mt. Dew	*Carbonated Soft Drink – PepsiCo Inc.*
Steam	*Internet-based gaming platform – Valve Corporation*

And of course…I would like to thank my friends and family for their love and support

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