NORTHEAST USA

INTEGRATED SCIENCES BUILDING

Thesis Proposal Revision I

January 14, 2011

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Executive Summary

The Integrated Sciences Building has high goals of being an energy efficient building and an icon for sustainability for the University it serves. This desire to excel provides good reason to experiment with different systems or modifications that enhance or replace the systems that are being implemented.

As a building with a relatively low load factor of 36%, which is largely due to the daytime operation and unoccupied nighttime hours, the building is a prime candidate for thermal storage. Shifting the cooling loads by storing chiller capacity during nighttime hours has proven successful in the past. Based on the design cooling profile, rough calculations suggest a Load Leveling Partial Storage system would be feasible. With storage capacity of approximately 2500 ton-hours, a tank size of 250,000 gallons would provide sufficient capacity to flatten the load profile of the building such that chiller size could be reduced by more than 50%. A small but sufficient clearing directly adjacent to the Integrated Sciences Building could hold the thermal storage tank. A further opportunity for educational experience lies in the design of the thermal storage tank foundation, which ensures the variables in deciding upon tank configuration are not neglected during the pursuit of an effective system. Therefore, based on these rough calculations, a thermal storage system will be designed and evaluated based on life cycle cost in an attempt to optimize the chilled water equipment on the site.

Because of the high load factor, and the uneven daily nature of the chiller load profile of the Integrated Sciences Building described above, the Primary/Secondary Chiller configuration will be compared to a Variable Primary Flow System, which can reduce energy consumption using variable flow primary pumps. This would effectively eliminate the need for the secondary pumps while decreasing the electrical load of the building. The opportunity for initial cost savings, along with reduced operating costs, presents opportunity for improvements in system configuration.

Additional sustainable energy practices and Architectural Engineering breadths will be investigated by the means of a study involving the installation of photovoltaic solar panels roof of the Integrated Sciences Building. Photovoltaic solar arrays have long been the subject of debate regarding whether they are cost effective and whether they can produce enough electricity to make an impact on a building performance in urban office buildings. A study on a new sustainable office and laboratory building will be a good opportunity to examine the nuances of this debate and to learn how photovoltaic arrays influence the rest of the building design.

Load calculations and energy simulations will be performed using Trane's TRACE 700 software package. Full year, 8,760 hour, simulations will ensure that weather related loads are specifically addressed in evaluating the success and life cycle cost justification of all redesigns. Life cycle cost will be the main gauge of success because of the nature of economics on dictating whether these types of systems actually come to fruition.

Current HVAC Design Description

The mechanical systems that are currently designed to serve the HVAC needs of the Integrated Sciences Building are very complex and are designed to be efficient in order to earn points toward LEED Certification. There are nine air handling units that serve the building. Three of the units are constant volume, terminal reheat systems that serve the electrical and data closets, auditorium, and atrium as well as providing adequate air for pressurization of the building. The other air handlers are all Variable Air Volume (VAV) Systems with hydronic terminal reheat that serve classrooms, offices, teaching laboratories, and research laboratories. The laboratory air handlers supply 100% outdoor air to the spaces they serve in order to provide adequate ventilation to the occupants and the purge the building of any contaminants that may result from the activities in those spaces. The laboratories are negatively pressurized relative to the remainder of the building to ensure that no contaminants enter the other occupied areas. Laboratory spaces are also equipped with VAV fume hood controls to limit the exhaust of the hoods and save energy when possible.

The thermal loads of the building are served by a chiller plant and purchased steam system. The chiller plant consists of two 620-ton two-stage centrifugal, water-cooled chillers with a coefficient of performance (COP) of 5.56 each. Heat is rejected via condenser water that is cooled by two 620-ton cooling towers. The purchased steam enters the building at 200 psi and maximum rate of 15,000 lbs/hr. The steam is used in four heat exchangers to make hot water to serve heating loads in the building's air handlers and hydronic reheat systems. Steam is also used to provide domestic hot water. Natural gas is used in the building, but not as a significant energy source. The natural gas consumption is limited to bench and fume hood use in the laboratories for scientific experiments.

Mechanical Design Objectives

The Heating, Ventilation, and Air Conditioning (HVAC) system for the Integrated Sciences Building was designed to accomplish many different objectives. Obviously, comfort of the human occupants based on temperature and humidity were of foremost concern. Another main concern was to provide ventilation air of good quality, which is a more difficult task to achieve in buildings with science laboratories such as the Integrated Sciences Building. The system was designed to meet or exceed ASHRAE Standard 62.1 as well as ASHRAE Standard 90.1. Energy efficiency was another focus of utmost concern in order to reduce operating costs and minimize the carbon footprint of the building.

