FINAL THESIS REPORT

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Mechanical Option
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STENGEL HALL – ACADEMIC CENTER FOR EXCELLENCE

Linden Hall School for Girls
Lititz, Pennsylvania

Stengel hall - academic center for excellence
Linden hall - lititz, pa

General | Keystruct Construction Inc.
- -22,600 square feet of new construction
- -14,300 square feet in renovations
- -3 occupied levels above grade, attic & 1 semi-occupied level below grade
- -approximately $6m in total costs
- -design-build contract
- -construction may 2011-august 2012

Structural | C.S. Davidson, Inc.
- -combination of masonry walls and hss columns
- -varying beam and girder layout
- -foundation consists of cast in place wall footings and base plates for columns
- -4" concrete slab on metal deck system
- -masonry shear wall support

Lighting & Electrical | Haller Enterprises, Inc.
- -120/208V, 3Ø, 1200A main distribution panel
- -(1) main lighting panel, receptical panel on each level, & (2) mechanical equipment panels
- -mdp feeds condensors directly
- -primarily overhead fluorescent indoor lighting
- -decorative exterior post lamps

Architecture | Chambers & Associates Inc.
- -exisiting building to mostly remain
- -provides modern learning enviroment and effective academic support for students
- -creates new public entry from main st., lititz
- -addition connects stengel hall to steinman performing arts center

Mechanical | H.B. McClure Company
- - (24) air handling units ranging from 1.5 to 5 tons serve spaces from attic & basement
- -(10) energy recovery ventilators assist ahu's & provide outside air to classroom spaces
- -(4) 310,000 btu/hr boilers located in basement provide hot water to all ahu's
- -(4) 15 ton & (1) 20 ton outdoor split system units on roof provide chilled water to all ahu's

Madeline Haus | Mechanical Option | www.engr.psu.edu/ae/thesis/portfolios/2012/mqh5051/index.html

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1.0 ACKNOWLEDGEMENTS

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I would also like to acknowledge the support from my fellow 5th-year AE classmates. For without the advice and support of all individuals listed, completing this report would not be possible.

2.0 EXECUTIVE SUMMARY

The following report is a study based on the renovation and addition to Stengel Hall-Center for Academic Excellence, an integral part of the Linden Hall School for Girls. The report examines the existing mechanical system and proposes alternatives to the designed mechanical system. The goal of the evaluated alternatives is to provide a more sustainable and maintainable mechanical system. Not only was Stengel Hall evaluated in this report but the entire Linden Hall Campus was included to determine the feasibility of a campus-wide heating and cooling system. The proposed alternatives included a geothermal heating and cooling system utilizing water-source heat pumps and a wood-fired biomass boiler.

Before evaluating either of these alternatives the peak heating and cooling demand loads were determined using Trane Trace and DesignBuilder. The peak heating and cooling loads determined for Stengel Hall were 764 kBTU/hr and 1087 kBTU/hr respectively. The evaluation estimated that the campus peak heating demand could be at 3190 kBTU/hr and peak cooling demand is 4525.2 kBTU/hr.

The geothermal study calculated the required ground loop piping loop for both Stengel Hall alone and the entire Linden Hall campus. The calculation resulted in heating dominant bore lengths of about 25,000 feet for Stengel Hall and about 109,000 feet for the entire campus. An energy study on the proposed ground source heat pump alternative for Stengel Hall resulted in an annual building energy savings of about 330,000 kBtu/year; an approximate 40% reduction. However, this only resulted in an annual utility cost savings of approximately $5,700 and a payback period of over 30 years.

The research conducted on biomass boilers concluded that the best choice application of biomass energy is a wood-fired boiler that uses green wood chips mixed with the equestrian waste produced on campus. This alternative did not prove to be cost effective to the school due to the high initial cost.

The construction management breath focused on estimating the initial cost of the proposed alternatives. The estimate concluded that the geothermal system proposed for Stengel Hall would cost about $465,000.00; an increase of about $285,000 over the existing mechanical design. The initial cost estimate for the wood-fired boiler was over 2.8 million dollars due to the extensive repairs necessary to the existing steam system. An electrical breadth study evaluated the increased electric load and suggested larger panel boards to handle the loads incurred by the geothermal system.

Of the two proposed alternatives, the final recommendation is to implement the ground source heat pump alternative because it was the most cost effective and showed reductions in the energy consumption of Stengel Hall. Likewise, the other campus buildings may also see similar reductions in energy.

3.0 BUILDING OVERVIEW

The following section delivers an overview of the existing Stengel Hall construction and renovations. Summaries of various systems are included to provide information on non-mechanical components of the building.

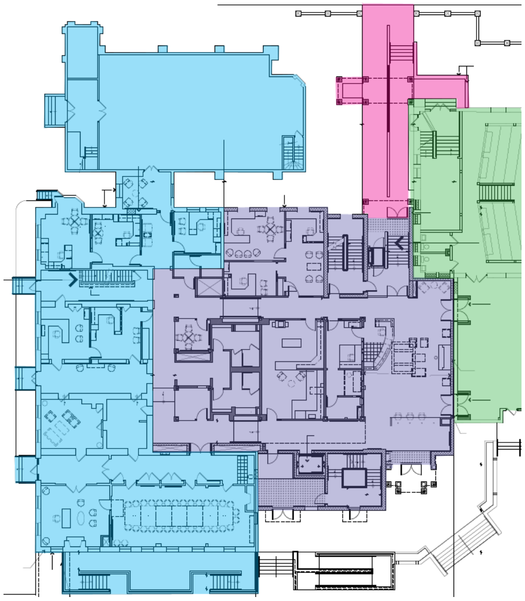
3.1 Introduction & Objectives

The Stengel Hall-Academic Center for Excellence is an essential part of the Linden Hall School for Girls, an independent boarding and day school for girls in grades 6-12. Founded in 1746 and located in the small town of Lititz, Pennsylvania, the school serves as the oldest and the top-ranked college preparatory school for girls in the United States. Stengel Hall serves as one of the main academic facilities for the school and provides offices for the administrative employees. The primary objective of the current renovation and addition to Stengel Hall is to upgrade the existing facilities to better serve the needs of the growing educational program.

The project involves 22,600 SF of new construction and approximately 14,300 SF in renovations to the existing building. Stengel Hall is comprised of one level below grade, three levels above grade, and an unoccupied attic which will be used for mechanical equipment. Construction for this design-build project started on May 28th, 2011 and the majority of the demolition and excavation was completed over the summer of 2011. Construction is expected to be complete before students return for the 2012 school year (August 2012).

3.2 Architecture

The Stengel Hall renovation and addition is designed to provide the Linden Hall students a 20th century learning environment while keeping its historical roots. In order to accomplish this, more recent additions to the original structure were demolished and the addition will infill the remaining U-shaped footprint. This infill will provide a valuable connection to the adjacent Steinman Performing Arts Center & Classrooms, another main academic facility at Linden Hall, on the first level and basement level as well as create a new campus entrance off Main Street on the north side of the building. This layout can best be understood in Figure-3.1 which highlights the key building blocks of the new design.



🟦 Existing Stengel Hall & Chapel
🟩 Existing Steinman Performing Arts Center
🟪 New Stengel Hall Addition
🟥 New Entrance from Main Street

Figure 3.1 | Plan Courtesy of Chambers & Associates

The basement level of Stengel Hall will mostly serve as mechanical space but a modern lecture and testing facility has been incorporated into the addition and connection to the adjacent building. The first and second levels of the existing structure will continue to mainly serve as administrative offices and conference rooms. The first level of the addition will primarily function as the central lobby, found in Figure-3.2, for the new public entrance. The second level of the addition features new classrooms and the Learning Center comprised of a 2-story atrium, found in Figure-3.3, which will allow daylight into computer labs, classrooms, and the library. The third level of the addition and existing structure will provide additional classroom space and flexible learning areas that will be used to accommodate the school's ever-changing needs. Overall, the addition and renovations will increase the functionality of the campus and stimulate learning for the students of Linden Hall with modern technology based classrooms and positive learning environments.

Figure 3.2 | Image Courtesy of Chambers & Associates

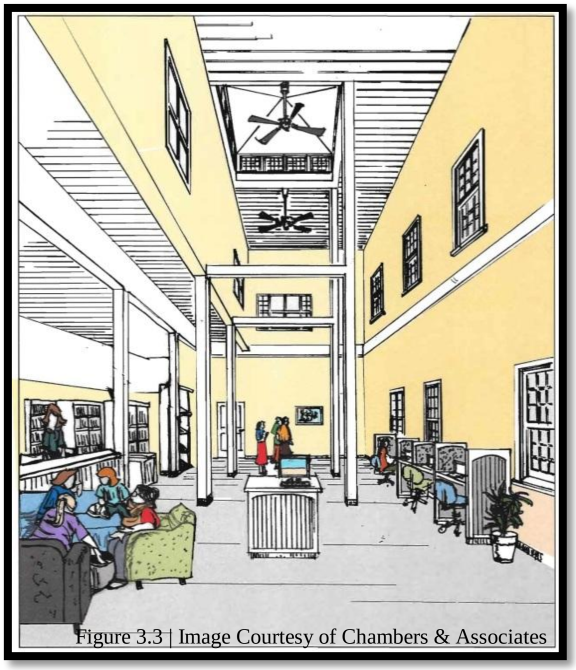


Figure 3.3 | Image Courtesy of Chambers & Associates

3.3 Historical Requirements

Located in the center of the small, quaint town of Lititz, PA, Stengel Hall dates back to 1748 and rightfully so must comply with many historical requirements. The zoning regulations require that any new construction must conform to the same size, scale, shape, orientation, patterns, materials, etc. of the surrounding buildings. There are also very strict regulations on demolition of buildings on this site. Any demolition of a building in the historical district must be reviewed by the Lititz Borough Historical Area Advisory Committee for approval and a permit.

The design for the Center for Academic Excellence includes 10,050 square feet of demolition to recently constructed additions. This will make room for the new addition and allow for a more functional space as it provides access to Main St. and connects Stengel Hall to the Steinman Performing Arts Center. This renovation was submitted and approved by the Historic District and Special Exception Lititz Borough Zoning Hearing Board in September 2012

3.4 Structural System

The existing structure of Stengel Hall consists of a varying combination of concrete foundation walls, brick, stone, and concrete masonry units. Specific information about the existing structure was unknown to the design team and this presented complications during demolition. There are many possible challenges when connecting two existing structures with an addition.

The new portion of Stengel Hall will meet the floor levels of both the existing structure of Stengel Hall and the Steinman Performing Arts Center. A concrete foundation will support the new addition and the perimeter of the new construction will consist of masonry walls. HSS columns and a 4” concrete slab on metal deck system will provide support to the interior portion of the Center for Academic Excellence as seen in Figure 3.4.

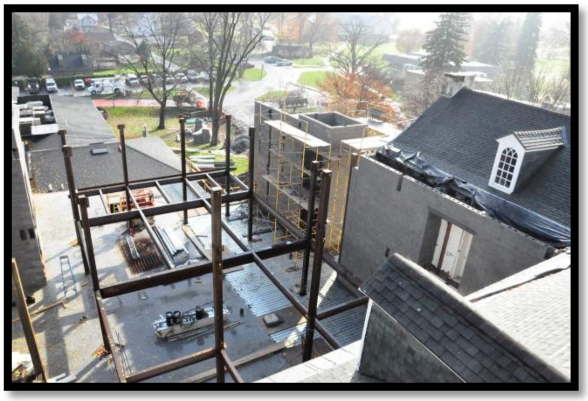


Figure 3.4 | View from roof of existing Stengel Hall

3.5 Electrical System

The existing electrical system in Stengel Hall was in need of many major updates. The new construction and renovations required a new service entrance which is now located along Main Street and enters the building underneath the new public entrance. One main 120/208V, 3-phase 1200A distribution panel serves the electrical load of the building.

This main distribution panel distributes power to four smaller receptacle panels on each floor, one main lighting panel, and two panels dedicated to mechanical equipment. Power is supplied to the rooftop condensing units and elevator directly from the main distribution panel. Emergency lighting and exit signs are connected to a local un-switched lighting circuit.

3.6 Lighting System

A combination of T8 and T5 fluorescent strip lighting fixtures and 6” recessed down light fixtures are planned to replace the existing fixtures and become standard in the newly constructed portion of Stengel Hall. Accent lighting in the lobby is comprised of under-counter LED light strips and incandescent hanging chandeliers. Many chandeliers existing and new are to remain in many entryways and add notable character to the spaces.

3.8 Sustainability Features

The Center for Academic Excellence construction was driven by costs and few sustainability features were incorporated into the new design. A Carlisle Green Roof System w/ ½” Densdeck is designed to be utilized on the lower roof level of the addition. The primarily will reduce storm-water runoff but is intended to be used as a learning tool for students.

4.0 MECHANICAL EVALUATION

A thorough investigation of the existing mechanical system was completed in order to grasp the current state of operation. The following section provides an overview of the existing mechanical design for the additions and renovations to Stengel Hall.

4.1 Design Influences & Objectives

There are many goals and requirements associated with the mechanical system of Stengel Hall that have been outlined by the Linden Hall School. The design is required to meet all requirements set forth by local codes and ASHRAE standards. It is also important that the system is designed to be energy efficient. Furthermore, a minimum outdoor air quantity of 15 cfm per student is requested by the school. Lastly, the school requires all equipment to be safe, protected, and should be in good working order eliminating any hazards that could harm the building occupants.

The mechanical design team for this project was required to face many issues that occur when renovating an existing structure. The existing Stengel Hall was heated by the central steam boiler and cooled using window AC units. Both of these systems were in need of being upgraded in order to provide adequate comfort to the staff and students. Additionally, due to the historical restrictions on the architectural design of the building, Stengel Hall was required to remain consistent with the existing structure. This limited the amount of glazing therefore aiding in the control of the solar heat gain to the building. However, the existing Stengel Hall has very low floor to floor heights which severely limited the amount of ductwork that could be distributed throughout the building. This eliminated the possibility of incorporating variable air volume terminal units due to their need for additional ceiling cavity space.

The Linden Hall School for Girls is a private school and any federal funding, if any, is most likely limited. Hence, it is understandable that the renovations and construction of this project were driven by costs in addition to the special constraints of the existing structure. Multiple potential solutions were evaluated when determining the mechanical system and the lowest initial cost option was ultimately chosen and the total costs of the mechanical system is summarize in Table 4.1.

TABLE 4.1-Costs

Building Area	Cost	Cost per SF
New Construction	$767,037.00	33.93 $/SF
Renovations	$255,679.00	17.88 $/SF
Total	$1,022,716.00	27.72 $/SF

4.2 Existing Mechanical Design

4.2.1 - Air Supply/Return

The air side of the mechanical design for Stengel Hall is mainly comprised of many small-scale constant volume fan coil units. Although the size of these units varies depending on the load, there are two main types; a horizontal unit and a vertical unit. The horizontal configuration is shown in the air-side flow diagram found in Appendix A-Figure A.1 and the vertical configuration can be viewed in Figure 4.1. Both of these units are packaged by the manufacturer and include the necessary filters, refrigerant cooling coils, hydronic heating coils, and properly sized fan. The vertical fan coil performs the same as the horizontal fan coil unit with the exception that the mixing box is located at the floor level and turns the air upwards through the filters and coils. The vertical configuration is utilized where necessary to save space throughout the building.


Figure 4.1-Vertical Fan Coil Unit

The mechanical equipment located in the basement provides air distribution at the ceiling level for occupied basement-level spaces as well as floor distribution to many of the offices on the first level in the existing portion of Stengel Hall. The first level of the addition portion is also served by the equipment located in basement, but air is distributed from the ceiling rather than the floor.

The majority of the air supply to the second and third levels is routed from equipment located in the unoccupied attic. These levels have a ceiling supply as well as high or low return which depend on the space. There are a few air handlers located within the occupied floor plan that distribute air to both the second and third level as necessary. Outdoor air is supplied from a single attic fresh air intake location to these air handlers.

In addition to the fan coil units supplying conditioned air to the spaces, energy recovery ventilators are utilized to precondition air for certain applications. The energy recovery configuration can be viewed in the air-side flow diagram (Figure A.1 in Appendix A) as it supplies mixed air to the typical classroom within Stengel Hall and exhausts contaminated air from classroom spaces to the outside. The energy recovery ventilators reduce both sensible (temperature) and latent (humidity) load on the coils in the fan coil units. These units are also manufacturer assembled and include the properly sized fan, filter, motor, and enthalpy wheel within the unit. These components can also be seen in Figure 4.2.

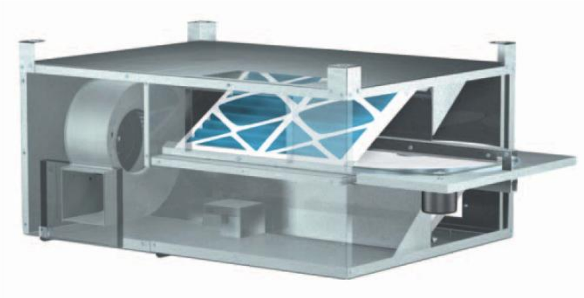


Figure 4.2-Energy Recovery Ventilator

4.2.2 - Hydronic Systems

The hydronic system is comprised of five outdoor split system units for cooling and four high-efficiency boilers to supply hot water. The outdoor split system units, located on the roof of the addition, supply refrigeration to the DX coils within each fan coil, as shown in hydronic flow diagram in Appendix A-Figure A.2. A dual manifold compressor is specified for all condensing units in the Stengel Hall project. Additionally, hot water is supplied to the fan coil units from the boilers located in the basement, also shown in the hydronic flow diagram. The boilers are supplied water from the domestic water supply and a backflow preventer protects the domestic water supply from being contaminated. The boilers are connected in series and filters and expansion tanks are in place within the system. Due to the constant volume air system variable frequency drives on pumps were necessary to provide sufficient control of the system.

4.2.3 – Mechanical Space

Due to the space limitations for ductwork throughout Stengel Hall both the attic and basement needed to be utilized for equipment as well as allotting some areas within the occupied floor plan. The areas are broken down by floor and summarized in Table 4.2. The resulting design dedicated twenty-five percent of the building's floor space mechanical equipment. The reason the design needed such a large portion of space is because the mechanical system is comprised of many small fan coils which all require their own individual clearances – quickly adding large areas to the overall mechanical space. The boilers are located in the basement mechanical room and exhaust out of the roof. The only exterior equipment for this design is the condenser units, which are concealed on the roof. This area was not included in this analysis of mechanical space.

TABLE 4.2 – Mechanical Space

LEVEL	RENOVATED (SF)	NEW (SF)	SHAFT (SF)	TOTAL (SF)
BASEMENT	1759	1565	0	3324
FIRST FLOOR	0	0	103	103
SECOND FLOOR	0	118	79	197
THIRD FLOOR	0	99	122	221
ATTIC	4618	616	0	5234
				9079 SF

4.3 Design Load Estimate

An energy model was created in order to estimate the design loads of Stengel Hall and for further analysis of proposed changes to the mechanical system. The first step performed in creating the energy model was to create a Revit model comprised of the exterior envelope and room layout. Trane Trace® was then used to determine the heating/cooling loads and energy consumption. For the purposes of this simulation the attic spaces, mechanical shafts, and elevator shafts were not analyzed. Although there is heat gain to the building from these spaces, they are not conditioned and it was assumed that there is little, if any, infiltration into conditioned spaces. In addition, stairwells were also not analyzed in this report. The stairwells are heated by cabinet unit heaters and even though they experience solar heat gain it was assumed that they had little effect on the building as a whole. The following sections provide a summary of the additional assumptions and internal loads used in the energy model for Stengel Hall and a summary of the results.

4.3.1 - Internal Loads

Many internal loads were taken into account for the setup of the energy model of Stengel Hall. First and foremost, the occupancy, which was provided in the architectural plans, of each space was established and a sensible load of 250BTU/hr and latent load of 200BTU/hr was estimated for the building. A summary of occupancies per space can be found in Appendix A-Table A.2.

In addition to occupancies, many specialized lighting and equipment loads were analyzed in the Stengel Hall simulation. The majority of the lighting in the renovation is fluorescent lighting either recessed (mostly corridors) or pendant mounted (mostly classrooms and offices). However, some more decorative luminaires and featured lighting displays are present in entryways and lobbies. The lighting densities were analyzed on a watt per square foot basis for each individual room and can also be found in Appendix A-Table A.2. In some of the existing newly renovated spaces, lighting information was not provided and in those cases the load was determined based on similar room function and size.

Lastly, The Academic Center for Excellence incorporates many new educational technologies into the learning spaces which result in added load to the space. Smart boards have nearly replaced traditional chalkboards and add significant load to the space while in use. Also, the Linden Hall School provides personal netbooks for every student and students are expected to use them during class. Each workstation in most of the classrooms accounted for this additional load resulting from the netbooks. Additional equipment loads, summarized in Table 4.3, were estimated based on general manufacturer's specifications as well as assumptions on a watt per square foot basis.

Table 4.3-Miscellaneous Loads

Load Source	Associated Load	Source of Value
Smart Boards	300W, in use	Manufacturer's Specifications
Netbooks	30W, charging	Average of varied manufacturers
Desktop Computer	30W	Average of varied manufacturers
Beverage Refrigerator	150W	Manufacturer's Specifications
Technology Server Room	25W/SF	Assumed
Elevator Equipment	400W	Assumed
Mechanical/Electrical Equipment	10W/SF	Assumed

4.3.2 - Airflows

To ensure that the outdoor air ventilation rates designed for this building were properly calculated in the simulation model a simplified method was used. Since Trace can either use ASHRAE Std. 62.1 ventilation rates or a prescribed ventilation rate, a prescribed ventilation rate was chosen to get a more accurate representation of the intentions of the designer. This rate was calculated by the following equation:

$$\text{Ventilation Rate} = \frac{\text{Sum of designed outdoor air [CFM]}}{\text{Sum of occupied spaces [SF]}}$$

This resulted in a ventilation rate of 0.306 CFM/SF which was applied to all occupied spaces with the exception of restrooms and stairwells because the mechanical design of these spaces rely on air transfer and infiltration, not ducted supply air. A disadvantage that was discovered using this method was that the ventilation loads for individual systems varied from the designed loads. However, the total ventilation load only varied by expected amounts and accurately represented the design. Also, an assumed value of 2 air changes per hour was assigned to all vestibule areas and spaces that provide access in and out of the building.

4.3.3 – Temperatures & Schedule

The indoor and outdoor temperatures used in the analysis of Stengel Hall are outlined in Table 4.4. Outdoor design conditions were determined from the ASHRAE Handbook – Fundamentals (2005). The most extreme weather data (0.4% and 99.6%) for Philadelphia, PA were used for this study. Indoor thermostat set points were not originally provided with the design information for Stengel Hall and an assumed set point for both heating and cooling was made. Eventually, the mechanical designer provided the set points for the building but at this point the model was completed.

Table 4.4 – Temperatures				
	Cooling		**Heating**	
Outdoor Design Conditions	11.3ºF		93.2ºF	
	Occupied	Unoccupied	Occupied	Unoccupied
Initial Assumed Indoor Set Point	72ºF	81ºF	70ºF	64ºF
Actual Designed Indoor Set Point	75ºF	80ºF	72ºF	67ºF

The last input that made a substantial impact on the energy model created for Stengel Hall was the building schedule. Table A.3 of Appendix A outlines the assumed schedule for a boarding school facility which was determined based on combination of high school and middle school schedules. Special considerations were given to the increased time students may spend outside of their dormitories and in the classroom areas.

4.3.4 – Energy Model Results

The results of the heating and cooling load analysis were within reason of the designed mechanical system. However, variations were immediately expected during this analysis because of the method used for determining the volume of spaces. In Revit the areas of spaces were determined from the centerline of the walls and therefore included the thickness of the walls as occupied space. This resulted in an average area increase of 15% in the simulation model versus the designed areas and at first glance the calculated loads were substantially greater than specified in the design. However, when the loads were compared, see Table 4.5, on load/ft^2 basis the results were an adequate reflection of the design.

Table 4.5 – Load Comparison			
	Designed	Computed	% Difference
Total Airflow (cfm/ft^2)	0.896	0.856	4.45%
Ventilation Airflow (cfm/ft^2)	0.275	0.269	2.18%
Cooling Load (ft^2/ton)	390.2	355.7	8.8%
Heating Load (Btuh/ft^2)	20.4	23.7	16%

In addition to the room areas differing from design, the plenum spaces were not modeled. Finished ceiling heights were not provided in the design documents because the majority of the spaces are open to the floor above. However, some spaces do have a ceiling cavity which was not accounted for. This added unnecessary load to the simulation and could have been a reason for the increase between computation and design.

Overall, when assessing the results on a zonal basis, the calculated cooling demand was approximately ½ ton greater than designed load. For the purposes of this analysis, this consistency was within reason. However, the calculated heating demand was substantially higher than the designed heating capacity and this increase may have been due to errors in outdoor air quantities. Even though outdoor air rates were prescribed on a square foot basis Trace reported many of the areas to use 100% outdoor air. This error was not able to be corrected for this report and will be taken into consideration when analyzing results of proposed systems.

4.4 Energy & Cost Analysis

The building energy usage, which was estimated using Trane Trace®, was used to determine the estimated annual energy consumption and operating costs. Typically, if the mechanical engineers for the project had created an energy model, a comparison would have been made to determine accuracy. However, due to the small size of the project and cost considerations it was not realistic or beneficial for the engineers to perform an energy analysis.

However, a facilities study of the entire Linden Hall campus was performed in 2007. This study includes, among other information, the 2007 state of all of the school's facilities. This discussed the mechanical and electrical program, condition, and projected costs of repair or modification. The report also provided a summary of the 2005 & 2006 annual energy costs of each building. For the purposes of this report the average 2005/2006 utility rates will be used to calculate and compare operating costs. Figure 4.2 compares the average 2005/2006 electric use to the calculated building electric use and gas consumption.

The peak electric load was not originally expected to occur in May but it makes sense because of the decreased occupancy and demand during the summer at a school. Another interesting outcome of the compared energy usage is the dramatic difference in electric usage during the winter months. It is not entirely clear why this occurs but the data provided may have included gas consumption in addition to electric consumption.

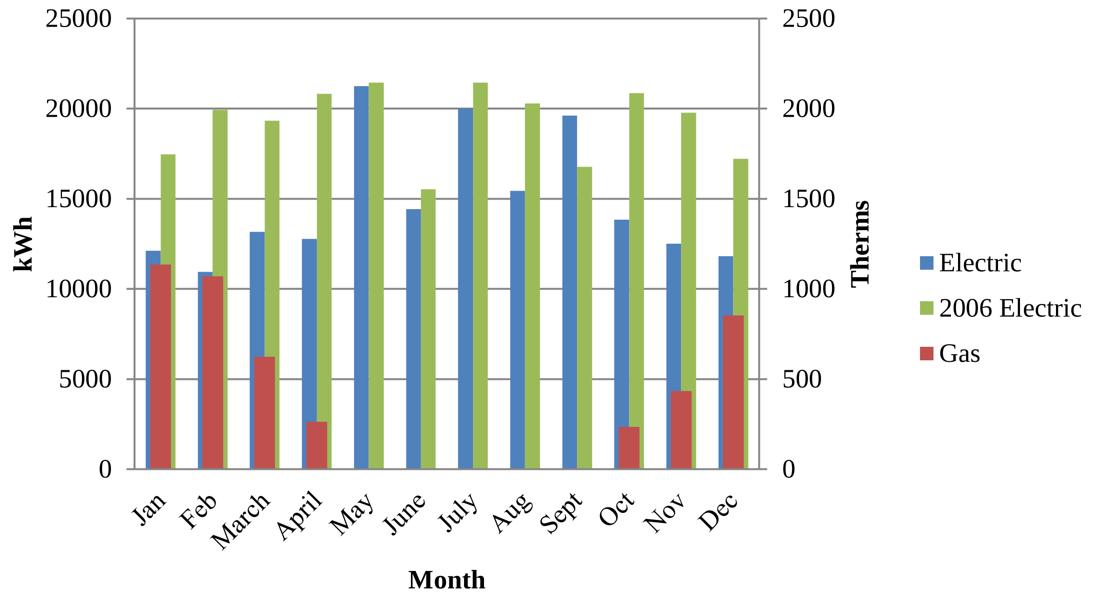


Figure 4.2 Monthly Energy Usage

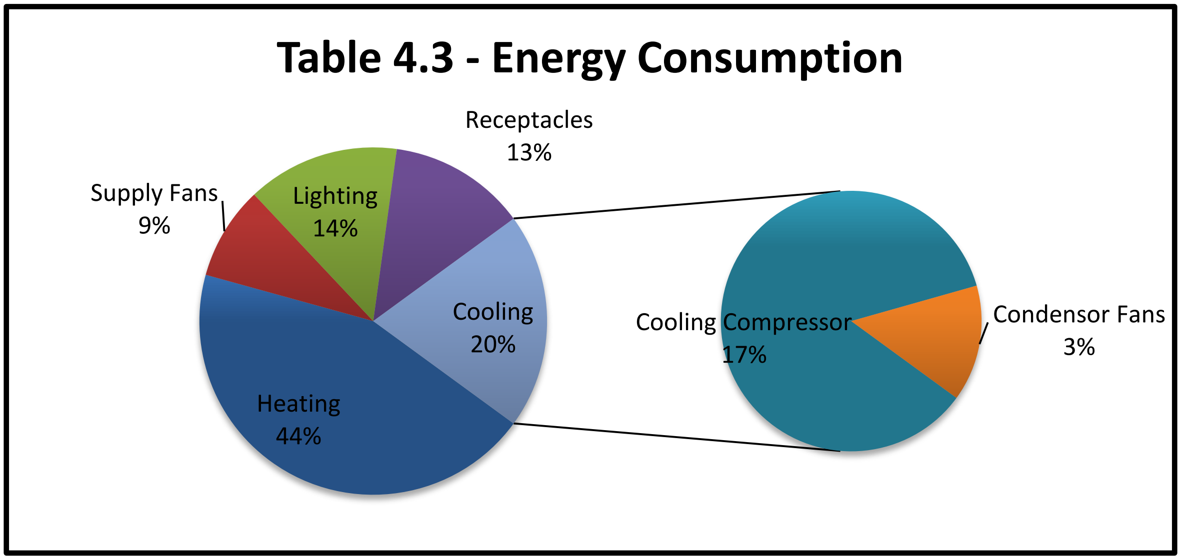
Table 4.6 breaks down the building energy usage by source and provides an annual operating cost. The electric rate below was determined based on the rates that were charged in 2006. The electric operating costs are representative of 2006 electric rates because they can be easily compared to the operating costs provided by the owner.

The computed operating cost of Stengel Hall is 0.62 $/SF and 2005/2006 the actual operating cost was 1.78 $/SF. It should be noted that the 2006 Stengel Hall is not completely representative of the newly renovated Stengel Hall but the electric consumption and costs are a helpful comparison. The operating cost of the entire Linden Hall campus was approximately 1.51 $/SF. In the facilities study, this value was compared to operating costs of 1.52 $/SF for other regional schools and at the time this study was conducted the preparer of the report, thought this cost was higher than expected because of the "residential nature" of Linden Hall.

Table 4.6 – Building Energy Consumption

SOURCE	ELECTRIC (KWh)	ELECTRIC OPERATING COST (0.0842 $/kWh)	GAS (Kbtu)	GAS OPERATING COST (1.718 $/ccf)	TOTAL ENERGY (kBTU/yr)
Heating	4,305	$362.48	586,424	$9,790.83	473,822
Supply Fans	25,192	$2,121.16			92,660
Lighting	44,748	$3,767.78			151,185
Receptacles	40,745	$3,430.73			136,333
Cooling	57,646	$4,853.79			214,557
TOTALS	**172,636**	**$14,535.94**	**586,424**	**$9,790.83**	**1,068,736**

In addition to Table 4.5 a breakdown of the computed energy system based on the load source is summarized below in Figure 4.3. Overall, the values seem to accurately represent the nature of the load sources of Stengel Hall.



Electricity for the Linden Hall campus is distributed from PPL Power and natural gas is supplied by UGI Utilities. The electric emissions rates were determined from the air quality report published by PPL electric and are included in Appendix A – Figure A.4. The natural gas emissions rates were determined from lecture material provided by Dr. Jim Freihaut and are representative of on-site combustion for commercial boilers. These rates are also included in Appendix A – Figure A.5. The total emissions due to the energy consumption of Stengel Hall are summarized in Table 4.7. It is important to note that these values are determined from the building energy use and do not include the decrease in efficiencies of burning or transmission.

Table 4.7 - Emissions

Fuel		SOX	NOX	CO2	
ELECTRIC	PPL Emissions	4.2	1.2	920	lbs/MWh
	Stengel Hall	725.07	207.16	158825.12	lbs
GAS	Natural Gas	0.111	0.000632	122	lbs/1000ft^3
	Stengel Hall	63.26	0.36	69,527	lbs
	TOTAL	788.33	207.52	228,352	lbs
		0.0202	0.0053	5.86	lbs/ft^2

4.5 LEED Analysis

At this point, the design team for the Stengel Hall-Center for Academic Excellence is not applying for any type of LEED certification. Many of the requirements for LEED credits would add cost to the project and this entire project is driven by costs. However, for the purposes of this analysis, LEED credits were explored based on feasibility to the project, i.e. could the owner or design accomplish certain criteria if it were attempted. The LEED for Schools New Construction & Major Renovations Rating Systems publication was used for this analysis and only credits involving the designed mechanical system were explored; a summary of these credits are found below.

- EA Prerequisite 1: Fundamental Commissioning of Building Energy Systems

The intent of this credit is simply to ensure that the energy-related systems are properly installed. To achieve this credit the project team would be required to designate a qualified person as the commissioning authority. Due to the small size of the project this person could be someone on the design or construction team. This is a feasible credit for this project but no points are award as it is required.

- EA Prerequisite 2: Minimum Energy Performance

This credit establishes a minimum level of energy efficiency for the building. The new construction must demonstrate a 10% energy improvement in relation to a case study building and the renovated areas must fulfill a 5% improvement in relation to the previous operating state. The design must also meet ASHRAE standards. This point is feasible and previously determined to comply with these requirements but is also a required credit and therefore does not receive any additional points.

- EA Prerequisite 3: Fundamental Refrigerant Management

The intent of this credit is to ensure that ozone-depleting refrigerants are not used within cooling components of the design. The refrigerant specified in the split system units is R-410A which complies with this requirement. No additional points awarded.

- EA Credit 1: Optimize Energy Performance

The intent of this credit is to increase energy performance beyond the minimum set by the prerequisite. Varying levels of points are awarded for increasing energy performance. To evaluate this credit the energy performance based was on the simulated energy results from Technical Assignment 2 and the 2006 energy bills as a basis for performance. The results of this comparison showed drastic improvements to the energy performance and this design may possible receive the full 19 points for this credit.

- EA Credit 2: On-site Renewable Energy

This credit recognizes efforts made to produce energy on site. Varying levels of points are granted for the increasing percentage of renewable energy. Renewable energy is not a component of the design for Stengel Hall or the Linden Hall Campus. No points would be awarded for this credit.

- IEQ Prerequisite 1: Minimum Indoor Air Quality Performance

The intent of this credit is to recognize buildings that provide proper amounts of ventilation to its occupants based on ASHRAE Standard 62.1. As previously analyzed this building meets all requirements set for ventilation rates by ASHRAE. This prerequisite is met.

- IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control

This credit protects the occupants from exposure to tobacco smoke. The school would be required to prohibit smoking in the building as well as within 25 feet of any opening to the building. This is a feasible credit to accomplish.

- IEQ Prerequisite 3: Minimum Acoustical Performance

The intent of this credit is to ensure a quiet learning environment for students. The background noise of HVAC equipment and reverberation time within learning spaces must be limited. Information on the acoustical characteristics of equipment was not provided however it is assumed to be considered in the design of the mechanical system.

- IEQ Credit 1: Outdoor Air Delivery Monitoring

The purpose of this credit is to promote occupant comfort and well-being. The design would require the monitoring of carbon dioxide throughout the building. This credit could be achieved by adding CO_2 monitors to areas that experience high occupancy.

- IEQ Credit 2: Increased Ventilation

The intent of this credit is to provide additional outdoor air ventilation. The current design does exceed the minimum set by ASHRAE Std 62.1 but not by the required 30% and would not receive points for this credit.

- IEQ Credit 6.2: Controllability of Systems – Thermal Comfort

This credit is intended to give thermal control to at least 50% of the building occupants. At this time, very little information on the controls of this mechanical system has been provided. Therefore, it cannot be determined if this credit will be met.

It certainly seems viable for the Center for Academic Excellence to achieve LEED certification but the steps necessary will add cost to the overall project. LEED certification does not add any observable benefits to the school, and may be the reason why it was not a goal of the project.

4.6 Design Evaluation

The overall mechanical design properly addresses the school’s need for an improved system. The previous two-pipe steam system has been replaced with high efficiency boilers serving individual fan coil units. The boilers not only decrease energy use but they provide a safer distribution system for the Academic Center for Excellence. The new mechanical design also provides air-conditioning to all occupied areas of the building. Therefore eliminating the use of window air conditioning units used in the existing Stengel Hall.

However, the design team did have to sacrifice the opportunity for higher efficiency due to cost restraints for the project. The added first costs of other potential mechanical systems were too high for the budget of Linden Hall and therefore the lower cost option was chosen for the Stengel Hall renovation and addition.

In addition to cost restraints, the physical limitations of the building were a major challenge the design team successfully overcame. The low floor to floor heights and exposed ceilings eliminated areas which would traditionally be utilized for ductwork. The amount of exposed outdoor units also needed to be carefully considered in order to pass Historical Review by the Lititz Borough. The finished design resulted in only five pieces of outdoor equipment which were concealed on the roof. The use of several small units to supply air to zones also allowed for certain parts of Stengel Hall to remain occupied during construction by relieving the need for the mechanical design to be completed all at once.

One downside to having a large number of fan coil units and energy recovery ventilators is the added maintenance involved. Each piece of equipment has its own filters, and additional components which must be serviced routinely. This will ultimately add to the amount of attention provided to the Stengel Hall mechanical system. Nonetheless, the mechanical system determined by the design team was in the best possible interest of the Linden Hall School for Girls at this time.

