Depth Proposal

David H. Koch Institute for Integrative Cancer Research

Massachusetts Institute of Technology

Cambridge, Ma



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Executive Summary

The David H. Koch Institute for Integrative Cancer research lab presents a multitude of HVAC design challenges. With the MIT's expectation of achieving LEED Gold Certification, design engineers were forced to provide innovative design solutions, resulting in an energy efficient HVAC system. In the previous technical report, the mechanical systems of the Koch Institute were evaluated, critiqued and ultimately found to be extremely well designed. This report attempts to propose a number of changes and additions to the existing design, providing annual energy savings for MIT as well as incorporating renewable technologies.

The evaluation of the mechanical systems in the last technical report made it evident that the VAV ventilation/cooling system will be responsible for a large portion of the building's energy consumption. This system therefore presents itself as a good candidate for a number of changes that will aim to reduce its energy consumption. This document proposes the following design changes and renewable technologies:

- **Heat Recovery from Specialty Exhaust**
- **Geothermal Heat Pump**

The existing system returns 30,000 cfm of return air from public spaces directly into the outdoor air plenum. This air is then supplied back to the spaces through the (10) 50,000 cfm AHU's. The design also includes a heat pipe heat recovery system between the AHU's and EAHU's, yet 53,810 cfm of specialty exhaust air does not utilize heat recovery. For this a glycol loop heat recovery system is proposed to recover wasted energy from these exhaust airstreams and use it to precondition the incoming airstreams of the main AHU's. If this glycol system turns out to be infeasible, utilizing the recovered energy to heat the stairways will be investigated.

A geothermal heat pump located in the quad adjacent to the Koch Institute will further reduce the ventilation/cooling load. Two applications of this geothermal heat pump will be evaluated in the coming months. This system could be used to meet the cooling loads of the penthouse and chilled beam applications, or to help precondition the incoming airstream of the 10 main AHU's.

With an efficient existing design, a large focus is placed on the addition of energy recover and renewable energy to the project. As a breadth, the construction of the geothermal heat pump will be planned to preserve site circulation and safety. Also, changes to the electrical service will be necessary with the addition of a geothermal pumping system. These additional changes will be designed to maintain the efficiency of the current electrical system of the Koch Institute, while incorporating renewable energy sources into the project.

Mechanical Summary

Introduction

A central VAV ventilation/cooling system provides fully conditioned 98% outside air to the Koch Institute, utilizing heat recovery between the supply and exhaust air streams. The remaining 2% is made up with two small return fans that dump a total of 30,000 cfm into the outdoor air plenum that the large units pull from. The central VAV ventilation/cooling system is made up of (10) 50,000 cfm factory built-up AHU's coupled (10) 50,000 cfm EAHU's, and is responsible for supplying and exhausting the entire building. The building is heated through hot water reheat coils and a perimeter radiant panel heating system. High intensity load and perimeter spaces are conditioned with fan coil units and chilled beam induction cooling to supplement the central VAV system.

Design Criteria and Objectives

It is essential in the design of any HVAC System to ensure that all spaces are properly ventilated, meeting all requirements of the occupants. A good design can meet these ventilation requirements while also creating comfortable space conditions by controlling temperature and humidity to pre-determined levels. Due to the diversity of building and space types, every project presents new challenges which results in uniquely designed HVAC systems.

In the case of the Koch Institute, a number of critical space types and occupancy requirements drove the design. A large amount of laboratory and classroom spaces demanded that the HVAC system should be capable of delivering large amounts of outdoor air to properly ventilate all spaces. Very large equipment loads required the design to adjust quickly to increased loads during equipment operation. Also, the nature and importance of the research being performed in the building called for a sophisticated, reliable emergency power system.

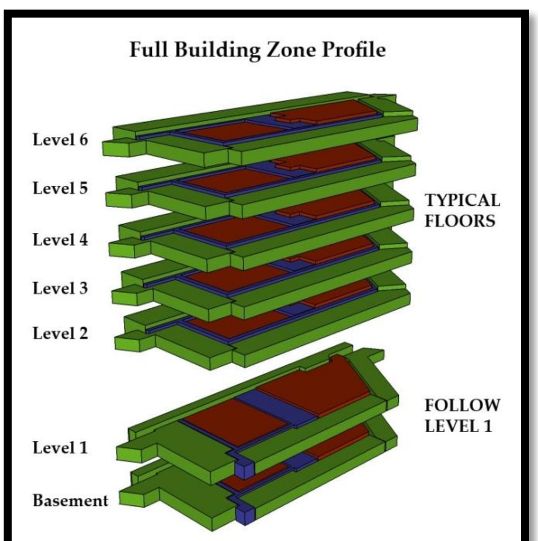

Figure 1 *–Building Zone Profile (level 7 not shown)*

Along with these space and occupancy criteria, the architecture of the Koch Institute presents additional challenges. The glass enclosed building is subjected to large amounts of solar gain, making all perimeter spaces critical. With a mechanical penthouse and two main shafts in the East and West sections of the building, the mechanical design engineers chose to employ a large centralized system that is divided between East and West service. With the exception of the seventh level, the spaces on each level were nearly identical and therefore could be treated similarly. Therefore, the architectural layout of the building dictated that the vivarium space on the seventh floor be conditioned separately than the other levels.

