SWATeam Recommendation

Name of SWATeam: Energy Generation, Purchasing, and Distribution

SWATeam Chair: Scott Willenbrock Date Submitted to iSEE: 2/5/2016

Specific Actions/Policy Recommended (a few sentences): Hire a consultant to undertake a study of electrifying most space and water heating on campus.

Rationale for Recommendation (a few sentences): Electrification of heating offers a path to zero carbon emissions associated with heating as the electric grid becomes decarbonized and/or we increase our purchase of low-carbon electricity. In some cases it may also be economically favorable regardless of carbon emissions.

Connection to iCAP Goals (a few sentences): Decarbonization of space and water heating is necessary if we are to achieve zero net carbon emissions.

Perceived Challenges (a few sentences): None

Suggested unit/department to address implementation: iSEE, F&S

Anticipated level of budget and/or policy impact (low, medium, high): Medium

Individual comments are required from each SWATeam member (can be brief, if member fully agrees):

Team Member Name	Team Member's Comments
Scott Willenbrock	I endorse this recommendation. I believe the study should first be done at a high level and consider all options for electrification as well as all building types.
Angus Rockett	
Mike Larson	I endorse the recommendation to study the electrification of the space and water heating on campus. NOTE: The proposed study assumes that 100% clean energy will be available for the UIUC campus by 2050. If at the conclusion of this study it is determined that the electrification of the campus heating and cooling system is a viable option for our campus, in my opinion a follow up study will need to be completed to determine if and how the campus can be served by 100% clean, reliable, cost effective energy by 2050. I do not believe that the plan as outlined by the Deep Carbonization Pathways Project outlines a viable solution.
Tim Mies	I agree with this recommendation for conducting this study as an option for campus energy needs. At such time as decarbonized electricity might become a reality to supply campus, this could address our goals. Continuing to pursue alternate options will still need be studied to have options in both the near and long term.
Jack Morrissey	I endorse this recommendation. Electrification of campus heating will likely be essential to decarbonization and as such should be a high priority in reaching the iCAP's goals.
Catherine Yee	I endorse this recommendation. While I believe that this is not the only option we should consider, I believe that this is a necessary step we must take in order to make any progress towards our goal.

Comments from Consultation Group (if any; these can be anonymous): While we do have a consultation group devoted to heat pumps, we did not ask for specific input on this proposal. We would engage this group if the proposal is approved.

100% Clean Campus Energy Plan

Energy Generation, Purchasing, and Distribution SWATeam

February 2016

We propose a study of the potential to electrify most heating on campus. Electrification of heating and decarbonization of electricity generation would result in 100% clean campus energy associated with heating, cooling, and electricity.

Background

The 2015 iCAP directs the Energy Generation, Purchasing, and Distribution SWATeam to develop a plan to heat, cool, and power the campus with 100% clean energy by 2050.

A study was recently completed by the Deep Decarbonization Pathways Project providing roadmaps to achieving 80% reduction in CO2 emissions (relative to 1990 levels) by 2050 in 15 countries, representing 70% of global CO2 emissions. This level of emissions would keep global average temperatures from exceeding 2 C above preindustrial temperatures. The Deep Decarbonization Pathways Project is the most extensive analysis of strategies to achieve deep reductions in global CO2 emissions.

The Pathways to Deep Decarbonization in the United States report argues that it is technically feasible to reduce CO2 emissions by 80% by 2050 with existing commercial or near-commercial technologies, at an incremental cost less than 1% of gross domestic product, with a wide uncertainty range. Several universal themes emerge from the study :

1. High levels of energy efficiency
2. Decarbonization of electricity generation
3. Electrification of most end uses
4. Switching the remaining end uses to lower carbon fuels

Historically, the university has heated buildings with steam derived from burning fossil fuels. However, the purely economic benefit of heating with electric-driven heat pumps has already been recognized on campus, including heat recovery chillers in the new ECE Building and the new Bousfield Hall dormitory. The US Deep Decarbonization project assumes that most heating will be electrified by 2050, and that electricity generation will be largely decarbonized.

We propose that the university undertake a study of the potential to electrify most heating (including both space and domestic water heating) This represents a major change in the university energy system, and it will take considerable time and resources to implement. However, it is important to construct a plan now that will guide decision making in the near and medium term.

One of our alumni, Matt Slager (Hanson Engineering) has thought deeply about the electrification of heating on university campuses. He sent us a letter last year (attached) and also visited campus to give a presentation on heat pumps. Matt developed the heat recovery chiller concept for the ECE Building. Hanson Engineering is on retainer and we recommend to hire them to study our options for electrification of campus heating.

