Technology and Engineering Development (TED) Building

Thomas Jefferson National Accelerator Facility

Newport News, VA

Revised Thesis Proposal

This document proposes system redesigns of the TED that will be studied throughout the Spring 2010 semester.

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Executive Summary

The TED is being built on the Jefferson Lab campus to upgrade and expand the existing engineering and support space for the Continuous Electron Beam Accelerator Facility (CEBF). As outlined in previous technical reports, the design incorporates many energy efficient design strategies that range from façade materials to lighting controls. The mechanical system design is no different. A central plant made up of multiple large heat pumps provides flexibility for hot and chilled water production while a hybrid geothermal condenser loop (also containing a closed circuit cooler), two outdoor air preconditioning total energy recovery units, and the use of variable frequency drives provide energy efficiency. Though already utilizing an energy-conscious design, this document proposes changes to the mechanical system that attempt to feasibly reduce energy use and cost even further.

The first change resizes the geothermal well field to the size required to meet full load capacity. Currently, the well field works in conjunction with an inline closed circuit cooler to meet the load. Sizing the well field to meet full capacity will eliminate fan and pump energy associated with the closed circuit cooler.

The second change introduces the use of radiant slabs with a parallel DOAS system. The thermal capacitance of the slab can be used to offset and shave peak loads through the use of radiant heating and cooling in the space. The parallel air system is sized to mitigate the latent load, remaining sensible load, and outdoor air ventilation supply as required by ASHRAE Std. 62.1.

Both changes have an effect on the construction cost and schedule due to the increased excavation and installment of geothermal wells and the requirement to lay piping through the floor slabs. Additionally, the proposed mechanical system changes have the intention of lowering the peak electrical load of the TED. Breadth analyses will be performed on these mentioned effects.

Software tools will include Trane TRACE 700, Microsoft Excel, and Engineering Equation Solver. Additionally, guidance will be attained through technical papers, journal articles, dissertations, and reference textbooks.

Section 1 Existing Mechanical System

1.1 Introduction

The Technology and Engineering Development (TED) Building is the new construction phase of a Technology and Engineering Development Facility project (TEDF) for the Thomas Jefferson National Accelerator Facility (Jefferson Lab). The TEDF is designed to upgrade and improve the technical support space for the Continuous Electron Beam Accelerator Facility (CEBAF). Jefferson Lab performs research in the areas of nuclear physics and is funded by the United States Department of Energy. The TED is two stories and comprises 68,000 ft^2. The first floor contains workspace and storage areas for physicists and electrical engineers while the second floor contains their offices and administration areas. In addition, a two-story high bay area for more extensive manufacturing is located adjacent to the first floor.

1.2 Design Objectives and Requirements

Besides adding new and improved technical space to Jefferson Lab, the TED, as part of the TEDF project, is designed to contribute to the upgrade of the workflow and functionality of the adjacent existing Test Lab building (also to be renovated and expanded as part of the TEDF project). Specifically for the heating, ventilation, and air-conditioning system, this upgrade represents an improvement in operational flexibility, service and maintenance of the mechanical equipment, and energy efficiency.

The project program set forth by Jefferson Lab requires the design of the TED to achieve LEED-NC Version 2.2 GOLD certification [2]. Part of this requirement entails compliance with both ASHRAE Standard 62.1-2007 for adequate ventilation and ASHRAE Standard 90.1-2007 for energy efficiency.

1.3 Site and Budget

The TED is currently under construction on the Jefferson Lab campus located in Newport News, VA. At the heart of the campus is the CEBAF, which houses the particle accelerator and is the primary instrument used for research into the structure of atoms and their nuclei. The existing Test Lab building has been used as the technical support center for the CEBAF. It was originally built for NASA in 1965 and was converted by Jefferson Lab for CEBAF support use in the 1980s. Since then, the building's use has outgrown its functionality, resulting in the need for an additional building [3].

The TED will sit adjacent to the Test Lab building and be connected by two corridors which will enclose a courtyard between the two buildings. As one of the first buildings that will be visible from the main driveway into the campus, the TED is designed to provide an aesthetically pleasing view, while also giving a profound implication of the technical work that goes on inside. In addition, the specific construction site on the Jefferson Lab campus is in close proximity with a large portion of the campus's forest and wetland areas. The TED is designed to disturb only the minimum amount of natural vegetation.