5.0 PROPOSED REDESIGN OVERVIEW

The current mechanical system meets the needs of Stengel Hall and will provide a much more comfortable atmosphere for learning. Due to the space limitations of Stengel Hall there are very few alternatives for air distribution within the building. The current terminal unit design is probably the best solution for the school, and therefore the area that has the most potential for improvement is at the source of the heating and cooling. The current system selection was driven by cost, ultimately the system with the lowest first-cost was selected, and there is great potential to increase sustainability in the renovation and addition to Stengel Hall and the entire campus.

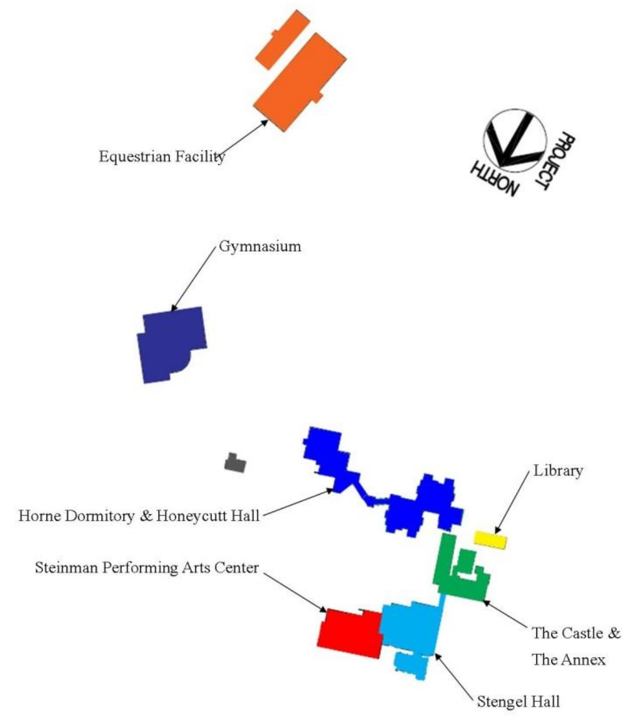


Figure 5.1 | Plan Courtesy of Chambers & Associates (labels & colors added)

The overall goal of the proposed redesign is to provide a more **sustainable** and **maintainable mechanical system** for Stengel Hall and the Linden Hall School for Girls. As per a facility study of the Linden Hall campus, one of the considerations of the school is to have a campus-wide heating and cooling system. The entire campus, found in Figure 5.1, is comprised of two classroom buildings, gymnasium, equestrian facility, admissions office, student lounge, library, dining facility, and three residential buildings. Most of the buildings are somehow connected or are in close proximity to one another with the exception of the gymnasium and equestrian facility. A campus-wide system could potentially reduce maintenance costs and provide a more efficient system. However, in order to evaluate the size of a system for the entire Linden Hall campus, the demand loads for the other campus buildings will need to be determined. These loads will be used in addition to the loads already calculated for Stengel Hall to explore possible campus-wide heating and cooling.

Both geothermal and biomass systems have been successful in other Pennsylvania schools and the Linden Hall campus could potentially benefit from these new developments. An additional benefit of implementing new technologies into a school such as Linden Hall is the educational value it adds for the students. For example, the addition and renovation of Stengel Hall includes a green roof that will be used as a learning tool for students. A biomass system or geothermal system will definitely provide the same kind of opportunities.

5.1 Ground Source Heat Pump


Figure 5.2 | Image Courtesy of bing.com (shading added)

Geothermal systems have become increasingly popular for schools because schools typically have land available for geothermal piping. Linden Hall does have space available for such piping within proximity to Stengel Hall and surrounding buildings. The available land can be seen in in Figure 5.2 which is a bird's-eye view of the campus. A cooling and heating system utilizing the grounds steady temperatures would drastically change the energy needs of the school and provide a much more energy source. In which case, an analysis will be conducted to determine the loop size, layout, and energy consumption associated by implementing ground source heat pump configuration. A cost analysis and energy savings will determine the potential benefits of implementing a geothermal system.

5.2 Biomass Energy System

By implementing a biomass system the school will be able to use renewable energy such as wood or local farm waste to generate heat and electricity. This type of system is also becoming popular for schools because of the advancing technology in the scalability of the system. Each system is now designed to meet the needs and goals of the client. Research on possible biomass systems will be conducted and, as in the ground source heat pump alternative, potential energy savings from such a system will be analyzed and compared to the existing mechanical system.

The Lititz Borough Historical Area Advisory Committee has strict regulations on many of the buildings on the Linden Hall campus including Stengel Hall. The façade must resemble that of the existing building and new construction must conform to the same size, shape, orientation, color, etc. Therefore, any exterior units must be carefully placed and also approved. There are parts of the Linden Hall campus that are not under quite as strict historical review and these areas are mostly used as athletic and equestrian facilities for the school. These areas provide an opportunity to place a small structure to house additional equipment that would be necessary in a biomass system.

5.3 Construction Management Breadth

The construction process will drastically be affected by either of the proposed mechanical systems. A further investigation of the impacts on the construction schedule and added costs will be conducted to fully evaluate the feasibility of either a geothermal system or biomass system.

The biomass system will require an entirely separate building to house additional equipment; an added expenditure that will play a heavy role in the viability of this system. Additionally, the Linden Hall School's schedule will play a heavy role on the flexibility to the construction schedule.

5.4 Electrical Breath

The proposed mechanical systems will introduce additional equipment to Stengel Hall as well as eliminating the need for some of the existing equipment. A study will be conducted researching how the proposed changes will affect the electrical needs of Stengel Hall. Calculations will be done to determine if the existing electrical distribution equipment is able to handle the additional equipment load, if it is insufficient new distribution equipment will be selected.

Additionally, the existing electrical service for the campus is comprised of five service entrances. Analysis will be performed to determine if the campus could efficiently operate with fewer service entrances. This could potentially lower the electric rates charged by the power company and save the school money. To do this, the electric bills for the Linden Hall campus will be utilized to determine the demand and the PPL rates for varying demand levels and electric uses will determine if there is any potential savings.

6.0 CAMPUS LOAD CALCULATIONS

In order to conduct a realistic evaluation of a campus-wide geothermal heat pump or biomass system, it was necessary to determine the heating and cooling loads for the other campus buildings. Using floor plans supplied by Chambers & Associates Inc. and DesignBuilder, basic building energy models were created for:

- Steinman Performing Arts Center & Classrooms
- The Castle & The Annex
- Taggart Frueauff Library (referred to as Library throughout report)
- Horne Dormitory & Honeycutt Hall
- Sweigart Sports & Fitness Center (referred to as Gymnasium throughout report)

EnergyPlus was then used to simulate the building loads and energy consumption for each model. The same basic procedure was used for each analysis and many assumptions were made due to the level of detail for analysis and lack of information regarding each building. The following climatic model inputs were retrieved from DesignBuilder templates and used as a standard for each simulation:

- Location: Reading, PA
- Heating design temperature: 9.14ºF
- Cooling design temperature: 91.2 ºF DB & 73.9 ºF WB

In addition to the climatic data above, the construction data for each facility remained nearly the same for every model. This was done to minimize the variations for each analysis and therefore, the default medium weight construction data was utilized. Lastly, to ensure the models were resulting in reasonable loads, the energy loads for heating, cooling, and ventilation were compared to the national average energy intensities found in the 2003 Commercial Buildings Energy Consumption Survey produced by the Energy Information Administration. This document can be found in Appendix B-Figure B.1. The following sections provide a brief overview the building analysis and summarize the resulting loads obtained from each simulation.

6.1 Steinman Performing Arts Center & Classrooms

The Steinman Performing Arts Center is approximately 20,600 square feet and is primarily utilized for classrooms and the school’s theater. Due to the mixed use of this facility the energy model was split into separate zones for the classroom portion and theater portion of the building. The following load assumptions were made for the purposes of the heating and cooling simulation:

- Schedule: Secondary school schedule revised to match the schedule of Stengel Hall
- Occupancy load: 0.01 people/SF (classroom zone) & 0.023 people/SF (theater zone)
- Lighting load: surface mount @ 2.3 W/SF

- Miscellaneous loads: computers @ 5 W/SF (classroom zone)
- Heating & cooling system: VAV with terminal reheat
- Environmental set points: based on the set points provided for Stengel Hall
    - Heating - 72ºF occupied & 67ºF unoccupied
    - Cooling - 75ºF occupied & 80ºF unoccupied
    - Ventilation – minimum 15 CFM/person as requested by school

The EnergyPlus simulation resulted in the HVAC energy intensities found in Table 6.1. These loads were compared to the national average intensities for educational facilities, which are also found in Table 6.1.

TABLE 6.1 – Steinman Performing Arts Center Building Energy Comparison (kBTU/SF)

	Heating	Cooling	Ventilation	Total
National Average	39.4	8.0	8.4	55.8
Calculated Value	21.6	20.6	11.39	53.6

It was concluded that the building model accurately represented a facility of this size and function due to the similarity of total energy intensities. Therefore, the peak loads for the Steinman Performing Arts Center were determined to be:

- Heating design load peak: 568 kBTU/hr
- Cooling design load peak: 815 kBTU/hr or approximately 68 tons

6.2 The Castle & The Annex

The Castle & The Annex are two mixed-use buildings that are connected, forming an L-shape and have a gross area of about 23,000 square feet. A 1,200 square foot student lounge, a recent addition to the campus and connected to The Castle, has also been included in this load analysis. Due to the variety of uses the model was split into separate zones based on function. The swimming pool is located in the basement of The Annex and the following assumptions were made for this zone:

- Schedule: Secondary school swimming pool
- Occupancy load: 0.016 people/SF
- Lighting load: surface mount @ 1.2 W/SF
- Heating & cooling system: Hot water radiator, not cooled
- Environmental set points: provided by DesignBuilder for pool facility
    - Heating – 82.4ºF occupied & 53.6ºF unoccupied
    - Cooling – 89.6ºF occupied & 82.4ºF unoccupied
    - Ventilation – minimum 25 CFM/person

The basement and third level of The Castle are primarily used for storage and the following assumptions were made for these zones:

- Schedule: Secondary school storage
- Occupancy load: 0.0 people/SF
- Lighting load: surface mount @ 2.0 W/SF
- Heating & cooling system: Hot water radiator, not cooled
- Environmental set points: provided by DesignBuilder for storage areas
    - Heating – 68ºF occupied & 53.6ºF unoccupied
    - Cooling – 73.4ºF occupied & 82.4ºF unoccupied
    - Ventilation – 0.197 CFM/SF

The remaining zones included the first and second levels of both The Annex and The Castle, as well as the student lounge. These areas are primarily used for student living and faculty apartments and the following load assumptions were made for these zones:

- Schedule: University bedroom
- Occupancy load: 0.005 people/SF
- Lighting load: surface mount @ 1.2 W/SF
- Miscellaneous loads: computers @ 1 W/SF
- Heating & cooling system: Hot water radiator, electric cooling
- Environmental set points: based on the set points provided for Stengel Hall
    - Heating – 72ºF occupied & 67ºF unoccupied
    - Cooling – 75ºF occupied & 80ºF unoccupied
    - Ventilation – minimum 20 CFM/person

The EnergyPlus simulation resulted in the HVAC energy intensities found in Table 6.2. These loads were compared to the national average intensities for lodging, which are also found in Table 6.2.

TABLE 6.2 –The Castle & The Annex Energy Comparison (kBTU/SF)

	Heating	Cooling	Ventilation	Total
National Average	22.2	4.9	2.7	29.8
Calculated Value	36	4.45	1.11	41.5

As expected there is a significant difference between national average for lodging and the calculated values for The Annex and The Castle, especially for heating. This could be due to the increased heating requirements for the pool zone as well as the differences in use between a typical lodging facility such as a hotel and a boarding school dormitory. Therefore, it was assumed the building model was an accurate representation and the peak loads for The Castle and The Annex were determined to be:

- Heating design load peak: 626 kBTU/hr
- Cooling design load peak: 778 kBTU/hr or approximately 65 tons

6.3 Library

The Taggart Frueauff Library was built in 1983 and is approximately 3,500 square feet. The library is a very simple 2-story building, and the following load assumptions were made for the purposes of the heating and cooling simulation:

- Schedule: Secondary school schedule revised to match the schedule of Stengel Hall
- Occupancy load: 0.0186 people/SF
- Lighting load: surface mount @ 2.2 W/SF
- Miscellaneous loads: computers & office equipment @ 1.5 W/SF
- Heating & cooling system: Hot water radiator, electric cooling
- Environmental set points: based on the set points provided for Stengel Hall
    - Heating - 72ºF occupied & 67ºF unoccupied
    - Cooling - 75ºF occupied & 80ºF unoccupied
    - Ventilation – minimum 15 CFM/person as requested by school

The EnergyPlus simulation resulted in the HVAC energy intensities found in Table 6.3. These loads were compared to the national average intensities for educational facilities, which are also found in Table 6.3.

TABLE 6.3 – Library (kBTU/SF)

	Heating	Cooling	Ventilation	Total
National Average	39.4	8.0	8.4	55.8
Calculated Value	36.8	13.9	0.98	51.7

It was concluded that the DesignBuilder model was an accurate representation of a school library by the comparison to the national average energy intensity for an educational facility. Therefore, the peak loads for the Library were determined to be:

- Heating design load peak: 192.3 kBTU/hr
- Cooling design load peak: 99.3 kBTU/hr or approximately 8 tons

6.4 Horne Dormitory & Honeycutt Hall

The Horne Dormitory & Honeycutt Hall serve as Linden Hall's primary dormitory and dining facility. Connected by an enclosed bridge the two buildings are approximately 36,000 total square feet. The building was split into several zones due to its mixed use. The dormitory section of this facility was assumed to have the same load assumptions as the student living portion of The Castle and The Annex (mentioned in section 6.2). The first level and a portion of the second level of Honeycutt Hall are primarily kitchen storage and a student lounge. For the purposes of this heating and cooling simulation the following assumptions were made for this zone:

- Schedule: University reception
- Occupancy load: 0.01 people/SF

- Lighting load: surface mount @ 1.2 W/SF
- Heating & cooling system: Hot water radiator, cooled
- Environmental set points: based on the set points provided for Stengel Hall
    - Heating - 72ºF occupied & 67ºF unoccupied
    - Cooling - 75ºF occupied & 80ºF unoccupied
    - Ventilation – minimum 15 CFM/person as requested by school

A second portion of the second level of Honeycutt Hall is used for the kitchen and serving area. The following internal loads were assumed for this zone:

- Schedule: Secondary school food prep
- Occupancy load: 0.0102 people/SF
- Lighting load: surface mount @ 1.2 W/SF
- Miscellaneous loads: additional equipment @ 3.7 W/SF (default from DesignBuilder)
- Heating & cooling system: Hot water radiator, cooled
- Environmental set points: provided by DesignBuilder for a food prep area
    - Heating – 62.6ºF occupied & 53.6ºF unoccupied
    - Cooling – 69.8ºF occupied & 82.4ºF unoccupied
    - Ventilation – minimum 25 CFM/person

The remaining section of Honeycutt Hall is Linden Hall's main dining facility. The following assumptions were made for this zone:

- Schedule: Secondary school cafeteria
- Occupancy load: 0.019 people/SF
- Lighting load: surface mount @ 1.2 W/SF
- Miscellaneous loads: additional equipment @ 1.85 W/SF
- Heating & cooling system: Hot water radiator, cooled
- Environmental set points: based on the set points provided for Stengel Hall
    - Heating – 72ºF occupied & 67ºF unoccupied
    - Cooling – 75ºF occupied & 80ºF unoccupied
    - Ventilation – minimum 20 CFM/person

The EnergyPlus simulation resulted in the HVAC energy intensities found in Table 6.4. These loads were compared to the national average intensities for both lodging and food service, which are also found in Table 6.4.

TABLE 6.4 – Library (kBTU/SF)

	Heating	Cooling	Ventilation	Total
National Average (mean value for food service and lodging)	32.5	11	8.15	52.25
Calculated Value	28.3	6.1	.83	35.2

The resulting energy intensity for the DesignBuilder model is much lower than the national average, especially for the ventilation loads. This could be due to setting the HVAC template to only account for natural ventilation (except for the food prep area) as that is how this facility currently operates. It is assumed that the lower than average energy intensities are accurate enough for the purposes of this analysis and the peak loads for the Horne Dormitory and Honeycutt Hall were determined to be:

- Heating design load peak: 562.9 kBTU/hr
- Cooling design load peak: 960 kBTU/hr or approximately 80 tons

6.5 Gymnasium

The approximately 18,300 square foot gymnasium is another recent addition to the Linden Hall campus and serves as the main fitness facility for the students. It includes a main gym, dance studio, fitness room, and locker rooms. The following assumptions were made for the purposes of the heating and cooling simulation:

- Schedule: Sport center (dry sport hall)
- Occupancy load: 0.005 people/SF
- Lighting load: surface mount @ 1.4 W/SF
- Heating & cooling system: Constant volume heating and cooling
- Environmental set points: provided by DesignBuilder for a dry sport center
    - Heating – 60.8ºF occupied & 53.6ºF unoccupied
    - Cooling - 77ºF occupied & 82.4ºF unoccupied
    - Ventilation – minimum 20 CFM/person

The EnergyPlus simulation resulted in the HVAC energy intensities found in Table 6.5. These loads were compared to the national average intensities for buildings between 10,001 and 25,000 square feet, which are also found in Table 6.5.

TABLE 6.5 – Gymnasium (kBTU/SF)

	Heating	Cooling	Ventilation	Total
National Average	28.2	4.5	4.1	36.8
Calculated Value	20.7	8.7	n/a	29.4

The DesignBuilder model for the gymnasium did not take ventilation loads into account based on the HVAC template selected. It was concluded, however, that the energy model is accurate enough for the basis of this analysis and the peak loads for the Gymnasium were determined to be:

- Heating design load peak: 477 kBTU/hr
- Cooling design load peak: 787 kBTU/hr or approximately 65.5 tons

6.6 Conclusion

The peak heating and cooling loads are summarized below in Table 6.6. As expected the peak cooling load is greater for every Linden Hall campus facility. Theses loads will be used to determine the size and feasibility of both campus ground source heat pumps and a campus biomass system.

TABLE 6.6 – Summary of Campus Loads

Building	Peak Heating Load [kBTU/hr]	Peak Cooling Load [kBTU/hr]
Stengel Hall	764.3	1087.2
Steinman Performing Arts Center	568	814
Library	192	99
The Castle & The Annex	626	778
Horne Dormitory and Honeycutt Hall	563	960
Gymnasium	477	787
Total	3190.3	4525.2

7.0 GEOTHERMAL STUDY

As previously discussed, the hot water and chilled water loads of Stengel Hall are handled using gas fired boilers and electric condensing units. Additionally, the heating and cooling systems in other campus buildings vary in operation and physical condition. The objective of this study is to determine if ground source heat pumps are a feasible heating and cooling solution to Stengel Hall. Investigation was also conducted to determine the additional requirements for incorporating the other campus buildings into a ground source heat pump system. This section provides a summary of the analysis.

7.1 Site Geology

The characteristics of a particular site influence many components of a properly designed ground source heat pump. It is important to have a thorough understanding of the presence or absence of water, rock/soil type, depth to rock, and the water/soil temperature. To accurately determine such characteristics sample boreholes and testing would need to occur prior to design. Unfortunately, this type of testing is expensive and was not conducted for the renovation and addition of Stengel Hall. For the purposes of this analysis, the information available from the Pennsylvania Department of Conservation and Natural Resources and geothermal reference material was used to estimate the necessary site characteristics.

Figure 7.1 illustrates the standard mean ground temperatures found in the United States. From this map we can determine that the undisturbed ground temperature for southeast Pennsylvania is approximately 52ºF.

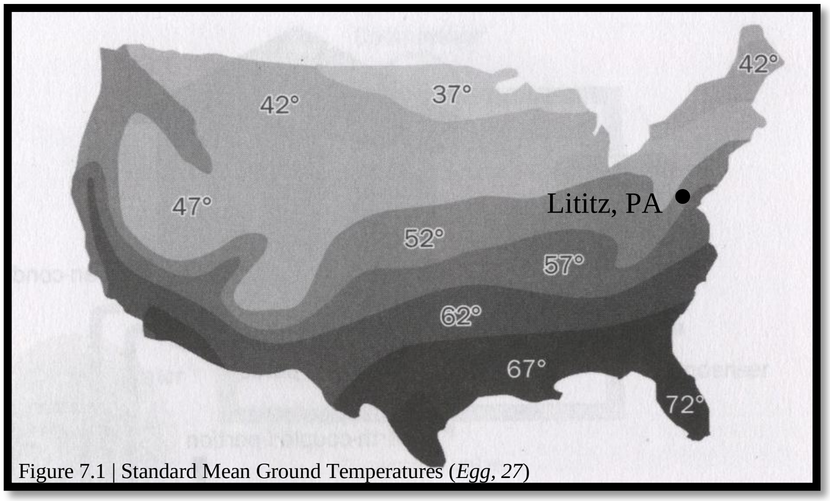
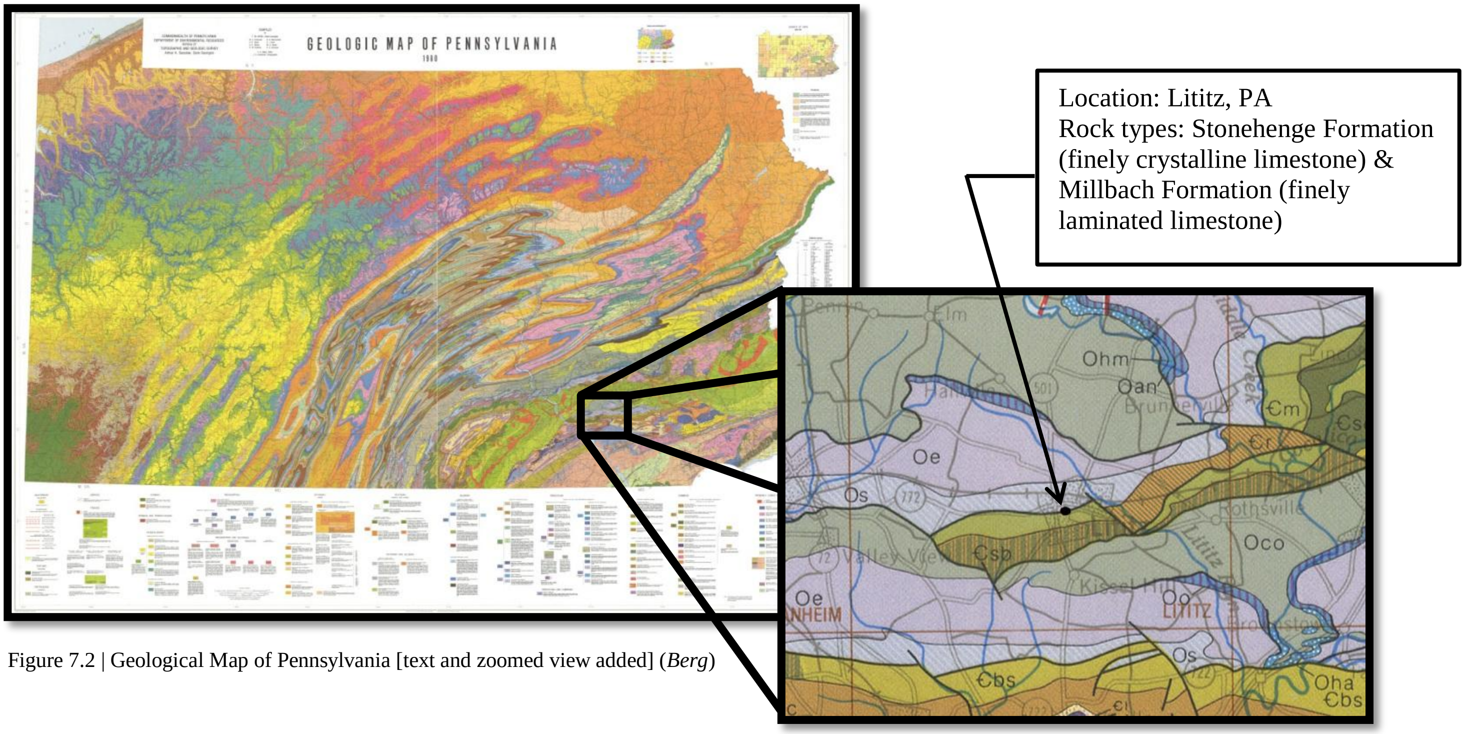


Figure 7.1 | Standard Mean Ground Temperatures (*Egg, 27*)

To determine the conductivity and diffusivity of soil characteristic to Lititz, Pennsylvania a geological map of Pennsylvania, Figure 7.2, was used. It was determined that the Linden Hall School for Girls site consists of compact limestone bed. Using Table 5 in Chapter 34 of the *2011 ASHRAE Handbook-HVAC Applications* values for the average ranges for conductivity and diffusivity were obtained. These values and the values assumed for this analysis can be found in Table 7.1.

Table 7.1 – Thermal Properties of Soil ***(from 2011 ASHRAE Handbook of Fundamentals)***

Rocks	Conductivity [Btu/h*ft*ºF]	Diffusivity [ft^2/day]
Limestone	1.4 to 2.2	0.9 to 1.4
Value used in analysis	1.8	1.15



Location: Lititz, PA
Rock types: Stonehenge Formation (finely crystalline limestone) & Millbach Formation (finely laminated limestone)

Figure 7.2 | Geological Map of Pennsylvania [text and zoomed view added] (*Berg*)

7.2 Initial Design Considerations

Before determining the loop size and selecting equipment it was important to determine the basic loop characteristics. From the geology survey, it was concluded that a closed loop system would be used as opposed to an open loop system uses available groundwater as a heat source much like a well. According to *Geothermal HVAC: Green Heating and Cooling*, a book recommended by ASHRAE that covers the principles of geothermal heating and cooling, a vertical-loop piping layout is the most common type of closed loop system. This is advantageous because the 2011 *ASHRAE Handbook –HVAC Applications* provides a method for determining a vertical loop size.

In addition to the piping layout, other initial design considerations were made by following recommendations found in *Geothermal HVAC*: *Green Heating and Cooling* and common industry methods. The piping material was selected to be high-density polyethylene (HDPE) as opposed to copper or PVC piping due to its good thermal conductivity, longevity, and low cost. Lastly, grout was selected to backfill the boreholes, which will provide greater conductivity than not backfilling the boreholes. Table 5 in Chapter 34 of the *2011 ASHRAE Handbook-HVAC Applications* provides conductivity of common grouts. These conductivities range from 0.42 to 1.40 Btu/h*ft*°F and for the purposes of this analysis an average conductivity of 1.0 was chosen which resulted in using 15% bentonite/85% sand.

7.3 Sizing Method

For the purposes of this analysis the sizing method outlined in Chapter 34 of *ASHRAE Handbook-HVAC Applications* was used to determine an appropriate piping length. This length will be sized to handle the heating and cooling loads of Stengel Hall alone as well as the entire campus. This method uses adjustments made by Kavanaugh (1985) to an equation developed and evaluated by Carslaw and Jaeger (1947) for the heat transfer from a cylinder buried in earth. The adjustments account for the U-bend arrangement found in vertical piping and changes in the thermal resistance of the ground.

The equations for determining the required bore length for heating and cooling are:

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

$$L_h = \frac{q_a R_{ga} + (q_{lh} - 3.41 W_h)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

The variables for these equations and their purpose are outlined below and a complete table of all values used is included in Appendix C-Figures C.4 & C.5:

Required Bore Length, L_c (cooling), L_h (heating)

The required bore length is what is being solved for. The larger of the two lengths should be selected in order to be sure the ground loop will be able to handle the full load. Results for this variable are discussed later in this section.

Short Circuit Heat Loss Factor, F_{sc}

This factor is used to account for degrades in performance due to the short-circuiting heat losses between upward- and downward- flowing legs of the U-bend loop. Values for this correction were obtained from the *2011 ASHRAE Handbook-HVAC Applications* and have been included in Appendix C-Figure C.2. For this analysis a flow rate of 3gpm/ton (recommendation from McQuay Design Manual) was used and only one bore/loop was planned for. This resulted in a short circuit heat loss factor of 1.04 which will increase to total length of the loop.

Part-Load Factor During Design Month, PLM_m

The part-load factor during design month is a factor that can be used to adjust the effective thermal resistance of the ground. Since part-load performance is unknown, for the purposes of this analysis a PLF of 1.0 was selected because it supports a worst-case condition.

Building Design Cooling/Heating Block Load, q_{lc} (cooling), q_{lh} (heating)

This is the load in which the ground loop should be able to support and was determined in previous analysis. The cooling load should be negative for the purposes of this calculation. Table 7.2 summarizes the loads used in this calculation.

Table 7.2 – Building Design Loads		
	Peak Heating Load [Btu/h]	Peak Cooling Load [Btu/h]
Stengel Hall	764,300	-1,087,200
Entire Linden Hall Campus	3,190,300	-4,525,200

Net Annual Average Heat Transfer to Ground, q_a

This term is estimated by the difference between the design heating load and cooling load. It essentially adjusts the size of the loop for the additional heat the ground is forced to absorb. In this case the net annual average heat transfer to ground will be 322,900 Btu/h for Stengel Hall and 1,334,900 Btu/h for the entire campus. This will also increase the size of the loop.

Thermal Resistance of Bore, R_b

The thermal resistance of the bore is dependent on the conductivity of the grout, the diameter of the bore, the piping material, and the U-tube diameter. Values for this correction were obtained from the *2011 ASHRAE Handbook-HVAC Applications* and have been included in Appendix C-Figure C.1. For this analysis, a U-tube diameter of 1-1/4" and borehole diameter of 6" were chosen because it was expected that the total bore length would decrease when coupled with larger pipe diameters. This would be beneficial for the large loads of the entire Linden Hall Campus. Using the grout conductivity previously determined of 1.0 Btu/h*ft*°F the resulting thermal resistance of the bore is 0.09 Btu/h*ft*°F.

Effective Thermal Resistance of Ground, R_{ga} (annual), R_{gd} (peak daily), R_{gm} (monthly)

The sizing method used for this analysis requires the equivalent thermal resistances of the ground over a series of heat-rate "pulses" to be calculated. This can be done using an annual, monthly, and peak daily heat pulse time period. The *2011 ASHRAE Handbook-HVAC Applications* suggests using heat pulses similar to the following: (τ = time of operation)

Annual – 1 year pulse;	$\tau_f = 365$ days
Monthly – 1 month pulse;	$\tau_1 = 365 + 30 = 368$ days
Peak Daily – 6 hour pulse;	$\tau_2 = 365 + 30 + 0.25 = 368.25$ days

The next step is to determine the Fourier numbers at each of the time pulses. The Fourier number depends on the time of operation, τ, the thermal diffusivity of the ground, α (found to be 1.15 ft^2/day from the geology study), and the diameter of the bore, d_b (0.5' as previously discussed). The following equation was used for this calculation as recommended by ASHRAE and the resulting Fourier numbers are listed in Table 7.3.

$$Fo = \frac{4\alpha\tau}{d_b^2}$$

The Fourier numbers were then used to determine the G-Factors necessary for the thermal resistances. The G-Factors were obtained from the Fourier/G-Factor Graph for Ground Thermal

Resistance which was included in Appendix C-Figure C.2. The resulting G-Factors are listed in Table 7.3. The effective thermal resistance values of the ground were finally determined using the following equations and the resulting values are listed in Table 7.3.

$$R_{ga} = \frac{(G_f - G_1)}{k_g} \qquad R_{gm} = \frac{(G_1 - G_2)}{k_g} \qquad R_{gd} = \frac{G_2}{k_g}$$

Table 7.3 – Effective Thermal Resistance Values

Time Pulse	Fourier Number	G-Factor	Thermal Resistance [ft*h*°F/Btu]
Annual	7272.6	0.76	0.1167
Monthly	556.6	0.55	0.172
Peak Daily	4.6	0.24	0.133

Undisturbed Ground Temperature, t_g

This value was determined in the geology study. The average undisturbed ground temperature for Lititz, PA is 52°F.

Temperature Penalty for Interference of Adjacent Bores, t_p

The temperature penalty for interference of adjacent bores is used to mitigate long-term heat build-up for small separation distances. The further apart the boreholes are the lower the temperature penalty and the smaller the required loop length. For this analysis an initial separation distance of 20ft was selected and the ground temperature was used in conjunction with estimated equivalent full load heating and cooling hours. The temperature penalty was determined to be 1.8°F, which was found using Table 7 of Chapter 34 in the *2011 ASHRAE Handbook-HVAC Applications* and has been included in Appendix C-Figure C.3.

Liquid Temperature for Heat Pump, t_{wi} (inlet), t_{wo} (outlet)

It was difficult to determine the appropriate liquid temperatures at the heat pump inlet and outlet. As per the recommendations in the *2011 ASHRAE Handbook-HVAC Applications*, t_{wi} should be approximately 20-30°F higher than the temperature of the ground during the cooling design months and approximately 10-20°F lower than the temperature of the ground during the heating design months. This allows for a reasonable tradeoff between loop length increase due to having t_{wi} close to the temperature of the ground and the system operating efficiency. For the purposes of this analysis this recommendation was followed in conjunction with the Trane heat pump specifications. A change in temperature of 10°F was assumed across the source coil. The resulting temperatures used for this analysis are summarized in Table 7.4.

Table 7.4 – Liquid Temperature for Heat Pump (source side)

	$t_{wi,}$ °F	$t_{wo,}$ °F
Heating Design	35	45
Cooling Design	65	75

System Power Input at Design Load, W_c (cooling), W_h (heating)

The system power input at design load is the additional load of the pump used for the system at its maximum capacity. This was initially estimated to be 10,000 W for both the heating and cooling calculations because the pumping requirement was unknown. After the pumping input was determined and a pump was selected the input could have been adjusted to approximately 5,600 W for both heating and cooling. However, this had *very* little effect on the total loop size and instead of adjusting the piping layout, the original input remained.

7.4 Piping Layout

Surprisingly, the bore length calculation resulted in a heating dominant ground loop. The goal of this analysis is to size the ground loop to handle both the heating and cooling load so therefore the loop will be sized on the total length required for heating. As suggested by ASHRAE and due to the available land on the Linden Hall campus the boreholes were spaced at 20 ft on-center. To avoid balancing issues throughout the ground loop, a reverse return piping layout was chosen, meaning the total length of pipe is the same for each borehole. The following sections illustrate the ground loop layouts for Stengel Hall alone and for the entire campus.

7.4.1 – Stengel Hall Layout

Through the bore length calculation, it was determined that Stengel Hall needed about 25,000 feet of bore to handle the full heating load. As per an industry recommendation from Kirk Mescher, a borehole depth of 400ft was chosen and this resulted in 63 necessary boreholes.

Construction sensitive areas and existing pathways were avoided in the selection of the well-field location but it was important to keep the wells as close to Stengel Hall as possible. As seen in Figure 7.3, an open area of campus behind the dormitories was chosen for the boreholes. Note that piping in Figure 7.3 was enlarged for readability purposes and the layout carefully considered the property lines and existing structures.

Figure 7.3 | Stengel Hall borehole layout (image courtesy of bing.com; layout added)

7.4.2 – Campus Layout

In addition to the layout for Stengel Hall, it was determined that the total bore length necessary for the remainder of the campus was 83,800 feet. This means that in order to convert the rest of the campus into using geothermal energy, it would require an additional 210 boreholes at a depth of 400 ft. In order to reduce piping and pumping requirements the well-field was split into three smaller distribution sections.

As seen in Figure 7.4, one section is planned to serve the Library, Stengel Hall, and The Steinman Performing Arts Center and is comprised of 114 boreholes (necessary for the loads from these buildings). This section was chosen due to the route in which the piping takes in order to get the Stengel Hall and because Stengel Hall and The Steinman Performing Arts Center are connected. A second distribution loop serves The Annex, The Castle, Horne Dormitory, and Honeycutt Hall and is comprised of 104 boreholes (necessary for the loads from these buildings). This piping section enters the building at a central point in Horne Dormitory and can be distributed from this point. The last looping section has 59 boreholes and is separate from the rest because it was located closer to the load in which it serves; the Gymnasium.

Figure 7.4 | Linden Hall campus borehole layout (image courtesy of Bing.com; layout added)

Overall, the well-fields for both piping layouts took property lines, building clearances, and existing development into consideration. Although additional landscaping will be required after drilling, there is no need for drilling in recreational locations such as the equestrian riding facility, and the school's sports fields. One issue with the proposed layout is around the corner of the Library and Horne Dormitory. This area does not provide exact reverse return because it must maneuver around the building (campus layout) and irregular borehole loops (Stengel Hall layout). Additional balancing valves may be required for this distribution loop. Further discussion of costs associated with the installation and scheduling of the ground source loops is discussed in the Construction Management section of this report.

7.5 Equipment Selection

The following section explains the process followed for selecting equipment for the geothermal system. For the purposes of this analysis, equipment was only selected for Stengel Hall. The goal of this section is to determine the most efficient and maintainable equipment for the proposed ground loop.

7.5.1 – Head Loss Calculation

Since the piping layout is reverse return, each bore should have the same head loss. Therefore, for this analysis, the total head was only calculated for one borehole location and this was calculated in two different sections; the main header and the branch loop. The branch loop was assumed to be the same pipe diameter as the U-tube, 1-1/4", and the main header was assumed to have a constant diameter to reduce the total lost head. Based on the peak flow of the loop and while trying to keep the total lost head at a minimum, the main header was determined to have a diameter of 4". The following steps show the calculation for the total lost head using an equivalent length procedure from McQuiston's *Heating, Ventilating, and Air Conditioning-Analysis and Design* and the appropriate *ASHRAE Handbook-Fundamentals* charts.

Equivalent length of branch and borehole = 400 ft (downward leg of borehole)
400 ft (upward leg of borehole)
100 ft (longest branch length; 5 bores at 20ft O.C.)
14 ft (2-tee fitting, branch @ 7ft each)
+ 14 ft (4-90° elbows @ 3.5ft loss each)
Total = 928 ft

See Appendix C-Figure C.6 for sample fitting calculation

$$\text{Lost head for branch} = 928ft * \frac{0.5\,ft}{100\,ft} = 4.64\ ft$$

See Appendix C-Figure C.4 for obtaining loss due to friction value

The value for the lost head of the branch length was then added to the lost head of the main header. This was calculated by determining the head lost through each section of the loop because as the flow decreases and the pipe size remains constant the head loss per 100ft of pipe also decreases. Table 7.5 summarizes this calculation which results in a total head loss of 66.3 ft.

