The

Gaige

Technology and Business
Innovation Building
Penn State Berks, Reading PA

Thesis Project Proposal

Proposed System Changes

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Technical Report Three

Executive Summary

In this report, a proposal for the future work to be done concerning changes to the Gaige Building is presented. Throughout the semester, the Gaige Building was thoroughly analyzed, and now, given the knowledge of the current operation of the systems, design changes are proposed that will be analyzed in the upcoming semester. These changes are thought to create strong improvements to the current system, even though it already operates at an efficient and high performing level.

First, an analysis will be performed to determine the feasibility of creating a campus-wide geothermal system at the Penn State Berks Campus. The impact of a geothermal system will first be analyzed thoroughly for the Gaige Building, and then, the option of having a campus-wide geothermal system will be broadly studied. This will help to demonstrate the gains that can be seen from serving a larger, more diverse load on a single central system, especially using a sustainable technology such as ground loop heat pumps. Along with the geothermal analysis, the resulting changes in the ventilation system and heating/cooling system will be determined. The option of using a dedicated outdoor air system along with heat pumps that will serve individual building spaces will be considered. This will help to separate the ventilation and heating and cooling system, to provide for more efficient outdoor air to the spaces and adequate heating and cooling potential from the geothermal energy source. With such a drastic change to the airside distribution system, a redesign of the air distribution ductwork systems will be performed and coordinated throughout the building's design.

Finally, two breadth analyses will be performed to analyze secondary effects that these large mechanical changes might have on the building. First, a cost and scheduling impact analysis will be performed to see the concerns associated with creating a geothermal system for a building as opposed to a standard building mechanical system design. This analysis will help to see major scheduling changes that will result from the boring now required during construction. Costs changes associated with construction will be weighed against the potential savings. Then, a breadth concerning the acoustics of noise sensitive spaces within the Gaige Building will be performed. With the redesign of the mechanical system and potential of locating units closer to noise sensitive areas, an analysis will be performed to ensure that classroom and offices spaces meet up to adequate background noise levels set to create proper acoustic environments in the Gaige Building.

Building Overview and Background

The Gaige Technology and Business Innovation Building is a 64,000 SF building located in Reading, PA, on the Berks commonwealth campus of Penn State University. The Gaige Building is a host of many functions, but primarily, it is used as classroom, office, and lab space for the college's engineering, business, and hotel and restaurant management programs.

The Gaige Building is three stories tall, and it was constructed between April 2010 and November 2011. It was operated on a design-bid-build project delivery method, and had a full range of consulting services, from cost-estimating to A-V consulting. Functionally, the first floor contains classroom and lab spaces primarily, with a large area for studying and relaxing called the Learning Loft. Once you move to the second floor, you see the same classroom and lab emphasis, but a corridor on the east-west wing of the building provides a large amount of conference and office space.

Once you move to the third floor, the east-west wing of the building is capped off at two stories, but the north-sound wing continues up to three stories to accommodate one more classroom space and ample office and conference space. The exterior of the building consists of weather-resistant terracotta panel, metal framed exterior glazing and curtain wall systems, and precast concrete panels. Together, all of these building elements provide an aesthetically pleasing, but sealed and energy efficient building façade and enclosure. More information on the architecture of the building can be found in the building statistics report performed on the Gaige Building through this same thesis project.

Mechanical System Overview

The Gaige Building has three main root top units (RTU-1, RTU-2, and RTU-3) that provide ventilation, conditioning, and exhaust for the majority of the spaces within the building's design. The units are sized to 20,500 CFM, 14,000 CFM, and 12,500 CFM respectively. Each of these units serve a variety of spaces within the first, second, and third floors of the building. Air is supplied from the roof top units at a supply temperature of 55 degrees, and it is ducted throughout the building.

