DILLON CONSULTING

UNIVERSITY OF KING'S COLLEGE

Campus Energy Master Plan

Final Report – August 21, 2022

August 21, 2022

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University of King's College
6350 Coburg Road
Halifax, Nova Scotia
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Attention: Mr. Ian Wagschal
Director of Facilities Management

University of King's College Campus Energy Master Plan

Please find enclosed the final version of the Campus Master Energy Plan for the University of King's College. The Plan identifies energy efficiency measures as part of the Campus Master Energy Plan and to reduce reliance on fossil fuels.

The aim of this study is to analyze the current energy performance of the campus buildings, conduct an onsite energy assessment, and produce a list of energy efficiency measures, and a preliminary opinion of probable costs. Various pathways to carbon neutrality were identified and included in the report to allow the University the option to explore different methods and technologies. Hence, several scenarios are presented along with our recommendations in this study.

Sincerely,

DILLON CONSULTING LIMITED

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David Inglis, PEng, CEM, HBDP, HFDP
Partner

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Executive Summary

Dillon Consulting Limited was engaged by the University of King's College to identify energy efficiency measures as part of the Campus Master Energy Plan to reduce greenhouse gas ("GHG") emissions and the associated reliance on fossil fuels.

This study provides an analysis of the current energy performance of the campus buildings based on an onsite energy assessment, and proposes a list of energy efficiency measures with an initial estimate of associated costs. Hence, various pathways are suggested to reduce GHG emissions and decrease reliance on fossil fuels. There are nine (9) scenarios presented in Table 1 that are based on Dillon's energy analysis and modeling simulations. Dillon will recommend two scenarios from Table 1 out of the proposed nine options that cover the various pathways and combinations thereof. Hence, the University can explore Dillon's recommendation and the mix of technologies and approaches in order to achieve its energy efficiency goals and financial objectives.

The summary table below presents a list of scenarios identified during the energy assessment of the campus along with estimated costs, savings and simple payback.

Table 1: Summary of EEMs

Pathways	Measure(s)	Opinion of Probable Cost	Estimated Savings (±15%)			Estimated Energy Savings Costs	Simple Payback
		($)	Electricity (kWh)	Steam (GJ)	GHG (tCO2e)	($)	(Years)
#1	BAS Controls Optimization & Lighting Controls	$680,000	-41,700	-1,600	-340	-$48,700	14.0
#2	#1 + Solar Energy & HVAC Upgrades & Building Envelope Upgrades	$1,940,000	-266,700	-4,300	-1,890	-$146,600	13.2
#3	#2+ Steam to Hydronic Conversions	$5,210,000	-294,500	-8,000	-2,240	-$253,500	20.5

Pathways	Measure(s)	Opinion of Probable Cost	Estimated Savings (±15%)			Estimated Energy Savings Costs	Simple Payback
		($)	Electricity (kWh)	Steam (GJ)	GHG (tCO2e)	($)	(Years)
#4	#3+ Geo-thermal Energy	$7,610,000	-55,300	-12,900	-3,430	-$363,500	20.9
#5	Solar Energy, Building Envelope Upgrade, BAS Controls Optimization & Lighting Controls	$1,410,000	-183,100	-3,800	-1,230	-$124,900	11.3
#6	#1+ Building Envelope Upgrades	$950,000	-78,100	-3,800	-570	-$113,800	8.0
#7	#6+ HVAC Upgrades	$1,470,000	-161,700	-4,300	-1,230	-$135,500	11.4
#8	#7+ Steam to Hydronic Conversions	$4,740,000	-189,500	-8,000	-1,580	-$242,400	19.9
#9	#8+ Geo-thermal Energy	$7,140,000	49,700	-12,900	-2,770	-$352,400	20.5

Dillon recommends the following two scenarios:

Scenario #1 (i.e., Pathway #3 in Table 1): Dillon recommends the University to consider the implementation of Pathway #3 as it uses a multiple of efficiency measures (EEMs) as follows:

- EEM-1: Building Automation Controls Optimization
- EEM-3: HVAC Upgrades (CAV to VAV, retrofitting fans with VFDs, implementing ERV's)
- EEM-4: Building Envelope Upgrades (incl. air sealing, window replacements, etc.)
- EEM-5: Solar Energy Implementation
- EEM-6: Conversion of central steam distribution to building to hot water distribution.

By implementing the recommended energy efficiency measures listed above, the following potential savings may be anticipated relative to the simulated baseline year:

- -294,500 kWh (42.4%) of electricity savings;
- -8,000 GJ [6,300,000 lb] (60.2%) of steam savings; and
- -2,240 tonnes (44.7%) of CO2e emissions

Scenario #2 (i.e., Pathway #4 in Table 1): Dillon recommends the University to consider enhancing the first scenario (Pathway #3) by adding a geothermal system. This is represented in Pathway #4 (Table 1) where the EEM of a 'Ground Source Heat' pump is added to all the EEM's listed in Pathway #3.

Accordingly, the following potential savings may be anticipated relative to the simulated baseline year:

- -55,300kWh (8%) of electricity savings; and
- -12,900 GJ [10,200,000 lb] (96.8%) of steam savings; and
- -3,430 tonnes (68.3%) of CO2e emissions

The second scenario is a strong contender due to its primary reliance on electricity, and nearly fully eliminating the need for fossil fuels.

In summary, it is recommended that the University consider Scenario #1 (i.e., Pathway #3 in Table 1) or Scenario #2 (i.e., Pathway #4 in Table 1) as they both present a solid option to reduce GHG and the reliance on fossil fuels. Further, the University can explore the other scenarios found in Table 1 as well. For example, Pathways: #6, #7, and #8 are potential candidates if the solar technology is not desired (see section 4.2 for visual comparisons of all scenarios). Finally, Dillon will provide any support required by the University of King's College in its efforts to decarbonize energy consumption.

1.0 Introduction

Dillon Consulting Limited was retained by the University of King's College ("Client") to conduct energy audits for seven (7) campus buildings at 6350 Coburg Rd, Halifax, Nova Scotia. The University comprises many buildings and spaces including a gym, library, lecture halls, research spaces, and dormitories.

The assessment involved a review of approximately 21,860 m^2 (235,300 ft^2) of campus space buildings which revealed the potential for implementation of energy efficiency measures that can improve the overall energy efficiency of the university and the reduction of fossil fuel use.

1.1 Purpose

Energy consumption in buildings worldwide accounts for approximately a third of global energy use and one-quarter of greenhouse gas emissions. If current trends continue, buildings will be the largest consumer of global energy by 2055, greater than the transportation and industrial sectors combined. Buildings, therefore, offer a great potential for reducing the world's energy consumption and limiting the negative impacts caused by the associated emission release from non-renewable energy used to power the buildings.

In Canada, about 81.1% of primary energy is extracted from non-renewable sources, in which buildings account for a major portion. As part of the Sustainable Development Goals Act, Nova Scotia set new targets to fight climate change, including reducing greenhouse gas emissions by 53% below the levels emitted in 2005 by 2030, and net zero emissions by 2050. In addition, Nova Scotia Power has committed to producing 80% of its electricity through renewable energy sources by 2030. They are on track to achieve 60% renewable energy in 2022, which entails greener electricity consumption over time - and the need to transition away from fossil fuels.

1.2 Report Structure

This reports provides a wide range of detailed information relating to most aspects of the systems consuming or otherwise using energy throughout the campus buildings. In an effort to improve the overall readability of this report, most of this information has been moved to Appendices. These Appendices have be included within the Table of Contents, however, they're listed below along with a brief description of the information contained within each.

- Appendix A Decision Tree: provides an overview of the various pathways.
- Appendix B Project Overview: provides an overview of the project scope of work.
- Appendix C Facility Description: provides an overview of the existing buildings and their systems.
- Appendix D Energy Simulation Methodology: provides development details for the models.
- Appendix E Strategy Sheet: provides a phasing plan for the measures.

- Appendix F Energy Modeling Results: provides a high-level summary of the energy models.
- Appendix G Financial Analysis: provides a high-level summary of the financial analysis.
- Appendix H Benchmarking and Analysis: provides an analysis and review of the pathways.
- Appendix I Hydronic Conversion: provides an overview of the proposed campus conversion.
- Appendix J Detailed Cost Estimates: provides a summary of the detailed cost estimates.

Of the various Appendices outlined above, Appendix A is perhaps the most useful for the reader to quickly understand and visualize the various pathways explored throughout this report. For convenience, a larger and combined decision tree was provided and this was then separated into smaller versions.

2.0 Energy Efficiency Measures

This section will review the energy efficiency measures best identified for the University, along with their associated risks, capital costs, and energy savings. This has been based on a thorough assessment of the existing energy systems currently in place.

Table 2: Risks, Costs, and Savings EEM Summary

Sustainability Improvement Measure	Technical Risks	Capital Costs	Energy Savings
Building Automation	Low	Medium	Medium
HVAC Upgrades	Medium	Low	Medium
Building Envelope	Medium	Low	Low
Solar Energy	Medium	Low	Medium
Steam to Hot Water	High	High	High
Geothermal Energy	High	High	High
Seasonal Heating Shutdown	Medium	Low	Medium
Centralized Cooling Loop	High	Medium	Low
Plug Load Control System	Low	Low	Medium

With the range categories falling under:

Table 3: Range Categories for EEMs

	Low	Medium	High
Technical Risks	Relatively Easy installation, no major interference with other systems.	Moderate work is required to implement the measure. Some interference with other systems.	Major re-work required. Interference with major systems. Requires scheduled shutdown of campus activities for implementation.
Capital Costs	$0 – $600K	$600K – $1M	$1M+
Energy Savings	5-15%	15-25%	25-40%

2.1 Design Considerations & Risks

The following section will expand on the design strategies and considerations for each energy efficiency measure.

2.1.1 Building Automation

Building Automation System ("BAS") and/or Energy Management and Control System ("EMCS") optimization and improvements, including conversion from pneumatic to electric, implementation of time-of-day schedules and temperature reset programs.

Building automation systems ("BAS"), often referred to as energy management and control systems ("EMCS"), provide automated control of the buildings' indoor environment, such as heating, ventilation, and air-conditioning ("HVAC") systems, lighting, fire safety, security, and more. BAS enables modern buildings to become more intelligent through real-time automatic monitoring and control, as well as recording historical trends and performance. An upgrade to the existing building automation system could provide savings of up to 15%, as older BAS versions tend to utilize outdated control systems and sequence of operations, as well as lack the ability of intelligent scheduling & monitoring.

Given that the campus largely uses a BAS designed, operated and maintained by Siemens Building Technology, the technical risks associated with upgrading that system (assuming that UKC continues to work with Siemens) are quite limited as the existing conditions are well documented, understood and the modifications required to convert them are well understood such that a financial proposal provided by Siemens would be considered low-risk. Where technical and financial risk tends to be introduced into a BAS upgrade or conversion from pneumatic to electronic is when the project is open-tendered and there is more uncertainty by the bidders regarding what (if any) of the existing systems can be maintained and re-used, to what extent sequences have been programmed and their degree of implementation, and the extent to which there are any redundant systems to remove.

The table below provides a high-level summary of the probable construction cost to implement the sustainability improvement measure within each building, along with a total for the campus. The cost estimate has been provided as a range recognizing uncertainty within the estimate. Given that the project is at a preliminary design stage (i.e., pre-schematic design) and specific details and quantities for the project are not yet available, typically such an estimate is expected to be within ±25% of the construction project value. It's important to note that recent global events (i.e., ongoing COVID-19 recovery, the Ukraine crisis, increasing global oil prices, uncertainty in manufacturing and raw material pricing, etc.) continue to significantly impact construction costs locally. As a result, accurate cost estimating and scheduling is becoming increasingly challenging.

Table 4: Building Automation Cost Estimate

Building	Cost Estimate	Notes - Building Automation
Alexandra Hall (including Chapel and Pit)	$102-126K	Includes scheduling, measurement, pneumatic to electronic, additional zones, lighting controls (scheduling, occupancy, daylight)
Library	$54-66K	Includes scheduling, measurement, lighting controls (scheduling, occupancy, daylight)
Prince Hall	$72-90K	Includes scheduling, measurement, pneumatic to electronic, additional zones, lighting controls (scheduling, occupancy, daylight)
New Academic Building (including Link)	$54-66K	Includes scheduling, measurement, lighting controls (scheduling, occupancy, daylight)
Gymnasium	$54-66K	Includes scheduling, measurement, lighting controls (scheduling, occupancy, daylight)
Arts & Administration (including North Pole, Cochran, and Wardroom)	$102-126K	Includes scheduling, measurement, pneumatic to electronic, additional zones, lighting controls (scheduling, occupancy, daylight)
Tri-Bays (including Radical, Middle, and Chapel)	$102-126K	Includes scheduling, measurement, pneumatic to electronic, additional zones, lighting controls (scheduling, occupancy, daylight)
Campus Central System	$72-90K	Includes scheduling, measurement, additional zone isolation valves and control
TOTAL:	**$612-756K**	**See notes above**

2.1.2 HVAC Upgrades

Conversion of library HVAC system from constant air volume ("CAV") to variable air volume ("VAV"), cafeteria A/C systems to CO2-based demand controlled systems, Prince Hall's system from CAV to VAV, cafeteria kitchen exhaust to demand controlled system (currently no make-up air), New Academic Building's system from DOAS CAV to a modified-mixed, partial-VAV.

In buildings where ventilation load is variable, VAV systems typically offer energy savings of up to 30% when compared with CAV systems. VAV systems offer more precise temperature control as the fan speed varies depending on the temperature in the space, while CAV systems supply a constant airflow. CAV systems are best-suited for applications where the ventilation load is constant for large periods of time, but the buildings specified more often experience frequent part-load conditions where occupancy rates are random and constantly changing.

Converting CAV systems to VAV systems pose a relatively low technical risk as the overall system intent isn't changed, only the terminal boxes, the wall controllers and the main system's motors (to be variable frequency drive ("VFD") compatible). Note that other, similar conversions are likewise being completed and are noted within the table below for each building. The table below provides a high-level summary of the probable construction cost to implement the sustainability improvement measure within each building, and the total for the campus. The cost estimate has been provided as a range recognizing uncertainty within the estimate. Given that the project is at a preliminary design stage (i.e., pre-schematic design) and specific details and quantities for the project are not yet available, typically, such an estimate is expected to be within ±25% of the construction project value. It's important to note that recent global events (i.e., ongoing COVID-19 recovery, the Ukraine crisis, increasing global oil prices, uncertainty in manufacturing and raw material pricing, etc.) continue to significantly impact construction costs locally and, as a result, relatively accurate cost estimating and scheduling is becoming increasingly challenging.

Table 5: HVAC Upgrades Cost Estimate

Building	Cost Estimate	Notes – HVAC Upgrades
Alexandra Hall (including Chapel and Pit)	$0K	No further upgrades, consideration being given to retrofitting system fans with VFDs or implementing an energy recovery system
Library	$96-126K	CAV to VAV conversion, building-wide recommissioning
Prince Hall	$96-126K	CAV to VAV conversion, building-wide recommissioning
New Academic Building (including Link)	$126-144K	CAV to VAV conversion, floor-level return airflow modifications.
Gymnasium	$0K	No further upgrades, consideration being given to retrofitting system fans with VFDs or implementing an energy recovery system
Arts & Administration (including North Pole, Cochran, and Wardroom)	$150-186K	Wardroom A/C unit modifications, server room A/C units modification, building-wide recommissioning.
Tri-Bays (including Radical, Middle, and Chapel)	$0K	No further upgrades, consideration being given to retrofitting system fans with VFDs or implementing an energy recovery system
TOTAL:	**$468-582K**	**See notes above**

2.1.3 Building Envelope

Building Envelope Upgrades (incl. air sealing, window & door replacements, weather stripping etc.) to decrease infiltration rates.

