UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Project on server room management

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EECE 496

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April 7, 2013

Dr. Andre Ivanov

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Dear Dr. Ivanov:

Subject: EECE 496 Final Project

In response to your request for the EECE 496 final report to fulfill the requirement of Electrical and Computer Engineering Department, I have prepared the enclosed report titled, “Energy Management for Server Room”.

This report presents an investigation of the feasibility of reducing energy consumption by raising the operational temperature in the Fred Kaiser server room while maintaining a healthy environment for the equipment

Should you require further information, please contact me at auburnleung@interchange.ubc.ca

Respectfully submitted,

Auburn Leung

Enclosure: EECE 496 Final Report

University of British Columbia

Department of Electrical and Computer Engineering

Project on server room management

Prepared by

Auburn Leung

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ECE technical supervisor: Andre Ivanov

ECE technical Co-supervisor: Paul Lusina

ABSTRACT

The electrical transmission at UBC is reaching its capacity. Reducing electricity consumption can delay the implementation of new infrastructures and reduce GHG emission. Server rooms are often over-cooled because IT manager are reluctant to allow high operating temperature which may decrease the dependability of server equipment. This report will determine the feasibility of reducing energy consumption by raising the operational temperature in the Fred Kaiser server room while maintaining a healthy environment for the equipment. The results will be based on costs calculations, technical interviews, and failure estimations.

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GLOSSARY

CO_2e	Carbon dioxide equivalent. It represents the global warming potential of various GHGs in terms of the amount of carbon dioxide required to produce the same effect.
UPS	An electrical apparatus that provides emergency power to server when the input power source fails.

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ECE	Electrical and Computer Engineering
GHG	Greenhouse gas
HVAC	Heating, Ventilation and Air-Conditioning
UPS	Uninterruptible power supply

1.0 INTRODUCTION

This report investigates the feasibility of reducing energy consumption by raising the operational temperature in the Fred Kaiser server room while maintaining a healthy environment for the equipment. This exemplifies UBC's determination to reduce greenhouse gases as well as energy consumptions by quantifying the benefits to UBC of setting server rooms temperature.

The objectives of this project are to evaluate the ASHRAE's recommended operational temperature, quantify the benefits[1] to UBC of raising the temperature and to provide a combination of literature review and audit of UBC facilities. To accomplish these objectives, my partner, Yu Chen and I consulted with ECE IT technicians, heating, ventilation and air conditioning professor, and our ECE technical Co-supervisor. This report focuses on the ECE server room at the Fred Kaiser building.

Sever rooms contain heat-generating equipment, which are cooled year-round to protect temperature sensitive equipment. However, server rooms are often over-cooled because IT manager are reluctant to allow high operating temperature because of concerns about equipment dependability and the high maintenance costs for replacing equipment failures. Generally, lower temperature may be required by older servers while new servers are more resilient to higher temperature, and therefore server room with newer equipment should reduce cooling needs. Excessive cooling consumes a large amount of energy and UBC's electrical transmission infrastructure is reaching its capacity. Reducing electricity consumption can delay the implementation of new infrastructures and result in energy savings.

[1] To evaluate an optimal temperature level with respect to cost versus benefit for UBC.

To fulfill our objectives, my partner and I have divided our work into two parts: Yu Chen is responsible for estimating the failure rate and evaluating the ASHRAE's recommended operational temperature; I am responsible for the cost related calculations, such as calculating the energy savings, GHG-footprint, and quantifying the benefits to UBC of raising the temperature. Energy savings will increase as the cooling needs is reduced and estimated failure and maintenance costs will increase as the cooling is reduced. Therefore, my energy savings calculations are to be compared with Yu Chen's failure estimation costs to determine the most cost beneficial operating temperature.

This project is a new project designed by the UBC sustainable office, so it has no preceding reference projects for us to refer. This project is different from other capstone projects that are based on demonstrating the synthesis or design of engineering systems; it requires us to obtain operation specific information from UBC staff and faculty members. This research involves many uncertainties and variables with little data records[2], so we are required to make appropriate assumptions to have conclusive results. Assumptions and calculations are explained in this report.

This report divides into the following primary sections:

- The methods of
- Problem analysis and ECE IT technicians assessment
- Assumption explanations
- Calculations
- Results and conclusion

[2]Data records – records of server systems such as energy consumption and temperature

2.0 METHODOLOGY

2.1 Problem Analysis

This an exploratory project because the outline of this research is open-ended. However, there are three main objectives: evaluate ASHRAE's standard temperature in server rooms, quantify the benefits to UBC of raising the temperature to reduce cooling energy consumption, and to provide a combination of literature review and audits of UBC facilities. The thermal guideline of ASHRAE TC 9.9 in 2010 states that server rooms should operate at 27 °C to have balance reliability on servers and cooling energy consumption, [1]. This justification is explained in Yu Chen's report. Since the outline does not strictly state how these objectives are to be completed, we have the freedom to decide how we achieve these objectives. We started by planning the methods and procedures on how the objectives are to be accomplished.

My responsibilities:

- Calculate the server operating consumptions
- Calculate the cooling energy consumptions at different operating temperatures
- Calculate GHG emissions and electricity costs
- Calculate the total cost benefits to UBC at different operating temperatures

Yu Chen's responsibilities:

- Research on the evaluation of ASHRAE's operating temperature at 27 degree Celsius
- Estimate the failure rate and the cost of maintenance
- Research for possible solutions to operate at a higher temperature

Responsibilities as a group:

- Prepare a list of questions for IT technicians to aid us understand
- Record the ECE IT technicians assessment of the impact of temperature on the server system
- Complete the final report with the results of individual research and conclude an optimal operating temperature

2.2 Technical Information

To start this research, we setup weekly meetings with our Co-supervisor, Dr.Lusina to determine progress and provide guidance and support. Dr.Lusina provides us the contacts of UBC staff that may help us with this project.

We arranged meetings with Chris Dumont, Manager, Technical & Physical Resources, to describe to us the fundamentals of server rooms and the associated policies at UBC and ECE. We were given a tour to several server rooms at UBC including the Macleod building, the ICICS building and the Fred Kaiser building. He provided reasons and benefits for operating server rooms at 21℃, such as the warranties of UPS[3] in server rooms are required to operate below 25℃ for 99% of the time and old equipment are less resilient to high operating temperature,[2]. Possible solutions to these restrictions are discussed in Yu Chen's report. The technical findings are included in the latter part of this report.

We have also consulted with Ken Madore, technician in labs and computer hardware, to estimate the cost of equipment failure, maintenance and installation cost. We were given a tour to the server room at Kaiser 3035 for additional data recordings to have a more accurate energy consumption analysis.

I am responsible for calculating the cooling energy consumption at different operating temperatures, so I consulted Dr.Atabaki, mechanical professor at UBC who specializes in HVAC, to guide me make appropriate assumptions and understand the basic principles of thermodynamics and heat transfer.

[3] Uninterruptible power supply- an electrical apparatus that provides emergency power to server when the input power source fails.