At the individual spaces, variable air volume boxes are provided for each zone. The VAV box takes the 55 degree air, and varies the volume of air being supplied to the space to meet the cooling requirement of the space at the current time. The load is monitored by a thermostat located in each of the zones separately. CO2 and occupancy sensors also are coordinated with the VAV boxes to allow for a reduction in outside air required to be supplied to each space. A minimum set point prevents the VAV box from supplying air less than the minimum outside air requirement for the space. A reheat coil prevents from overcooling the space when providing minimum outside air at a time when cooling requirements are reduced.

Two 1300 MBH boilers provide the hot water service for the building and all mechanical heating requirements. Four split system air conditioners are required to provide individual space cooling for the telecom/data rooms in the building, and one computer room air conditioner is required for the IT storage and equipment room, also supplied with an air-cooled chiller. Unit heaters are provided throughout the building as needed in semi-heated spaces, such as the vestibules at the building entrances.

Finally, the heating loads for the building are met by radiant-heating panels and fin-tube heat exchangers placed at exterior walls of spaces that don't experience a year round cooling load. This allows for simultaneous heating and cooling throughout the building in spaces that contain these heating elements. Although it provides poor energy efficiency, the VAV boxes are equipped with reheat coils, so some heating in spaces without panes or fin-tubes could potentially have some heating capacity, but that is not the primary design intent.

Mechanical System Design Objectives

Below is discussed the overall design objectives of the mechanical system of the Gaige building. The main goal of energy efficiency and performance is discussed, as well the building's role in the overall context of a college campus. The following discussion is given to provide an overall context as to why certain decisions for the Gaige Building were made. Also, this discussion will provide the necessary context to understand why the proposed alterations to the current design are suggested.

Design Objectives

One of the main focuses of the Gaige Building was the need for energy performance. As a Penn State building, it was expected that The Gaige Building would over perform the ASHRAE Standards baseline building by at least 30%. This could be accomplished through the envelope construction of the building as well as the mechanical system used by the building. This need for energy efficiency led to a decision to incorporate very high performance windows and glazing into the façade of the building, a step towards the 30% reduction expectation. As well, the rooftop units for the Gaige Building are each equipped with energy recovery wheels that help to pre-heat outside air in the winter with exhaust air, or pre-cool in the summer.

As well, since the Gaige Building is simply a standalone classroom building, all of the heating and cooling systems are provided from boiler and air-cooled chillers on-site. As a result of the lower loads associated with this type and size of building, a centralized heating boiler plant is used, but all cooling required is provided by separate systems. Each rooftop unit is equipped with internal equipment that provides the necessary cooling, and the individual air-conditioning units are connected to air-cooled chillers that provide the cooling needed for each unit.

The final key design objective was for water efficiency throughout the design of the Gaige Building. To accomplish this goal, the Gaige Building incorporates a rainwater harvesting and storage system that provides for nearly 100% of the building's non-potable water usage.

Overall, the Gaige Building is designed to be a building that is a landmark for the Penn State Berks campus. It is a building unlike any other on campus. It acts as a showcase for students, a standard for the building community, and an educational tool for the Reading community. With its energy efficiency, water efficiency, and status in the area, it will be a landmark for much of the future to come. The Gaige Building, as it educates students at the Penn State Berks campus, will be long remembered.

Alternatives Considered

Below is an outline containing the various alternatives that are being considered for the depth topics of the mechanical option thesis project that will be undertaken next semester. Each proposed design alteration will be explained and justified in terms of its potential benefits to the current design. As well, potential coordination impacts and any potential negative impacts to the overall design will be explained.

Centralized Cooling units for Building

In the Gaige Building, currently the design uses three roof top units and five chillers to provide for the cooling in the Gaige Building. The three rooftop units provide most of the cooling, but the five chillers provide service to the individual telecommunications rooms, the elevator room, and the computer room. The three rooftop units have simple air cooled condensers built in. These units operate efficiently for their size, but there are some clear opportunities that can be realized if a centralized system were considered. First, since the load of all the building would be seen by the same equipment, efficiency gains can first be seen.