As campus buildings age, the building insulation tends to degenerate over time, and likely, would not meet the current requirements for efficient building envelopes. For this study, the campus building condition were considered poor and minor retrofits are needed. This assessment is based largely on the fact that existing insulation levels within the exterior walls of the buildings cannot be cost effectively changed –

particularly considering the historic nature of the buildings and the level of interior partitions throughout the buildings that make both exterior and interior access to the walls difficult and expensive. As a result, the evaluation focused on quantifying the air leakage and infiltration rates and, by extension, the proposed retrofits focus on minimizing air leakage and infiltration rates. Minor renovations can be done to improve the thermal efficiency through this measure, such as sealing any cracks / leaks for a more air tight building.

Building envelope upgrades tend to be one of the more difficult energy efficiency measures to evaluate, quantify and then to realize. The challenge lies in the technical and financial risk associated with quantifying the scope of work and establishing the likely energy savings to result. For example, while it would be relatively easy to identify walls with very limited insulation and then quantify the likely energy savings resulting from upgrading the insulation levels, the challenge becomes quantifying the installation cost and identifying the technical risks around the particular installation details for doing so in an older building. Alternatively, while it may be relatively low risk to retain an envelope contractor to identify and remediate envelope sealing, weather stripping and patching to decrease infiltration rates, quantifying the likely savings from this is incredible difficult and tends to be anecdotal.

Given the ages and configurations of the buildings throughout the campus, and as discussed in detail above, this energy efficiency measure focuses on decreasing overall infiltration rates throughout the buildings. It's highly unlikely that a significant envelope remediation and upgrade project would be viable for the campus considering the exterior construction and character of the buildings – meaning that any additional insulation would need to be done from the interior of the buildings which would cause significant disruption to the building and incur a significant cost. As a result, a detailed review of openings, cracking, and of the windows and doors of the buildings was conducted, and a conservative estimate of the likely savings to be realized if an envelope contractor were to be retained with some general direction relating to areas to reduce overall infiltration. This particular measure does present a moderate amount of technical and financial risk, however, the analysis completed was relatively conservative in an effort to compensate for such concern. As noted above, the evaluation focused on quantifying the air leakage and infiltration rates and, by extension, the proposed retrofits focus on minimizing air leakage and infiltration rates.

Table 6: Building Envelope Upgrades Cost Estimate

Building	Cost Estimate	Notes – Building Envelope
Alexandra Hall (including Chapel and Pit)	$41-55K	None noted.
Library	$10-14K	None noted.
Prince Hall	$41-55K	None noted.
New Academic Building (including Link)	$41-55K	None noted.
Gymnasium	$10-14K	None noted.

Arts & Administration (including North Pole, Cochran, and Wardroom)	$41-55K	None noted.
Tri-Bays (including Radical, Middle, and Chapel)	$41-55K	None noted.
TOTAL:	**$224-303K**	**See notes above**

2.1.4 Steam Based Heating to Hot Water

Conversion from steam distribution heating (provided by DAL) to hydronic distribution.

Steam boilers and radiators tend to be inefficient due to their age and design, and conversion to hot water can yield considerable energy savings. Hot water systems offer a faster heating response time than steam radiators, while having reduced maintenance costs and providing safer operation. In addition, as the steam-based heating system ages, the likelihood of faults and leaks increases. Automation can be deployed for the entire hot water system, achieving the lowest possible operating cost. A heating system conversion project by the University of British Columbia achieved an efficiency increase from 60 to 85 percent. Steam-based systems have higher maintenance expenses, which can be over 10 times higher than those of an equivalent hot water system.

Generally speaking, understanding the intent is to convert the steam heating infrastructure to hydronic heating, all existing steam plant infrastructure would be demolished, including steam-to-water converters and condensate receiver tanks. All existing steam supply and condensate return piping, equipment and infrastructure would be demolished in its entirety throughout the facility. For the most part these systems are located within mechanical service spaces or utility corridors, with a few notable exceptions (i.e., the Arts & Administration, Library, New Academic, and Chapel buildings). Wherever deemed appropriate, the existing steam supply piping could be reused, however, at this time (given that pipe integrity testing has not been completed) this was assumed to not be a viable option due largely to the age of the infrastructure as well as that high-pressure steam distribution piping doesn't lend itself well to hydronic conversion due to smaller pipe sizes (i.e., low-pressure steam supply piping can often be a straight conversion).

Please note that it is recognized that most of the campus buildings have already been converted to hot water heating systems, however, much of the primary heating distribution infrastructure within those buildings (i.e., the campus-level infrastructure) remained as a steam distribution system, along with the heating infrastructure specific to a few buildings (see notes below as well as Appendix H Hydronic Conversion for additional information).

An energy exchange station would be installed within the basement of the North Pole Bay (i.e., where the primary service from Dalhousie University enters the campus). The energy exchange station would hydraulically isolate Dalhousie University's hydronic heating system (likely to be a medium-pressure, high-temperature system) from King's hydronic system. With hot water generated centrally, all other steam-to-water convertors throughout the campus would simply be removed and not replaced with additional heat exchangers. Where there are glycol-water heating systems, smaller heat exchangers will be installed for these sub-systems. All secondary circulators will remain installed and unchanged (i.e., the circulators currently on the load-side of the existing steam-to-water convertors). Primary loop circulators, located with the energy exchange station in the basement of the North Pole Bay, will distribute hot water throughout the campus.

Alternate heating sources for a number of kitchen appliances in Prince Hall (currently served by direct steam), humidification in the Library (currently served by a steam-to-steam humidifier), and various steam radiators within the Tri-Bay building including Radical, Middle & Chapel Bays and the Arts & Administration building. A small electric steam boiler will be installed for the kitchen appliances in Prince Hall, an electric humidifier will be installed to provide humidification in the Library and the steam radiators throughout will be replaced with hydronic radiators.

The table below provides a high-level summary of the probable construction cost to implement the sustainability improvement measure within each building, along with a total for the campus. The cost estimate has been provided as a range recognizing uncertainty within the estimate. Given that the project is at a preliminary design stage (i.e., pre-schematic design) and specific details and quantities for the project are not yet available, typically such an estimate is expected to be within ±25% of the construction project value. It's important to note that recent global events (i.e., ongoing COVID-19 recovery, the Ukraine crisis, increasing global oil prices, uncertainty in manufacturing and raw material pricing, etc.) continue to significantly impact construction costs locally and, as a result, relatively accurate cost estimating and scheduling is becoming increasingly challenging.

Table 7: Steam to Hot Water Cost Estimate

Building	Cost Estimate	Notes – Steam to Hot Water
Alexandra Hall (including Chapel and Pit)	$270-306K	Hydronic heating, two (2) 1,000-MBH (estimated) steam convertors. Circulated by two (2) (duty/standby) Grundfos UPS-80 with 3-HP motors
Library	$270-306K	Hydronic heating, two (2) 1,000-MBH steam convertors located in the basement provide hydronic heating. Circulated by two (2) (duty/standby) circulators with 2-HP motors
Prince Hall	$270-306K	Hydronic heating, one (1) 1,000-MBH (estimated) steam converter located in the basement provides for the facility's radiators. Circulated by two (2) (duty/standby) circulators with 2-HP motors, one (1) 1,000-MBH (estimated) steam converter located in the basement provides glycol heating water for four (4) reheat coils used to maintain the high bay area at

Building	Cost Estimate	Notes – Steam to Hot Water
		set-point. Circulated by two (2) (duty/standby) circulators with 1-HP motors
New Academic Building (including Link)	$390-438K	Hydronic heating, one (1) 1,305-MBH steam convertor located in the basement provides hydronic heating. Circulated by two (2) (duty/standby) circulators with unknown motor size, one (1) 565-MBH steam converter located in the basement provides glycol water heating. Circulated by one (1) circulator with an unknown motor size
Gymnasium	$210-258K	Hydronic heating, one (1) 1,000-MBH (estimated) steam converter located in the basement provides hydronic heating for the facility's radiators. Circulated by two (2) (duty/standby, manually switched) circulators with unknown motors, combination of fan coil units and force flows used, domestic hot water is produced by an indirect hot water tank (on hydronic system) and complete with a recirculation pump. No schedules.
Arts & Administration (including North Pole, Cochran, and Wardroom)	$474-522K	Mixed steam radiation and hydronic heating, one (1) unknown steam converter located in the North Pole basement and one (1) unknown steam converter located in the Cochran Bay basement provide hydronic heating for the facility's radiation. Each is circulated by two (2) (duty/standby, manually switched) circulators with unknown motors, domestic hot water is produced by an indirect hot water tank (on a hydronic system) and complete with a recirculation pump
Tri-Bays (including Radical, Middle, and Chapel)	$510-558K	Similar to Arts & Administration above except all steam radiation
Campus Central System	$690-756K	Includes installation of 2-pipe hydronic heating distribution system throughout campus and central plant upgrades
TOTAL:	**$3-3.5M**	**See notes above**

2.1.5 Solar Energy

Installation of photovoltaic arrays to offset electricity loads on Prince Hall and New Academic Building roofs.

Many net zero energy buildings utilize solar energy to offset the energy demands required from the operation of the building. Buildings require energy both in the form of heat and electricity, and solar energy utilization is an effective way to deliver both and provide on-site renewable energy to buildings.

Solar energy utilization is particularly effective in this study to offset the campus electricity loads as electricity has a high GHG emission intensity in Nova Scotia, and any offsets would yield considerable GHG reductions.

Solar thermal collectors and photovoltaic ("PV") modules are used and commonly placed on the buildings roofs, facades, and parking lots. Consideration is being given to install solar systems on Prince Hall and New Academic building roofs. It is important to examine the structural feasibility before initiating a roof-mounted solar project. The structural elements of the existing building roof must be examined and investigated to determine their load carrying capacities. The roof frames should have enough capacity to accommodate the additional load imposed from the installation of the solar system, with a considerable margin of safety.

Detailed information pertaining to the roof structural element is needed to accurately assess those elements' load carrying capacities. In the case that the structural drawings are not available *(note - only mechanical and architectural drawings are available to Dillon, structural drawings may not be available or exist as a hard copy)*, a structural site survey is required to gather information and assess site feasibility. If necessary, reinforcement options are available to increase the existing building's roof load capacity to install on buildings' roofs. An average cost estimate for a 100kW photovoltaic system is approximately:

Table 8: Photovoltaic Array Cost Estimate

Building	Cost Estimate	Notes - Solar Energy
Campus Central System	$420-510K	Installation of a 100kW photovoltaic array , installed on Prince Hall and New Academic Building Roofs

2.1.6 Geothermal Energy

Development of geothermal heat pump system using Quad-area.

Ground source heat pumps ("GSHP") or geothermal heat pumps ("GHP") use an underground heat exchanger for heating and cooling residential, industrial and commercial buildings. GSHPs use the thermal capacity of the ground to gain and dispense heat through underground piping. The pipes are buried in boreholes which are connected to a heat pump that transfers heat to and from a secondary HVAC system. GSHP has the capacity to fully eliminate the heating requirement for a building generated by fossil fuels, and is a very attractive method in reducing overall greenhouse gas emissions.

Installation and maintenance of a ground source heat pump is a challenging process, as it requires more aspects and pieces than conventional heating methods. GSHP design requires the building load profile, performance parameters of the heat pump, as well as the thermal ground properties. The performance

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of the system depends on factors such as underground water availability, soil quality and thermal properties - in which the borehole size and layouts are designed. Specialized workforce and equipment are needed to drill boreholes and install the pipelines. Risks include degradation of the soil quality around the extraction site in the long run, which could affect the performance of the system as heat transfer differences can affect the heat held underground.

A ground source heat pump system is a logical follow-up step to the hydronic conversion of the campus' heating systems. From a sustainability perspective, many universities are moving towards electrification of their heating and cooling systems recognizing that many electrical utilities are moving towards more sustainably produced electricity with lower associated greenhouse gas emissions. The general idea being that, if the production of electricity becomes carbon neutral, then by association an energy consumption that has been electrified would also be considered carbon neutral. Furthermore, heat pump technology provides a more efficient approach than simply relying on straight electricity for heating (i.e., electric resistive) by providing a coefficient of performance which essentially means that in most circumstances each unit of energy into a heat pump system provides anywhere from 1 to 4 (sometimes higher) units of energy outcome.

With the campus converted to hydronic heating and cooling, installing a ground source heat pump system would be costly; however, it would be relatively low risk from a technical and financial perspective. Given that a borehole test would be completed prior to its installation, the overall performance of the field would be known ahead of time, allowing for the opportunity to right size the system. Furthermore, the system would be borehole and equipment weighted, which means cost estimating becomes less risky (particularly compared to the hydronic conversion estimate) since the scope of work is limited to mechanical rooms, and is generally not impacted too much by site conditions or coordination issues with existing systems. It is a significant investment though – and it is an investment that should be made with an in-depth understanding of the maintenance requirements of the system, which generally requires a specialized workforce to complete and maintain the performance of the system overall. This workforce is available within Halifax.

Table 9: Geothermal System Cost Estimate

Building	Cost Estimate	Notes – Geothermal Energy
Campus Central System	$2-2.8M	None noted.

2.2 Additional Measures Identified

The following measures were not accounted for in the modeling process due to their variability in requirements, but have been included as they are feasible EEMs for reducing emissions.

2.2.1 Seasonal Heating Shutdowns

Seasonal shutdown of campus heating system.

Seasonal shutdown of the campus heating system would provide savings on steam for all buildings not in use - of up to 12% of the annual steam usage and costs. The objective for this measure is to isolate / turn off the steam lines during the warmer summer months for buildings not-in-use to reduce consumption & line losses as much as possible.

Table 10: Summer Steam 2018 Consumption

Steam Consumption - 2018	
Summer Consumption [May-August]	1,166,677 lbs. of steam / 69 tCO2e
Summer Cost - 2018	$24,256
Summer Cost [Forecasted 2022]	$40,834
Annual Consumption	10,343,595 lbs. of steam / 611 tCO2e
Annual Cost	$232,396
Annual Cost [Forecasted 2022]	$362,025

For buildings in use, specific steam lines could stay on for heating purposes, or by installing alternative systems such as electric domestic hot water ("DHW") heaters, steam boilers, and humidifiers. This would be necessary for buildings like Prince Hall (for kitchen appliances and DHW), Library (for humidification), Alex Hall and Gym (for DHW). Generally, it can be assumed that the occupancy rates would be at a lower level due to students being on break - which entails less heating load requirements that can be supplemented from an alternative system.

Table 11: Seasonal Shutdowns Cost Estimates & Savings

Seasonal Shutdowns	Cost Estimate	Notes – Seasonal Shutdowns
Cost Savings [of up to.]	$24-30k	For the case when the entire steam line is turned off.
Electric Water Heater	$6-12k	Each unit for buildings requiring year-round service.
Electric Humidifier	$5-10k	
Electric Steam Boiler	$6-12k	

Costs provided above are a rough estimate of pricing for each unit; there could be a lot of variability when installing these systems and interconnecting them with the existing systems, which should be kept in consideration.

2.2.2 Development of a Centralized Cooling Loop

Consolidation of cooling systems (i.e., creation of a central cooling loop).

With the development of a centralized cooling loop, the campus would be better positioned to handle future air conditioning loads than having to rely on less efficient packaged direct expansion ("DX") refrigerant systems (i.e., the typical air conditioner technology). Currently, there is a relatively small amount of air conditioning currently used on the campus, and installation of such a system would increase the overall electricity consumption. However, as buildings on campus undergo HVAC and envelope upgrades, it is worth considering this measure to allow buildings the ability of cooling and expanding their utility.

Given this, this option wasn't explored further at this point in time – namely because it would increase electricity consumption and greenhouse gas emissions. However, it may be something worth considering while completing the hydronic conversion of the campus' heating systems. Consider that the plan for such a conversion would already require a contractor to organize for the installation of a hydronic distribution system through the buildings, it would simply be the additional cost of the cooling piping to incorporate it into such a project. Then the campus could either connect such a system to either a ground source heat pump system or some other centralized cooling system – or perhaps it interconnects a few such cooling systems (i.e., think of the chiller in the library and an additional chiller added to the rooftop of another building). Given the wide range of options and objectives that such a project could incorporate, the costing for such a project varies significantly, as do the ongoing operational and maintenance costs.