2.3 Assumptions

The main objective for my part of this research is to calculate the energy consumption, so it is necessary to choose a specific server room to simplify my analysis. Chris Dumont gave us a tour to three server rooms at UBC, and they are located at the Macleod building, the ICICS building and the Kaiser building. The structure of each server room is quite different; each has a different equipment age, layout, room size and cooling system model. The server room at Kaiser 3035 has a similar design to modern server rooms; it utilizes the hot aisle, cool aisle layout[4]. The size of this server room is the smallest of the three, so the theoretical heat leakage through walls and windows is the lowest, which increases the accuracy of the energy consumption calculation. Unlike the Macleod server room, where equipment is mixed with old computers, network switches and UPS units, Kaiser 3035 has unify systems with similar equipment age and models. The UPS units are isolated from the server room and heat dissipated by UPS can be neglected. The Kaiser 3035 server room uses chiller as its cooling system, and the ICICS server room uses fan coil, which is less powerful. Chillers are more likely to be installed in future servers because it can cool more servers. For these reasons, the Kaiser 3035 server room is most likely to have a similar structure to future server rooms at UBC, in addition, energy consumption calculations can be more accurately simplified because of its size and its unifying equipment models and age.

To calculate the energy cost of cooling, I need to calculate the annual energy consumption. I assume that the power input to the servers is dissipated to heat completely, Equation 1.0.

$$P_{output} = P_{input} \qquad \text{Equation 1.0}$$

This is an appropriate assumption because the server input power is primarily transformed into noise, mechanical energy (fans and hard drive motors) and heat, where noise and mechanical energy are negligible.

[4] Hot aisle, cool aisle is a layout design for server racks to enhance air flow, conserver energy and lower cooling cost.

I assumed that the cooling energy consumption has a linear relationship with the rate of air flow, $M(\frac{kg}{s})$. This assumption provides a direct relationship in calculating energy consumption as operating temperature differs. The rate of air flow factor is explained in the calculation part of this report.

The heat energy dissipated by the server room is calculated to be approximately 19kWhr, and the size of the server room is only 37 square meters,[3]. After consulting Dr.Atabaki, mechanical professor at UBC who specializes in HVAC, he suggests the heat energy leakage in the Kaiser server room is negligible compared to the heat dissipation,[4]. In addition, I assumed that lights and IT personals do not dissipate enough heat to have an effect on energy calculations because lights are only turned on when IT technicians work in server rooms, and they don't work in server rooms unless there's a problem.

The coefficient of performance, a coefficient that measures the efficiency of a cooler is approximated to be 4 when the operating temperature of the server room is 21℃ and the outdoor temperature is 11℃ ,and 11℃ is the average annual temperature in Vancouver,[5].

The energy consumption during peak hours and off-peak hours are relatively similar, and therefore I assumed that the monthly server load is constant throughout the year, [2].

3.0 CALCUALTION

3.1 Energy Consumption Calculations

$$P_{output} = P_{input}$$ Equation 1.0

$$P_{input} = V_{Line} * \sum I$$ Equation 1.1

$$P_{Cooling} = \frac{P_{output}}{COP}$$ Equation 1.2

$$V_{Line} = \sqrt{3} * 120 = 208V$$

$$\sum I \approx 91.65$$

$$COP \approx 4$$

General equation for heat dissipation

$$Q = M * C_p * \Delta T$$,[4] Equation 2.0

Q is the Cooling capacity $[kW]$

M is the mass rate $[kg/s]$

C_p is the specific heat capacity for air$\approx 1[\frac{kJ}{kg}.°K]$

ΔT is the temperature difference $[°K]$

$$Q_{gen} + Q_{leakage} = M * C_p * (T_{server\ room} - T_{outdoor}) \qquad \text{Equation 2.1}$$

$$Q_{leakage} = \sum U * A * (T_{Kaiser} - T_{server\ room}) \qquad \text{Equation 2.2}$$

$$Q_{gen} = P_{Output} * Time \qquad \text{Equation 2.3}$$

$T_{server\ room} = 21$°C (Kaiser 3035 Operating temperature)

$T_{outdoor} = 11$°C (Average annual temperature at Vancouver)

$T_{Kaiser} = 25$°C (Ambient temperature of the Kaiser building)

$Q_{leakage}$ is the heat transferred from the server room to its ambient environment, which is the Kaiser building, T_{Kaiser}.

U is the overall heat transfer coefficient, which can be obtained through experiments.

A is the areas of wall inside the server room.

Q_{gen} is the heat energy generated by servers inside the server room.

From equation 1.0 and 1.1, the power output can be calculated by multiplying the line voltage to the summation of currents measured at the Kaiser server room.

$$208\text{V} * 91.65\text{A} \approx 19\text{kW}$$

Then, apply equation 1.2 to calculate the cooling consumption.

$$P_{Cooling} = \frac{19kW}{4} \approx 4.762kW$$

Assuming leakage is negligible; we can determine the rate of air flow from equation 2.1,

$$19kW + 0 = M * 1 * (21 - 11)$$

$$M = 1.9kg/s$$

Therefore cooling power is 4.762kW when the rate of air flow is 1.9kg/s

Equation 2.4 is a derivation of equation 1.2 and equation 2.1; it relates the cooling power consumption to the mass rate.

$$P_{Cooling} = \frac{4.762\text{kW}}{1.9\text{kg}/_{s}} * M \qquad \text{Equation 2.4}$$

Hence, I can calculate the cooling energy consumption as a function of air flow, where the rate of air flow can be calculated from equation 2.1 at different operating temperatures.

At a constant $T_{outdoor}$; as $T_{server\ room}$ decrease, M, the rate of air flow needs to increase to maintain a low operating temperature.

For example at $T_{outdoor} = 11$°C , mass rate is much higher if we operate at $T_{server\ room}$ =20°C than at $T_{server\ room}$ =30°C. More air flow is needed to keep the server room cooler than a warmer server room.

At operating temperature of 21°C and outdoor temperature of 11°C , the $P_{Cooling}$ is calculated to be $\approx 4.762kW$. The cooling energy can be calculated by applying equation 2.3.

$$Monthly\ cooling\ energy\ consumption = 4.762kW * \frac{24hr}{day} * \frac{30day}{month} = 3428.64kWh$$

I apply this formula to every month and plot the energy cooling consumption at different operating temperatures, shown in figure 2.