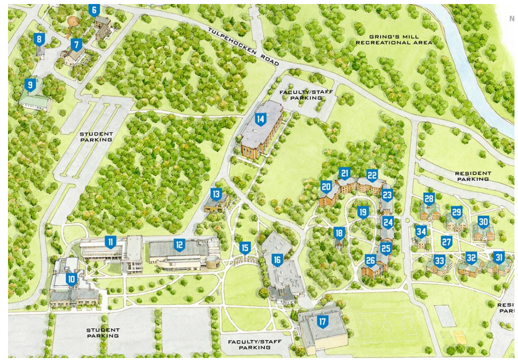
By combining the load from the three roof-top units, and cooling the building at a central location, more efficiency can be gained. With a greater load, larger and more efficient equipment can be used. Also, since not all of the building will be in use at one time, some diversity in load could be found to increase the efficiency of the system. Highly efficient centralized chillers for the building will be more expensive, but they can be used in a way that would help save energy costs and pay back over time. Depending upon the size of the loads, even more efficient systems, such as modular chillers can be used, but the size and efficiencies of the chosen system need to be weighed against the size and life cycle cost of the system.

Geothermal Heating and Cooling with a DOAS

Another option for the Gaige Building is swapping the heating and cooling systems in the building with a geothermal system. The Gaige Building is located in Reading, PA, where ground temperatures tend to be favorable for year-round geothermal heating and cooling potential. At the Penn State Berks Campus, there is available space right next to the Gaige building for geothermal well field to supply the Gaige Building. By using the ground as a heat source in the winter, when the ground temperature is much warmer than the air and as a heat sink in the summer when the ground temperature is cooler than the air, much energy efficiency can be realized. Ground temperatures tend to be relatively constant, no matter what season it is, once you dig about ten to twenty feet below the surface. By taking advantage of these relatively constant temperatures, energy can be saved year round.

Currently, the building uses separate heating and cooling systems that run off of natural gas and electricity. By using 'free' energy that is simply sitting in the ground temperature around the building, great savings could be determined. There will still be pumping costs and initial cost increases in construction and piping, but these costs could easily be outweighed by the potential gains of the system. These options of the system will be determined, analyzed, and compared to the current design in such an analysis.

Campus-wide Centralized Heating and Cooling



Finally, one key aspect of the Gaige Building is the fact that it is a part of a much larger campus. In the figure to the left, you can see the entire Berks campus in Reading, PA. At the Penn State Berks Campus, they have nine campus operation type buildings, ranging from classroom builidngs to storage type facilities. Also, they have 16 residential building for oncampus housing. With such a large campus with such a diverse type of builidng, clear benefits could be found from operating the entire campus system on a central heating and cooling site.

First, by combining the load of the buildings on campus into a central system, much greater efficiency can be found since larger, more efficient, and better operating equipement can be used, as opposed to entirely separate systems throughout campus. Also, you will see a large amount of load diversity from the campus buildings. Since classroom buildings operate mainly during the day, before dinner, and are then unoccupied, they have mechancial equipment that is out of use most of the night hours. On the other hand, the residential buildings will be heavily used at night, but less used during the day, while students are out at class, or at other places around campus. By connecting these building into a combined, central, campus system, the equipment can operate on a more steady basis, with a diverse building type it services. Thus, equipment can be designed to operate in a more efficient mannor and have a 'flatter' loading profile.

Mechanical Proposal

With the previous alternatives that were considered, a final proposal for changes to the mechanical system is suggested below. This proposal includes first combining two topic alternatives considered. First, a geothermal system will be implemented due to the good ground temperatures in Reading, PA. To further increase the efficiency and benefits of the system, a centralized geothermal system will be considered. By doing this, a diversity in loads from the different building types will help to provide better efficiency using larger capacity heating and cooling equipment. Also, once geothermal service is provided, the type of heating and cooling equipment within the Gaige Building will be considered from multiple options. Heat pumps will be considered, along with standard air handling units to determine the best possible system for the Gaige Building.

