Queen’s University TEAM Program, Final Report:
Meeting the Demand for Air Conditioning

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EXECUTIVE SUMMARY

Queen's University faces the dual challenge of a shortage of air conditioning on campus, coupled with already prohibitively high air conditioning related electrical costs. Queen's University's Physical Plant Services is responsible for finding solutions to these complementary challenges. This report was consigned, and is intended, to help enable them to accomplish this goal.

Upon cursory inspection, these complementary challenges, to provide more air conditioning while simultaneously reducing the related electrical costs, would appear to be at odds with each other. However, upon further investigation, it is evident that there is a very strong connection between them, and that they are both symptoms of the same underlying problem. That problem is the disconnect between the capital and operational budgets at Queen's.

Under the current system, the departments and faculties at Queen's are responsible for the allocation of their own capital budgets, while the University is responsible for the operational costs of maintaining the campus. This means that the departments and faculties are responsible for any initial capital outlay involved in financing an air conditioning solution, and that the University is then responsible for the ongoing electrical expenses. When considering an air conditioning solution and the costs involved, there is a trade-off between the initial and ongoing costs. As shown in this report through a case study analysis of air conditioning in Etherington Hall, the life-cycle costs for larger units are lower than for small units.

It is the assertion of this report that this situation provides economic incentives that directly result in the aforementioned air conditioning problem at Queen's. Departments and faculties, in the interest of minimizing costs, will attempt to meet their air conditioning needs by use of the least capital-intensive option available. As explained, this results in the purchase and installation of inefficient air conditioners, with the University carrying the burden of the high electrical costs.

Ultimately, the goal of this report is to illustrate through the use of economic analysis, research, and reporting that the air conditioning problems faced by Queen's PPS are in fact a systematic response to a larger root problem: the disaggregated capital and operations budgets at Queen's.

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1. Introduction

In today's modern world, ubiquitous air conditioning is becoming the norm. More and more, people expect all indoor environments to be climate-controlled 12 months of the year. Today, no longer considered a luxury, air conditioning in the work environment is considered a requirement. This puts tremendous pressure on employers to ensure that the air conditioning needs of their employees are met. However, this task is made difficult because of the high costs associated with air conditioning. Initial costs, (hardware and installation) and ongoing costs, (maintenance and electricity) can be prohibitively expensive. Another obstacle to providing ubiquitous air conditioning is that this requires not only that all new buildings and facilities be equipped with air conditioning, but also that older buildings and facilities be renovated or retrofitted in order to provide adequate cooling. However, regardless of the costs involved, it is clear that the trend is towards ubiquitous air conditioning. The challenge then is how to provide it in the most cost effective manner.

1.1 Problem

In the case of Queen's University, there is unmet demand for air conditioning on campus. Some employees of the University who work in environments without air conditioning have argued that summer time conditions are oppressive and are not suitable for working in. This puts tremendous pressure on the University, and Queen's Physical Plant Services (PPS) in particular, to provide air conditioning in all areas of campus. At the same time, there is pressure on PPS to reduce the very high electrical costs associated with the air conditioning already in place on Queen's campus This puts PPS in a difficult position, asked both to provide air conditioning to more people, and to reduce the marginal cost of air conditioning related electrical consumption.

The challenge is two-fold:

1. There is an increasing and as yet unmet demand for air conditioning at Queen's University that must be satisfied.
2. The air conditioning related electrical costs to the University are prohibitively high and must be reduced. (Note that reducing the electrical costs will most likely involve a decrease in the marginal cost, and not in the absolute cost.)

1.2 Current Situation

In general, all recent and future buildings constructed on the Queen's campus are, and will be, fully and centrally air-conditioned. The challenge lies with the many older buildings that were not designed with air conditioning in mind. For these buildings, and the rooms, offices, and laboratories inside of them, the decision to provide air conditioning is governed in an ad hoc manner by the Queen's University Air Conditioning Policy, which dates from 1978 and is included as Appendix D. This policy states that 'the University does not permit the air conditioning of University office or laboratory space unless special circumstance dictate otherwise.' There are three of these special circumstances, two of which deal with laboratory spaces, and one of which deals with office spaces. For laboratories, it must be shown that either equipment or environmental conditions necessary for experimentation require air conditioning. The interpretation of the circumstances needed to air condition an office space is less straightforward: there must be 'unusually oppressive working conditions where other solutions are either not possible or not practical.' Requests for air conditioning must be examined by PPS and then approved by the Vice-Principle (Operations & Finance) who will be working on the recommendation of PPS.

In the case of a large requirement for air conditioning (whether one single large requirement, or several requirements in the same physical location), PPS might at their discretion plan the installation of a larger and somewhat central air conditioning unit, depending on the exact nature of the location and requirement. However, for the most part, these individual demands for air conditioning are met with the installation of one or more individual window type air conditioning units. There are several drawbacks to this: small, window sized units are less efficient than larger units in terms of electrical consumption, window units cover up window space, and they are an eye soar on campus. There are also several advantages: window units are cheap and easy to purchase and install, and they immediately address a need for air conditioning.

The result of this policy is, for the most part, unsurprising; most if not all laboratory spaces on campus that require air conditioning have it, while many office spaces do not. In terms of meeting the demand for air conditioning, this simply means providing air conditioning for those offices that do not yet have it. However, in terms of reducing or controlling air conditioning related electrical consumption, the answer is less clear.

1.3 Objectives & Approach

In this section, the team's approach to helping Queen's PPS to address their two-fold problem with air conditioning will be explained. Included is a discussion of the evolution of the aims and objectives of this project. While this progression and evolution do not have any direct impact or bearing upon the conclusions of this report, it is important to show that these conclusions were reached independently, and that the project direction and conclusions were not unduly directed or biased by Queen's PPS, or any other party.

1.3.1 Objectives

Ultimately, there were two objectives for this project:

1 - to find the underlying and most significant root cause of the challenges now facing PPS.

2 - to highlight the cause with this report.

1.3.2 Approach

As will be explained in section 1.3.3, objective one was not initially part of the plan. It was only determined that this should be an objective after it became apparent both that there was a particular and significant root cause to the problems at hand, and what that root cause was. As such, there was no specific approach taken to meet this objective, though the cause was explored and defined in detail.

In order to meet the second of these objectives, a case study was written examining the differences in associated costs between two alternatives to providing a building with air conditioning: one, a large scale air conditioning solution including a single building sized unit, and two, air conditioning the same building using window sized units. An analysis of the case study highlighting its conclusions followed.

As well, a detailed analysis and discussion of the most significant root cause to the problem was performed. The way that new air conditioning projects are funded was found to be counterproductive to minimizing electrical costs. The departments buy new equipment and therefore they do not minimize the total cost of the air conditioning, (including electricity), only the equipment cost in minimized.

1.3.3 Evolution of Objectives & Approach

Those who are interested only in the conclusions of this report will find that this section has no direct bearing upon them and may be omitted. This section is intended to highlight the fact that the direction of this project has at all times been under the control of the students performing the analysis, and that at no point did Queen's PPS or any other person or group influence or bias the project. The team feels that it is important to highlight and expand upon this point in order to provide evidence of the impartial and independent nature of this project, and of its conclusions.

Please note that the definition of the problem facing Queen's PPS was never in question. Rather, the manner in which the team could best help PPS to address it. Throughout the early stages of this project the objectives and the approach of the team changed considerably.

1.3.3.1 Initial

Upon first encountering the problem at hand, the approach was to deal directly with the problems at hand by examining and evaluating air conditioning solutions that would directly address the University's needs. That is, solutions that would provide more air conditioning on campus, and would be efficient in terms of electrical consumption. In other words, to explore and recommend alternative solutions to the ad hoc window unit approach that was currently in place. A few examples of specific solutions that were to be explored include the use of tinted window glazing and window awnings, the use of cool air flow (as opposed to actually cooling the air), as well as things such as a more coordinated approach to summertime room booking in order to reduce the amount of air conditioning used, or the possibility of an educational campaign to reduce air conditioning usage on campus.

