CyberGreen:
Hands-On Engineering Research in Sustainability and Supercomputing

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2012 ASEE North Central Section Conference

Agenda

- Class description and design
- What didn't work
- What worked
- Future Plans

Initial Goals

- Develop a research seminar that focused on STEM (science, technology, engineering, math)
- Accessible to students from any academic major
- Accessible to first- and second-year students
- Develop skills in problem-solving, critical-thinking and communications

Class overview

- First semester - Background
  - Brainstorming sessions
  - Hands on experience with fluid dynamics
  - Project selection
- Second Semester – Research Projects
  - Individual research projects
  - Campus wide poster presentation

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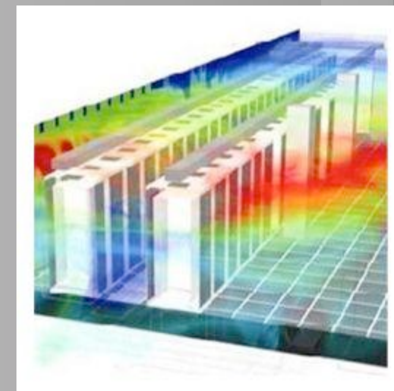
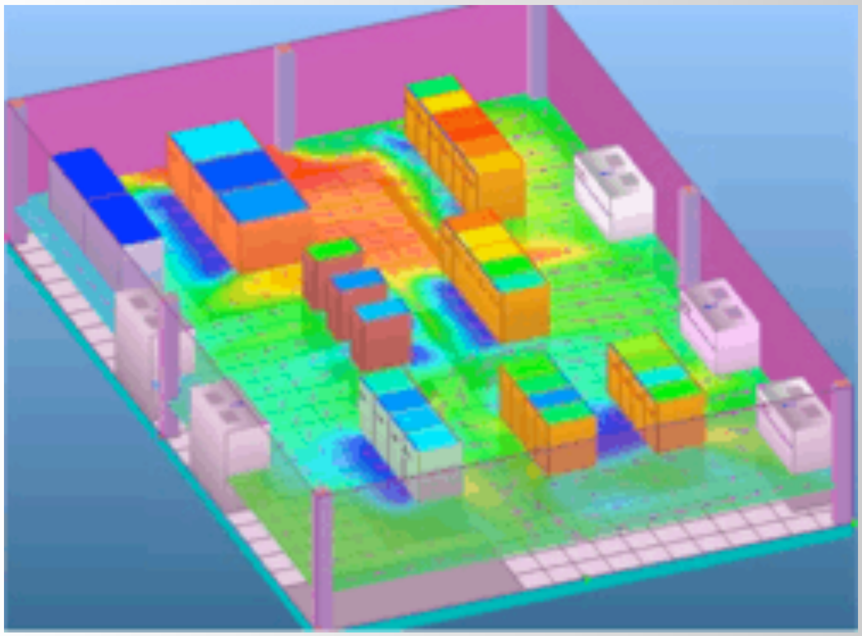
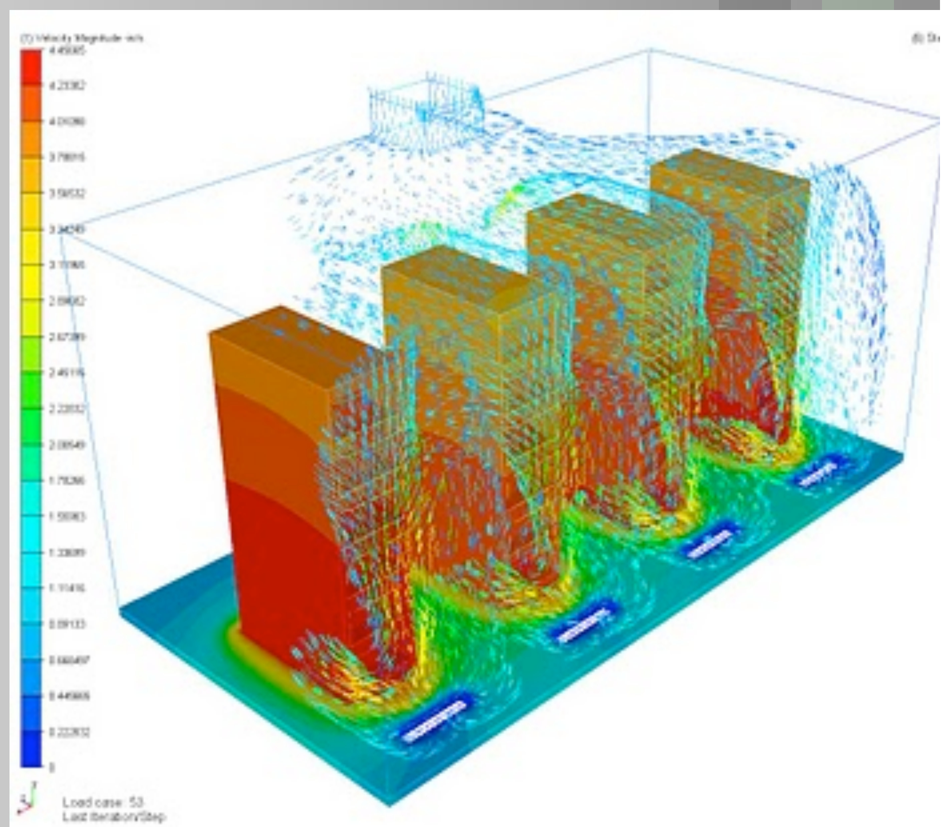
Semester Assignment Server Room Fluid Dynamics