The building owner has an outline of minimum building performance requirements for all of its many construction projects. This building was required to follow those requirements, which apply to all areas of design and construction, including mechanical systems. In addition to those requirements, the owner wanted the Integrated Sciences Building to excel as an icon of energy efficiency. The original goal of the building was to become LEED Silver certified, but through the design phase, it is expected to reach LEED Gold status.

Finally, because the building is ultimately owned by a private educational organization, construction and operating costs are of great concern as well. The energy efficiency and comfort objectives were to be met in ways that made sense in a financial manner. A large emphasis in selecting systems was the ability to recoup the original installation and construction costs through energy and operational savings

Original System Evaluation

One of the goals of the Integrated Sciences Building was to establish the owner, which in this case is an urban University organization, as a leader in sustainable construction and technology. There are many factors that play a role in determining the success of a building's "sustainability" and mechanical systems are major factor in that evaluation. In many cases, the LEED rating systems is used to quantify some of the sustainable features of a building. Whether or not that LEED is a good measure for determining sustainability can be a matter of opinion.

The features that immediately provide evidence of a responsible design that was intended to reduce energy consumption. One of the first that plays a major role in the building's performance is the choice of a VAV system. Although VAV systems are more expensive than a constant volume air system, they have proven to be effective in reducing energy consumption. For the types of occupancy in the Integrated Sciences Building, which includes many classrooms and offices, VAV systems are often used in new buildings for this reason. In the laboratory spaces, the need for high volumes of outside air to ensure air quality also made it easy to see how a VAV system could reduce the energy use of the building. Even a relatively minor change in air volume delivered to a space can change energy consumption a great deal, especially over the course of a year or the life of the building.

The type of energy used in the Integrated Sciences Building was another area which could make a huge impact on the sustainability of a project. Since the building has access to a district steam system, it removed the need for a boiler within the building. This can easily be seen as a cost-saving measure, but is often a more efficient use of fossil fuels than on sit combustion. Since larger steam plants operate more efficiently than small, locally-sized boilers, the access to district steam was a perfect opportunity to improve the mechanical design of the building.

One of the most impressive features of the Integrated Sciences Building is the Glycol Heat Recovery System which makes large strides in an effort to use energy which would otherwise be wasted. The simple concept of exchanging heat from exhaust air to incoming supply air, as well as heat from steam condensate, is projected to save a large portion of the energy cost of the building. As someone who is fairly inexperienced with building mechanical systems, it was very easy to see how a very simple system can be very effective.

The cost of initial installation of mechanical systems as well as the operating cost is also a very good way to gauge the success of a building design. The improvements made above the ASHRAE baseline building are project to save 25% of the annual energy costs of the building, according to the energy modeling engineer. Although this does not qualify the building for the most LEED points, it is a significant annual savings given that the building is predominantly a conventional VAV system with an extra heat recovery loop. The cost of the mechanical system is 23% of the total building cost, but when considering the amount of energy savings, is in line with the typical 15-20% of the total building cost which some engineers use as a rule of thumb for total system cost.

Overall, the building seems to have very simple systems which perform very well. The building is expected to reach LEED Gold certification, which may or may not render it a "success" in the eyes of some engineers. Points and ratings aside, it will be very challenging to come up with a design to improve the performance of the Integrated Sciences Building. Realizing that improving the building is a tall task, as well as some of the qualitative evaluations in this and previous technical reports, provides reason to render the building successful.

List of Considered Alternatives

The system that was originally selected for the Integrated Sciences Building was chosen because of its level of success in meeting the building's mechanical load requirements while providing a reasonable balance of first-cost versus operational costs. The variable-air-volume configuration and the run-around heat recovery loop are the features that are responsible for most of the energy savings in the system.

The next phase of research regarding this building will investigate other methods of improving the efficiency and cost of the building. There are many ways to enhance a building performance, but there is always a point of diminishing returns due to first cost, operating cost, construction scheduling, or available space. The following are a list of possibilities for investigation surrounding the Integrated Sciences Building systems.