An estimate for the total cost of the TED is \$15.68 million, or \$229/ft^2. This value does not include overhead, taxes, fees, or insurance. The heating, ventilation, and air-conditioning system is estimated to cost \$3.14 million, making up 20% of the total cost. This HVAC first cost equates to approximately \$45.84/ft^2 and includes a geothermal field that costs \$688,000 to install.

1.4 Equipment and Operation Summary

Conditioned air is delivered to zones throughout the TED by the use of two VAV systems with terminal box reheat. Each system contains a 32,000 air handling unit (AHU) that supplies air to series powered fan boxes at exterior zones and damper modulated boxes at interior zones. AHU-1 serves zones located on the first floor and in the high bay area while AHU-2 serves zones located on the second floor. In addition to the VAV systems, cabinet unit heaters serve heating loads in two exit stairwells and water cooled room air conditioning units serve cooling loads in three data closets.

Each AHU is coupled with an outdoor air preconditioning unit (OAU) that utilizes a total energy wheel to exchange sensible and latent heat between incoming outdoor air and building exhaust air. The inclusion of these OAUs reduces cooling and dehumidification loads on the cooling coil in the summer while also reducing humidification and heating loads on the heating coil and humidifier in the summer. Unconditioned outdoor can also be used for free cooling by the inclusion of economizer sections on both AHUs.

Chilled and hot water that serve AHU, terminal box, unit heaters, and water cooled room air conditioners is produced by a combination of twelve water to water heat pumps. Through strategic piping and valve positions, seven of these heat pumps are dedicated to chilled water production, two are dedicated to hot water production, and three can produce either chilled or hot water depending on the load conditions. In addition, a gas fired boiler is included for backup heat incase of heat pump failure and to prevent freezing of condenser water lines. Chilled water is distributed at 42 F and hot water is distributed at 120 F.

The condenser water serving these heat pumps runs through a hybrid geothermal system. This system contains 192 vertical bore ground loops along with a closed circuit cooler that operates at peak load conditions. Condenser water is circulated through these loops at design temperatures of 95 F (leaving heat pump) and 85 F (entering heat pump) during peak cooling and 45 F (leaving heat pump) and 55 F (entering heat pump) during peak heating.

Variable frequency drives (VFD) are utilized on each air handler supply and return fan, each chilled, hot, and condenser water distribution pump, and on the closed circuit cooler fan. The addition of VFDs on these pumps and fan adds significant flexibility and energy savings to the system.

1.5 Current Systems Evaluation

To successfully evaluate the mechanical system, the design requirements and objectives must be revisited. Four different requirements or objectives were determined in the opening section of this report: operational flexibility, easier maintenance, efficiency, and LEED GOLD attainable.

Operational Flexibility

The mechanical system provides a large amount of operational flexibility. In the air system, the combination of terminal boxes and the use of a VFD on the supply fan allows for large variations in air quantities to be delivered to separate zones without wasting unneeded fan energy. With each terminal box having its own air damper, heating coil, and thermostat, the zone temperatures can be controlled with acceptable accuracy. In addition, the ability to humidify and dehumidify the supply air leads to further thermal comfort acceptances. Lastly, the inclusion of both an economizer section in the AHUs as well as the coupling of an OAU to each AHU allows for greater flexibility in the use of outdoor air for heating, cooling, and ventilation over a more traditional system. One caution in the use of VAV systems, however, is the accountability of proper ventilation delivery rates for each zone. If certain terminal boxes are operating at minimum flow, slightly askew outdoor air fractions can lead to improper ventilation air amounts to those zones.