We have identified two potentially-viable options for low-carbon heating on campus that would allow for the continued use of steam for heating: biomass and carbon capture and sequestration (CCS), as well as the combination of the two, called bioenergy carbon capture and sequestration (BECCS), which has the potential for negative carbon emissions. We have been actively studying the options for biomass use on campus and will continue to do so, learning from the experiences of other universities that have deployed biomass on their campuses. We have been doing this study « in house » and do not feel the need for an external consultant at this time, but may request this at a later date. Carbon capture and sequestration of coal-fired heating and power at Abbott Power Plant is being studied by the Illinois Sustainable Technologies Center (ISTC) via a grant from the Department of Energy.

In the long run, it may turn out that our campus achieves 100% clean energy via a combination of electrification, biomass, and CCS. We propose that electrification merits a high-level study to consider the costs and benefits of various options for implementation on campus.

The Deep Decarbonization Pathways Project matches US energy supply and demand in 2050 on an hourly basis, using a variety of techniques (including heating buildings during times of high electricity supply). A similar study by the National Renewable Energy Laboratory (NREL) also considers hourly load balancing. We have some concern about the reliability of electricity supply on shorter time scales. If electrification of the campus heating and cooling system is deemed a viable option, a follow up study may be needed to determine if and how the campus can be served by 100% clean energy by 2050.

References

1. Williams, J. H., B. Haley, F. Kahrl, J. Moore, A. D. Jones, M. S. Torn, H. McJeon (2014). *Pathways to deep decarbonization in the United States*. The U. S. report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. http://usddpp.org/

2. Hand, M. M., Baldwin, S., DeMeo, E., Reilly, J. M., Mai, T., Arent, D., Porro, G., Meshek, M., Sandor, D. (2012). *Renewable Electricity Future Study*, National Renewable Energy Laboratory. http://www.nrel.gov/analysis/re_futures/

Energy Generation, Purchasing, and Distribution SWATeam

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August 31, 2015

Sent Via E-mail willen@uiuc.edu

Mr. Scott Willenbrock
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1110 West Green St
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RE: Proposed UIUC Campus
Heat Pump Master Plan Study

Dear Mr. Willenbrock:

Since I graduated from UIUC in 2004, I have spent a large part of my career working on facilities projects for UIUC. Over that period of time, I have given a lot of thought to how UIUC can transition to a more efficient campus heating system in a cost effective way. I have had a few informal discussions with facilities personnel over the years; however your interest in the heat recovery concept has prompted me to document some of my thoughts in this letter.

In 2010, as part of the Illinois Climate Action Plan (iCAP), the University stated a goal of reaching a level of net-zero carbon emissions by 2050. The 2015 iCAP plan recommended the evaluation of accelerating net zero carbon goals to 2035. In addition to renewable electricity, the iCAP plan also recognizes the need to transition away from fossil fuels to sustainable thermal energy in order to achieve those goals. The plan also provides a list of potential strategies for doing so. Geothermal heat pumps and air source heat pumps are listed in Chapter 3 as potential technology. Geothermal heat pumps are an obvious technology for minimizing energy use and several higher education institutions have already converted their campus to utilize geothermal heat pumps. There are a number of ways to implement campus geothermal systems. One of those ways is listed in the iCAP report and presents Ball State University as the example that uses a centralized geothermal plant to produce heating and chilled water that is distributed through a four-pipe system across the campus. That is certainly one option; however other configurations and heat recovery concepts should be considered in lieu of or in conjunction with a centralized system.

A centralized geothermal plant, like the one at Ball State University, requires a four-pipe network of heating water and chilled water supply and return piping. UIUC only has a two-pipe campus chilled water system. Building out a heating water piping network throughout campus or portions of campus may be a daunting logistical task and requires a long-term commitment to that system and an upfront commitment to the distribution network capacity. It also locks buildings into a single set of design parameters on the heating water side. Central plants are nice from the standpoint of centralizing maintenance; however that comes at the expense of higher capital cost. Another example of a campus geothermal system with lower capital cost is the one-pipe system used at Lakeland Collage in in Mattoon IL. However, an even better option that UIUC should also consider is a two-pipe system that utilizes the existing chilled water network.

The two-pipe system is best described as a distributed network of heat recovery chillers and geothermal heat pumps that are all tied into the existing chilled water system. The existing chilled water piping network can act as a bidirectional thermal conduit that provides cooling and acts as a heat source for a distributed heat pump/heat recovery system.