With all of these challenges comes another extremely important factor of the design, and that is the owners design intent. The Koch Institute is designed with the goal of achieving LEED Gold Certification. Energy conscious design makes up a large portion of LEED Credits, and therefore, the mechanical system must be very efficient in all areas. Having all of these challenges and design requirements in mind, the design engineer has all the tools needed to design the optimum system for the owner. The components of the system must be selected to operate efficiently over the buildings lifetime to reduce large energy costs for the owner.

Outdoor and Indoor Design Conditions

The desired indoor conditions and the location specific outdoor conditions heavily influence the design of a building. The Koch Institute is located in Cambridge, MA where a New England climate produces harsh winters and hot summers. This area experiences the same outdoor conditions as Boston, MA which has the following ASHRAE Weather Data:

Outdoor Design Conditions	
Weather Location	Boston, MA
Summer Dry Bulb (°F)	88
Summer Wet Bulb (°F)	74
Winter Dry Bulb (°F)	9
Summer Clearness	0.85
Winter Clearness	0.85
Summer Ground Reflectiveness	0.2
Winter Ground Reflectiveness	0.2
Carbon Dioxide Level	400

Figure 2 *–Outdoor Design Conditions*

With summer temperatures in the high 80's and winter in the single digits, the building will exposed to high heating and cooling loads. The system will have to overcome these loads to condition the spaces to the desired thermal conditions, while also maintaining proper humidity levels. With laboratories and classroom space making up a large portion of the building, the indoor design conditions follow the requirements associated with these space types.

Thermostat Settings	
Cooling Dry Bulb (°F)	74
Heating Dry Bulb (°F)	72
Relative Humidity %	50
Cooling Driftpoint (°F)	90
Heating Driftpoint (°F)	55

Sensor Locations	
Thermostat	Room

Humidity	
Moisture Capacitance	Medium
Humidistat Location	Room

Figure 3 *–Indoor Design Conditions*

Those temperatures and humidity's are shown in ***Figure 3*** to the left. The individual room temperatures may vary based on zone set points or changes in thermostat settings.

The humidity levels in the spaces are controlled by dehumidification performed in the main air handling system in the penthouse. The only floor to need additional humidification is level seven due to its vivarium spaces and specific space needs. Therefore, level seven has its own dedicated air handlers AHU-5 and AHU-6 that are supplemented by individual ducted humidifiers that provide the appropriate humidity levels for the spaces they serve.

System Design and Equipment Summaries

As outlined above, there were many design objectives, requirements and conditions that drove the engineers to the current MEP design for the Koch Institute. To best portray the system in this report, numerous diagrams and equipment summaries were created.

Air Supply System

The Primary air supply system utilizes (10) 50,000 CFM Factory Built-Up AHU's that utilize 98% outdoor air and 2% return air to the entire building. These units make up the entire central VAV ventilation/cooling system that was described in the introduction of this report. These air handlers are divided up into 3 groups, AHU – 1 to 4; AHU-5 & 6; and AHU-7 to 10. AHU's 1-4 deliver 200,000 cfm of conditioned air down the west shaft to the west zones of levels B-6. AHU-5 & 6 serve the seventh level vivarium spaces and AHU's-7-10 deliver 200,000 cfm of conditioned air down the east shaft to the east zones of levels B-6. These AHU's are summarized in the following table shown in ***Figure 4***. As can be seen, these are cooling units that utilize a heat recovery system from their respective exhaust airstream to pre-condition the incoming outdoor air.