The hydronic system also exhibits large amounts of operational flexibility. The primary example is the arrangement of the twelve water to water heat pumps. The three heat pumps that are piped to operate in either cooling or heating mode replace the otherwise required six "unimode" heat pumps to provide enough cooling or heating for peak loads. This flexibility comes from the realization that peak heating and peak cooling loads will not occur at the same time. At $28,400 each, not purchasing three extra heat pumps saves a significant amount of first cost. Additionally, the ability for the boiler to run instead of hot water heat pumps when freeze protection of the condenser lines is needed saves on energy cost. This is due to the price of natural gas being cheaper per unit energy than that of electricity, which would be used if one of the heat pumps remained operating for the same function.

Ease of Maintenance

The mechanical system is largely centralized into one mechanical room that is located on the second floor. Though this location makes installation and removal more difficult, it is the optimum place when considering lost useable space. From the second floor, the mechanical system has access to both the first floor ceiling and the roof; eliminating the need for mechanical shafts and opening the floor plan for more useable space.

Though it was exemplified in the previous section, this flexible, yet highly dynamic, system can prove to be more difficult to maintain and operate than a more traditional system. With so many moving parts comes the increased possibility of malfunction. Though safeties and alarms are implemented to deter damage or safety risks, improper sequencing or actuations can lead to a constant stream of problems that frustrates any building operator. This may be especially true as longevity becomes a factor and parts begin to need replacement at various time intervals.

Efficiency

The overall system is designed to operate with a large amount of energy efficiency. The use of VFDs, energy recovery units (OAUs), economizers, heat pump/boiler staging, geothermal well fields, etc. all contribute significantly to energy use and cost savings. It is modeled to use as much as 65% less energy than a baseline ASHRAE 90.1 building as well as save 50% on energy costs. Also, the TED is projected to operate at a lower energy density for a building of similar size, location, and occupancy. However, this is all based on an energy simulation performed by a commercialized energy simulator that may be limited in modeling highly non-traditional systems such as this. It will be interesting to see how the building actually performs once it is fully constructed, commissioned, and occupied.

LEED GOLD Attainability

The assessment performed in this report revealed many opportunities for the TED to gain LEED points for the mechanical system alone. Additionally, through the research performed for all three technical reports, many opportunities for LEED points have presented themselves throughout other building systems. The TED should be able to attain LEED GOLD certification.

Section 2 Mechanical System Alternatives

The TED mechanical designer incorporated many strategies and technologies to produce an efficient and low-energy system. This is not to say, however, that improvements are not possible. With ideals such as carbon neutrality and net zero energy use becoming more prevalent in the building industry, building designers are challenged to produce designs that represent the optimum in energy efficiency. These designs may include any or all of the following: decreasing the thermal loads on the building, the use of on-site renewable energy, the use of low-energy equipment, and the implementation of energy efficient strategies.

Research and analysis performed for three technical reports completed throughout the semester has revealed that all four design solutions listed above have been included in the TED by the entire design team. Therefore, the focus of this thesis is to compare other highly efficient alternative systems to the current system in terms of energy use, energy cost, first cost, and reliability. This section will outline mechanical system alternatives to be analyzed as well as identify each alternative's ability to be studied and implemented.

2.1 Geothermal Well Field Redesign and Optimization

Geothermal systems use the ground as a heat exchanger to reject or add heat to the system. Because of its large thermal capacitance, the ground a few feet below the surface is maintained at relatively constant moderate temperatures throughout the year. These generally range from 45 F to 75 F throughout the country. During the summer, the ground temperature is cooler than the air temperature, which allows for more heat to be dissipated to the ground. The reverse is true during the winter, when the ground temperature is warmer than the air temperature and heat can be added to the system. This duality works very well in coordination with heat pumps, air-conditioning equipment that can be run to produce a heating or cooling effect.

The TED, located just a few miles from Norfolk, VA, utilizes a hybrid geothermal system that does not utilize the geothermal aspect to the fullest extent. The condensing water running through this system serves all twelve water source heat pumps in the TED as well as heat pumps located in the adjacent Building 58 renovation. Jefferson Lab was in favor of using a geothermal system, however, was not willing to yield the appropriate amount of space to size the system for full cooling load capacity. The reason for resisting allocation of the appropriate amount of land was to preserve a group of trees located to the northwest of the TED. Therefore, the design team elected to design the geothermal system as large as possible and add a closed circuit cooler sized with a capacity 28% of the geothermal loop.