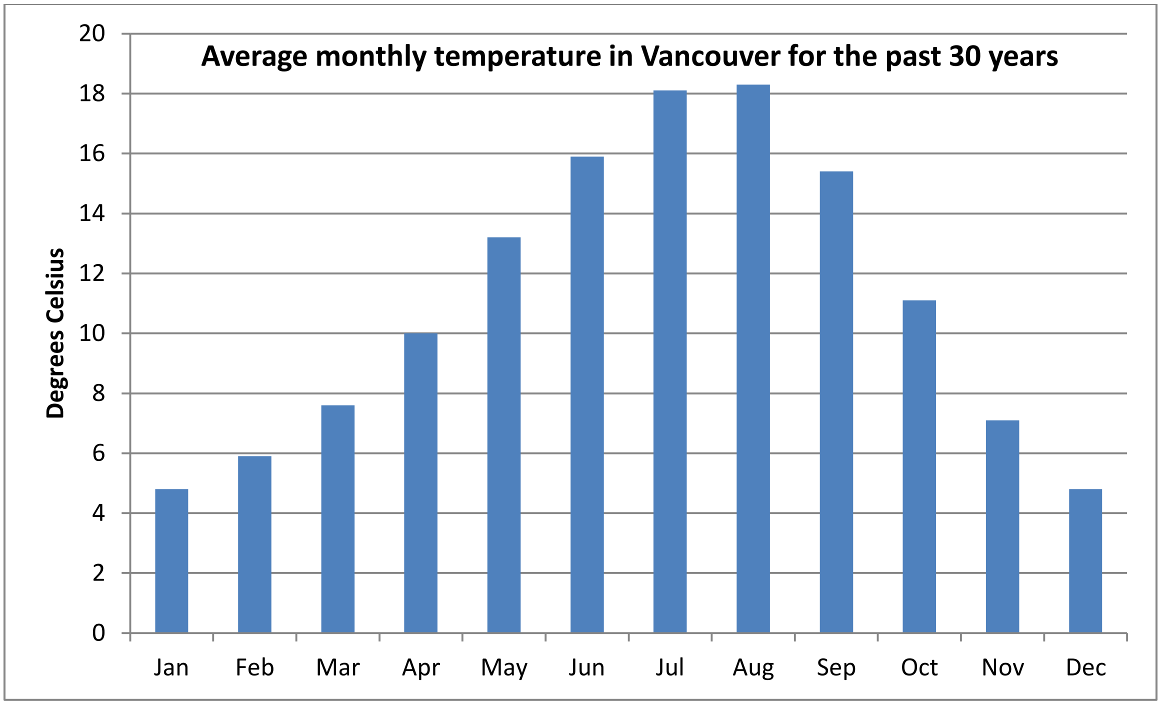

Figure 1: Average monthly temperature ,[5]

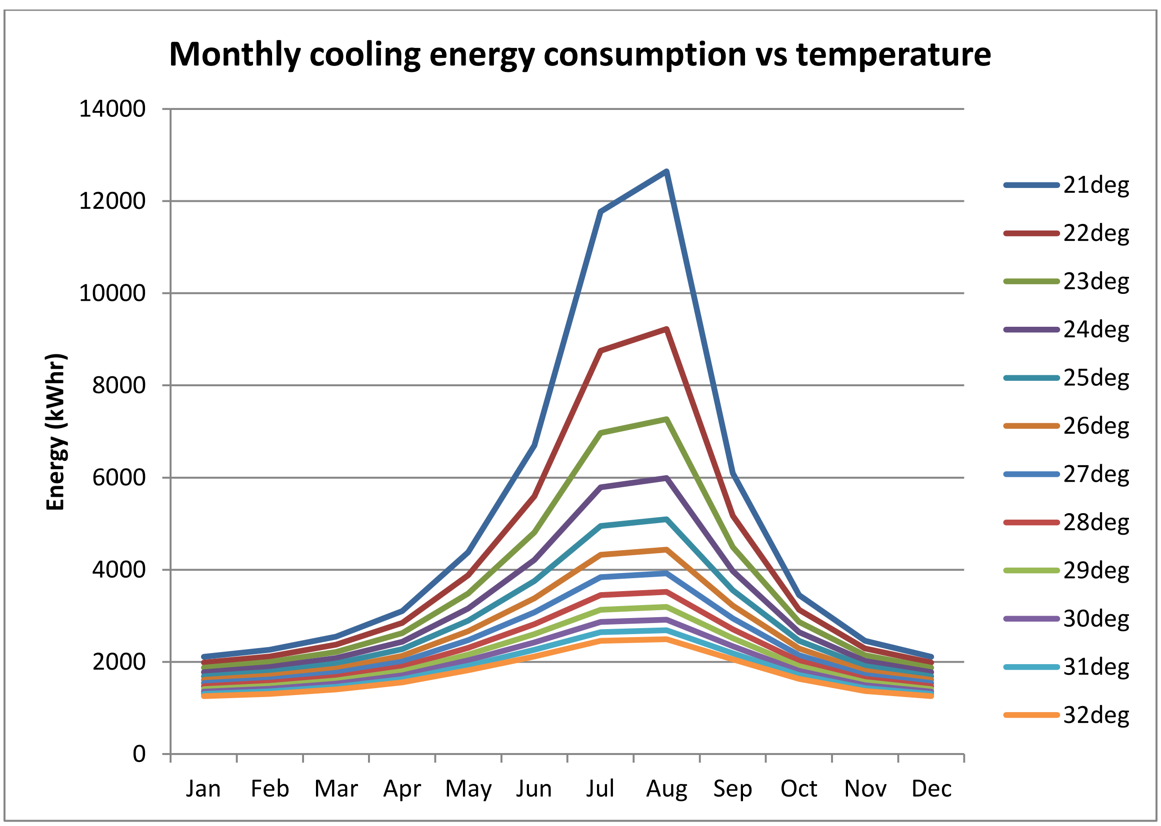

Figure 2: Annual cooling consumption at different operating temperatures

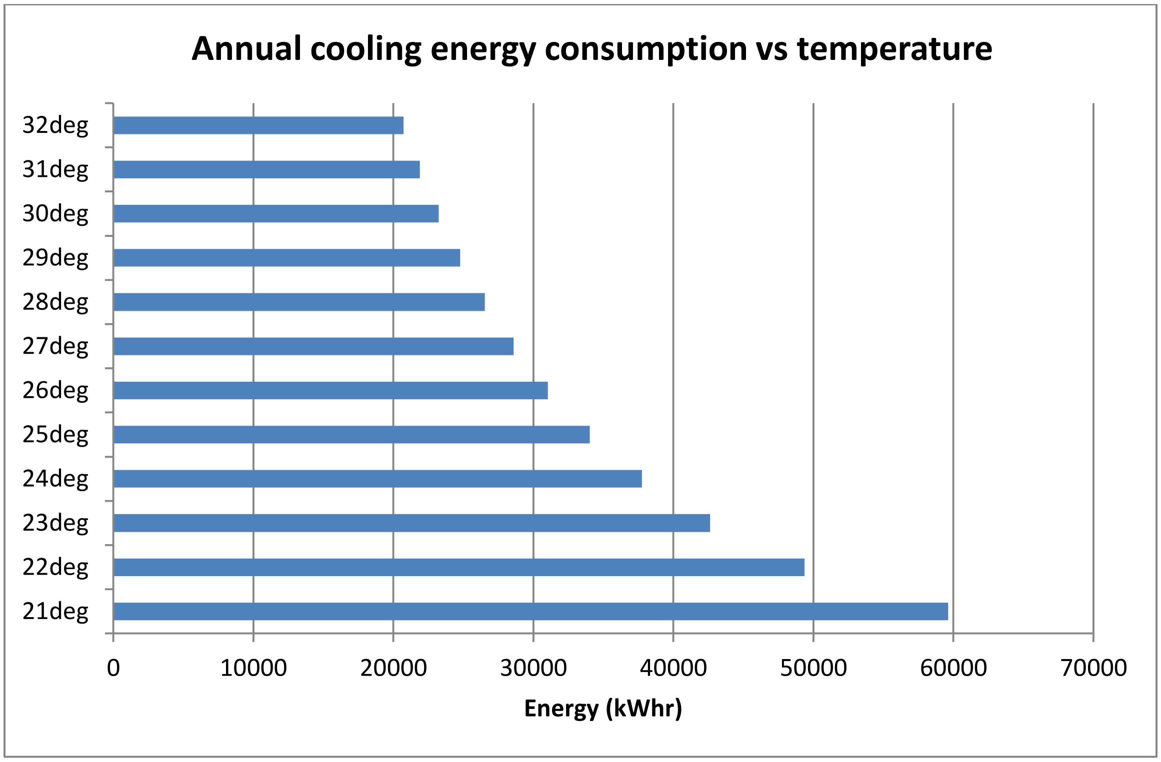

Figure 3: Annual cooling energy consumption at different operating temperatures

3.2 Carbon Footprint Calculations

$$Monthly\ CO_2e\ (Cooling) = Monthly\ Cooling\ Energy\ Consumption * Emission\ factor$$

Equation 3.0

$$Monthly\ CO_2e\ (Opearte) = Monthly\ Operating\ Energy\ Consumption * Emission\ factor$$

Equation 3.1

$$Total\ Monthly\ CO_2e = Monthly\ CO_2e\ (Opearte) + Monthly\ CO_2e\ (Cooling)$$

Equation 3.2

$$Emission\ factor = \frac{25\ tons\ CO_2e}{GWh}$$,[6]

GHG footprint refers to the amount of GHG that are emitted during the process of generating electricity. The total annual CO_2e can be calculated by applying equation 3.0, 3.1 and 3.2 respectively.