2.2.3 Plug Load Control System

Implementation of plug-load control system.

Plug loads refer to energy used by equipment that is plugged into an outlet. Key plug loads include computer and monitors, printers, and copiers. Implementation of a plug-load control system allows for automatic disconnection from power when appliances are not in use, and can save up to 5-25% of electricity costs. Implementation of a successful plug load management system requires coordination from the people who use the equipment, those who maintain the equipment, as well as those who may determine which types of equipment are purchased/leased. They will be valuable contributors to identify the true system needs, and allow the facility staff to appropriately design / choose the schedules. Plug loads are significant factors in energy budgets and there are no-cost and low cost options available to reduce plug loads. Reducing plug load electricity consumption will have a direct impact on GHG emissions, as the electricity emission factor is the highest in Nova Scotia out of all provinces in Canada.

Some solutions include:

- Enabling power management features in computers, copiers, and printers;

- Installing schedule timed plug strips;
- Energy efficient equipment / Energy Star equipment;
- Establish effective energy policies; and
- Staff Training and Occupant Awareness.

Table 12: Plug Load Control System Cost Estimates

Building	Cost Estimate	Notes – Plug Load Control System
Campus Buildings	$25-35K	

2.3 Financial Risks

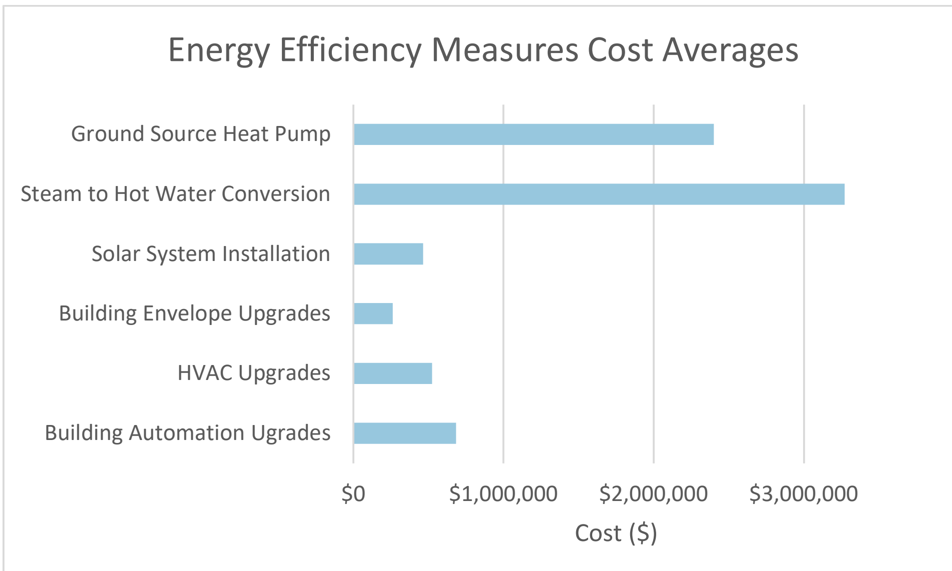


Figure 1: EEM Cost Estimates

As Canada and other countries around the world are recovering from the pandemic, extreme inflation has been occurring here and globally. Statistics Canada release of its latest numbers show an 8.1% increase in the Consumer Price Index compared to last year, and in Halifax consumer prices increased 9.1%. Canada's inflation rate currently is at its highest for the past 40 years (7.7% in May of 2022).

Therefore, it is a challenge to estimate construction and project costs at this time. The numbers listed in this study were based off 2021 construction costing data and updated to reflect the significant inflation experienced throughout the first half of 2022, so there is a very high likelihood that the cost estimate numbers may rise an additional 10-20% (+) in the short term.

As discussed above, alongside the various construction cost estimates provided, a high-level summary of the probable construction cost to implement the sustainability improvement measure within each building, along with a total for the campus, was provided for each measure. The cost estimate has been provided as a range recognizing uncertainty within the estimate. Given that the project is at a preliminary design stage (i.e., pre-schematic design) and specific details and quantities for the project are not yet available, typically such an estimate is expected to be within ±25% of the construction project value. However, it's also important to note that recent global events (i.e., ongoing COVID-19 recovery, the Ukraine crisis, increasing global oil prices, uncertainty in manufacturing and raw material pricing, etc.) continue to significantly impact construction costs locally and, as a result, relatively accurate cost estimating and scheduling is becoming increasingly challenging.

In addition to these geo-political forces impacting local construction pricing, the impact on local market is also further compounded by a significant labour shortage which is impacting some trades more so than others. There is a significant number of construction projects underway within the greater-Halifax area and not only are those projects experiencing material delivery issues but they're also experiencing labour shortages that are not only impacting project schedules but also project budgets. Given that most contractors are busy with extensive work backlogs and the freedom to pick among the many competing potential projects, the tender bid prices being received are demonstrating this with construction pricing within the last 6-8 months often exceeding initial estimates by as much as 40-80%. In speaking with various representatives throughout the construction industry, this is anticipated to slow and fizzle over the next 6-12 months as the recent changes made by the Bank of Canada work to reduce inflation, as several major projects locally are finished and housing prices (potentially) cool-off, and, perhaps most importantly, as design and construction teams better learn how to deal with the new realities of a post-COVID world and the construction impacts that go along with it.

3.0 Energy Efficiency Measures Summary

The following table highlights the primary energy efficiency measures recommended in this report.

Table 13: Energy Efficiency Measures Summary

Sustainability Improvement Measure	Description
Building Automation	Applies for all buildings - EMCS upgrades (incl. scheduling, measurement, pneumatic to electronic, additional heating zones).
HVAC Upgrades	For Library, Prince Hall, New Academic (incl. Link): - CAV to VAV conversion. - Building-wide Recommissioning For Arts & Admin Bldg: - Wardroom A/C unit modifications. - Server Room A/C units modification. - Building-wide Recommissioning. For Alex Hall, Gym, Tri Bays: - No further upgrades, consideration being given to retrofitting system fans with VFDs or implementing an energy recovery system
Building Envelope	For Tri Bays, Arts & Admin, New Academic (incl. Link), Prince Hall, Alex Hall: - Envelope upgrades (incl. air sealing, window replacements). For Library, Gymnasium: - No further upgrades, consideration being given to minor envelope improvements such as sealing and strategic window replacements.
Solar Energy	Campus Central System: - Installation of a 100 kW photovoltaic array, installed on Prince Hall and New Academic Building roofs.
Steam to Hot Water	For all buildings: - Convert central steam distribution to building to hot water distribution. - Convert steam radiators to hydronic radiators (AA, Cochran, Radical, & Middle). Campus Central System: - Convert centrally distributed steam piping to hydronic piping.
Geothermal Energy	Campus Central System: - Installation of ground source heat pump system, interconnection with heating and cooling central loops.

3.1 Pathways Summary

	Energy Efficiency Measures Implemented
Pathway 1	EMCS Upgrades & Lighting Controls
Pathway 2	Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Controls
Pathway 3	Steam to Hydronic Conversions, Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Controls
Pathway 4	GSHP, Steam to Hydronic Conversions, Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Controls
Pathway 5	Solar Energy, Building Envelope Upgrades, EMCS & Lighting Controls
Pathway 6	Building Envelope Upgrades, EMCS & Lighting Controls
Pathway 7	Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Controls
Pathway 8	Steam to Hydronic Conversions, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Controls
Pathway 9	GSHP, Steam to Hydronic Conversions, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Controls

3.2 Results and Graphs

The following charts display various comparisons of all the scenarios. These charts offer visual insights on each pathway as it is compared with its peers in terms of electricity-, steam-, carbon-savings, and financial costs.

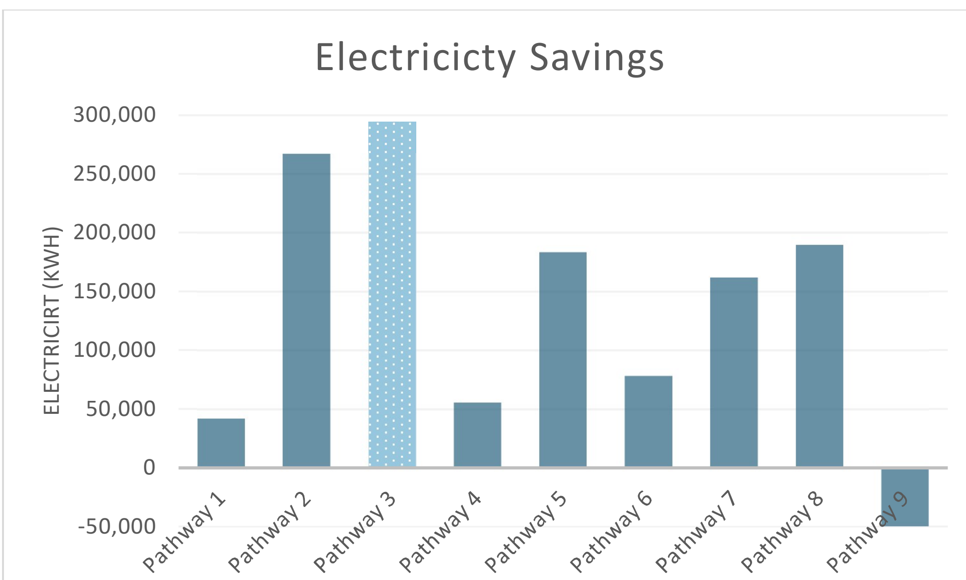


Figure 2: Electricity Savings

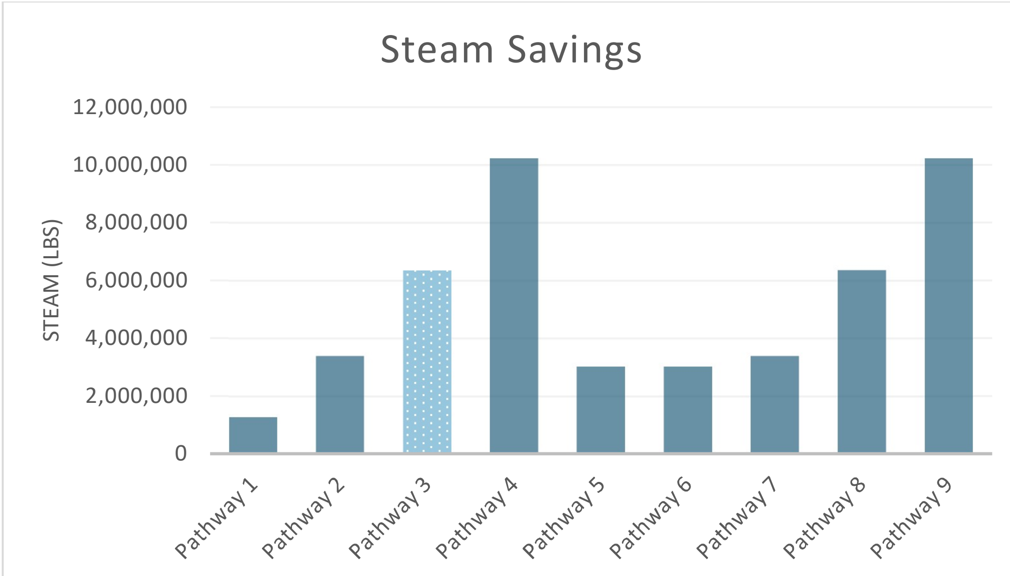


Figure 3: Steam Savings

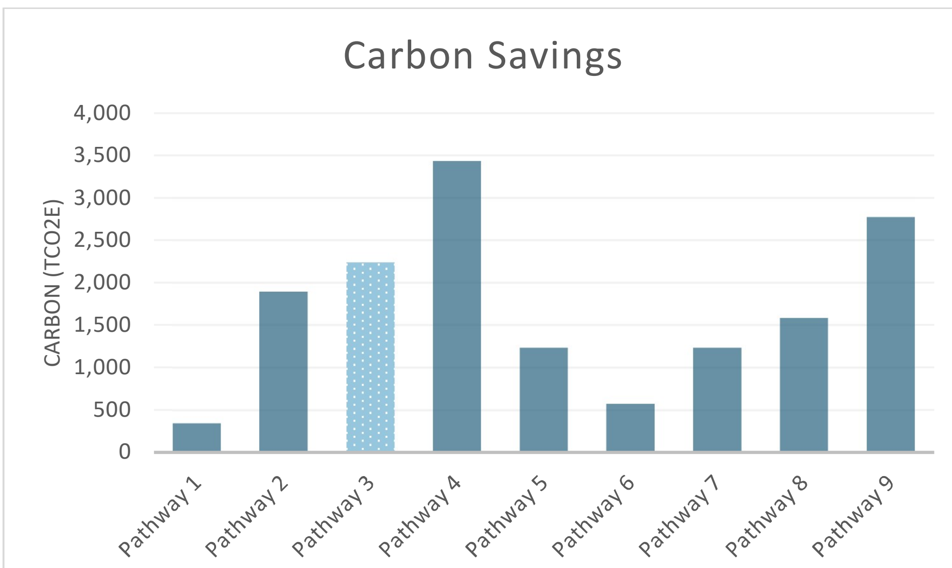


Figure 4: Carbon Savings

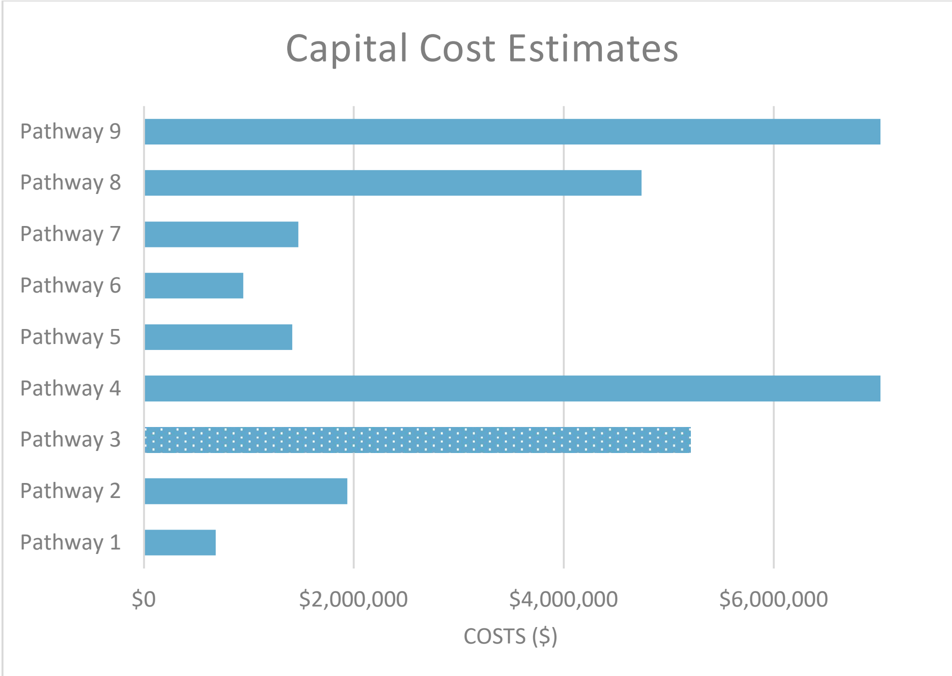


Figure 5: Capital Costs Estimates

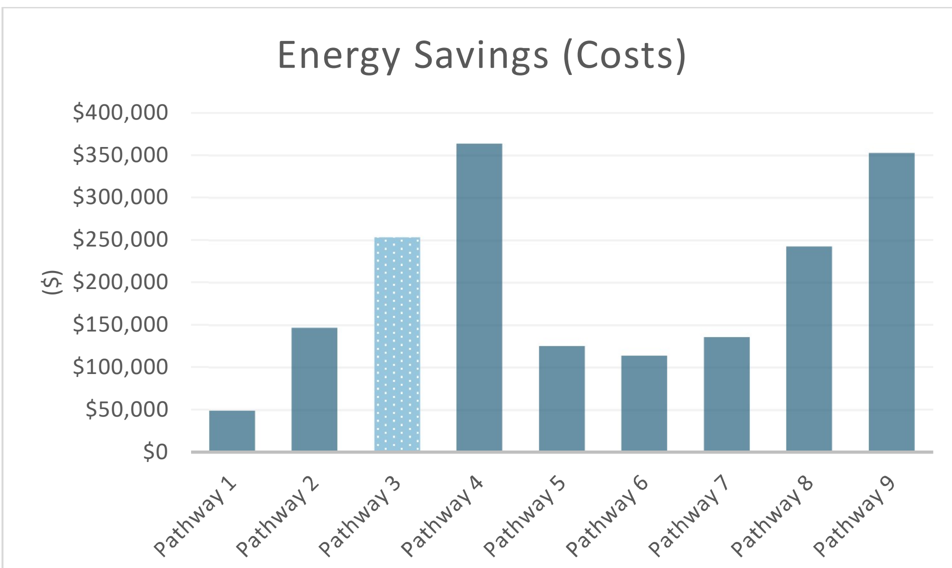


Figure 6: Energy Savings (Costs)

4.0 Implementation Approach

The approach when creating the energy strategy was to evaluate the various options to be implemented in the University within a five phase timeline. These phases are not time dependent but rather a representation of the order in which the measures could be implemented in a rational approach that allows the University an opportunity to pause and collect information before progressing to each subsequent step or phase. It is recommended that the measures that have the least interruption to the occupants and university functioning would be implemented first.