The focus of this alternative is to resize the geothermal system to full load capacity, utilizing the land occupied by a group of trees previously determined off limits. The benefit associated with this resize is the elimination of the closed circuit cooler, which includes its associated fan and pump energy.

Three different geothermal field types were researched in order to determine the optimized layout for the TED. The first type is a horizontal field created by excavation. For this type, a large area of land is excavated to a depth below the frost line and the heat exchanger tubing is laid parallel to the ground surface inside the resulting trench. This type of field layout is generally the easiest and cheapest to install at $600 to $800 per ton, however, require a large amount of space of approximately 2500 ft^2/ton [4].

The second type of field layout is the vertical bore, where heat exchanger pipes are placed perpendicular to the ground surface with depths ranging from 200' to 400' deep. Though this layout is generally more expensive to install, between $900 and $1300 per ton, it requires less land area than a horizontal layout; approximately 250 ft^2/ton [4].

The third type is a horizontal field bored by horizontal directional drilling (HDD). This type of drilling allows installment of a horizontal bore field with minimal land disturbance. HDD utilizes a directional drill bit that can change the direction of the drill during the drilling process while under ground. This allows installers to begin drilling at an angle into the ground to a prescribed depth and then continue parallel to the ground surface until the bore length is met. The drill is then directed to the surface where the heat exchanger pipe is attached and pulled back through the bore hole. With this type of drilling, a geothermal field can be installed under obstacles such as roads, ponds, or trees. Additionally, the cost can be approximately 20% to 30% lower than vertical bore drilling [9].

For the TED, an HDD geothermal field will be explored in an attempt to serve the loads without disturbing the vegetation described as off-limits.

The increase in geothermal field size has disadvantages as well. The first, though less influential, is the addition of pump head, leading to larger pump sizes and more pump power. The second, more influential, disadvantage is the increase in construction costs and construction time. An interesting study will be the comparisons of construction and installation cost savings associated with the current system with the operational and energy costs of the proposed system.

2.2 Radiant Slabs with DOAS

Coupling a radiant heating and cooling system with a Dedicated Outdoor Air System (DOAS) can produce significant energy use and cost savings. These savings come from the ability to separate the sensible loads, to be taken care of by the radiant system, and the latent loads, to be taken care of by the DOAS system. Rather than conditioning and moving large amounts of air, as traditional VAV systems do, hot or chilled water is pumped through building surfaces to cool or heat the space while the DOAS system treats and supplies only the minimum ventilation air required by ASHRAE Std. 62.1. At the same time, the DOAS dehumidifies the supply air to prevent condensation on radiant surfaces during cooling. It has been shown that there are significant energy savings with the use of radiant floor slabs [5].

This alternative proposes to replace the existing, more traditional, VAV system with radiant slabs coupled with a DOAS system. This replacement will take place in the first floor work and second floor office spaces. A separate air-conditioning system may be used for the high bay area due to the probable inability to control humidity and infiltration in this space resulting from the presence of large loading dock doors. However, further analysis is to be done on this particular matter.

Humidity Control with Radiant Systems

With the TED being located just outside of Norfolk, VA (92 DB, 77 WB summer design), space humidity control is of great concern in order to prevent condensation on radiant surfaces. Therefore, this lends itself well to an exploration and analysis of traditional and emerging dehumidification technologies such as desiccant wheels, liquid desiccants, or membrane-based dehumidification. Also, there are current design characteristics of the building that can help mitigate this concern. The first is the compliance of the building envelope with ASHRAE Std. 90.1 in terms of air leakage and infiltration, as outlined in Technical Report I. Also, the building is designed to be positively pressurized to minimize uncontrolled infiltration. Lastly, there is only one main entrance to the building, helping to determine a main source of infiltration. This entrance also contains a vestibule, which can be used to control the humidity of air infiltrating from this point.

Radiant Concrete Floor Slab System

There are multiple solutions for radiant systems, each of which can be used for heating and cooling. These include chilled beams, radiant ceiling panels, and radiant floors. A preliminary study suggests that the use of radiant floor slabs could be the most beneficial for the reasons of radiant area and thermal storage.