Therefore the pump will be sized for a head loss of 71ft and a capacity of 270 GPM. For the purposes of this assignment the head loss was only calculated for the Stengel Hall loop.

Table 7.5 – Lost Head for Main Header

Loop Section	Length [FT]	Flow Rate [GPM]	Head Loss [ft/100ft]	Fittings	Fitting Equivalent Length [ft]	Total Head Loss [ft]
Header	1290	270	4.1	(10) 90d Elbows	110	57.4
Branch 1	40	249	3.9	(2) Tee, through	14	2.1
Branch 2	40	228	3.2	(2) Tee, through	14	1.7
Branch 3	40	203	2.5	(2) Tee, through	14	1.4
Branch 4	40	178	2.2	(2) Tee, through	14	1.2
Branch 5	40	153	1.5	(2) Tee, through	14	0.8
Branch 6	40	147	1.4	(2) Tee, through	14	0.8
Branch 7	40	126	1	(2) Tee, through	14	0.5
Branch 8	40	105	0.8	(2) Tee, through	14	0.4
Branch 9	40	84	0	(2) Tee, through	14	0.0
Branch 10	40	63	0	(2) Tee, through	14	0.0
Branch 11	40	42	0	(2) Tee, through	14	0.0
Branch 12	40	21	0	(2) Tee, through	14	0.0
				TOTAL HEAD LOSS		66.3

7.5.2 – Pump Selection

The pump required for the Stengel Hall ground loop was selected based on the previous total head loss calculation and the peak flow of the loop. Bell & Gossett has published helpful pump selection figures for determining appropriate pump with optimum efficiency. A base-mounted centrifugal pump, as seen in Figure 7.5, was determined to be appropriate for the task of pumping water through the ground loop piping and to the heat pumps throughout the building. Figure C.7 of Appendix C was helpful in determining the recommended pump model number that would have the best performance. This diagram narrowed down the selection to three possible models, each having a different speed. The pump with the greatest efficiency was chosen resulting in a speed of 1,750rpm. This pump performance curve is included in Appendix C – Figure C.8. Table 7.6 outlines the key characteristics of the selected pump in a pump schedule. Two pumps would typically be specified for this application for redundancy. This will ensure that the school will not lose heating and cooling if a pump goes down and allows for regular maintenance.

Figure 7.5 | Base-mounted centrifugal pump (Image courtesy of Bell & Gossett)

Table 7.6 - Ground Source Pump Schedule

Equipment Tag	Manufacturer	Model No.	Flow [gpm]	Head [ft wc]	Impeller Diameter	Operating Efficiency	RPM	Motor		
								HP	Frame Type	Volt/Hz/Ph
GSWP-1	Bell & Gossett	Series 1510: 2-1/2 BB	270	71	9"	76.5%	1750	7.5	213T	460/60/3
GSWP-2	Bell & Gossett	Series 1510: 2-1/2 BB	270	71	9"	76.5%	1750	7.5	213T	460/60/3

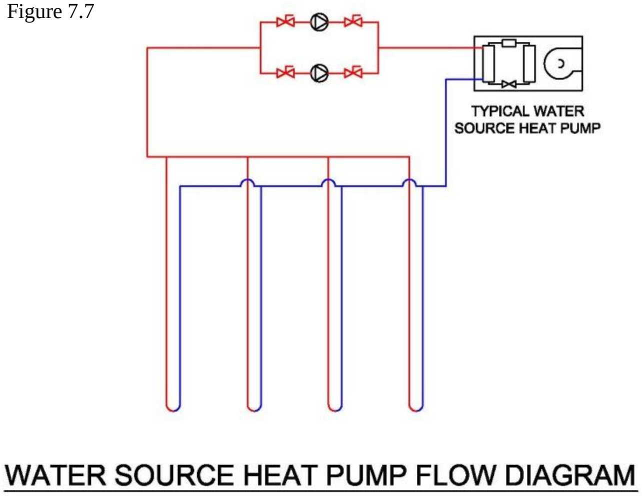
7.5.3 – Heat Pump Selection

The proposed system will require water-source heat pumps to replace the existing fan coil units. Although expensive, it is intended that each fan coil unit be replaced with a water source heat pump of the same nominal tonnage and total airflow rate. Trane manufactures such heat pumps ranging from ½ to 5 tons, that can be installed horizontally or vertically (see Figure 7.6) similar to the existing fan coil units designed for the space. Performance data for the specified heat pumps has been included in Appendix C – Figure C.9.

Figure 7.6 | Water Source Heat Pump (Image courtesy of Trane)

Figure 7.7 illustrates the flow diagram of the proposed ground source heat pump configuration. As previously stated, the ground source loop will eliminate the need for the condensing units and boilers from the existing mechanical system.

Figure 7.7



7.6 Energy & Emissions Comparison

An energy comparison was made using the Trane Trace model previously created for the existing mechanical system of Stengel Hall. Modeling the ground loop system began as a challenge but with the assistance of the Trace Tech Support team the proper adjustments were made for the integration of using the ground as the heat sink and heat source. Since, the capacity, loop size, and total head was already determined the ground source loop was set to handle the full heating and cooling load of Stengel Hall. Otherwise, Trace may have relied on backup energy consumption as a secondary source of heating and cooling.

Table 7.7 shows the energy consumption summary for the existing boilers and condensing units and the proposed ground source heat pumps. As expected the primary heating consumption for the heat pumps is solely electric use and the gas consumption was eliminated from Stengel Hall. The cooling energy consumption was slightly less than the heating consumption which reflects the previous findings of the ground loop being heating dominant.

However, the biggest and most influential load for ground source heat pumps is the pumping requirement. The pump selected for Stengel hall was 7 ½ hp and is assumed to be constant volume. ASHRAE Standard 90.1 requires that any pump over 10hp must have a variable flow, so it may not be uncommon to use a variable flow pump in this situation. However, for the purposes of this analysis a constant volume pump was selected. The pumping energy accounts for approximately 22% of the entire building energy consumption. This is to be expected considering the purpose and application of using a ground loop. One concern with this comparison is the calculated gas load for the boilers. This calculated load is approximately 16% more than the designed heating load, so making a direct comparison may not be the most accurate. However, once adjusted and converted to kBtu/yr the total building energy usage for the ground source heat pump application is approximately 42% lower than the existing mechanical system. (See below for calculations)

Table 7.7 - Energy Consumption Summary

	Electricity		Gas	
	kWh		kBtu	
	Boilers & Condensing Units	Ground Source Heat Pumps	Boilers & Condensing Units	Ground Source Heat Pumps
Heating				
Primary Heating	0	32,670	586,424	0
Other Heating Accessories	4,305	62	0	0
Cooling				
Cooling Compressor	39,706	28,963	0	0
Tower/Cond Fans	16,039	0	0	0
Other Heating Accessories	1,901	55	0	0
Auxiliary				
Supply Fans	25,192	24,877	0	0
Pumps	0	48,391	0	0
Totals				
Building Consumption	87,143 kWh/yr	134,963 kWh/yr	-	0
	297,332 kBtu/yr	460,681 kBtu/yr	586,424 kBtu/yr	

$$586{,}424 * (1 - 0.16) = 492{,}596\ kBtu/yr$$

$$492{,}596 + 297{,}332 = 789{,}928\ kBtu/yr$$

$$\frac{789{,}928 - 460{,}681}{789{,}928} * 100\% = 41.6\%$$

It was also interesting to compare the estimated monthly electric usage trends for the two systems. Figure 7.7 illustrates the calculated monthly electrical usage, and during the summer months the trends are very reflective of each other. Even though the geothermal electric use is slightly lower than the existing systems during these months, it was reassuring that the energy model was producing electrical loads with same trend during months of pure cooling. As expected the geothermal system has an increased electrical load during the winter months because during the heating season the existing mechanical design depends on gas fired boilers.

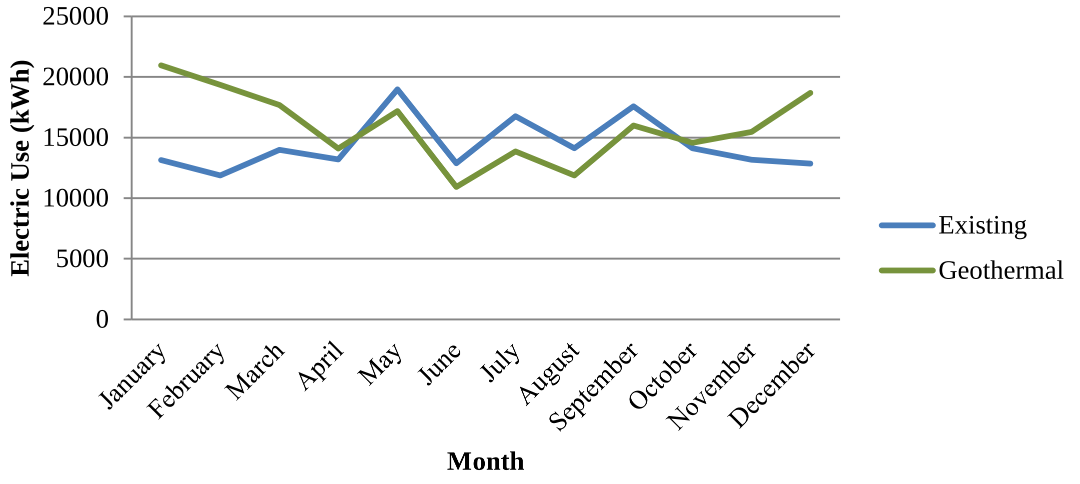


Figure 7.7 Monthly Estimated Electrical Comparison

Using the emissions rates previously determined for both the electric produced from PPL Power and natural gas, an emissions comparison between the proposed ground source heat pumps and the existing system. For the purposes of this calculation it was assumed the receptacle and lighting loads remained constant between the two systems and therefore were not included. Table 7.8 summarizes the emissions calculations and provides a percentage increase or decrease in pollutants based on the existing system.

Table 7.8 - Emissions Comparison

Pollutant	**Rate**		**Existing System**			**Geothermal (electric only) [lbs]**	Difference [%]
	Electric [lbs/MWh]	Gas [lbs/1000ft^3]	Electric [lbs]	Gas [lbs]	**Total [lbs]**		
NO_x	4.2	0.111	366	63.3	**429**	**567**	32%
SOx	1.2	0.000632	105	0.360	**105**	**162**	54%
CO_2	920	122	80,172	69,527	**149,699**	**124,166**	-17%

The added dependency on electricity actually decreased the CO_2 emissions but ended up increasing the amount of nitrogen oxides and sulfur dioxides released into the atmosphere. This is because natural gas emissions do not contain a large amount of NO_x and SO_x particulates.

7.7 Cost Comparison

The estimated cost of the proposed geothermal system was determined in the construction management breadth of this report and resulted in a total cost of about $465,080.00. This includes the cost of the ground loop piping, pumps, and water source heat pumps which are proposed to replace the fan coil units, boilers, and condensing units. Using RS Means Mechanical Cost Data the cost of these existing elements was estimated because detailed mechanical costs could not be obtained. The results are as follows:

- Fan Coil Units: $29,709
- Gas-Fired Boilers: $45,900
- Split System Condensers: $104,310

This resulted in an increase of about $285,080.00 to install the proposed geothermal system instead of the existing system. Using the energy information presented in the previous section and the utility rates previously defined, an annual utility cost savings of $5,764.39 was determined. This included an in electricity costs of $4,026.44 and decrease in gas costs by $9,790.83 annually.

To determine the payback period of the proposed geothermal system constant inflation rates were assumed. Although the electricity and gas market tend to be competitive with one another, an inflation rate of 2% was assumed for natural gas and an inflation rate of 1% was assumed for electricity. These are hypothetical values used for the purposes of comparison. Maintenance costs between the two systems were assumed to be very similar and were not included in this calculation. The simple payback period was then determined to be approximately **32 years** and this calculation can be found in Figure C.10 of Appendix C.

8.0 BIOMASS STUDY

Developing practical applications of renewable energy has been the focus of many engineers for decades. However, some of these technologies are proving to be a worthwhile investment. The objective of this study is to research the applications of biomass energy and evaluate the feasibility of implementing bioenergy technology into the Linden Hall campus. The goal of this analysis is to provide a sustainable, maintainable, and cost effective system. The following sections provide a summary of research findings, a recommended system, and expected energy use.

8.1 Biomass Energy Background

Defining "biomass" was the first step taken in the research for this analysis because the term seemed to have a broad meaning and swept over a range of fuel sources. Therefore, in this analysis, biomass is defined as a renewable organic material, typically plant matter, that can be converted into a source of heat or electricity. Most common forms of biomass are materials such as wood, grasses, and manure. The fuel sources will be discussed in more depth in the next section. As per the U.S. Energy Information Administration, biomass has come to be the dominant fuel source for renewable energy (see Figure 8.1).

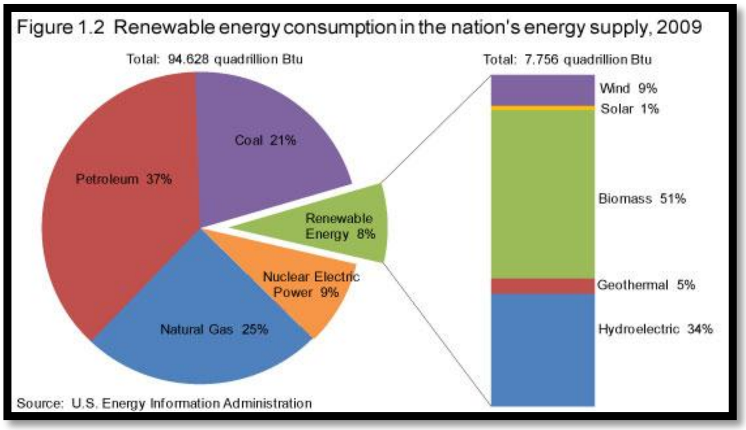


Figure 8.1 | Image courtesy of U.S. EIA

The most common form of converting biomass fuel to "biopower" is through direct burning. The burning of biomass can easily be used to produce hot water or steam power that can be used for heating applications. However, recent developments have found efficient was biomass can also be used to produce electricity. This process involves the turning of a turbine that in return produces electricity and there are a number of ways to achieve this.

The most common way of producing electricity with biomass is with direct combustion which again involves the production of steam but instead of heating is used to turn a turbine. However, this method is very wasteful and could lead to producing excess pollution. A more efficient way of producing electricity is through biomass gasification. This involves controlled heating of biomass and oxygen which can be used to produce a gas mixture of hydrogen and carbon monoxide. This gas can then be used to power a gas turbine for electricity. Lastly, an increasingly popular form of producing biopower is through anaerobic digestion. This process involves the use of an anaerobic digester to break down the biomass with micro-organisms to produce methane gas. The methane gas is then, once again, burned to produce heat and power.

Although there are many uses and applications for biomass fuels careful attention to must be paid to the impacts biomass use has on the environment. Although renewable many forms of biomass have the potential to harm ecosystems if harvested too quickly. Most states have existing forest management plans that protect the over-harvesting of woody biomass and perennial crops like switch grass will typically be fully harvested and replanted each season. However, there is still potential for over-harvesting any form of biomass if best management practices are not followed.

8.2 Fuel Selection

Selecting an appropriate type of biomass fuel is a critical step in determining the feasibility of implementing a biomass system. There are many factors that contribute to the selection of one fuel over another but, as you can imagine, the selection of fuel is driven by costs. The main contributor to cost is the availability of particular source. For instance, sugar cane stalks would not be a practical source of fuel for a biomass system in Lititz, PA because there is very little if any sugar cane grown in Pennsylvania. Likewise, animal waste would not be a practical source of fuel for an urban location because animal waste is not a typical product found in cities. The practical fuel sources considered for the Linden Hall School for Girls are:

- Switch grass (Figure 8.2)
- Manure
- Green wood chips (Figure 8.3)
- Kiln dried wood chips (Figure 8.4)
- Woody pellets (Figure 8.5)

Lititz is located in the heart of Lancaster County, an area known for its farming and agriculture. The Penn State Bioenergy Symposium on February 29,2012, provided helpful insight into the outlook for biomass crops and discussion from industry professionals aided in selecting an appropriate fuel. Switch grass, although a perennial, farmed crop, has not been popular with Lancaster County farmers because it must compete with food crops and in comparison is not advantageous. Woody pellets and kiln dried wood chips have about a 50% higher energy content than green wood chips but pellets are about four times more expensive and kiln dried wood chips are not commonly found in most areas of the United States.

Figure 8.2 | Image courtesy of Union of Concerned Scientists

Figure 8.3 | Image courtesy of Weaber Lumber

Figure 8.4 | Image courtesy of Weaber Lumber

Figure 8.5 | Image courtesy of Biomass Magazine

This leaves manure and green wood chips as potential fuels for a biomass system at Linden Hall. Weaber Lumber Inc., located in Lebanon, PA (about 17 miles from Lititz) is a major producer of hardwood lumber and sells the secondary hardwood products produced from the generated wood waste. Table 8.1 summarizes the costs associated with the delivery and production of Weaber Lumber wood chips. Additionally, Linden Hall has an extensive equestrian program on campus and currently pays an outside contractor to remove the horse waste. Estimates, summarized in Table 8.1, on the amount of waste produced and costs of removal were obtained from the maintenance staff at Linden Hall. Paul Lewandowski, from AFS Energy Solutions, a leading biomass boiler manufacturer located in central Pennsylvania, the equestrian waste can easily be mixed with green wood chips to produce an ideal fuel for the Linden Hall School.

Table 8.1 - Biomass Fuel Costs for Linden Hall

Biomass Fuel	Initial Cost [per Ton]	Cost of Delivery [per Ton]	Tons/ Delivery	Rental Dumpster Cost [per month]	Cost to Empty	Empties/ Month	Total Cost of Delivery/Removal
Green Wood Chips	$40.00	$10.00	25				$1,250.00 per delivery
Equestrian Waste				$1,100.00*	$865.00	3	$2,830.00 per month

*Includes emptying dumpster once

8.3 System Recommendation

8.3.1 – Case Studies

The selection of an appropriate biomass system was based on case studies and industry recommendations from Paul Lewandowski, a representative of AFS Energy Systems located in Lemoyne, PA (about 35 miles from Lititz, PA). AFS Energy Systems is a leading biomass systems manufacturer that designs, builds, and installs biomass boilers.

According to Lewandowski and other schools operating on biomass energy, combined heat and power is not a feasible alternative for small scale projects such as the Linden Hall School for Girls. Producing electricity, whether using direct combustion or anaerobic digestion, has very high initial costs due to the additional equipment and setup. This results in very long payback periods and is not always a worthwhile investment.

However, using a biomass boiler is not only sustainable but can lead to cost savings over time. Bennington College located in Bennington, VT discovered the benefits of utilizing a wood-fired boiler system after deciding to reduce the college's dependency on #4 oil. Originally, the school was solely interested in "going green" and implementing a sustainable form heating. However, after AFS Energy Systems installed the 400 horsepower wood-fired boiler the school noticed immediate results which combated to rising oil costs.

Likewise, many Pennsylvania school districts have begun implementing wood-fired boilers. Most notably, Sullivan County Schools recently installed a biomass boiler system that reduces

Sullivan County’s dependence on imported oil by over 50,000 gallons of fuel annually, as per the press release on AFS Energy Systems’ website. Penns Valley School District has also recently implemented a biomass boiler system to provide steam heating to the district’s elementary and intermediate school. This system is expected to reduce the district’s oil use by over 60,000 gallons per year (Mahon). However, both Penns Valley and Sullivan County schools were eligible to receive grants to offset the high initial costs of their biomass systems. It is assumed that because Linden Hall is a private institution they will not have the same advantage.

8.3.2 – System Selection

The system that was recommended and selected for the Linden Hall School for Girls is a 100 boiler-horsepower wood-fired boiler. An elevation of this system can be seen in Figure 8.6 and the specification sheet is included in Appendix D – Figure D.1. This system will be able to provide low pressure (15 psig) steam to the entire Linden Hall campus. A biomass boiler for only Stengel Hall was not a cost effective investment and was not analyzed in this analysis.

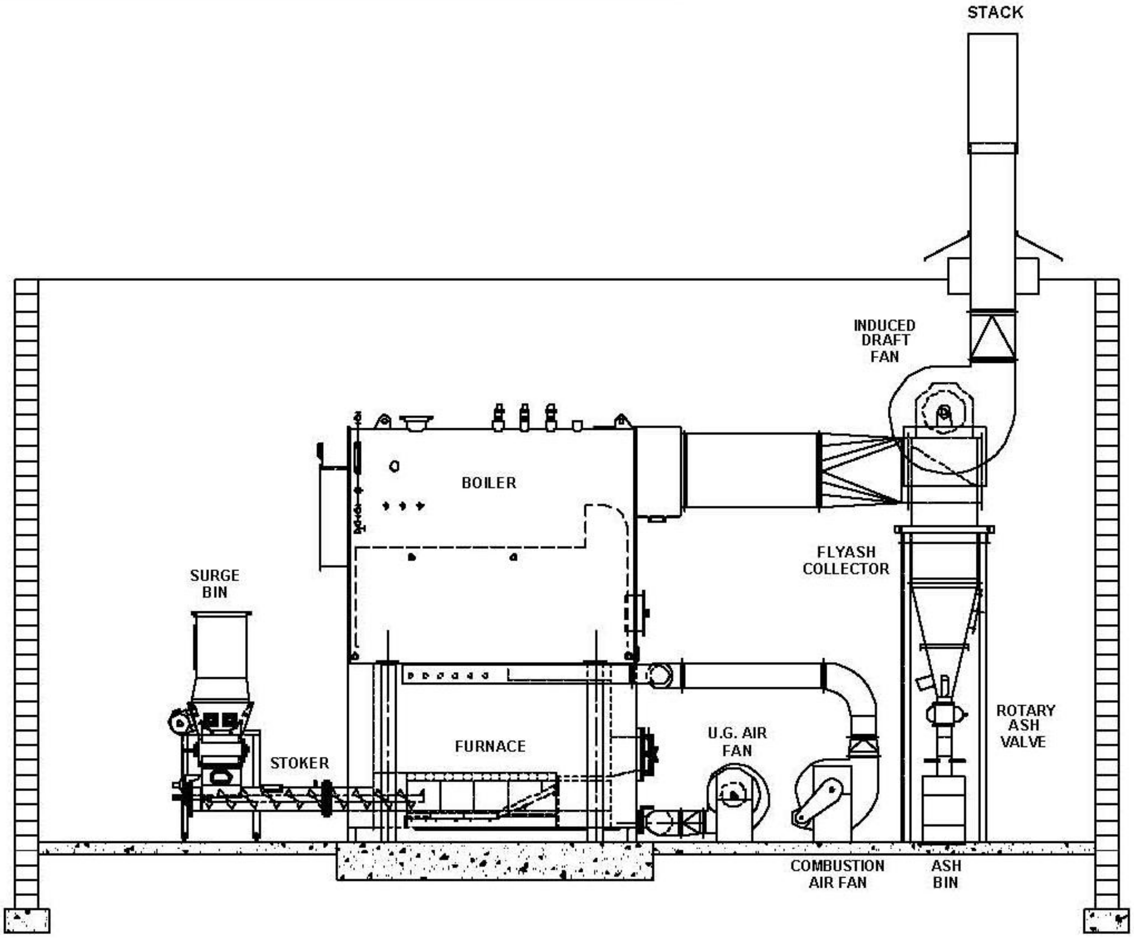


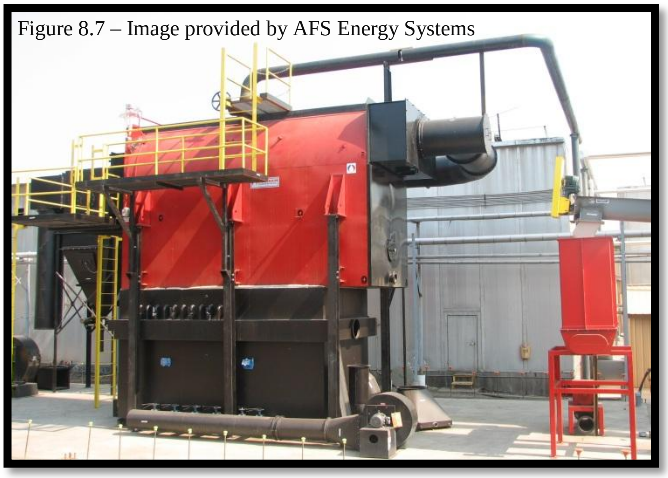
Figure 8.6 – Image provided by AFS Energy Systems

This setup includes a self-feeding bin which limits the attention required by the maintenance staff. A fly-ash collector is also included as an element of this system to collect the ashes from the burnt wood and manure. This filter reduces the emissions released into the atmosphere but needs to be emptied about once a week. Further information on emissions will be discussed in the conclusion of this report.

8.3.3 – Mechanical Room Layout

The selected type of boiler can encompass a very large space as seen in Figure 8.7. However, the 100 horsepower system is much smaller than the one photographed here and can fit indoors. The basement of the Steinman Performing Arts Center houses the existing steam boilers and is large enough to house this system. However, the location is not convenient because there is not an area for the delivery and storage of fuel. In addition, the school has previously stated that having a large boiler system within a classroom facility is not ideal for safety purposes. So, a separate structure, as seen in Figure 8, to house the biomass boiler and fuel is necessary. Since, the Linden Hall campus is within a historic zoning district a separate structure may be scrutinized if it is located near the historic section of campus. So, the suggested location for this structure is between the existing maintenance shed and equestrian facility as seen in Figure 8.9. This location has a separate entrance that prevents large vehicles from driving through the main part of campus. It is also in close proximity to the equestrian facility so the waste being used as fuel will not need to be transported very far.

Figure 8.7 – Image provided by AFS Energy Systems



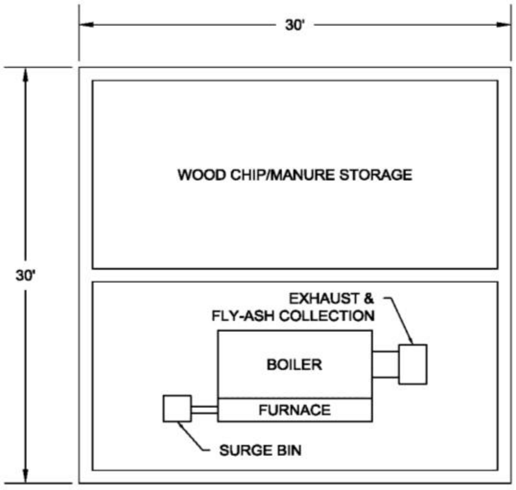


Figure 8.8 - Proposed Boiler Building

Figure 8.9 – Image from Bing.com

8.3.4 – Flow Diagram

The flow diagram, included in Appendix D-Figure D.1, for the new biomass boiler system changes very little from the existing hydronic system because it simply replaces the existing boilers with new. However, the proposed biomass boiler will serve all of the campus building instead of only Stengel Hall. The flow diagram shows the proposed cooling system for Stengel Hall to remain, and the replacement of the four existing boilers with a wood fired boiler system.

8.4 Energy & Cost Analysis

It is assumed that the proposed system will simply update and expand the existing steam system and the demand loads will remain constant. Since the type of fuel is the biggest change from the existing system, the efficiency of the fuel will need to be taken into account. The specification sheet for the low pressure boiler suggests that the boiler will use 1,054 pounds of wood chips per hour. This is assuming that the wood chips have a moisture content of 50%. As per industry suggestions, the wood chips provided by Weaber Lumber Inc. can be assumed to have a moisture content of closer to 30% and have an energy content of 4,692 BTU/lb. Unfortunately, there is not any existing data to make a direct comparison. So, for the purposes of this comparison a hypothetical boiler of equal size will be used to represent the existing system

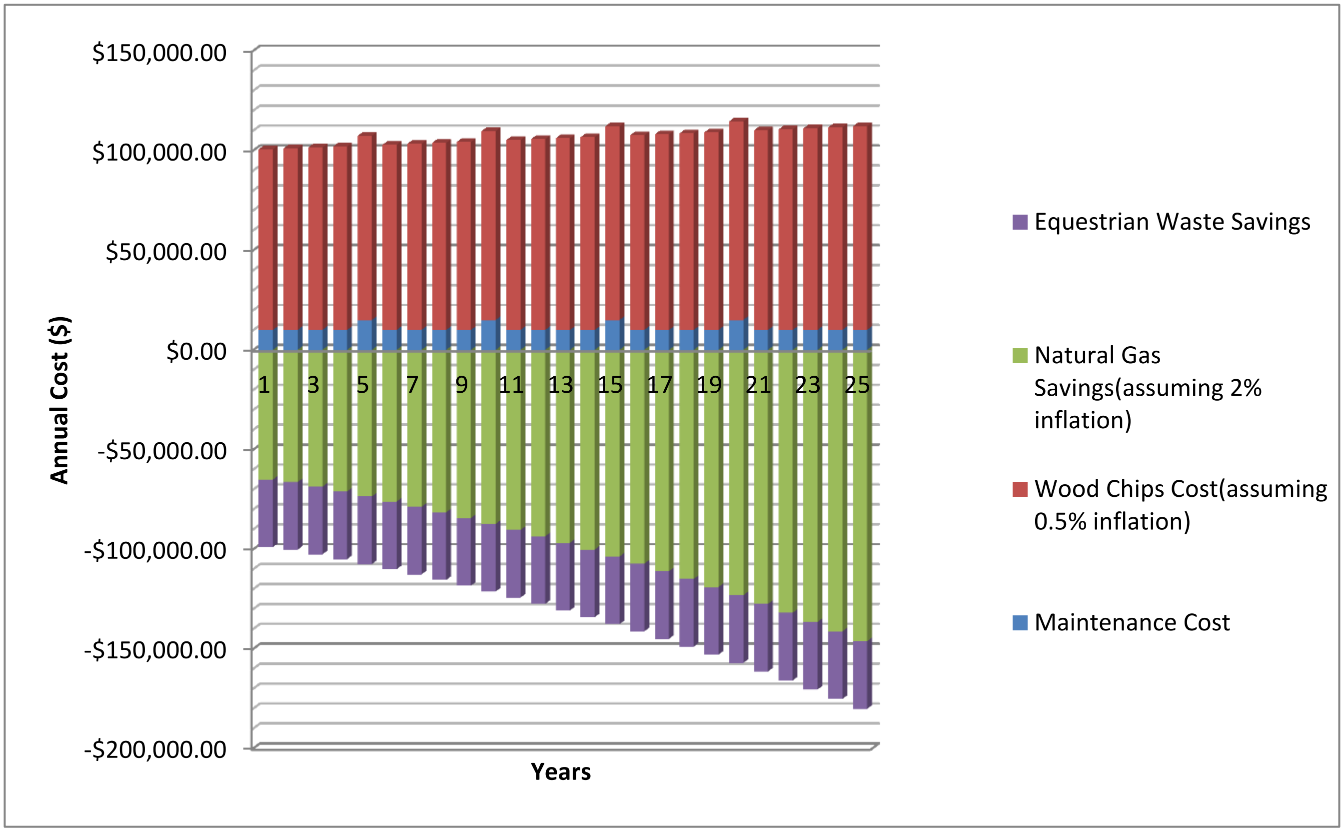
To compare the efficiencies in energy, an energy cost calculator (provided by AFS Energy Systems) was used. A screenshot of the comparison was included in Appendix D – Figure D.3. The results show that there will be an increase in cost of about $25,572 per year by switching to green wood residue from natural gas. For the purposes of this calculation, the use of equestrian waste was not included in this analysis because the manure is being mixed with the wood chips and does not produce as many BTU/lb. It is assumed that the manure will lessen the required amount of wood chips but this amount was not determined. Therefore, the suggested annual cost of primary fuel is the worst case scenario and the cost savings associated with the equestrian waste will only be analyzed in the life cycle costs.

The energy cost calculator determined that initially the use of wood chips is more expensive than natural gas but the calculator does not account for the changes in fuel prices over the life of the boiler. Historically, wood fuel is much more stable than natural gas and the costs do not fluctuate as much. For the purposes of this analysis a steady inflation rate will be used for both wood fuel and natural gas to determine the possible cost savings over time.

The life-cycle costs of the proposed boiler were evaluated over a span of 25 years. Figure 8.10 illustrates the increase in the annual cost of wood chips at an inflation rate of 0.5% and annual natural gas costs increasing (which is offsetting the cost of wood chips) at an assumed inflation rate of 2.0%. This figure also includes an annual savings of $33,960 ($2,830.00/month) from eliminating the costs of equestrian waste removal. Rough maintenance costs of $10,000/year with an additional $5,000 every 5 years were also included for the purposes of this calculation to address the cost of maintain the boiler each year.

You can see that the annual savings in equestrian waste removal and natural gas cost quickly surpasses the maintenance and wood chip costs. In the construction management section found later in this report an initial cost of $2,858,888.94 was estimated for the proposed system. Using this initial estimate and the annual cost savings over time found in Figure 8.10 a simple payback calculation was conducted. The results of this calculation, found in Appendix D-Figure D.4, determined that the initial costs of the wood-fired boiler system would be much greater than the eventual energy savings and would not prove to be a cost effective alternative.

Figure 8.10 – Annual Costs/Savings



8.5 Emissions

To fully evaluate the wood-fired boiler system it is important to evaluate the emissions it produces. The direct air emissions for a wood-fired boiler were determined from the Union of Concerned Scientists and have been included in Appendix D-Figure D.5. Table 8.11 calculates the pounds of wood residue emissions from the proposed 100Bhp estimated to be in operation for 3,300 equivalent full-load hours per year (3,237.6 MWh/yr). This is compared to a natural gas boiler of equivalent size (10,735.42 kcf/yr). You can see there is a significant increase in NO_x and SO_x particulates but a decrease in carbon emissions. However, it is important to note that these emissions rates given are without any filtration system and the proposed AFS Energy boiler is installed with a particulate filter. It is assumed that the fly-ash collector specified for this setup will eliminate a large majority of the harmful emissions but this value was not determined for this report.

Table 8.2 - Emissions Comparison

Pollutant	**Rate**		Gas Emissions [lbs/yr]	Wood Boiler [lbs/yr]	**Difference [%]**
	Natural Gas [lbs/1000ft^3]	Wood Fuel [lbs/MWh]			
NO_x	0.111	2.1	1192	6799	**471 %**
SOx	0.000632	0.008	7	26	**282 %**
CO_2	122	12.2	1,309,721	39,499	**-96.98 %**

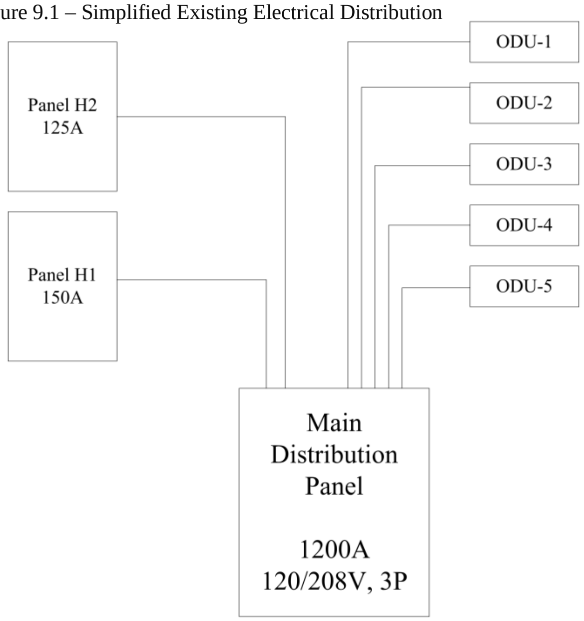
9.0 ELECTRICAL BREADTH

The following section includes two very different studies. The first study evaluates the existing electrical system of Stengel Hall to determine if the equipment selected for the proposed geothermal system will be able to operate on the existing panelboards. The second study explores the electrical rates set by PPL Electric and determines if it is possible to reduce the number of service entrances on the Linden Hall campus.

9.1 Increased Load Due to Ground Source Heat Pumps

When equipment changes are made within a building, it is important to be sure the electrical supply is sufficient for the new equipment. The proposed biomass boiler has little effect on the existing electrical systems within the classroom buildings, except that it will eliminate any electric heat that may exist. However, this does not require any panelboards to be resized and therefore is not analyzed in this report. The focus of this study is on the equipment selected for the geothermal heating and cooling of Stengel Hall.

Figure 9.1 – Simplified Existing Electrical Distribution



Recall that the existing electric condensing units were removed from the design and all fan coil units are replaced with water source heat pumps. Figure 9.1 is a simplified electrical diagram of the existing power supply to the relevant mechanical equipment. The outdoor condensing units are supplied power directly from the Main Distribution Panel and Panel H1 and H2 are both designated for mechanical equipment only. The ground source heat pumps selected for the proposed system have a minimum circuit ampacity much higher than the fan coil units. Table 9.1 and Table 9.2 summarize the quantity of units at a given tonnage and the minimum circuit ampacity for each size unit. The minimum circuit ampacity for the fan coil units was determined from an equipment submittal and the ampacity for the water source heat pumps was determined from the manufacturer's data (included in Appendix E-Figure E.1).

From these values we can find the increase in demand due to the added ampacity for the ground source heat pumps. In addition to the changes in ampacity between the terminal units, two 7 ½ horsepower pumps will be added to the main distribution and the condensing units will be eliminated, as seen in Figure 9.2. The five condensing units have a total ampacity of 796A (taken from panelboard information) and the two pumps have a total ampacity of 61A.