These options were to be examined for their effectiveness and costs, with the most efficient options to be recommended for implementation. The goal of this approach was to help the University bridge the gap between the situation today (lack of air conditioning, and use of inefficient air conditioning units) and a fully centralized campus-wide air conditioning solution, assumed to be implemented in 10-20 years time. Please note that this assumption was vetted by PPS and was based upon an independent consultants report (Campus Cooling Economic Evaluation, prepared by H.H. Angus & Associates Ltd.), which is a recommendation and plan for a fully centralized solution to air conditioning at Queen's (a summary of Campus Cooling Economic Evaluation is included as Appendix C.)

1.3.3.2 First revision

As the current situation at Queen's was explored, it became increasingly evident that there was an underlying problem that was contributing to the challenges being faced by Queen's PPS, and that providing alternative solutions to meeting the demand for air conditioning would serve to deal only with the symptoms of the problem, and not with the root cause. As such, the project was revised by limiting the scope of the exploration of said alternative solutions, and to include a discussion of the underlying cause of the situation.

1.3.3.3 Final revision

Finally, although the team felt that the University would benefit from a better understanding of the alternatives to installing air conditioners on campus, it became clear that efforts would best be served by focusing solely on illustrating the underlying root cause of the problem. The efforts to explore alternative solutions were abandoned, and the objectives and approach revised to be inline with this decision.

A case study analyzing the costs of alternative air conditioning strategies for Etherington Hall would be carried out, along with an exploration and discussion of the causes of the problems faced by PPS.

2. Case Study – Etherington Hall

2.1 Background & Current Situation

2.1.1 Building History and Background

Etherington Hall is located on Stuart Street at Queen's University in Kingston. Built in 1959, and named for Dr. Frederick Etherington, Dean of the Queen's Faculty of Medicine from 1929-1943, Etherington Hall is home to the Departments of Medicine, and the Medical Art and Photography Service. The building is connected to Richardson Lab and Kingston General Hospital on the east side. The hospital and some of its related buildings surround Etherington Hall on the east, south and west sides. To the north of the building is for the most part open space comprising of tennis courts and a rugby field.

As shown below in Figure 1, Etherington Hall is a long and narrow building that runs North-South. The building is comprised of four levels, not including a small basement section and penthouse mechanical room.

Figure 1: North-west view of Etherington Hall.

The main feature at the north end of the building is a large lecture theatre that encompasses two levels. Above the lecture theatre on the upper two floors are general offices. The south wing of the building is comprised of four levels, primarily office and laboratory space.

Etherington Hall was selected for this case study for two reasons. 1) The building currently has approximately 65 window unit air conditioners. No other building on campus has nearly this amount of window units. 2) There are currently no long term plans for air conditioning this building. The 2001 report, *Campus Cooling Economic Evaluation*, prepared by H.H. Angus & Associates Ltd., did not include Etherington Hall in its plans. The building, along with Richardson Lab, was said to be too isolated from other campus buildings to justify linking them to another precinct or district cooling system. The short term plan appears to be to continue replacing and installing window units to meet the needs of the building.

2.1.2 Current Cooling Situation

As mentioned previously, Etherington Hall is being cooled by approximately 65 window unit air conditioners. The aforementioned consultants report from 2001 reports 59 units at the time of their study; it is therefore evident that the number is growing. A larger unit with an approximate capacity of 2 tons is also located within the building and was installed to cool some areas that did not have exterior windows. However, since the time of installation, the ductwork has been altered to supply more offices (with exterior windows) from the same unit.

Cooling statistics provided by PPS indicate that in 2002, 10,010 ft^2 of the total 44,681 ft^2 in Etherington Hall were cooled. This represents 22.4% of the total building area. If we assume that each window unit in the building has a capacity of 0.75 tons of cooling, the total cooling capacity supplied to the building is about 50 tons. Using 50 tons to cool 10,010 ft^2 of building area means each ton cools only 200 ft^2. This number is only half of the 400 ft^2/ton that PPS uses and suggested as a figure to determine the cooling load of the building. Clearly, the 65 window units provide an excess amount of cooling for the areas where they are located.

Each air conditioning window unit has an average working life span of 7 years. The units are relatively cheap with an installed cost of roughly $850. Very few, if any, units are maintained, and as such, the maintenance costs are negligible. Units that do require repairs are either covered under warranty, or simply replaced with a new unit.

The major drawback to window units is their poor efficiencies. The efficiency of each window unit was assumed to be 1.5 kW/ton. We feel this is an optimistic estimate considering the lack of maintenance performed on the units. The general wear and tear that results from the fact that they are often left outside to face the elements throughout the winter months would further reduce the efficiency.

Other intangibles such as the aesthetics of the building are certainly compromised by the window units. The water damage caused by the dripping units are clearly visible around the building, however this cost has not been included in the economic evaluation. Figure 2 below shows three window units that are easily seen from the sidewalk on Stuart Street.

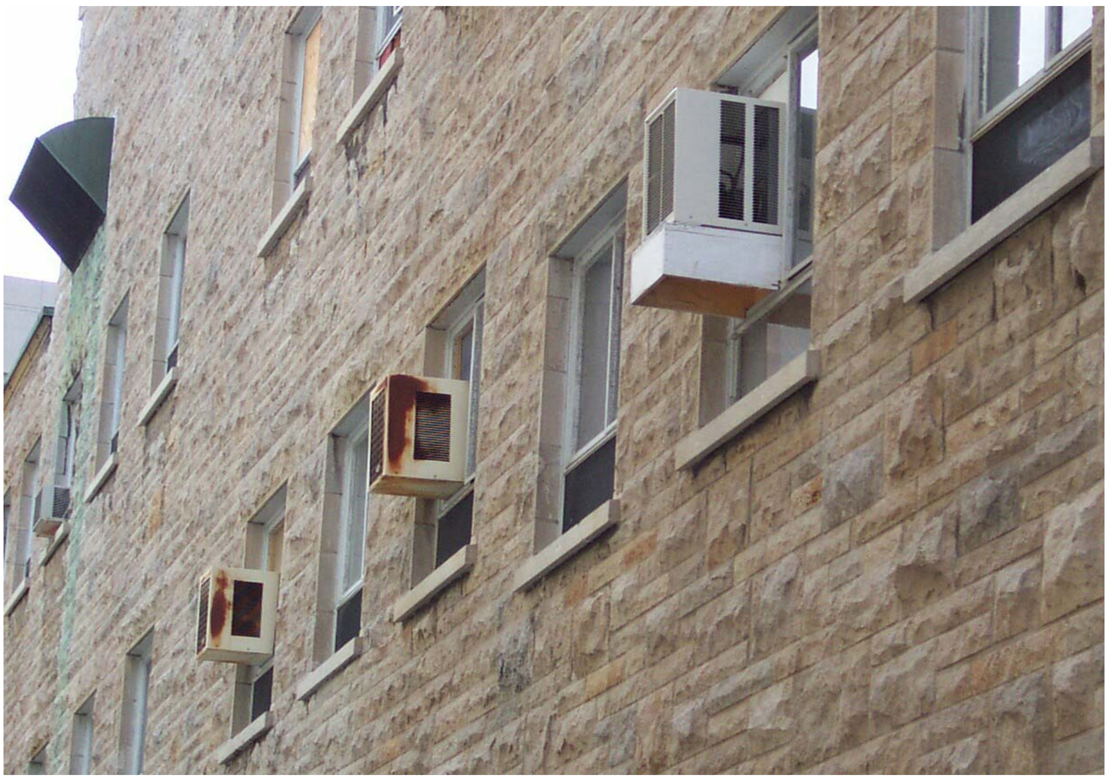


Figure 2: East side of Etherington Hall from Stuart Street.

2.2 Case Study Approach and Factors Explained

2.2.1 Proposed Building Unit Cooling Schemes

Three building unit cooling schemes will be proposed and compared to the current cooling scheme based on their life cycle costs. The three building unit schemes are:

A) Cooling an equal area to what is being cooled presently by window units (22.4%).
B) Cooling so that the life cycle costs of the two systems are equal.
C) Cooling 75% of the building by area.