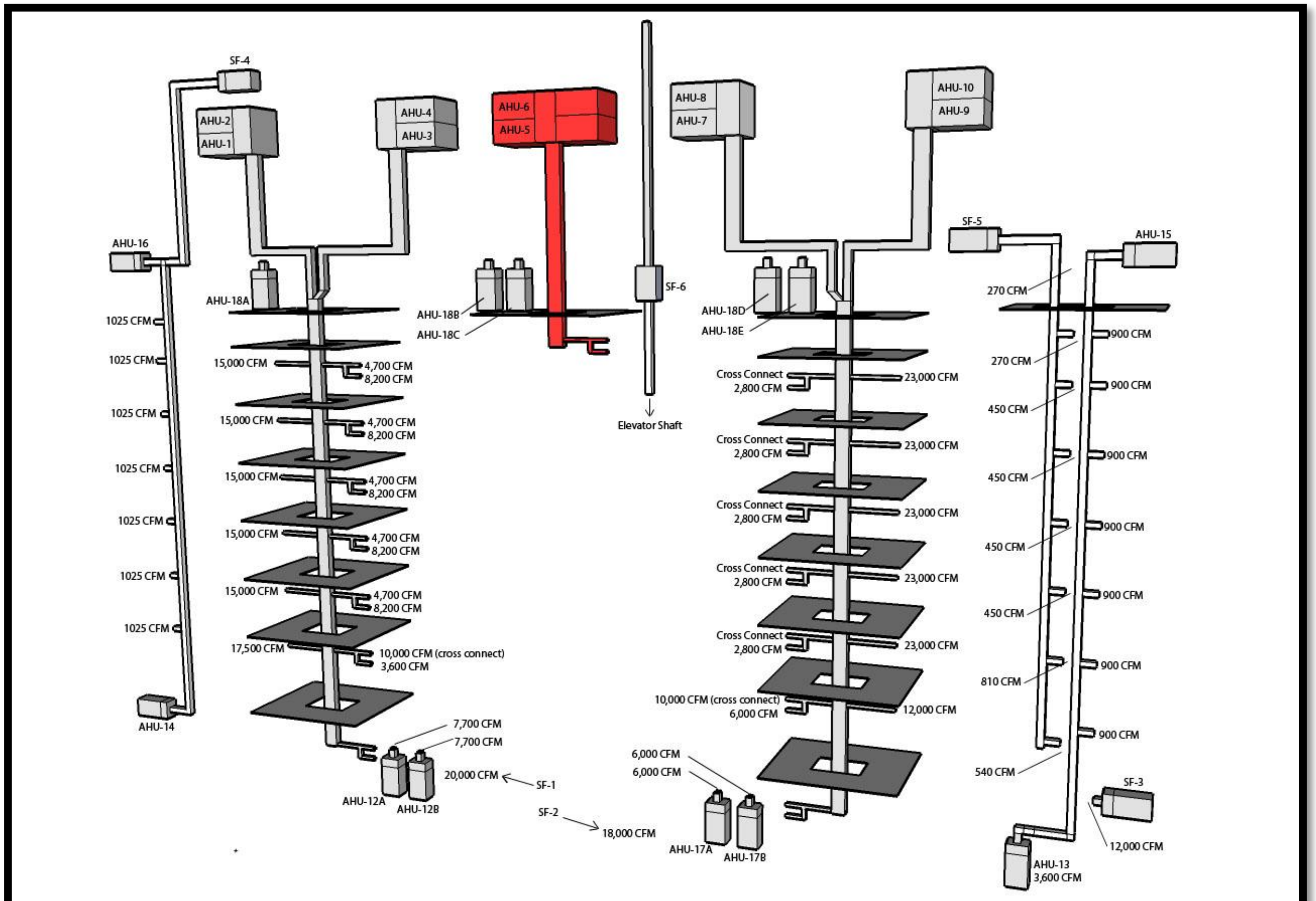

Figure 4 *–Supply Air Riser Diagram*

Figure 4 on the previous page shows the full layout of the central VAV ventilation/cooling system. The 10 large air handling units that make up this system are depicted in what will be the penthouse level of the Koch Institute. The air handling units shown in red (AHU-5 & 6) are not completely depicted in this picture due to their extensive humidification system. To simplify the drawing and maintain readability, a separate drawing for these air handling units was created and is shown below in ***Figure 5***. To maintain the desired space conditions on level 7, after leaving the (2) 50,000 cfm air handlers, the supply air is humidified by its respective humidifier shown in ***Figure 5***.

