IPRO 345: Chicago Sister Cities China: Fuel Cell/Geothermal Sustainable Energy USX Site

FINAL REPORT

Spring 2008

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1 Introduction

Few people today doubt the importance of energy conservation. The major problem is finding a way to significantly reduce energy consumption. Individuals and large entities alike must be convinced that their own efforts can be significant and that the sacrifices that are necessary to reduce their own energy consumption are actually worthwhile.

IPRO 345 has been given the task to develop software that will aid in the effort to convince people to use energy saving technology. Specifically, the software will analyze the use of fuel cell and ground source heat pump technology in housing developments. These two technologies would replace typical energy sources for HVAC and electrical systems in housing developments. Our software essentially performs a cost-benefit analysis comparing the "green" technology with typical technology. We also incorporated comprehensive databases containing environmental conditions, laws, and building codes in Chicago so that the user would have an easy way to assess the feasibility of the project.

This semester, we compiled an initial database of information and designed a basic software program which will be used to analyze the use of this technology at the former USX site on the South Side of Chicago. Further iterations of this project will produced more refined and robust versions of this software.

2 Background

The Chicago Sister Cities China Architecture and Engineering subcommittees, as well as the HNTB companies, established and secured sponsorship for the formations of our team. Our group is an internationally jointed team of faculty, students and university administrators are from University of Illinois at Chicago (UIC), Illinois Institute of Technology (IIT), and Tong-ji University (TU) in Shanghai. Our project integrates two different technologies in developing the process. Fuel cell technology is used to generate electrical power as well as to supplement heating power. A molten carbonate fuel cell was selected to be used due to its high operating heat, its ability to utilize a variety of hydrocarbon fuels, and its high efficiency. A geothermal heat pump is being used as the primary source of heating and cooling power. A geothermal heating system is environmentally friendly and can cheaply supply heating and cooling power throughout the year. When necessary the waste heat from the molten carbonate fuel cell can be used to augment the heating abilities of the heat pump system.

Fuel Cell technology has been around well over 100 years, in the early 1900's there were many attempts to develop fuel cells that will convert carbon into electricity, but the advent of the internal combustion engine put the fuel cell technology on stand by. In 2000, the US Army Corps of Engineers published a study examining the use of a molten carbonate fuel cell for supplying power to the Rock Island Arsenal, IL. In addition to supplying power to the facility, the study also examined using the waste heat of the fuel cell along with additional heat provided by a geothermal heat pump system to offset heating costs. The study found that by using these two systems in conjunction with each other the Rock Island Arsenal could significantly reduce energy costs, as well as significantly reducing environmental pollutants such as CO_2. This shows that a combined molten carbonate fuel cell/ geothermal heat pump system can be feasible in certain locations.

There are three sets of parameters that are involved in the designing process. The first branch is the environment and law unit which will address the issues of permits needed as well as the environmental regulations. It will also investigate the weather conditions and the areas' needs. The second is economics unit which will investigate the grants and subsidies along with the price of excess energy created by the system. Another area of parameters that must be investigated is the design of the system, which includes the energy needed to supply heating and cooling, the amount of power generated, and the mechanics of the system. After the completion of the research phase, the information gathered was be organized and entered into text files and then compiled into a computer program. A rough prototype of the software was made and it is able to analyze a selected site in the Chicago area to determine if a combined fuel cell and heat pump system would be technically, economically and ethically feasible.

This software will assist in introducing an unfamiliar technology to society, so it is very important that the ethical, moral and cultural issues will be addressed. These issues will set a guide for future use of the new technology and will create boundaries that must be held. To begin with, the more pertinent issue of the project is concerning the regulations for digging, constructing, and fully implementing the system into a society. To prevent a society from rejecting this system, one must be aware of environmental issues and also be knowledgeable about the fuel cell and its positive effects on the environment. Other benefits in using this technology include promoting local jobs, efficient energy, health benefits/environmental, reduced energy costs and reduce dependency on depleting resources.