Not all of these schemes are a practical way to cool Etherington Hall, but they are useful cases for showing the underlying trends between the costs associated with window and building unit cooling systems.

2.2.2 Building Unit Factors

The life span of a building sized cooling unit is typically 20 years. There are units at Queen's University that are older than this, but it is usually after 20 years when costly repair, upgrading and maintenance need to be done. The annual maintenance cost of the larger units is loosely related to size, and is a difficult figure to determine. In our calculations a value of $15 per ton annually was chosen. Efficiencies of these building units are typically around 1.0 kW/ton.

The figure used for equipment and installation costs is $2000 per ton. This number includes the cost of the equipment, infrastructure, labour and engineering involved to complete the project. However, in the cases where only a small portion of the building is to be cooled, only the equipment cost is reduced. The infrastructure, labour and engineering costs would remain about the same. As a result, the figure is raised to $3000 per ton for the case where only 22.4% of the building is cooled. In all cases, a contingency factor of 10% was added to the total capital cost of the project.

2.2.3 Life Cycle Costs

The life cycle costs are based on the service life of a building sized unit, which is 20 years. The electricity costs used are $0.10 per kWh with an increase of 3% a year (figures supplied by PPS). The demand for electricity to power the cooling system is 800 hours per year. For the building units, the cooling load of 400 ft^2 per ton suggested by PPS was used.

The capital cost for the building unit was calculated and entered in the first year of the life cycle. All other years showed no cost for capital equipment. On the other hand, the equipment cost of the window units were evenly spread over the 20 year span. Finally, the net present value of the total life cycle cost was calculated using a real interest rate (nominal interest less inflation) of 5%.

Using these sets of conditions represents what was determined to be the most likely scenario. Sensitivity analysis will also be performed on these variables.

2.3 Cases

2.3.1 Case A

The first scenario involves using a building unit to cool the same area that is currently being cooled by the window units. For this special case the equipment cost of the building unit was increased to $3000 per ton to account for the infrastructure and engineering costs that are independent of chiller size.

The net present value of the life cycle cost for the window units is $160,000, while the building unit amounted to $121,000. In this situation, only 22.4% of the building is being cooled.

2.3.2 Case B

The second scenario sets the cost of the two systems equal to one another. Again, the equipment cost of the building unit was increased to $2500 per ton. The net present value of both the building and window unit systems were set at $160,000. Under the current window unit system, this cools 22.4% of the building area. However, this amount of money will cool approximately 33% of the building area using a 37 ton building unit. Nearly 50% more cooling by area is achieved at the same cost when switching over to a centralized building unit.

2.3.3 Case C

The final scenario is a more realistic plan that could be implemented. In this case, 75% of the building area is to be cooled. This figure is based on cooling the entire building minus the hallways, stairwells, mechanical room and half basement.

The net present value life cycle cost for a central building unit in this case amounts to $313,000. It would incorporate an 84 ton chilling system. Cooling this much of the building by window units would take extraordinary measures. A very crude estimate purely for comparative purposes would be to say $160,000 cools 22.4%, so $536,000 would cool 75%.

Factors	**Window Unit**	**Building Unit**
Life Span (years)	7	20
Equipment Efficiency (kW/ton)	1.5	1.0
Annual Maintenance Cost ($/ton)	0	15
Installed Equipment Cost ($/ton)	850	2000 – 3000
Number of Units	65	1

Table 1: Constant Equipment Factors

Cooling Load (ft^2 / ton)	400
Cost of Electricity ($/kWh)	0.10
Yearly Electricity Increase	3%
Electricity Demand (h/year)	800
Real Interest Rate	5%

Table 2: Variable Factors

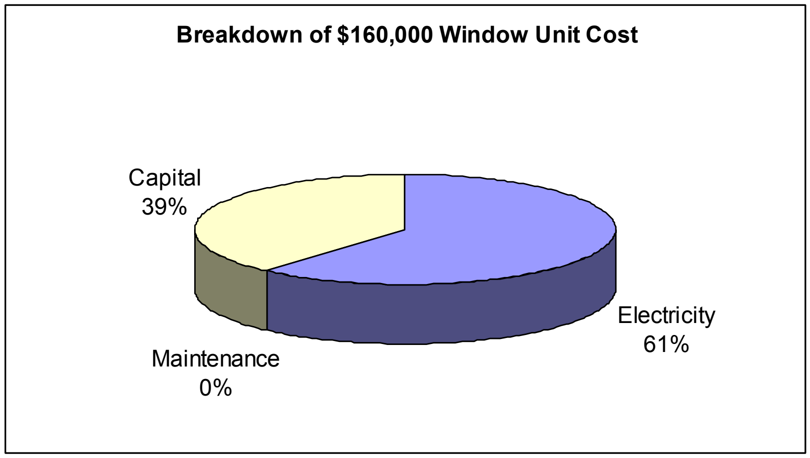
System	Case	A	B	C
Window Units	Percentage Cooled	22.4%	22.4%	75%
	Cooling Supply (tons)	49	49	164
	Life Cycle Cost	$160,000	$160,000	$536,000
Building Unit	Percentage Cooled	22.4%	33%	75%
	Cooling Supply (tons)	25	37	84
	Life Cycle Cost	$121,000	$160,000	$313,000

Table 3: Summary of the Three Cases

2.4 Sensitivity Analysis

Some of the figures used in the calculations of the three cases are not precisely accurate, but were used as a best estimate given the information available. In the following analysis, the building and window unit costs from Case B (equal life cycle costs) are compared. Variables are changed one at a time to determine how much of an effect they may have.

Figure 3 below shows the breakdown of expenses for the case of equal life cycle cost for both systems. Essentially the costs are reversed in the two cases. The window unit system has high electricity costs and low equipment cost, while the building unit shows the opposite trend. The cost of air conditioning equipment has not changed very much in the past 15 years, while the cost of electricity has fluctuated dramatically, and given the uncertain regulatory framework, is still unstable. It can be clearly seen from these graphs that the window unit system is more affected by fluctuating electricity costs.



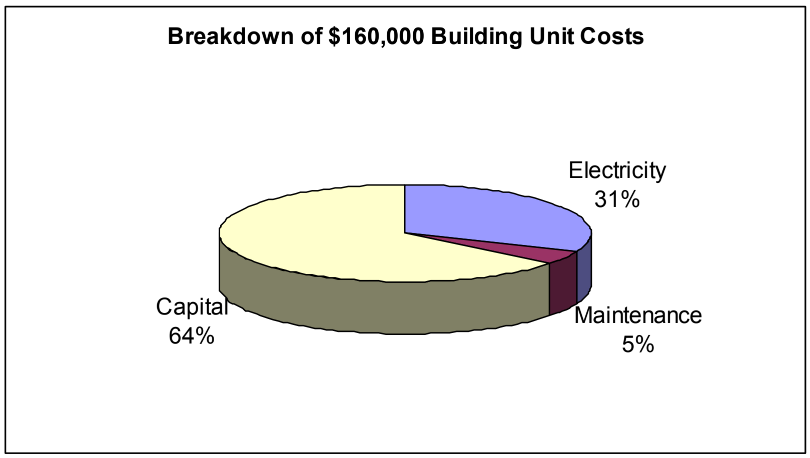


Figure 3: Breakdown of the Life Cycle Costs for Case B.

2.4.1 Rate of Increase of Electricity Costs

The cost of electricity was assumed to be increasing at the rate of 3% per year. If this rate is altered by 2% in either direction the following results are obtained:

Annual Increase	Window Unit Cost	Change	Building Unit Cost	Change
1%	$145,000	-9.4%	$152,000	-5.0%
3%	$160,000	--	$160,000	--
5%	$179,000	11.9%	$170,000	6.3%

Table 4: Effects of Annual Electricity Increase

As expected, the costs of the window units fluctuate more by changes in the annual increase in electricity prices.