The following table summarizes the measures implemented for each year during the summer months, keeping in mind the busy school semesters during fall and winter. These guidelines are high-level timeline estimates and can vary considerably upon feedback and discussions. Next, the implementation plans will be presented for Scenario #1 (i.e., Pathway #3 in Table 1), and Scenario #2 (i.e., Pathway #4 in Table 1) as follows. Please note that the dates provided below are intended only to provide an indication of the possible scheduling requirements and the corresponding impact anticipated to University operations (i.e., work shown occurring during the summer months should be considered moderately disrupting).

Table 14: Rough Implementation Timeline – Pathway #3

	Target Date	Measures Implemented
Phase 1	Summer 1 [May-August]	Phase 1: The objective is to get control of things, establish a baseline, and implement the simplest retrofits for the buildings. Measure(s): Lighting and Building Automation
Phase 2	Summer 2 [May-August]	Phase 2: focuses on upgrading outdated A/C systems and recommissioning the rest of the buildings with the new measures implemented. Measure(s): HVAC Upgrades
Phase 3	Spring & Summer 3 [April-November]	Phase 3: brings in the addition of renewable energy on campus, as well as upgrading the existing building envelope for poorly insulated buildings. Measure(s): Building Envelope and Solar Energy
Phase 4	Summer 4 [May-October]	Phase 4: focuses on upgrading the campus steam system to hot water and converting steam piping / radiators to hydronic. Measure(s): Steam based Heating to Hot Water
Phase 5	Summer 5 [May-October]	Phase 5: would allow for implementing existing measures not yet completed, in addition to testing, integration, auditing and finalization.

Table 15: Rough Implementation Timeline – Pathway #4

Phase 1 to 4	Summer 1- 4 [May-October]	Phases: 1- 4 would follow the previous implementation (Table 17) and would be combined with preparation work required for the Geothermal infrastructure.
Phase 5	Summer 5 [May-October]	Phase 5 would allow for implementing existing measures not yet completed, in addition to testing, integration, auditing and finalization. Measure(s): Geothermal Energy (GSHP). That is, installation of a ground source heat pump and interconnection with the central heating and cooling loops.

5.0 Conclusions and Recommendations

An energy efficiency feasibility study was conducted on the University of King's College campus to examine the current energy systems in place. Seven buildings were examined and involved in a detailed 8,760-hour energy simulation to analyze the impacts and costs of various energy efficiency measures.

Dillon recommended two scenarios as follows:

Scenario #1 (i.e., Pathway #3 in Table 1), which includes the following measures:

- EEM-1: Building Automation Controls Optimization
- EEM-2: Lighting Upgrades & Controls (incl. scheduling, occupancy sensors, daylight controls).
- EEM-3: HVAC Upgrades (CAV to VAV, retrofitting fans with VFDs, implementing ERV's)
- EEM-4: Building Envelope Upgrades (incl. air sealing, window replacements, etc.)
- EEM-5: Photovoltaic Array on Prince Hall and New Academic Building Roofs
- EEM-6: Conversion of central steam distribution to building to hot water distribution.

This yields saving estimates of,

- -294,500kWh (42.4%) of electricity savings; and
- -8,000 GJ (60.2%) of steam savings; and
- -2,240 tonnes (44.7%) of CO_2e emissions

Scenario #2 (i.e., Pathway #4 in Table 1), it utilizes all EEM's in the first scenario (Pathway #3) in addition to the geothermal EEM of 'Ground Source Heat' pump. This is a strong candidate given that the load is nearly fully electrified, and GHG emissions associated with this load would be reduced as the overall percentage of renewable power supplied by the grid increases.

The resultant savings from Pathway #4 are:

- -55,300kWh (8%) of electricity savings; and
- 12,900 GJ [10,200,000 lb] (96.8%) of steam savings; and
- 3,430 tonnes (68.3%) of CO_2e emissions

Of importance, the University is further encouraged to explore the other scenarios discussed in this report as well. For example, Pathways: #6, #7, and #8 are potential candidates if the solar technology is not desired (please check section 3.2 for visual comparisons of all scenarios).

It must be noted that the prime goal of this study was to identify the energy savings opportunities that likely meet the University sustainability targets. Energy savings and installation costs are estimates only, and detailed design is always recommended before proceeding. The saving calculations are our estimates of saving potentials through modeling and are not a guarantee. Our opinions of probable costs are intended for budgeting purposes and are subject to change due to inflationary trends.

The scope of work and the actual costs of the work recommended can only be determined after a detailed examination of the site element in question, understanding of the site restrictions, kind considerations of the effects on the ongoing operations of the site/building, definition of the construction schedule, and preparation of tender documents.

As discussed above, alongside the various construction cost estimates provided, a high-level summary of the probable construction cost to implement the sustainability improvement measure within each building, along with a total for the campus, was provided for each measure. The cost estimate has been provided as a range recognizing uncertainty within the estimate. Given that the project is at a preliminary design stage (i.e., pre-schematic design) and specific details and quantities for the project are not yet available, typically such an estimate is expected to be within ±25% of the construction project value. However, it's also important to note that recent global events (i.e., ongoing COVID-19 recovery, the Ukraine crisis, increasing global oil prices, uncertainty in manufacturing and raw material pricing, etc.) continue to significantly impact construction costs locally and, as a result, relatively accurate cost estimating and scheduling is becoming increasingly challenging.

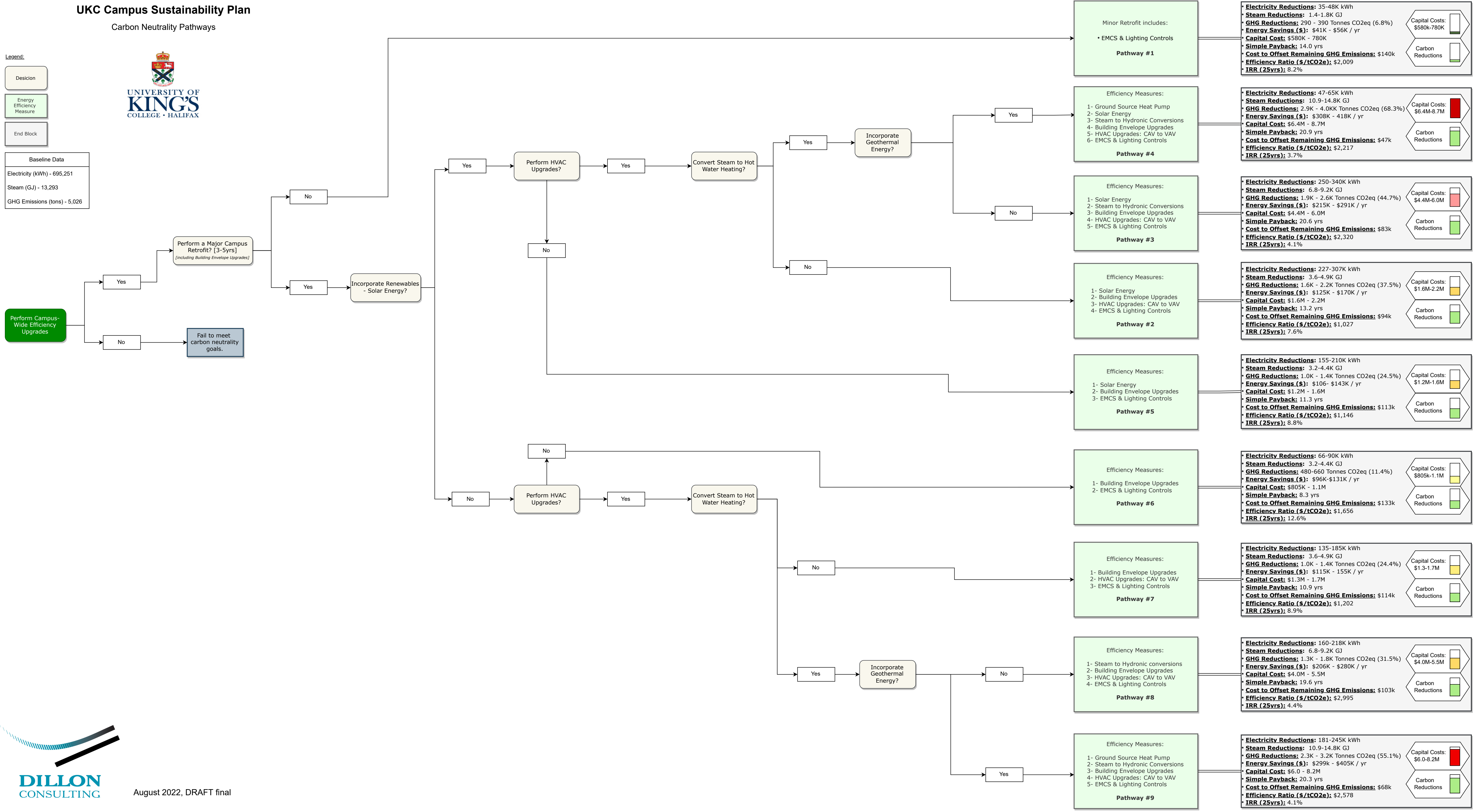
In addition to these geo-political forces impacting local construction pricing, the impact on local market is also further compounded by a significant labour shortage which is impacting some trades more so than others. There is a significant number of construction projects underway within the greater-Halifax area and not only are those projects experiencing material delivery issues but they're also experiencing labour shortages that are not only impacting project schedules but also project budgets. Given that most contractors are busy with extensive work backlogs and the freedom to pick among the many competing potential projects, the tender bid prices being received are demonstrating this with construction pricing within the last 6-8 months often exceeding initial estimates by as much as 40-80%. In speaking with various representatives throughout the construction industry, this is anticipated to slow and fizzle over the next 6-12 months as the recent changes made by the Bank of Canada work to reduce inflation, as several major projects locally are finished and housing prices (potentially) cool-off, and, perhaps most importantly, as design and construction teams better learn how to deal with the new realities of a post-COVID world and the construction impacts that go along with it.

Appendix A

Decision Tree

UKC Campus Sustainability Plan

Carbon Neutrality Pathways



August 2022, DRAFT final

UKC Campus Sustainability Plan

Carbon Neutrality Pathways

Pathways #1-5

August 2022, DRAFT final

UKC Campus Sustainability Plan

Carbon Neutrality Pathways
Pathway #6-9

August 2022, DRAFT final

Appendix B

Project Overview

Project Overview

The detailed energy assessment consists of an on-site facility assessment, a utility analysis, and a detailed review and analysis of Energy Efficiency Measures (EEMs). The energy assessment report is organized as follows:

- Introduction;
- Facility Description;
- Energy Efficiency Measures;
- Implementation Guidelines; and
- Conclusions and Recommendations.

The University of King's college provided the following documents to Dillon for review:

- Utility records;
- Facility drawings (floor plans & mechanical drawings);
- Operations and control manuals;
- Lighting inventory spreadsheet; and
- Siemens design brief of existing buildings (2017)

The following appendices referenced below provide further background that forms part of this report:

- Strategy Sheet – Years 1 to 5
- Modeling Data Results
- Decision Tree

The assessment took into account the seven campus buildings including:

- Alexandra Hall, including the Chapel and Pit;
- Library;
- Prince Hall;
- New Academic Building including the Link;
- Gymnasium;
- Arts & Administration including the North Pole and Cochran Bays; and
- Tri-Bays including the Radical, Middle and Chapel Bays

The report highlights the strategies and approach in selecting the appropriate energy efficiency technologies. Energy modeling was conducted to establish a performance baseline and each building was involved in a detailed 8,760-hour energy simulation to analyze the impacts and costs of various energy efficiency measures. Several pathways were identified with the focus of carbon neutrality, and were compared on a number of factors such as capital cost required, GHG emission reductions, and energy savings. Recommendations are provided at the end of the report.

The following table summarizes key client information related to this project.

Table 16: Key Client Information Summary

Project Number - #21-322	
Customer Name	University of King's College
Site Address	6350 Coburg Rd, Halifax, Nova Scotia
Contact Person	Ian Wagschal
Client Information	ian.wagschal@ukings.ca
Utility Provider	Electricity - NS Power Steam - Dalhousie University

Appendix C

Facility Description

Facility Description

The following section summarizes the existing equipment and systems currently on campus.

Table 17: Building Systems Description

Building	Description	Current Systems
Campus Central Steam		• The central steam system serves about 240,000 sq.ft. and buildings with an occupancy of about 1,000 people. Steam is supplied from DAL's central service as a high-pressure steam system into the basement of the North Pole Bay (i.e., part of the Arts & Administration building).
Alexandra Hall, incl. Chapel & Pit	1969, 47,600 sq.ft., 5-storey residence	• Hydronic Heating, two (2) 1,000-MBH (estimated) steam convertors. Circulated by two (2) (duty/standby) Grundfos UPS-80 with 3-HP motors. Operates based on outdoor air temperature reset. • A single zone valve for radiators services many rooms with a common single set-point pneumatic thermostat. No schedules. • Ventilation limited to four (4) exhaust fan systems without make-up air systems. Controlled by time-of-day schedule. • Domestic hot water is produced by an indirect hot water tank (on hydronic system) and completed with recirculation pump. No schedules.
Library	1991, 24,900 sq.ft., 2-storey library	• Central air handling system operating as constant volume with terminal reheat system, with 13,400-CFM supply fan at 10-HP and 10,000-CFM return fan at 5-HP. Heating is provided within the unit via a steam heating coil, chilled water is provided by a water-cooled chiller and humidification is generated with a steam-to-steam humidifier. • Dedicated exhaust fans, including washrooms (EF1, 1,400-CFM, 0.25-HP), archivist room (EF2, 290-CFM, 0.33-HP), and a transfer exhaust fan for the elevator machine room. • Two (2) 1,000-MBH steam convertors located in the basement provide hydronic heating. Circulated by two (2) (duty/standby) circulators with 2-HP motors. Pneumatic controls throughout. • Primary building air conditioning is produced using a McQuay WGZ water-cooled 40-tonsR chiller providing four (4) stages of cooling circulated by two (2) (duty/standby) circulators with 3-HP motors. Condenser water is circulated by two (2) (duty/standby) circulators with 3-HP motors through an Evapco LSTA-4-61 cooling tower using a fan with a 2-HP motor. • The archives area uses a 2.5-tonsR split system (equivalent to Liebert iCOM). • Domestic hot water is produced by a 15-kW electric hot water tank and complete with a recirculation pump. No schedules.