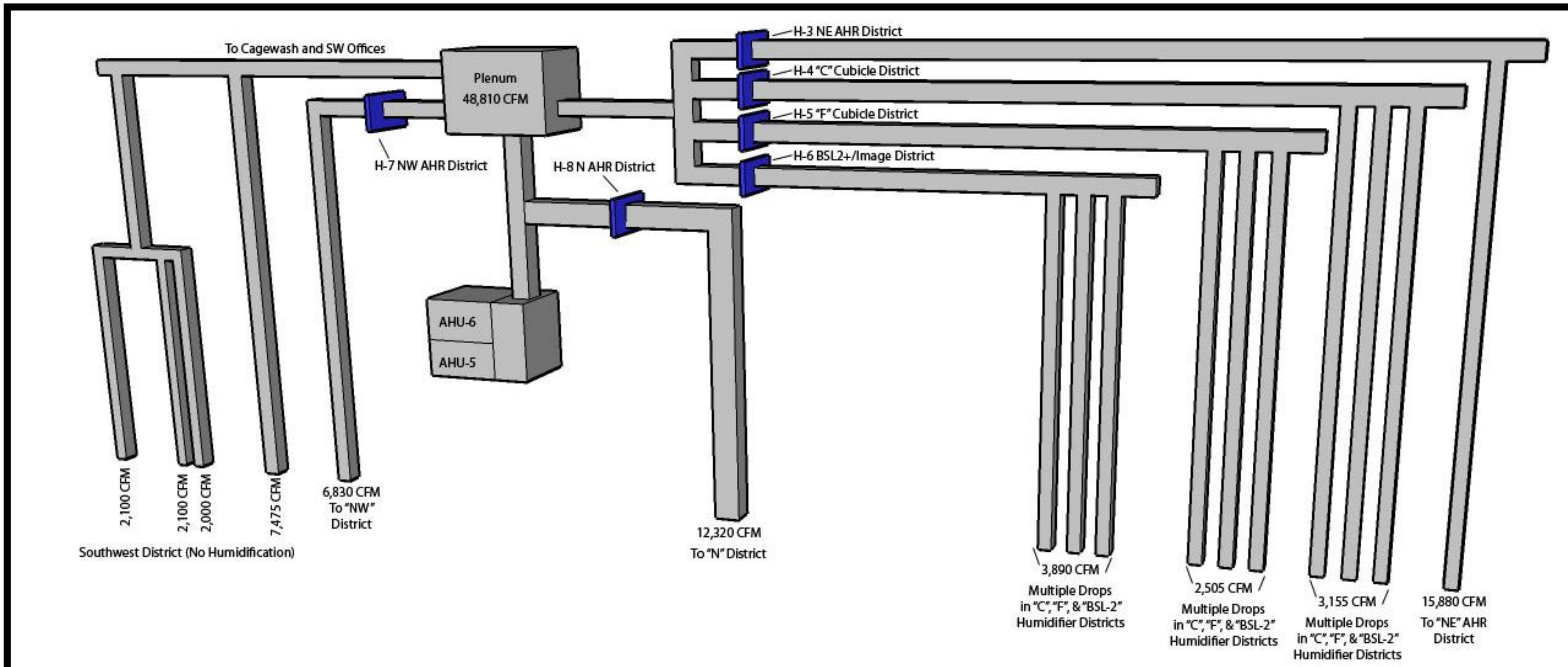

Figure 5 *–AHU 5 & 6 Supply Air Riser Diagram*

The smaller packaged air handling units shown in the main supply drawing (***Figure 4***) are responsible for spot cooling the penthouse and basement, as well as heating/cooling the East and West Stair Shafts. The four air handlers that have heating coils (AHU-13-15) are responsible for heating and cooling the stair shafts. The remaining units are utilized to cool the penthouse and electric service room. The remaining supply fans shown in ***Figure 5*** are used to pressurize the loading dock, stairwells and passenger elevator shafts.

Air Exhaust/Return System

The exhaust/return system utilizes (10) 50,000 CFM Factory Built-Up EAHU's to exhaust air from entire building. These exhaust air handlers are paired up with their respective AHU and exhaust air from the same spaces. Similar to the supply system, the exhaust system has the 10 main EAHU'S along with a number of smaller Exhaust Fans to deal with smaller spaces. Lastly, two small return fans that return air directly into the Outdoor Air Plenum are shown in ***Figure 6***. There are a number of future special exhaust fans on the design documents that were not shown in this drawing.