Depth 1: Centralized Geothermal Campus Service

The main analysis of the Gaige Building will be the option of creating a centralized service for the entire Berks campus, supplied by a field of geothermal wells. The wells would be vertical bores located in some of the existing open space that is already central to campus operations. Not only will drastic benefits be seen by installing a geothermal system on campus buildings, but a strong amount of load diversity will be gained as well. First, an analysis of the cost and benefits of utilizing the geothermal potential in Reading, PA will be analyzed, and then, the overall gains will be determined from creating a campus-wide system, gaining load diversity all across the many different campus building types. Below, figure one shows the current campus map, and the many different building that are present on campus. As you can see, the red circles highlight key areas of campus that have large, open spaces. These areas are good spaces where geothermal wells could be bored to create a central service to the entire campus. And if the wooded area is meant to be conserved, bores could be done under current parking areas or some of the athletic fields as well. The area is not extremely urban or dense, so such a field could be a feasible option.

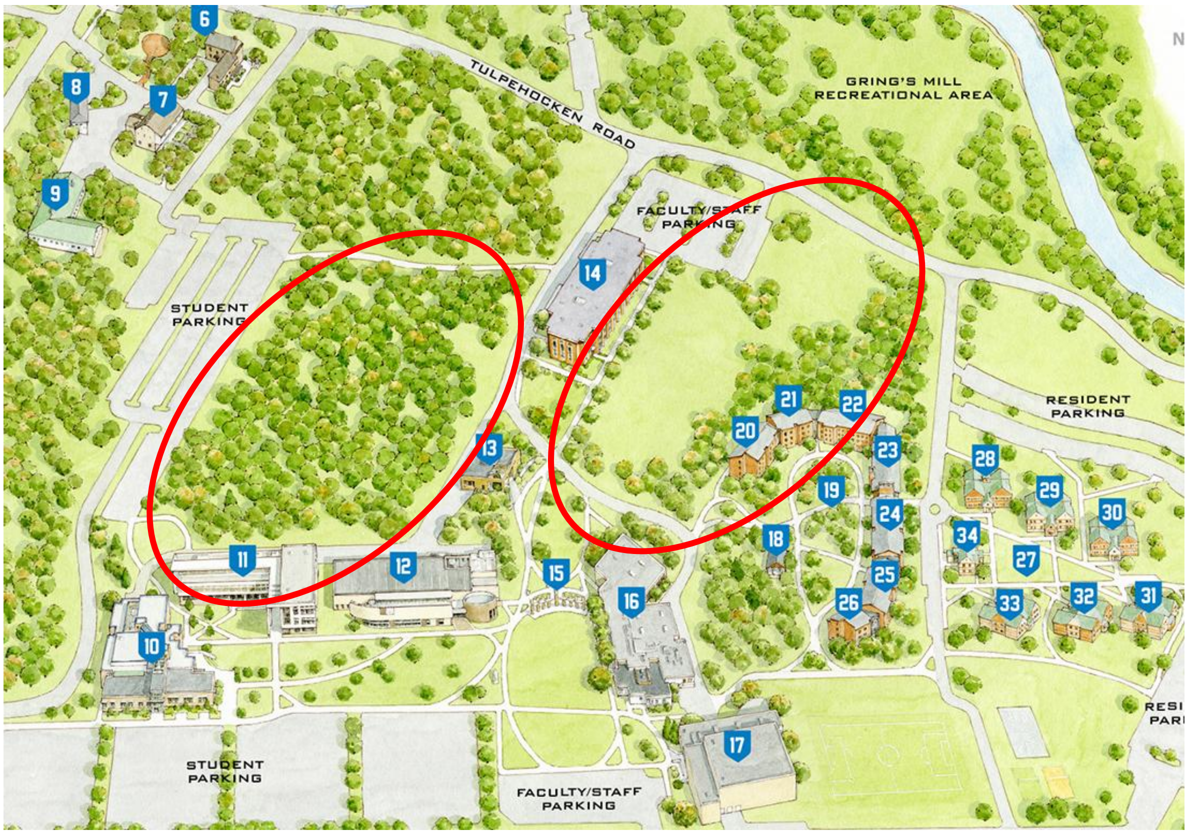


Figure 1: A campus map showing the large amount of open, used space for potential geothermal well sites

Trace 700 will be used to analyze first the impact of a geothermal system specifically on the Gaige Building, and then a simplified trace model will help to show the overall benefits of the potential impact on the campus as a whole. The trace model of the whole campus will simplify each building to a space type with certain loading criterion and diversity profiles, simply to see the benefits that might be reached. The changes to a geothermal system will be analyzed and reported success will be shown using life-cycle cost analysis to show feasibility. This will serve as the first, and most significant, depth for the thesis work coming up in the fall.