Table 9.1 - Panel H1

Quantity	Nominal Tonnage	Minimum Circuit Ampacity	
		Fan Coil	GSHP
1	1.5	3.88	12.9
2	2	3.88	18.1
1	2.5	4.5	19.73
2	3	4.5	24.48
1	4	4.5	29.55
1	4.5	4.5	45.81
1	5	4.5	45.81
TOTAL		39	239
DIFFERENCE		200	Amps

Table 9.2 - Panel H2

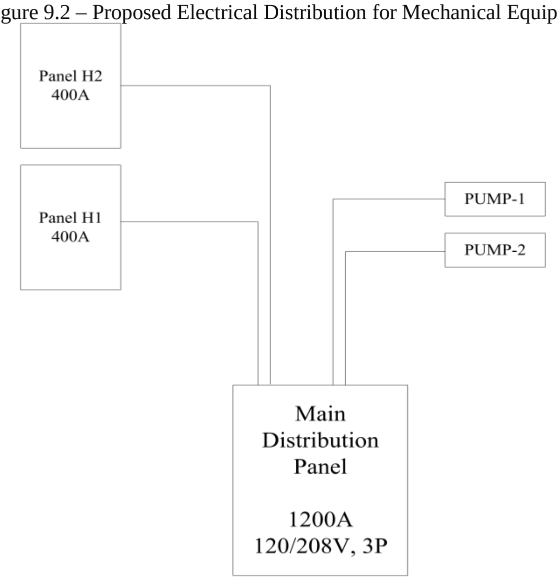
Quantity	Nominal Tonnage	Minimum Circuit Ampacity	
		Fan Coil	GSHP
3	1.5	3.88	12.9
8	2	3.88	18.1
1	3	4.5	24.48
2	4.5	4.5	45.81
TOTAL		56	300
DIFFERENCE		243	Amps

Due to the added ampacity from the heat pumps, it is suggested that Panel H2 and H1 both be increased to 400A panels, also seen in Figure 9.2, to fully handle the load. The following calculation verifies the Main Distribution Panel will be able to handle the increase in panel size:

$$\begin{aligned} &796A\ reduction\ from\ ODU's \\ &\qquad - 61A\ pumping\ requirement \\ &\qquad - 525A\ increase\ in\ panel\ size \\ &\qquad = 210A\ still\ available \end{aligned}$$

In conclusion, although there is a greater load from the heat pumps, overall equipment is reduced in Stengel Hall and this does not require the school to increase their electrical demand.

Figure 9.2 – Proposed Electrical Distribution for Mechanical Equipment



9.2 Exploration of Electric Rates

Currently, the Linden Hall School for Girls has five main service entrances and plans for an additional entrance to provide additional electricity to Stengel Hall. These service entrances are at a secondary voltage and are stepped down by PPL Electric before entering the Linden Hall campus. The goal of this study is to determine if having fewer service entrances would affect the electric rate for Linden Hall.

According to the rates and tariffs section of the PPL Electric Utilities Corporation's website, there are few available rate schedules available for general customers like the Linden Hall School for Girls. It is assumed that the school currently falls under Rate Schedule GS-3. This is large (>25kW demand/month) general service at secondary voltage and the net monthly rate is outlined below.

Distribution Charge: $30.00 per month (customer charge) plus
$4.510 per kilowatt for all kilowatts of the Billing KW

Since Linden Hall now has six service entrances they have a total distribution charge of $180.00 per month. If a primary voltage is available in the vicinity of the campus, Linden Hall could be supplied service at 12,470 Volts (3-phase) and be classified under Rate Schedule LP-4. This rate schedule is outlined as follows:

Distribution Charge: $160.19 per month (customer charge) plus
$2.136 per kilowatt for all kilowatts of the Billing KW

Under this rate schedule the customer must "furnish and maintain all equipment necessary to transform the energy from line voltage." This would require Linden Hall to add a transformer to their campus but they could reduce the number of service entrances from six to one. After the voltage is transformed to a secondary voltage it can then be distributed to each of the buildings as it was before. This would reduce the total distribution charge by about $20.00/month and cut the kilowatt rate in half. It is not known whether a supply of primary voltage is available but for the purposes of this investigation it was assumed obtainable.

10.0 CONSTRUCTION MANAGEMENT BREADTH

Both of the proposed mechanical systems will change the costs associated with the mechanical system of Stengel Hall and the entire Linden Hall campus. The following section explores the expected initial costs associated with the geothermal system and the biomass boiler. In addition, since the current construction and main focus on this project is Stengel Hall, the construction schedule impacts of the geothermal system are acknowledged in this analysis.

10.1 Geothermal System Estimate & Scheduling

The ground loop piping for the proposed geothermal system introduces several unique costs to the overall mechanical system. Since Stengel Hall is the primary focus of this report, an estimate of the major components required for the Stengel Hall geothermal system was conducted for this analysis. RS Means Mechanical Cost Data was the primary source of estimates but recommendations from industry professionals were used as well.

The majority of the quantities used in this estimate are take-offs directly from the loop piping layout and equipment selected for Stengel Hall. However, borehole and trench volume needed to be calculated, see below, in order to determine the amount of sand and bentonite required. Recall that the grout specified contained 15% bentonite and 85% sand. In addition to the borehole volume, an estimation for sand to be included in the bedding of the header trenches was also included.

$$Total\ Borehole\ Volume = \pi * (3/12)^2 * 400\frac{ft}{bore} * 63\ bores = 4{,}948\ ft^3$$

$$Total\ bentonite = 4{,}948\ ft^3 * \ 0.15 = 742.2\ ft^3\ @\ 0.625\frac{ft^3}{bag} = 1188\ bags$$

$$Sand\ required\ for\ boreholes = 4{,}948ft^3 * 0.85 = \frac{4205.8\ ft^3}{\frac{27ft^3}{yd^3}} = \ 156\ yd^3$$

$$Sand\ required\ for\ trenches = \left(\frac{8"}{12"} - \pi * \left(\frac{4"}{12"}\right)^2\right) * 1' * 3{,}518' = \frac{480.7\ ft^3}{\frac{27ft^3}{yd^3}} = \ 18\ yd^3$$

A summary of the estimated initial costs are included in Appendix F-Figure F.1. As expected, the largest costs are from the borehole drilling and water source heat pumps. Both of the costs for these items came from recommendations from industry professionals. Kirk Mescher, from CM Engineering, provided information on the typical costs of drilling and expected the cost per linear foot to be around $6.50 for the location of the building. The water source heat pump was estimated on a per ton basis and this information was provided by Trane Sales Representative, Wade McCorkel. The cost per ton was based on the sale of other water source heat pumps of similar size and quantity on two different projects. The overall cost of the proposed geothermal system for Stengel Hall is about **$465,080.00**.

The most labor intensive part of the proposed geothermal system is expected to be the drilling and piping of the ground loop. The construction schedule for Stengel Hall has all excavation on initial sitework scheduled during the summer months when students are not typically on campus. It is my recommendation that the drilling and trenching required for the ground loop piping should also occur during this time. This will ensure that any equipment already on site for demolition will be efficiently utilized and also address safety concerns associated with the students' proximity to the well field.

10.2 Biomass System Estimate

Recall that the wood-fired biomass boiler proposed is sized to meet the needs of the entire Linden Hall campus. This is because it was very quickly recommended by industry professional Paul Lewandowski that a boiler sized only for Stengel Hall would not be cost effective. Therefore this section explores the estimated initial costs of the campus-wide biomass boiler and does not address the construction schedule of Stengel Hall.

A variety of sources were used in determining the initial costs associated with the installation of a biomass boiler for Linden Hall. The facilities study of the Linden Hall campus included the estimated costs and building areas associated with repairing the existing steam system (see Table 10.1). This steam system was in much need of updating and it was assumed that the estimate of $22.00 per square foot for repairs could also be applied to new piping required in Honeycutt Hall and Library. The gymnasium was not included in the estimate for steam piping because it was recently constructed and was assumed the existing piping would suffice.

Table 10.1 - Repairs & New Installation* of Steam Piping

Building	Total Repair/ Installation Area	Cost/SF	Cost
Stengel Hall	39,000	$22.00	$ 858,000.00
Steinman Performing Arts Center	20,600	$22.00	$ 453,200.00
The Castle & The Annex	24,395	$22.00	$ 536,690.00
Library*	3,500	$22.00	$ 77,000.00
Honeycutt Hall*	12,500	$22.00	$ 275,000.00
*new steam piping		**Total**	**$ 2,199,890.00**

In addition to the facilities study, 2011 RS Means Square Foot Costs were used to estimate the cost of building an additional structure to support the proposed boiler and wood-chip storage. The cost per square foot for the proposed building was compared to the cost per square foot of a small warehouse because of the simplicity in the building envelope. However, the added costs of interior finishes, HVAC, plumbing, and electrical systems were subtracted from the total building cost because it is assumed that any necessary elements of these systems are included in the cost of installation of the boiler system. This left the substructure, shell, fire protection, contractor fees, and architect fees as part of the total cost per square foot. A location factor of 0.918 was used to correct the total cost of material and installation for this structure. The RS

Means data used is included in Appendix F – Figure F.2 and the calculation for initial costs is outlined below.

Concrete Block (Concrete Frame) = 149.25 $/SF for exterior wall perimeters of 220 L.F.
- 18.70 $/100 L.F. (because the 30'x30' building proposed only has a perimeter of 120')
- 22.9% (Interiors)
- 10.2% (HVAC)
- 1.8% (Plumbing)
-10.4% (Electrical)
= $71.41/SF

$$\frac{\$71.41}{SF} * 30'x30' = \$64{,}269 * 0.918\ (location) = \$\mathbf{58,998.94}$$

The cost of the wood-fired boiler system was determined from manufacturer's suggestions for boiler systems of equal size. Therefore, the total initial cost of the biomass boiler system for the Linden Hall School for Girls is estimated to be $2.86 million as per calculation below.

$$\$2{,}199{,}890.00\ (steam\ repairs\ and\ piping) + \$58{,}998.94\ (boiler\ building) + \$600{,}000\ (manufacturer\ recommended\ cost\ of\ all\ boiler\ components) = \$\mathbf{2,858,888.94}$$

For the purposes of this analysis, this cost assumed accurate. The biomass boiler recently installed for the Penns Valley School District had an initial cost of approximately $2.7 million and also included updates for steam piping, and an additional structure to house the boiler and fuel.

11.0 CONCLUSION

The studies included in this report intended to investigate sustainable alternatives for the mechanical system Stengel Hall and research the feasibility of a campus-wide heating and cooling system. With respect to Stengel Hall, the main focus of this project, the ground source heat pump option would provide a much more sustainable approach to heating and cooling. The proposed system has a building energy reduction of nearly 500,000 kBtu annually. However this only resulted in an annual cost savings of just over $5,700. With the higher initial cost of the system this option proved to have an extremely long payback period. However, the heating and cooling systems of the remainder of the campus buildings vary in type and efficiency and the proposed ground loop layout could prove to be an effective way to provide heating and cooling the entire campus. Exact values on the payback and costs associated with implementing geothermal energy to the entire campus were not evaluated due to limited information on the other buildings.

The second alternative explored in this study was a wood-fired boiler that would provide low-pressure steam to the entire Linden Hall School for Girls Campus. The entire campus was the main focus of this study because a biomass boiler would not be cost effective if only providing heat to Stengel Hall. This option resulted in an energy savings over time when compared to a natural gas boiler of equal size. Although the heating systems of the buildings vary, a direct comparison was made to a natural gas boiler for simplicity purposes of this study. The wood-fired boiler system did not see a feasible payback period when compared to natural gas but the emissions from this alternative proved to be the lowest on a lb/sf basis. Table 11.1 summarizes the emissions of the three systems evaluated in this report.

Table 11.1 – Emissions Comparison

		System Emissions [lbs/sf]		
SYSTEM:		**Existing**	**Ground Source Heat Pump**	**Wood-Fired Boiler**
AREA:		**39,000**	**39,000**	**144,275**
Pollutant	**NO_x**	0.011	0.0145	0.047
	SOx	0.0027	0.0042	0.00018
	CO_2	3.84	3.18	0.274

Either alternative proposed would provide a more sustainable and maintainable system for the school. In addition, the costs of either proposed system could be offset by state grants and tax incentives not explored in this study. There is also an added educational value associated with either system that surely cannot be quantified as a cost benefit. From the two alternatives evaluated, a geothermal system for Stengel Hall would be recommended for the Linden Hall School for Girls.

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Figure A.1 – Existing Air Side Flow Diagram

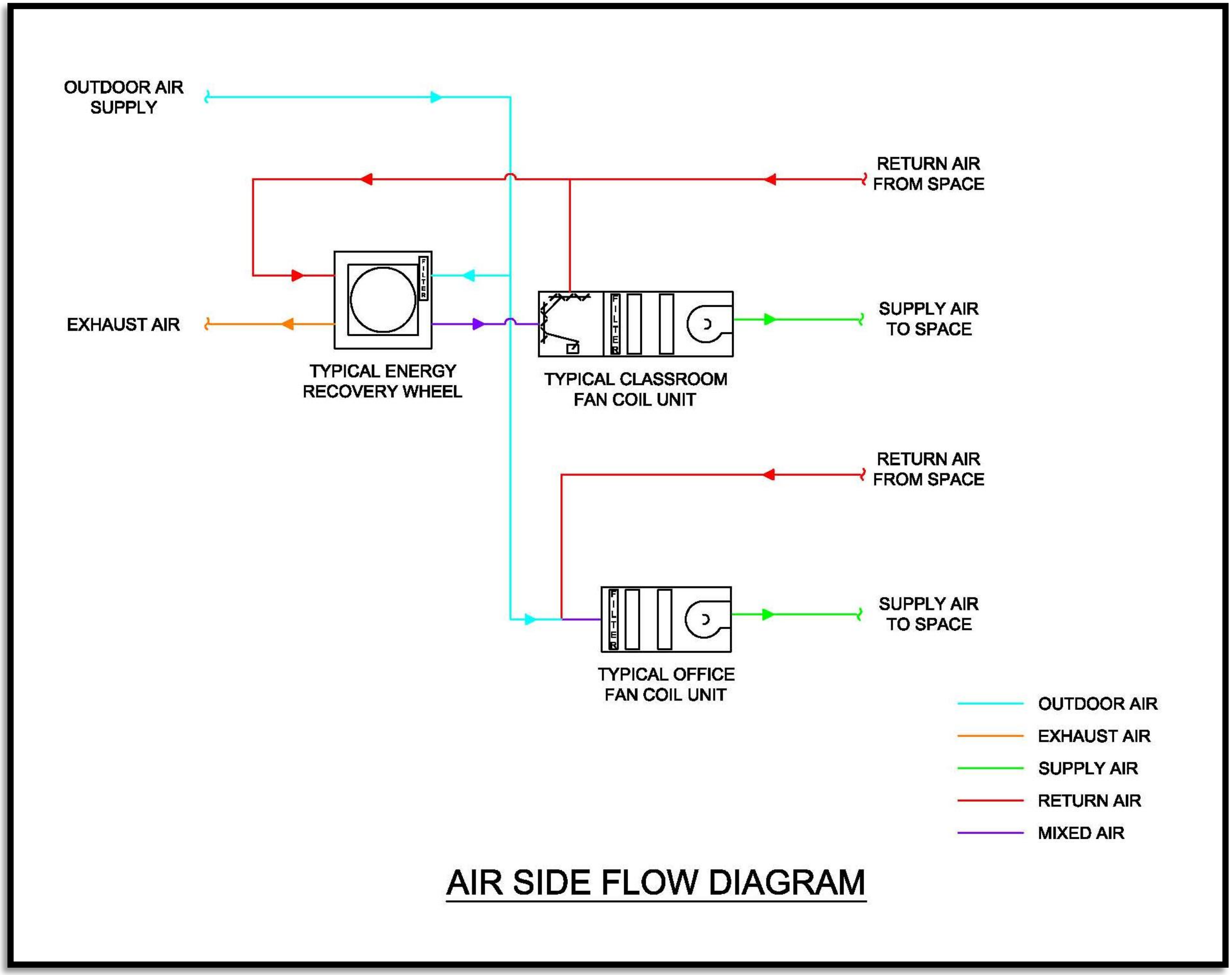


Figure A.2 – Existing Air Side Flow Diagram

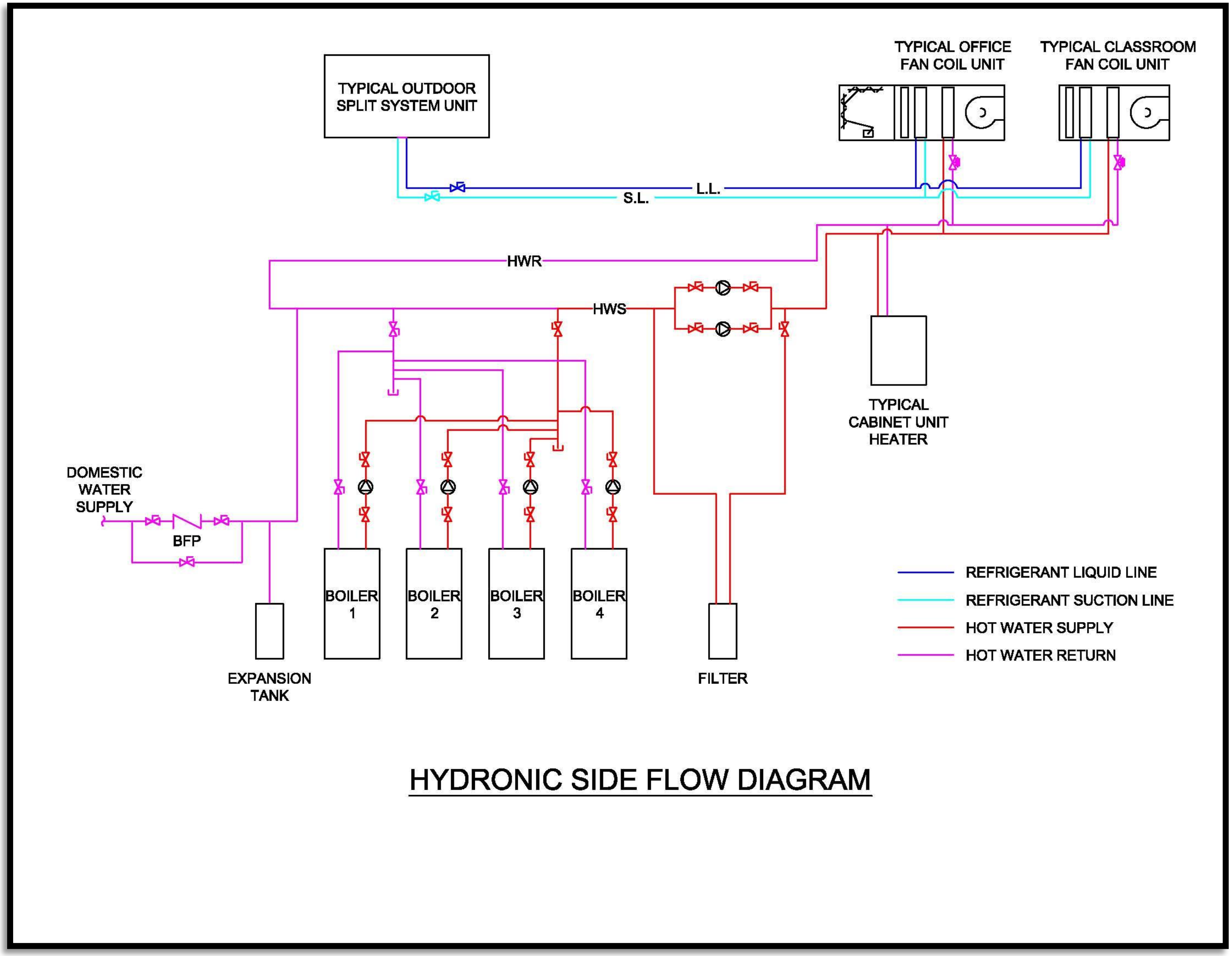


TABLE A.2 – Internal Load Summary					
Room #	**Room Name**	**Occupancy [People]**	**Lighting Load [watts]**	**Lighting Load [W/SF]**	**Additional Equipment Loads**
BASEMENT					
1	Corridor		260	0.67	
2	Corridor		130	0.58	
3	Testing/Lecture	65	1228	0.94	Smartboard, Netbooks
3A	Storage		64	0.85	
4	Elev. Equipment		64	1.07	Equipment (400W)
5	Elev. Lobby		186	0.87	
6	Corridor		130	0.47	
7	Day Lounge	35	962	0.70	Netbooks
8	E. Mech/Elec		256	0.34	Equipment (10W/sf)
9	Unisex R. Rm.	1	64	1.23	
10	Unisex R. Rm.	1	64	1.23	
11	Mech/Boiler/Elec	4	576	0.60	Equipment (10W/sf)
12	Mech/Elec	2	384	0.65	Equipment (10W/sf)
FIRST LEVEL					
101	North Entry		150	0.60	
102	Centre Lobby	19	937	1.31	
103	Receptionist	1	502	4.33	Computer
104	South Entry		153	0.79	
105	Corridor		312	0.64	
106	Vestibule		104	0.46	
107	Cot	1	128	1.66	
107A	Toilet	1	64	1.07	
108	Work Room	1	134	0.91	Netbooks
109	Faculty Work Room	4	320	1.24	Computer (.5 wst/pers)
110	Faculty	4	268	1.06	Computer (.5 wst/pers), Refrigerator
111	Men	2	160	1.19	
112	Women	2	160	1.16	
113	Conference	4	108	1.15	Netbooks
114	Passage		78	0.62	
115	Display	2	550	5.85	
116	Corridor		208	0.99	
117	Corridor		234	0.66	
118	Administrative Assistant	4	324	1.16	Computer (.25 wrk/pers)
119	Director of Admissions	1	216	0.86	Computer
120	Asst. Director of Admissions	1	108	0.72	Computer
121	Manager	1	216	1.34	
122	Janitor		64	1.36	

TABLE A.2 – Internal Load Summary, *continued*

Room #	Room Name	Occupancy [People]	Lighting Load [watts]	Lighting Load [W/SF]	Additional Equipment Loads
123	Mechanical		64	1.73	Equipment (10W/sf)
124	Corridor		108	0.78	
126	Advancement Office	1	216	1.03	Computer
127	Director of Advancement	1	216	0.84	Computer
128	Existing Passage		200	0.98	
129	Business Manager	1	216	1.01	Computer
130	Business Assistant	1	216	0.97	Computer
131	Existing Passage		200	0.74	
132	Conference	5	216	0.86	Computer @ .75 workstation/person
133	Mechanical/Storage	1	128	0.75	
134	Existing Entry		100	0.60	
135	Headmaster	1	696	1.99	Computer
136	Board Room	32	502	0.70	Laptops @ .5 workstations/person
137	Existing Passage		456	1.41	Refrigerator
SECOND LEVEL					
201	Classroom	23	648	1.03	Netbooks, Smartboard
202	Learning Center	20	740	1.03	(4) Computer Stations
203	Conference	12	212	0.98	Netbooks @ .75 workstations/person
204	Learning center	21	432	0.87	(2) Computer Stations
205	Conference	5	108	1.00	Netbooks @ .75 workstations/person
206	Work Room	1	160	1.88	Computer Station @ 50W
207	Library Office Work Room	1	366	2.44	
208	Bookshelves	6	856	1.80	Smartboard, Refrigerator
209	Passage		156	0.54	
210	Toilet	1	64	1.21	
211	Passage		128	0.56	
212	Toilet	1	64	1.21	
213	College Counseling	4	160	0.95	(2) Computer Stations
214	Office	1	108	0.98	Computer
215	Office	1	108	0.98	Computer
216	Corridor		156	0.78	
217	Classroom	16	428	0.99	Netbooks, Smartboard
218	Corridor		130	0.77	
219	Academic Dean	1	268	1.07	Computer
220	Corridor		182	0.65	
221	Assistant	1	216	1.15	Computer
222	Tech Office/Server	2	216	1.19	Server (25W/sf)
223	Computer Lab	8	324	0.94	Computer
224	Assistant Head	1	216	1.40	Computer
225	Conference	6	216	1.17	Netbooks @ .75 workstations/person

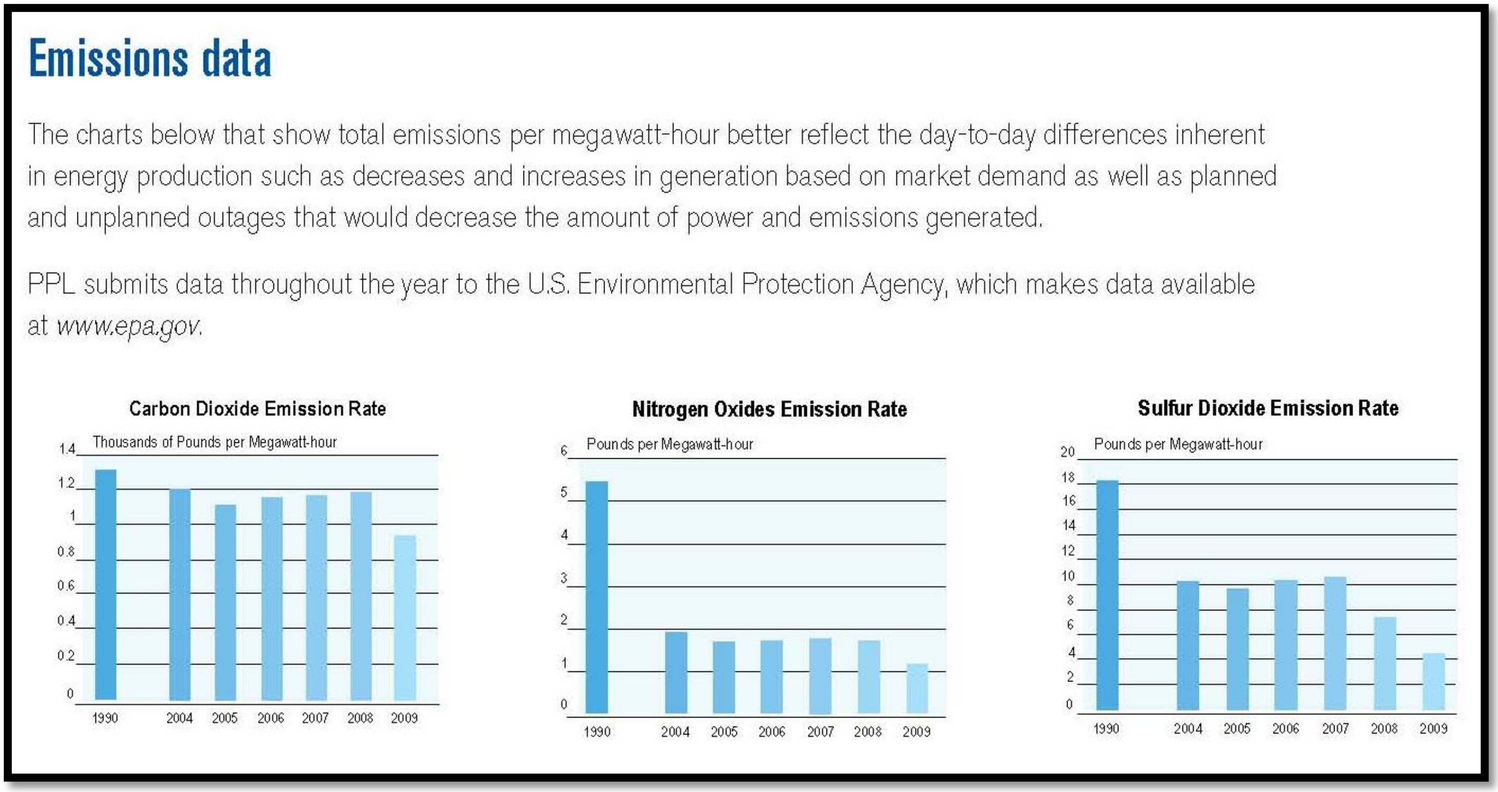
TABLE A.2 – Internal Load Summary, *continued*

Room #	Room Name	Occupancy [People]	Lighting Load [watts]	Lighting Load [W/SF]	Additional Equipment Loads
226	Passage		300	0.87	
227	Classroom	15	324	0.68	Netbooks, Smartboard
228	Passage		78	0.66	
231	Classroom	13	216	0.90	Netbooks, Smartboard
THIRD LEVEL					
301	Classroom	26	432	0.69	Netbooks, Smartboard
302	Corridor		208	0.57	
303	Mechanical				Equipment (10W/sf)
304	Classroom	11	216	0.68	Netbooks, Smartboard
305	Passage		78	1.18	
306	Mechanical				Equipment (10W/sf)
307	Classroom	9	216	0.94	No added equip loads due to nature of classroom design
308	Classroom	9	216	0.92	
309	Classroom	15	324	0.78	
311	Mechanical				Equipment (10W/sf)
312	Corridor		208	0.51	
313	Passage		136	0.60	
314	Toilet	1	64	1.21	
315	Toilet	1	64	1.21	
316	Corridor		216	1.14	
317	Mechanical				Equipment (10W/sf)
318	Classroom	17	324	0.83	Netbooks, Smartboard
319	Existing Classroom	11		0.90	Netbooks
320	Existing Classroom	21		0.90	Netbooks
321	Existing Classroom	23		0.90	Netbooks
322	Corridor			0.70	
323	Existing Classroom	21		0.90	Netbooks, Smartboard
324	Existing Work Room/Archives		192	1.09	
325	Passage			0.70	
326	Office	4	216	0.71	Computers
327	Existing Storage		150	2.00	

Table A.3 – Assumed School Schedule

	MONTHS	TIME	%
WEEKDAY	JANUARY -MAY	12AM-6AM	0
		6AM-7AM	10
		7AM-8AM	20
		8AM-11AM	80
		11AM-1PM	90
		1PM-3PM	80
		3PM-6PM	60
		6PM-12AM	0
	JUNE-AUGUST	12AM-8AM	0
		8AM-6PM	15
		6PM-12AM	0
	SEPTEMBER-DECEMBER	12AM-6AM	0
		6AM-7AM	10
		7AM-8AM	20
		8AM-11AM	80
		11AM-1PM	90
		1PM-3PM	80
		3PM-6PM	60
		6PM-12AM	0
WEEKEND	JANUARY-DECEMBER	12AM-8AM	0
		8AM-4PM	15
		4PM-12AM	0

Figure A.4 – Electric Emissions Rates *(PPL Power)*



Emissions data

The charts below that show total emissions per megawatt-hour better reflect the day-to-day differences inherent in energy production such as decreases and increases in generation based on market demand as well as planned and unplanned outages that would decrease the amount of power and emissions generated.

PPL submits data throughout the year to the U.S. Environmental Protection Agency, which makes data available at *www.epa.gov*.

Figure A.5 – Natural Gas Emissions Rates *(Dr. Jim Freihaut)*

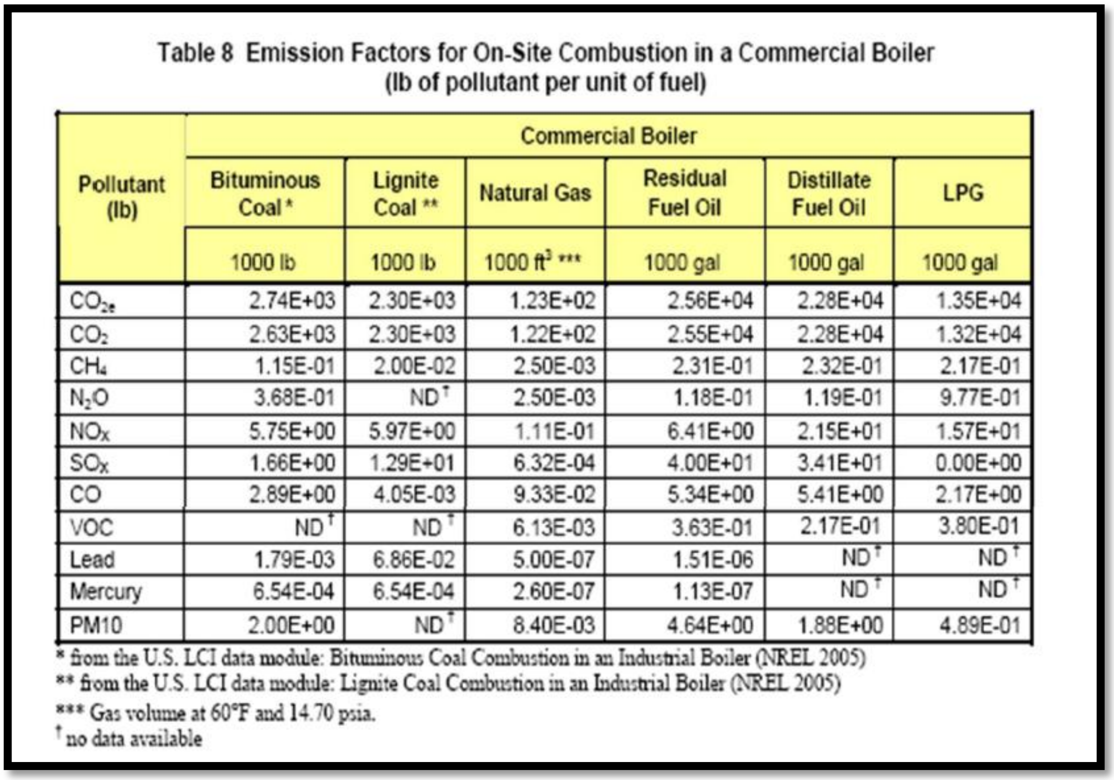
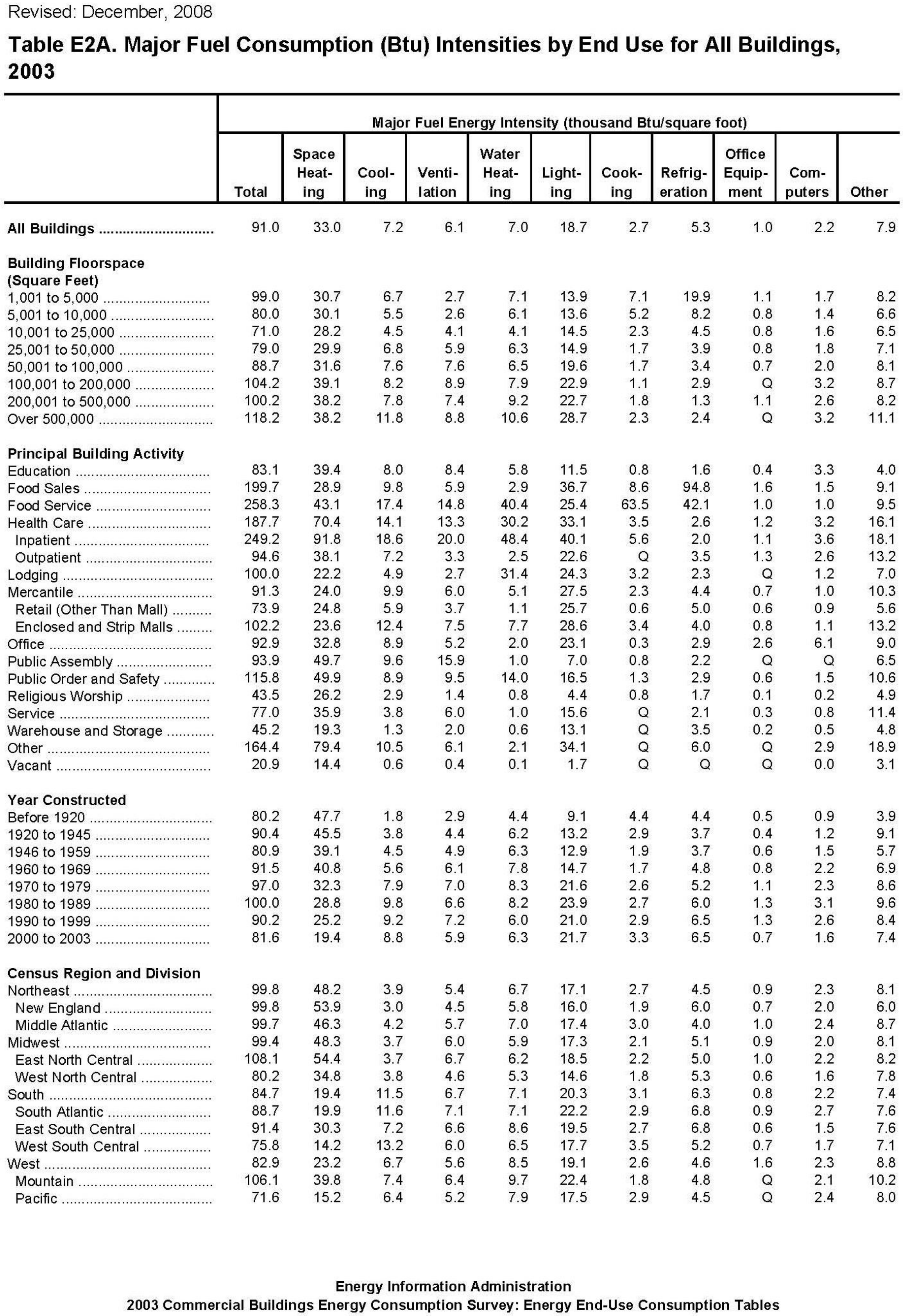


Table 8 Emission Factors for On-Site Combustion in a Commercial Boiler
(lb of pollutant per unit of fuel)

Pollutant (lb)	Commercial Boiler					
	Bituminous Coal *	Lignite Coal **	Natural Gas	Residual Fuel Oil	Distillate Fuel Oil	LPG
	1000 lb	1000 lb	1000 ft^3 ***	1000 gal	1000 gal	1000 gal
CO_{2e}	2.74E+03	2.30E+03	1.23E+02	2.56E+04	2.28E+04	1.35E+04
CO_2	2.63E+03	2.30E+03	1.22E+02	2.55E+04	2.28E+04	1.32E+04
CH_4	1.15E-01	2.00E-02	2.50E-03	2.31E-01	2.32E-01	2.17E-01
N_2O	3.68E-01	ND†	2.50E-03	1.18E-01	1.19E-01	9.77E-01
NO_X	5.75E+00	5.97E+00	1.11E-01	6.41E+00	2.15E+01	1.57E+01
SO_X	1.66E+00	1.29E+01	6.32E-04	4.00E+01	3.41E+01	0.00E+00
CO	2.89E+00	4.05E-03	9.33E-02	5.34E+00	5.41E+00	2.17E+00
VOC	ND†	ND†	6.13E-03	3.63E-01	2.17E-01	3.80E-01
Lead	1.79E-03	6.86E-02	5.00E-07	1.51E-06	ND†	ND†
Mercury	6.54E-04	6.54E-04	2.60E-07	1.13E-07	ND†	ND†
PM10	2.00E+00	ND†	8.40E-03	4.64E+00	1.88E+00	4.89E-01