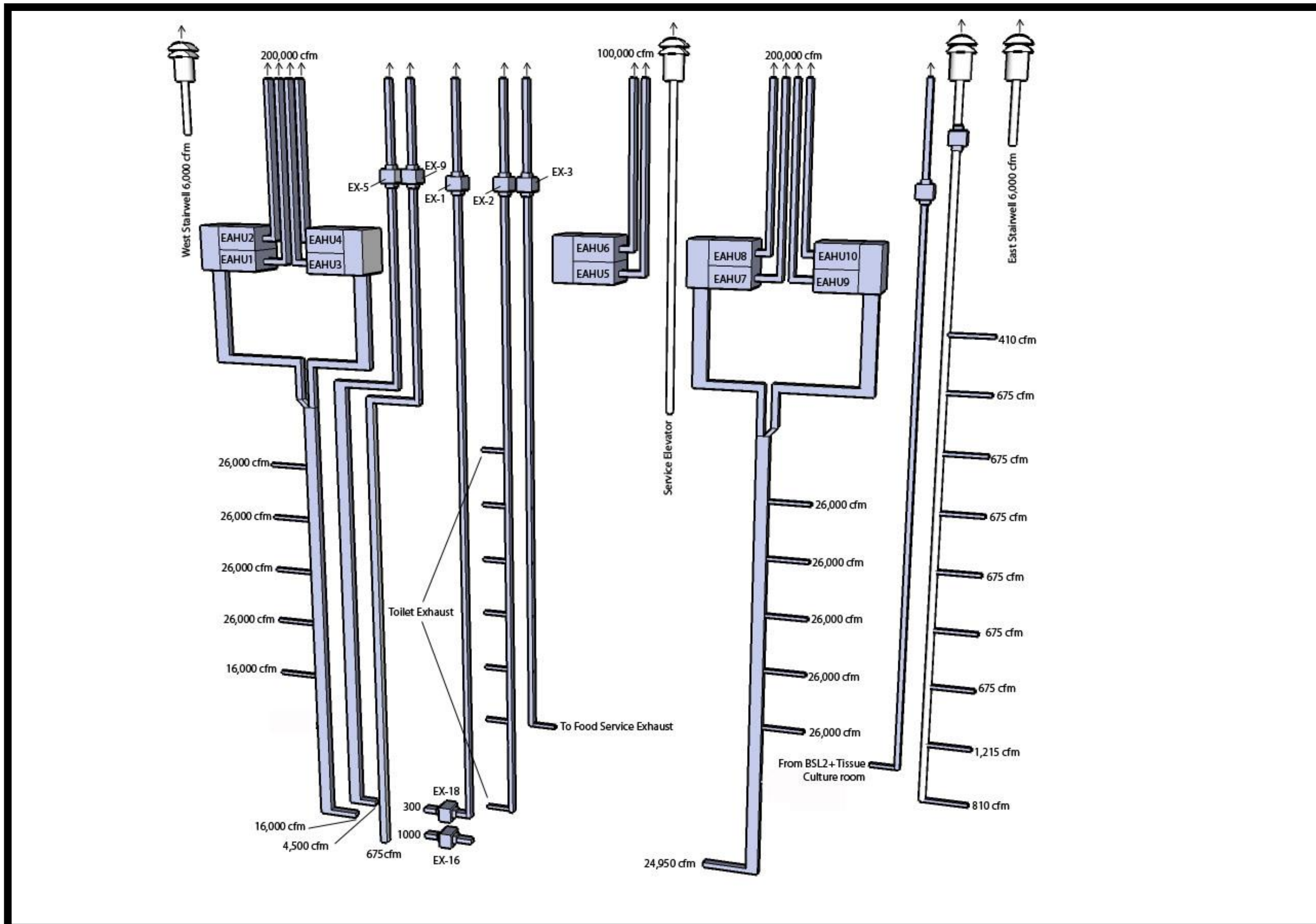

Figure 6 *–Exhaust Air Riser Diagram*

Chilled Water System

The chilled water system for the Koch Institute is fed through an existing MIT Campus chilled water loop. A maximum flow of 6,200 gpm chilled water enters the building through a 24” directly buried supply line and passes through the MIT Standard Meter. The chilled water is then distributed throughout the building. One 200 ton water cooled rotary screw chiller was added to the design to provide redundancy for the vivarium spaces. The ten large AHU’s require three cooling coils and therefore 450 gpm of chilled water is piped to each through (3) 6” pipes to each unit, which is shown in ***Figure 7***. Chilled water also serves fan coil units and process loads on all floors through East and West Risers.