Depth 2: Dedicated Outdoor Air System and Heat Pump System

If a geothermal system is installed in the Gaige Building, the ventilation air system will then need to be separated from the rest of the building's heating and cooling system. To do this, a dedicated outdoor air system (DOAS) will be used to provide variable levels of outside air to the building spaces. Also, a new heating and cooling system will need to be used in the Gaige Building. For this system, various alternatives will be considered, but the main, and most compatible system with geothermal design are heat pumps. With the addition of a heat pump system on a space-to-space basis, the entire ductwork system, for both the heating and cooling system and the heat pump system, will need to be redesigned and coordinated.

The second depth of the thesis will consist of the ductwork redesign and the implementation of separate ventilation and heating/cooling systems. With a DOAS system, also the benefits from reduced outside air consumption will be determined and included in the analysis. The new systems will be coordinated in the redesign of the ductwork system. Now, two separate but smaller in size duct systems will be running throughout the building, creating some necessary coordination issues that will need to be resolved. A Revit model will be created to help assist with the redesign of the ductwork in the Gaige Building.

Breadth Topics

In response to the changes proposed in the mechanical depth topics, two breadth reports will be conducted to analyze the effects of providing a centralized geothermal system. First, the overall cost and schedule of the project will be considered and the influence of such a geothermal system be analyzed. This will help see the initial impacts of the new system, which must not outweigh the long term benefits of geothermal systems. Finally, a breadth in acoustics will be considered, looking into the changes in acoustical requirements for the building with newly considered systems. Results and recommendations will be provided following the breadth reports.

Breadth One: Cost and Scheduling Impact

The one major concern that always results from switching to a geothermal system is the impact on cost and scheduling of the building's construction. To determine this, a breath in the construction cost and scheduling of the building will be performed. Major impacts of the expensive and time sensitive boring process will be considered, and how these constraints affect the building as a whole will be considered. The Gaige Building was on a tight schedule, for it needed to be opened for classroom use as soon as it possibly could. Also, along with work in the depths to determine the financial feasibility of such a geothermal system, the initial increased upfront construction costs will be outweighed against the savings that the campus will see over its lifetime. These analyses will help to address concerns on either of these topics and help inform the possibility of a centralized geothermal system.

Breadth Two: Room Acoustics and Noise Control

The second breadth for this thesis project will be an acoustics breadth considering the noise control and background noise levels present in the offices and classrooms in the Gaige Building. Since the mechanical system is being proposed to undergo such a drastic change, the new design of the mechanical system will be analyzed to ensure that mechanical noise is not creating a poor acoustic environment in noise sensitive spaces. With a heat pump system, mechanical equipment will be located much closer to the occupied building spaces, as opposed to the rooftop where the main mechanical equipment is located right now. Transmission loss calculation will be performed to ensure that mechanical equipment located near, or even potentially in spaces such as classrooms or offices will not exceed background noise level requirements. Also, the ductwork systems will be modeled and airflow induced noise into the building spaces will be calculated. Changes to the mechanical system will be made to ensure that an appropriate level of background noise is maintained from the air distribution systems.

Honors Work

In order to create an additional aspect of my senior thesis project to help satisfy the honors requirement for a scholars graduation, I plan to take actual onsite measurements at the Gaige Building of room acoustical parameters, to ensure that the noise sensitive and acoustically sensitive spaces (such as offices and classrooms) are properly isolated from other spaces. As well, the room acoustics of these spaces will be analyzed based upon actual onsite measurements. This will serve as a very important educational experience for myself, for I have a strong interest and focus in acoustics through my studies as an architectural engineer here at Penn State.