Project Milestones

- Project Milestone #1
  - Research Sustainability in computing and define the types of problems that you would like to solve.
- Milestone #2 – Project Proposals
  - List of Criteria/metrics you will use to pick a project
  - Three or more projects you would like to do for your research.
- Milestone #3 – Project plan
  - Rough Timeline of the project
  - List of next actions with due dates

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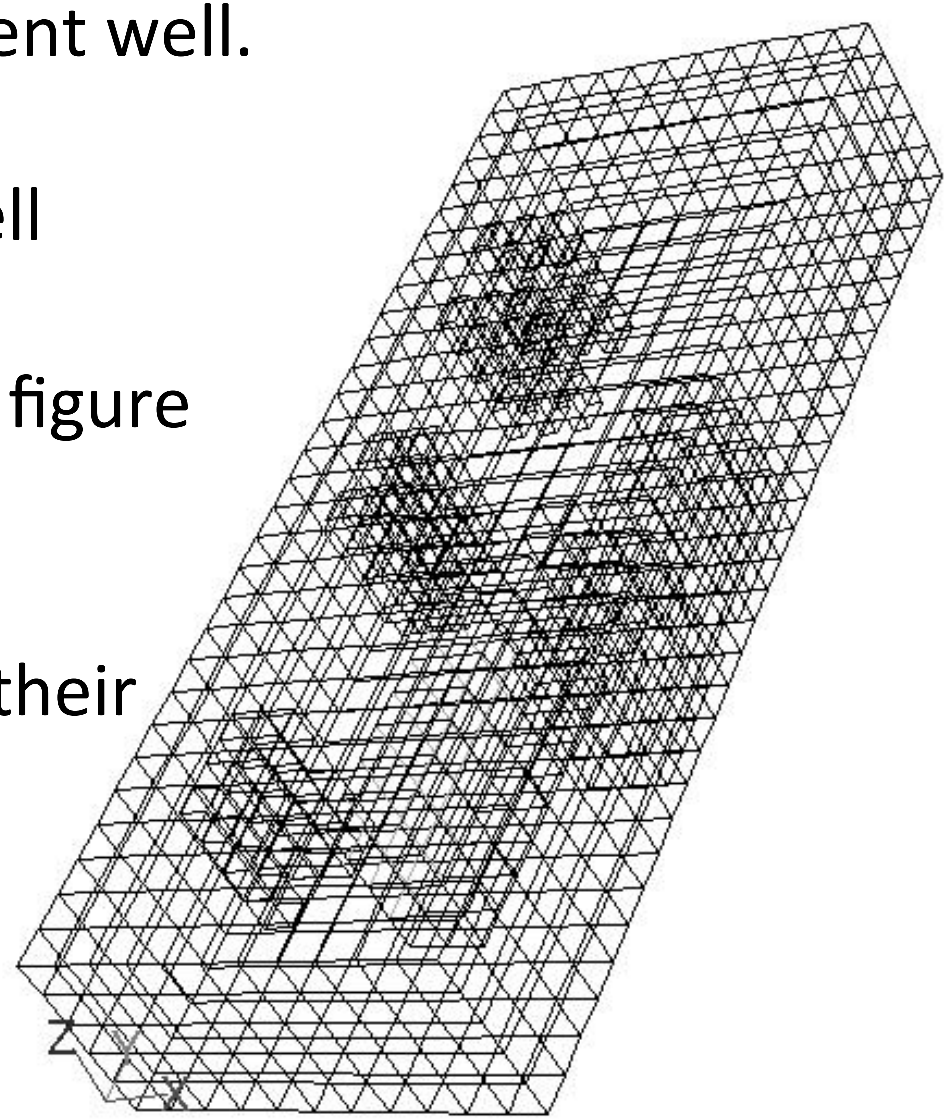
What didn't work