The larger use of radiant surface area in treating the sensible load can result in the use of higher surface temperatures during cooling and lower surface temperatures during heating; decreasing the amount of energy needed and improving conditions to prevent condensation [6].

Radiant floors present an interesting opportunity for the examination of slab thermal storage; where the thermal capacitance of the concrete floor slab can be used to shift and shave central plant cooling and heating loads. Ongoing research at the Massachusetts Institute of Technology suggests that a slab that is optimally primed during the night can save as much as 25% on energy during a typical summer week in Atlanta, GA. This research incorporates 24-hour weather forecasts into a program that predicts the performance of the slab for the following 24 hours. With this information, a compressor schedule is established that can optimize its associated power function with constraints on personal comfort and chiller freezing [7]. Additionally, a case study on the Pennsylvania Convention Center in

Philadelphia, PA, shows that a radiant slab thermal storage system was actually implemented to flatten and reduce cooling loads [8].

This has the potential for significant equipment cost, energy cost, and energy use savings. By addressing part of the sensible load in the space by a radiant slab, less supply air is needed, significantly reducing associated fan power or size. Additionally, less air to condition lowers the load on the heat pumps and saves energy.

Section 3 Breadth Work

3.1 Construction Process Analysis

Geothermal well fields are often dismissed by building owners due to a high cost and time of installment. Enlarging the field currently utilized by the TED will have a significant effect on the existing construction schedule and cost. Additionally, laying radiant system piping into the concrete will affect the cost and time needed to pour these slabs. An analysis must be completed on how both of these changes would affect the TED construction schedule and associated costs.

3.4 Electrical System Impact Analysis

Converting currently designed floor slabs into radiant thermal slabs should have a significant effect on the size of the electrical system. By addressing a portion of the sensible load in each space the radiant slab is applied, less conditioned air will need to be supplied to each space; a change that can drastically reduce the associated fan power. Additionally, a lesser quantity of air to condition will require a lesser amount of chilled water and lower distribution pump power. The use of the thermal capacitance of the slab will allow peak cooling or heating demand to be shaved and distributed more evenly throughout the day; lessening the total electrical load of the HVAC system. An analysis of the electrical system loads will be done to properly resize important components such as transformers, main panels, breakers, and conduit.

Section 4 Methodologies and Tools

4.1 Load and Energy Modeling

Trane TRACE 700 will likely be the primary modeling program of choice. This is due to its availability at Penn State (EnergyPlus and IES are not readily available) and the existence of a TRACE block model already constructed. The block model will be examined for accuracy and revised accordingly, particularly the central plant and necessary zone areas. Unfortunately, TRACE does not have the capability of modeling a radiant floor slab in parallel with an air system. A design-specific model based on loads developed by TRANE Trace will have to be developed using other software for analysis of the radiant system and its energy use.