Also, I hope to incorporate some other AE students into this measurement trip, to allow third year students taking AE 309 the opportunity to take acoustical measurements at a building. As a third year, much work is done in the classroom, and many of the projects are done simply on a computer, so I hope that some students with an interest in acoustics might find it beneficial to get some real life measurement experiences. Measurements of reverberation time, transmission loss, and background noise level will be taken in various spaces, and the overall acoustics performance of the Gaige Building will be presented.

Project Methods

Below, both the project tools are provided, along with a proposed schedule for the plan of work to be undertaken during the spring semester. First, the tools that will be used during the semester are outlined and described below. Then, a detailed semester schedule is given, providing for project milestones, project phases, and important due dates and presentations that will occur in the upcoming semester for the AE senior thesis project.

Tools to be used

Below is a summary of the computer programs and other design tools that will be utilized to help determine the effectiveness of the proposed changes mentioned above that will be analyzed. Each program is listed, and its functionality is described below. As well, how each program will tie into the overall analysis is discussed, and all are tied back into the overall project and assessment. Along with programs, tools are listed that will be used for some onsite measurements that will take place.

Trane Trace

Trane Trace has already been used in the technical assignments in the previous semester, and it will be used to conduct new assessments of the different systems that will be considered for the Gaige Building. Models of the overall building and a simplified model of the campus wide operation will be considered. The benefits will be analyzed using Trane Trace along with various excel spreadsheets developed for more specific calculations. All load estimation and energy consumption will be analyzed using this program for consistency's sake across models and simulations.

Dynasonics AIM Software

This software is used to calculate background noise levels due to mechanical airflow noise into a room. It utilized built in transmission loss levels from different geometries and types of ductwork. By creating numerical models of the ductwork systems into a room, you can estimate the background noise in particular rooms due to the mechanical airflow system. With new ductwork design, this system will help to ensure that proper background noise levels are met in noise sensitive spaces such as classroom and offices throughout the building.

Life Cycle Cost Analysis

Life cycle cost analysis will be performed to verify the feasibility of the design changes that will be analyzed in the upcoming semester. There are life cycle cost capability within Trace 700, but in order to have the most control over design variables, various excel spreadsheets will be used to perform these analyses. These spreadsheets will be used to help determine the feasibility of the geothermal system for the Gaige Building, and then to help determine the feasibility of creating a campus-wide geothermal system. When solutions involve much more expensive and sophisticated equipment in upfront systems cost, these changes must be justified in a long term sense.