3 Purpose

The overall objective of the project is to demonstrate the efficient and cost effective use of the combined system of the fuel and geothermal energy in urban residential development, including development planned at the former USX South Lakefront Site in Chicago. The goal will be for the academic collaborative teams to prepare and present a comprehensive design study by the end of the summer of 2008 to the Chicago Sister Cities China Committee. This project will also provide additional support to the City of Chicago as it develops plans for including energy efficient technologies in new construction, and the retrofit of existing buildings.

To accomplish our groups' goals as stated above. We established the following objectives at the beginning of the semester.

- We proposed to create a working software tool that assists in the capacity of planning, decision making and accessing the economic feasibility of implementing an integrated fuel cell technology and geothermal energy system.

- Through a case study approach, we also planned to research and evaluate the energy needed in residential homes to use as a basis for determining the algorithms employed in the software development.
- Our third objective for the semester was to demonstrate the viability of the integrated fuel cell and geothermal system in a specific location through the prototype testing of the database tool.
- By providing a tool that analyzes the design and economic parameters required to implement an integrated fuel cell and geothermal system. Our IPRO hoped to make installing these systems much easier, thereby giving developers an incentive for investigating relatively clean energy sources.
- In order to achieve our objectives we researched on all parameters needed for our projects' implementation including environmental laws and regulations, permits, funding, weather, population, and energy consumption.

Our work as an IPRO group is completed. However, the research and information that we gathered during the course of the semester will transferred to graduate students in the Chemical Engineering Department at IIT who would complete the final phase of the project. The IIT and UIC teams will prepare and submit a written report by end of each of the 2008 spring and summer semesters. The Final Report will be delivered by the end of the 2008 summer semester.

In our team of twenty- five students, we had representatives from the Chemical Engineering, Mechanical Engineering and Architecture disciplines of study. However, we needed to create a database tool and no one our group members are skilled in programming. To address this issue, we hired two programmers to assist us with the software design of our project.

Overall, defining the scope of our project and making our design and costing assumptions required more time than we initially anticipated. Hence we were able to create a database of information which would be transferred to our database tool platform. The graduate students would commence the prototype testing phase of our software tool by summer 2008.

4 Research Methodology

At the beginning of the semester, we established that our research activities would be conducted in the step by step sequential manner as shown. **Modifications to our proposed plan are highlighted using the bold face.**

A. Design and implement software for assessing the feasibility of implementing of a hybrid energy system consisting of geothermal energy and fuel cell technology.

- **We generated an optimization algorithm for our proposed software program.**
- **We also created a database of information which would be utilized in the creation of our proposed software tool**

B. In order to accomplish said task in section 3.0A the team will focus on the potential implementation of the project at the 640-acre U.S. Steel Duluth Works site (USX site). By using this site we can gain an understanding of all factors that need to be addressed. As a group we have decided to move through the research and development phases as a complementary and cohesive procedure. Through this process we hope to all gain a better understanding of the fuel cell/geothermal system and also to have a more fruitful end result.

The final phase of the project which is the prototype testing phase would be implemented at the USX site by the end of summer 2008.

C. We have a large team which provides us with an array of technical and professional skills sets. In the research segment of the group we have scheduled many presentations in which each member of the group shares information with the other team members. However, the design team is primarily responsible for finding and coordinating the data organization process with the contract programmer.

- **Throughout the semester, we held bi-weekly meetings. We spent the first half of the first meeting listening to progress reports from each of our five sub teams.**
- **We also had the opportunity to receive feedback from a Vice President from HNTB, who are one of the sponsors of our project.**
- **We also maintained direct contact with the team at UIC. As a result, we received a copy of their report which is attached as an appendix in our final report.**

D. The parameters and information needed for our project will be complied into an organized format that will come from the collaboration between our sub teams. We are all responsible for creating a comprehensive and understandable way to organize the algorithms that will complement our software.

- **This objective was fully satisfied. We created textfiles that organized each subgroups’ information in a n efficient and concise manner which can easily be interpreted by our programmers.**

E. In the final stage, we will be presenting to The Chicago Sister Cities China Architecture and Engineering subcommittee as well as our parallel team from UIC.