Building	Description	Current Systems
Prince Hall	1961, 20,100 sq.ft., 2-Storey cafeteria	• One (1) 1,000-MBH (estimated) steam converter located in the basement provides hydronic heating for the facility's radiators. Circulated by two (2) (duty/standby) circulators with 2-HP motors. Pneumatic controls throughout. • One (1) 1,000-MBH (estimated) steam converter located in the basement provides glycol heating water for four (4) reheat coils used to maintain the high bay area at set-point. Circulated by two (2) (duty/standby) circulators with 1-HP motors. Pneumatic controls throughout. • The loading dock and breezeway entrance all use electric force flow heaters. • There are four (4) air conditioning units dedicated to the cafeteria area. These are 5-tonsR packaged HVAC units with 1.5-HP supply fans, outdoor air economizer packages and a minimum outdoor airflow of 1,000-CFM. Controlled by time-of-day schedule. • A 20-tonsR packaged HVAC unit with 7.5-HP supply fan, 2-stages of cooling and 54-kW heating coil provides HVAC for the lower levels. The unit is equipped with an outdoor air economizer package and power relief exhaust fan. The system operates as a CAV system without a known time-of-day schedule. • Dedicated exhaust fans, including pizza oven hood (EF1, 800-CFM), kitchen exhaust hood (EF2, 10,000-CFM, 2-HP), electrical room exhaust (EF3, 1,000-CFM, 1-HP), washroom (EF4, unknown), bakery exhaust (EF5, 1,100-CFM, 0.25-HP), washroom breezeway (EF?, unknown), convertor room (EF?, 800-CFM, 0.25-HP). • Domestic hot water is produced by an 825-MBH (estimated) steam converter located in the basement complete with a recirculation pump and indirect storage tank. No schedules. Kitchen dishwasher complete with a 15-kW booster heater.
New Academic Building incl. Link	2001, 36,600 sq.ft., 4-storey classroom	• Central air handling system operating as constant volume dedicated outdoor air system, with 21,165-CFM supply fan at 30-HP equipped with a VFD without a speed control program (typically operating between 60-80%) and 19,500-CFM return fan at 20-HP without a VFD. Heating is provided within the unit via a glycol heating coil, a glycol run-around loop (with the exhaust) complete with a 3-HP circulator, no cooling is provided and humidification is generated with a steam-to-steam humidifier (this has been disabled). Electronic controls throughout, minimal scheduling or resets. • One (1) 1,305-MBH steam convertor located in the basement provides hydronic heating. Circulated by two (2) (duty/standby) circulators with unknown motor size. Electronic controls throughout, minimal scheduling or resets.

Building	Description	Current Systems
		• One (1) 565-MBH steam converter located in the basement provides glycol water heating. Circulated by one (1) circulator with an unknown motor size. Electronic controls throughout, minimal scheduling or resets. • Domestic hot water is produced by a 15-kW electric hot water tank and complete with a recirculation pump. No schedules.
Gymnasium	1960, 21,900 sq.ft., 2-storey athletic	• Student locker room and studio ventilation system with 100% outdoor and exhaust CAV systems, each providing 1,000-CFM. A steam heating coil and steam reheat coils for each of the zones provide temperature conditioning. No scheduling or occupancy control. Pneumatic controls only. • Dance studio has a 5-tonsR water-cooled unit. No scheduling or occupancy control. • Varsity and staff lockers have a dedicated exhaust fan. No scheduling or occupancy control. Pneumatic controls only. • The gym and fitness studio are served by a Trane Climate Changer with a 2-speed supply fan with a 2-HP motor and an estimated flow rate of 3,000-CFM at high-speed. There are two (2) exhaust fans, each with 1-HP motors. No heating or cooling, mixed air temperature control only. No scheduling or occupancy. Pneumatic controls only. • Basement classroom has a dedicated HRV. • One (1) 1,000-MBH (estimated) steam converter located in the basement provides hydronic heating for the facility's radiators. Circulated by two (2) (duty/standby, manually switched) circulators with unknown motors. Pneumatic controls throughout. Combination of fan coil units and force flows used. • Domestic hot water is produced by an indirect hot water tank (on hydronic system) and complete with a recirculation pump. No schedules.
Arts & Administration incl. North Pole & Cochran Bays	1929, 42,200 sq.ft., 4-storey mixed use	• Central heat recovery ventilation unit serving the residence rooms and exhausts from the washrooms. • Ward room equipped with a 10-tonsR packaged AC unit. • Miscellaneous 5-tonsR packaged AC units serving the Committee, IT, Bar Cooler, Laundry and Common rooms. • Additional split AC systems serve the Bursar's office and computer laboratories 1 and 2. There are also a few areas (e.g., computer laboratory 3) that are seasonally outfitted with portable window style air conditioning units. • One (1) unknown steam converter located in the North Pole basement and one (1) unknown steam converter located in the Cochran Bay basement provide hydronic heating for the facility's radiation. Each is circulated by two (2) (duty/standby, manually switched) circulators with unknown motors. Pneumatic controls throughout.

Building	Description	Current Systems
		• The Arts & Administration as well as the Cochran Bay sections of the building are served by steam radiation, whereas the North Pole Bay has been converted to hydronic radiation. • Domestic hot water is produced by an indirect hot water tank (on a hydronic system) and complete with a recirculation pump. No schedules. System recently renovated. • Facility has a 400-ft long snow melt system along the edge of the building. No known controls associated with the system.
Tri-Bays incl. Radical, Middle & Chapel Bays	1929, 42,000 sq.ft., 4-storey mixed use	• No mechanical drawings available, floor plans only. • Based on a walk-through of the facility, as well as discussions with the facility operators, this building is quite similar to the Arts & Administration building noted above. The entire building is heated using steam radiation (i.e., no hydronic heating conversion to-date).

Please note that upgrades to lighting and lighting control systems (i.e., scheduling, occupancy sensors, and daylight controls) as well as exterior lighting systems were considered, however, it was noted that the recommended upgrades have already been completed.

Lighting solutions are integral to reducing carbon emissions and for efficient operation of a carbon neutral building. Smart lighting control systems employ techniques to automatically control lights and adjust light intensities based on occupants' visual comfort and other factors. It considers parameters such as natural daylight available in the building, user preferences, user movement, and occupancy in the building to control illuminance, with the goal to achieve energy efficiency without sacrificing the visual comfort of the occupants.

Lighting upgrade projects tend to be considered a low risk project, both technically and financially, as the scope of work is often well contained and limited. As part of this analysis we completed a detailed take-off of the lighting quantities and types throughout the campus, as a result, the energy savings and associated replacement costs are well documented and understood. Areas of the campus that have already had a lighting upgrade – or were otherwise renovated with modern fixtures – were excluded from the analysis.

The energy supply for the University of King's college comes from Dalhousie University central heating plant, which consists of a natural gas boiler system. Dalhousie operates a large central heating and cooling plant and a district energy network which services all three Halifax campuses and King’s. The steam supplied to King’s is located in the basement of the North Pole Bay (i.e., part of the Arts & Administration building) and distributed to the rest of the campus buildings. The central steam system serves about 240,000 sq.ft. of buildings with occupancy of about 1,000 people.

The years taken in consideration in the analysis for the energy supply were 2017-2019, as they were the most accurate representation of the university in session prior to the COVID-19 pandemic. The peak consumption load was recorded at 4,200 lbs/hr.

Table 18: Summary of Steam Data

Year	Consumption (lbs)	Cost ($)
Jan-2017 to Dec-2017	10,529,274	$225,562
Jan-2018 to Dec-2018	10,490,858	$199,647
Jan-2019 to Dec-2019	10,343,595	$232,396

Appendix D

Energy Simulation Methodology

Energy Simulation Methodology

Energy simulation was completed using eQUEST building energy simulation tool and Microsoft Excel based calculations. The modeling accounted for various building aspects including the building footprint, number of floors, square footage, weather data, HVAC systems, envelope construction, lighting power density and more. The campus steam consumption baseline was established through the utility bills provided by the university.

The approach for modeling first consisted of data collection, reviewing site conditions, and reviewing available reports / drawings / utility bills provided by the University. Building schedules were set when the school was in session and out of session. The schedules incorporated in the energy model analysis are:

Table 19: University Schedules Modelled

Schedule	Dates
Winter Semester [8am-7pm]	Jan 7th - Feb 22, Mar 1 - Apr 23
Fall Semester [8am-7pm]	Sep 6th - Dec 17
Summer Semester [8am-5pm]	June 7 - Aug 20
Closed (Holiday, Reading Week, etc.)	Weekends & all dates in between.

This allowed for creating the "Baseline" models - which are the campus buildings under existing energy systems and conditions. The baseline models were simulated over a 1 year period using Halifax's weather data, in which the annual load and consumption profiles were established. Energy efficiency measures were then simulated to identify and compare potential saving opportunities. This was completed for the seven buildings, and the cost, energy, and carbon savings were established.

The measures modeled in the energy simulation accounted for:

- Building automation controls optimization and improvements.
- Upgrades to lighting Systems and controls.
- Building envelope improvements including minor renovations and reduced air leakage.
- HVAC Upgrades: converting CAV systems to VAV for 4 buildings.
- Conversion from a steam-based heating distribution system to a hydronic heating distribution system.
- Installation of Solar Panels on building roofs.
- Modeling a geothermal grid/loop (ground source heat pump) to energize the heating and cooling loops.

The "Energy Efficiency Measure Wizard" on eQUEST was used to test and compare the results of each measure. The results were tabulated in "pathways" and compared in section 6 of the report.

Other measures identified, but not included in the model are:

- Seasonal shutdown of the campus heating system during the summer months.
- Consolidation of cooling systems (i.e., creation of a central cooling loop) and conversion of air-source air conditioning systems (i.e., direct expansion or heat pump units) to water-source air condition systems (i.e., heat pumps).
- Implementation of plug-load control system.

These measures weren't included for a few reasons, not the least of which is they have a significant amount of variability depending on the assumptions made. For example, the implementation of a plug-load control system would likely reduce energy consumption within a building by 5-25% depending on the nature of the loads (which for this application are quite unpredictable) and the structure of the electrical distribution system. While this measure wasn't broken out, an allowance (both in terms of cost and savings) was made with the general energy management and control system upgrades to include the more significant loads.

Regarding the consolidation of the cooling systems, given the relatively small amount of air conditioning currently used on the campus, this would actually increase overall energy consumption, however, it would better position the campus for future air conditioning loads (i.e., they would have a central system into which they could connect) without having to rely on package DX systems which are one of the more inefficient means of air conditioning. It would increase overall energy consumption at this time because the energy cost of operating a centralized system would be disproportionately high relative to the smaller load.

Given the extensive amount of data entry and inputs required to develop the energy simulation for a university campus, a high-level summary of the key inputs and conversions used for the base case energy simulation are provided below. This list is not meant to be exhaustive or all encompassing.

Table 20: Summary of Inputs

Energy Simulation Program	eQUEST
Number of Simulated Hours	8760 hours per year
Weather Data	Halifax, Nova Scotia
Building Envelope Characteristics	Varies
Lighting Characteristics	Based on lighting inventory sheet
Windows Characteristics	Double Clr Windows - Air Fill

Infiltration	Varies (0.04 to 0.1 cfm per square foot of exterior wall area)
HVAC Systems	Based on Siemens design briefs & building facility descriptions
Building Operation Schedule	Provided above
Heating Set point	Occupied 70°F Unoccupied 64°F
Cooling Set point *[for buildings with cooling – library & prince hall]*	Occupied 76°F Unoccupied 82°F
HVAC Schedule	Systems operates 1 hour before open and 1 hour after close
Steam Conversion Rate	1,194 BTUs for every pound of steam
GHG Emission Factor: Steam	48.75 gCO2e / GJ
GHG Emission Factor: Electricity	629.7 gCO2e / kWh
Utility: Steam Rate	$35 / 1000lb
Utility: Electricity Rate	$0.1057 / kWh

The calibration process consisted of running the simulation program with the default software inputs for typical building characteristics. Iterations followed by modifying the building envelope insulations, window properties, and infiltration levels to more closely match the annual heating data for the campus. Additionally, the interior lighting load consumption has been calibrated with existing data provided by the university. Plug and miscellaneous loads were accounted for in the simulation through software default inputs and remained constant when adding the EEM's. The modeling of the seven buildings were calibrated against the actual steam consumption data from 2017-2019 and is within 5% of the annual consumption value. The baseline model has been used as the basis for the end-use breakdowns of the EEM's in the subsequent sections.

It is worth noting that eQUEST does not have district steam heating as a heating system option, so a natural gas condensing HW Boiler with low efficiency has been taken into consideration, and the steam usage equivalent has been converted in the analysis.

The annual baseline energy consumption for the campus has been determined as follows in the Energy Model. With the baseline established, energy conservation measures (ECM's) can be applied to the campus buildings and the resulting savings estimated. ECM's will be grouped in combinations or "Pathways," as demonstrated in the following section. Steam consumption data for 2019 is also listed in the table below for reference comparison.

Table 21: Summary of Simulated Baseline Year Energy Consumption

Year	Electricity - Model		Steam - Model		Steam – 2019 (actual)
	Consumption	Cost	Consumption	Forecasted Cost (2022)	Consumption
	(kWh)	($)	(lbs)	($)	(lbs)
Model Baseline	695,251	$73,494	10,553,015	$369,355	10,343,595

With rising costs and inflation, it is worth mentioning the expected increase in utility and construction costs. At Dalhousie, the rate of steam costs is expected to rise by 30% in 2022 [as per feedback from facilities], and forecasted to be over $35/1000lb by October 2022. For this study, it was considered at $35/1000lb of steam.

Appendix E

Strategy Sheet

Baseline Notes

Electricity Consumption (kWh)	*695,251*
Steam Consumption (GJ)	*13,293*
Steam Consumption (lbs)	*10,553,015*
Modelling Tolerance	*(±) 15%*
eGHG Emissions (tons)	*5,026*

	Year 1 - "Getting Control of Things and Confirming Where we Are"							
	Measure(s) Implemented	**eGHG Reduct. (ton)**	**Electricity Reduct. (kWh)**	**Heating Reduct. (GJ)**	**Cost ($)**	**Cost/Model Uncertainty**	**Technical Risk**	**Code Violation Concern**
Alexandra Hall (incl. Chapel and Pit) (1969, 47,600 sq.ft., 5-storey residence)	- EMCS upgades (incl. scheduling, measurement, pneumatic to electronic, additional heating zones). - Lighting controls (incl. scheduling, occupancy sensors, daylight controls).	-55	-6,448	-303	$114,000	(±) 15%	LO	NO
Library (1991, 24,900 sq.ft., 2-storey library)	- EMCS uprades (incl. scheduling, measurement). - Lighting controls (incl. scheduling, occupancy sensors, daylight controls).	-36	-5,258	-58	$60,000	(±) 15%	LO	NO
Prince Hall (1961, 20,100 sq.ft., 2-storey cafeteria)	- EMCS uprades (incl. scheduling, measurement, pneumatic to electronic, additional heating zones). - Lighting controls (incl. scheduling, occupancy sensors, daylight controls).	-44	-4,668	-301	$81,000	(±) 15%	LO	NO
New Academic (incl. Link) (2001, 36,600 sq.ft., 4-storey classroom)	- EMCS uprades (incl. scheduling, measurement). - Lighting controls (incl. scheduling, occupancy sensors, daylight controls).	-58	-7,403	-228	$60,000	(±) 15%	LO	NO
Gymnasium (1960, 21,900 sq.ft., 2-storey athletic facility)	- EMCS uprades (incl. scheduling, measurement, pneumatic to electronic, additional heating zones). - Lighting controls (incl. scheduling, occupancy sensors, daylight controls).	-47	-5,981	-199	$60,000	(±) 15%	LO	NO
Arts and Administration (incl. North Pole, Cochran, and Wardroom) (1929, 42,200 sq.ft., 4-storey mixed-use)	- EMCS upgades (incl. scheduling, measurement, additional heating zones). - Lighting controls (incl. scheduling, occupancy sensors, daylight controls).	-66	-7,979	-321	$114,000	(±) 15%	LO	NO
Tri-Bays (incl. Radical, Middle, and Chapel) (1929, 42,100 sq.ft., 4-storey mixed-use).	- EMCS upgades (incl. scheduling, measurement, pneumatic to electronic, additional heating zones). - Lighting controls (incl. scheduling, occupancy sensors, daylight controls).	-34	-3,977	-185	$114,000	(±) 15%	LO	NO
Campus Central System	- EMCS upgrades (incl. scheduling, measurement). - Additional zone isolation valves and control. - Lighting Upgrades for Exterior & Cochran Bay ***- NOTE: COSTS AND REDUCTIONS INCLUDED IN BUILDINGS.***	0	0	0	$81,000	-	LO	NO
Sub-Total	-	-340	-41,715	-1,595	$684,000	(±) 15%	-	-
Percentage of Current Consumption	-	7%	6%	12%	-	(±) 15%	-	-
Amount Remaining to Carbon Neutral (or Net Zero)	-	4,686	653,536	11,698	-	(±) 15%	-	-