For example: at $T_{outdoor} = 11$℃ and $T_{server\ room}$ =21℃ , the monthly cooling energy consumption is calculated to be $3428.64kWh$. Apply Equation 3.0 to calculate the annual cooling CO_2e emission.

$$Monthly\ CO_2e\ (Cooling) = \frac{3428.64kWh}{month} * \frac{25\ tons\ CO_2e}{GWh}$$

$Monthly\ CO_2e\ (Cooling) =$ 0.085716 Tonne

$$Monthly\ CO_2e\ (Opearting) = \frac{19kWh}{hr} * \frac{24hr}{day} * \frac{30days}{month} * \frac{25\ tons\ CO_2e}{GWh}$$

$Monthly\ CO_2e\ (Opearting) =$ 0.342 Tonne

Lastly, apply Equation 3.2.

$Total\ Monthly\ CO_2e$ =0.085716 +0. 342 Tonne= 0.427716 Tonne

The monthly CO_2e is calculated instead of the annual CO_2e is because the average temperature is different for each month, and the annual CO_2e emission is the sum of the emission in 12 months. Figure 4 shows the annual CO_2e emission at different operating temperatures.

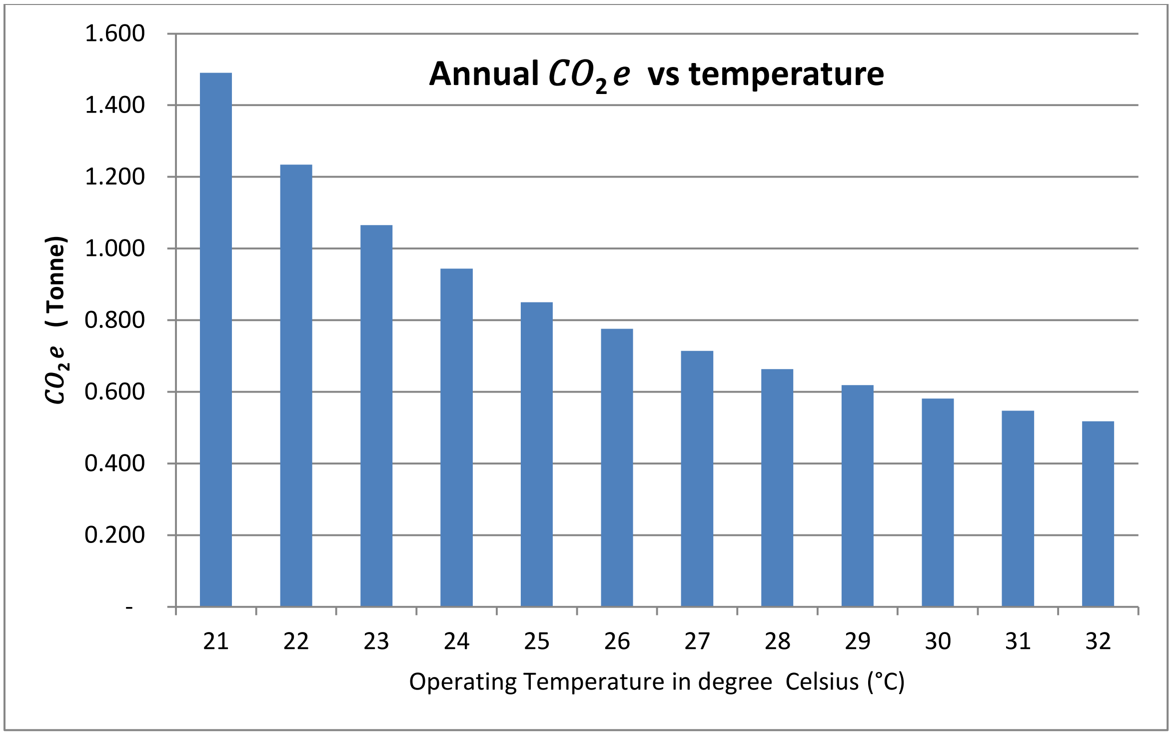

Figure 4: Annual CO2e at different operating temperatures

3.3 Cost Calculations

$$Cost_{Electricity} = E_{Annual(cooling+operate)} * (Rate_{Electricity} + Rate_{Tax} + Rate_{Rider}) \quad \text{Equation 4.0}$$

$$Rate_{Electricity} = 0.03814/kWh, \text{[6]}$$

$$Rate_{Tax} = 9.05\% \text{ , [6]}$$

$$Rate_{Rider} = 5.20\% \text{ , [6]}$$

Manual calculation is not shown because the total energy consumption varies each month. Applying equation 4.0 in Excel, the electricity cost at different temperatures are shown in figure 5.