* from the U.S. LCI data module: Bituminous Coal Combustion in an Industrial Boiler (NREL 2005)
** from the U.S. LCI data module: Lignite Coal Combustion in an Industrial Boiler (NREL 2005)
*** Gas volume at 60°F and 14.70 psia.
† no data available



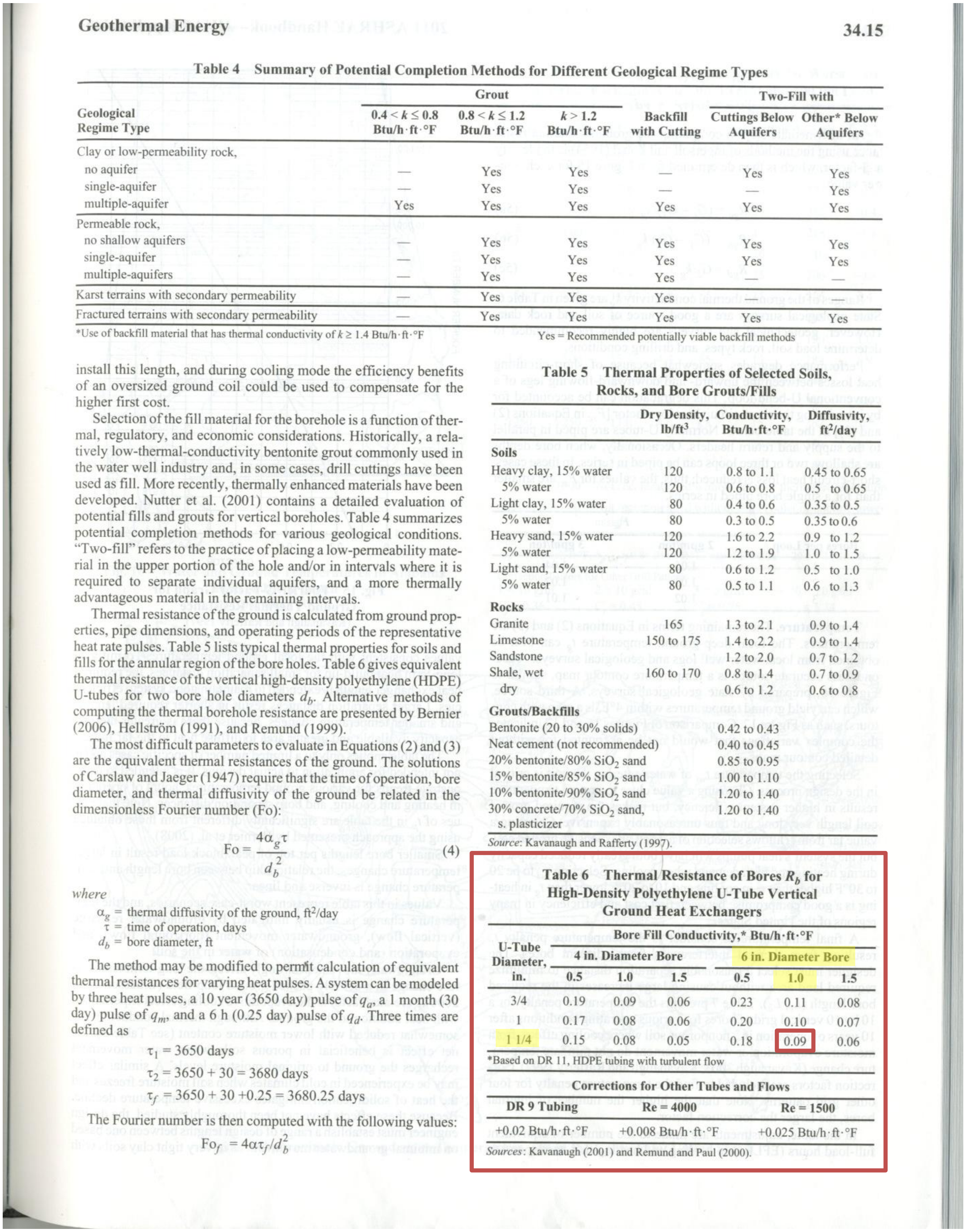
Revised: December, 2008

Table E2A. Major Fuel Consumption (Btu) Intensities by End Use for All Buildings, 2003

	Major Fuel Energy Intensity (thousand Btu/square foot)										
	Total	Space Heating	Cooling	Ventilation	Water Heating	Lighting	Cooking	Refrigeration	Office Equipment	Computers	Other
All Buildings	91.0	33.0	7.2	6.1	7.0	18.7	2.7	5.3	1.0	2.2	7.9
Building Floorspace (Square Feet)											
1,001 to 5,000	99.0	30.7	6.7	2.7	7.1	13.9	7.1	19.9	1.1	1.7	8.2
5,001 to 10,000	80.0	30.1	5.5	2.6	6.1	13.6	5.2	8.2	0.8	1.4	6.6
10,001 to 25,000	71.0	28.2	4.5	4.1	4.1	14.5	2.3	4.5	0.8	1.6	6.5
25,001 to 50,000	79.0	29.9	6.8	5.9	6.3	14.9	1.7	3.9	0.8	1.8	7.1
50,001 to 100,000	88.7	31.6	7.6	7.6	6.5	19.6	1.7	3.4	0.7	2.0	8.1
100,001 to 200,000	104.2	39.1	8.2	8.9	7.9	22.9	1.1	2.9	Q	3.2	8.7
200,001 to 500,000	100.2	38.2	7.8	7.4	9.2	22.7	1.8	1.3	1.1	2.6	8.2
Over 500,000	118.2	38.2	11.8	8.8	10.6	28.7	2.3	2.4	Q	3.2	11.1
Principal Building Activity											
Education	83.1	39.4	8.0	8.4	5.8	11.5	0.8	1.6	0.4	3.3	4.0
Food Sales	199.7	28.9	9.8	5.9	2.9	36.7	8.6	94.8	1.6	1.5	9.1
Food Service	258.3	43.1	17.4	14.8	40.4	25.4	63.5	42.1	1.0	1.0	9.5
Health Care	187.7	70.4	14.1	13.3	30.2	33.1	3.5	2.6	1.2	3.2	16.1
Inpatient	249.2	91.8	18.6	20.0	48.4	40.1	5.6	2.0	1.1	3.6	18.1
Outpatient	94.6	38.1	7.2	3.3	2.5	22.6	Q	3.5	1.3	2.6	13.2
Lodging	100.0	22.2	4.9	2.7	31.4	24.3	3.2	2.3	Q	1.2	7.0
Mercantile	91.3	24.0	9.9	6.0	5.1	27.5	2.3	4.4	0.7	1.0	10.3
Retail (Other Than Mall)	73.9	24.8	5.9	3.7	1.1	25.7	0.6	5.0	0.6	0.9	5.6
Enclosed and Strip Malls	102.2	23.6	12.4	7.5	7.7	28.6	3.4	4.0	0.8	1.1	13.2
Office	92.9	32.8	8.9	5.2	2.0	23.1	0.3	2.9	2.6	6.1	9.0
Public Assembly	93.9	49.7	9.6	15.9	1.0	7.0	0.8	2.2	Q	Q	6.5
Public Order and Safety	115.8	49.9	8.9	9.5	14.0	16.5	1.3	2.9	0.6	1.5	10.6
Religious Worship	43.5	26.2	2.9	1.4	0.8	4.4	0.8	1.7	0.1	0.2	4.9
Service	77.0	35.9	3.8	6.0	1.0	15.6	Q	2.1	0.3	0.8	11.4
Warehouse and Storage	45.2	19.3	1.3	2.0	0.6	13.1	Q	3.5	0.2	0.5	4.8
Other	164.4	79.4	10.5	6.1	2.1	34.1	Q	6.0	Q	2.9	18.9
Vacant	20.9	14.4	0.6	0.4	0.1	1.7	Q	Q	Q	0.0	3.1
Year Constructed											
Before 1920	80.2	47.7	1.8	2.9	4.4	9.1	4.4	4.4	0.5	0.9	3.9
1920 to 1945	90.4	45.5	3.8	4.4	6.2	13.2	2.9	3.7	0.4	1.2	9.1
1946 to 1959	80.9	39.1	4.5	4.9	6.3	12.9	1.9	3.7	0.6	1.5	5.7
1960 to 1969	91.5	40.8	5.6	6.1	7.8	14.7	1.7	4.8	0.8	2.2	6.9
1970 to 1979	97.0	32.3	7.9	7.0	8.3	21.6	2.6	5.2	1.1	2.3	8.6
1980 to 1989	100.0	28.8	9.8	6.6	8.2	23.9	2.7	6.0	1.3	3.1	9.6
1990 to 1999	90.2	25.2	9.2	7.2	6.0	21.0	2.9	6.5	1.3	2.6	8.4
2000 to 2003	81.6	19.4	8.8	5.9	6.3	21.7	3.3	6.5	0.7	1.6	7.4
Census Region and Division											
Northeast	99.8	48.2	3.9	5.4	6.7	17.1	2.7	4.5	0.9	2.3	8.1
New England	99.8	53.9	3.0	4.5	5.8	16.0	1.9	6.0	0.7	2.0	6.0
Middle Atlantic	99.7	46.3	4.2	5.7	7.0	17.4	3.0	4.0	1.0	2.4	8.7
Midwest	99.4	48.3	3.7	6.0	5.9	17.3	2.1	5.1	0.9	2.0	8.1
East North Central	108.1	54.4	3.7	6.7	6.2	18.5	2.2	5.0	1.0	2.2	8.2
West North Central	80.2	34.8	3.8	4.6	5.3	14.6	1.8	5.3	0.6	1.6	7.8
South	84.7	19.4	11.5	6.7	7.1	20.3	3.1	6.3	0.8	2.2	7.4
South Atlantic	88.7	19.9	11.6	7.1	7.1	22.2	2.9	6.8	0.9	2.7	7.6
East South Central	91.4	30.3	7.2	6.6	8.6	19.5	2.7	6.8	0.6	1.5	7.6
West South Central	75.8	14.2	13.2	6.0	6.5	17.7	3.5	5.2	0.7	1.7	7.1
West	82.9	23.2	6.7	5.6	8.5	19.1	2.6	4.6	1.6	2.3	8.8
Mountain	106.1	39.8	7.4	6.4	9.7	22.4	1.8	4.8	Q	2.1	10.2
Pacific	71.6	15.2	6.4	5.2	7.9	17.5	2.9	4.5	Q	2.4	8.0

Energy Information Administration
2003 Commercial Buildings Energy Consumption Survey: Energy End-Use Consumption Tables

Figure C.1 – Excerpt from Chapter 34 of the 2011 ASHRAE Handbook-HVAC Applications



Geothermal Energy **34.15**

Table 4 Summary of Potential Completion Methods for Different Geological Regime Types

Geological Regime Type	Grout				Two-Fill with	
	$0.4 < k \le 0.8$ Btu/h·ft·°F	$0.8 < k \le 1.2$ Btu/h·ft·°F	$k > 1.2$ Btu/h·ft·°F	Backfill with Cutting	Cuttings Below Aquifers	Other* Below Aquifers
Clay or low-permeability rock,						
no aquifer	—	Yes	Yes	—	Yes	Yes
single-aquifer	—	Yes	Yes	—	—	Yes
multiple-aquifer	Yes	Yes	Yes	Yes	Yes	Yes
Permeable rock,						
no shallow aquifers	—	Yes	Yes	Yes	Yes	Yes
single-aquifer	—	Yes	Yes	Yes	Yes	Yes
multiple-aquifers	—	Yes	Yes	Yes	—	—
Karst terrains with secondary permeability	—	Yes	Yes	Yes	—	—
Fractured terrains with secondary permeability	—	Yes	Yes	Yes	Yes	Yes

*Use of backfill material that has thermal conductivity of $k \ge 1.4$ Btu/h·ft·°F

Yes = Recommended potentially viable backfill methods

install this length, and during cooling mode the efficiency benefits of an oversized ground coil could be used to compensate for the higher first cost.

Selection of the fill material for the borehole is a function of thermal, regulatory, and economic considerations. Historically, a relatively low-thermal-conductivity bentonite grout commonly used in the water well industry and, in some cases, drill cuttings have been used as fill. More recently, thermally enhanced materials have been developed. Nutter et al. (2001) contains a detailed evaluation of potential fills and grouts for vertical boreholes. Table 4 summarizes potential completion methods for various geological conditions. "Two-fill" refers to the practice of placing a low-permeability material in the upper portion of the hole and/or in intervals where it is required to separate individual aquifers, and a more thermally advantageous material in the remaining intervals.

Thermal resistance of the ground is calculated from ground properties, pipe dimensions, and operating periods of the representative heat rate pulses. Table 5 lists typical thermal properties for soils and fills for the annular region of the bore holes. Table 6 gives equivalent thermal resistance of the vertical high-density polyethylene (HDPE) U-tubes for two bore hole diameters d_b. Alternative methods of computing the thermal borehole resistance are presented by Bernier (2006), Hellström (1991), and Remund (1999).

The most difficult parameters to evaluate in Equations (2) and (3) are the equivalent thermal resistances of the ground. The solutions of Carslaw and Jaeger (1947) require that the time of operation, bore diameter, and thermal diffusivity of the ground be related in the dimensionless Fourier number (Fo):

$$\text{Fo} = \frac{4\alpha_g \tau}{d_b^2} \tag{4}$$

where

α_g = thermal diffusivity of the ground, ft²/day
τ = time of operation, days
d_b = bore diameter, ft

The method may be modified to permit calculation of equivalent thermal resistances for varying heat pulses. A system can be modeled by three heat pulses, a 10 year (3650 day) pulse of q_a, a 1 month (30 day) pulse of q_m, and a 6 h (0.25 day) pulse of q_d. Three times are defined as

$$\tau_1 = 3650 \text{ days}$$

$$\tau_2 = 3650 + 30 = 3680 \text{ days}$$

$$\tau_f = 3650 + 30 + 0.25 = 3680.25 \text{ days}$$

The Fourier number is then computed with the following values:

$$\text{Fo}_f = 4\alpha\tau_f/d_b^2$$

Table 5 Thermal Properties of Selected Soils, Rocks, and Bore Grouts/Fills

	Dry Density, lb/ft³	Conductivity, Btu/h·ft·°F	Diffusivity, ft²/day
Soils			
Heavy clay, 15% water	120	0.8 to 1.1	0.45 to 0.65
5% water	120	0.6 to 0.8	0.5 to 0.65
Light clay, 15% water	80	0.4 to 0.6	0.35 to 0.5
5% water	80	0.3 to 0.5	0.35 to 0.6
Heavy sand, 15% water	120	1.6 to 2.2	0.9 to 1.2
5% water	120	1.2 to 1.9	1.0 to 1.5
Light sand, 15% water	80	0.6 to 1.2	0.5 to 1.0
5% water	80	0.5 to 1.1	0.6 to 1.3
Rocks			
Granite	165	1.3 to 2.1	0.9 to 1.4
Limestone	150 to 175	1.4 to 2.2	0.9 to 1.4
Sandstone		1.2 to 2.0	0.7 to 1.2
Shale, wet	160 to 170	0.8 to 1.4	0.7 to 0.9
dry		0.6 to 1.2	0.6 to 0.8
Grouts/Backfills			
Bentonite (20 to 30% solids)		0.42 to 0.43	
Neat cement (not recommended)		0.40 to 0.45	
20% bentonite/80% SiO_2 sand		0.85 to 0.95	
15% bentonite/85% SiO_2 sand		1.00 to 1.10	
10% bentonite/90% SiO_2 sand		1.20 to 1.40	
30% concrete/70% SiO_2 sand, s. plasticizer		1.20 to 1.40	

Source: Kavanaugh and Rafferty (1997).

Table 6 Thermal Resistance of Bores R_b for High-Density Polyethylene U-Tube Vertical Ground Heat Exchangers

U-Tube Diameter, in.	Bore Fill Conductivity,* Btu/h·ft·°F					
	4 in. Diameter Bore			6 in. Diameter Bore		
	0.5	1.0	1.5	0.5	1.0	1.5
3/4	0.19	0.09	0.06	0.23	0.11	0.08
1	0.17	0.08	0.06	0.20	0.10	0.07
1 1/4	0.15	0.08	0.05	0.18	0.09	0.06

*Based on DR 11, HDPE tubing with turbulent flow

Corrections for Other Tubes and Flows

DR 9 Tubing	Re = 4000	Re = 1500
+0.02 Btu/h·ft·°F	+0.008 Btu/h·ft·°F	+0.025 Btu/h·ft·°F

Sources: Kavanaugh (2001) and Remund and Paul (2000).

Figure C.2 – Excerpt from Chapter 34 of the 2011 ASHRAE Handbook-HVAC Applications

$$\mathrm{Fo}_1 = 4\alpha(\tau_f - \tau_1)/d_b^2$$

$$\mathrm{Fo}_2 = 4\alpha(\tau_f - \tau_2)/d_b^2$$

An intermediate step in computing the ground's thermal resistance using the methods of Ingersoll and Zobel (1954) is to identify a G-factor, which is then determined from Figure 15 for each Fourier value.

$$R_{ga} = (G_f - G_1)/k_g \qquad (5a)$$

$$R_{gm} = (G_1 - G_2)/k_g \qquad (5b)$$

$$R_{gd} = G_2/k_g \qquad (5c)$$

Ranges of the ground thermal conductivity k_g are given in Table 6. State geological surveys are a good source of soil and rock data. However, geotechnical site surveys are highly recommended to determine load soil, rock types, and drilling conditions.

Performance degrades somewhat because of short-circuiting heat losses between the upward- and downward-flowing legs of a conventional U-bend loop. This degradation can be accounted for by introducing the short-circuit heat loss factor [F_{sc} in Equations (2) and (3)] in the table below. Normally U-tubes are piped in parallel to the supply and return headers. Occasionally, when bore depths are shallow, two or three loops can be piped in series. In these cases, short-circuit heat loss is reduced; thus, the values for F_{sc} are smaller than for a single bore piped in series.

	F_{sc}	
Bores per Loop	**2 gpm/ton**	**3 gpm/ton**
1	1.06	1.04
2	1.03	1.02
3	1.02	1.01

Temperature. The remaining terms in Equations (2) and (3) are temperatures. The local deep-ground temperature t_g can best be obtained from local water well logs and geological surveys. A second, less accurate source is a temperature contour map, similar to Figure 16, prepared by state geological surveys. A third source, which can yield ground temperatures within 4°F, is a map with contours, such as Figure 17. Comparison of Figures 16 and 17 indicates the complex variations that would not be accounted for without detailed contour maps.

Selecting the temperature t_{wi} of water entering the unit is critical in the design process. Choosing a value close to ground temperature results in higher system efficiency, but makes the required ground coil length very long and thus unreasonably expensive. Choosing a value far from t_g allows selection of a small, inexpensive ground coil, but the system's heat pumps will have both greatly reduced capacity during heating and high demand when cooling. Selecting t_{wi} to be 20 to 30°F higher than t_g in cooling and 10 to 20°F lower than t_g in heating is a good compromise between first cost and efficiency in many regions of the United States.

A final temperature to consider is the temperature penalty t_p resulting from thermal interferences from adjacent bores. The designer must select a reasonable separation distance to minimize required land area without causing large increases in the required bore length (L_c, L_h). Table 7 presents the temperature penalty for a 10 by 10 vertical grid of bores for various operating conditions after 10 years of operation in a nonporous soil where cooling effects from moisture evaporation or water movement do not mitigate temperature change (Kavanaugh 2003; Kavanaugh and Rafferty 1997). Correction factors are included to find the temperature penalty for four other grid patterns. Note that the higher the number of internal bores, the larger the correction factor.

In the table, adjustments are made to the number of equivalent

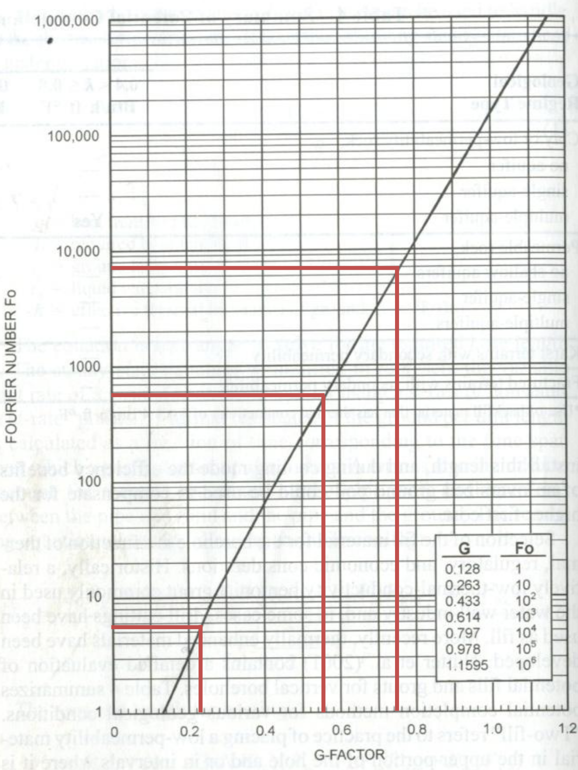


Fig. 15 Fourier/G-Factor Graph for Ground Thermal Resistance
(Kavanaugh and Rafferty 1997)

values consistent with the local ground temperature. To mitigate long-term heat build-up for small separation distances, the required heat exchanger length is extended to maintain good system efficiencies. Larger separation distances result in shorter required lengths and smaller temperature changes, because there is greater thermal capacity available and greater area to diffuse heat to the far field.

The table applies only to a limited number of specific cases and is not intended for application to actual designs. It is intended to demonstrate trends for various ground temperatures, hours of operation in heating and cooling, and bore separation distances. Note that values of t_p in the table are significantly different from those obtained using the approach presented by Bernier et al. (2008).

Smaller bore lengths per ton of peak block load result in larger temperature changes; the relationship between bore length and temperature change is inverse and linear.

Values in this table represent worst-case scenarios, and the temperature change is usually mitigated by groundwater recharge (vertical flow), groundwater movement (horizontal flow), and evaporation (and condensation) of water in the soil.

Groundwater movement strongly affects the long-term temperature change in a densely packed ground loop field (Chiasson et al. 2000). A related factor is the evaporative cooling effect experienced with heat addition to the ground. Although thermal conductivity is somewhat reduced with lower moisture content (see Table 5), the net effect is beneficial in porous soils when water movement recharges the ground to original moisture levels. A similar effect may be experienced in cold climates when soil moisture freezes and the heat of solidification mitigates excessive temperature decline. Because these effects have not been thoroughly studied, the design engineer must establish a range of design lengths between one based

Figure C.3 – Excerpt from Chapter 34 of the 2011 ASHRAE Handbook-HVAC Applications

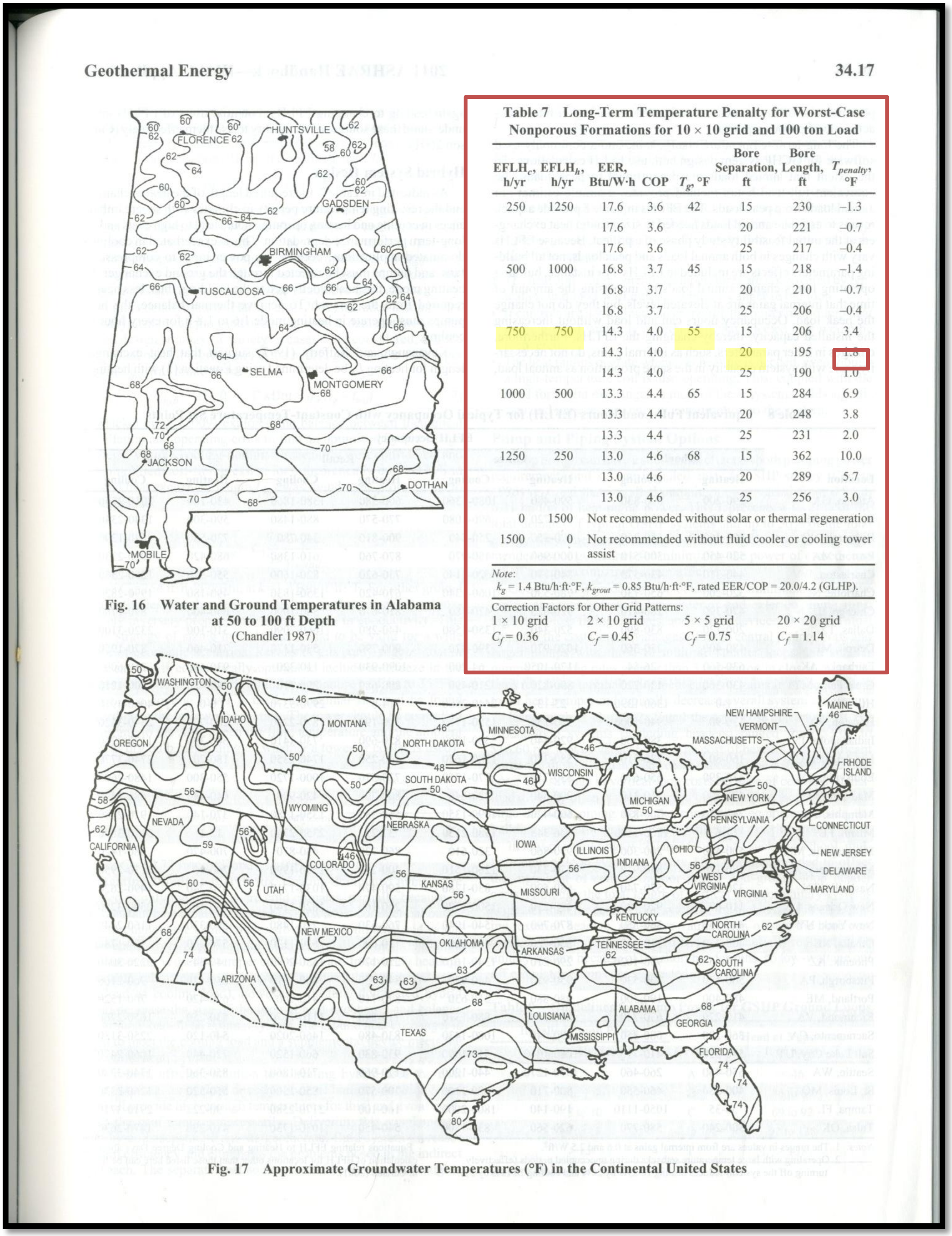


Table 7 Long-Term Temperature Penalty for Worst-Case Nonporous Formations for 10 × 10 grid and 100 ton Load

$EFLH_c$, h/yr	$EFLH_h$, h/yr	EER, Btu/W·h	COP	T_g, °F	Bore Separation, ft	Bore Length, ft	$T_{penalty}$, °F
250	1250	17.6	3.6	42	15	230	−1.3
		17.6	3.6		20	221	−0.7
		17.6	3.6		25	217	−0.4
500	1000	16.8	3.7	45	15	218	−1.4
		16.8	3.7		20	210	−0.7
		16.8	3.7		25	206	−0.4
750	750	14.3	4.0	55	15	206	3.4
		14.3	4.0		20	195	1.8
		14.3	4.0		25	190	1.0
1000	500	13.3	4.4	65	15	284	6.9
		13.3	4.4		20	248	3.8
		13.3	4.4		25	231	2.0
1250	250	13.0	4.6	68	15	362	10.0
		13.0	4.6		20	289	5.7
		13.0	4.6		25	256	3.0
0	1500	Not recommended without solar or thermal regeneration					
1500	0	Not recommended without fluid cooler or cooling tower assist					

Note:
k_g = 1.4 Btu/h·ft·°F, k_{grout} = 0.85 Btu/h·ft·°F, rated EER/COP = 20.0/4.2 (GLHP).

Correction Factors for Other Grid Patterns:

1 × 10 grid	2 × 10 grid	5 × 5 grid	20 × 20 grid
C_f = 0.36	C_f = 0.45	C_f = 0.75	C_f = 1.14

Fig. 16 Water and Ground Temperatures in Alabama at 50 to 100 ft Depth (Chandler 1987)

Fig. 17 Approximate Groundwater Temperatures (°F) in the Continental United States

Figure C.4 - Required Bore Length for Cooling

Variable	Units	Coefficient	Stengel Hall	Linden Hall Campus
Short Circuit Heat Loss Factor		F_{sc}	1.04	
Part Load Factor During Design Month		PLF_m	1.0	
Building Design **Cooling** Block Load	Btu/h	q_{lc}	-1087200	-4525200
Net Annual Average Heat Transfer to Ground	Btu/h	q_a	-322900	-1334900
Thermal Resistance of Pipe	h*ft*°F/Btu	R_b	0.09	
Effective Thermal Resistance of Ground (annual pulse)	h*ft*°F/Btu	R_{ga}	0.117	
Effective Thermal Resistance of Ground (monthly pulse)	h*ft*°F/Btu	R_{gm}	0.172	
Effective Thermal Resistance of Ground (daily pulse)	h*ft*°F/Btu	R_{gd}	0.133	
Undisturbed Ground Temperature	°F	t_g	52	
Temperature Penalty for Interference of Adjacent Bores	°F	t_p	1.8	
Liquid Temperature at Heat Pump Inlet	°F	t_{wi}	65	
Liquid Temperature at Heat Pump Outlet	°F	t_{wo}	75	
Power Input at Design **Cooling** Load	W	W_c	10000	10000
Required Bore Length for **Cooling**	ft	L_c	**24605**	**100177**

Figure C.5 - Required Bore Length for Heating

Variable	Units	Coefficient	Stengel Hall	Linden Hall Campus
Short Circuit Heat Loss Factor		F_{sc}	1.04	
Part Load Factor During Design Month		PLF_m	1.0	
Building Design **Heating** Block Load	Btu/h	q_{lh}	764300	3190300
Net Annual Average Heat Transfer to Ground	Btu/h	q_a	-322900	-1334900
Thermal Resistance of Pipe	h*ft*°F/Btu	R_b	0.09	
Effective Thermal Resistance of Ground (annual pulse)	h*ft*°F/Btu	R_{ga}	0.117	
Effective Thermal Resistance of Ground (monthly pulse)	h*ft*°F/Btu	R_{gm}	0.172	
Effective Thermal Resistance of Ground (daily pulse)	h*ft*°F/Btu	R_{gd}	0.133	
Undisturbed Ground Temperature	°F	t_g	52	
Temperature Penalty for Interference of Adjacent Bores	°F	t_p	1.8	
Liquid Temperature at Heat Pump Inlet	°F	t_{wi}	35	
Liquid Temperature at Heat Pump Outlet	°F	t_{wo}	45	
Power Input at Design **Heating** Load	W	W_h	10000	10000
Required Bore Length for **Heating**	ft	L_h	**25006**	**108779**

Figure C.5 – Friction Loss for Branch Piping *(ASHRAE)*

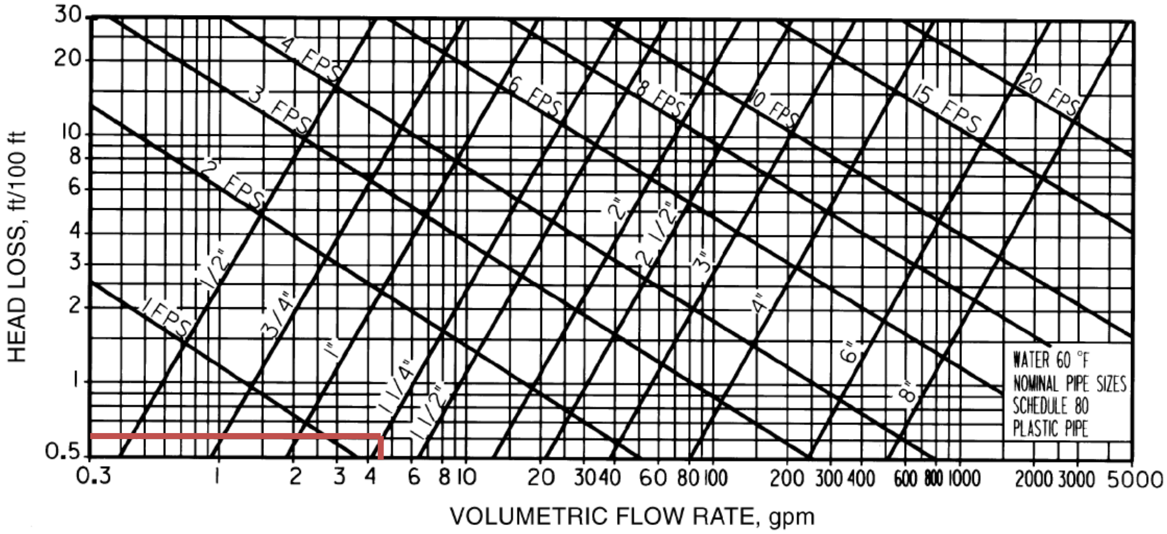


Fig. 6 Friction Loss for Water in Plastic Pipe (Schedule 80)

Figure C.6 – Friction Loss for Main Header Piping *ASHRAE)*

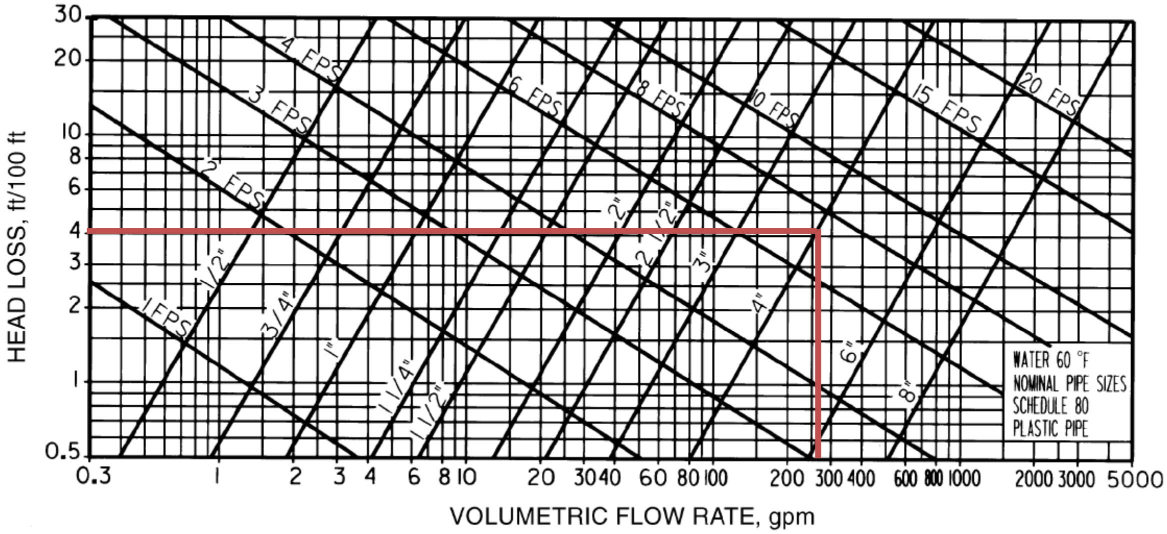


Fig. 6 Friction Loss for Water in Plastic Pipe (Schedule 80)

Figure C.6 – Sample Equivalent Length Calculation (*McQuiston, 323)*

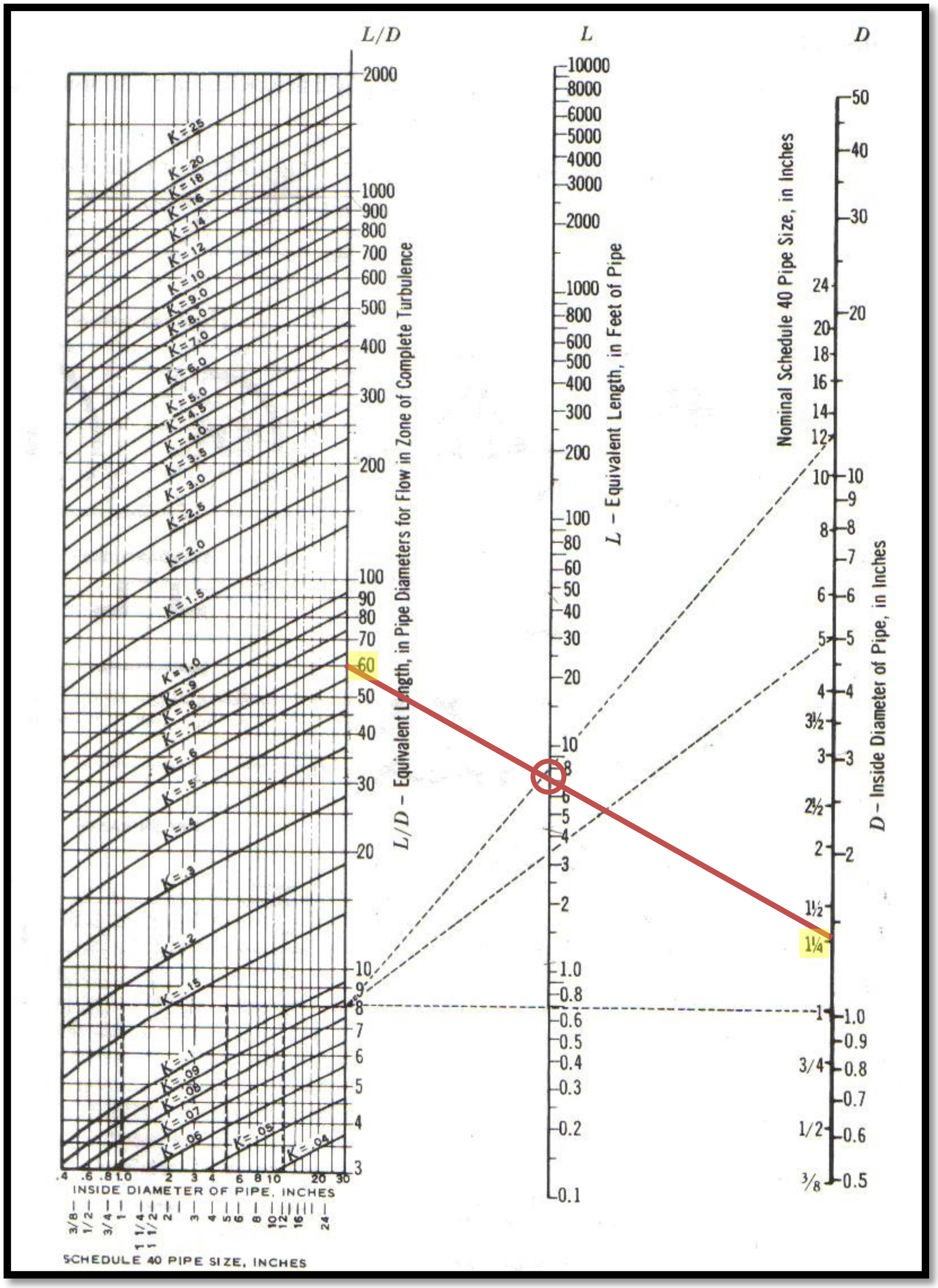


Figure C.7 – Recommended Pump Curve (*Bell & Gossett*)