	Year 2 - "Fixing Old A/C Systems and Recommissioning Everything Else"							
	Measure(s) Implemented	**eGHG Reduct. (ton)**	**Electricity Reduct. (kWh)**	**Heating Reduct. (GJ)**	**Cost ($)**	**Cost/Model Uncertainty**	**Technical Risk**	**Code Violation Concern**
Alexandra Hall (incl. Chapel and Pit) (1969, 47,600 sq.ft., 5-storey residence)	- No further upgrades, consideration being given to retrofitting system fans with VFDs or implementing an energy recovery system.				$0	(±) 15%	MED	YES
Library (1991, 24,900 sq.ft., 2-storey library)	- CAV to VAV conversion. - Building-wide Recommissioning.	-220	-33,679	-153	$111,000	(±) 15%	LO	NO
Prince Hall (1961, 20,100 sq.ft., 2-storey cafeteria)	- CAV to VAV conversion. - Building-wide Recommissioning.	-56	-8,690	-17	$111,000	(±) 15%	LO	NO
New Academic (incl. Link) (2001, 36,600 sq.ft., 4-storey classroom)	- CAV to VAV conversion. - Floor-Level Return Airflow Modifications. Building-wide Recommissioning.	-99	-12,889	-363	$135,000	(±) 15%	LO	NO
Gymnasium (1960, 21,900 sq.ft., 2-storey athletic facility)	- No further upgrades, consideration being given to retrofitting system fans with VFDs or implementing an energy recovery system.				$0	(±) 15%	MED	YES
Arts and Administration (incl. North Pole, Cochran, and Wardroom) (1929, 42,200 sq.ft., 4-storey mixed-use)	- Wardroom A/C unit modifications. - Server Room A/C units modification. - Building-wide Recommissioning.	-301	-41,304	-838	$168,000	(±) 15%	LO	YES
Tri-Bays (incl. Radical, Middle, and Chapel) (1929, 42,100 sq.ft., 4-storey mixed-use).	- No further upgrades, consideration being given to retrofitting system fans with VFDs or implementing an energy recovery system.				$0	(±) 15%	MED	YES
Campus Central System	- No further upgrades.	0	0	0	$0	-	-	-
Sub-Total	-	-675	-96,561	-1,371	$525,000	(±) 15%	-	-
Percentage of Current Consumption	-	13%	14%	10%	-	(±) 15%	-	-
Amount Remaining to Carbon Neutral (or Net Zero)	-	4,011	556,975	10,327	-	(±) 15%	-	-

Baseline Notes

Electricity Consumption (kWh)	*695,251*
Steam Consumption (GJ)	*13,293*
Steam Consumption (lbs)	*10,553,015*
Modelling Tolerance	*(±) 15%*
eGHG Emissions (tons)	*5,026*

	Year 3 - "Sealing the Place Up and Harvesting the Sun"							
	Measure(s) Implemented	**eGHG Reduct. (ton)**	**Electricity Reduct. (kWh)**	**Heating Reduct. (GJ)**	**Cost ($)**	**Cost/Model Uncertainty**	**Technical Risk**	**Code Violation Concern**
Alexandra Hall (incl. Chapel and Pit) (1969, 47,600 sq.ft., 5-storey residence)	- Envelope upgrades (incl. air sealing, weather stripping, window replacements).	-28	-2,735	-222	$48,000	(±) 30%	LO	NO
Library (1991, 24,900 sq.ft., 2-storey library)	- No further upgrades, consideration being given to minor envelop improvements such as sealing and strategic window replacements.	0	0	0	$12,000	-	-	-
Prince Hall (1961, 20,100 sq.ft., 2-storey cafeteria)	- Envelope upgrades (incl. air sealing, weather stripping, window replacements).	-146	-16,424	-881	$48,000	(±) 30%	LO	NO
New Academic (incl. Link) (2001, 36,600 sq.ft., 4-storey classroom)	- Envelope upgrades (incl. air sealing, weather stripping, window replacements).	-17	-2,124	-71	$48,000	(±) 30%	LO	NO
Gymnasium (1960, 21,900 sq.ft., 2-storey athletic facility)	- No further upgrades, consideration being given to minor envelop improvements such as sealing and strategic window replacements.	0	0	0	$12,000	-	-	-
Arts and Administration (incl. North Pole, Cochran, and Wardroom) (1929, 42,200 sq.ft., 4-storey mixed-use)	- Envelope upgrades (incl. air sealing, weather stripping, window replacements).	0	0	0	$48,000	(±) 30%	LO	NO
Tri-Bays (incl. Radical, Middle, and Chapel) (1929, 42,100 sq.ft., 4-storey mixed-use).	- Envelope upgrades (incl. air sealing, weather stripping, window replacements).	-19	-2,120	-121	$48,000	(±) 30%	LO	NO
Campus Central System	Installation of 100 kW photovoltaic array, installed on Prince Hall and New Academic Building roofs.	-661	-105,000	0	$465,000	(±) 15%	LO	NO
Sub-Total	-	-872	-128,404	-1,294	$729,000	(±) 30%	-	-
Percentage of Current Consumption	-	17%	18%	10%	-	(±) 30%	-	-
Amount Remaining to Carbon Neutral (or Net Zero)	-	3,139	428,571	9,033	-	(±) 30%	-	-

	Year 4 - "Finish Buttoning the Place Up and Getting Ready to Switch Off Steam"							
	Measure(s) Implemented	**eGHG Reduct. (ton)**	**Electricity Reduct. (kWh)**	**Heating Reduct. (GJ)**	**Cost ($)**	**Cost/Model Uncertainty**	**Technical Risk**	**Code Violation Concern**
Alexandra Hall (incl. Chapel and Pit) (1969, 47,600 sq.ft., 5-storey residence)	- Continuation of envelope upgrades (no additional savings or costs included). - Convert central steam distribution to building to hot water distribution.	-83	-5,781	-947	*$288,000*	(±) 15%	*LO*	*NO*
Library (1991, 24,900 sq.ft., 2-storey library)	- Convert central steam distribution to building to hot water distribution.	-10	-850	-85	*$288,000*	(±) 15%	*LO*	*NO*
Prince Hall (1961, 20,100 sq.ft., 2-storey cafeteria)	- Continuation of envelope upgrades (no additional savings or costs included). - Convert central steam distribution to building to hot water distribution.	-56	-4,721	-548	*$288,000*	(±) 15%	*LO*	*NO*
New Academic (incl. Link) (2001, 36,600 sq.ft., 4-storey classroom)	- Continuation of envelope upgrades (no additional savings or costs included). - Convert central steam distribution to building to hot water distribution.	-24	-1,003	-358	*$414,000*	(±) 15%	*LO*	*NO*
Gymnasium (1960, 21,900 sq.ft., 2-storey athletic facility)	- Convert central steam distribution to building to hot water distribution.	-71	-6,259	-656	*$237,000*	(±) 15%	*LO*	*NO*
Arts and Administration (incl. North Pole, Cochran, and Wardroom) (1929, 42,200 sq.ft., 4-storey mixed-use)	- Continuation of envelope upgrades (no additional savings or costs included). - Convert steam radiators to hydronic radiators (AA & Cochran). - Convert central steam distribution to building to hot water distribution.	-47	-3,189	-552	*$498,000*	(±) 15%	*MED*	*NO*
Tri-Bays (incl. Radical, Middle, and Chapel) (1929, 42,100 sq.ft., 4-storey mixed-use).	- Continuation of envelope upgrades (no additional savings or costs included). - Convert steam radiators to hydronic radiators (Radical & Middle). - Convert central steam distribution to building to hot water distribution.	-67	-6,040	-597	*$534,000*	(±) 15%	*MED*	*NO*
Campus Central System	- Convert centrally distributed steam piping to hydronic piping. ***- NOTE: COSTS AND REDUCTIONS INCLUDED IN BUILDINGS. CONSIDERING CENTRAL COOLING & DISTRIBUTED HEAT PUMP OPTIONS.***	0	0	0	$723,000	-	MED	NO
Sub-Total	-	-358	-27,842	-3,742	$3,270,000	(±) 15%	-	-
Percentage of Current Consumption	-	7%	4%	28%	-	(±) 15%	-	-
Amount Remaining to Carbon Neutral (or Net Zero)	-	2,781	400,729	5,291	-	(±) 15%	-	-

Baseline Notes

Electricity Consumption (kWh)	*695,251*
Steam Consumption (GJ)	*13,293*
Steam Consumption (lbs)	*10,553,015*
Modelling Tolerance	*(±) 15%*
eGHG Emissions (tons)	*5,026*

	Year 5 - "Digging into the Ground and Saying Goodbye to Steam"							
	Measure(s) Implemented	**eGHG Reduct. (ton)**	**Electricity Reduct. (kWh)**	**Heating Reduct. (GJ)**	**Cost ($)**	**Cost/Model Uncertainty**	**Technical Risk**	**Code Violation Concern**
Alexandra Hall (incl. Chapel and Pit) (1969, 47,600 sq.ft., 5-storey residence)	- No further building-specific upgrades, there may be some additional measured identified through measurement and monitoring from Year #1.	0	0	0	$0	-	-	-
Library (1991, 24,900 sq.ft., 2-storey library)	- No further building-specific upgrades, there may be some additional measured identified through measurement and monitoring from Year #1.	0	0	0	$0	-	-	-
Prince Hall (1961, 20,100 sq.ft., 2-storey cafeteria)	- No further building-specific upgrades, there may be some additional measured identified through measurement and monitoring from Year #1.	0	0	0	$0	-	-	-
New Academic (incl. Link) (2001, 36,600 sq.ft., 4-storey classroom)	- No further building-specific upgrades, there may be some additional measured identified through measurement and monitoring from Year #1.	0	0	0	$0	-	-	-
Gymnasium (1960, 21,900 sq.ft., 2-storey athletic facility)	- No further building-specific upgrades, there may be some additional measured identified through measurement and monitoring from Year #1.	0	0	0	$0	-	-	-
Arts and Administration (incl. North Pole, Cochran, and Wardroom) (1929, 42,200 sq.ft., 4-storey mixed-use)	- No further building-specific upgrades, there may be some additional measured identified through measurement and monitoring from Year #1.	0	0	0	$0	-	-	-
Tri-Bays (incl. Radical, Middle, and Chapel) (1929, 42,100 sq.ft., 4-storey mixed-use).	- No further building-specific upgrades, there may be some additional measured identified through measurement and monitoring from Year #1.	0	0	0	$0	-	-	-
Campus Central System	- Installation of ground source heat pump system, interconnection with heating and cooling central loops.	1,269	239,228	-4,870	$2,400,000	(±) 30%	HI	NO
Sub-Total	-	1,269	239,228	-4,870	$2,400,000	(±) 30%	-	-
Percentage of Current Consumption	-	-25%	-34%	37%	-	(±) 30%	-	-
Amount Remaining to Carbon Neutral (or Net Zero)	-	2,742	317,747	15,197	-	(±) 30%	-	-

Appendix F

Energy Modelling Results

Energy Modeling - Energy Efficiency Measures Summary - eQUEST 3.65

- Natural Gas: "1. Baseline Design" natural Gas is calibrated according to steam bills
- Area Lights: "1.Baseline Design" and "3. Lighting Controls + Upgrades" are calibrated according to "Lighting Upgrades" sheet.
- All Energy models have been multiplied with a compensation factor each year representing EMCS Upgrades and Building Wide Recommisioning.
- Solar energy reductions were accounted for outside of eQUEST energy modeling software.

Compensation Factors	Electricity	Heating
EMCS Upgrades	0.94	0.88
Building Wide Recommisioning	0.97	0.93
EMCS Upgrades + Building Wide Recomissioning	0.9118	0.8184

	1. Alex Hall
Existing	1. Baseline Design
Phase 1	2. EMCS Upgrades + Lighting Controls
Phase 3	3. Improved Building Envelope & Air Sealing 4. Window Upgrades (Double Clr/Tint to Double Low-E)
Phase 4	5. Steam to Hot Water Conversions (Condensing HW Boiler Eff from 69% to 91.5%)
Phase 5	6. GSHP Installation, Rectangular 4x4, 450ft depth

	2. Library
Existing	1. Baseline Design
Phase 1	2. EMCS Upgrades + Lighting Controls
Phase 2	3. CAV to VAV (Standard VAV - Chilled Water Coils) + Building Wide Recommisioning
Phase 3	4. Window Upgrades (Double Clr/Tint to Double Low-E)
Phase 4	5. Steam to Hot Water Conversions (Condensing HW Boiler Eff from 69% to 91.5%)
Phase 5	6. GSHP Installation, Rectangular 4x4, 450ft depth

	3. Prince Hall
Existing	1. Baseline Design
Phase 1	2. EMCS Upgrades + Lighting Controls
Phase 2	3. CAV to VAV (Packaged RTU) + Building Wide Recommisioning
Phase 3	4. Improved Building Envelope & Air Sealing 5. Window Upgrades (Double Clr/Tint to Double Low-E)
Phase 4	6. Steam to Hot Water Conversions (Condensing HW Boiler Eff from 69% to 91.5%)
Phase 5	7. GSHP Installation, Rectangular 4x4, 450ft depth

	4. New Academic Building incl. Link
Existing	1. Baseline Design
Phase 1	2. EMCS Upgrades + Lighting Controls
Phase 2	3. CAV to VAV (Packaged RTU) + Building Wide Recommisioning
Phase 3	4. Exterior Wall Insulation (R-19 to R-38) 5. Window Upgrades (Double Clr/Tint to Triple Low-E)
Phase 4	6. Steam to Hot Water (Condensing HW Boiler Eff from 69% to 91.5%)
Phase 5	7. GSHP Installation, Rectangular 4x4, 450ft depth

	5. Gym
Existing	1. Baseline Design
Phase 1	2. EMCS Upgrades + Lighting Controls
Phase 3	3. Window Upgrades (Double Clr/Tint to Double Low-E)
Phase 4	4. Steam to Hot Water Conversions (Condensing HW Boiler Eff from 69% to 91.5%)
Phase 5	5. GSHP Installation, Rectangular 4x4, 450ft depth

	6. Art & Admin, NP and Cochran Bay
Existing	1. Baseline Design
Phase 1	2. EMCS Upgrades + Lighting Controls
Phase 2	3. CAV to VAV (Packaged RTU) + Building Wide Recommisioning
Phase 3	4. Improved Building Envelope & Air Sealing 5. Window Upgrades (Double Clr/Tint to Double Low-E)
Phase 4	6. Steam to Hot Water Conversions (Condensing HW Boiler Eff from 69% to 91.5%)
Phase 5	7. GSHP Installation, Rectangular 4x4, 450ft depth

	7. Tri-Bays incl. Radical, Middle & Chapel Bays
Existing	1. Baseline Design
Phase 1	2. EMCS Upgrades + Lighting Controls
Phase 3	4. Improved Building Envelope & Air Sealing 5. Window Upgrades (Double Clr/Tint to Double Low-E)
Phase 4	6. Steam to Hot Water Conversions (Condensing HW Boiler Eff from 69% to 91.5%)
Phase 5	7. GSHP Installation, Rectangular 4x4, 450ft depth