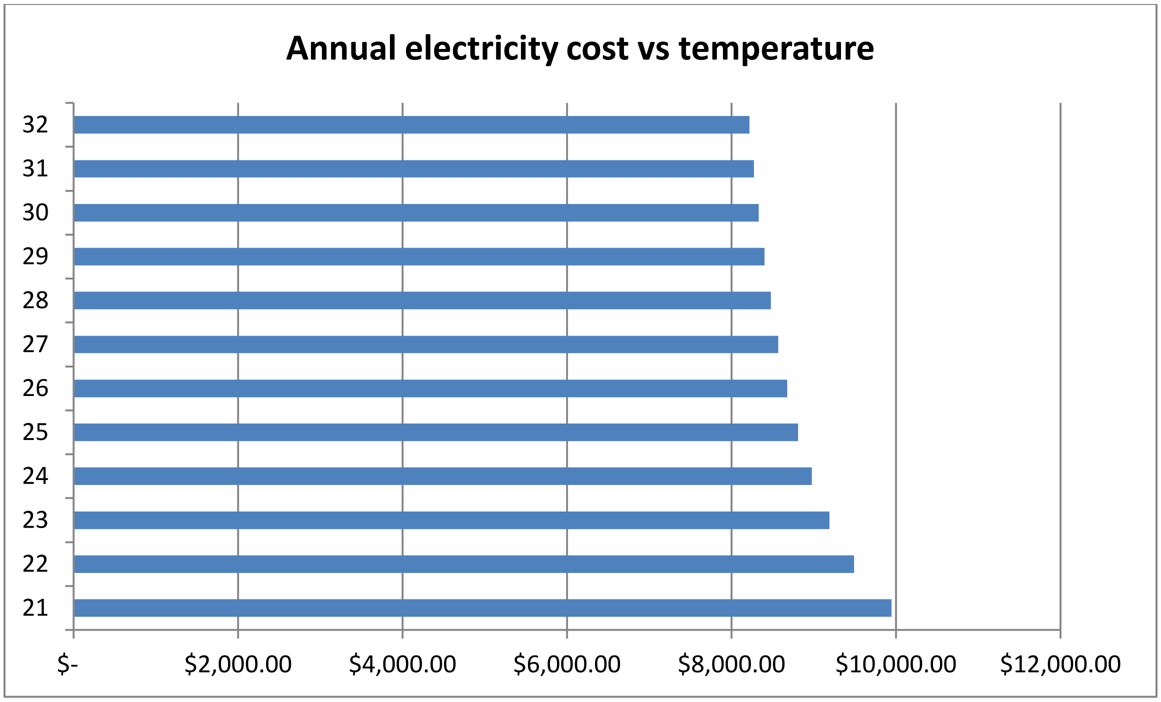

Figure 5: Annual electricity cost at different operating temperatures

$$Cost_{GHG\ Footprint} = E_{Annual(cooling+operate)} * (Rate_{Emission} * Cost_{Offset}) \quad \text{Equation 4.1}$$

$$Rate_{Emission} = \frac{25\ tons\ CO_2e}{GWh}, [6]$$

$$Cost_{Offset} = \frac{\$25}{tons\ CO_2e}, [6]$$

Figure 6 shows the annual cost of GHG footprints at different temperatures by applying equation 4.1 in Excel. The cost of GHG footprint is cheap compared to the cost of electricity shown in figure 5.

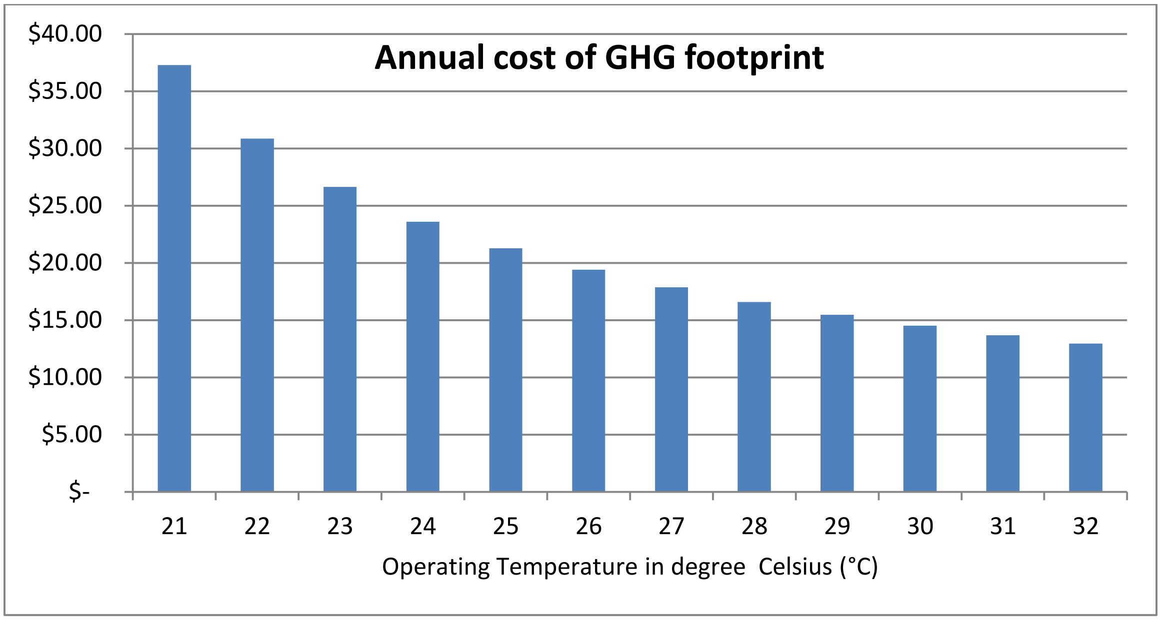

Figure 6: Annual cost of GHG footprint

$$Cost_{Operational} = Cost_{Electricity} + Cost_{GHG\ Footprint} \quad \text{Equation 4.2}$$

Equation 4.2 is the sum of equation 4.0 and equation 4.1. Figure 7 represents the annual total cost, including the cost of electricity and GHG footprint at different operating temperatures.

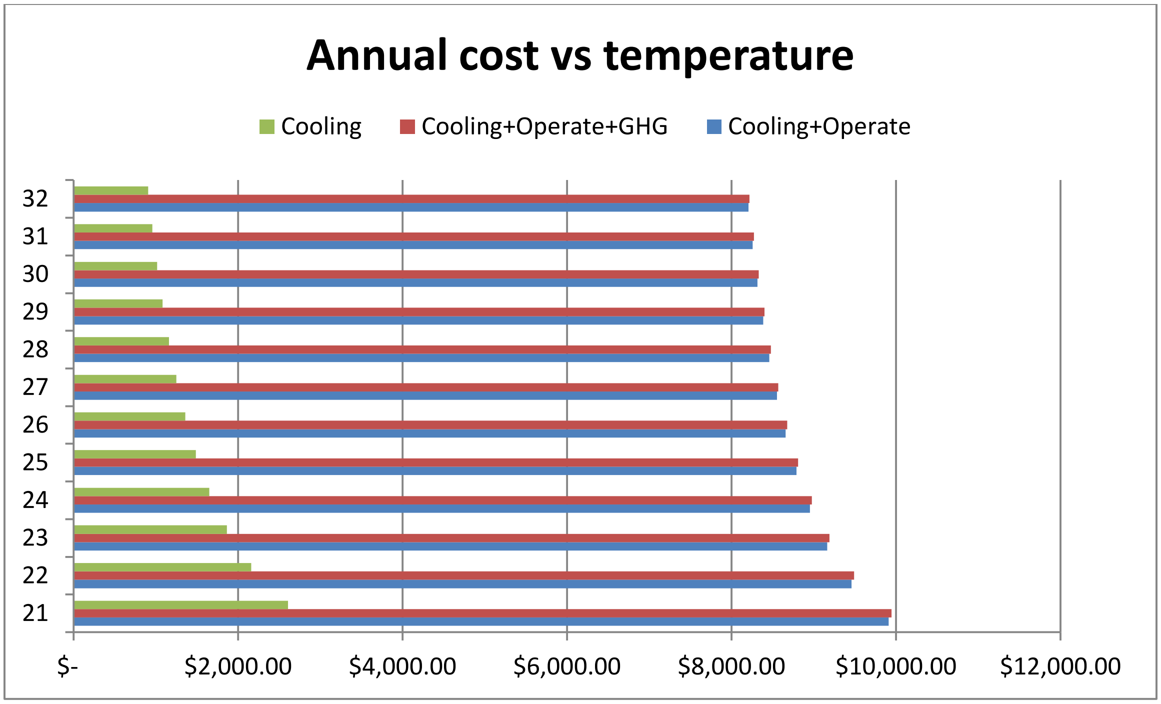

Figure 7: Annual cost at different operating temperatures

From figure 7, it is obvious that the cost of GHG adds little to the overall cost. The operating cost is fixed because the energy consumption during peak hours and off-peak hours are relatively similar and therefore I assumed that monthly server load is constant dissipating 19kW throughout the year, [2].