- Modeling of the room went well.
- However, running the simulations was not a well described task.
- Students were unable to figure out details on their own.
- Not really important for their research projects.



What Worked

- All research projects were outstanding
- Brainstorming of projects
- Instructor assigned projects
- Lots of in-class time to work on assignments.

Project Assignments

- Alternative Energy Sources – Hydropower
- Geothermal Energy - Red Cedar Cooling
- Environmental influences - Invite the Burglars
- Alternative Heat Conduction - Deep Fried Server
- Thermo-Electric Power - Thermal Recycling
- CPU Supply Chain Management

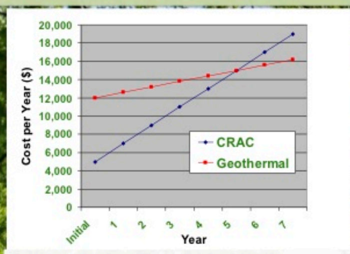
Red Cedar Water Table Cooling

Kayla Hunt

Mentor: Dr. Dirk Colbry

The HPCC at Michigan State University:

- Stands for the High Performance Computer Center.
- The center of these services provided by the HPCC can be found in the server room in the Engineering Building.
- This room currently has the clusters of computers used to accomplish the work of researchers all across campus.



Graph of Break-Even Point of the Cost

Research:

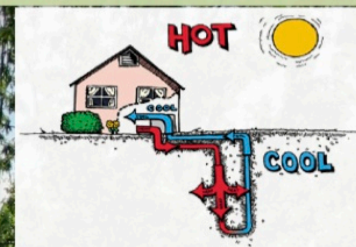
- Installing the geothermal system involves digging the hole, putting the pipes into the ground, and replacing the compressor in the current air conditioning system.
- The geothermal system cools the air in the server room by running it through a cooling system (heat exchanger) powered by the circulating water, and then the water is re-cooled by going back through the pipes in the ground in order to re-cool the air.
- Data was collected using online sources of three different companies, Water Furnace, FHP Manufacturing, and Econar, that specialize in setting up geothermal cooling units.
- The average installation costs, cost of running the systems, and the running life of the geothermal cooling systems was collected.

Geothermal Cooling System Companies

Company	Initial Cost	Cost to Run (per year)	Running Life
Water Furnace	$12,650	$500	15-30 years
FHP Manufacturing	$13,000	$1,050	up to 40 years
Econar	$10,000	$360-$600	18-23 years

Purpose of this Project:

- To find a more productive way to cool the HPCC in the server room.
- Researched by using water for the Red Cedar water table in the form of geothermal cooling.
- Is a geothermal cooling system more energy and cost efficient than the current computer room air conditioning (CRAC) system?



Model of Geothermal Cooling System

Conclusions:

- It would take about 5 years for the geothermal system to reach the current operating costs of the CRAC if a new one was to be bought.
- After the 5th year mark, the geothermal system becomes more cost efficient.
- When combining the cost per year to run each cooling system and adding on the original buy cost, it only takes five years for the geothermal system to become more cost efficient.
- When considering the fact that the geothermal system lasts twice as long as the CRAC, the geothermal system is more beneficial.
- The energy efficiency will immediately improve if the geothermal cooling system is put in.

Comparison of CRAC and Geothermal Cooling Systems

Cooling System	Cost to Run (per year)	Life Span (years)	Initial Cost (U.S. $)
CRAC	2,000	≈10 years	5,000
Geothermal	600	≈20 years	12,000

- Combining the cost and energy efficiency, it is suggested that the server room should use the geothermal system of cooling.