2.4.2 Demand for Electricity

Another variable that relates directly to electricity is the demand. It was originally assumed that the demand for cooling was equivalent to 800 hours of full operation per year. This was based on the fact that Stauffer Library at Queen's University runs at 900 hours per year. The operating hours of Etherington Hall are not as long as those of the library; consequently, it was estimated that the demand would be approximately 800 hours per year. The true value is expected to lie within 100 hours of this estimate. Also, note that PPS is able to control the amount of electrical demand with a central building unit, but cannot do so with individual window units as they have no direct control of the hours of operation. For this reason it is believed that the electrical demand would be greater for window units, but by how much is difficult to determine. In our calculations, the electrical demand is assumed to be the same for both window and building units.

Electrical Demand	Window Unit Cost	Change	Building Unit Cost	Change
700 hours	$148,000	-7.5%	$154,000	-3.8%
800 hours	$160,000	--	$160,000	--
900 hours	$172,000	7.5%	$166,000	3.8%

Table 5: Effects of Electricity Demand

Again, the window unit costs are affected more by changes in electricity. This time the electricity changes stems from a change in electricity demand.

2.4.3 Real Interest Rate

The real interest rate used to calculate the net present value is also not precisely known. The estimate is 5%, but altering it by a percentage point results in the following:

Real Interest Rate	Window Unit Cost	Change	Building Unit Cost	Change
4%	$174,000	8.8%	$165,000	3.1%
5%	$160,000	--	$160,000	--
6%	$148,000	-7.5%	$156,000	-2.5%

Table 6: Effects of Real Interest Rate

The real interest rate also affects the window unit costs more than the building unit costs. This is because of the large initial expenditure for the building unit. The cost of the system is front loaded instead of being spread out fairly evenly as is the case with the window units.

2.4.4 Cooling Load

The cooling load in terms of square feet per ton only significantly impacts the analysis of the building sized units. In designing a central building system, Physical Plant Services aims at a target of 400 ft^2/ton. The following summarizes the change in cost of Etherington Hall cooled at 75%, for different cooling loads.

Cooling Load (ft^2/ton)	**Chiller Size (tons)**	**Building Unit Cost**	**Change**
300	112	$417,000	33%
400	84	$313,000	--
500	67	$250,000	-20%

Table 7: Effects of Cooling Load

These results make perfect sense as decreasing the area cooled by a ton increases the chiller size needed, and in turn increases the cost of the system.

2.4.5 Financing of Initial Capital Costs

The final analysis looks at the costs if the initial capital cost of the building unit was financed. It was assumed that a loan was received, payable over the 20 year life cycle at an interest rate of 7%. The following table compares this financed scenario to the original three cases discussed.

System	Case	A	B	C
Window Units	Percentage Cooled	22.4%	22.4%	75%
	Cooling Supply (tons)	49	49	164
	Life Cycle Cost	$160,000	$160,000	$536,000
Building Unit	Percentage Cooled	22.4%	33%	75%
	Cooling Supply (tons)	25	37	84
	Life Cycle Cost	$121,000	$160,000	$313,000
Financed Building Unit	Percentage Cooled	22.4%	30%	75%
	Cooling Supply (tons)	25	34	84
	Life Cycle Cost	$139,000	$160,000	$353,000

Table 8: Financed Building Unit

Financing increases the cost of the building unit in cases A and C by 15% and 11%, respectively. In case B, the area cooled for $160,000 decreases from 33% to 30%. In general terms, financing decreases the economic benefits of the building units because now interest must be included as an added expense.

2.4.6 Remarks

As mentioned previously, the figures used in the original calculation are the best guesses based on the information available. We hope that the preceding analysis has given some insight into what factors may affect the life cycle costs and by what magnitude.

2.5 Summary

Cleary, the current ad hoc process of installing window units into Etherington Hall is highly inefficient. Not economically significant, but also important, is the poor aesthetics that this causes to an historic and beautiful campus.

2.5.1 Lessons Learned

The case study of Etherington Hall was intended to bring to light the problems in one building. In the three simple cases analyzed, direct and obvious lessons are learned.

2.5.1.1 Case A

Case A shows that even when cooling less than a quarter of your building with window units it is still economically more efficient to use a central building unit. The large initial outlay of capital required for infrastructure changes are easily offset by the ongoing electricity costs.

2.5.1.2 Case B

Case B shows that for the same cost, the area cooled by a building unit is nearly 50% greater than that cooled by window units.

2.5.1.3 Case C

Case C shows that cooling the majority of a building is only economically feasible when installing large building units. The costs of cooling an entire building are high, so there must be sufficient demand to warrant such an expenditure.

2.6 Conclusion

As expected, increasing electrical costs further reduces the economic justification behind window units. As the theory of global warming predicts, the summers will only get hotter and increase the demand for air conditioning and the electricity needed to supply it.

It is plain to see that this is not a simple problem of economics. If that were the case, a cheaper central unit would have replaced the window units in Etherington Hall long ago. The economics clearly and definitively support the use of centralized air conditioning units.

3. Discussion of Financial Allocations

As can be seen in the case study conducted on Etherington Hall, it is clearly less expensive over the life cycle of air conditioners to use larger units. It is therefore worth asking why these less expensive units have not been used in the past. The answer can be found in the way that Queen's has paid for these projects. In order to minimize the costs of air conditioning at Queen's, we need to examine how expenses are covered.

The costs associated with air conditioning can be split between capital or equipment costs, and electrical and operating expenses. Individual departments and faculties within the university only pay for equipment cost. If a department decides to make air-conditioning a priority, it must find the funds needed to buy the equipment. Funds can be raised from outside sources or funds can be taken from the department's operating budget. Once the equipment is in place, the electricity is paid for from the university's general operating funds. This way of splitting the costs associated with air conditioning leads to the purchasing of less efficient and ultimately more expensive units.

Since the departments of the university are not responsible for paying for the electricity that is used by the air conditioners, it is not usually a consideration when purchasing equipment. This lack of responsibility for the long-term costs leads departments to purchase the best available window unit that fits within their budget. By minimizing the costs of equipment, departments pay less for air conditioning, but end up costing Queen's University more in the long run.

Those responsible for operations at Queen's take a more long-term view since they do see the electricity costs associated with cooling. The departments, when purchasing equipment for air conditioning, do not necessarily consider electric costs in their decision since they are not responsible for paying for it. In the long term, the disjoint between PPS and each department increases the expenses of air conditioning for the university.

The problem rests primarily in the fact that the departments have no incentive to try to reduce electric costs. In fact, the reverse is true; there are disincentives in place. Since the equipment cost of more efficient units is generally higher, this actually represents a disincentive for departments to buy more energy efficient units. It is therefore apparent that some incentives for the departments to buy more efficient units must be put in place.

Assuming that Queen's intends to cool all of campus, as seems to be the general consensus among the administration, a more centralized long-term view is needed in order to do so in the most cost effective way possible. A centralized approach would consider the university as a whole. Planning would be made with a view towards achieving cooling of the whole campus rather than individual departments. Under a centralized approach, a central authority would make decisions regarding the purchasing of new cooling equipment and the implementation of complete cooling on campus. The costs associated with air conditioning for the university as a whole must be considered.

Some examples of a more centralized approach in cooling already exist. A new chiller is to be placed in Gordon Annex during the renovations of that building. This new chiller will not only cool Gordon hall and Gordon Annex, but also Douglas library as well as Richardson Hall. Another example of a more centralized approach can be found in Watson Hall. The chiller in Watson Hall also cools Jeffery Hall.

Efforts to better utilize existing equipment are also occurring. Humphrey Hall will soon be cooled using excess capacity available from chillers in the Biosciences Complex. Similarly, the new business building, Goodes Hall, is cooled with chillers in Stauffer library. Chillers used to full capacity are more efficient than partially used chillers. Thus, these efforts to use existing equipment to its full capacity show a concern for the efficiency.

As encouraging as these examples of a centralized approach for the entire university are, it is more informative to look at examples of the opposite. Unfortunately, such examples are easily found. Etherington Hall, the building featured in this report, is an example of absolutely no centralized approach at all. The effects of this lack of vision in terms of the overall cost are clearly outlined in the case study.