- **This objective would be accomplished by the end of summer 2008**

F. Final adjustments to the programming and software will be worked out with the contract programmer hired to assist with the prototype testing phase.

- **We are on track to accomplish the stated objective by the end of summer 2008**

G. An IPRO deliverable report will be generated by individual subgroups being responsible for their topics as well as by cohesively working with the other subgroups. The rough draft will be posted on the igroups website and will be read by all group members. We will have an open forum for any suggestions to make any necessary changes.

- **This objective is also on track for completion**

Our IPRO group learned a great deal from the challenges that we faced as a large group of twenty five students. In developing and modifying our research methodology we learned that it is important to have milestones at the beginning of the project, in order to monitor our groups' progress throughout the semester.

- **To overcome our communication challenges, we effectively utilized our communication resources such as iknow and igroups.**
- **Our group also created a website which contains all our relevant information including our project plan, midterm presentation and other deliverables.**

5 Assignments

Our team determined that there were five main areas which were designated into subteams: Design, Economics, Environmental, Ethics and Deliverables. We had a team leader to oversee the entire project and to work closely with the advisor to keep our team on track. We also had subteam leaders to oversee specific parts of the project. Once the ethics subteam was done with Code of Ethics, the team members were reassigned into the subteams that needed extra help. The environmental subteam also finished their tasks ahead of schedule, so all team members joined the Deliverables subteam to help with all the deliverables for IPRO Day.

Daisy Agose (team leader and environmental subteam)

- Coordinated group meetings

- Researched site conditions for geothermal system
- Coordinated database and software data

Brian Hogan (design subteam leader)

- Decided on molten carbonate fuel cells because of the hot exhaust that could then be used for heating
- Developed the idea of what the system should look like
- Performed case studies of the proposed system

Jonathan Lockridge (economics subteam leader)

- Assigned tasks, scheduled meetings, and compiled reports for the economics subteam
- Trained team members to use e-Quest software
- Researched technical data

Eliza Bober (environmental and deliverables subteam leader)

- Researched into environmental issues that could possibly be part of our project
- Worked on posters, abstract, and final presentation

Raisa Pelae (ethics and environmental subteam)

- Compiled Code of Ethics
- Took meeting minutes, attendance, and compiled weekly reports
- Helped with the website
- Worked on the ethics subteam part of the project plan and the final report

Nyah Zarate (ethics, deliverables, and economics subteam)

- Wrote Project Plan report
- Organized and presented midterm presentation
- Worked on sponsor presentation
- Edited Code of Ethics
- Helped with the economic analysis
- Edited the final report and part of final presentation

Alexander Horner (design subteam)

- Researched about electricity, heat exchangers, and heat pumps
- Worked on two case studies to design and cost heat exchangers
- Worked on the very basic main algorithm for the design of the software
- Worked on the source code for two of the sub-functions included in the main algorithm

Min Zheng (design subteam)

- Assisted in the heat exchanger design calculation
- Worked on designing the algorithm of the fuel cell system

Chris Wolcott (design subteam)

- Researched technical information for fuel cells and geothermal heat pump systems

Oluwafunso Ajigbo (economics subteam)
- Researched grants and subsidies (state level) for fuel cells and geothermal heat pump systems
- Worked on text filling
- Worked on equations for the economics subteam.

Sukhwan Yun (environmental sutbteam)
- Researched codes and laws pertaining to fuel cells – international, federal, state (Illinois, California, and Ohio), and Chicago
- Researched the case-study about the companies and organizations using fuel cells
- Summarized all the research, wrote and organized a paragraph about software
- Assisted in the making presentation slides

Yoonsung Chung (economic subteam)
- Researched on the geothermal energy in California, the cost of natural gas, and the cost of heating oil
- Made word files, text files, and excel sheets about the results from all the research
- Studied and researched a cost benefit analysis and did the cost benefit analysis for a school

Maruja V. Yoshimura (environmental subteam)
- Researched benefits and negative effects of fuel cells
- Helped put the final presentation together