Thermal Recycling

Using Thermo-Electrics to Convert Heat into Electricity

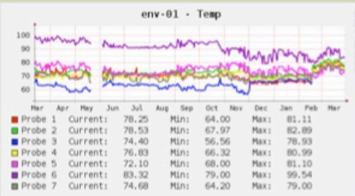
Bob Valentic

Mentor: Dr. Dirk Colbry

Background

The goal of this project is to increase sustainability in high-performance computing; specifically the high-performance computing cluster (HPCC) in the Engineering Building. Thermoelectrics could be used to recycle power with the Seebeck effect. This effect[1] states that when opposing sides of a metal have temperature differences, an electrical current is created. This is demonstrated with the following equation:

$$V = \int_{T_1}^{T_2} (S_B(T) - S_A(T))\, dT$$



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With the Seebeck effect, it is possible to convert some otherwise wasted heat into electricity, which can be used to save power in the long run. The instruments used in this process are thermal exchangers, or TE generators. This process will make the cooling process more energy efficient and allow the HPCC to use less energy. However, the project will cost money to install, will need to convert a lot of energy to be cost-effective, and may be inefficient.

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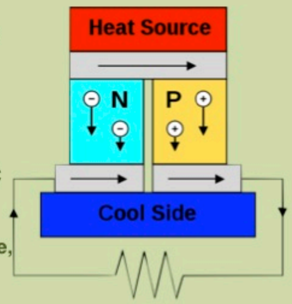
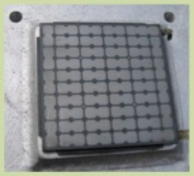


Research

The Hi-Z Corporation[2] was chosen to provide our generators, due to lower model prices. The HZ-14 and HZ-2 models were used for experiments. Using the heat released from a MacBook Pro, a small voltage was found. The Hi-Z website contained a useful spreadsheet (below) that calculated and predicted the amount of energy created based on model and temperature difference.

In conducting small-scale experiments (temperature differences of ~15° F), nominal results were found similar to that predicted in the spreadsheet(~.01 watts). Even with larger temperatures, it was found that the amount of wattage created with the HZ-14 was minimal; .23 watts with a 40° F (or 22° C) temperature difference.



Module Properties				
Module	HZ-14			
Hot Side Temperature	43.333333333	°C	110.0	°F
Cold Side Temperature	21.1111111111	°C	70.0	°F

3

Module			
Voc =	0.31	Volts	open circuit
V =	0.16	volts	at matched load
Ri =	0.11	ohms	internal resistance
Power =	0.23	Watts	at matched load
Q =	31	Watts	
efficiency =	0.72	%	at matched load

Watts	Hours of Use	kWh	Cost Saved	Payback
0.23	8760	1.988	0.2984	449.4

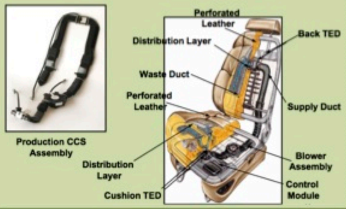
4

Properties of the 14-Watt Module, HZ-14		
Thermal Properties	**Value**	**Tolerance**
Width and Length	2.47" (6.27 cm)	±0.01 (0.25)
Thickness (Special Order)	0.2" (0.508)	±0.002 (0.05)
Weight	82 grams	±3 grams
Compressive Yield Stress	10 ksi (70 MPa)	minimum
Number of active couples	49 couples	----
Thermal Properties	**Value**	**Tolerance**
Design Hot Side Temperature	230°C (450°F)	±10 (20)
Design Cold Side Temperature	30°C (85°F)	±5 (10)
Maximum Continuous Temperature	250°C (480°F)	----
Minimum Continuous Temperature	none	----
Maximum Intermittent Temperature	400°C (750°F)	----
Thermal Conductivity*	0.024 W/cm*K	+0.001
Heat Flux*	9.54 W/sqcm	±0.5
Electrical Properties (as a generator)*	**Value**	**Tolerance**
Power**	13 Watts	minimum
Load Voltage	1.65 Volts	±0.1
Internal Resistance	0.15 Ohm	±0.05
Current	8 Amps	±1
Open Circuit Voltage	3.5 Volts	±0.3
Efficiency	4.5%	minimum

* At Design Temperatures
** At Matched Load, refer to the graphs for properties at various operating temperatures and conditions.