4.0 RESULTS

4.1 Technical Interview Results

From the meeting with Chris Dumont, we were given the fundamental operations of server rooms. The operating temperature of ECE server rooms are set to 21 degrees mainly because the UPS inside the server room must operate at 25 degrees at 99% of the time or the warranty will be void. In Chris's perspective, the dependability of servers is far greater than energy saving, primarily because the ECE department has a limited budget for purchasing new equipment.

In the MacLeod building server room, UPS, servers, old personal computers and network switches are mixed together. The personal computers are over ten years old, and they are less resilient to higher operating temperature. In addition, the UPS require a low operating temperature to maintain its warranty. Therefore, the Macleod server room must operate at a low temperature.

To maximize the ventilation, the layouts of server rooms are important. Mixing old personal computers and servers limits the airflow of this room because of its irregular layout. The hot aisle, cool aisle configuration is a standard layout design that increases the efficiency of cooling. Figure 8 shows the hot aisle, cool aisle configuration. Server racks are lined up with cool aisle facing each other, so the intake of one row does not come from the hot exhaust air from another row.

The raised floor server room in the ICICS building has one of the racks installed backwards; this configuration increases the intake air of that disorientated rack to 31 degrees. Reinstalling this server rack and setting up temperature sensors will take days to implement, so it is best to plan ahead.

In two of the rooms in the ICICS building, each of them only contains one rack of server because the cooling capacities of the rooms are very low. These rooms were designed about forty years ago, and they are equipped with fan coils as cooling system. It is very difficult to install additional cooling units because they are installed on the roof of the building and connected via a duct to the server room. It is more efficient if the two racks can be moved to the raised floor server room instead of having three separate rooms with two of the rooms only containing one server rack each, but the power output of the raised floor server room has reached its output limit. This problem can be avoided if the power outputs of future server rooms are designed to support a maximum number of racks that server room can take.

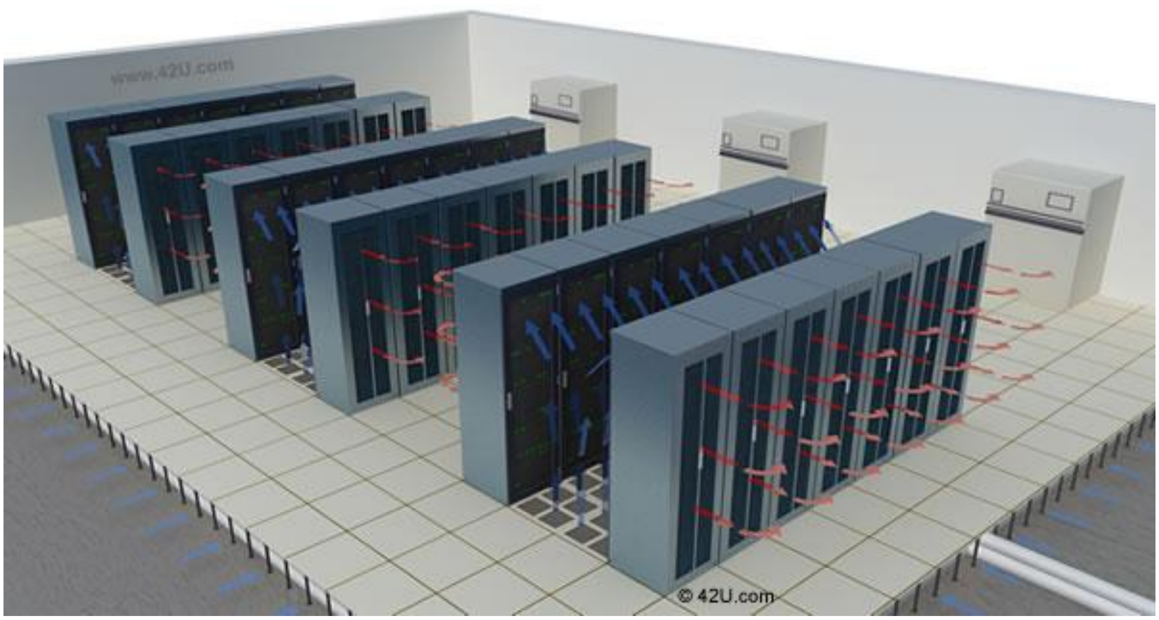

Figure 8: Hot aisle, cool aisle configuration ,[7]

4.2 Calculation Results

In figure 2, the cooling energy consumption during the summer is significantly more than the winter because the outdoor temperature is much higher, which means chillers have to move air quicker to maintain a certain operating temperature. The energy consumption peaks between operating at 21 degree and 24 degree are more than twice as much, so it is beneficial to operate at a higher temperature. In figure 10, the marginal saving decreases as the operating temperature increases, and the curve flattens at 28 degrees, so it is cost beneficial to operate a few degrees above 21 degrees.

Comparing the failure costs, figure 11, and operational costs, figure 13; it shows that the failure costs are only portion of the total costs saving.

The estimate failure cost in figure 12, done by Yu Chen, shows a slight increase as temperature increases. The sum of the failure costs and operating cost in figure 13 suggests that the price of the total cost will continue to decrease as temperature increases. In addition, the cost benefit in figure 11 has a much steeper slope than the failure cost in figure 12 because the failure costs are less than the energy saving benefit. However, the failure costs are only an estimate because the cost of each failure varies and the amount of time necessary to replace these failures can only be roughly estimated.