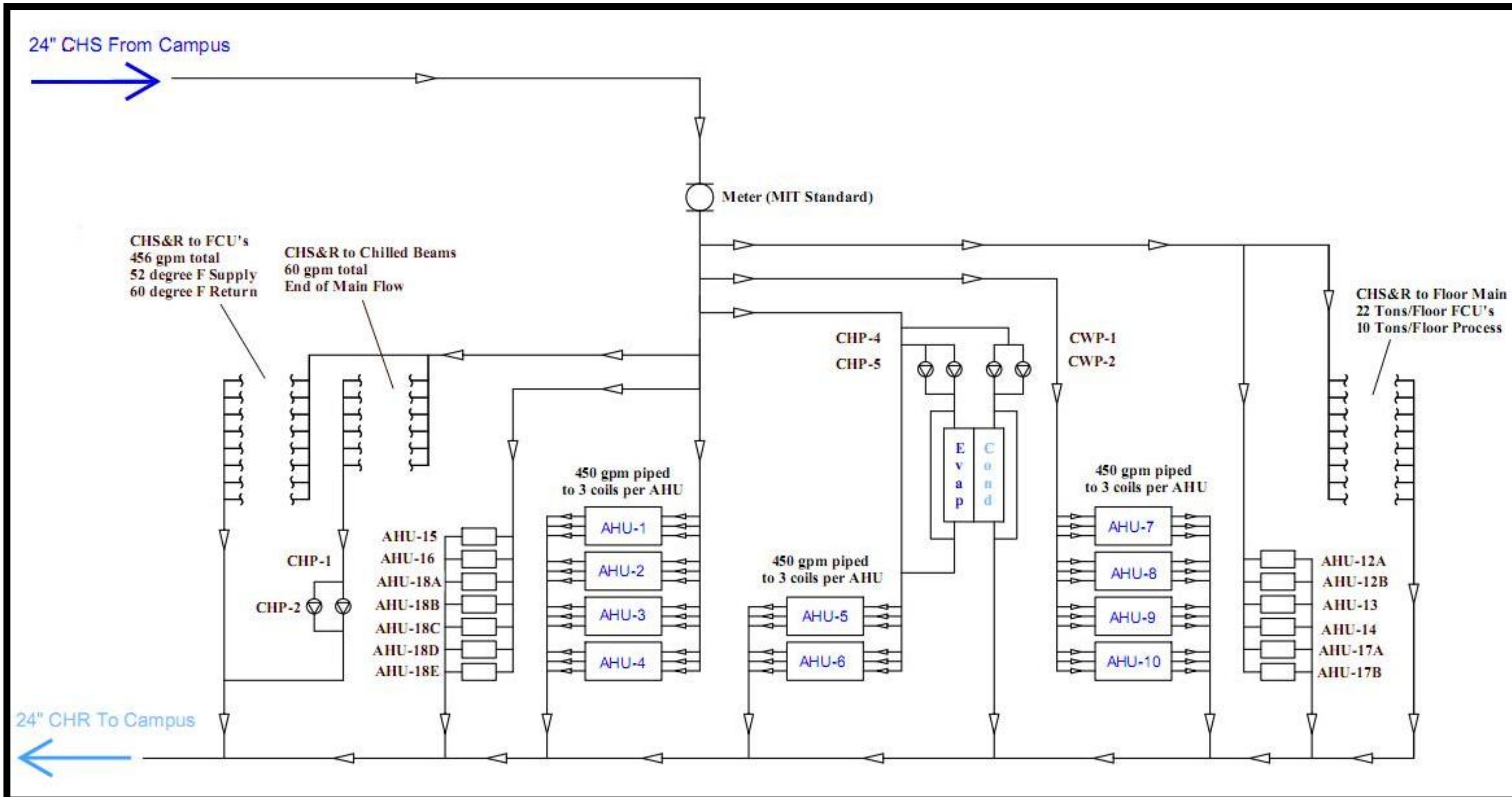

Figure 7 *–Chilled Water Riser Diagram*

Hot Water System

The hot water system for the Koch Institute consists of three shell and tube heat exchangers that produce 180 degree F hot water from low pressure steam (4 psig). As shown in ***Figure 8*** below, the hot water is then pumped to building reheat, vivarium reheat and AHU's 15 & 16. To maintain separation from the other systems, the vivarium space has its own heat exchanger HE-1.

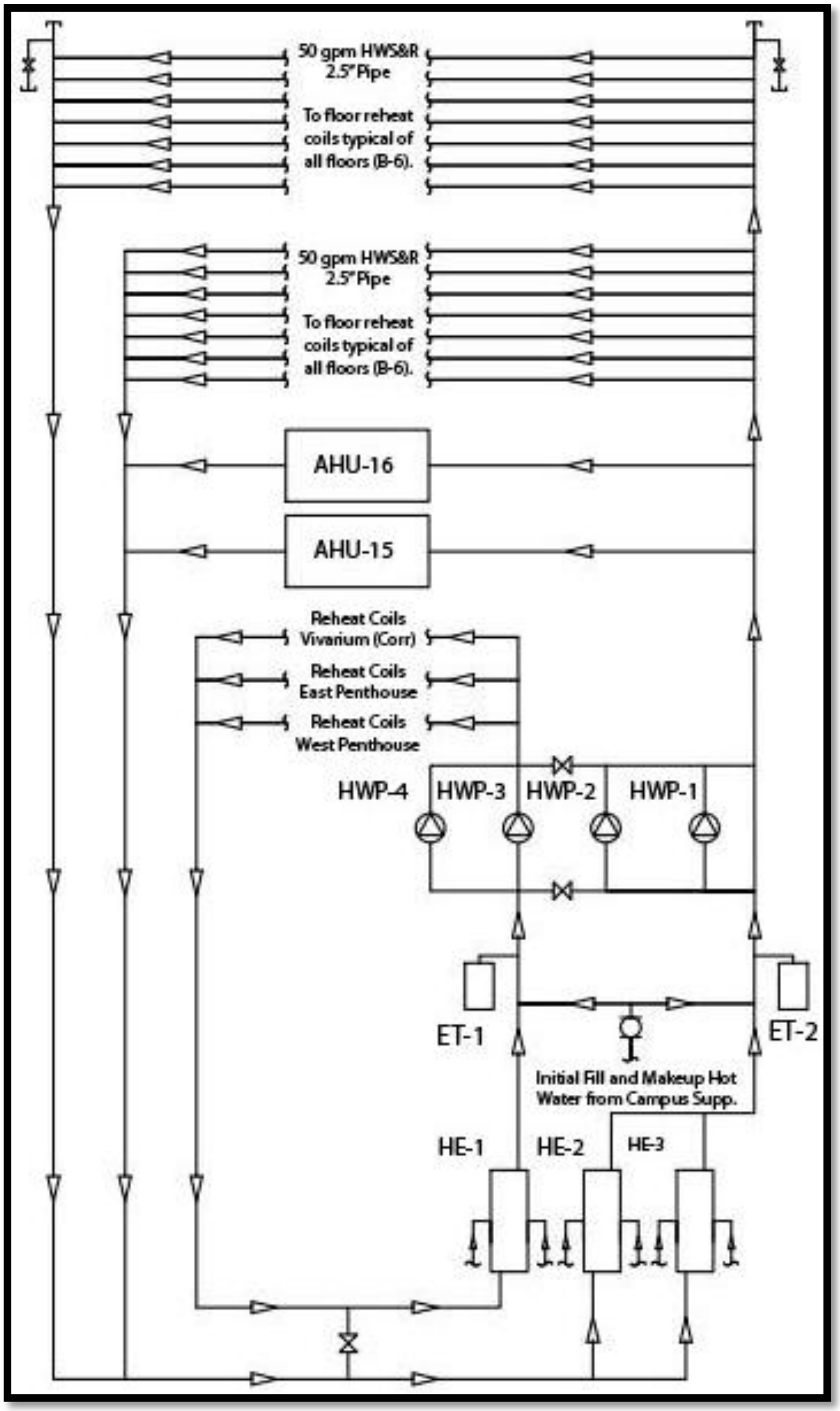

Figure 8 *–Hot Water Riser Diagram*

The vivarium's hot water is served via HWP-3 and HWP-4. To once again add redundancy for the vivarium, this system is isolated with three normally closed valves depicted in the figure to the left. If these valves are opened it integrates into the rest of the system, utilizing the capacity of all three heat exchangers to provide hot water to the entire building. Prior to the expansion tanks, ET-1 & 2, is a connection to the campus hot water system that will act to initially fill the system as well as provide make-up hot.