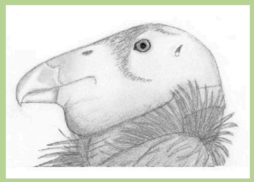
Conclusions

It was concluded that the generators are able to recycle power, albeit a small amount. With 0.23W generated, running constantly, nearly 30¢ would be saved every year. The current 14-watt models cost $134[4]. At this rate, it would take nearly 450 years to pay off. The time needed to pay off is simply too great for this to currently be practical. The TE generators are designed for high-temperature commercial use, with differences of ~100° C. Even then, the energy generated will not pay off for years. If TE became more efficient and produced more power with the same difference, the benefit would offset the cost. The potential of TE is still promising, however. Heating and cooling soldiers in the field, recharging wristwatches, or using TE for automobile combustion engines could be possible and is being looked into[5].



...eebeck_effect.html
2. Hi-Z Corporation: http://www.hi-z.com
3. Module Spreadsheet & Properties of HZ-14:http://www.hi-z.com/hz14.php
4. Average HPCC temperature: http://...11.html

Condor System



Katrina Suchoski

Mentor: Dr. Dirk Colbry

Overlying Problem:

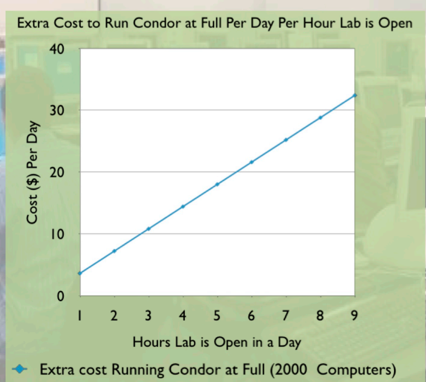
- The running of multiple, single core, High Throughput Computing (HTC) jobs on a High Performance Computing (HPC) system can be seen as wasteful. HPC systems, such as the one provided by Michigan State University's (MSU) High Performance Computing Center (HPCC), are primarily designed for research jobs that require many nodes communicating to each other though a high speed network. Typical HTC jobs can not take full advantage of these high speed networks and, by their very nature, HTC jobs can quickly utilize all of the cores in a HPC cluster making it more difficult for truly HPC jobs to be able to run on these shared resources.

Solution: Condor

- Condor is a specialized workload management system used for compute intensive HTC jobs. Its objective is to disperse single CPU jobs that are in the queue of the HPCC and dispatch them to computer labs that have computers sitting idle on campus.

Data Collected:

- Cost for power: $.06/kWh
- Single HPC Intel 2010 Cluster Core
  - Power Consumption: 23.75W
  - Total cost to run intel10 (including cost to buy): $.013/h
- For a single computer running Condor:
  - Extra power used: 30W
  - Total cost to run Condor: $.0018/h

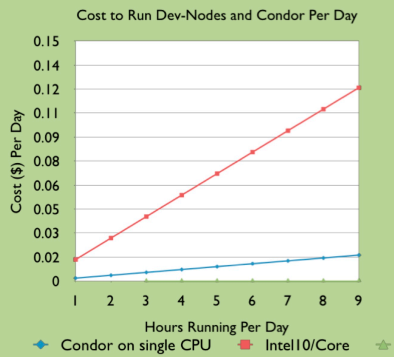


Conclusion:

- Running Condor is clearly more cost effective than buying and running more cluster nodes. The $.0018/h cost to run Condor on a single computer is much cheaper than the $.013/h cost to run a single core of the intel10 cluster.

Future Work:

- Experimentation with the Condor system by running it in a computer lab would allow for more detailed figures.
- There are also factors that are not included in the calculation such as cooling cost that would need to be researched further.
- Michigan State University will be installing Condor in a few of their computer labs on campus.



Students outside of Engineering

- Students from:
  - Electrical Engineering
  - Supply Chain Management
  - Astrophysics
  - Mathematics
  - Education
  - Packaging
- All were able to find a project that fit class and personal interests

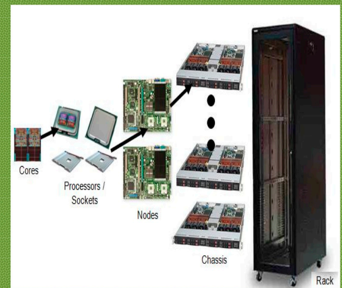
Cost Effectiveness in MSU High Performance Computing Center

Su Xiao

Mentor: Dr. Dirk Colbry

Introduction

The High Performance Computing Center (HPCC) at Michigan State University now has four kinds of hardware. Amd05 is the oldest one and its efficiency is reducing gradually. HPCC is considering replacing amd05 with a newly designed cluster called intel10 which has a faster computing speed. One concern with the upgrade is that intel10 may consume more electricity than amd05, thus costs more for HPCC and violates the sustainability principle of HPCC. This research compares the two kinds of hardware from a cost-efficient point of view.