	8. Lodge & Chapel
	None, not included in analysis

Steam Utility Baseline - Compared to Bills:

Percent Errors		Utility Bill in lbs. steam	Utility Bill in MMBTU	Energy Model in MMBTU	% Error
	2017	10,529,274	12571.95316	12,600.30	-0.22548
	2018	10,490,858	12526.08445		-0.59249
	2019	10,343,595	12350.25243		-2.02464

Results - Energy Efficiency Measures Runs (1/2)

1. Alex Hall

1. Baseline Design

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.51	2,147.20	0	0
HP Supp.	0	0	0	0
Hot Wate	0	125.1	0	0
Vent. Fan	30.58	0	0	0
Pumps &	4.47	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	48.02	0	0	0
Task Ligh	0	0	0	0
Area Ligh	56.03	0	0	0
Total	140.6	2,272.30	0	0

2. Lighting Controls (Daylighting)

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.51	2,154.10	0	0
HP Supp.	0	0	0	0
Hot Wate	0	125.1	0	0
Vent. Fan	30.59	0	0	0
Pumps &	4.47	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	48.02	0	0	0
Task Ligh	0	0	0	0
Area Ligh	53.82	0	0	0
Total	138.41	2,279.20	0	0

3. Lighting Controls + Upgrades

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.59	2,267.60	0	0
HP Supp.	0	0	0	0
Hot Wate	0	125.2	0	0
Vent. Fan	30.9	0	0	0
Pumps &	4.53	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	48.02	0	0	0
Task Ligh	0	0	0	0
Area Ligh	22.42	0	0	0
Total	107.46	2,392.70	0	0

4. Improved Insulation in Walls (from R-27 to R-35)

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.41	2,028.40	0	0
HP Supp.	0	0	0	0
Hot Wate	0	125.1	0	0
Vent. Fan	28.65	0	0	0
Pumps &	4.04	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	48.02	0	0	0
Task Ligh	0	0	0	0
Area Ligh	22.42	0	0	0
Total	104.55	2,153.60	0	0

2. Library

1. Baseline Design

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	14.54	0	0	0
Heat Reje	0.62	0	0	0
Refrigera	0	0	0	0
Space He	0.2	246.88	0	0
HP Supp.	0	0	0	0
Hot Wate	6.82	0	0	0
Vent. Fan	23.28	0	0	0
Pumps &	10.55	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	12.23	0	0	0
Task Ligh	0	0	0	0
Area Ligh	83.23	0	0	0
Total	151.47	246.88	0	0

2. Lighting Controls (Daylighting)

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	12.83	0	0	0
Heat Reje	0.57	0	0	0
Refrigera	0	0	0	0
Space He	0.19	247.54	0	0
HP Supp.	0	0	0	0
Hot Wate	6.82	0	0	0
Vent. Fan	22.95	0	0	0
Pumps &	9.2	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	12.23	0	0	0
Task Ligh	0	0	0	0
Area Ligh	81.66	0	0	0
Total	146.46	247.54	0	0

3. Lighting Controls + Upgrades

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	12,417	0	0	0
Heat Reje	548	0	0	0
Refrigera	0	0	0	0
Space He	294	454.4	0	0
HP Supp.	0	0	0	0
Hot Wate	6,840	0	0	0
Vent. Fan	22,419	0	0	0
Pumps &	8,972	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	12,234	0	0	0
Task Ligh	0	0	0	0
Area Ligh	23,914	0	0	0
Total	87,639	454.4	0	0

4. CAV to VAV (Standard VAV - Chilled Water Coils)

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	4,151	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	206	311.68	0	0
HP Supp.	0	0	0	0
Hot Wate	6,848	0	0	0
Vent. Fan	3,131	0	0	0
Pumps &	2,929	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	12,234	0	0	0
Task Ligh	0	0	0	0
Area Ligh	23,914	0	0	0
Total	53,413	311.68	0	0

3. Prince Hall

Note - each EEM is added on top of the one before.

1. Baseline Design

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	6,586	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	2,285	2,304.40	0	0
HP Supp.	0	0	0	0
Hot Wate	0	49.9	0	0
Vent. Fan	33,911	0	0	0
Pumps &	4,322	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	19,148	0	0	0
Task Ligh	0	0	0	0
Area Ligh	25,587	0	0	0
Total	91,839	2,354.30	0	0

2. Lighting Controls (Daylighting)

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	6,542	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	2,283	2,306.50	0	0
HP Supp.	0	0	0	0
Hot Wate	0	49.9	0	0
Vent. Fan	33,855	0	0	0
Pumps &	4,315	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	19,148	0	0	0
Task Ligh	0	0	0	0
Area Ligh	23,999	0	0	0
Total	90,142	2,356.40	0	0

3. Lighting Controls + Upgrades

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	6,322	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	2,286	2,329.30	0	0
HP Supp.	0	0	0	0
Hot Wate	0	49.9	0	0
Vent. Fan	33,717	0	0	0
Pumps &	4,305	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	19,148	0	0	0
Task Ligh	0	0	0	0
Area Ligh	12,028	0	0	0
Total	77,806	2,379.30	0	0

4. CAV to VAV (Packaged RTU)

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	4,098	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	11,981	2,488.40	0	0
HP Supp.	0	0	0	0
Hot Wate	0	49.9	0	0
Vent. Fan	18,396	0	0	0
Pumps &	5,030	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	19,148	0	0	0
Task Ligh	0	0	0	0
Area Ligh	12,028	0	0	0
Total	70,682	2,538.30	0	0

5. Envelope Upgrades

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	2,805	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	5,521	1,468.60	0	0
HP Supp.	0	0	0	0
Hot Wate	0	49.9	0	0
Vent. Fan	8,942	0	0	0
Pumps &	4,225	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	19,148	0	0	0
Task Ligh	0	0	0	0
Area Ligh	12,028	0	0	0
Total	52,669	1,518.50	0	0

4. New Academic and Link

1. Baseline Design

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.53	1,601.20	0	0
HP Supp.	0	0	0	0
Hot Wate	21.33	0	0	0
Vent. Fan	23.09	0	0	0
Pumps &	7.5	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	38.22	0	0	0
Task Ligh	0	0	0	0
Area Ligh	86.15	0	0	0
Total	177.83	1,601.20	0	0

2. Lighting Controls (Daylighting)

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.54	1,628.10	0	0
HP Supp.	0	0	0	0
Hot Wate	21.33	0	0	0
Vent. Fan	23.39	0	0	0
Pumps &	7.54	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	38.22	0	0	0
Task Ligh	0	0	0	0
Area Ligh	84.54	0	0	0
Total	176.57	1,628.10	0	0

3. Lighting Controls + Upgrades

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.63	1,800.60	0	0
HP Supp.	0	0	0	0
Hot Wate	21.34	0	0	0
Vent. Fan	23.7	0	0	0
Pumps &	7.58	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	38.22	0	0	0
Task Ligh	0	0	0	0
Area Ligh	30.91	0	0	0
Total	123.38	1,800.60	0	0

4. CAV to VAV (Packaged RTU)

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	9.94	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.27	1,516.00	0	0
HP Supp.	0	0	0	0
Hot Wate	21.44	0	0	0
Vent. Fan	7.1	0	0	0
Pumps &	5.07	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	38.22	0	0	0
Task Ligh	0	0	0	0
Area Ligh	30	0	0	0
Total	113.06	1,516.00	0	0

5. Envelope Upgrades

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	9.67	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.2	1,433.90	0	0
HP Supp.	0	0	0	0
Hot Wate	21.43	0	0	0
Vent. Fan	6.83	0	0	0
Pumps &	4.85	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	38.22	0	0	0
Task Ligh	0	0	0	0
Area Ligh	28.53	0	0	0
Total	110.73	1,433.90	0	0

5. Gym

1. Baseline Design

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.01	1,320.40	0	0
HP Supp.	0	0	0	0
Hot Wate	0	101.8	0	0
Vent. Fan	27.7	0	0	0
Pumps &	3.54	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	39.14	0	0	0
Task Ligh	0	0	0	0
Area Ligh	71.3	0	0	0
Total	142.68	1,422.30	0	0

2. Lighting Controls (Daylighting)

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.01	1,324.70	0	0
HP Supp.	0	0	0	0
Hot Wate	0	101.8	0	0
Vent. Fan	27.71	0	0	0
Pumps &	3.53	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	39.14	0	0	0
Task Ligh	0	0	0	0
Area Ligh	69.8	0	0	0
Total	141.18	1,426.60	0	0

3. Lighting Controls + Upgrades

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1,088	1,468.20	0	0
HP Supp.	0	0	0	0
Hot Wate	0	101.9	0	0
Vent. Fan	28,034	0	0	0
Pumps &	3,512	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	39,136	0	0	0
Task Ligh	0	0	0	0
Area Ligh	27,919	0	0	0
Total	99,689	1,570.10	0	0

6. A&A , Cochran Bay

1. Baseline Design

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	18.15	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	2.24	2,343.00	0	0
HP Supp.	0	0	0	0
Hot Wate	0	119.3	0	0
Vent. Fan	44.94	0	0	0
Pumps &	4.59	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	40.75	0	0	0
Task Ligh	0	0	0	0
Area Ligh	65.34	0	0	0
Total	176.01	2,462.40	0	0

2. Lighting Controls (Daylighting)

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	17.92	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	2.23	2,345.60	0	0
HP Supp.	0	0	0	0
Hot Wate	0	119.3	0	0
Vent. Fan	44.64	0	0	0
Pumps &	4.57	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	40.75	0	0	0
Task Ligh	0	0	0	0
Area Ligh	61.49	0	0	0
Total	171.6	2,464.90	0	0

3. Lighting Controls + Upgrades

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	16.76	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	2.26	2,419.80	0	0
HP Supp.	0	0	0	0
Hot Wate	0	119.4	0	0
Vent. Fan	43.53	0	0	0
Pumps &	4.54	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	40.75	0	0	0
Task Ligh	0	0	0	0
Area Ligh	25.16	0	0	0
Total	132.99	2,539.20	0	0

4. CAV to VAV (Packaged RTU)

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	15,268	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1,196	1,639.90	0	0
HP Supp.	0	0	0	0
Hot Wate	0	120	0	0
Vent. Fan	7,657	0	0	0
Pumps &	1,781	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	40,746	0	0	0
Task Ligh	0	0	0	0
Area Ligh	25,156	0	0	0
Total	91,804	1,759.90	0	0

5. Envelope Upgrades

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	15,268	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1,196	1,639.90	0	0
HP Supp.	0	0	0	0
Hot Wate	0	120	0	0
Vent. Fan	7,657	0	0	0
Pumps &	1,781	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	40,746	0	0	0
Task Ligh	0	0	0	0
Area Ligh	25,156	0	0	0
Total	91,804	1,759.90	0	0

7. Tri Bays

1. Baseline Design

	Electricity kWh (x00(	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1.29	1,266.70	0	0
HP Supp.	0	0	0	0
Hot Wate	0	71	0	0
Vent. Fan	18	0	0	0
Pumps &	3	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	22	0	0	0
Task Ligh	0	0	0	0
Area Ligh	56	0	0	0
Total	101	1,337.70	0	0

2. Lighting Controls (Daylighting)

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1,298	1,276.70	0	0
HP Supp.	0	0	0	0
Hot Wate	0	71	0	0
Vent. Fan	18,001	0	0	0
Pumps &	2,867	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	22,487	0	0	0
Task Ligh	0	0	0	0
Area Ligh	53,113	0	0	0
Total	97,765	1,347.70	0	0

3. Lighting Controls + Upgrades

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1,394	1,392.90	0	0
HP Supp.	0	0	0	0
Hot Wate	0	71	0	0
Vent. Fan	18,399	0	0	0
Pumps &	2,762	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	22,487	0	0	0
Task Ligh	0	0	0	0
Area Ligh	21,245	0	0	0
Total	66,287	1,464.00	0	0

4. Envelope Upgrades

	Electricity kWh	Natural G MBtu	Steam Btu	Chilled Water Btu
Space Co	0	0	0	0
Heat Reje	0	0	0	0
Refrigera	0	0	0	0
Space He	1,249	1,262.60	0	0
HP Supp.	0	0	0	0
Hot Wate	0	71	0	0
Vent. Fan	16,418	0	0	0
Pumps &	2,634	0	0	0
Ext. Usag	0	0	0	0
Misc. Equ	22,487	0	0	0
Task Ligh	0	0	0	0
Area Ligh	21,245	0	0	0
Total	64,032	1,333.60	0	0

Baseline - Compared to Bills:

		Utility Bill in MMBTU	Energy Model in MMBTU	% Error
Percent Errors	2017	12571.95	12,600.30	-0.22548
	2018	12526.08		-0.59249
	2019	12350.25		-2.02464

1. Totals - Individuals (Baseline) -

	Electricity kWh	Natural Gas MBtu	Gj
1. Alex Hall	107,460	2,393	2524.299
2. Library	87,639	454	479.392
3. Prince Hall	77,806	2,379	2510.162
4. New Academic Building incl. Link	123,380	1,801	1899.633
5. Gym	99,689	1,570	1656.456
6. Art & Admin, NP and Cochran Bay	132,990	2,539	2678.856
7. Tri-Bays incl. Radical, Middle & Chapel E	66,287	1,464	1544.52
Total	695,251	12,600	13293.32

3. Totals - Individuals (HVAC Upgrades)

	Electricity kWh	Natural Gas MBtu	Gj	
1. Alex Hall	107,460	2,393	2524.299	
2. Library	53,413	312	328.8224	HVAC Upgraded
3. Prince Hall	70,682	2,538	2677.907	HVAC Upgraded
4. New Academic Building incl. Link	113,060	1,516	1599.38	HVAC Upgraded
5. Gym	99,689	1,570	1656.456	
6. Art & Admin, NP and Cochran Bay	91,804	1,760	1856.695	HVAC Upgraded
7. Tri-Bays incl. Radical, Middle & Chapel E	66,287	1,464	1544.52	
Total	602,395	11,553	12188.08	

4. Totals - Individuals (Envelope Upgrades)

	Electricity kWh	Natural Gas MBtu	Gj
1. Alex Hall	104,550	2,154	2272.048
2. Library	53,413	312	328.8224
3. Prince Hall	52,669	1,519	1602.018
4. New Academic Building incl. Link	110,730	1,434	1512.765
5. Gym	99,689	1,570	1656.456
6. Art & Admin, NP and Cochran Bay	91,804	1,760	1856.695
7. Tri-Bays incl. Radical, Middle & Chapel Ba	64,032	1,334	1406.948
Total	576,887	10,081	10635.75

Results - Energy Efficiency Measures Runs (2/2)

GSHP

Results:

	Electricity	Natural Gas (Mbtu)	Nat Gas (GJ)
Alex Hall	141,580	125	132
A&A	147,110	120	126
Gym	128,060	102	108
Library	65,150	0	0
New Acad/Link	162,010	0	0
Tri Bays	84,466	71	75
Prince Hall	79,201	51	54
Total	807,577	469	495

Alex Hall		
	Electricity	Natural Gas
	kWh (x000	MBtu
Space Coc	2.03	0
Heat Reje	0	0
Refrigerat	0	0
Space Hea	44.24	0
HP Supp.	0	0
Hot Wate	0	125.37
Vent. Fan	17.88	0
Pumps &	8.18	0
Ext. Usage	0	0
Misc. Equ	48.02	0
Task Light	0	0
Area Light	21.23	0
Total	141.58	125.37

A&A		
	Electricity	Natural Gas
	kWh (x000	MBtu
Space Coc	1	0
Heat Reje	0	0
Refrigerat	0	0
Space Hea	53	0.00
HP Supp.	0	0
Hot Wate	0	119.84
Vent. Fan	18	0
Pumps &	8	0
Ext. Usage	0	0
Misc. Equ	41	0
Task Light	0	0
Area Light	27	0
Total	147	119.84