Cheryl Mukai (ethics and deliverables subteam)
- Worked on the a presentation for the ethics part
- Helped with the webpage
- Took group and individual photos

Nick Leep (environmental subteam)
- Researched geothermal laws and current “carbon credit” policies
- Helped put together the final PowerPoint presentation

Christian Arnoux (ethics, environmental, and design subteam)
- Worked on the Code of Ethics
- Summarized laws in the environmental subteam in a format suitable for the software
- Worked on heat exchanger design
- Looked up risk assessments for fuel cells

Mathew Dado (economics subteam)
- Researched costs for different aspects of the project
- Worked on e-Quest to find electrical and heating loads of a multifamily low rise

- Generated text files of research

Richard Byrne (economics subteam)
- Researched federal grant research, worked on excel spreadsheets
- Worked on fuel cell economics data research
- Worked on shared findings with team and igroups

Jaehyuk Kim (design subteam)
- Researched case studies of MCFC, researched general information about fuel cells
- Worked with e-Quest

Abhishek Prabha Kumar (environmental subteam)
- Did research on environmental impacts of geothermal heat pumps and on renewable power systems
- Made slides for the final presentation and worked on the abstract

Yunjin Lee (economics subteam)
- Research the cost of fuel cell
- Made the cost analysis excel sheet organize equation for cost analysis
- Helped with the website
- Attempted to coordinate data base tool
- Made the economics PowerPoint for the sponsor

Gregory Enadeghe (economics subteam)
- Tried to find local funding for project through subsidies
- Tried to find similar systems and operational cost
- Used e-Quest to pull up house load data

Wonwoo Park (design subteam)
- e-Quest analysis for a health center
- Researched a case a study of MCFC, piping system, and geothermal energy process
- Researched calculations of energy use

Jennifer Peavler (design and deliverables subteam)
- Researched fuel cell designs
- Researched energy loads
- Complied list of potential IPRO questions

Jae hyung Park (design subteam)
- Set up a primary design
- Researched fuel cells, geothermal, cost of electricity and heat pump
- Worked on equations of heat exchanger

6 Obstacles

Our most difficult obstacle was defining the scope of the project, from the locations we would be investigating, to the information that we want to consider in the development of this software. Through many group discussions we decided to focus on Chicago for this semester. At the beginning of the semester, many students in the IPRO were unaware of the computer programming nature of the project. We discovered that that our team did not comprise of at least one computer science major.

Another obstacle faced was juggling all of the team roles. This IPRO is comprised of senior-level chemical engineering students (CHE 496), general IPRO students (IPRO 345), and sophomore level chemical engineering students (CHE 296).The latter group only earns one credit hour, and they spent the first quarter learning a simulation software. Because of this structure, it made assigning tasks a little more challenging. The subteam leaders were careful to assign proper amount of work to the team members based on individual skills and level of involvement.

Additionally, the CHE 296 students' level of involvement affected the sub-team leaders designating roles, it also affected, their motivation to find time to complete tasks. This team has overcome this by assigning fair roles to the CHE 296 students and making the class time productive and fun.

As the second half of the semester approached, our team ran into new obstacles. Our team had done all the research the first half of the semester but the information was very hard to find because it was on igroups into several different files. Then the information that was found to be relevant had to be selected from the great deal of research and then organized into text files so it could be read computer program. As a class we met and specifically decided how everyone was to organize their text file and then each subteam designated a person to work closely with the programmers to make sure that all the research was properly organized in a readable database.

Communication was found to be one of the biggest problems in our group; there were communicative barriers between subgroups and even within subgroups. Also, a more detailed level of communication was missing between UIC and IIT mainly due to time constraints. At certain points, subgroups were doing the same research and also needed information from the other subgroups in order to proceed with their own work. This major problem was discovered when there was a lack of coordination between subgroups to put together a presentation for the project sponsor. The problem was resolved by having more detailed updates during our class time to make sure that everyone knew where each group was and what each subgroup was working on. Also, IIT attended a meeting with UIC in order for our team to know what to expect from UIC's geothermal research and incorporate it into our project.