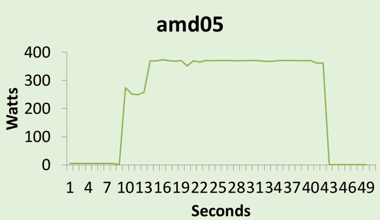
Research Model

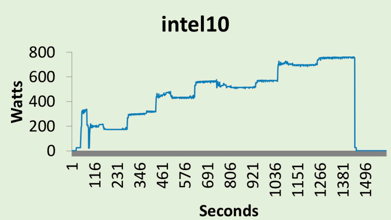
Assumption 1. Amd05 is running perfectly with no efficiency deduction.
Assumption 2. There is no maintenance cost for amd05.
Assumption 3. Every cluster is running at 100% of its designed power consumption.

$$\text{Break-even point} = \frac{\text{Buy-In Cost of Intel10 per Node}}{\text{Power Consumption of Amd05} - \text{Power Consumption of Intel10}}$$

Data Collection

In order to get the data of power consumptions of amd05 and intel10, the high performance computers are booted up to record the change of their electricity consumptions.





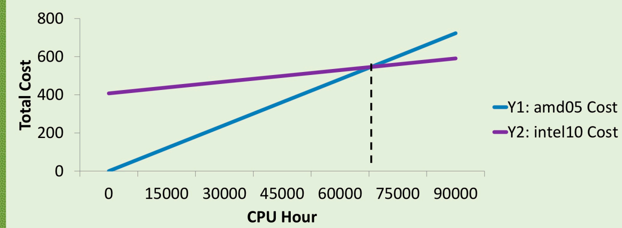
Cluster	Power/Chassis	Power/Node	Power/Core	Price/Core
amd05	0.375	0.375	0.09375	0.008025
intel10	0.76	0.19	0.02375	0.002033

Results

According to my formula, the break-even point is calculated.

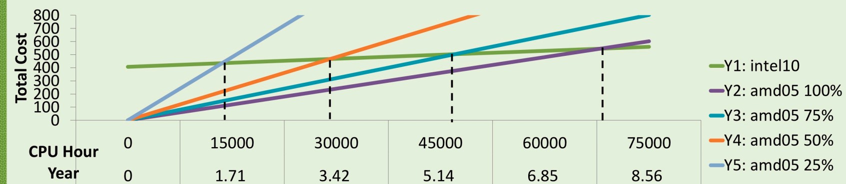
$$\text{Break-even point} = \frac{\$407.5}{(\$0.008/\text{core} - \$0.002/\text{core})}$$

= 68000 CPU hours (about 7.75 years)



Further Research

Unlike intel10, the working condition of amd05 is much worse than assumed. Due to the extreme difficulty to measure its regular frequency of breaking down, it is uneasy to calculate its efficiency. So a better approach is just to make up a number to see if it matters. Three efficiency percentages are used which are 75%, 50%, and 25%, meaning it takes as much as 1.3, 2, 4 times respectively for amd05 to process the computations.



Conclusions

The research presented in this paper provided an insight to a key component in comparison between the two clusters of amd05 and intel10. In general, from a cost-efficient point of view, it is worthwhile to replace the old amd05 clusters with intel10 when the running efficiency of amd05 keeps decreasing.

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Linking with capstone

- Matching up student projects with senior level capstone.
  - Freshmen / Sophomores modeled as the clients
  - The clients could come up with the concept in the fall and the Senior design class could build it in the spring.

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Window Cooling in the High Performance Computing Center