A similar example of ad-hoc air conditioning can be found in MacDonald Hall. Recent renovations have added a new entrance and stairway to the front of the building. A new air conditioning unit was used to cool this. In addition, the building has separate units to cool various parts of the building including classrooms and a computer lab. There does not appear to be any central approach to air conditioning in this building.

The Integrated Learning Centre (ILC) can be seen as an example of good intentions mixed with poor application. This new building is adjacent to

Dupuis Hall, Goodwin Hall, and Walter Light Hall. As with all new buildings, the ILC was originally planed to have a chiller with capacity to air condition the entire building. It was suggested that a larger unit be put in the ILC that could serve to cool the adjacent buildings. However, the money to pay for this larger unit would have come from the budget for building the ILC. The extra money was not available, and so only a slightly larger unit was bought. Although the example of the ILC moves in the right direction, (a larger unit was bought), it does not go as far as it should. Despite the larger unit, there is enough demand for cooling in the adjacent buildings for a unit twice the size.

All of these examples show that while there is a trend at Queen's towards a more centralized approach to meeting cooling needs, a great deal more should be done. An important step in achieving a more centralized plan is putting in place incentives for departments and faculties within the university to be more energy efficient. One possible incentive could be to reward departments that decrease their electricity consumption, or alternately, to penalize departments that increase their consumption. Another possibility is to put in place cost sharing mechanisms whereby the departments share the costs of the electricity and in return receive assistance in the purchasing of equipment. Or, it may be feasible to simply subsidize the purchasing of efficient units in order to favour them in the selection process. Once these incentives are in place, the departments may be willing to take a more centralized approach that could reduce the overall cost to the university.

4. Ergonomics

In response to a specific request by PPS, a brief study into the optimal temperature at which to operate central air conditioning systems was done, with the comfort of office workers the primary consideration. This study is by no means comprehensive and is intended only to present the general consensus available in literature as to the conditions necessary for a comfortable work environment.

If considering only the occupational health and safety act, there is no maximum temperature for a workplace. The act is concerned with minimum temperatures that must be maintained and does not address issues of comfort arising during the summer months. Therefore, the operating temperature for air conditioners is chosen on the basis of worker productivity and comfort, and not on strict reliance or restrictions set out in law.

The two factors considered are air temperature and relative humidity. Air temperature is self-explanatory. Relative humidity has an impact on the comfort of people. At high relative humidity people will feel hotter and will be less productive. Too low a relative humidity, a concern in air-conditioned buildings, can result in dryness in the nose and throat, as well as dry skin, chapped lips, and eye irritation.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) established a recommended comfort zone. This zone is between 73°F and 77°F (22.75°C – 25.0°C) and between 20% and 60% relative humidity. This standard provides a general guideline for suitable operating conditions.

Acclimatisation, habits, and established conventions can also affect people's comfort temperatures. This explains why preferred room temperature is higher in the summer than in the winter, and higher in the United States than in Canada. (Sanders and McCormick, 1993) Because of this, it is recommended that PPS use the cooler area of the ranges presented as their target operating range. For instance, a suitable set point may be 74°F and 40% humidity. It is recommended that PPS try various settings to determine what temperature is needed. Ultimately, PPS's own experience with operations may be more informative than any data available from a reference book.

5. Conclusions and Recommendations

The future plans of cooling the campus of Queen's University by means of large building units, precinct units or district systems will not proceed until the method of allocating funds for this specific project are revisited and revised. There exists no incentive for a department to invest money in a larger, more efficient unit. The capital and operating costs of the systems are currently split, and tying them together is the only way to initiate any plans for a more efficient, centralized air conditioning system.

The results found from the case study of Etherington Hall are not surprising. Even with less than a quarter of the building being cooled, it is economically favourable to install a centralized system. When cooling an entire building, a centralized building unit becomes increasingly obvious as the most economically sound choice. However, the question that must be answered is if there is sufficient demand to warrant the costs of cooling the entire building.

Currently, the capital cost of new cooling equipment is paid for by the department involved. Once equipment is in place, the electricity bill is covered by the university's operating budget. This means that departments have little or no incentive to purchase larger, more efficient units. Since departments do not see the electricity costs, they have no incentive to pay the higher initial capital expense. As a result, efficiency is sacrificed, and no long-term plan can proceed. It is recommended that Queen's review its policies so as to put in place incentives and mechanisms to focus decision-making on the complete life cycle costs.

A study of literature revealed accepted ranges of operating conditions for air conditioning during the summer. This range is between 73°F and 77°F (22.75°C – 25.0°C) and between 20% and 60% relative humidity. Other factors such as acclimatisation and habits can affect people's comfort temperature. Due to this, it is recommended that Physical Plant Services try various operating conditions to determine what temperature is acceptable to the population of Queen’s University.

The case study revealed that the economics involved in cooling strategies is clear. Larger more efficient units are less expensive overall than smaller window units. Until incentives are put in place such that those purchasing cooling equipment consider the overall cost, rather than just the equipment cost, the university will be made to pay more for air conditioning than is necessary. Queen’s University should review its policies to put incentives in place that encourage the minimization of the total costs of projects for the university as a whole.

References:

American Society of Heating, Refrigeration, and Air-Conditiong Engineers (ASHRAE). *Handbook of Fundamentals*. New York: Publisher, (1981).

FinAid! *The SmartStudent Guide to Financial Aid*. www.finaid.org/calculators/compoundinterest.phtml, (2003).

H.H. Angus & Associates Ltd. *Campus Cooling Economic Evaluation*. (2001).

H.H. Angus & Associates Ltd. *Precinct Cooling Preliminary Evaluation*. (2002).

Sanders, Mark S., and McCormick, Ernest J. *Human Factors in Engineering and Design.* Toronto: McGraw-Hill Inc., (1993).

Appendix A: Spreadsheet Analysis

Case A: Page 1 of 4

Etherington Hall								
Case A:	**Cooling 22.4% of the Building**							
	Built in 1959					**Window Unit Factors**		
	Total Area:	44681	ft^2			Life Span:	7	years
	Cooled Area:	10010	ft^2			Number of Units:	65	units
	Percentage Cooled:	22.4%				Average Cooling per Unit:	0.75	tons/unit
						Equipment Efficiency:	1.5	kW/ton
		Cooling Load				Maintenance Cost:	0	$/ton year
		22%	area cooled			Equipment Cost:	850	$/ton
		400	ft^2/ton					
		25.0	tons			**Building Unit Factors**		
						Life Span:	20	years
	Electricity Factors					Equipment Efficiency:	1.0	kW/ton
	Cost of Electricity:	0.10	$/kWh			Maintenance Cost:	15	$/ton year
	Increase Factor:	1.03				Equipment Cost:	3000	$/ton
	Electricity Demand:	800	h/year					
	Intermediate Calculations					**Conversion Factors**		
	Window Units				12000	Btu/h =	1	ton
		Total Cooling:	48.75	tons	0.2931	W =	1	Btu/h
		Maintenance Cost:	$0	/year	1000	W =	1	kW
		Equipment Efficiency:	0.426	kW/kW				
		Life Cycle Equipment Cost:	$41,438					
		20 Year Equipment Cost:	$118,393					
	Building Unit					Rate for Net Present Value		5.0%
		Total Cooling:	25.0	tons				
		Maintenance Cost:	$375	/year				
		Equipment Efficiency:	0.284	kW/kW				
		20 Year Equipment Cost:	$75,064					
		10% Contingency Factor	$7,506					