- Envelope Load Flattening – Exterior Enclosure material investigation
- Thermal Storage System
- Dedicated Outside Air System (DOAS)
- Chilled Beams
- Radiant Floor Heating
- Demand Control Ventilation
- Variable Primary Flow vs. Primary/Secondary Flow Chiller Configuration
- Bio-Wall Indoor Air Quality Analysis
- Laboratory Indoor Air Quality Simulation

The lack of a large site, which is a result of the urban location of the Integrated Sciences Building, diminishes opportunity for an extensive ground source heat pump system, which could potentially be a rewarding study. Additionally, since the building purchases district steam for heating purposes, very few options are available surrounding the central heating system of the building. District steam is a good source for energy and eliminates the construction and equipment costs required by that equipment. Life Cycle Cost Analysis (LCCA) is a major factor in determining the success of a redesign, so installing a boiler or heating system is not necessarily a good way to improve the cost performance of a building when other heating sources are available.

Three of the above topics were chose for detailed study and are described below. These topics include a Thermal Storage system, and an investigation into Primary/Secondary Chiller Configuration versus Variable Primary Flow.

Proposed Mechanical Studies

Thermal Storage (MAE Depth)

Thermal Storage is a technique that is used to reduce energy costs of a building, not necessarily by reducing energy efficiency or energy consumption. Savings for thermal storage can also be largely a result of electricity rate structures. If the rate structure has "on-peak" and "off-peak" rates, the electricity charge during the daytime, which is when the loads on the cooling equipment are at their peak, will be more than the "off-peak" or nighttime rate. Other rate structures do exist where this is not the case, such as the Integrated Sciences Building. This building is owned by an organization that also owns several other large buildings in the vicinity. As is the case with many large owners, the electricity rates are negotiated so that the rates are the same during all hours of the day. Since thermal storage often has a tendency to help lower these rates, some assumptions may be made in order to reflect that possibility during the energy simulation. Attempts will also be made to contact the energy company that supplies electricity to determine how they might handle pricing with thermal storage.

Savings are possible with thermal storage because it is a way to shift the load profile of the building so that the load factor for the chiller equipment is higher. For office and educational buildings, including a university laboratory building, cooling loads peak during the middle of the day, and are reduced during the night. Shifting the peak of the load profile so that it is flatter throughout the day provides a situation where the chillers which produce the cold water, or ice generation capacity, are operating a full load for a larger percentage of the day. This could also reduce the size of the chillers, which would be a substantial first-cost savings opportunity.

Shown below are some images that suggest the potential for a successful thermal storage application for the Integrated Sciences Building. Figure 1 is a diagram which shows how a "Load Leveling Partial Storage" system works. The dark region, at peak load, shows the portion of the cooling load which would be served by the thermal storage tanks during daily operation. The "Charging Storage" portions show when the chiller(s) would run at low demand times of day, with the output being stored and then drawn from during the daytime.

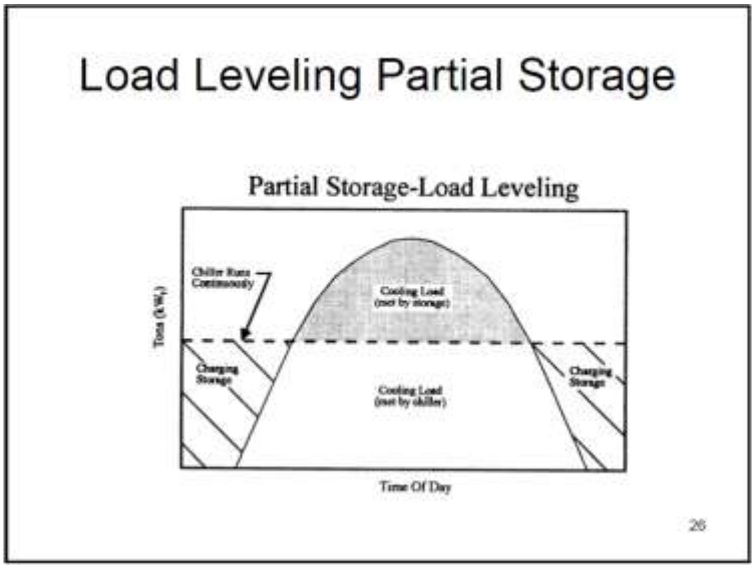

Figure 1 – Thermal Storage Load Level Curve.