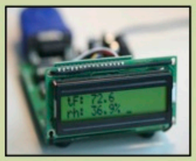
Michael Mock

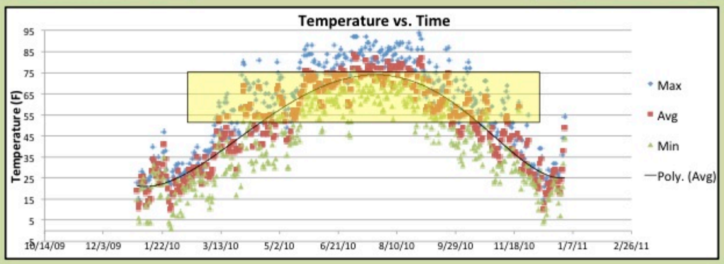
Mentor: Dr. Dirk Colbry

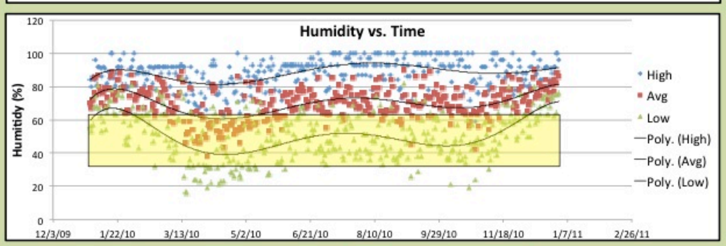
Concept:
Modern server rooms are cooled with advanced compressor systems which require a lot of power and money. A more sustainable design involves the implementation of a self monitoring system capable of opening and closing a window to use Mother Nature's cooling when the timing is right. This hypothetical design inspired this research which explores using a window as a viable and cost effective option for cooling the High Performance Computing Center here in the Engineering Building at Michigan State University. By studying weather patterns and server room ideal climate conditions, this research and conservative data analysis shows that money can be saved by using the window cooling method.

Key Questions Answered:
Do weather patterns in Michigan support the implementation of a window cooling system?
If so, how much energy/money could be saved per year with window cooling?

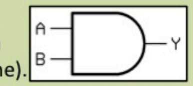
Ideal Server Room Conditions	
Maximum Temperature	75°
Minimum Temperature	50°
Maximum Humidity	60%
Minimum Humidity	30%

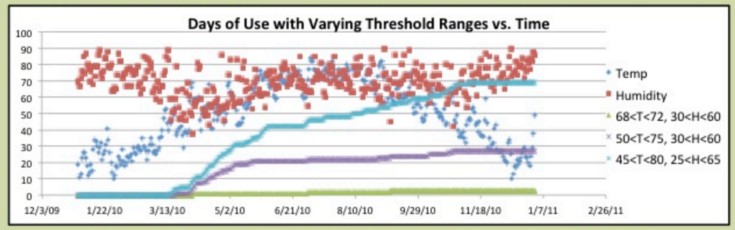






Using AND logic on the Temperature (A) and Humidity (B) condition constraints (see left: yellow boxes) resulted in an estimated **27** days (Y) of viable usage (see below: purple line).

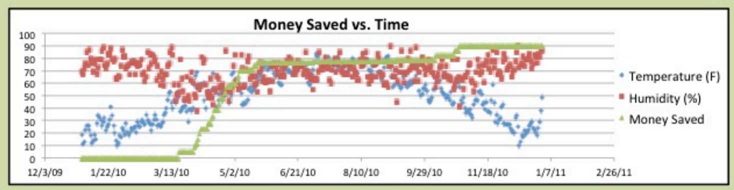




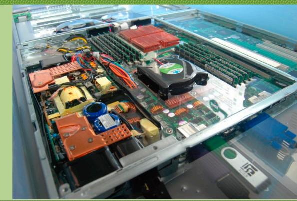
Using the Ideal Gas (Air) Thermodynamics equations: $Q = Cp \times m \times T$

$PV = mRT$

Calculated a conservative estimate of **4.078 MJ** saved per year by replacing warmer air inside with colder air outside using window cooling. Knowing that (1 kWh = 3600 kJ) revealed that window cooling saves approximately **$90.37** per year!



Deep Fried Server



Nickolas Salic

Mentor: Dr. Dirk Colbry

Overlying Problem:

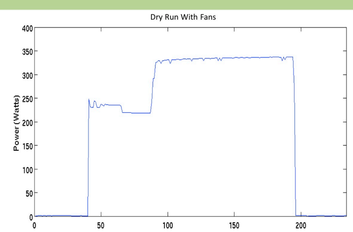
- The problem is that the current system used for sustainability in HPCC uses a lot of energy. This is very expensive and harmful to the environment. The current cooling system uses an air conditioning unit on top of the engineering building to blow chilled air through the nodes in the server room. This system is effective when it comes to cooling the servers, but it is also an inefficient method of cooling the computers.