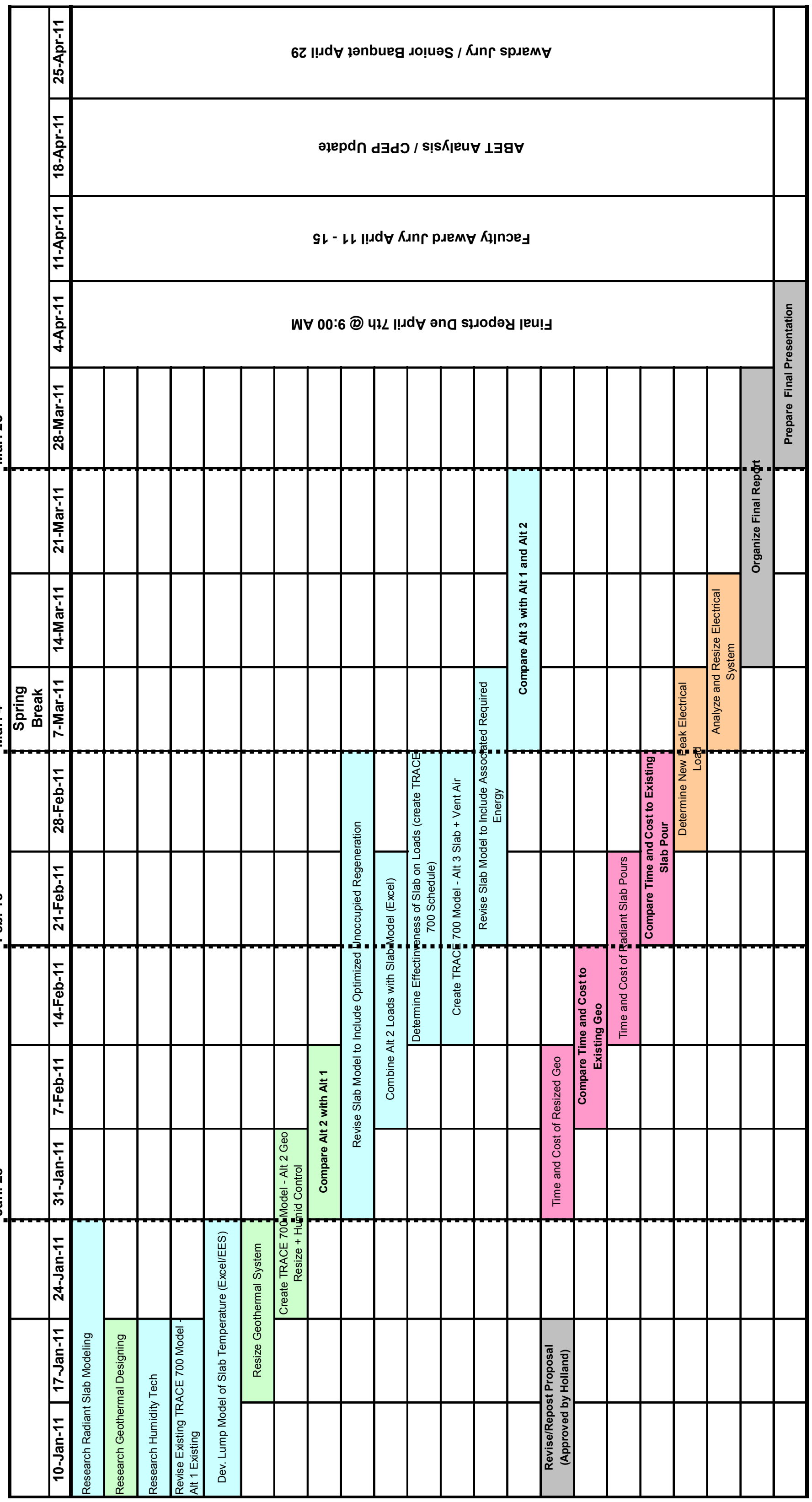
4.2 Microsoft Excel and Engineering Equation Solver

Excel and EES will be used to help develop a model of the proposed radiant floor system. This model will correlate time-dependent total space loads generated by TRACE with slab surface temperatures, resulting in the ability to predict the slab's transient contributions to lessening the loads on the parallel air system. These contributions will be entered back into the TRACE model as miscellaneous loads in the form of a schedule associated with the transient contributions calculated in the spreadsheet model. The model will also allow the prediction of cooling and heating loads with associated energy costs required specifically for the slab. These energy costs will be combined with those calculated for the air system by TRACE.

4.3 Other References

Preliminary research on the topics of this proposal has generated possible useful references in the form of: Technical papers, journal articles, dissertations, manufacturer data, ASHRAE handbooks, and fundamental heat transfer texts. Guidance and data found throughout these sources will be used in all aspects of thesis work next semester.

Section 5 Spring 2010 Work Schedule



	Milestones
1	Geothermal System Resized, Radiant Slab Modeling Procedure Finalized
2	Determine Radiant Slab Effectiveness, Determine Geothermal System Construction Effects
3	Complete Radiant Slab Model, Determine Radiant Slab Construction Effects
4	Analyze Electrical System, Finalize Report

Task	To Do	Completed
Geothermal Resizing		
Radiant Slab with DOAS		
Breadth 1: Constr. Cost/Sched. Impact		
Breadth 2: Electrical System Impact		
Thesis Organization and Report		

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