Campus geothermal systems are attractive because they allow multiple buildings with differing peak load times to better utilize the geothermal heat exchangers through diversity, and they also enable the ability to utilize the heat in one building and cooling in another building on a single refrigeration cycle, which improves efficiency. Both of those things can be done with the existing two-pipe distribution network.

There is already a history on campus of applying this technology successfully in a way that had outstanding return on investment. At UIUC, the heat recovery chiller technology was pioneered by this author on the ECE building and I understand it has since been applied to other facilities. These systems utilize the campus chilled water system as an energy source to produce heating water for buildings. While making heating water for the building, the heat pump produces chilled water as a byproduct and feeds that chilled water back into the campus chilled water system for use at another building. There is a general perception that because the wintertime demand for chilled water on the campus is only around 3000 tons, the application of heat recovery is limited to a few buildings up to the point that the current chilled water demand is satisfied. That is not true. Below is a description of how the technology can be applied campus wide and how geothermal may also be incorporated:

<u>Description of a Distributed Heat Recovery Chiller and Geothermal Heat Pump System</u>

There are a number of ways to apply heat pump technology within a building HVAC system. These include water to water heat pumps, water to air heat pumps, and water source Variable Refrigerant Flow (VRF) among others. For simplicity, the following simply compares the status quo with what was done at the new ECE building using modular heat recovery chillers using scroll compressors.

Heat recovery chillers (water to water heat pumps) would be installed in each building. They would be sized and controlled to produce heating water to satisfy the buildings heating load. Chilled water would be produced on the other side of the heat recovery chiller as a byproduct and pumped back into the campus chilled water loop.

A separate heat pump would be used to produce 100 percent of the domestic water. That domestic water heater could be an air source unit that helps cool a mechanical room, or it could be a water source unit that uses the campus chilled water system as the heat source.

The economics of the heat recovery chiller installed at the new ECE building were very good. In fact it was by far the largest energy saving feature of the building and also one with the shortest payback. This is partially because you get both heating water and chilled water from one refrigeration cycle with a very high effective Coefficient of Performance (COP). Of course there must be chilled water load concurrent with heating demand for this to work. At the time we started the ECE building design we were told that the campus chilled water system had a 3000 ton baseload.

A large portion of the economic savings for a heat recovery chiller is from heating water production, regardless of the value of chilled water production. So the problem with spreading this concept to eventually serve many more buildings on campus is not because of economics, it is because of a perceived lack of demand for chilled water in the winter.

There are a number of ways in which you could generate more chilled water demand when heating demand is high, and in doing so enable a system of water based heat recovery not only within buildings, but between buildings. The following are some examples of ways to generate chilled water demand in the winter:

1. Utilize the existing stratified thermal storage tank to bank waste chilled water at night to use the next day when chilled water demand is higher.
2. On existing air handling units across campus, turn off the airside economizers and utilize the chilled water coils instead. You have the campus control network in place to do this in many buildings already. It is primarily just software changes needed to create this “false chilled water load”.
3. For air handling units with airside energy recovery, do number 2 above, and then modulate the heat recovery device back on to recovery exhaust heat to further load the chilled water coils.
4. Modulate the water side economizer on the petascale supercomputer down or off and instead use chilled water to transfer that heat to other buildings using the chilled water network.
5. If the four things listed above cannot create enough chilled water demand on their own, install one or more ground heat exchangers. You could get quite a bit of load out of the ground just by running the chilled water directly through the closed loop ground heat exchanger. You would want to utilize this ground heat exchanger in the summer as a heat sync for a chiller plant in order to balance the load. You can think of the ground heat exchanger as seasonal thermal storage. One low cost way to implement this is to locate separate ground heat exchangers adjacent to buildings that have heat recovery chillers. Those heat recovery/heat pump chillers can be designed to function both in full heat recovery mode, making heating water and chilled water simultaneously and still be able to switch to reject heat to the ground in the summer to generate only chilled water.

It is not completely clear how much heat recovery is available in the middle of winter before a geothermal heat exchanger is required. On average, the petascale supercomputer alone uses an average of 9.9 MW of electricity. If wintertime cooling could recover 9 MW of heat, that is equivalent to 30,735,000 MMBTU/Hr of recovered energy. Add that to the compressor energy from the heat pumps and that building alone could supply enough recovered energy to displace around 43,541 lbs per hour of steam demand without having to build a geothermal heat exchanger.

Once the heat recovery opportunities are exhausted and geothermal heat exchangers are added to the distributed system, they would only need to be utilized on days when heat recovery will not satisfy the loads. The sizing of ground heat exchangers depend not only on the peak heating and cooling loads, but also on the total seasonal heat load put in to and taken out of them. Therefore, it is possible that the extensive use of heat recovery will allow downsizing of the ground heat exchanger by a percentage greater than what the peak load contribution would suggest.