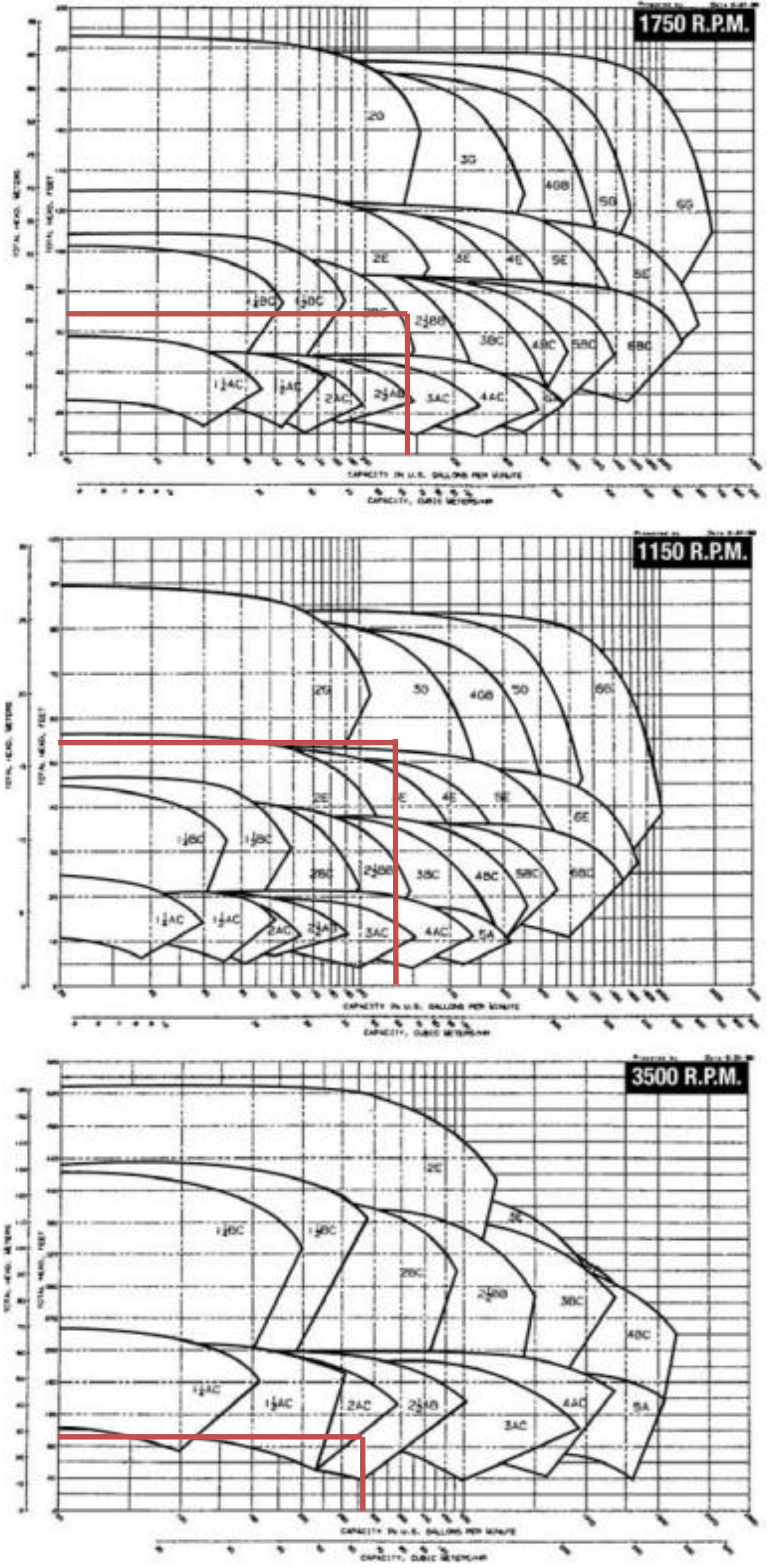


Figure C.8 – Pump Curve Selected (*Bell & Gossett)*

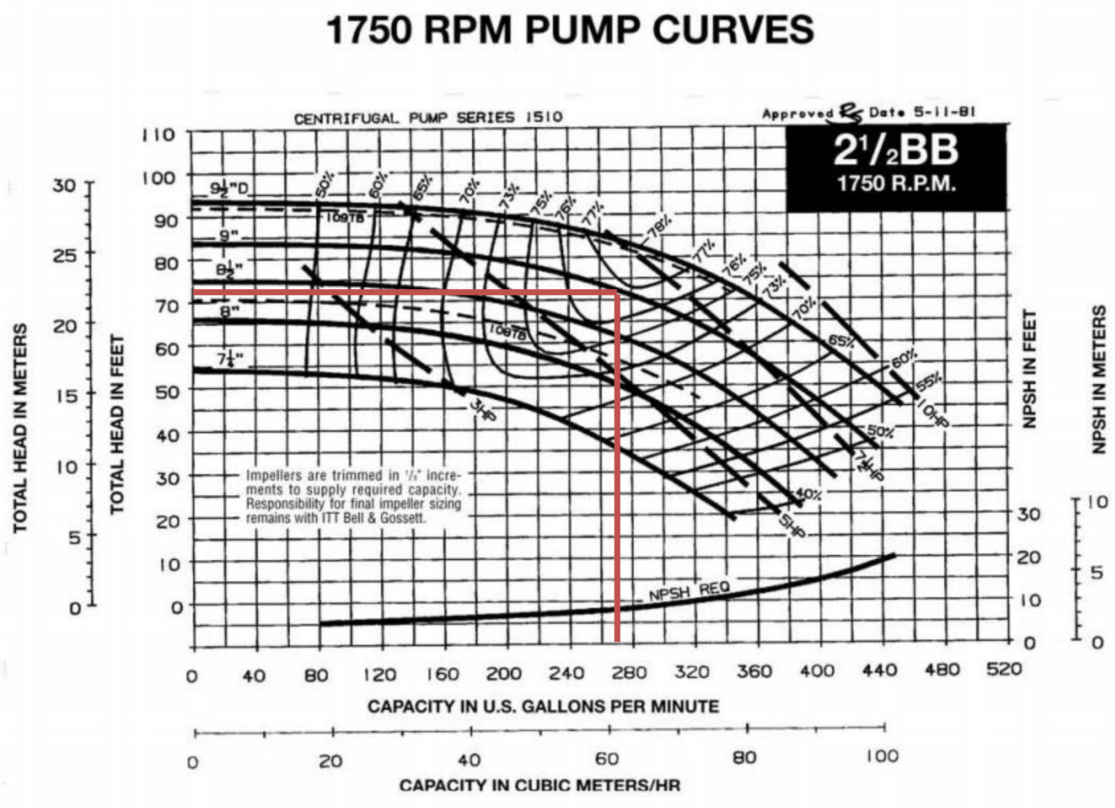
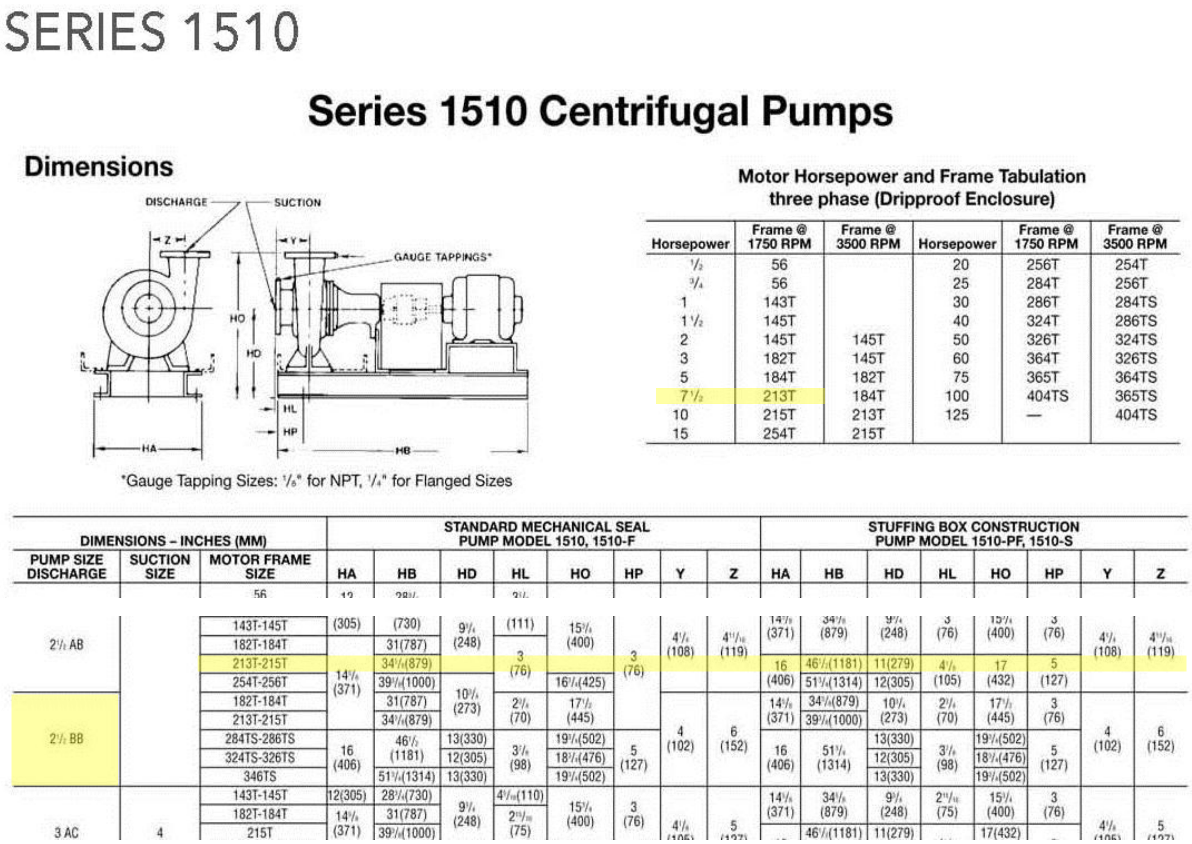


Figure C.9 – Selected Pump Specifications (*Bell & Gossett)*



SERIES 1510

Series 1510 Centrifugal Pumps

Dimensions

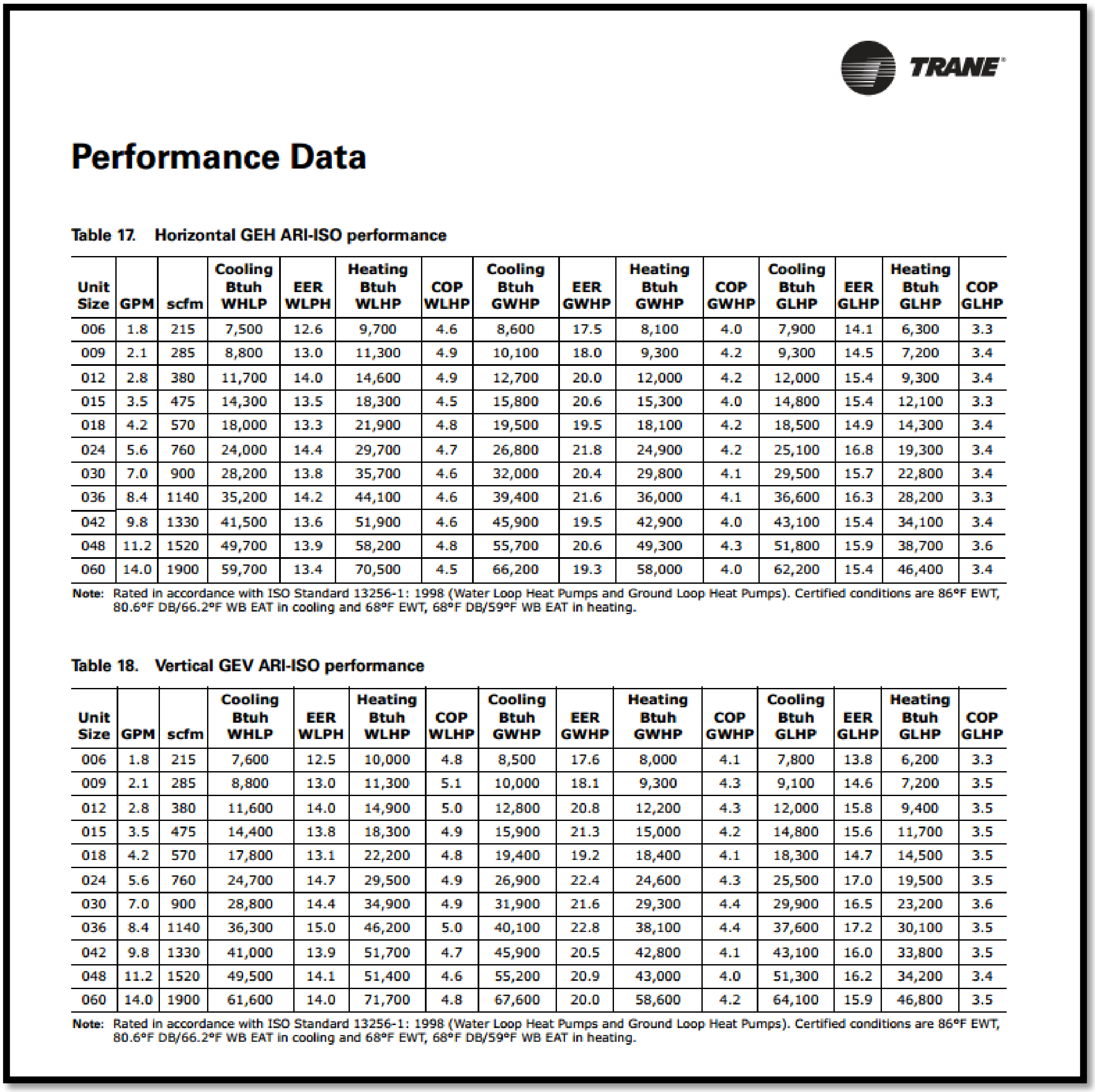
*Gauge Tapping Sizes: 1/8" for NPT, 1/4" for Flanged Sizes

Motor Horsepower and Frame Tabulation
three phase (Dripproof Enclosure)

Horsepower	Frame @ 1750 RPM	Frame @ 3500 RPM	Horsepower	Frame @ 1750 RPM	Frame @ 3500 RPM
1/2	56		20	256T	254T
3/4	56		25	284T	256T
1	143T		30	286T	284TS
1 1/2	145T		40	324T	286TS
2	145T	145T	50	326T	324TS
3	182T	145T	60	364T	326TS
5	184T	182T	75	365T	364TS
7 1/2	213T	184T	100	404TS	365TS
10	215T	213T	125	—	404TS
15	254T	215T			

DIMENSIONS – INCHES (MM)			STANDARD MECHANICAL SEAL PUMP MODEL 1510, 1510-F								STUFFING BOX CONSTRUCTION PUMP MODEL 1510-PF, 1510-S							
PUMP SIZE DISCHARGE	SUCTION SIZE	MOTOR FRAME SIZE	HA	HB	HD	HL	HO	HP	Y	Z	HA	HB	HD	HL	HO	HP	Y	Z
		56	12															
2 1/2 AB		143T-145T	(305)	(730)	9 3/4 (248)	(111)	15 3/4 (400)	3 (76)	4 1/4 (108)	4 11/16 (119)	(371)	(879)	(248)	(76)	(400)	(76)	4 1/4 (108)	4 11/16 (119)
		182T-184T	14 5/8 (371)	31(787)		3 (76)												
		213T-215T		34 5/8(879)							16 (406)	46 1/2(1181)	11(279)	4 1/8 (105)	17 (432)	5 (127)		
		254T-256T		39 3/8(1000)	10 3/4 (273)		16 3/4(425)					51 3/4(1314)	12(305)					
2 1/2 BB		182T-184T		31(787)		2 3/4 (70)	17 1/2 (445)		4 (102)	6 (152)	14 5/8 (371)	34 5/8(879)	10 3/4 (273)	2 3/4 (70)	17 1/2 (445)	3 (76)	4 (102)	6 (152)
		213T-215T		34 5/8(879)								39 3/8(1000)						
		284TS-286TS	16 (406)	46 1/2 (1181)	13(330)	3 7/8 (98)	19 3/4(502)	5 (127)			16 (406)	51 3/4 (1314)	13(330)	3 7/8 (98)	19 3/4(502)	5 (127)		
		324TS-326TS			12(305)		18 3/4(476)						12(305)		18 3/4(476)			
		346TS		51 3/4(1314)	13(330)		19 3/4(502)						13(330)		19 3/4(502)			
3 AC	4	143T-145T	12(305)	28 3/4(730)	9 3/4 (248)	4 5/16(110)	15 3/4 (400)	3 (76)	4 1/8	5	14 5/8 (371)	34 5/8 (879)	9 3/4 (248)	2 15/16 (75)	15 3/4 (400)	3 (76)	4 1/8	5
		182T-184T	14 5/8 (371)	31(787)		2 15/16 (75)												
		215T		39 3/8(1000)								46 1/2(1181)	11(279)		17(432)			

Figure C.9 – Selected Heat Pump Performance Data (*Trane)*



Performance Data

Table 17. Horizontal GEH ARI-ISO performance

Unit Size	GPM	scfm	Cooling Btuh WHLP	EER WLPH	Heating Btuh WLHP	COP WLHP	Cooling Btuh GWHP	EER GWHP	Heating Btuh GWHP	COP GWHP	Cooling Btuh GLHP	EER GLHP	Heating Btuh GLHP	COP GLHP
006	1.8	215	7,500	12.6	9,700	4.6	8,600	17.5	8,100	4.0	7,900	14.1	6,300	3.3
009	2.1	285	8,800	13.0	11,300	4.9	10,100	18.0	9,300	4.2	9,300	14.5	7,200	3.4
012	2.8	380	11,700	14.0	14,600	4.9	12,700	20.0	12,000	4.2	12,000	15.4	9,300	3.4
015	3.5	475	14,300	13.5	18,300	4.5	15,800	20.6	15,300	4.0	14,800	15.4	12,100	3.3
018	4.2	570	18,000	13.3	21,900	4.8	19,500	19.5	18,100	4.2	18,500	14.9	14,300	3.4
024	5.6	760	24,000	14.4	29,700	4.7	26,800	21.8	24,900	4.2	25,100	16.8	19,300	3.4
030	7.0	900	28,200	13.8	35,700	4.6	32,000	20.4	29,800	4.1	29,500	15.7	22,800	3.4
036	8.4	1140	35,200	14.2	44,100	4.6	39,400	21.6	36,000	4.1	36,600	16.3	28,200	3.3
042	9.8	1330	41,500	13.6	51,900	4.6	45,900	19.5	42,900	4.0	43,100	15.4	34,100	3.4
048	11.2	1520	49,700	13.9	58,200	4.8	55,700	20.6	49,300	4.3	51,800	15.9	38,700	3.6
060	14.0	1900	59,700	13.4	70,500	4.5	66,200	19.3	58,000	4.0	62,200	15.4	46,400	3.4

Note: Rated in accordance with ISO Standard 13256-1: 1998 (Water Loop Heat Pumps and Ground Loop Heat Pumps). Certified conditions are 86°F EWT, 80.6°F DB/66.2°F WB EAT in cooling and 68°F EWT, 68°F DB/59°F WB EAT in heating.

Table 18. Vertical GEV ARI-ISO performance

Unit Size	GPM	scfm	Cooling Btuh WHLP	EER WLPH	Heating Btuh WLHP	COP WLHP	Cooling Btuh GWHP	EER GWHP	Heating Btuh GWHP	COP GWHP	Cooling Btuh GLHP	EER GLHP	Heating Btuh GLHP	COP GLHP
006	1.8	215	7,600	12.5	10,000	4.8	8,500	17.6	8,000	4.1	7,800	13.8	6,200	3.3
009	2.1	285	8,800	13.0	11,300	5.1	10,000	18.1	9,300	4.3	9,100	14.6	7,200	3.5
012	2.8	380	11,600	14.0	14,900	5.0	12,800	20.8	12,200	4.3	12,000	15.8	9,400	3.5
015	3.5	475	14,400	13.8	18,300	4.9	15,900	21.3	15,000	4.2	14,800	15.6	11,700	3.5
018	4.2	570	17,800	13.1	22,200	4.8	19,400	19.2	18,400	4.1	18,300	14.7	14,500	3.5
024	5.6	760	24,700	14.7	29,500	4.9	26,900	22.4	24,600	4.3	25,500	17.0	19,500	3.5
030	7.0	900	28,800	14.4	34,900	4.9	31,900	21.6	29,300	4.4	29,900	16.5	23,200	3.6
036	8.4	1140	36,300	15.0	46,200	5.0	40,100	22.8	38,100	4.4	37,600	17.2	30,100	3.5
042	9.8	1330	41,000	13.9	51,700	4.7	45,900	20.5	42,800	4.1	43,100	16.0	33,800	3.5
048	11.2	1520	49,500	14.1	51,400	4.6	55,200	20.9	43,000	4.0	51,300	16.2	34,200	3.4
060	14.0	1900	61,600	14.0	71,700	4.8	67,600	20.0	58,600	4.2	64,100	15.9	46,800	3.5

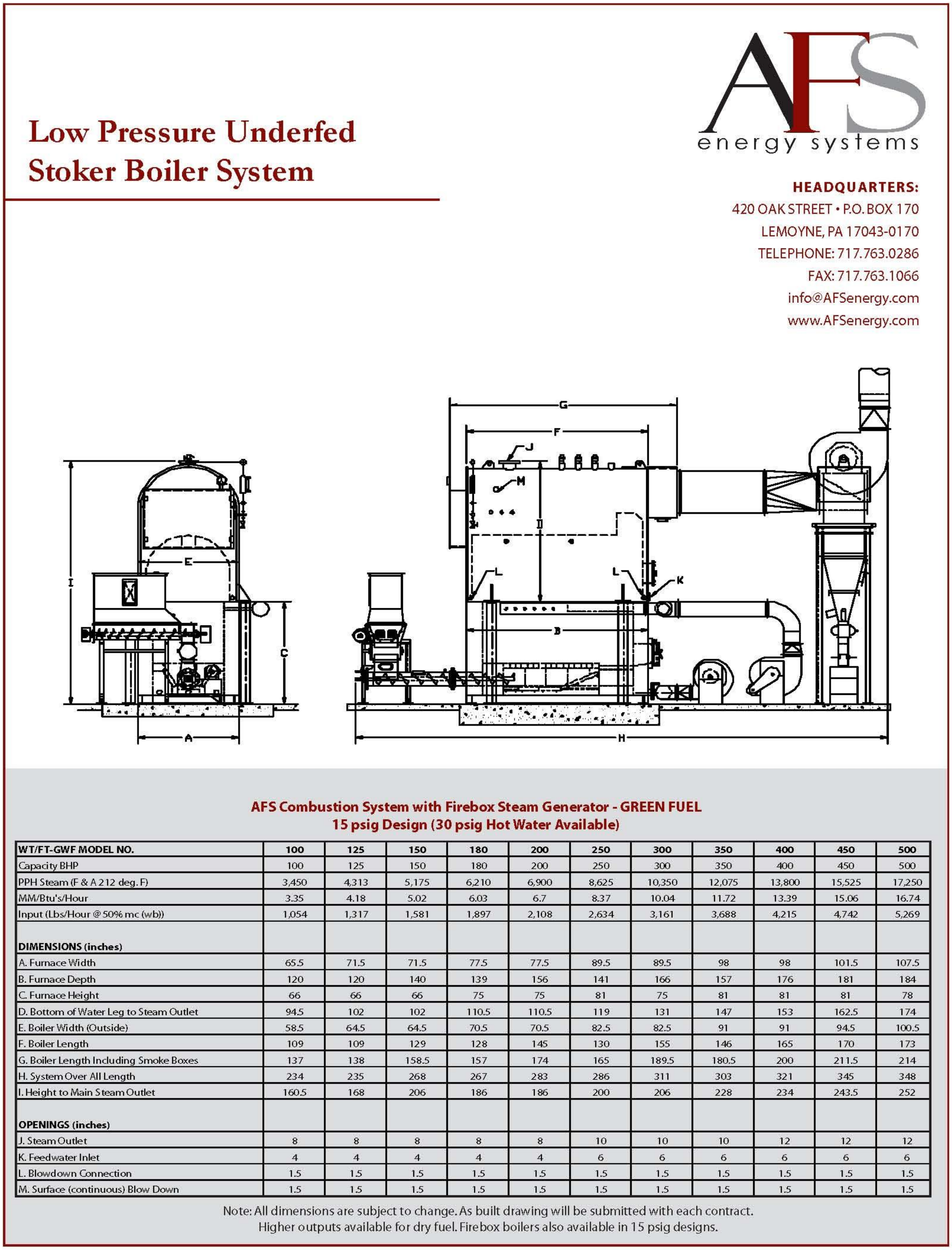
Note: Rated in accordance with ISO Standard 13256-1: 1998 (Water Loop Heat Pumps and Ground Loop Heat Pumps). Certified conditions are 86°F EWT, 80.6°F DB/66.2°F WB EAT in cooling and 68°F EWT, 68°F DB/59°F WB EAT in heating.

Figure C.10 – Payback Period of Geothermal System

Year	Increased Electric Cost (assuming 1% inflation)	Gas Savings (assuming 2% inflation)	Sum of Annual Costs & Savings	Cumulative Cost of System
1	$4,026.00	-$9,790.83	$279,315.17	$279,315.17
2	$4,066.26	-$9,986.65	-$5,920.39	$273,394.78
3	$4,106.92	-$10,186.38	-$6,079.46	$267,315.33
4	$4,147.99	-$10,390.11	-$6,242.12	$261,073.21
5	$4,189.47	-$10,597.91	-$6,408.44	$254,664.77
6	$4,231.37	-$10,809.87	-$6,578.50	$248,086.27
7	$4,273.68	-$11,026.06	-$6,752.38	$241,333.89
8	$4,316.42	-$11,246.59	-$6,930.17	$234,403.72
9	$4,359.58	-$11,471.52	-$7,111.94	$227,291.78
10	$4,403.18	-$11,700.95	-$7,297.77	$219,994.01
11	$4,447.21	-$11,934.97	-$7,487.76	$212,506.25
12	$4,491.68	-$12,173.67	-$7,681.99	$204,824.27
13	$4,536.60	-$12,417.14	-$7,880.54	$196,943.72
14	$4,581.96	-$12,665.48	-$8,083.52	$188,860.21
15	$4,627.78	-$12,918.79	-$8,291.01	$180,569.20
16	$4,674.06	-$13,177.17	-$8,503.11	$172,066.09
17	$4,720.80	-$13,440.71	-$8,719.91	$163,346.18
18	$4,768.01	-$13,709.53	-$8,941.52	$154,404.66
19	$4,815.69	-$13,983.72	-$9,168.03	$145,236.64
20	$4,863.85	-$14,263.39	-$9,399.54	$135,837.09
21	$4,912.49	-$14,548.66	-$9,636.17	$126,200.92
22	$4,961.61	-$14,839.63	-$9,878.02	$116,322.90
23	$5,011.23	-$15,136.42	-$10,125.20	$106,197.70
24	$5,061.34	-$15,439.15	-$10,377.81	$95,819.89
25	$5,111.95	-$15,747.94	-$10,635.98	$85,183.90
26	$5,163.07	-$16,062.89	-$10,899.82	$74,284.08
27	$5,214.70	-$16,384.15	-$11,169.45	$63,114.63
28	$5,266.85	-$16,711.84	-$11,444.99	$51,669.64
29	$5,319.52	-$17,046.07	-$11,726.55	$39,943.09
30	$5,372.71	-$17,386.99	-$12,014.28	$27,928.81
31	$5,426.44	-$17,734.73	-$12,308.29	$15,620.51
32	$5,480.70	-$18,089.43	-$12,608.72	$3,011.79
33	$5,535.51	-$18,451.22	-$12,915.71	-$9,903.92

APPENDIX D

Figure D.1 – Biomass Boiler Specification Sheet *(AFS Energy Systems)*



AFS energy systems

Low Pressure Underfed Stoker Boiler System

HEADQUARTERS:
420 OAK STREET • P.O. BOX 170
LEMOYNE, PA 17043-0170
TELEPHONE: 717.763.0286
FAX: 717.763.1066
info@AFSenergy.com
www.AFSenergy.com

AFS Combustion System with Firebox Steam Generator - GREEN FUEL
15 psig Design (30 psig Hot Water Available)

WT/FT-GWF MODEL NO.	100	125	150	180	200	250	300	350	400	450	500
Capacity BHP	100	125	150	180	200	250	300	350	400	450	500
PPH Steam (F & A 212 deg. F)	3,450	4,313	5,175	6,210	6,900	8,625	10,350	12,075	13,800	15,525	17,250
MM/Btu's/Hour	3.35	4.18	5.02	6.03	6.7	8.37	10.04	11.72	13.39	15.06	16.74
Input (Lbs/Hour @ 50% mc (wb))	1,054	1,317	1,581	1,897	2,108	2,634	3,161	3,688	4,215	4,742	5,269
DIMENSIONS (inches)											
A. Furnace Width	65.5	71.5	71.5	77.5	77.5	89.5	89.5	98	98	101.5	107.5
B. Furnace Depth	120	120	140	139	156	141	166	157	176	181	184
C. Furnace Height	66	66	66	75	75	81	75	81	81	81	78
D. Bottom of Water Leg to Steam Outlet	94.5	102	102	110.5	110.5	119	131	147	153	162.5	174
E. Boiler Width (Outside)	58.5	64.5	64.5	70.5	70.5	82.5	82.5	91	91	94.5	100.5
F. Boiler Length	109	109	129	128	145	130	155	146	165	170	173
G. Boiler Length Including Smoke Boxes	137	138	158.5	157	174	165	189.5	180.5	200	211.5	214
H. System Over All Length	234	235	268	267	283	286	311	303	321	345	348
I. Height to Main Steam Outlet	160.5	168	206	186	186	200	206	228	234	243.5	252
OPENINGS (inches)											
J. Steam Outlet	8	8	8	8	8	10	10	10	12	12	12
K. Feedwater Inlet	4	4	4	4	4	6	6	6	6	6	6
L. Blowdown Connection	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
M. Surface (continuous) Blow Down	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Note: All dimensions are subject to change. As built drawing will be submitted with each contract.
Higher outputs available for dry fuel. Firebox boilers also available in 15 psig designs.

Figure D.2 – Flow Diagram for Biomass Boiler

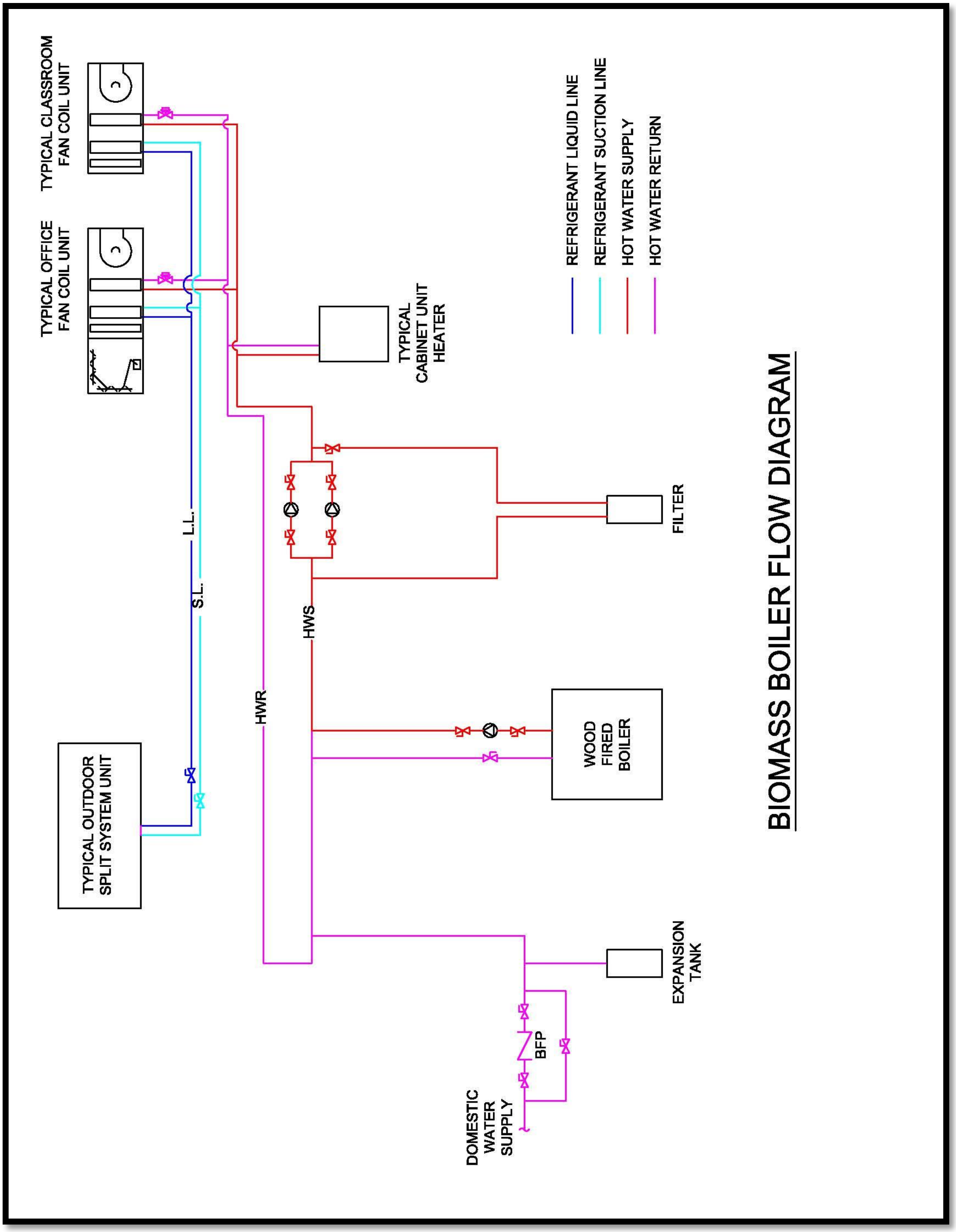
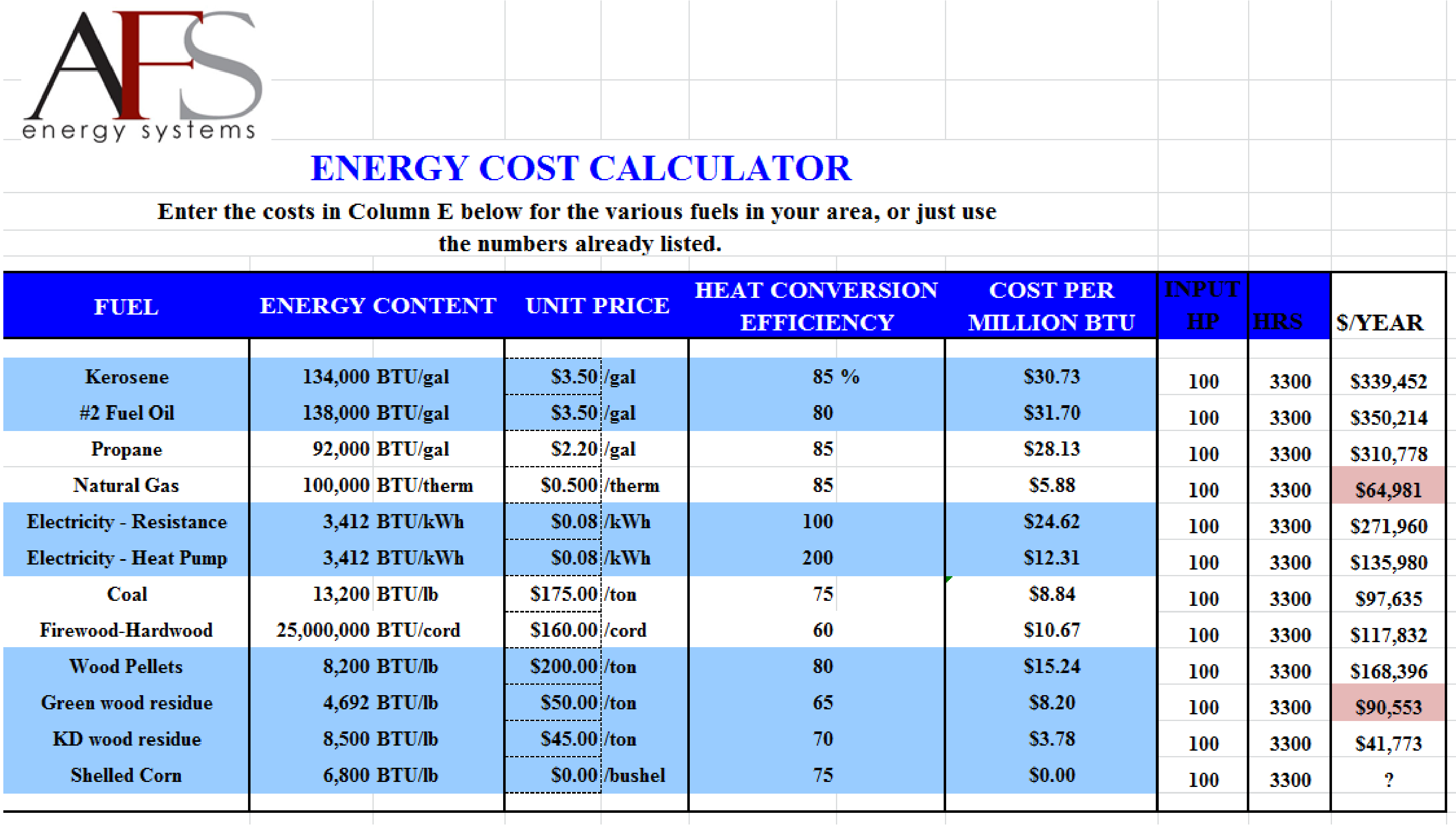


Figure D.3 – Energy Cost Calculator *(AFS Energy Systems)*



ENERGY COST CALCULATOR

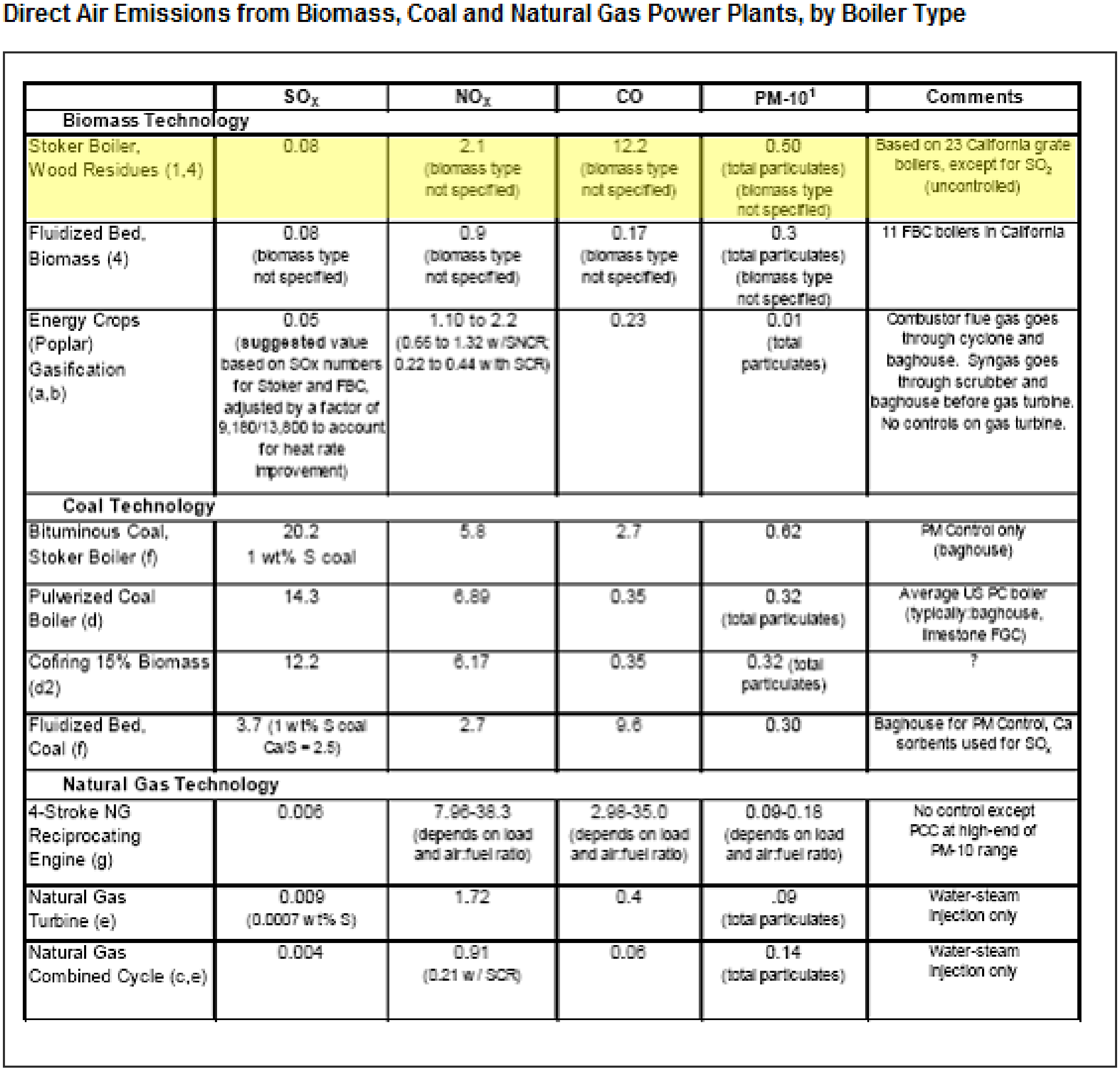
Enter the costs in Column E below for the various fuels in your area, or just use the numbers already listed.