7 Results

By midterm of the semester,

- Our ***design*** sub-team had selected the type of fuel cell which this design tool will eventually be used for was determined to be a Molten Carbonate Fuel Cell because of its high operating temperature. Additionally, the design team realized that part of the objectives was to select a proper design of the heat exchanger/heat pump system since none has been investigated in depth by the other teams involved in the project(UIC)

- There had also been some progress made with the database component of the project, but it has been limited since the focus has been primarily on research. A database file structure and template has been created, and as the project moves away from the purely research phase and progresses into the database phase it will be quick to format the research into the proper templates.

- The ***economics*** sub-team researched the cost of installation, the cost of fuel, the federal subsidies which would apply to this type of energy source installation, and the social implications like the reduced hospital visit due to decreased pollution.

- *The* ***environmental/law sub-team*** had completed the environmental impact research. They have determined that the fuel cell/geothermal system, when properly installed, has little negative affect on the environment, but enormous benefits, especially in terms of the fossil fuels that it saves. The research on federal law concerning a fuel cell/geothermal system has also been completed. There are few laws concerning this system, since it is a relatively new technology. Laws that do exist are usually energy laws which do not affect the placement of the technology. Some research has been completed on the site conditions such a system requires. There are some soil conditions that regulate whether the geothermal pump component will be cost-effective. There are no site restrictions on a fuel cell system. In Chicago the soil conditions are more suited for a vertical or lake system, since the large quantity of debris in the soil makes digging horizontal trenches more expensive than deep holes.

Additionally, ***a code of ethics*** was written up by the ethics sub-team, and the midterm presentation was completed.

By the end of the semester,

- *The* ***design subteam*** created an optimization algorithm that would facilitate the creation of the software/database tool
- The economics subteam has completed the initial estimation of the project costs which also includes a simple payback period.
- *The* ***environmental and ethics sub team*** where re-organized to form the *IPRO* ***deliverables subteam*** since they had accomplished their respective tasks.

On April 2 2008, we presented to a representative from HNTB. The insights we gained from that meeting were integrated into the cost analysis of our project. Throughout the course of the semester, the group also learned a lot about the importance of defining and reviewing the scope of the project throughout the semester. Overall we were able to establish that our project is potentially economically feasible and it is environmentally friendly. By the end of the summer, the IIT and UIC subteam would present the final conclusions and recommendations to HNTB and the Chicago Sister Cities China Architecture and Engineering subcommittees

8 Recommendations

Since this was the first semester for this project, our team worked mostly on defining the scope of the project and also doing the basic research for Chicago, Illinois. Recommendations for future work include enhancing the database for wider implementation which would include environmental and economic analysis from more locations. There also a need to work on increasing thoroughness of economic analysis, minimization assumptions of design equations, and developing optimization protocols. Once the software is developed, it has to be tested against real world case study to ensure the integrity of the results and the degree of marketability has to be determined.

9 References

- Fuel Cell HandBook (Sixth Edition) by EG&G Technical Services, Inc Science Applications International Corporation.
- Molten Carbonate Fuel Cells(MCFCs) for Department of Defense Applications Rock Island Arsenal MCFC by Franklin H.Holcomb et al
- Equest Multifamily lowrise reports(pdf)
- The Center for research solutions(pdf) 2006 Green-e energy Verification Report
- Paratherm NF thermal oil: http://paratherm.com/biodiesel/index.asp
- MultiTherm IG-4 thermal oil: http://www.multitherm.com/multitherm-ig-4.html
- Our group website :http://sustainable.iit.edu/~ipro345/
- **A comprehensive database of all of our referenced files and documents can be seen in the subgroup categorized files on groups.**

10 Acknowledgements

Our group is very grateful for the efforts of our academic collaborative teams and our faculty support at IIT. We specifically like to acknowledge:

UIC: (Lead Faculty and Project Coordinator: Sohail Murad)
They focused on the geothermal aspects of the project and their research conclusions are crucial to the final implementation of our project

IIT: (Lead Faculty: Said Al-Hallaj) and Professor Satish Parulekar
With their help and direction, the IIT graduate research assistants would implement the database tool by the end of the summer

HNTB: (Lead Advisor: Philip Hanegraaf)
He provided the overall project management and coordination for activities in the project.