Depth Proposal

Introduction

In the previous report, the mechanical systems of the Koch Institute were evaluated and critiqued. It was found that the designed mechanical systems successfully exceed the design objectives set forth by the Massachusetts Institute of Technology, resulting in a clean, energy conscious design. With this current design, the Koch Institute is projected to attain 42 of the possible 69 LEED credits, qualifying it for LEED Gold Certification. In this report and in the following months, alternative and additional approaches to the Koch Institute's design will be evaluated in the attempt to optimize its systems further.

The outdoor air ventilation/cooling system described in the mechanical summary above is responsible for a large portion of the buildings energy consumption making it a prime candidate for possible energy savings. Measures to reduce the fan energy such as utilizing return air from public spaces as make up air for laboratory spaces will be evaluated.

It was also noticed in previous reports that a number of fan coil units and chilled beam applications are utilized to heat and cool offices and load intense spaces. Alternative cooling/heating schemes and a geothermal heat pump system will be discussed in this report to reduce the need for extra units. Lastly, energy recovery that has not been incorporated in the original design will be evaluated for feasibility and possible energy savings.

Heat Recovery on Specialty Exhaust

The central ventilation/cooling unit utilizes a large heat pipe heat recovery system between the supply and exhaust airstreams. For a nearly 100% outdoor air system this is an energy conscious approach given the strict laboratory ventilation requirements. Due to specific needs, it was also required to provide the Koch Institute with a number of specialty exhaust fans. These fans do not currently employ any heat recovery systems. The exhaust air diagram shown above (Figure #) depicts the specialty exhaust fans that are responsible for the stairs and all levels of the building with the exception of level seven.

The building design utilizes 18 specialty exhaust fans that exhaust 53,810 cfm of conditioned air without retrieving any energy. To account for increased need for specialty exhaust, the design also includes an additional 14 future exhaust fans (of unknown size). Therefore, there is a lot of potential for energy savings if energy is recovered from all of these exhaust airstreams and utilized to pre-condition the supply airstream.

The design currently utilizes a heat pipe to recover the energy from the exhaust airstream which requires side by side airstreams. Due to the varying location of all the specialty exhaust fans, a side by side airstream is not feasible. To incorporate the specialty exhaust heat recovery successfully, a glycol loop system will be researched. The glycol loop is capable of collecting energy from sources in various locations and placing it all in the supply airstream. Optimizing this system will take time given the varying airstreams, but with 53,810 cfm of conditioned air being exhausted, the energy recovery should be significant.

Geothermal Heat Pump

MIT's campus plant utilizes a 25 MW Micro-turbine to produce 80% of the campuses electrical energy, while also utilizing the waste heat in the turbine's exhaust for a number of applications within the plant. Therefore, the existing energy sources are very efficient. That being the case, any attainable renewable sources that help to reduce the buildings energy consumption can largely benefit the already efficient campus system. For that reason, over the course of the upcoming months the application of geothermal heat pumps to reduce the load on the central plant will be analyzed.

Geothermal heat pumps are an increasingly attractive option for commercial buildings. First utilized in the 1950's, they are now recognized as a reliable source of renewable energy when designed properly. In commercial applications where cooling loads exceed heating loads, as is the case in this project, the long term efficiency can drop due to an increase in the ground temperature. To avoid this dilemma, a hybrid system will be looked at for a number of possible applications.

Research will be performed to incorporate a geothermal heat pump into any of the following three options:

- **Providing cooling to the penthouse and areas conditioned by chilled beams**
- **Providing heating and cooling to the East and West Stair Shafts**
- **Preconditioning the (10) 50,000 cfm AHU's incoming outdoor air stream**

These options will be evaluated and a geothermal system will be employed to reduce loads on the existing systems, resulting in a reduction in work for the central plant as well as the designed ventilation/cooling system. It will provide redundancy as well as shed some load from the existing system during proper conditions.

In the beginning stages of research into geothermal heat pumps, it has been found that the average ground temperature in Boston, Ma is approximately 50°F. The following graph in ***Figure 9*** shows that at shallow depths, variation in the average ground temperature is higher. With the reliability of the system in mind, it is more feasible to utilize the vertical loop system that reaches deeper into the ground.