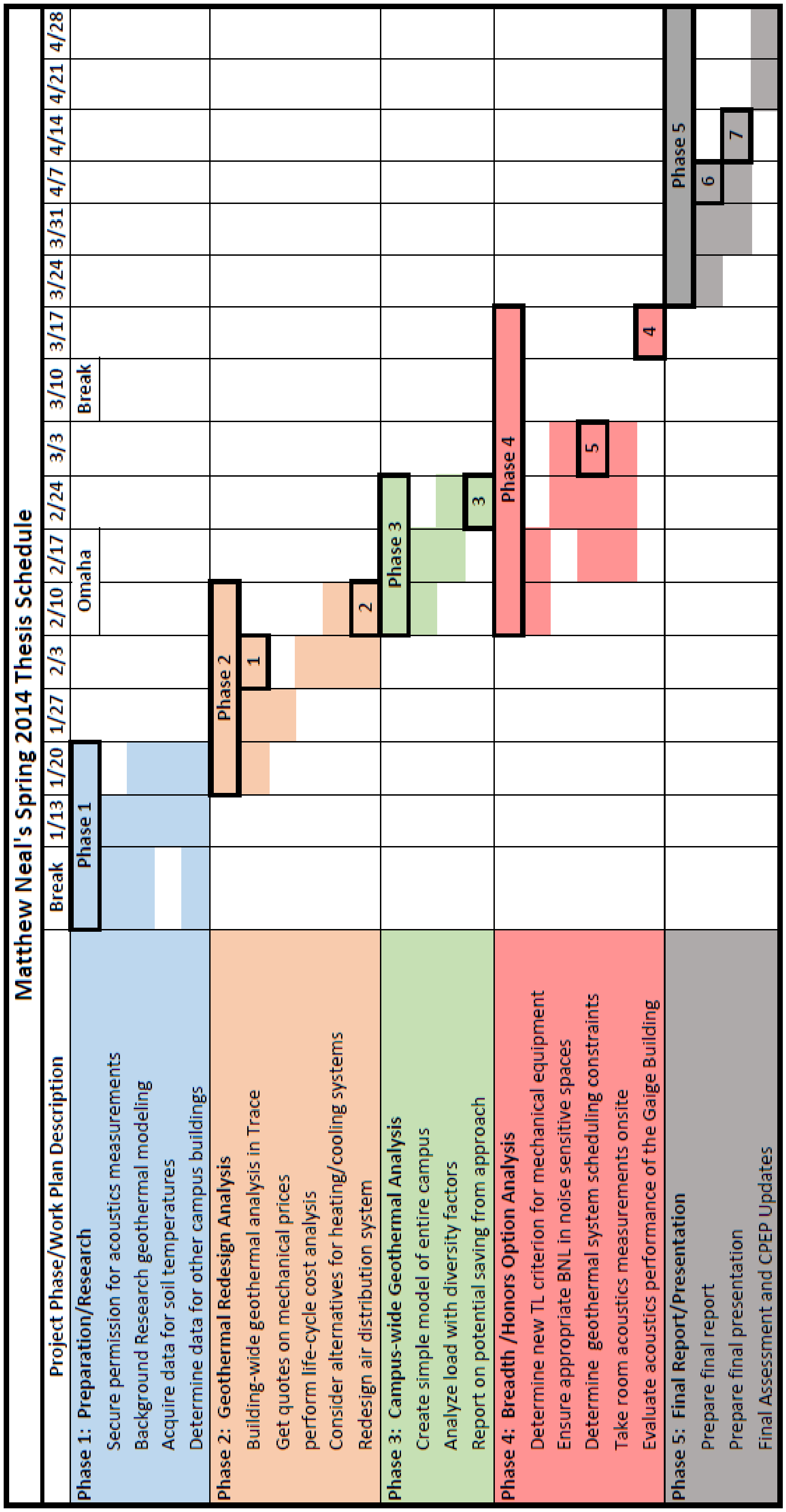
Bruel and Kjær Sound Level Analyzer and JBL Loudspeaker

In order to conduct onsite existing conditions acoustical measurements, equipment from the Graduate Program in Acoustics and the Sound Perception and Room Acoustics Laboratory will be used. I have strong familiarity with using such equipment from my involvement in acoustics research through the Sound Perception and Room Acoustics Laboratory. The loudspeaker will be used as the sound source in the different room for the transmission loss measurements, and the sound level meter will be used to record the measurements. Also, the balloon popping method will be used to measure the reverberation time in the source and receiver rooms needed for the overall transmission loss calculations.

Revit

Revit will be used to help coordinate and redesign the ductwork system within the Gaige Building. Since there will be much more coordination issues resulting from the separation of the ventilation and heating/cooling systems, two separate duct systems will need to be coordinated. Using the three dimensional coordination power of Revit, the duct systems will be redesigned and coordinated throughout the building's design.

Proposed Semester Work Plan



Milestones

			3	Cent. Geothermal Complete	2/28/2014			
1	Geothermal Redesign of Gaige Building Complete	2/7/14	4	Breadth/Honors Req. Complete	3/7/2014	6	Final Report Complete	4/9/2014
2	Airside Redesign of Gaige Building Complete	2/14/14	5	Scheduling Breadth Complete	3/22/2014	7	Final Presentation	4/14/2014

Preliminary Research

Below is a summary of some key sources and references that will be useful during the next semester of work. The references are provided that will help with the planned analyses that were outlines previously. More research will be done before and in the early stages of next semester as well.

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