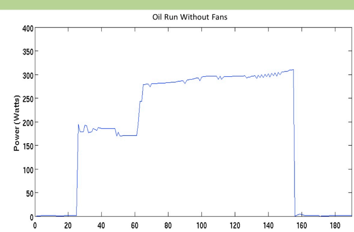
Solution: Mineral Oil

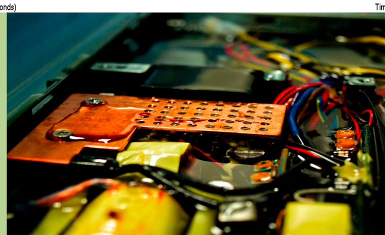
- A proposed solution would be to dip the computers in non-conducting oil to cool them. Mineral oil has a higher heat capacity and better heat transfer rate than air. Benefits would include a lower energy usage to cool the computers.

Data and Test Results

- In the dry run with the fans, the watt reading consistently stayed around 335 Watts once breakin was running. In the oil run without fans, watt readings maxed out around 310 watts and were well below 310 watts for the majority of the time that breakin was running.
- For the majority of the run, over 25 watts were saved simply by removing the fans. When applied to multiple nodes in the server room, the energy saved would be substantially high.







Conclusion:

- Dipping the servers in mineral oil would be an effective solution for sustainability in HPCC at MSU. In the oil run without fans, we did discover that some circulation of the oil was required to prevent overheating. Less circulation would be required with the oil opposed to air circulation.

Future Work:

- A senior design team would need to design a container to dip the server columns in.
- Further data would need to be collected in order to determine exactly how much circulation of the oil is required and how much energy would be saved if the air conditioning unit was replaced with a more efficient system that cooled the oil.

Linking with capstone

- Logistically difficult
- Funding model is difficult

- Seems like it would be easy to overcome these limitations in the future.

If I were to do it again

- Make an easier example of fluid dynamics or remove this as a requirement
- Two instead of four research seminars and pick ones we could go to as a class.
- Work harder on the logistics to make this work with a senior capstone class.

Next time

- Scientific Imaging
  – Taking measurements from digital images and video
  – Appeals to a broader audience
  – Projects can start at a very low level and move up in complexity
  – Lots of easy individual projects to pick from on campus

Acknowledgements

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- Institute for Cyber Enabled Research
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  - Andrew Keen
  - Bill Punch
  - Farhad Jabari

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Class Description

Cyber Green – Sustainability in Super Computing.

•This seminar will introduce students to conducting research using High Performance Computing. In the first semester, students will learn how to use Computer Aided Design and High Performance Computing to study and model the energy consumption of a modern supercomputer. This honors research seminar will also allow the students to use the knowledge they gained to explore their own research projects to invent and research ways to make the ever-growing need of bigger and faster computational resources sustainable into the future.

Grading

- Class Attendance
- Attendance at a minimum of 4 Research Events with blog posts
- Class Assignments and project milestones
- 80% or more to pass the class
- Students must pass both semesters of the class.

Class Assignments

- Each week we had one or more assignments.
- Most could be done in class
- Students were required to complete assignments and turn them in on or before the next class
- Late assignments were automatically be reduced by 20% (i.e. just passing)

Brainstorming

- What is the operation range for the humidity of the room?
  - What is Max Humidity Temp on Stats website?
  - What is probe x on the stats website?
- What price should we estimate for Kwatt hours?
- What is the historical single cpu usage as cpu hours?
- How much power does the compressor use?
- How much min/max power does each node type use?
- Historically, how much has the amd05 and intel07 clusters been running since they went out of warranty?
- Ask CSE about number of computers in labs
- Get datatables for graphs for past year.
- How hot is the top of the CPU? Or the side of the box.

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Research Events

- Attend and report on a minimum of four research related events
  - iCER Research Seminar
    - http://wiki.hpcc.msu.edu/
  - HPCC Mid Morning Breaks
    - http://wiki.hpcc.msu.edu/
  - Undergraduate Research Workshops
    - http://urca.msu.edu/event
  - MSU Science at the Edge Seminar
    - http://www.qbmi.msu.edu/seminars.php
  - Others

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What Didn't work

- 4 research events
  - Too vague of a task
  - Students uncomfortable attending research seminars
  - Students are not on any seminar lists

First Semester Classes

- Overview of computational science
- Developing a research project
- Evaluation Metrics
- Scientific measurements
- HPC hardware and power consumption
- Introductions to HPC, CAD, Fluent

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Second Semester Classes

- How to give an effective presentation
- Writing an effective abstract
- Effective poster presentations
- Practice poster session