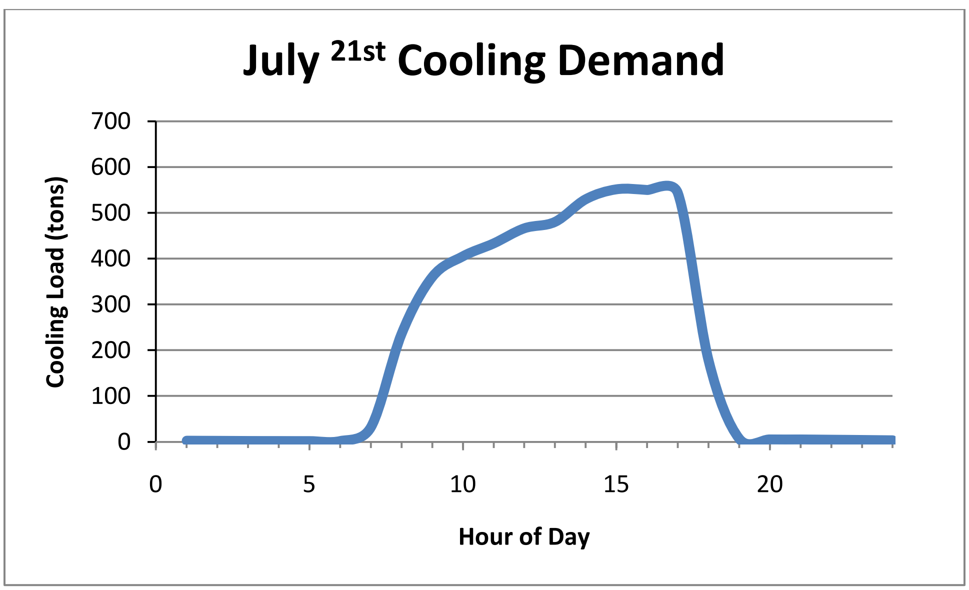

Figure 2 – July 21st Peak Cooling Demand

Construction costs of mechanical systems which include are often assumed to be higher than systems that do not. However, under some circumstances, the initial cost of the equipment can be less. If the thermal storage system allows for reduced peak load as a result of load shifting, the chiller equipment can be smaller. To illustrate the magnitude of chiller size reduction possibility, the entire cooling load for the design day, shown in Figure 2, above can be integrated and divided by the total hours in the day. Integrated the above curve gives a 4801 ton-hour design day load. Dividing this by 24 hours gives a maximum chiller capacity of 200 tons. The maximum load for July 21st according to the graph above is 551tons. Assuming this is the most extreme cooling load of any day in a year, which is a fair assumption because it is for July 21st, there is a potential to decrease the chiller size by about approximately 350 tons. This is a very crude estimate and thermal storage does have parasitic losses, but the simple calculation shows how noteworthy thermal storage impacts can be on chiller size selection. During the upcoming investigation, modifications will be made to the energy model which will more accurately predict the magnitude of chiller size reduction.

Since chillers are often the most expensive pieces of equipment, the cost of the tanks, pumps, and piping may not be as much of a burden as initially perceived. Also, with less peak chilling demand comes less peak electricity demand, thus reduced cost of electrical utility service equipment.

Maintainability can often be a concern when introducing mechanical systems with uncommon equipment or systems such as that of thermal storage. However, because the owner of the Integrated Sciences Building also controls several other buildings within the immediate area, there is a staff that is qualified in overseeing larger systems. An inherent benefit of employing skilled building operators and engineers is that they are equipped to maintain more complicated systems.

The educational value of studying a thermal storage system includes a wide range of benefits. Thermal storage is not a typical system, but can have very positive effects on building performance. In an industry where energy consumption, and particularly energy costs, are increasingly becoming a major factor in building design decisions, these types of systems are very valuable. Additionally, electric utility companies sometimes provide incentives that make thermal storage an even more attractive option because of how load shifting and load profile flattening benefits the power plant. Understanding how the building industry and the power industry are linked is valuable knowledge in understanding how to make buildings more successful.

There are some challenges involving thermal storage design for the Integrated Sciences Building, most notably the location of the thermal storage tanks. The building is located in an urban environment without large amounts of extra space. There is a small plaza area of about 10,000 ft^2 directly adjacent to the building, but the legal or aesthetic possibilities of placing a tank in that area requires further communication with the design team and owner. The Integrated Sciences Building also has only a partial basement, approximately 25% of the overall building footprint. Underground storage tanks or ice storage vessels may be investigated which could be placed either under the building, or perhaps partially buried in the plaza space to reduce the aesthetic issue.

A rough sizing estimate can be very quickly performed to make an initial estimation of tank sizing for sensible thermal storage. With the above estimation of 4800 ton-hours of load per day on the building, and a load flattening approach to the design, we can size the system for half of the daily thermal storage, or about 2500 ton-hours. A rule of thumb of 100 gallons/ton-hour gives volume estimate of 250,000 gallons. A volume of 250,000 gallons is approximately 33,500 ft^3. A tank which could hold this volume of water would, without specific manufacturing information, be about 28 feet in diameter and 55 feet tall. The footprint of this tank would be approximately 615 ft^2. This size tank could be a possible fit in the space shown by red circles in the image below. This proves that a tank is feasible from a rough calculation standpoint and that thermal storage deserves a study for the Integrated Sciences Building.