To summarize: Using airside and waterside economizers does reduce cooling cost, however you can also think of it as throwing away valuable thermal energy that could otherwise be used to heat buildings and domestic hot water. You already have a campus chilled water loop that can be used as an energy conduit. It doesn't have to be used just for cooling. By locating heat recovery chillers in each building, with the appropriate coil changes to handle the water temperatures, the existing chilled water network can become a bidirectional thermal conduit.

Advantages of a Two-Pipe Distributed System:

- No campus heating water network is required, reducing capital cost and logistical construction issues.
- Distributed networks are potentially more resilient.
- Each building or group of buildings could utilize different heating water temperatures that are compatible with the building type and the HVAC system. It would not hamstring the entire system to the worst case building.
- The most economical way to retrofit HVAC systems is when they are near the end of their useful lives. A distributed system can be implemented one building at a time based simply on end of useful life opportunity.
- This option is not mutually exclusive of central or regional heating plants. It can work in combination with them if later deemed appropriate.

<u>Energy & Energy Cost Savings for a Two-Pipe Distributed Heat Pump System</u>

As demonstrated by the ECE building, HVAC systems can be designed to need a maximum of 130° heating water and reset to a cooler temperature most of the year as long as the right coils are used. The COP for a heat recovery chiller using scroll compressors that operates on a reset between 130° in the winter and 105° in the summer is approximately 3.4 to 4.9 respectively and yields a seasonal average around 3.7 (without pump power), or around 3.5 with pump power. In other words, the annual site energy use for heating could be cut by approximately 71-73 percent. That ignores any value for the chilled water, which has some value for a portion of the year. At times when the heat pumps produce 105° heating water temperature, while the chilled water is needed, the system could reach a combined COP exceeding 8.8.

Electricity is more expensive than steam, so the energy cost savings will be lower than the energy savings measured in BTUs. According to FY 2015 UIUC utility rates, steam is worth $17.41/klb ($17.41/MMBTU) and electricity is worth $0.0829/kwh ($24.28/MMBTU). Thus a unit of electrical energy is 39 percent more expensive than a unit of steam energy. Even ignoring the value of the chilled water produced, the UIUC utility rates suggest an energy cost savings using a heat pump would be around 60-63 percent.

This is a very simplified analysis. One thing that is not considered above is that both the steam and electric utility rates include O&M costs, personnel costs, and distribution costs. The marginal cost for electric and steam is a fraction of each, so the energy cost savings needs further study. That study would also need to consider the value of cooling produced as well as water savings and water treatment savings associated with reducing steam and water cooled chiller usage.

UIUC used approximately 1,548,590 MMBTU of steam in FY 2014 at a cost of thirty-two million four hundred sixty-four thousand one hundred and eight-seven dollars ($32,464,187). A 60 percent savings or anything close to that would go a long way toward funding the transition away from fossil fuel heat. Please keep in mind these are very rough numbers and should be investigated further in a study.

Proposed Campus Heat Pump Master Plan Study

The two-pipe distributed heat pump/heat recovery option is an alternative that should be considered along with or in conjunction with centralized plants. Either way, the options listed for increasing winter chilled water demand should be utilized to maximize heat recovery and reduce the central or distributed system ground heat exchanger size and cost.

The first step should be to create a master plan to evaluate options and provide a roadmap for the transition to a sustainable heating system that maximizes heat recovery and supplements with geothermal where possible:

- Evaluate if there are there other chiller/heat pump types or distributed concepts that could improve efficiency further.
- Evaluate the Life Cycle Cost of central or distributed heat pump concepts.
- Estimate the approximate amount of heat recovery available form disabling air and waterside economizers and engaging airside energy recovery on existing buildings.
- Evaluate if variable ventilation effectiveness control on existing VAV systems could decrease the outside air requirements and increase heat recovery in select buildings.
- Conceptualize ground heat exchanger locations and utilization schemes.
- Identify a preliminary priority list for which buildings to convert first based on remaining equipment life.
- Propose design standards and standard details for the heat recovery chiller/heat pumps.

UIUC has an opportunity to transform the way the campus uses energy and become a leader among universities with that regard. I look forward to further discussions regarding applying heat pumps for heat recovery and geothermal heating and cooling on the UIUC campus.

Sincerely,

HANSON PROFESSIONAL SERVICES INC.

Matthew A. Slager, P.E.
Chief Mechanical Engineer