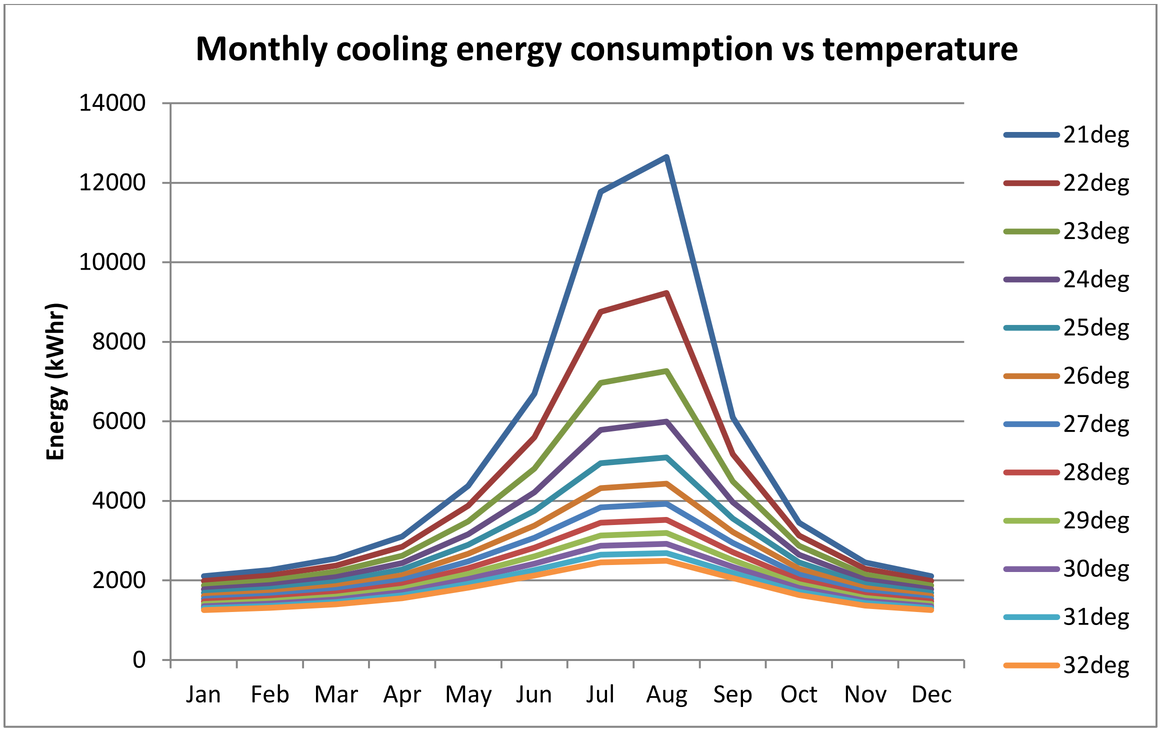

Figure 9: Annual cooling energy consumption at different operating temperatures

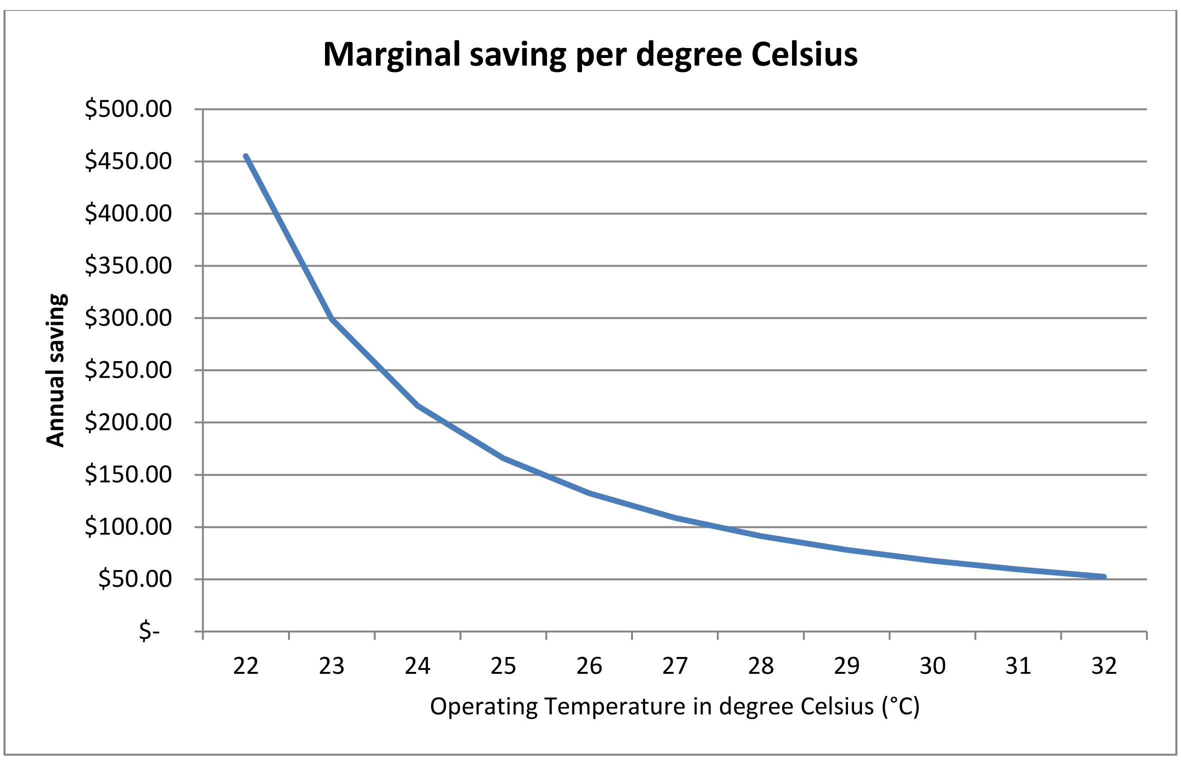

Figure 10: Marginal saving per degree Celsius

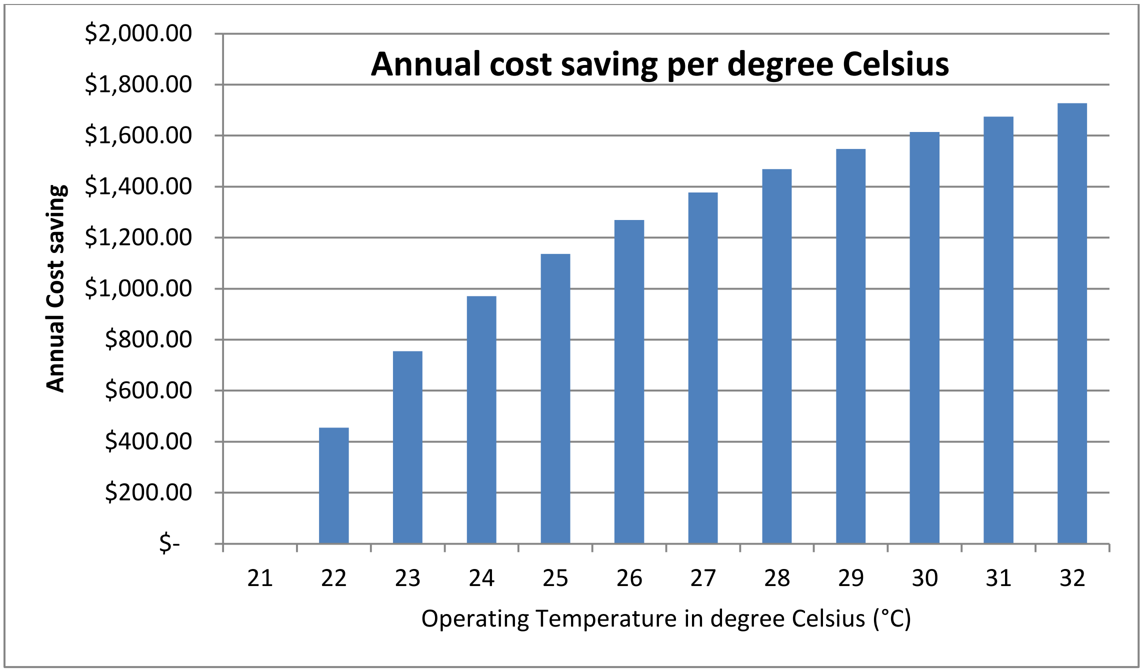

Figure 11: Annual cost saving per degree Celsius

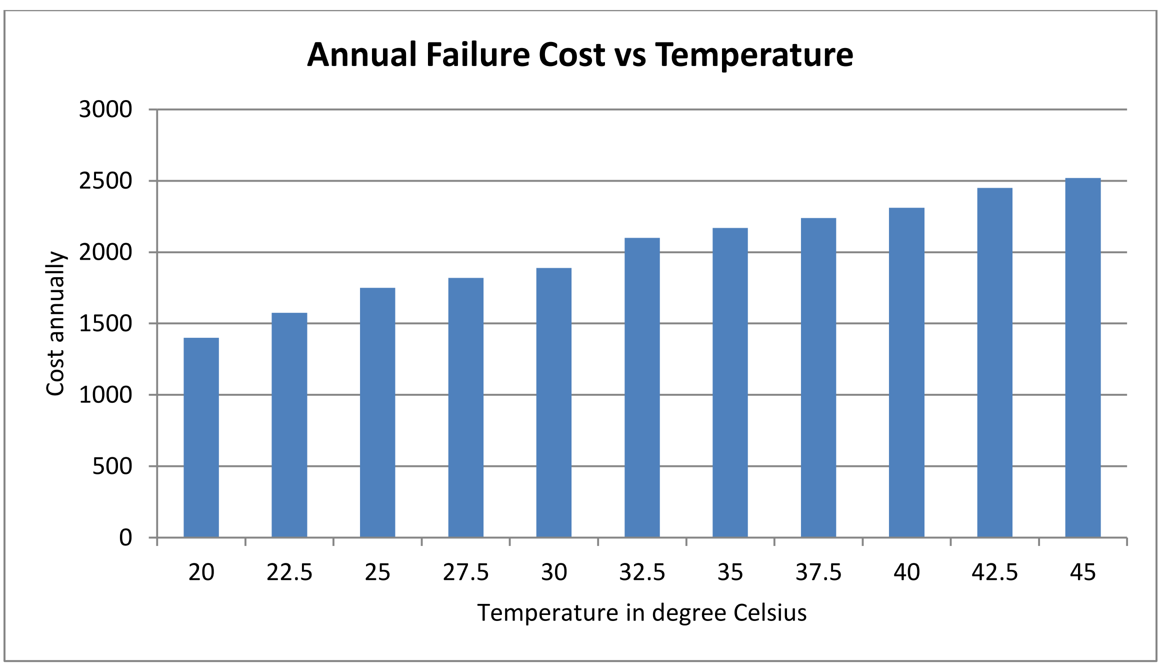

Figure 12: Annual Failure Cost per degree Celsius, Yu Chen

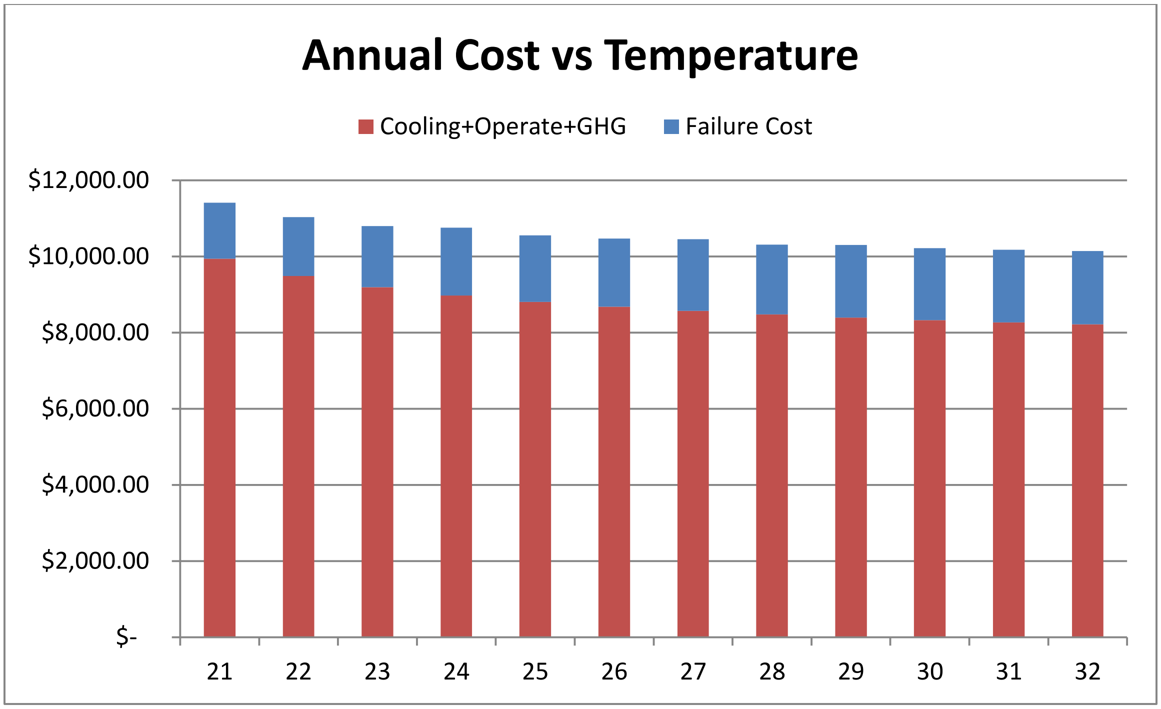

Figure 13: Annual Cost per degree Celsius

4.3 Suggestions for future development

We have a better understanding of fundamental server room operations after meeting with Chris Dumont. There are a few design flaws with some of the old server rooms mentioned previously in this report. This research is to benefit UBC and possibly reduce GHG footprint in the future, so setting the server room to a more environmentally friendly operating temperature is crucial. The primary reason that most of the server rooms at ECE are set to operate at 21 degree Celsius is because UPS needs a low operating temperature to maintain the warranty. This can be resolved by isolating UPS from servers, and only cool the UPS to a low temperature rather than cooling the entire server room at a low temperature. In addition, UPS do not generate a lot of heat; if USP are well isolated, minimum cooling is needed to maintain a low operating temperature.

Likewise, if future server rooms are equipped with a higher cooling capacity as well as power output limit, additional servers can be added without occupying extra rooms and cooling units. In the ICICS server room, although the racks are not filled with servers, the chiller has reached its maximum cooling capacity and thus two servers are placed into two smaller rooms. This method of adding servers is inefficient and occupies extra space.

The layout of the server room is also important because it increases the efficiency of ventilation; thus the hot aisle, cool aisle configuration should be implemented to all future server rooms.