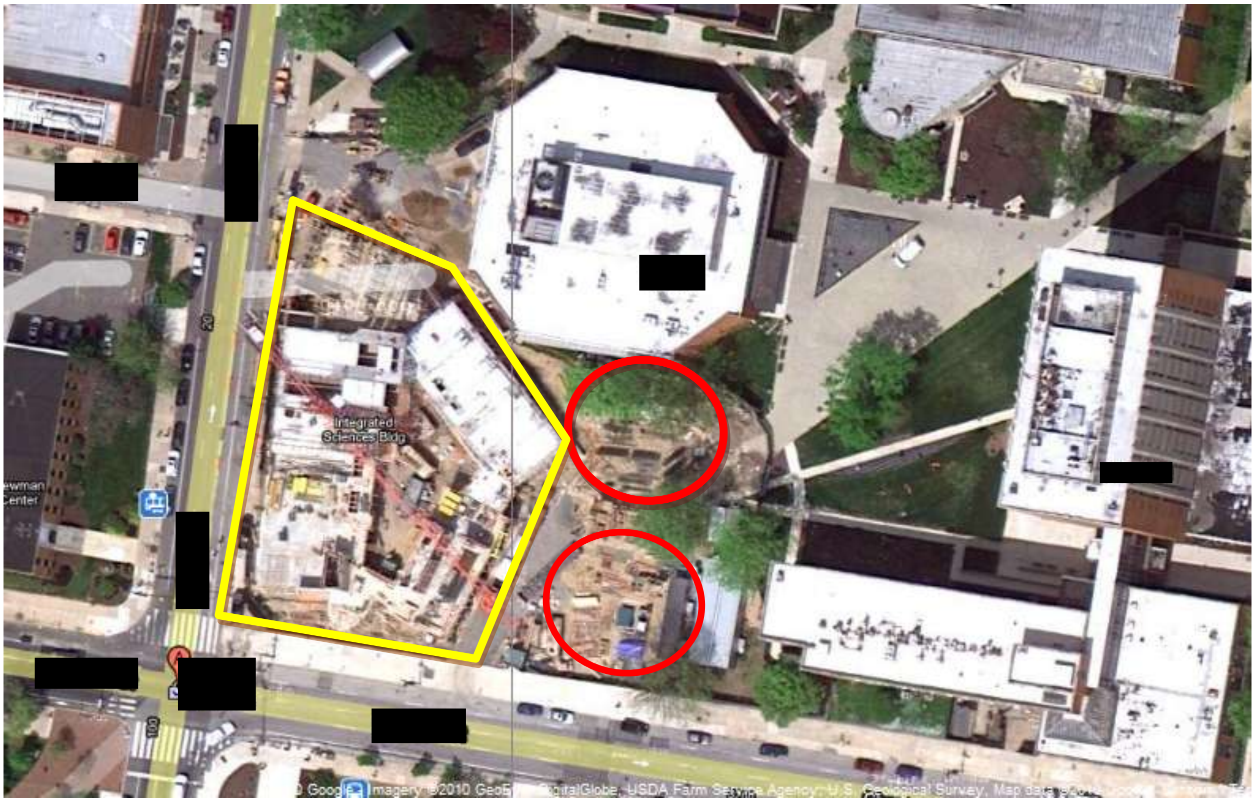

Figure 3 – ISB Building Footprint (Yellow), and Potential Thermal Storage Tank Locations (Red).

Primary/Secondary versus Variable Primary Flow (MAE Depth)

Chilled water system configuration is a simple but important consideration when designing a building that includes central cooling equipment. The Integrated Sciences Building was initially designed with a Primary/Secondary chilled water system. This system features chillers that operate under constant flow through the evaporators. There is a decoupler in these systems that allows chiller water bypass the building loads and go directly back to the chillers during times of partial load. As a result, the chillers do not need as much capacity in low load situations because the water going into the evaporator does not need as much heat removed in order to meet the load of the building. Thus, despite part load conditions in the building, pumping energy at the chillers remains constant when it does not necessarily need to be.

Variable Primary Flow chiller configuration removes the excess constant volume pumping energy from the Primary/Secondary configuration. Since flow through the chillers can be modulated based on the cooling load of the building, pumping energy is saved during part load conditions. As a result, case studies show pump energy reduction can be as much as 25-50%.