Window Units

Case A: Cooling 22.4% of the Building

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Window Unit Cost	Net Present Value Cost
1	$5,850	$0	$5,850	$4,736	$10,586	$10,586
2	$6,026	$0	$6,026	$4,736	$10,761	$10,249
3	$6,206	$0	$6,206	$4,736	$10,942	$9,925
4	$6,392	$0	$6,392	$4,736	$11,128	$9,613
5	$6,584	$0	$6,584	$4,736	$11,320	$9,313
6	$6,782	$0	$6,782	$4,736	$11,517	$9,024
7	$6,985	$0	$6,985	$4,736	$11,721	$8,746
8	$7,195	$0	$7,195	$4,736	$11,930	$8,479
9	$7,411	$0	$7,411	$4,736	$12,146	$8,221
10	$7,633	$0	$7,633	$4,736	$12,369	$7,973
11	$7,862	$0	$7,862	$4,736	$12,598	$7,734
12	$8,098	$0	$8,098	$4,736	$12,833	$7,503
13	$8,341	$0	$8,341	$4,736	$13,076	$7,281
14	$8,591	$0	$8,591	$4,736	$13,327	$7,067
15	$8,849	$0	$8,849	$4,736	$13,584	$6,861
16	$9,114	$0	$9,114	$4,736	$13,850	$6,662
17	$9,388	$0	$9,388	$4,736	$14,123	$6,470
18	$9,669	$0	$9,669	$4,736	$14,405	$6,285
19	$9,959	$0	$9,959	$4,736	$14,695	$6,106
20	$10,258	$0	$10,258	$4,736	$14,994	$5,934

Total 20 Year Life Cycle Cost:	**$251,906**
Cost Per Ton of A/C:	**$5,167**
Total 20 Year Life Cycle Cost (NPV):	**$160,032**
Cost Per Ton of A/C (NPV):	**$3,283**

Building Unit

Case A: Cooling 22.4% of the Building

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Building Unit Cost	Net Present Value Cost
1	$2,002	$375	$2,377	$82,570	$84,948	$84,948
2	$2,062	$375	$2,437	$0	$2,437	$2,321
3	$2,124	$375	$2,499	$0	$2,499	$2,267
4	$2,187	$375	$2,563	$0	$2,563	$2,214
5	$2,253	$375	$2,628	$0	$2,628	$2,162
6	$2,321	$375	$2,696	$0	$2,696	$2,112
7	$2,390	$375	$2,765	$0	$2,765	$2,064
8	$2,462	$375	$2,837	$0	$2,837	$2,016
9	$2,536	$375	$2,911	$0	$2,911	$1,970
10	$2,612	$375	$2,987	$0	$2,987	$1,926
11	$2,690	$375	$3,065	$0	$3,065	$1,882
12	$2,771	$375	$3,146	$0	$3,146	$1,839
13	$2,854	$375	$3,229	$0	$3,229	$1,798
14	$2,940	$375	$3,315	$0	$3,315	$1,758
15	$3,028	$375	$3,403	$0	$3,403	$1,719
16	$3,119	$375	$3,494	$0	$3,494	$1,681
17	$3,212	$375	$3,587	$0	$3,587	$1,643
18	$3,309	$375	$3,684	$0	$3,684	$1,607
19	$3,408	$375	$3,783	$0	$3,783	$1,572
20	$3,510	$375	$3,885	$0	$3,885	$1,538

Total 20 Year Life Cycle Cost:	**$143,864**
Cost Per Ton of A/C:	**$5,750**
Total 20 Year Life Cycle Cost (NPV):	**$121,036**
Cost Per Ton of A/C (NPV):	**$4,837**

Building Unit

Case A: Cooling 22.4% of the Building (Financed)

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Building Unit Cost	Net Present Value Cost
1	$2,002	$375	$2,377	$7,680	$10,057	$10,057
2	$2,062	$375	$2,437	$7,680	$10,117	$9,635
3	$2,124	$375	$2,499	$7,680	$10,179	$9,233
4	$2,187	$375	$2,563	$7,680	$10,243	$8,848
5	$2,253	$375	$2,628	$7,680	$10,308	$8,481
6	$2,321	$375	$2,696	$7,680	$10,376	$8,130
7	$2,390	$375	$2,765	$7,680	$10,445	$7,795
8	$2,462	$375	$2,837	$7,680	$10,517	$7,474
9	$2,536	$375	$2,911	$7,680	$10,591	$7,168
10	$2,612	$375	$2,987	$7,680	$10,667	$6,876
11	$2,690	$375	$3,065	$7,680	$10,745	$6,597
12	$2,771	$375	$3,146	$7,680	$10,826	$6,330
13	$2,854	$375	$3,229	$7,680	$10,909	$6,075
14	$2,940	$375	$3,315	$7,680	$10,995	$5,831
15	$3,028	$375	$3,403	$7,680	$11,083	$5,598
16	$3,119	$375	$3,494	$7,680	$11,174	$5,375
17	$3,212	$375	$3,587	$7,680	$11,267	$5,162
18	$3,309	$375	$3,684	$7,680	$11,364	$4,958
19	$3,408	$375	$3,783	$7,680	$11,463	$4,763
20	$3,510	$375	$3,885	$7,680	$11,565	$4,577

Total 20 Year Life Cycle Cost:	**$214,893**
Cost Per Ton of A/C:	**$8,588**
Total 20 Year Life Cycle Cost (NPV):	**$138,961**
Cost Per Ton of A/C (NPV):	**$5,554**

Etherington Hall								
Case B:	**Cooling at an equal cost**							
	Built in 1959					**Window Unit Factors**		
	Total Area:	44681	ft^2			Life Span:	7	years
	Cooled Area:	10010	ft^2			Number of Units:	65	units
	Percentage Cooled:	22.4%				Average Cooling per Unit:	0.75	tons/unit
						Equipment Efficiency:	1.5	kW/ton
		Cooling Load				Maintenance Cost:	0	$/ton year
		33%	area cooled			Equipment Cost:	850	$/ton
		400	ft^2/ton					
		37.3	tons			**Building Unit Factors**		
						Life Span:	20	years
	Electricity Factors					Equipment Efficiency:	1.0	kW/ton
	Cost of Electricity:	0.10	$/kWh			Maintenance Cost:	15	$/ton year
	Increase Factor:	1.03				Equipment Cost:	2500	$/ton
	Electricity Demand:	800	h/year					
	Intermediate Calculations					**Conversion Factors**		
	Window Units							
		Total Cooling:	48.75	tons	12000	Btu/h =	1	ton
		Maintenance Cost:	$0	/year	0.2931	W =	1	Btu/h
		Equipment Efficiency:	0.426	kW/kW	1000	W =	1	kW
		Life Cycle Equipment Cost:	$41,438					
		20 Year Equipment Cost:	$118,393					
	Building Unit						Rate for Net Present Value	5.0%
		Total Cooling:	37.3	tons				
		Maintenance Cost:	$560	/year				
		Equipment Efficiency:	0.284	kW/kW				
		20 Year Equipment Cost:	$93,317					
		10% Contingency Factor	$9,332					

Window Units

Case B: Cooling at an equal cost

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Window Unit Cost	Net Present Value Cost
1	$5,850	$0	$5,850	$4,736	$10,586	$10,586
2	$6,026	$0	$6,026	$4,736	$10,761	$10,249
3	$6,206	$0	$6,206	$4,736	$10,942	$9,925
4	$6,392	$0	$6,392	$4,736	$11,128	$9,613
5	$6,584	$0	$6,584	$4,736	$11,320	$9,313
6	$6,782	$0	$6,782	$4,736	$11,517	$9,024
7	$6,985	$0	$6,985	$4,736	$11,721	$8,746
8	$7,195	$0	$7,195	$4,736	$11,930	$8,479
9	$7,411	$0	$7,411	$4,736	$12,146	$8,221
10	$7,633	$0	$7,633	$4,736	$12,369	$7,973
11	$7,862	$0	$7,862	$4,736	$12,598	$7,734
12	$8,098	$0	$8,098	$4,736	$12,833	$7,503
13	$8,341	$0	$8,341	$4,736	$13,076	$7,281
14	$8,591	$0	$8,591	$4,736	$13,327	$7,067
15	$8,849	$0	$8,849	$4,736	$13,584	$6,861
16	$9,114	$0	$9,114	$4,736	$13,850	$6,662
17	$9,388	$0	$9,388	$4,736	$14,123	$6,470
18	$9,669	$0	$9,669	$4,736	$14,405	$6,285
19	$9,959	$0	$9,959	$4,736	$14,695	$6,106
20	$10,258	$0	$10,258	$4,736	$14,994	$5,934