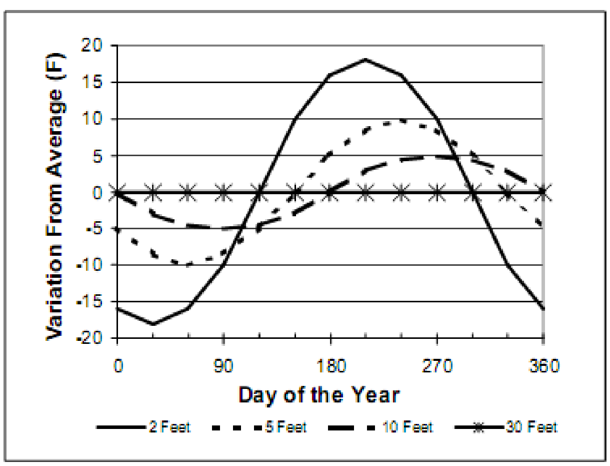

Figure 9 *–Average Ground Temp. Variation with Depth*

Also, the land area necessary for proper amounts of heat transfer for a system of this size deems a horizontal loop system impractical. With a city environment, there is not enough land to utilize a horizontal system, making vertical loop the most obvious choice. There are drilling challenges in the Boston area due to high levels of rock that will have to be evaluated to ensure the system's feasibility. If properly designed and installed, this system could greatly decrease the load on MIT's campus plant, while also adding renewable energy to the Koch Institute's plethora of energy conscious initiatives.

Figure 10 *–Conceptual Vertical Loop System*

The theoretical vertical loop system shown to the left in ***Figure 10*** was taken from McQuay's *Geothermal Heat Pump Design Manual*. After comparing this picture to the site of the Koch Institute, the quad to the south of the Koch Institute presents itself as a possible location for this system. This area is depicted on the following page in ***Figure 11.***

The quad located in the center of ***Figure 11*** is the proposed area for the vertical loop geothermal heat pump. This closed loop design will reduce pump work and will require approximately 250 to 300 ft^2/ton to be a succesfully sized system.

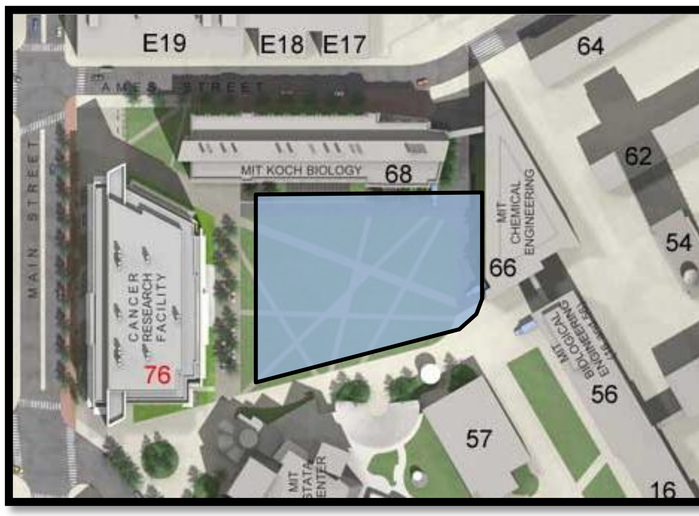

Figure 11 *–Proposed Location for the GSHP*

The next steps following this proposal will be to research the feasibility of this system in regards to the forementioned applications. Data on the specific ground content of the site will be gathered and evaluated to ensure efficient heat transfer between the fluid and the ground.

Once all the data has been evaluated for this site and the application of this ground source heat pump is specified, the necessary heat load of the system can be calculated. This can be done with the following equation:

$$Q_c = L\,(t_g - t_w)/R$$

Qc = the heat load, Btu/hr
Tg = ground temperature, °F
R = thermal resistance to heat transfer
L = pipe length, feet
tw = fluid temperature, °F

Breadth Proposal

Construction Management Breadth

The construction of the proposed geothermal heat pump on the campus quad will be invasive to campus life. Many precautions will be taken to maintain safety and necessary circulation on the site throughout the construction process. To accomplish this in the months to come, site safety plans as well as site utilization plans will be generated. These plans will make it possible to preserve access to the buildings surrounding the quad while also planning the construction phases efficiently. Re-direction of the paths shown below in ***Figure 13*** will no doubt be necessary throughout the construction to make this acheivable.

Figure 12 *–Proposed site for CM Breadth*

Scheduling of this construction proccess will also be evaluated to reduce the amount of time this construction will impact the MIT campus. If possible, this construction will be proposed for the summer months when the campus is least active.

In conclusion, the construction management breadth of this project will act to preserve site circulation, ensure safety for MIT students and faculty and create an efficient schedule of construction to minimize the impact on MIT's campus.

Electrical Breadth

The addition of a geothermal pumping system will result in necessary changes to the electrical service of the Koch Institute. The ground source heat pump will be powered electronically and therefore will have to be tied into the existing design. The cooling and heating that this system will provide may also result in significat changes in HVAC equipment. All of these additional system components and changes to the existing electrical design will be investigated. New service panels will be incorporated to operate the pumping system efficiently. All of the changes to the buildings demand load will be determined to correctly adjust the incoming electrical service.

List of Figures

Proposed Work Schedule