Another cost savings feature of Variable Primary Flow systems is the need for only one set of pumps for the chillers and building distribution system instead of both Primary and Secondary pumps which are required in Primary/Secondary configuration. Pumps can be a significant cost when designing a new system, so removing one set of pumps is not a trivial reduction. Also, fewer pumps means that less space is required, which is very favorable in congested mechanical spaces.

There are some negative characteristics of Variable Primary Flow configuration, which will require investigation during this study. Chiller flow variation must be compatible with the nature of the building loads so that the evaporator flow velocity does not vary beyond an acceptable range as specified by the manufacturer. Also, controls can become fairly complicated in Variable Primary Flow systems with respect to chiller and pump staging. The decreased system turnover time which is a characteristic of Variable Primary Flow systems when compared to Primary/Secondary systems may lead to system stability problems, which must be examined to prevent operation problems.

Since some mechanical designers have their own opinions about the success, or lack thereof, regarding chiller system configuration, the educational value in this study is that it provides a chance to form opinions based on experience and not on literature. Variable Primary Flow systems are becoming more prevalent within the industry, so experience in analyzing them is very valuable.

Architectural Engineering Breadth Study Topics

Electrical Breadth – Solar Photovoltaic System with DC Lighting

The Integrated Sciences Building has approximately 25,000 of roof area. This area provides envelope area that accounts for a large portion of the thermal envelope loads on the building, especially during summer months when the sun has a greater azimuth angle. In order take advantage of some of this energy, a Photovoltaic (PV) array will be investigated with the intent of using solar energy to usable electricity. This system will have high first cost, but will reduce monthly electricity bills.

Solar Photovoltaic array systems are not as simple as many students and consumers perceive them to be. There is a vast market of different types of equipment. The systems themselves require more than just solar panels, including the panel structural frame, the electrical cabling, power inverters, and electricity metering. All of this equipment will be selected, with cost in mind as well as payback period. Payback period will be the main tool used to determine the success of a PV array on the building.

Structural – Thermal Storage Tank Foundation

The thermal storage system which will be investigated, as described above, will include a large water storage tank to hold the chilled water it produces. With a tank that may be in excess of 250,000 gallons of water, a significant part of this design is the foundation for that load. Since the density of water in a thermal storage tank is approximately 62.4 lb/ft^3, the weight of water alone in a 250,000 gallon tank could be in excess of 2 million pounds. With the added load of a steel tank, or possibly a partially-buried concrete tank, this load is very significant. Foundations for these tanks are normally ring-walls under the perimeter tank shell with sand base in the middle. Geotechnical characteristics of the soil must be considered to determine whether this type of foundation will be acceptable, or whether another design is required. Tank design will be dictated by the American Water Works Association (AWWA) D100 for steel tanks and D110 for concrete tanks. Section 12 of ANSI/AWWA D100-96 gives information on ring-wall steel tank foundation, which is the most common type of thermal storage tank. Analysis of tank foundation is a breadth of Architectural Engineering which is integral to the thermal storage system design decisions. Performing a study of this type of structural design will provide a good opportunity to integrate mechanical and structural breadths to complete a system design.

Work required for this breadth topic will include, but not be limited to, rebar sizing and placement, geotechnical and soil bearing investigation, tank construction methods, and tank sizing. Because the foundation of the tank is often a major cost, different types of tanks, buried and above ground, may be considered.

Tools & Methods

Trane TRACE 700

Trane's TRACE 700 software is a very powerful tool when analyzing building energy loads and consumption. For both mechanical studies, TRACE has functions for modeling the configurations that have been outlined. TRACE is fundamentally and HVAC modeling tool, and has the capability of performing comparisons between different systems within the same building.

The TRACE software also has options for different types of heating and cooling plants. This includes Variable Primary Flow systems, Primary/Secondary systems, and Thermal Storage systems. Therefore, TRACE will be one of the best and most effective tools in modeling the alternatives described in this report. TRACE also has the ability to perform Life Cycle Cost Analysis when the proper pricing information inputs are used. In addition, the TRACE help hotline is a great source of information when problems arise.

One major drawback of the TRACE software is that most of the calculations are hidden and cannot be examined by the user. Therefore, great care must be taken when outlining the inputs. Other programs listed below will therefore be used during the initial phases of the alternative designs to ensure proper inputs are being examined.