I recommend operating at a higher temperature to conserve energy, especially in the summer, because the energy consumption in July at 21 degree Celsius is twice as much as operating at 23 degree Celsius. This is because the chiller intake temperature is closer to the operating temperature in the summer and thus the mass rate must increase to maintain a low operating temperature. This can be justified in equation 2.0. If the energy dissipation (Q) is fixed, then as the change in temperature decreases (ΔT), mass rate (M) increases.

To further improve the accuracy of this research I suggest installing measurement equipment in future server rooms. If the power intakes of the cooling system and server are recorded along with the operating temperatures and chiller intake temperatures, the accuracy of this research can be greatly improved and thus a more conclusive operating temperature can be justified.

5.0 CONCLUSION

This report investigated the feasibility of reducing energy consumption by raising the operational temperature in server rooms while maintaining a healthy environment for the equipment. Server rooms were often over-cooled because IT manager were reluctant to allow high operating temperature because of concerns about equipment dependability and the high maintenance costs for replacing equipment failures.

This report suggests raising the operating temperature at the Fred Kaiser 3035 server room because of the following reasons:

- The cost benefit of reducing the cooling energy consumption is greater than the failure rate cost
- GHG footprint can be reduced significantly in the summer
- Marginal cooling energy cost saving is high compared to the marginal failure cost
- Servers in the Fred Kaiser building are relatively newer and are more resilient to higher operating temperature
- Reducing electricity consumption can delay the implementation of new transmission infrastructure

The accuracy of this report can be improved by future researchers if measuring equipment are installed to record the temperatures and energy consumptions in server rooms. Appropriate assumptions have been made to minimize the lack of energy and temperature information.

6.0 REFERENCES

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[2] Chris Dumont, Manager, Technical & Physical Resources

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