Total 20 Year Life Cycle Cost:	**$251,906**
Cost Per Ton of A/C:	**$5,167**
Total 20 Year Life Cycle Cost (NPV):	**$160,032**
Cost Per Ton of A/C (NPV):	**$3,283**

Building Unit

Case B: Cooling at an equal cost

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Building Unit Cost	Net Present Value Cost
1	$2,986	$560	$3,546	$102,649	$106,195	$106,195
2	$3,076	$560	$3,636	$0	$3,636	$3,463
3	$3,168	$560	$3,728	$0	$3,728	$3,381
4	$3,263	$560	$3,823	$0	$3,823	$3,302
5	$3,361	$560	$3,921	$0	$3,921	$3,226
6	$3,462	$560	$4,022	$0	$4,022	$3,151
7	$3,566	$560	$4,126	$0	$4,126	$3,079
8	$3,673	$560	$4,232	$0	$4,232	$3,008
9	$3,783	$560	$4,343	$0	$4,343	$2,939
10	$3,896	$560	$4,456	$0	$4,456	$2,872
11	$4,013	$560	$4,573	$0	$4,573	$2,807
12	$4,134	$560	$4,693	$0	$4,693	$2,744
13	$4,258	$560	$4,817	$0	$4,817	$2,683
14	$4,385	$560	$4,945	$0	$4,945	$2,623
15	$4,517	$560	$5,077	$0	$5,077	$2,564
16	$4,652	$560	$5,212	$0	$5,212	$2,507
17	$4,792	$560	$5,352	$0	$5,352	$2,452
18	$4,936	$560	$5,496	$0	$5,496	$2,398
19	$5,084	$560	$5,644	$0	$5,644	$2,345
20	$5,236	$560	$5,796	$0	$5,796	$2,294

Total 20 Year Life Cycle Cost:	**$194,086**
Cost Per Ton of A/C:	**$5,200**
Total 20 Year Life Cycle Cost (NPV):	**$160,032**
Cost Per Ton of A/C (NPV):	**$4,287**

Building Unit

Case B: Cooling at an equal cost (Financed)

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Building Unit Cost	Net Present Value Cost
1	$2,681	$503	$3,184	$8,574	$11,758	$11,758
2	$2,761	$503	$3,264	$8,574	$11,838	$11,274
3	$2,844	$503	$3,347	$8,574	$11,921	$10,813
4	$2,929	$503	$3,432	$8,574	$12,006	$10,371
5	$3,017	$503	$3,520	$8,574	$12,094	$9,950
6	$3,108	$503	$3,611	$8,574	$12,185	$9,547
7	$3,201	$503	$3,704	$8,574	$12,278	$9,162
8	$3,297	$503	$3,800	$8,574	$12,374	$8,794
9	$3,396	$503	$3,899	$8,574	$12,473	$8,442
10	$3,498	$503	$4,001	$8,574	$12,575	$8,106
11	$3,603	$503	$4,106	$8,574	$12,680	$7,784
12	$3,711	$503	$4,214	$8,574	$12,788	$7,477
13	$3,822	$503	$4,325	$8,574	$12,899	$7,183
14	$3,937	$503	$4,440	$8,574	$13,014	$6,901
15	$4,055	$503	$4,558	$8,574	$13,132	$6,632
16	$4,177	$503	$4,679	$8,574	$13,253	$6,375
17	$4,302	$503	$4,805	$8,574	$13,379	$6,129
18	$4,431	$503	$4,934	$8,574	$13,508	$5,893
19	$4,564	$503	$5,067	$8,574	$13,641	$5,668
20	$4,701	$503	$5,204	$8,574	$13,778	$5,452

Total 20 Year Life Cycle Cost:	**$253,569**
Cost Per Ton of A/C:	**$7,567**
Total 20 Year Life Cycle Cost (NPV):	**$163,710**
Cost Per Ton of A/C (NPV):	**$4,885**

Case C: Page 1 of 4

Etherington Hall								
Case C:	**Cooling 75% of the building**							
	Built in 1959					**Window Unit Factors**		
	Total Area:	44681	ft^2			Life Span:	7	years
	Cooled Area:	10010	ft^2			Number of Units:	217	units
	Percentage Cooled:	22.4%				Average Cooling per Unit:	0.75	tons/unit
						Equipment Efficiency:	1.5	kW/ton
		Cooling Load				Maintenance Cost:	0	$/ton year
		75%	area cooled			Equipment Cost:	850	$/ton
		400	ft^2/ton					
		83.8	tons			**Building Unit Factors**		
						Life Span:	20	years
	Electricity Factors					Equipment Efficiency:	1.0	kW/ton
	Cost of Electricity:	0.10	$/kWh			Maintenance Cost:	15	$/ton year
	Increase Factor:	1.03				Equipment Cost:	2000	$/ton
	Electricity Demand:	800	h/year					
	Intermediate Calculations					**Conversion Factors**		
	Window Units				12000	Btu/h =	1	ton
		Total Cooling:	162.75	tons	0.2931	W =	1	Btu/h
		Maintenance Cost:	$0	/year	1000	W =	1	kW
		Equipment Efficiency:	0.426	kW/kW				
		Life Cycle Equipment Cost:	$138,338					
		20 Year Equipment Cost:	$395,250					
	Building Unit						Rate for Net Present Value	5.0%
		Total Cooling:	83.8	tons				
		Maintenance Cost:	$1,257	/year				
		Equipment Efficiency:	0.284	kW/kW				
		20 Year Equipment Cost:	$167,554					
		10% Contingency Factor	$16,755					

Window Units

Case C: Cooling 75% of the building

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Window Unit Cost	Net Present Value Cost
1	$19,530	$0	$19,530	$15,810	$35,340	$35,340
2	$20,116	$0	$20,116	$15,810	$35,926	$34,215
3	$20,719	$0	$20,719	$15,810	$36,529	$33,133
4	$21,341	$0	$21,341	$15,810	$37,151	$32,092
5	$21,981	$0	$21,981	$15,810	$37,791	$31,091
6	$22,641	$0	$22,641	$15,810	$38,451	$30,127
7	$23,320	$0	$23,320	$15,810	$39,130	$29,199
8	$24,019	$0	$24,019	$15,810	$39,829	$28,306
9	$24,740	$0	$24,740	$15,810	$40,550	$27,446
10	$25,482	$0	$25,482	$15,810	$41,292	$26,617
11	$26,247	$0	$26,247	$15,810	$42,057	$25,819
12	$27,034	$0	$27,034	$15,810	$42,844	$25,050
13	$27,845	$0	$27,845	$15,810	$43,655	$24,309
14	$28,680	$0	$28,680	$15,810	$44,490	$23,594
15	$29,541	$0	$29,541	$15,810	$45,351	$22,905
16	$30,427	$0	$30,427	$15,810	$46,237	$22,241
17	$31,340	$0	$31,340	$15,810	$47,150	$21,600
18	$32,280	$0	$32,280	$15,810	$48,090	$20,982
19	$33,249	$0	$33,249	$15,810	$49,059	$20,385
20	$34,246	$0	$34,246	$15,810	$50,056	$19,809

Total 20 Year Life Cycle Cost:	**$840,978**
Cost Per Ton of A/C:	**$5,167**
Total 20 Year Life Cycle Cost (NPV):	**$534,261**
Cost Per Ton of A/C (NPV):	**$3,283**