Mark Haase: (Graduate Research Assistant)
He served as the graduate research assistant throughout the course of the semester.

IPRO 496-345: (Group Members)
For the consistent level of hard work and dedication shown by each individual team member.

IPRO Office: (Faculty and Staff)
For providing with an opportunity to improve upon our project management, communication and professional development skills.

Appendix

UIC Geothermal Energy Project: Grant Hall

Report Prepared:

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1. Geothermal Heat Pumps

Motivation: Because of the temperature extremes experienced in Chicago, it is an ideal site for a Geothermal Energy Project. Geothermal heat pumps (GHPs) use the almost constant temperatures (45°F to 70°F) of soil and water beneath the frost line as an energy source to provide efficient heating and cooling all year long. This can be accomplished by a system of pipes called bores that are often drilled to depths of about 300 ft, but if land rights are available it is acceptable not to go as deep but configure them horizontally as well. A typical geothermal unit is shown in Figure 1.

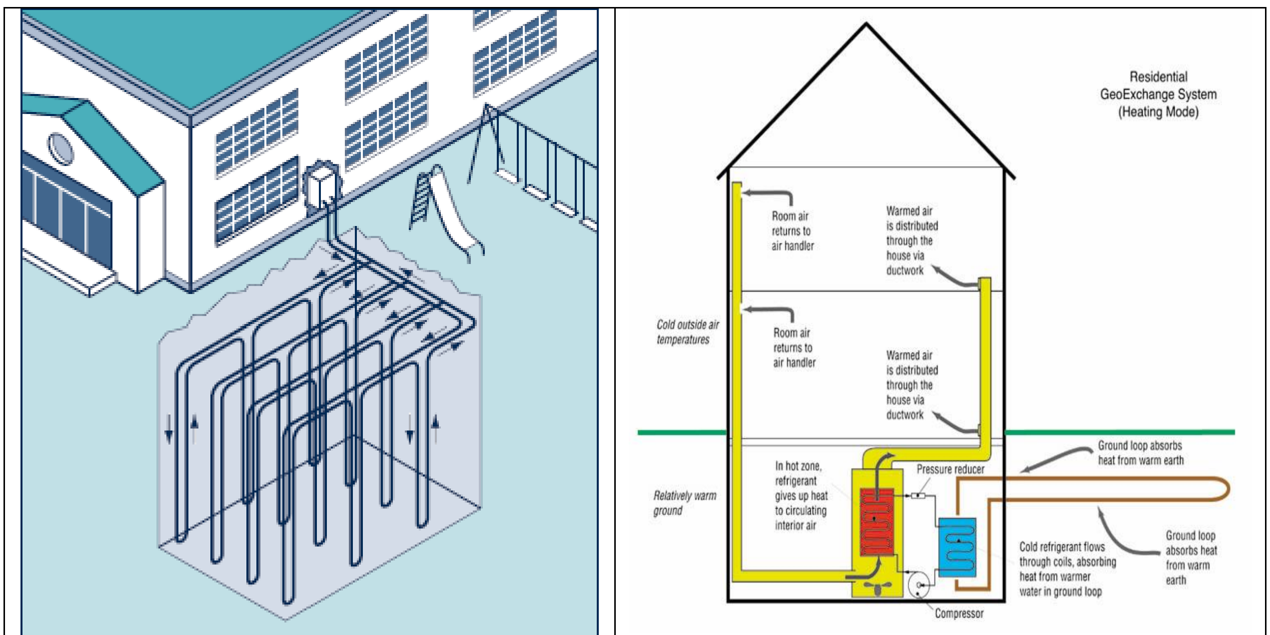

Figure 1: Two geothermal systems showing the vertical and horizontal drilling configurations.