FUEL	ENERGY CONTENT	UNIT PRICE		HEAT CONVERSION EFFICIENCY	COST PER MILLION BTU	INPUT HP	HRS	$/YEAR
Kerosene	134,000 BTU/gal	$3.50	/gal	85 %	$30.73	100	3300	$339,452
#2 Fuel Oil	138,000 BTU/gal	$3.50	/gal	80	$31.70	100	3300	$350,214
Propane	92,000 BTU/gal	$2.20	/gal	85	$28.13	100	3300	$310,778
Natural Gas	100,000 BTU/therm	$0.500	/therm	85	$5.88	100	3300	$64,981
Electricity - Resistance	3,412 BTU/kWh	$0.08	/kWh	100	$24.62	100	3300	$271,960
Electricity - Heat Pump	3,412 BTU/kWh	$0.08	/kWh	200	$12.31	100	3300	$135,980
Coal	13,200 BTU/lb	$175.00	/ton	75	$8.84	100	3300	$97,635
Firewood-Hardwood	25,000,000 BTU/cord	$160.00	/cord	60	$10.67	100	3300	$117,832
Wood Pellets	8,200 BTU/lb	$200.00	/ton	80	$15.24	100	3300	$168,396
Green wood residue	4,692 BTU/lb	$50.00	/ton	65	$8.20	100	3300	$90,553
KD wood residue	8,500 BTU/lb	$45.00	/ton	70	$3.78	100	3300	$41,773
Shelled Corn	6,800 BTU/lb	$0.00	/bushel	75	$0.00	100	3300	?

Figure D.4 - Simple Payback Calculation of Biomass Boiler

Year	Maintenance Cost	Wood Chips Cost (assuming 0.5% inflation)	Natural Gas Savings (assuming 2% inflation)	Equestrian Waste Savings	Sum of Annual Costs & Savings (includes initial cost)	Cumulative Cost of System
1	$ 10,000.00	$ 90,553.00	$ (64,981.00)	$ (33,960.00)	$ 2,860,500.94	**$2,860,500.94**
2	$ 10,000.00	$ 91,005.77	$ (66,280.62)	$ (33,960.00)	$ 765.14	**$2,861,266.09**
3	$ 10,000.00	$ 91,460.79	$ (68,600.44)	$ (33,960.00)	$ (1,099.65)	**$2,860,166.44**
4	$ 10,000.00	$ 91,918.10	$ (71,001.46)	$ (33,960.00)	$ (3,043.36)	**$2,857,123.08**
5	$ 15,000.00	$ 92,377.69	$ (73,486.51)	$ (33,960.00)	$ (68.82)	**$2,857,054.26**
6	$ 10,000.00	$ 92,839.58	$ (76,058.54)	$ (33,960.00)	$ (7,178.96)	**$2,849,875.30**
7	$ 10,000.00	$ 93,303.77	$ (78,720.58)	$ (33,960.00)	$ (9,376.81)	**$2,840,498.49**
8	$ 10,000.00	$ 93,770.29	$ (81,475.81)	$ (33,960.00)	$ (11,665.51)	**$2,828,832.98**
9	$ 10,000.00	$ 94,239.14	$ (84,327.46)	$ (33,960.00)	$ (14,048.31)	**$2,814,784.66**
10	$ 15,000.00	$ 94,710.34	$ (87,278.92)	$ (33,960.00)	$ (11,528.58)	**$2,803,256.08**
11	$ 10,000.00	$ 95,183.89	$ (90,333.68)	$ (33,960.00)	$ (19,109.79)	**$2,784,146.30**
12	$ 10,000.00	$ 95,659.81	$ (93,495.36)	$ (33,960.00)	$ (21,795.55)	**$2,762,350.75**
13	$ 10,000.00	$ 96,138.11	$ (96,767.70)	$ (33,960.00)	$ (24,589.59)	**$2,737,761.16**
14	$ 10,000.00	$ 96,618.80	$ (100,154.57)	$ (33,960.00)	$ (27,495.77)	**$2,710,265.39**
15	$ 15,000.00	$ 97,101.90	$ (103,659.98)	$ (33,960.00)	$ (25,518.08)	**$2,684,747.31**
16	$ 10,000.00	$ 97,587.40	$ (107,288.08)	$ (33,960.00)	$ (33,660.67)	**$2,651,086.64**
17	$ 10,000.00	$ 98,075.34	$ (111,043.16)	$ (33,960.00)	$ (36,927.82)	**$2,614,158.82**
18	$ 10,000.00	$ 98,565.72	$ (114,929.67)	$ (33,960.00)	$ (40,323.95)	**$2,573,834.87**
19	**$ 10,000.00**	**$ 99,058.55**	**$ (118,952.21)**	**$ (33,960.00)**	**$ (43,853.66)**	**$2,529,981.21**
20	$ 15,000.00	$ 99,553.84	$ (123,115.54)	$ (33,960.00)	$ (42,521.70)	**$2,487,459.52**
21	$ 10,000.00	$ 100,051.61	$ (127,424.58)	$ (33,960.00)	$ (51,332.97)	**$2,436,126.55**
22	$ 10,000.00	$ 100,551.87	$ (131,884.44)	$ (33,960.00)	$ (55,292.57)	**$2,380,833.97**
23	$ 10,000.00	$ 101,054.63	$ (136,500.39)	$ (33,960.00)	$ (59,405.77)	**$2,321,428.20**
24	$ 10,000.00	$ 101,559.90	$ (141,277.91)	$ (33,960.00)	$ (63,678.01)	**$2,257,750.20**
25	$ 10,000.00	$ 102,067.70	$ (146,222.64)	$ (33,960.00)	$ (68,114.94)	**$2,189,635.26**

Figure D.5 – Biomass Boiler Emissions Data *(UCSUSA)*

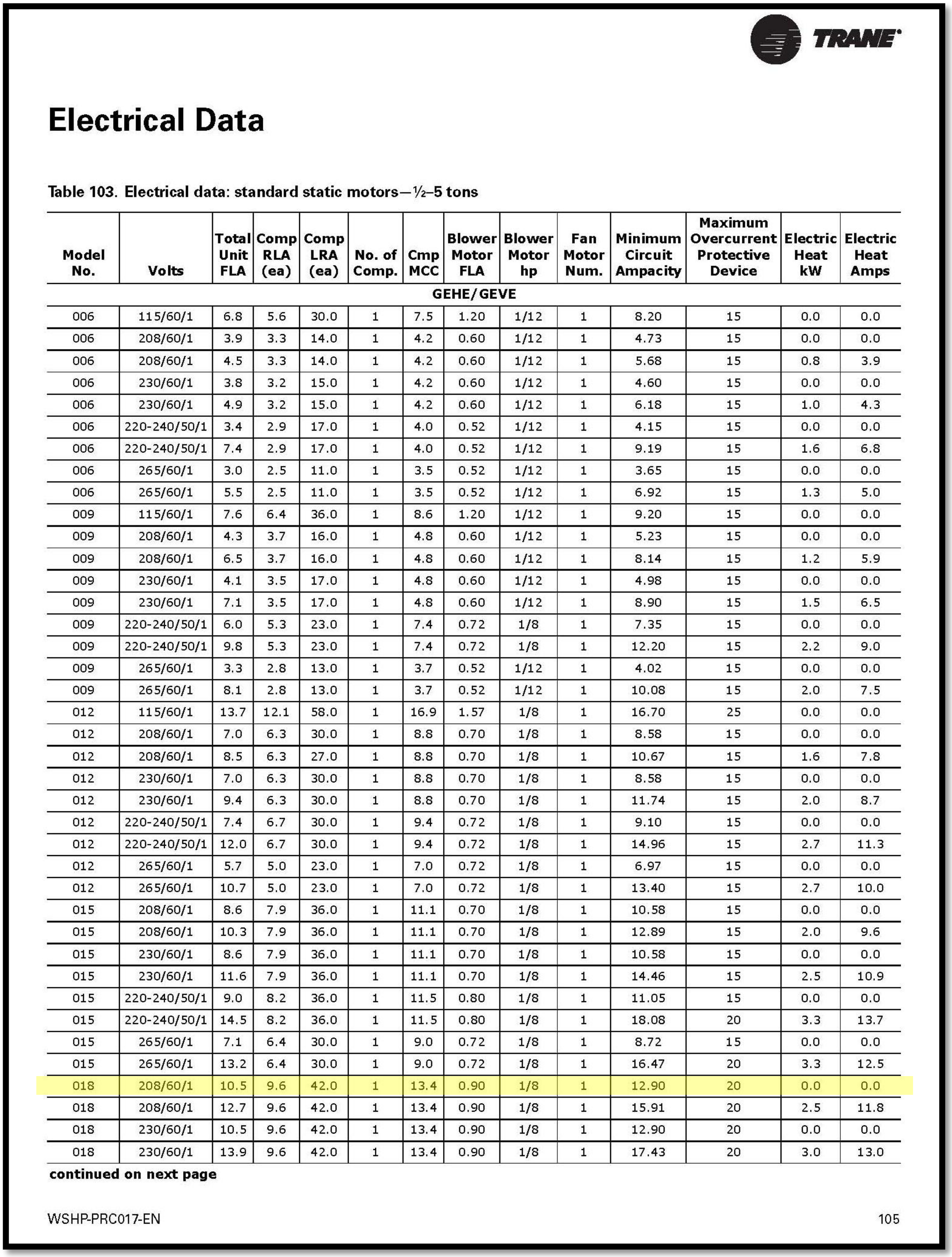


Direct Air Emissions from Biomass, Coal and Natural Gas Power Plants, by Boiler Type

	SO_X	NO_X	CO	PM-10[1]	Comments
Biomass Technology					
Stoker Boiler, Wood Residues (1,4)	0.08	2.1 (biomass type not specified)	12.2 (biomass type not specified)	0.50 (total particulates) (biomass type not specified)	Based on 23 California grate boilers, except for SO_2 (uncontrolled)
Fluidized Bed, Biomass (4)	0.08 (biomass type not specified)	0.9 (biomass type not specified)	0.17 (biomass type not specified)	0.3 (total particulates) (biomass type not specified)	11 FBC boilers in California
Energy Crops (Poplar) Gasification (a,b)	0.05 (suggested value based on SOx numbers for Stoker and FBC, adjusted by a factor of 9,180/13,800 to account for heat rate improvement)	1.10 to 2.2 (0.66 to 1.32 w/SNCR; 0.22 to 0.44 with SCR)	0.23	0.01 (total particulates)	Combustor flue gas goes through cyclone and baghouse. Syngas goes through scrubber and baghouse before gas turbine. No controls on gas turbine.
Coal Technology					
Bituminous Coal, Stoker Boiler (f)	20.2 1 wt% S coal	5.8	2.7	0.62	PM Control only (baghouse)
Pulverized Coal Boiler (d)	14.3	6.89	0.35	0.32 (total particulates)	Average US PC boiler (typically baghouse, limestone FGC)
Cofiring 15% Biomass (d2)	12.2	6.17	0.35	0.32 (total particulates)	?
Fluidized Bed, Coal (f)	3.7 (1 wt% S coal Ca/S = 2.5)	2.7	9.6	0.30	Baghouse for PM Control, Ca sorbents used for SO_x
Natural Gas Technology					
4-Stroke NG Reciprocating Engine (g)	0.006	7.96-38.3 (depends on load and air:fuel ratio)	2.98-35.0 (depends on load and air:fuel ratio)	0.09-0.18 (depends on load and air:fuel ratio)	No control except PCC at high-end of PM-10 range
Natural Gas Turbine (e)	0.009 (0.0007 wt% S)	1.72	0.4	.09 (total particulates)	Water-steam injection only
Natural Gas Combined Cycle (c,e)	0.004	0.91 (0.21 w/ SCR)	0.06	0.14 (total particulates)	Water-steam injection only

(Source: DOE, 2003 [18])

Figure E.1 – Electrical Data for Ground Source Heat Pumps *(Trane)*



Electrical Data

Table 103. Electrical data: standard static motors—½–5 tons

Model No.	Volts	Total Unit FLA	Comp RLA (ea)	Comp LRA (ea)	No. of Comp.	Cmp MCC	Blower Motor FLA	Blower Motor hp	Fan Motor Num.	Minimum Circuit Ampacity	Maximum Overcurrent Protective Device	Electric Heat kW	Electric Heat Amps
GEHE/GEVE													
006	115/60/1	6.8	5.6	30.0	1	7.5	1.20	1/12	1	8.20	15	0.0	0.0
006	208/60/1	3.9	3.3	14.0	1	4.2	0.60	1/12	1	4.73	15	0.0	0.0
006	208/60/1	4.5	3.3	14.0	1	4.2	0.60	1/12	1	5.68	15	0.8	3.9
006	230/60/1	3.8	3.2	15.0	1	4.2	0.60	1/12	1	4.60	15	0.0	0.0
006	230/60/1	4.9	3.2	15.0	1	4.2	0.60	1/12	1	6.18	15	1.0	4.3
006	220-240/50/1	3.4	2.9	17.0	1	4.0	0.52	1/12	1	4.15	15	0.0	0.0
006	220-240/50/1	7.4	2.9	17.0	1	4.0	0.52	1/12	1	9.19	15	1.6	6.8
006	265/60/1	3.0	2.5	11.0	1	3.5	0.52	1/12	1	3.65	15	0.0	0.0
006	265/60/1	5.5	2.5	11.0	1	3.5	0.52	1/12	1	6.92	15	1.3	5.0
009	115/60/1	7.6	6.4	36.0	1	8.6	1.20	1/12	1	9.20	15	0.0	0.0
009	208/60/1	4.3	3.7	16.0	1	4.8	0.60	1/12	1	5.23	15	0.0	0.0
009	208/60/1	6.5	3.7	16.0	1	4.8	0.60	1/12	1	8.14	15	1.2	5.9
009	230/60/1	4.1	3.5	17.0	1	4.8	0.60	1/12	1	4.98	15	0.0	0.0
009	230/60/1	7.1	3.5	17.0	1	4.8	0.60	1/12	1	8.90	15	1.5	6.5
009	220-240/50/1	6.0	5.3	23.0	1	7.4	0.72	1/8	1	7.35	15	0.0	0.0
009	220-240/50/1	9.8	5.3	23.0	1	7.4	0.72	1/8	1	12.20	15	2.2	9.0
009	265/60/1	3.3	2.8	13.0	1	3.7	0.52	1/12	1	4.02	15	0.0	0.0
009	265/60/1	8.1	2.8	13.0	1	3.7	0.52	1/12	1	10.08	15	2.0	7.5
012	115/60/1	13.7	12.1	58.0	1	16.9	1.57	1/8	1	16.70	25	0.0	0.0
012	208/60/1	7.0	6.3	30.0	1	8.8	0.70	1/8	1	8.58	15	0.0	0.0
012	208/60/1	8.5	6.3	27.0	1	8.8	0.70	1/8	1	10.67	15	1.6	7.8
012	230/60/1	7.0	6.3	30.0	1	8.8	0.70	1/8	1	8.58	15	0.0	0.0
012	230/60/1	9.4	6.3	30.0	1	8.8	0.70	1/8	1	11.74	15	2.0	8.7
012	220-240/50/1	7.4	6.7	30.0	1	9.4	0.72	1/8	1	9.10	15	0.0	0.0
012	220-240/50/1	12.0	6.7	30.0	1	9.4	0.72	1/8	1	14.96	15	2.7	11.3
012	265/60/1	5.7	5.0	23.0	1	7.0	0.72	1/8	1	6.97	15	0.0	0.0
012	265/60/1	10.7	5.0	23.0	1	7.0	0.72	1/8	1	13.40	15	2.7	10.0
015	208/60/1	8.6	7.9	36.0	1	11.1	0.70	1/8	1	10.58	15	0.0	0.0
015	208/60/1	10.3	7.9	36.0	1	11.1	0.70	1/8	1	12.89	15	2.0	9.6
015	230/60/1	8.6	7.9	36.0	1	11.1	0.70	1/8	1	10.58	15	0.0	0.0
015	230/60/1	11.6	7.9	36.0	1	11.1	0.70	1/8	1	14.46	15	2.5	10.9
015	220-240/50/1	9.0	8.2	36.0	1	11.5	0.80	1/8	1	11.05	15	0.0	0.0
015	220-240/50/1	14.5	8.2	36.0	1	11.5	0.80	1/8	1	18.08	20	3.3	13.7
015	265/60/1	7.1	6.4	30.0	1	9.0	0.72	1/8	1	8.72	15	0.0	0.0
015	265/60/1	13.2	6.4	30.0	1	9.0	0.72	1/8	1	16.47	20	3.3	12.5
018	208/60/1	10.5	9.6	42.0	1	13.4	0.90	1/8	1	12.90	20	0.0	0.0
018	208/60/1	12.7	9.6	42.0	1	13.4	0.90	1/8	1	15.91	20	2.5	11.8
018	230/60/1	10.5	9.6	42.0	1	13.4	0.90	1/8	1	12.90	20	0.0	0.0
018	230/60/1	13.9	9.6	42.0	1	13.4	0.90	1/8	1	17.43	20	3.0	13.0

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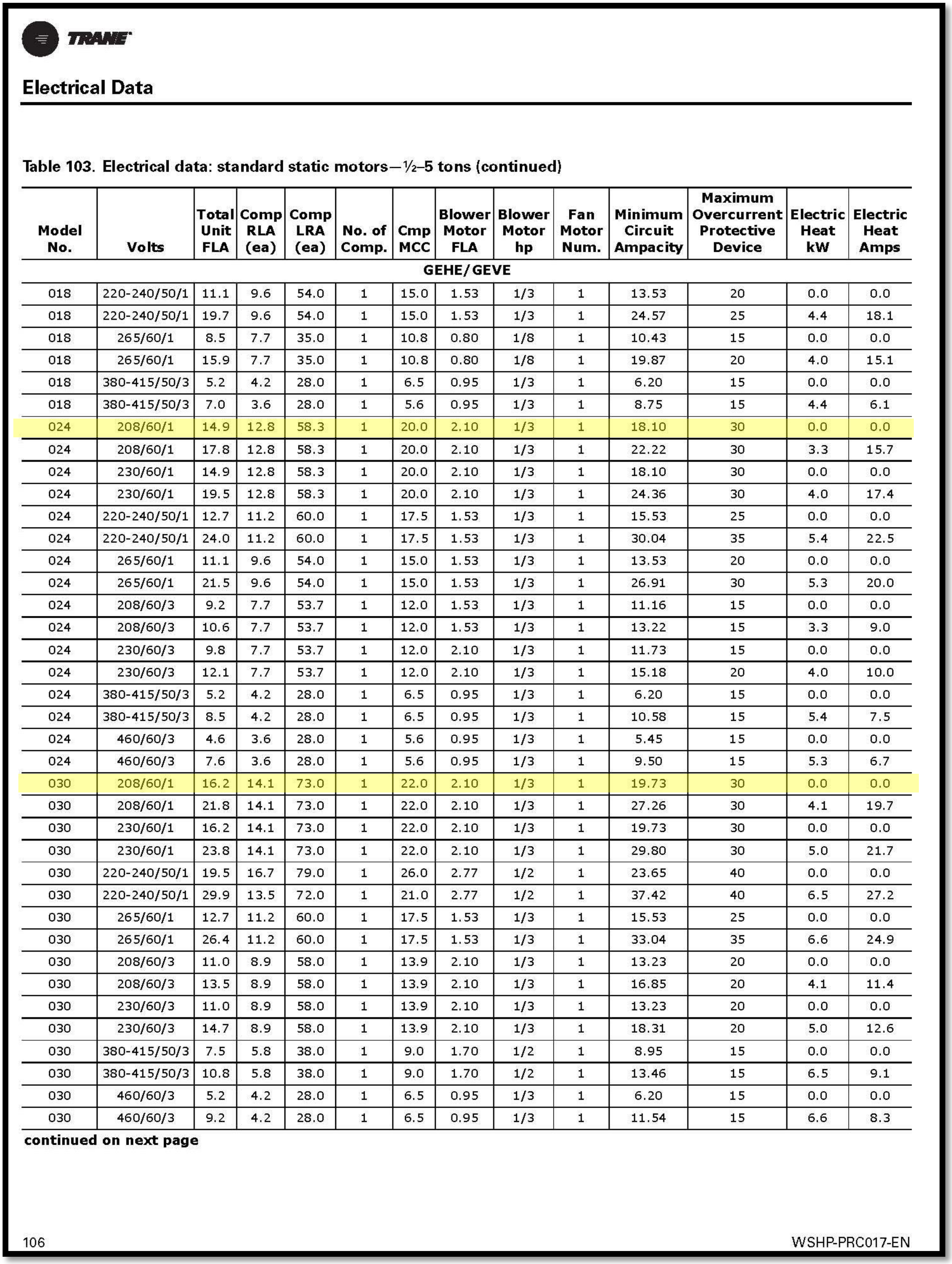
Figure E.1 – Electrical Data for Ground Source Heat Pumps (continued)



Electrical Data

Table 103. Electrical data: standard static motors—½–5 tons (continued)

Model No.	Volts	Total Unit FLA	Comp RLA (ea)	Comp LRA (ea)	No. of Comp.	Cmp MCC	Blower Motor FLA	Blower Motor hp	Fan Motor Num.	Minimum Circuit Ampacity	Maximum Overcurrent Protective Device	Electric Heat kW	Electric Heat Amps
GEHE/GEVE													
018	220-240/50/1	11.1	9.6	54.0	1	15.0	1.53	1/3	1	13.53	20	0.0	0.0
018	220-240/50/1	19.7	9.6	54.0	1	15.0	1.53	1/3	1	24.57	25	4.4	18.1
018	265/60/1	8.5	7.7	35.0	1	10.8	0.80	1/8	1	10.43	15	0.0	0.0
018	265/60/1	15.9	7.7	35.0	1	10.8	0.80	1/8	1	19.87	20	4.0	15.1
018	380-415/50/3	5.2	4.2	28.0	1	6.5	0.95	1/3	1	6.20	15	0.0	0.0
018	380-415/50/3	7.0	3.6	28.0	1	5.6	0.95	1/3	1	8.75	15	4.4	6.1
024	208/60/1	14.9	12.8	58.3	1	20.0	2.10	1/3	1	18.10	30	0.0	0.0
024	208/60/1	17.8	12.8	58.3	1	20.0	2.10	1/3	1	22.22	30	3.3	15.7
024	230/60/1	14.9	12.8	58.3	1	20.0	2.10	1/3	1	18.10	30	0.0	0.0
024	230/60/1	19.5	12.8	58.3	1	20.0	2.10	1/3	1	24.36	30	4.0	17.4
024	220-240/50/1	12.7	11.2	60.0	1	17.5	1.53	1/3	1	15.53	25	0.0	0.0
024	220-240/50/1	24.0	11.2	60.0	1	17.5	1.53	1/3	1	30.04	35	5.4	22.5
024	265/60/1	11.1	9.6	54.0	1	15.0	1.53	1/3	1	13.53	20	0.0	0.0
024	265/60/1	21.5	9.6	54.0	1	15.0	1.53	1/3	1	26.91	30	5.3	20.0
024	208/60/3	9.2	7.7	53.7	1	12.0	1.53	1/3	1	11.16	15	0.0	0.0
024	208/60/3	10.6	7.7	53.7	1	12.0	1.53	1/3	1	13.22	15	3.3	9.0
024	230/60/3	9.8	7.7	53.7	1	12.0	2.10	1/3	1	11.73	15	0.0	0.0
024	230/60/3	12.1	7.7	53.7	1	12.0	2.10	1/3	1	15.18	20	4.0	10.0
024	380-415/50/3	5.2	4.2	28.0	1	6.5	0.95	1/3	1	6.20	15	0.0	0.0
024	380-415/50/3	8.5	4.2	28.0	1	6.5	0.95	1/3	1	10.58	15	5.4	7.5
024	460/60/3	4.6	3.6	28.0	1	5.6	0.95	1/3	1	5.45	15	0.0	0.0
024	460/60/3	7.6	3.6	28.0	1	5.6	0.95	1/3	1	9.50	15	5.3	6.7
030	208/60/1	16.2	14.1	73.0	1	22.0	2.10	1/3	1	19.73	30	0.0	0.0
030	208/60/1	21.8	14.1	73.0	1	22.0	2.10	1/3	1	27.26	30	4.1	19.7
030	230/60/1	16.2	14.1	73.0	1	22.0	2.10	1/3	1	19.73	30	0.0	0.0
030	230/60/1	23.8	14.1	73.0	1	22.0	2.10	1/3	1	29.80	30	5.0	21.7
030	220-240/50/1	19.5	16.7	79.0	1	26.0	2.77	1/2	1	23.65	40	0.0	0.0
030	220-240/50/1	29.9	13.5	72.0	1	21.0	2.77	1/2	1	37.42	40	6.5	27.2
030	265/60/1	12.7	11.2	60.0	1	17.5	1.53	1/3	1	15.53	25	0.0	0.0
030	265/60/1	26.4	11.2	60.0	1	17.5	1.53	1/3	1	33.04	35	6.6	24.9
030	208/60/3	11.0	8.9	58.0	1	13.9	2.10	1/3	1	13.23	20	0.0	0.0
030	208/60/3	13.5	8.9	58.0	1	13.9	2.10	1/3	1	16.85	20	4.1	11.4
030	230/60/3	11.0	8.9	58.0	1	13.9	2.10	1/3	1	13.23	20	0.0	0.0
030	230/60/3	14.7	8.9	58.0	1	13.9	2.10	1/3	1	18.31	20	5.0	12.6
030	380-415/50/3	7.5	5.8	38.0	1	9.0	1.70	1/2	1	8.95	15	0.0	0.0
030	380-415/50/3	10.8	5.8	38.0	1	9.0	1.70	1/2	1	13.46	15	6.5	9.1
030	460/60/3	5.2	4.2	28.0	1	6.5	0.95	1/3	1	6.20	15	0.0	0.0
030	460/60/3	9.2	4.2	28.0	1	6.5	0.95	1/3	1	11.54	15	6.6	8.3

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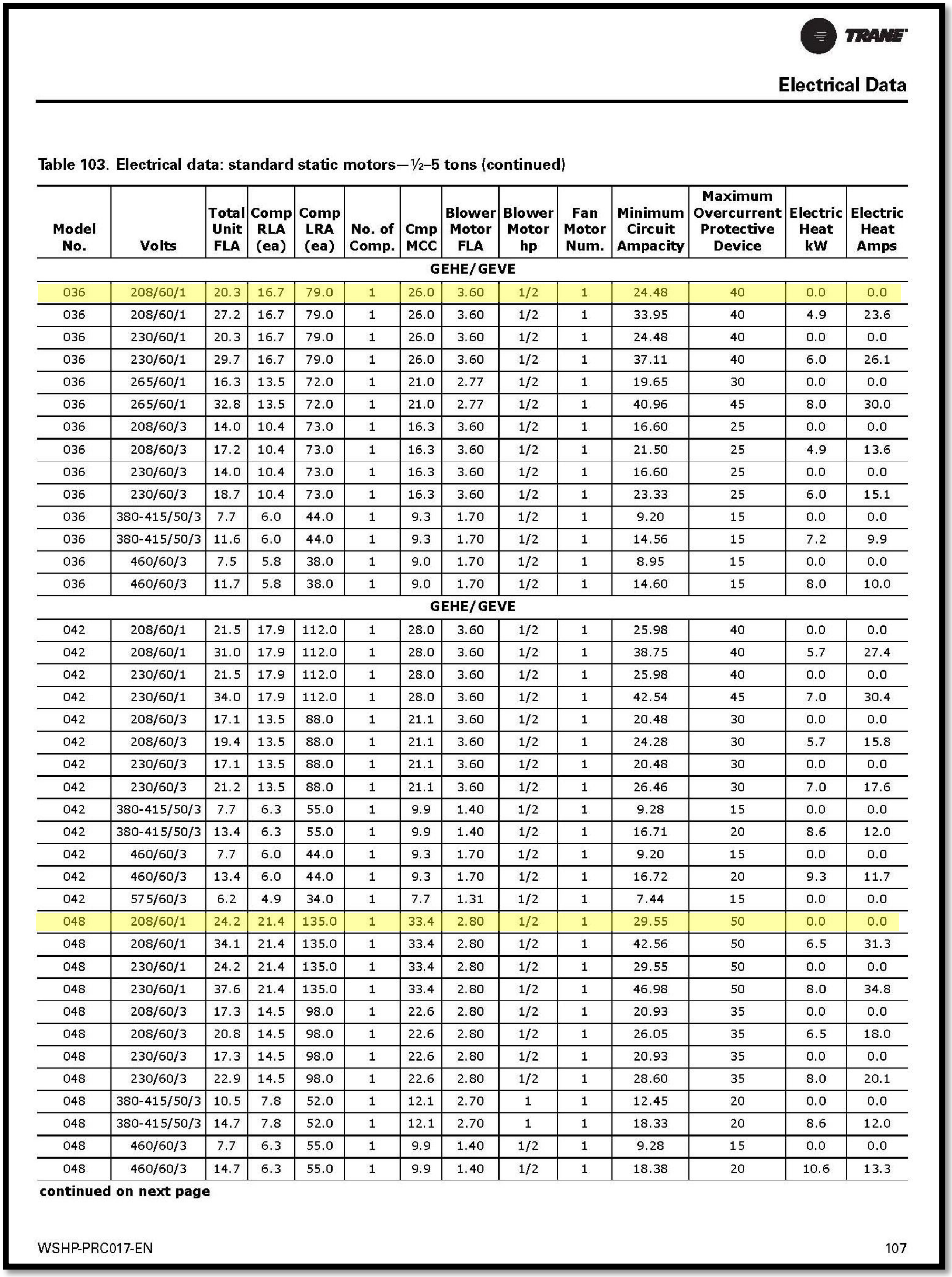
Figure E.1 – Electrical Data for Ground Source Heat Pumps (continued)



Electrical Data

Table 103. Electrical data: standard static motors—½–5 tons (continued)

Model No.	Volts	Total Unit FLA	Comp RLA (ea)	Comp LRA (ea)	No. of Comp.	Cmp MCC	Blower Motor FLA	Blower Motor hp	Fan Motor Num.	Minimum Circuit Ampacity	Maximum Overcurrent Protective Device	Electric Heat kW	Electric Heat Amps
GEHE/GEVE													
036	208/60/1	20.3	16.7	79.0	1	26.0	3.60	1/2	1	24.48	40	0.0	0.0
036	208/60/1	27.2	16.7	79.0	1	26.0	3.60	1/2	1	33.95	40	4.9	23.6
036	230/60/1	20.3	16.7	79.0	1	26.0	3.60	1/2	1	24.48	40	0.0	0.0
036	230/60/1	29.7	16.7	79.0	1	26.0	3.60	1/2	1	37.11	40	6.0	26.1
036	265/60/1	16.3	13.5	72.0	1	21.0	2.77	1/2	1	19.65	30	0.0	0.0
036	265/60/1	32.8	13.5	72.0	1	21.0	2.77	1/2	1	40.96	45	8.0	30.0
036	208/60/3	14.0	10.4	73.0	1	16.3	3.60	1/2	1	16.60	25	0.0	0.0
036	208/60/3	17.2	10.4	73.0	1	16.3	3.60	1/2	1	21.50	25	4.9	13.6
036	230/60/3	14.0	10.4	73.0	1	16.3	3.60	1/2	1	16.60	25	0.0	0.0
036	230/60/3	18.7	10.4	73.0	1	16.3	3.60	1/2	1	23.33	25	6.0	15.1
036	380-415/50/3	7.7	6.0	44.0	1	9.3	1.70	1/2	1	9.20	15	0.0	0.0
036	380-415/50/3	11.6	6.0	44.0	1	9.3	1.70	1/2	1	14.56	15	7.2	9.9
036	460/60/3	7.5	5.8	38.0	1	9.0	1.70	1/2	1	8.95	15	0.0	0.0
036	460/60/3	11.7	5.8	38.0	1	9.0	1.70	1/2	1	14.60	15	8.0	10.0
GEHE/GEVE													
042	208/60/1	21.5	17.9	112.0	1	28.0	3.60	1/2	1	25.98	40	0.0	0.0
042	208/60/1	31.0	17.9	112.0	1	28.0	3.60	1/2	1	38.75	40	5.7	27.4
042	230/60/1	21.5	17.9	112.0	1	28.0	3.60	1/2	1	25.98	40	0.0	0.0
042	230/60/1	34.0	17.9	112.0	1	28.0	3.60	1/2	1	42.54	45	7.0	30.4
042	208/60/3	17.1	13.5	88.0	1	21.1	3.60	1/2	1	20.48	30	0.0	0.0
042	208/60/3	19.4	13.5	88.0	1	21.1	3.60	1/2	1	24.28	30	5.7	15.8
042	230/60/3	17.1	13.5	88.0	1	21.1	3.60	1/2	1	20.48	30	0.0	0.0
042	230/60/3	21.2	13.5	88.0	1	21.1	3.60	1/2	1	26.46	30	7.0	17.6
042	380-415/50/3	7.7	6.3	55.0	1	9.9	1.40	1/2	1	9.28	15	0.0	0.0
042	380-415/50/3	13.4	6.3	55.0	1	9.9	1.40	1/2	1	16.71	20	8.6	12.0
042	460/60/3	7.7	6.0	44.0	1	9.3	1.70	1/2	1	9.20	15	0.0	0.0
042	460/60/3	13.4	6.0	44.0	1	9.3	1.70	1/2	1	16.72	20	9.3	11.7
042	575/60/3	6.2	4.9	34.0	1	7.7	1.31	1/2	1	7.44	15	0.0	0.0
048	208/60/1	24.2	21.4	135.0	1	33.4	2.80	1/2	1	29.55	50	0.0	0.0
048	208/60/1	34.1	21.4	135.0	1	33.4	2.80	1/2	1	42.56	50	6.5	31.3
048	230/60/1	24.2	21.4	135.0	1	33.4	2.80	1/2	1	29.55	50	0.0	0.0
048	230/60/1	37.6	21.4	135.0	1	33.4	2.80	1/2	1	46.98	50	8.0	34.8
048	208/60/3	17.3	14.5	98.0	1	22.6	2.80	1/2	1	20.93	35	0.0	0.0
048	208/60/3	20.8	14.5	98.0	1	22.6	2.80	1/2	1	26.05	35	6.5	18.0
048	230/60/3	17.3	14.5	98.0	1	22.6	2.80	1/2	1	20.93	35	0.0	0.0
048	230/60/3	22.9	14.5	98.0	1	22.6	2.80	1/2	1	28.60	35	8.0	20.1
048	380-415/50/3	10.5	7.8	52.0	1	12.1	2.70	1	1	12.45	20	0.0	0.0
048	380-415/50/3	14.7	7.8	52.0	1	12.1	2.70	1	1	18.33	20	8.6	12.0
048	460/60/3	7.7	6.3	55.0	1	9.9	1.40	1/2	1	9.28	15	0.0	0.0
048	460/60/3	14.7	6.3	55.0	1	9.9	1.40	1/2	1	18.38	20	10.6	13.3