Building Unit

Case C: Cooling 75% of the building

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Building Unit Cost	Net Present Value Cost
1	$6,702	$1,257	$7,959	$184,309	$192,268	$192,268
2	$6,903	$1,257	$8,160	$0	$8,160	$7,771
3	$7,110	$1,257	$8,367	$0	$8,367	$7,589
4	$7,324	$1,257	$8,580	$0	$8,580	$7,412
5	$7,543	$1,257	$8,800	$0	$8,800	$7,240
6	$7,770	$1,257	$9,026	$0	$9,026	$7,072
7	$8,003	$1,257	$9,259	$0	$9,259	$6,909
8	$8,243	$1,257	$9,499	$0	$9,499	$6,751
9	$8,490	$1,257	$9,747	$0	$9,747	$6,597
10	$8,745	$1,257	$10,001	$0	$10,001	$6,447
11	$9,007	$1,257	$10,264	$0	$10,264	$6,301
12	$9,277	$1,257	$10,534	$0	$10,534	$6,159
13	$9,556	$1,257	$10,812	$0	$10,812	$6,021
14	$9,842	$1,257	$11,099	$0	$11,099	$5,886
15	$10,138	$1,257	$11,394	$0	$11,394	$5,755
16	$10,442	$1,257	$11,698	$0	$11,698	$5,627
17	$10,755	$1,257	$12,012	$0	$12,012	$5,503
18	$11,078	$1,257	$12,334	$0	$12,334	$5,381
19	$11,410	$1,257	$12,667	$0	$12,667	$5,263
20	$11,752	$1,257	$13,009	$0	$13,009	$5,148

Total 20 Year Life Cycle Cost:	**$389,531**
Cost Per Ton of A/C:	**$4,650**
Total 20 Year Life Cycle Cost (NPV):	**$313,101**
Cost Per Ton of A/C (NPV):	**$3,737**

Building Unit

Case C: Cooling 75% of the building (Financed)

Year	Electricity	Maintenance	Total Operating Expenses	Capital Cost	Total Building Unit Cost	Net Present Value Cost
1	$6,702	$1,257	$7,959	$17,147	$25,106	$25,106
2	$6,903	$1,257	$8,160	$17,147	$25,307	$24,102
3	$7,110	$1,257	$8,367	$17,147	$25,514	$23,142
4	$7,324	$1,257	$8,580	$17,147	$25,727	$22,224
5	$7,543	$1,257	$8,800	$17,147	$25,947	$21,347
6	$7,770	$1,257	$9,026	$17,147	$26,173	$20,507
7	$8,003	$1,257	$9,259	$17,147	$26,406	$19,705
8	$8,243	$1,257	$9,499	$17,147	$26,646	$18,937
9	$8,490	$1,257	$9,747	$17,147	$26,894	$18,203
10	$8,745	$1,257	$10,001	$17,147	$27,148	$17,500
11	$9,007	$1,257	$10,264	$17,147	$27,411	$16,828
12	$9,277	$1,257	$10,534	$17,147	$27,681	$16,185
13	$9,556	$1,257	$10,812	$17,147	$27,959	$15,569
14	$9,842	$1,257	$11,099	$17,147	$28,246	$14,979
15	$10,138	$1,257	$11,394	$17,147	$28,541	$14,415
16	$10,442	$1,257	$11,698	$17,147	$28,845	$13,875
17	$10,755	$1,257	$12,012	$17,147	$29,159	$13,358
18	$11,078	$1,257	$12,334	$17,147	$29,481	$12,863
19	$11,410	$1,257	$12,667	$17,147	$29,814	$12,388
20	$11,752	$1,257	$13,009	$17,147	$30,156	$11,934

Total 20 Year Life Cycle Cost:	**$548,162**
Cost Per Ton of A/C:	**$6,543**
Total 20 Year Life Cycle Cost (NPV):	**$353,166**
Cost Per Ton of A/C (NPV):	**$4,216**

Appendix B: Report Review - Precinct Cooling Preliminary Evaluation

The report was completed by H.H. Angus & Associates Ltd. on May 30, 2002. It looks at the preliminary sizing and costing of a precinct cooling plant to serve Gordon Hall, Gordon Annex, Douglas Library and Richard Hall. The plant is to be steam driven, and three locations were investigated.

The most likely place for the cooling plant is in the basement of Frost Wing. This building is going to be demolished, and the plan is to dig the basement deeper to have room for the equipment. Landscaping will be done over top of the plant to disguise it and access will be available through Gordon Annex. The Base Case cost is the highest at this location ($854,500) because of large excavation costs.

The second location is on the roof of Gordon Hall and Gordon Annex. The Base Case cost is $756,500. The major downside to this location is that the equipment will be clearly visible from ground level. The equipment would cover most of the roof and is 15 feet tall, resulting in an odd-looking limestone building with a large modern cooling unit on top of it.

The consulting firm also suggested placing the unit in the back of Gordon Annex on the ground floor. A lot of savings would result, as only soundproofing and adding another entrance to the room would be required. The Base Case is the lowest at $694,500 at this location. However, this space is to be used for offices and it is unlikely that the University will be willing to give up this office space.

In all three cases, the cooling tower will be located on the roof of Gordon Annex with screens to minimize the visual impact from ground level. The Base Case has a 500-ton chiller, but estimates for a 600-ton chiller were also included. Another option included a larger pipe crossing University Ave. to service Richardson Hall. This larger pipe would allow 500 tons instead of only 100, and provide enough cooling to hook into another nearby building in the future.

For further details, refer to the H.H. Angus & Associates Ltd. report *Precinct Cooling Preliminary Evaluation*.

Appendix C: Report Review - Campus Cooling Economic Evaluation

This report focused on developing strategies to cool all of the main campus of Queen's University. It was recommended that Queen's opt for a district cooling strategy with a few large chillers cooling groups of buildings throughout campus.

Currently one third of buildings on campus are not cooled, one third are less than 50% cooled, and the remaining third are between 50 and 100 % cooled. The total cooling load that would be needed to cool all of main campus is 11,600 tons. The current chilled water cooling capacity is 4350 tons with additional cooling coming from rooftop and window cooling units.

The report examined four possible strategies, local or building cooling (which seems to be the current strategy), precinct (several groups of three or four buildings), district (three or four centralized cooling stations), and central (one central station). The payback period of the precinct, district and central cooling strategies vs. the local cooling was found to be between 10 and 16 years.

The report went into great detail regarding the loads on various buildings and the amount of cooling required for each building, as well as the amount of chilling currently available. The percentage of each building that is currently cooled was also found.

There were also detailed plans regarding the potential layouts of the precinct and district cooling systems. These include the zoning as well as the piping sketches. It seems that these layouts are unlikely to be ultimately used by Queen's however, as plans are already in place for some precinct cooling which disregards these plans, (see Gordon Hall consultant's report).

The report recommends that Queen's undertake a centralized cooling strategy. An interconnected district cooling system would offer the best payback period while taking into account the limited space available on campus, and allowing for future expansion.

Appendix D: Air Conditioning Policy – August 4, 1978

In response to numerous requests for air conditioning a reiteration of the University's Air Conditioning Policy and the procedure used in handling all air conditioning requests is in order.

Present University policy applies to all sectors of the University community and does not permit the air conditioning of University office or laboratory space unless special circumstances dictate otherwise. These special circumstances are limited to:

1. Establishing environmental conditions essential for the proper functioning of specialized laboratory equipment, to be employed in the laboratory in question, or

2. Establishing controlled environmental conditions which are a necessary prerequisite for the experimentation being conducted in the laboratory in question, or

3. Correcting unusually oppressive working conditions where other solutions are either not possible or not practical.

    All requests for air conditioning must receive the approval of the Vice-Principal (Operations & Finance) before any work is commenced or any equipment is ordered, regardless of the source of funding.

    As a matter of routine, the Department of Physical Plant Services will be asked to examine each request and to report on the circumstances relating to it. In assessing the special circumstances outlined above, it will be necessary to examine the operating manuals of all equipment falling within category 1) above, and to obtain written confirmation from the Department Head of experimental circumstances falling with category 2) above.

    In circumstances where air conditioning equipment appears justified under categories 1), 2) or 3) above and where other air conditioning equipment is in use in the department in question, it will be necessary to examine the current justification for this existing air conditioning equipment. Any existing air conditioning equipment, the use of which can no longer be justified in the context of the special circumstances outlined above, must be redeployed or removed before new requests are approved.

    While no attempt will be made to identify and remove unjustified air conditioning installations, except in the trade-off circumstances outlined above, such units will not be replaced when they become inoperative. That is, all requests for replacement air conditioning units will be treated as new requests and must be justified on the basis of current special circumstances.