Economics: The installation cost of GHPs is higher than conventional systems (additional drilling and excavation expenses) but is quickly offset by their high efficiency (see Figure 2). Up to 50 percent savings over conventional heating and cooling systems are possible as shown in the figure below. This allows the additional capital costs to be recovered in less than five years on average (GHP's have an average lifespan of at least 30 years). In addition GHPs are space efficient and because of fewer moving components have lower maintenance costs.

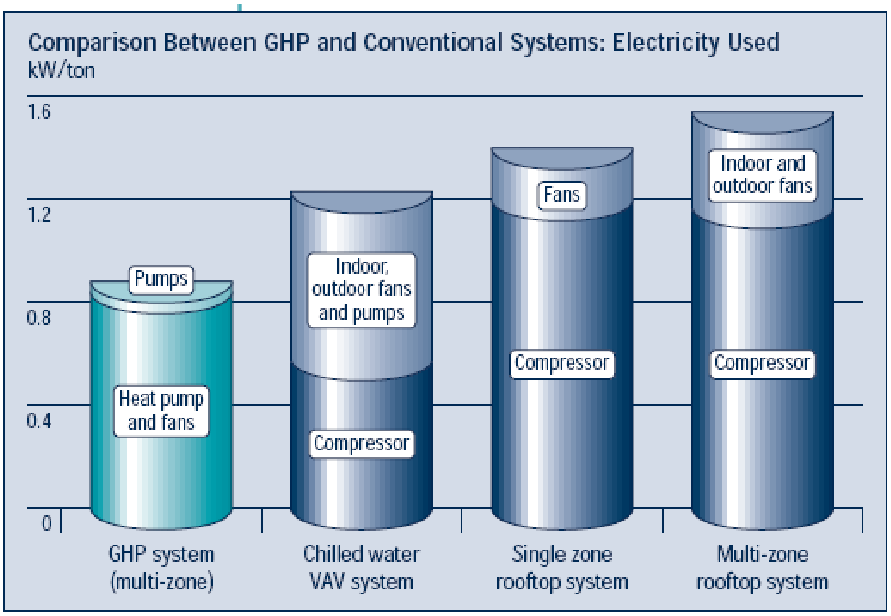

Figure 2: Energy consumption of a heat pump compared to other conventional systems.

2. <u>UIC Geothermal Project</u>

UIC recently initiated a program for renovating some of its older buildings. The first building to be so renovated is Grant Hall, just East of University Hall (the main campus administration building). It reopened on September 19th as the Sandi Port Errant Language and Culture Learning Center. A key feature of the renovation is that the building is environmentally green. Innovations that make this possible include the addition of a geothermal energy system and an increased use of natural light. Since its opening, the efficiency of the building has been closely monitored. To date it has not had a single failure. The temperature has been maintained at almost the constant desired temperature of 70-72 ^{o}F. Grant Hall has a floor area of 15,000 ft^2, and the use of geothermal energy has cut its energy consumption by 90%. The geothermal system consists of 28 bores of tubes that have been bored to a depth of 500 ft. They carry water which is pumped using a conventional pumping system. The water circulated is fed to a heat pump (see description of a heat pump that follows) that is designed to operate within the temperature range of 45-85 ^{o}F. If the water returning after circulating underground does not meet these specifications, it is supplied to two heat exchangers. If the temperature is above 85 ^{o}F, it is cooled using chilled water (which was previously used in the building for cooling); if it is below 45 ^{o}F, then it is heated using hot water/steam heat exchanger. This is a precautionary measure, and not expected to be often needed, since as stated earlier the underground temperature is 45°F to 70°F and with bores going 500 ft deep, there is enough time for adequate heating and cooling to take place underground. There are plans now to extend this project to two additional buildings Lincoln Hall and Douglas Hall, to have a cluster of buildings operating on geothermal energy.

A heat pump, which is an integral part of a geothermal unit, is a device that can enable heat to be transferred from a lower temperature to a higher temperature with minimal consumption of energy. A simple heat pump is shown in Figure 3. An example of a simple heat pump is a refrigerator (or air conditioning system) at home. A refrigerator removes (takes) heat form the inside of a refrigerator (for the purpose of this discussion we can assume it is at 38°F and is shown by the blue arrow in the Figure 3) and then discards (delivers) it to the kitchen (again for the purposes of this discussion at 70°F and shown by the red arrow). Thus a refrigerator is ***pumping*** heat from the inside of the refrigerator to the outside, using a compressor, and hence the name heat pump. Normally heat goes from a hot area to a cold area.