Engineering Equation Solver

Engineering Equation Solver (EES) is a simple but very powerful mathematical tool which has many features that are useful in performing initial data evaluation studies. EES has been used for parametric studies during several MAE graduate-level courses. Due to this experience, it may be a very valuable tool in these investigations. One major advantage of EES is that any equation or set of equations can be evaluated simultaneously using a wide range of different inputs. This is very valuable when examining pump or fan energy consumption, among other things. However, because equations are largely defined by the user and are not embedded within the software, troubleshooting any errors can be difficult and time consuming due to the necessity of finding errors without much outside help.

Microsoft Excel

Microsoft Excel is another very powerful piece of software which is often taken for granted. Excel has the ability to perform parametric studies, similar to EES, based on user-defined equations. One benefit of using Microsoft Excel is during initial life cycle cost analysis formation. Graduate level course assignments involving life cycle costs have provided a pre-programmed spreadsheet which is already available for performing financial analyses. Excel can be used in many different ways, and is flexible much like EES.

Building Life Cycle Cost Program (BLCC)

The National Institute of Standards and Technology (NIST) has developed the Building Life Cycle Cost Program (BLCC) as a tool for analyzing capital investments in buildings. This program was designed specifically to compare alternative systems based on initial cost and operating costs. According to the Department of Energy (DOE) website, the program is especially useful for evaluating costs and benefits of energy and water conservation. The software is available for free download on the DOE website, and provides a more sophisticated life cycle cost interface than Microsoft Excel can. Since Life Cycle Costs are a large meter of project feasibility, this tool will be very important in analyzing the success of the designs performed for this project.

R.S. Means

Life cycle cost analysis is valuable tool, but cannot be performed without knowing cost information for equipment, maintenance, and installation. R.S. Means is a source of cost information for construction estimators for nearly any material or system. Where possible, attempts will be made to communicate with sales engineers that are available as a result of networking with fellow engineers that have been met during summer internships. However, R.S. Means provides a good way to estimate prices that may not be available from equipment sales representatives.

Integration & Coordination

One of the major goals of the Integrated Sciences Building was to be a building that was an icon of efficiency and sustainability for the urban university that owns it. The combination of the topics discussed above directly relate to reducing energy consumption and improving the environmental and energy responsibility of the building. The intention is to introduce systems that reduce energy consumption or energy costs with a reasonable payback period which makes them feasible in real life.

Thermal storage systems have proven to be effective in a wide range of applications, from moderately sized buildings to central cooling plants. Transferring load from peak hours to nighttime hours, as well as decreasing the amount of money spent on electricity on an annual basis is a huge advantage both mechanically and financially. Investigation of chiller equipment configuration enhancements from Primary/Secondary to Variable Primary Flow has the potential to further decrease energy consumption of the chilled water equipment. Combining these methods has the potential to significantly reduce the electricity costs and consumption of the Integrated Sciences Building.

The breadth topics that were selected for investigation do not stray far from the objectives of the mechanical studies. The Photovoltaic array also aims to decrease the electricity consumption of the building in the most efficient way possible. Decreasing utility electricity consumption also works towards to the goal of the mechanical studies, discussed above, which is to reduce operating costs of the building. The foundation design of thermal storage equipment is a major factor is tank selection and the type of storage for chilled water. The results of this foundation design and cost information may influence the overall success of the thermal storage system.

When all of the topics of study are combined, they have the potential to greatly enhance a building that is already designed to be efficient. The learning experience that these studies are sure to create will be very valuable, not only individually, but as a whole with respect to the building's energy characteristics.

MAE Course Related Topics

As an extra requirement for this report, MAE students must incorporate graduate-level coursework into the proposed design changes or modifications for this project. AE 557, Centralized Cooling Production and Distributions Systems, is the course which directly applies to the studies proposed in this report. During this course, both Variable Primary Flow Systems and Thermal Storage Systems were discussed in detail. The course emphasized the difference between Variable Primary Flow and Primary/Secondary Systems, with discussion of how they are operate and are controlled. Both benefits and potential problems were discussed, providing a well rounded debate of how Variable Primary Flow systems can affect chilled water systems. Thermal Storage systems were also a topic of conversation with discussion on how they work, the potential for energy cost savings, different configurations that have been successful, case studies, and actual operational data.

Preliminary Research

Thermal Storage

Bahnfleth, William. "Cool Thermal Storage: Is It Still Cool." HPAC Engineering. April (2002): 49-53. Print.