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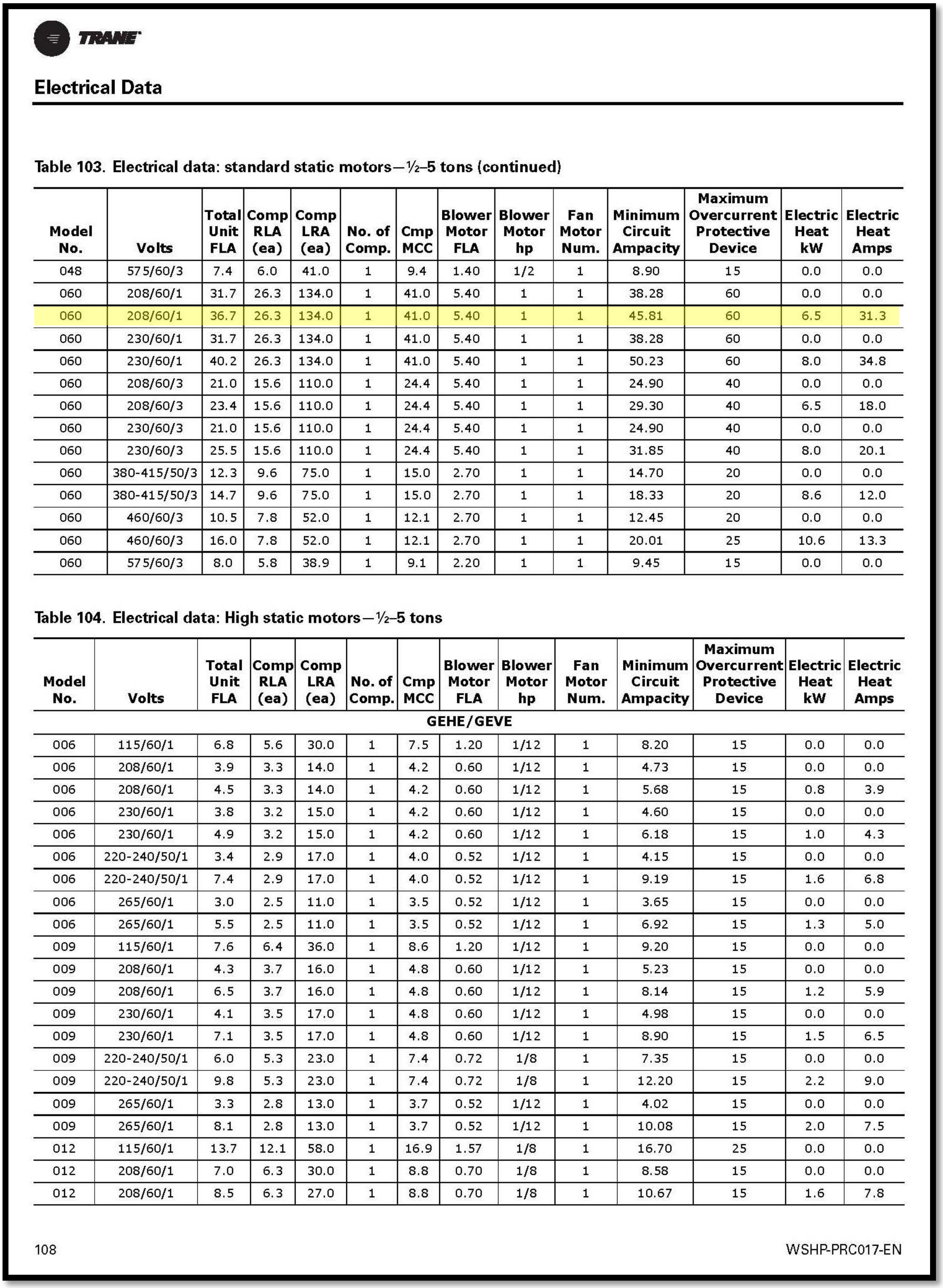
Figure E.1 – Electrical Data for Ground Source Heat Pumps (continued)



Electrical Data

Table 103. Electrical data: standard static motors—½–5 tons (continued)

Model No.	Volts	Total Unit FLA	Comp RLA (ea)	Comp LRA (ea)	No. of Comp.	Cmp MCC	Blower Motor FLA	Blower Motor hp	Fan Motor Num.	Minimum Circuit Ampacity	Maximum Overcurrent Protective Device	Electric Heat kW	Electric Heat Amps
048	575/60/3	7.4	6.0	41.0	1	9.4	1.40	1/2	1	8.90	15	0.0	0.0
060	208/60/1	31.7	26.3	134.0	1	41.0	5.40	1	1	38.28	60	0.0	0.0
060	208/60/1	36.7	26.3	134.0	1	41.0	5.40	1	1	45.81	60	6.5	31.3
060	230/60/1	31.7	26.3	134.0	1	41.0	5.40	1	1	38.28	60	0.0	0.0
060	230/60/1	40.2	26.3	134.0	1	41.0	5.40	1	1	50.23	60	8.0	34.8
060	208/60/3	21.0	15.6	110.0	1	24.4	5.40	1	1	24.90	40	0.0	0.0
060	208/60/3	23.4	15.6	110.0	1	24.4	5.40	1	1	29.30	40	6.5	18.0
060	230/60/3	21.0	15.6	110.0	1	24.4	5.40	1	1	24.90	40	0.0	0.0
060	230/60/3	25.5	15.6	110.0	1	24.4	5.40	1	1	31.85	40	8.0	20.1
060	380-415/50/3	12.3	9.6	75.0	1	15.0	2.70	1	1	14.70	20	0.0	0.0
060	380-415/50/3	14.7	9.6	75.0	1	15.0	2.70	1	1	18.33	20	8.6	12.0
060	460/60/3	10.5	7.8	52.0	1	12.1	2.70	1	1	12.45	20	0.0	0.0
060	460/60/3	16.0	7.8	52.0	1	12.1	2.70	1	1	20.01	25	10.6	13.3
060	575/60/3	8.0	5.8	38.9	1	9.1	2.20	1	1	9.45	15	0.0	0.0

Table 104. Electrical data: High static motors—½–5 tons

Model No.	Volts	Total Unit FLA	Comp RLA (ea)	Comp LRA (ea)	No. of Comp.	Cmp MCC	Blower Motor FLA	Blower Motor hp	Fan Motor Num.	Minimum Circuit Ampacity	Maximum Overcurrent Protective Device	Electric Heat kW	Electric Heat Amps
GEHE/GEVE													
006	115/60/1	6.8	5.6	30.0	1	7.5	1.20	1/12	1	8.20	15	0.0	0.0
006	208/60/1	3.9	3.3	14.0	1	4.2	0.60	1/12	1	4.73	15	0.0	0.0
006	208/60/1	4.5	3.3	14.0	1	4.2	0.60	1/12	1	5.68	15	0.8	3.9
006	230/60/1	3.8	3.2	15.0	1	4.2	0.60	1/12	1	4.60	15	0.0	0.0
006	230/60/1	4.9	3.2	15.0	1	4.2	0.60	1/12	1	6.18	15	1.0	4.3
006	220-240/50/1	3.4	2.9	17.0	1	4.0	0.52	1/12	1	4.15	15	0.0	0.0
006	220-240/50/1	7.4	2.9	17.0	1	4.0	0.52	1/12	1	9.19	15	1.6	6.8
006	265/60/1	3.0	2.5	11.0	1	3.5	0.52	1/12	1	3.65	15	0.0	0.0
006	265/60/1	5.5	2.5	11.0	1	3.5	0.52	1/12	1	6.92	15	1.3	5.0
009	115/60/1	7.6	6.4	36.0	1	8.6	1.20	1/12	1	9.20	15	0.0	0.0
009	208/60/1	4.3	3.7	16.0	1	4.8	0.60	1/12	1	5.23	15	0.0	0.0
009	208/60/1	6.5	3.7	16.0	1	4.8	0.60	1/12	1	8.14	15	1.2	5.9
009	230/60/1	4.1	3.5	17.0	1	4.8	0.60	1/12	1	4.98	15	0.0	0.0
009	230/60/1	7.1	3.5	17.0	1	4.8	0.60	1/12	1	8.90	15	1.5	6.5
009	220-240/50/1	6.0	5.3	23.0	1	7.4	0.72	1/8	1	7.35	15	0.0	0.0
009	220-240/50/1	9.8	5.3	23.0	1	7.4	0.72	1/8	1	12.20	15	2.2	9.0
009	265/60/1	3.3	2.8	13.0	1	3.7	0.52	1/12	1	4.02	15	0.0	0.0
009	265/60/1	8.1	2.8	13.0	1	3.7	0.52	1/12	1	10.08	15	2.0	7.5
012	115/60/1	13.7	12.1	58.0	1	16.9	1.57	1/8	1	16.70	25	0.0	0.0
012	208/60/1	7.0	6.3	30.0	1	8.8	0.70	1/8	1	8.58	15	0.0	0.0
012	208/60/1	8.5	6.3	27.0	1	8.8	0.70	1/8	1	10.67	15	1.6	7.8

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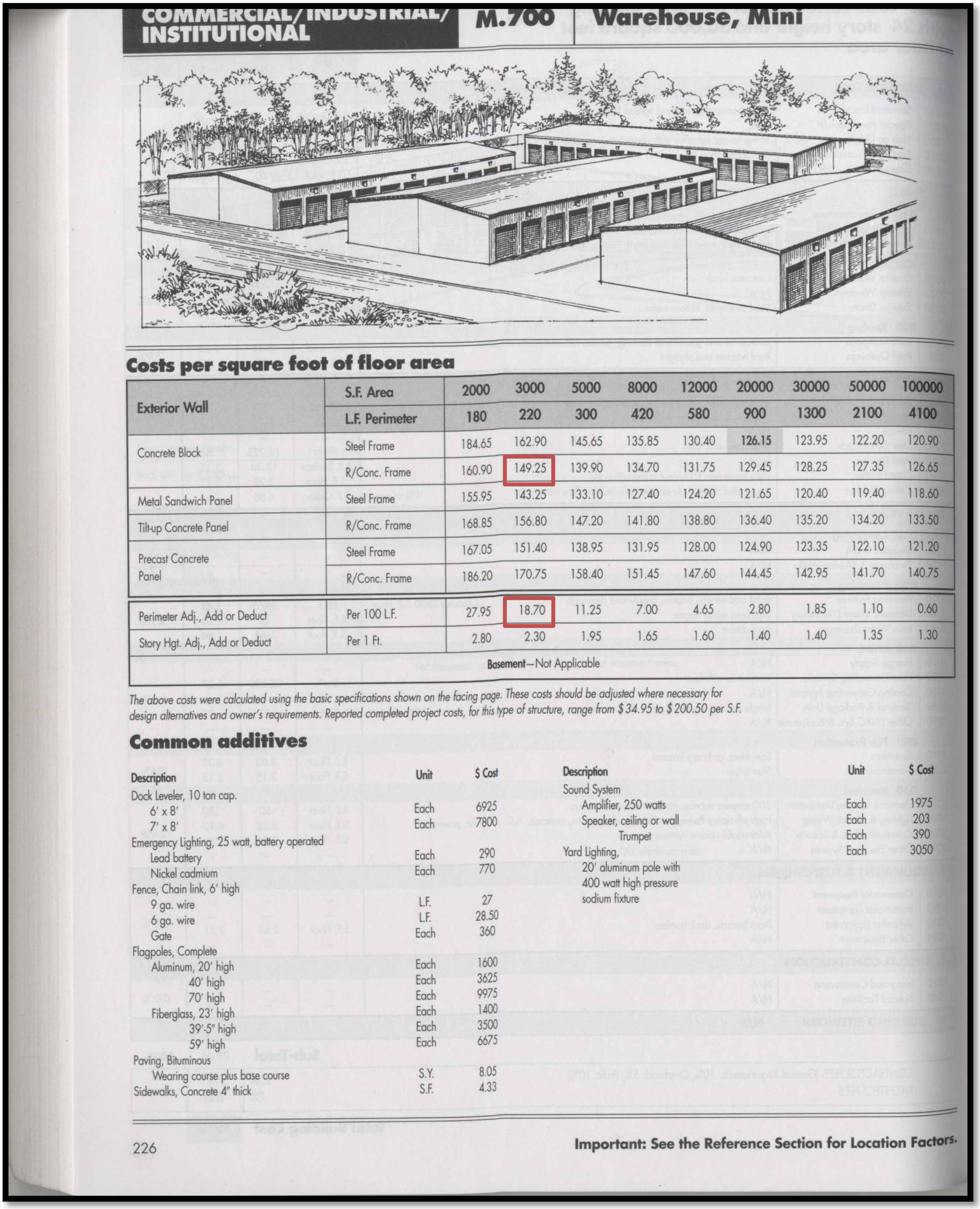
APPENDIX F

Figure F.1 - Initial Cost of Geothermal System

System Component	Unit	Material [$/Unit]	Labor [$/Unit]	Quantity	COST		
					Material	Labor	TOTAL
Drill Boreholes, 6" diameter	L.F.	$0.00	$6.50	25,000	$0.00	$162,500.00	$162,500.00
Trench Excavation for Header, 8" wide, 48" deep and backfill	L.F.	$0.00	$1.03	3518	$0.00	$3,623.54	$3,623.54
U-tube piping, 1-1/4" HDPE	L.F.	$0.91	$0.00	52,392	$47,676.72	$0.00	$47,676.72
Header Piping, 4" HDPE	L.F.	$3.05	$0.00	1526	$4,654.30	$0.00	$4,654.30
Fusion for HDPE joint, 1-1/4" (every 40' of piping)	EA	$0.00	$8.30	718	$0.00	$5,959.40	$5,959.40
Fusion for HDPE joint, 4" (every 40' of piping)	EA	$0.00	$18.85	88	$0.00	$1,658.80	$1,658.80
Sand, grout mixture and pipe bedding in trench	C.Y.	$1.60	$0.81	523	$836.80	$423.63	$1,260.43
Granular Bentonite, 50lb bag (0.625 ft^3)	Bag	$9.80	$0.81	1188	$11,642.40	$962.28	$12,604.68
90d Elbow, 4" HDPE	EA	$18.70	$0.00	36	$673.20	$0.00	$673.20
90d Elbow, 1-1/4" HDPE	EA	$6.70	$0.00	252	$1,688.40	$0.00	$1,688.40
Tee, 4" HDPE	EA	$22.50	$0.00	22	$495.00	$0.00	$495.00
7-1/2 hp, 1750RPM Centrifugal Pump, end suction, base mounted	EA	$7,600.00	$465.00	2	$15,200.00	$930.00	$16,130.00
Water Source Heat Pump	ton	$1,800.00	$500.00	90	$162,000.00	$45,000.00	$207,000.00
					$244,866.82	**$221,057.65**	**$465,924.47**

Figure F.2 - RS Means Square Foot Cost of Small Warehouse



COMMERCIAL/INDUSTRIAL/ INSTITUTIONAL **M.700** **Warehouse, Mini**

Costs per square foot of floor area

Exterior Wall	S.F. Area	2000	3000	5000	8000	12000	20000	30000	50000	100000
	L.F. Perimeter	180	220	300	420	580	900	1300	2100	4100
Concrete Block	Steel Frame	184.65	162.90	145.65	135.85	130.40	126.15	123.95	122.20	120.90
	R/Conc. Frame	160.90	149.25	139.90	134.70	131.75	129.45	128.25	127.35	126.65
Metal Sandwich Panel	Steel Frame	155.95	143.25	133.10	127.40	124.20	121.65	120.40	119.40	118.60
Tilt-up Concrete Panel	R/Conc. Frame	168.85	156.80	147.20	141.80	138.80	136.40	135.20	134.20	133.50
Precast Concrete Panel	Steel Frame	167.05	151.40	138.95	131.95	128.00	124.90	123.35	122.10	121.20
	R/Conc. Frame	186.20	170.75	158.40	151.45	147.60	144.45	142.95	141.70	140.75
Perimeter Adj., Add or Deduct	Per 100 L.F.	27.95	18.70	11.25	7.00	4.65	2.80	1.85	1.10	0.60
Story Hgt. Adj., Add or Deduct	Per 1 Ft.	2.80	2.30	1.95	1.65	1.60	1.40	1.40	1.35	1.30
Basement—Not Applicable										

The above costs were calculated using the basic specifications shown on the facing page. These costs should be adjusted where necessary for design alternatives and owner's requirements. Reported completed project costs, for this type of structure, range from $ 34.95 to $ 200.50 per S.F.

Common additives

Description	Unit	$ Cost
Dock Leveler, 10 ton cap.		
6′ x 8′	Each	6925
7′ x 8′	Each	7800
Emergency Lighting, 25 watt, battery operated		
Lead battery	Each	290
Nickel cadmium	Each	770
Fence, Chain link, 6′ high		
9 ga. wire	L.F.	27
6 ga. wire	L.F.	28.50
Gate	Each	360
Flagpoles, Complete		
Aluminum, 20′ high	Each	1600
40′ high	Each	3625
70′ high	Each	9975
Fiberglass, 23′ high	Each	1400
39′-5″ high	Each	3500
59′ high	Each	6675
Paving, Bituminous		
Wearing course plus base course	S.Y.	8.05
Sidewalks, Concrete 4″ thick	S.F.	4.33

Description	Unit	$ Cost
Sound System		
Amplifier, 250 watts	Each	1975
Speaker, ceiling or wall	Each	203
Trumpet	Each	390
Yard Lighting, 20′ aluminum pole with 400 watt high pressure sodium fixture	Each	3050

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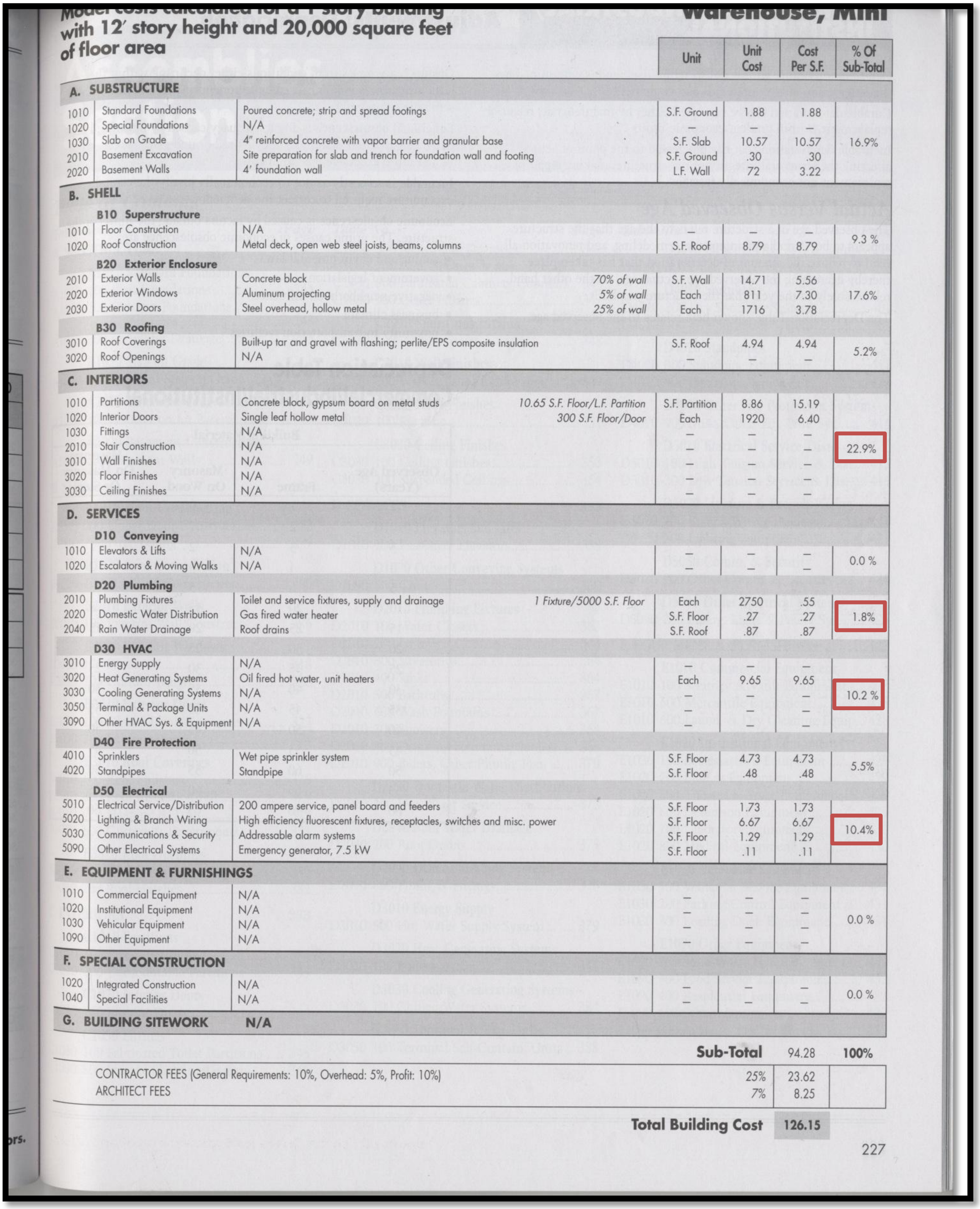
Important: See the Reference Section for Location Factors.

Figure F.2 – RS Means Square Foot Cost of Small Warehouse, continued



Model costs calculated for a 1 story building
with 12′ story height and 20,000 square feet
of floor area

Warehouse, Mini

				Unit	Unit Cost	Cost Per S.F.	% Of Sub-Total
A. SUBSTRUCTURE							
1010	Standard Foundations	Poured concrete; strip and spread footings		S.F. Ground	1.88	1.88	16.9%
1020	Special Foundations	N/A		—	—	—	
1030	Slab on Grade	4″ reinforced concrete with vapor barrier and granular base		S.F. Slab	10.57	10.57	
2010	Basement Excavation	Site preparation for slab and trench for foundation wall and footing		S.F. Ground	.30	.30	
2020	Basement Walls	4′ foundation wall		L.F. Wall	72	3.22	
B. SHELL							
B10 Superstructure							
1010	Floor Construction	N/A		—	—	—	9.3 %
1020	Roof Construction	Metal deck, open web steel joists, beams, columns		S.F. Roof	8.79	8.79	
B20 Exterior Enclosure							
2010	Exterior Walls	Concrete block	*70% of wall*	S.F. Wall	14.71	5.56	17.6%
2020	Exterior Windows	Aluminum projecting	*5% of wall*	Each	811	7.30	
2030	Exterior Doors	Steel overhead, hollow metal	*25% of wall*	Each	1716	3.78	
B30 Roofing							
3010	Roof Coverings	Built-up tar and gravel with flashing; perlite/EPS composite insulation		S.F. Roof	4.94	4.94	5.2%
3020	Roof Openings	N/A		—	—	—	
C. INTERIORS							
1010	Partitions	Concrete block, gypsum board on metal studs	*10.65 S.F. Floor/L.F. Partition*	S.F. Partition	8.86	15.19	22.9%
1020	Interior Doors	Single leaf hollow metal	*300 S.F. Floor/Door*	Each	1920	6.40	
1030	Fittings	N/A		—	—	—	
2010	Stair Construction	N/A		—	—	—	
3010	Wall Finishes	N/A		—	—	—	
3020	Floor Finishes	N/A		—	—	—	
3030	Ceiling Finishes	N/A		—	—	—	
D. SERVICES							
D10 Conveying							
1010	Elevators & Lifts	N/A		—	—	—	0.0 %
1020	Escalators & Moving Walks	N/A		—	—	—	
D20 Plumbing							
2010	Plumbing Fixtures	Toilet and service fixtures, supply and drainage	*1 Fixture/5000 S.F. Floor*	Each	2750	.55	1.8%
2020	Domestic Water Distribution	Gas fired water heater		S.F. Floor	.27	.27	
2040	Rain Water Drainage	Roof drains		S.F. Roof	.87	.87	
D30 HVAC							
3010	Energy Supply	N/A		—	—	—	10.2 %
3020	Heat Generating Systems	Oil fired hot water, unit heaters		Each	9.65	9.65	
3030	Cooling Generating Systems	N/A		—	—	—	
3050	Terminal & Package Units	N/A		—	—	—	
3090	Other HVAC Sys. & Equipment	N/A		—	—	—	
D40 Fire Protection							
4010	Sprinklers	Wet pipe sprinkler system		S.F. Floor	4.73	4.73	5.5%
4020	Standpipes	Standpipe		S.F. Floor	.48	.48	
D50 Electrical							
5010	Electrical Service/Distribution	200 ampere service, panel board and feeders		S.F. Floor	1.73	1.73	10.4%
5020	Lighting & Branch Wiring	High efficiency fluorescent fixtures, receptacles, switches and misc. power		S.F. Floor	6.67	6.67	
5030	Communications & Security	Addressable alarm systems		S.F. Floor	1.29	1.29	
5090	Other Electrical Systems	Emergency generator, 7.5 kW		S.F. Floor	.11	.11	
E. EQUIPMENT & FURNISHINGS							
1010	Commercial Equipment	N/A		—	—	—	0.0 %
1020	Institutional Equipment	N/A		—	—	—	
1030	Vehicular Equipment	N/A		—	—	—	
1090	Other Equipment	N/A		—	—	—	
F. SPECIAL CONSTRUCTION							
1020	Integrated Construction	N/A		—	—	—	0.0 %
1040	Special Facilities	N/A		—	—	—	
G. BUILDING SITEWORK		**N/A**					
					Sub-Total	94.28	**100%**
	CONTRACTOR FEES (General Requirements: 10%, Overhead: 5%, Profit: 10%)				*25%*	23.62	
	ARCHITECT FEES				*7%*	8.25	
					Total Building Cost	**126.15**	

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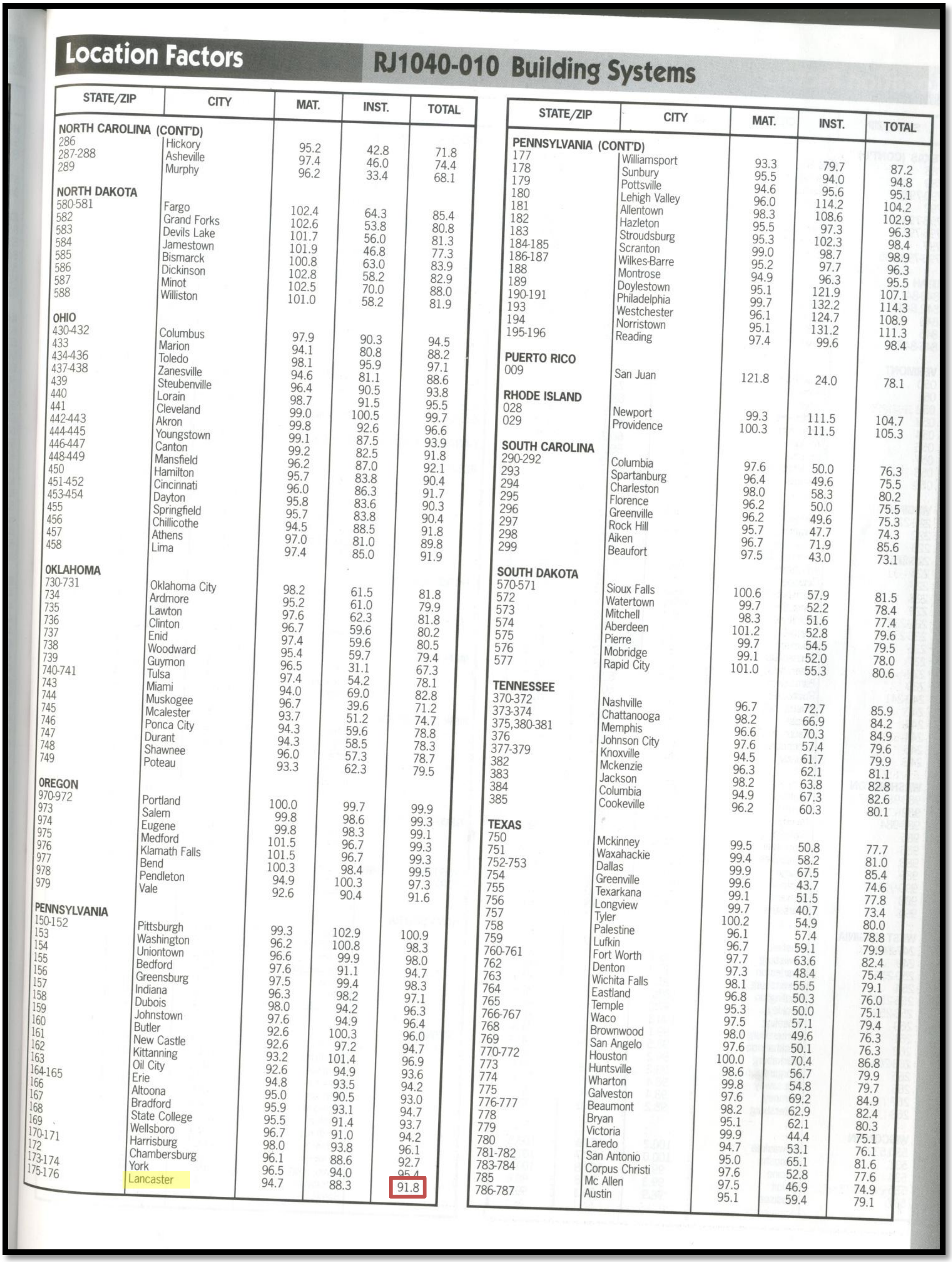
Figure F.3 – RS Means Location Correction Factors



Location Factors RJ1040-010 **Building Systems**

STATE/ZIP	CITY	MAT.	INST.	TOTAL
NORTH CAROLINA (CONT'D)				
286	Hickory	95.2	42.8	71.8
287-288	Asheville	97.4	46.0	74.4
289	Murphy	96.2	33.4	68.1
NORTH DAKOTA				
580-581	Fargo	102.4	64.3	85.4
582	Grand Forks	102.6	53.8	80.8
583	Devils Lake	101.7	56.0	81.3
584	Jamestown	101.9	46.8	77.3
585	Bismarck	100.8	63.0	83.9
586	Dickinson	102.8	58.2	82.9
587	Minot	102.5	70.0	88.0
588	Williston	101.0	58.2	81.9
OHIO				
430-432	Columbus	97.9	90.3	94.5
433	Marion	94.1	80.8	88.2
434-436	Toledo	98.1	95.9	97.1
437-438	Zanesville	94.6	81.1	88.6
439	Steubenville	96.4	90.5	93.8
440	Lorain	98.7	91.5	95.5
441	Cleveland	99.0	100.5	99.7
442-443	Akron	99.8	92.6	96.6
444-445	Youngstown	99.1	87.5	93.9
446-447	Canton	99.2	82.5	91.8
448-449	Mansfield	96.2	87.0	92.1
450	Hamilton	95.7	83.8	90.4
451-452	Cincinnati	96.0	86.3	91.7
453-454	Dayton	95.8	83.6	90.3
455	Springfield	95.7	83.8	90.4
456	Chillicothe	94.5	88.5	91.8
457	Athens	97.0	81.0	89.8
458	Lima	97.4	85.0	91.9
OKLAHOMA				
730-731	Oklahoma City	98.2	61.5	81.8
734	Ardmore	95.2	61.0	79.9
735	Lawton	97.6	62.3	81.8
736	Clinton	96.7	59.6	80.2
737	Enid	97.4	59.6	80.5
738	Woodward	95.4	59.7	79.4
739	Guymon	96.5	31.1	67.3
740-741	Tulsa	97.4	54.2	78.1
743	Miami	94.0	69.0	82.8
744	Muskogee	96.7	39.6	71.2
745	Mcalester	93.7	51.2	74.7
746	Ponca City	94.3	59.6	78.8
747	Durant	94.3	58.5	78.3
748	Shawnee	96.0	57.3	78.7
749	Poteau	93.3	62.3	79.5
OREGON				
970-972	Portland	100.0	99.7	99.9
973	Salem	99.8	98.6	99.3
974	Eugene	99.8	98.3	99.1
975	Medford	101.5	96.7	99.3
976	Klamath Falls	101.5	96.7	99.3
977	Bend	100.3	98.4	99.5
978	Pendleton	94.9	100.3	97.3
979	Vale	92.6	90.4	91.6
PENNSYLVANIA				
150-152	Pittsburgh	99.3	102.9	100.9
153	Washington	96.2	100.8	98.3
154	Uniontown	96.6	99.9	98.0
155	Bedford	97.6	91.1	94.7
156	Greensburg	97.5	99.4	98.3
157	Indiana	96.3	98.2	97.1
158	Dubois	98.0	94.2	96.3
159	Johnstown	97.6	94.9	96.4
160	Butler	92.6	100.3	96.0
161	New Castle	92.6	97.2	94.7
162	Kittanning	93.2	101.4	96.9
163	Oil City	92.6	94.9	93.6
164-165	Erie	94.8	93.5	94.2
166	Altoona	95.0	90.5	93.0
167	Bradford	95.9	93.1	94.7
168	State College	95.5	91.4	93.7
169	Wellsboro	96.7	91.0	94.2
170-171	Harrisburg	98.0	93.8	96.1
172	Chambersburg	96.1	88.6	92.7
173-174	York	96.5	94.0	95.4
175-176	Lancaster	94.7	88.3	91.8
PENNSYLVANIA (CONT'D)				
177	Williamsport	93.3	79.7	87.2
178	Sunbury	95.5	94.0	94.8
179	Pottsville	94.6	95.6	95.1
180	Lehigh Valley	96.0	114.2	104.2
181	Allentown	98.3	108.6	102.9
182	Hazleton	95.5	97.3	96.3
183	Stroudsburg	95.3	102.3	98.4
184-185	Scranton	99.0	98.7	98.9
186-187	Wilkes-Barre	95.2	97.7	96.3
188	Montrose	94.9	96.3	95.5
189	Doylestown	95.1	121.9	107.1
190-191	Philadelphia	99.7	132.2	114.3
193	Westchester	96.1	124.7	108.9
194	Norristown	95.1	131.2	111.3
195-196	Reading	97.4	99.6	98.4
PUERTO RICO				
009	San Juan	121.8	24.0	78.1
RHODE ISLAND				
028	Newport	99.3	111.5	104.7
029	Providence	100.3	111.5	105.3
SOUTH CAROLINA				
290-292	Columbia	97.6	50.0	76.3
293	Spartanburg	96.4	49.6	75.5
294	Charleston	98.0	58.3	80.2
295	Florence	96.2	50.0	75.5
296	Greenville	96.2	49.6	75.3
297	Rock Hill	95.7	47.7	74.3
298	Aiken	96.7	71.9	85.6
299	Beaufort	97.5	43.0	73.1
SOUTH DAKOTA				
570-571	Sioux Falls	100.6	57.9	81.5
572	Watertown	99.7	52.2	78.4
573	Mitchell	98.3	51.6	77.4
574	Aberdeen	101.2	52.8	79.6
575	Pierre	99.7	54.5	79.5
576	Mobridge	99.1	52.0	78.0
577	Rapid City	101.0	55.3	80.6
TENNESSEE				
370-372	Nashville	96.7	72.7	85.9
373-374	Chattanooga	98.2	66.9	84.2
375,380-381	Memphis	96.6	70.3	84.9
376	Johnson City	97.6	57.4	79.6
377-379	Knoxville	94.5	61.7	79.9
382	Mckenzie	96.3	62.1	81.1
383	Jackson	98.2	63.8	82.8
384	Columbia	94.9	67.3	82.6
385	Cookeville	96.2	60.3	80.1
TEXAS				
750	Mckinney	99.5	50.8	77.7
751	Waxahackie	99.4	58.2	81.0
752-753	Dallas	99.9	67.5	85.4
754	Greenville	99.6	43.7	74.6
755	Texarkana	99.1	51.5	77.8
756	Longview	99.7	40.7	73.4
757	Tyler	100.2	54.9	80.0
758	Palestine	96.1	57.4	78.8
759	Lufkin	96.7	59.1	79.9
760-761	Fort Worth	97.7	63.6	82.4
762	Denton	97.3	48.4	75.4
763	Wichita Falls	98.1	55.5	79.1
764	Eastland	96.8	50.3	76.0
765	Temple	95.3	50.0	75.1
766-767	Waco	97.5	57.1	79.4
768	Brownwood	98.0	49.6	76.3
769	San Angelo	97.6	50.1	76.3
770-772	Houston	100.0	70.4	86.8
773	Huntsville	98.6	56.7	79.9
774	Wharton	99.8	54.8	79.7
775	Galveston	97.6	69.2	84.9
776-777	Beaumont	98.2	62.9	82.4
778	Bryan	95.1	62.1	80.3
779	Victoria	99.9	44.4	75.1
780	Laredo	94.7	53.1	76.1
781-782	San Antonio	95.0	65.1	81.6
783-784	Corpus Christi	97.6	52.8	77.6
785	Mc Allen	97.5	46.9	74.9
786-787	Austin	95.1	59.4	79.1