The key to the operation of the heat pump is the fact the most fluids boil at different temperatures when pressure is changed (the same reason why water boils at lower temperatures at higher elevations – Boulder, CO for example). In a heat pump boiling (boiling removes heat from the environment – just like boiling water takes heat from the stove – blue arrow) takes place at a lower pressure and consequently lower temperature (let's assume 40^{o}F, so that it can effectively remove heat from the water supplied from the geothermal unit at 50^{o}F). The steam so produced from the boiling can be compressed (marked 4 in Figure 3 -- this is where energy is consumed in the geothermal unit, in addition to the cost of pumping water underground) to higher pressure so that now it will condense (the opposite of boiling) at a much higher temperature. The heat removal to condense is now done by the building (shown with the read arrow) so that the steam while condensing will provide heat at a much higher temperature to the area being heated. Finally a throttle (similar to faucets used to run water at home is used to lower the pressure (shown with a green arrow in Figure 3) to complete the closed cycle. By switching the direction of the heat pump, it can be used for heating as well.

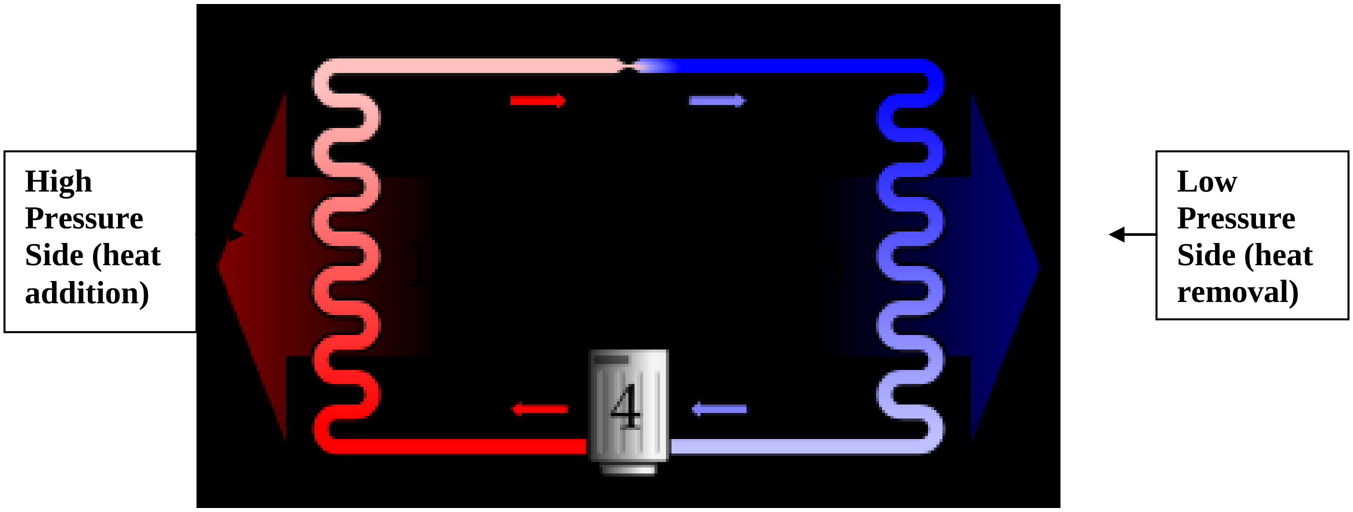

Figure 3: A typical vapor compression heat pump for cooling used with a Geothermal System.

In conclusion, geothermal systems are highly adaptable, and if properly designed, can be used to economically retrofit existing buildings (City Hall would be an excellent choice) as well as being used in any new developments planned in Chicago (e.g. USX South Lake Front Development Project)