This article from HPAC Engineering discusses many of the main points which were covered in AE 557 when Thermal Storage design was introduced as a widely successful method to decrease energy costs and shift chiller load peaks. It also discusses the link between thermal storage and utility companies, which includes electricity pricing strategies and the fact that flattening loads in buildings through thermal storage has a positive effect on the power grid.

MacCracken, Mark M. "Thermal Energy Storage Muths." ASHRAE Journal (2003): 36-42. Print.

This is an ASHRAE Journal Article which discusses some misconceptions surrounding Thermal Energy Storage. In proving myths wrong, this article gives information on how effective thermal energy storage can really be. Some of the issues that are discussed are the perceptions that thermal storage is too risky, is not cost effective, control complexity is limiting, and required storage tank space is restrictive. Although some of these issues, such as storage space, are unique to most sites, the article presents the many positive features of thermal storage as reason to explore it thoroughly.

Variable Primary Flow

Bahnfleth, William P., and Eric Peyer. Variable Primary Flow Chilled Water Systems: Potential Benefits and Application Issues. Tech. no. ARTI-21CR. Arlington, VA: Air Conditioning and Refrigeration Technology Institute, 2004. Print.

This report is the compilation of result from parametric studies of Variable Primary Flow system benefits. Findings show that systems with fewer chillers, long cooling seasons, and lower than anticipated temperature differences are ideal candidates for Variable Primary flow systems. The Integrated Sciences Building is designed with two chillers which alternate run times. Although the site is not in the southern United States, Philadelphia summers can be very harsh and often extend from late April or early May through September. As expected, the main area of savings was reported to be from pump energy savings. The report goes on to discuss many facets of the Variable Primary Flow configuration, including cost studies, comparisons to other systems, and feedback from industry engineers. This article is a great source of information of VPF systems and covers many different aspects of the system.

Moses, Terry. "Variable-Primary Flow: Important Lessons Learned." HPAC Engineering (2004): 40-43. Print.

This articled discusses information that was learned by the author based on industry experience. It discusses some information on how to sequence chillers, control schemes, and the belief that Variable Primary Flow systems (in 2004) would become the standard for chilled water systems. Information learned from making mistakes is sometimes the most important, especially for someone who has little experience designing such a system. Not only does this provide tips on what not to do during design, but offers solutions to problems and insight on the proper way to design systems.

Schwedler, Mark. "An Idea for Chilled Water Plants Whose Time Has Come: Variable Primary Flow Systems." Trane Engineers Newsletter 28/3 (1999): 1-4. Print.

This Trane newsletter shows the support that Variable Primary Flow systems have gain among a prolific chiller equipment manufacturer. It discusses the differences between constant flow and variable flow chillers, some pros and cons of the system type, and tips for what type of applications are ideal for VPF systems.

Photovoltaic Array

Hren, Stephen, and Rebekah Hren. A Solar Buyer's Guide for the Home and Office: Navigating the Maze of Solar Options, Incentives, and Installers. White River Junction, VT: Chelsea Green Pub., 2010. Print.

This book is a very basic guide to navigating the solar energy options, equipment, and incentives. This book, although geared for residential consumers, provides a good understanding of how to work through the design and construction process, whether one is purchasing or constructing the system. It also provides a basic summary of the different types of equipment that are required for different solar systems.

Dunlop, James P. Photovoltaic Systems. Orland Park, IL: American Technical, 2010. Print.

This is a textbook-style reference book that guides the reader through the installation of commercial photovoltaic systems. It includes detailed coverage of how photovoltaics work, and how systems should be designed to be the most effective. The textbook also includes CD-ROM based software to assist in some solar calculations and solar system design procedures.

Work Plan Task Outline

I. Mechanical – Thermal Storage System
   A. Thermal Storage Energy Model Simulation
   B. Determine Equipment Requirements
   C. Equipment Selection & Design
   D. Life Cycle Cost Analysis
II. Mechanical – VPF vs. Primary/Secondary
   A. Parametric Study of Energy Consumption & Savings Opportunity
   B. Variable Primary Flow Alternative Energy Model
   C. Equipment Selection & System Design Modifications
   D. Life Cycle Cost Analysis
III. Electrical Breadth – Solar PV Array & Equipment
   A. Annual Solar Analysis Feasibility Study
   B. Equipment Selection & Design
   C. Cost Estimate
IV. Structural Breadth – Thermal Storage Tank Foundation
   A. Determine Tank Type & Location
   B. Determine Tank Loads
   C. Design Structural Foundation Components
   D. Cost Estimation
V. Final Presentation
   A. Organize and Format Final Report
   B. Arrange Final Presentation

Work Plan Schedule