Gym		
	Electricity	Natural Gas
	kWh (x000	MBtu
Space Coc	2.39	0
Heat Reje	0	0
Refrigerat	0	0
Space Hea	35.6	0
HP Supp.	0	0
Hot Wate	0	101.92
Vent. Fan	17.22	0
Pumps &	6.89	0
Ext. Usage	0	0
Misc. Equ	39.14	0
Task Light	0	0
Area Light	26.84	0
Total	128.06	101.92

Library		
	Electricity	Natural Gas
	kWh	Btu
Space Coc	804	0
Heat Reje	0	0
Refrigerat	0	0
Space Hea	13,356	0
HP Supp.	0	0
Hot Wate	6,825	0
Vent. Fan	5,686	0
Pumps &	3,012	0
Ext. Usage	0	0
Misc. Equ	12,234	0
Task Light	0	0
Area Light	23,232	0
Total	65,150	0

New Academic & Link		
	Electricity	Natural Gas
	kWh (x000	Btu
Space Coc	0.69	0
Heat Reje	0	0
Refrigerat	0	0
Space Hea	43.66	0
HP Supp.	0	0
Hot Wate	21.37	0
Vent. Fan	21.04	0
Pumps &	8.51	0
Ext. Usage	0	0
Misc. Equ	38.22	0
Task Light	0	0
Area Light	28.53	0
Total	162.01	0

Tri Bays		
	Electricity	Natural Gas
	kWh	Btu (x000)
Space Coc	610	0
Heat Reje	0	0
Refrigerat	0	0
Space Hea	27,823	0
HP Supp.	0	0
Hot Wate	0	71,112
Vent. Fan	9,035	0
Pumps &	4,868	0
Ext. Usage	0	0
Misc. Equ	22,487	0
Task Light	0	0
Area Light	19,643	0
Total	84,466	71,112

Prince Hall		
	Electricity	Natural Gas
	kWh	Btu (x000)
Space Coc	3,870	0
Heat Reje	0	0
Refrigerat	0	0
Space Hea	28,346	0
HP Supp.	0	0
Hot Wate	0	50,880
Vent. Fan	10,873	0
Pumps &	6,079	0
Ext. Usage	0	0
Misc. Equ	19,148	0
Task Light	0	0
Area Light	10,885	0
Total	79,201	50,880

Steam to Hot Water

Results:

	Electricity	Natural Gas (Mbtu)	Nat Gas (GJ)
Alex Hall	98,400	1,133	1,196
A&A	88,307	1,121	1,183
Gym	93,031	864	911
Library	52,481	213	224
New Acad/Link	109,630	1,020	1,076
Tri Bays	57,607	691	729
Prince Hall	47,491	884	933
Total	546,947	5,926	6,251

Alex Hall		
	Electricity	Natural Gas
	kWh	MBtu
Space Cool	0	0
Heat Reject.	0	0
Refrigeration	0	0
Space Heat	1,018	1,008.30
HP Supp.	0	0
Hot Water	0	125.1
Vent. Fans	24,725	0
Pumps & Aux.	3,405	0
Ext. Usage	0	0
Misc. Equip.	48,019	0
Task Lights	0	0
Area Lights	21,233	0
Total	98,400	1,133.40

A&A		
	Electricity	Natural Gas
	kWh	MBtu
Space Cool	12,131	0
Heat Reject.	0	0
Refrigeration	0	0
Space Heat	956	1,000.90
HP Supp.	0	0
Hot Water	0	120
Vent. Fans	6,200	0
Pumps & Aux.	1,546	0
Ext. Usage	0	0
Misc. Equip.	40,746	0
Task Lights	0	0
Area Lights	26,728	0
Total	88,307	1,120.90

Gym		
	Electricity	Natural Gas
	kWh	MBtu
Space Cool	0	0
Heat Reject.	0	0
Refrigeration	0	0
Space Heat	799	762.13
HP Supp.	0	0
Hot Water	0	101.83
Vent. Fans	23,339	0
Pumps & Aux.	2,922	0
Ext. Usage	0	0
Misc. Equip.	39,136	0
Task Lights	0	0
Area Lights	26,836	0
Total	93,031	863.96

Library		
	Electricity	Natural Gas
	kWh	MBtu
Space Cool	4,110	0
Heat Reject.	0	0
Refrigeration	0	0
Space Heat	185	212.69
HP Supp.	0	0
Hot Water	6,842	0
Vent. Fans	2,978	0
Pumps & Aux.	2,900	0
Ext. Usage	0	0
Misc. Equip.	12,234	0
Task Lights	0	0
Area Lights	23,232	0
Total	52,481	212.69

New Academic & Link		
	Electricity	Natural Gas
	kWh (x000)	MBtu
Space Cool	9.52	0
Heat Reject.	0	0
Refrigeration	0	0
Space Heat	1.14	1,019.80
HP Supp.	0	0
Hot Water	21.42	0
Vent. Fans	6.06	0
Pumps & Aux.	4.73	0
Ext. Usage	0	0
Misc. Equip.	38.22	0
Task Lights	0	0
Area Lights	28.53	0
Total	109.63	1,019.80

Tri Bays		
	Electricity	Natural Gas
	kWh	MBtu
Space Cool	0	0
Heat Reject.	0	0
Refrigeration	0	0
Space Heat	899	619.83
HP Supp.	0	0
Hot Water	0	70.98
Vent. Fans	12,438	0
Pumps & Aux.	2,140	0
Ext. Usage	0	0
Misc. Equip.	22,487	0
Task Lights	0	0
Area Lights	19,643	0
Total	57,607	690.81

Prince Hall		
	Electricity	Natural Gas
	kWh	MBtu
Space Cool	3,326	0
Heat Reject.	0	0
Refrigeration	0	0
Space Heat	3,472	834.11
HP Supp.	0	0
Hot Water	0	49.85
Vent. Fans	6,782	0
Pumps & Aux.	3,943	0
Ext. Usage	0	0
Misc. Equip.	19,148	0
Task Lights	0	0
Area Lights	10,819	0
Total	47,491	883.96

Energy Calculations

*Efficiency Ratio is the capital cost per tonne of CO2e Reduced

Capital Cost & Efficiency Ratio

Uncert. Range: Cost: 15%

	Capital Cost	Range -	Range +	% Budget - 8M	tCO2e Reductions	*Efficiency Ratio $/tCO2e Red.	IRR (25 yrs)
Pathway 1	$684,000	$581,400	$786,600	9%	-340	$2,009	8.2%
Pathway 2	$1,938,000	$1,647,300	$2,228,700	24%	-1,887	$1,027	7.6%
Pathway 3	$5,208,000	$4,426,800	$5,989,200	65%	-2,245	$2,320	4.1%
Pathway 4	$7,608,000	$6,466,800	$8,749,200	95%	-3,432	$2,217	3.7%
Pathway 5	$1,413,000	$1,201,050	$1,624,950	18%	-1,233	$1,146	8.8%
Pathway 6	$948,000	$805,800	$1,090,200	12%	-572	$1,656	12.6%
Pathway 7	$1,473,000	$1,252,050	$1,693,950	18%	-1,226	$1,202	8.9%
Pathway 8	$4,743,000	$4,031,550	$5,454,450	59%	-1,584	$2,995	4.4%
Pathway 9	$7,143,000	$6,071,550	$8,214,450	89%	-2,771	$2,578	4.1%

Energy Savings -

Uncert. Range: 15%

Utility Rate: 0.1057092

Electricity	kWh	Cost at $0.105/kWh	$ Savings	Total Savings	Simple Payback	Savings Low	Savings High
Baseline	695,251	$73,494				-	+
Pathway 1	653,536	$69,085	$4,410	$48,732	14.0	$41,422	$56,042
Pathway 2	428,571	$45,304	$28,191	$146,565	13.2	$124,580	$168,549
Pathway 3	400,729	$42,361	$31,134	$253,482	20.5	$215,460	$291,505
Pathway 4	639,957	$67,649	$5,845	$363,500	20.9	$308,975	$418,025
Pathway 5	512,198	$54,144	$19,350	$124,925	11.3	$106,186	$143,664
Pathway 6	617,198	$65,243	$8,251	$113,826	8.0	$96,752	$130,900
Pathway 7	533,571	$56,403	$17,091	$135,465	11.4	$115,145	$155,785
Pathway 8	505,729	$53,460	$20,034	$242,383	19.9	$206,025	$278,740
Pathway 9	744,957	$78,749	-$5,254	$352,400	20.5	$299,540	$405,260

Steam Rate: 35

Steam	Steam (lbs)	Cost at $35 / 1000 lb	$ Savings
Baseline	10,553,015	$369,356	
Pathway 1	9,286,653	$325,033	$44,323
Pathway 2	7,170,896	$250,981	$118,374
Pathway 3	4,200,198	$147,007	$222,349
Pathway 4	334,311	$11,701	$357,655
Pathway 5	7,536,594	$263,781	$105,575
Pathway 6	7,536,594	$263,781	$105,575
Pathway 7	7,170,896	$250,981	$118,374
Pathway 8	4,200,198	$147,007	$222,349
Pathway 9	334,311	$11,701	$357,655

Percent Remainder Table

	GHG Emisions	Total Emissions	% Remaining	% Reduced	in Tonnes	Cumalitive Cost	Carbon Offset Cost at $30/Tonne
	Baseline	5,026					$150,781
Pathway 1	Year 1 - Lighting & EMCS	4,686	93.2	6.8	-340	$684,000	$140,568
Pathway 2	Year 3 - Envelope Upgrades & Solar	3,139	62.5	37.5	-1,887	$1,938,000	$94,172
Pathway 3	Year 4 - Centralized H&C	2,781	55.3	44.7	-2,245	$5,208,000	$83,440
Pathway 4	Year 5 - GSHP	1,594	31.7	68.3	-3,432	$7,608,000	$47,826
Pathway 5	P5 - Solar + Lighting + Building Envelope	3,793	75.5	24.5	-1,233	$729,000	$113,777
Pathway 6	P6 - Lighting + Building Envelope	4,454	88.6	11.4	-572	$264,000	$133,612
Pathway 7	Year 3 - Envelope Upgrades (No Solar)	3,800	75.6	24.4	-1,226	$1,550,500	$114,008
Pathway 8	Year 4 - Centralized H&C	3,443	68.5	31.5	-1,584	$4,820,500	$103,275
Pathway 9	Year 5 - GSHP	2,255	44.9	55.1	-2,771	$7,220,500	$67,662

	Electricity	Total kWh	% Remaining	% Reduced	in kWh
	Baseline	*695,251*			
Pathway 1	Year 1 - Lighting & EMCS	653,536	94.0	6.0	-41,715
Pathway 2	Year 3 - Envelope Upgrades & Solar	428,571	61.6	38.4	-266,680
Pathway 3	Year 4 - Centralized H&C	400,729	57.6	42.4	-294,522
Pathway 4	Year 5 - GSHP	639,957	92.0	8.0	-55,294
Pathway 5	P5 - Solar + Lighting + Building Envelope	512,198	73.7	26.3	-183,053
Pathway 6	P6 - Lighting + Building Envelope	617,198	88.8	11.2	-78,053
Pathway 7	Year 3 - Envelope Upgrades (No Solar)	533,571	76.7	23.3	-161,680
Pathway 8	Year 4 - Centralized H&C	505,729	72.7	27.3	-189,522
Pathway 9	Year 5 - GSHP	744,957	107.1	-7.1	49,706

	Steam	Total GJ	% Remaining	% Reduced	in GJ
	Baseline	*13,293*			
Pathway 1	Year 1 - Lighting & EMCS	11,698	88.0	12.0	-1,595
Pathway 2	Year 3 - Envelope Upgrades & Solar	9,033	68.0	32.0	-4,260
Pathway 3	Year 4 - Centralized H&C	5,291	39.8	60.2	-8,002
Pathway 4	Year 5 - GSHP	421	3.2	96.8	-12,872
Pathway 5	P5 - Solar + Lighting + Building Envelope	9,494	71.4	28.6	-3,800
Pathway 6	P6 - Lighting + Building Envelope	9,494	71.4	28.6	-3,800
Pathway 7	Year 3 - Envelope Upgrades (No Solar)	9,033	68.0	32.0	-4,260
Pathway 8	Year 4 - Centralized H&C	5,291	39.8	60.2	-8,002
Pathway 9	Year 5 - GSHP	421	3.2	96.8	-12,872

Pathways Summary:	Energy Efficiency Measures Combinations
Pathway 1	EMCS & Lighting Controls
Pathway 2	Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS
Pathway 3	Steam to Hydronic Conversions, Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS
Pathway 4	GSHP, Steam to Hydronic Conversions, Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS
Pathway 5	Solar Energy, Building Enveolpe Upgrades, EMCS
Pathway 6	Building Enveolpe Upgrades, EMCS
Pathway 8	Steam to Hydronic Conversions, Building Envelope Upgrades, HVAC Upgrades, EMCS
Pathway 9	GSHP, Steam to Hydronic Conversions, Building Envelope Upgrades, HVAC Upgrades, EMCS

	Baseline	Pathway #1	Pathway #2	Pathway #3	Pathway #4	Pathway #5	Pathway #6	Pathway #7	Pathway #8	Pathway #9
Electricity (kWh)	695,251	653,536	428,571	400,729	639,957	512,198	617,198	533,571	505,729	744,957
Steam (lbs)	10,553,015	9,286,653	7,170,896	4,200,198	334,311	7,536,594	7,536,594	7,170,896	4,200,198	334,311
GHG Emmisions (tCO2e)	5,026	4,686	3,139	2,781	1,594	3,793	4,454	3,800	3,443	2,255
Utility Rate at $0.010/kWh	$73,494	$69,085	$45,304	$42,361	$67,649	$54,144	$65,243	$56,403	$53,460	$78,749
Steam Rate at $35/1000lb	$369,356	$325,033	$250,981	$147,007	$11,701	$263,781	$263,781	$250,981	$147,007	$11,701
Total Savings		$48,732	$146,565	$253,482	$363,500	$124,925	$113,826	$135,465	$242,383	$352,400
Capital Costs		$680,000	$1,940,000	$5,210,000	$7,610,000	$1,410,000	$950,000	$1,470,000	$4,740,000	$7,140,000
Simple Payback (Yrs)		14.0	13.2	20.6	20.9	11.3	8.3	10.9	19.6	20.3
Carbon Offsets ($)	$150,781	$140,568	$94,172	$83,440	$47,826	$113,777	$133,612	$114,008	$103,275	$67,662

Reductions

± 15%

GHG Emisions	in Tonnes	Low	High	Range	% Reduced
Baseline	5,026				
Pathway 1	-340	-289	-392	290 - 390	6.8%
Pathway 2	-1,887	-1,604	-2,170	1.6K - 2.2K	37.5%
Pathway 3	-2,245	-1,908	-2,581	1.9K - 2.6K	44.7%
Pathway 4	-3,432	-2,917	-3,947	2.9K - 4.0K	68.3%
Pathway 5	-1,233	-1,048	-1,419	1.0K - 1.4K	24.5%
Pathway 6	-572	-486	-658	480 - 660	11.4%
Pathway 7	-1,226	-1,042	-1,410	1.0K - 1.4K	24.4%
Pathway 8	-1,584	-1,346	-1,821	1.3K - 1.8K	31.5%
Pathway 9	-2,771	-2,355	-3,186	2.3K - 3.2K	55.1%

Electricity	in kWh	Low	High	Range	% Reduced
Baseline	695,251				
Pathway 1	-41,715	-35,458	-47,972	35K - 48K	6.0%
Pathway 2	-266,680	-226,678	-306,682	227K - 307K	38.4%
Pathway 3	-294,522	-250,344	-338,700	250K - 340K	42.4%
Pathway 4	-55,294	-47,000	-63,588	47K - 65K	8.0%
Pathway 5	-183,053	-155,595	-210,511	155K - 210K	26.3%
Pathway 6	-78,053	-66,345	-89,761	66K - 90K	11.2%
Pathway 7	-161,680	-137,428	-185,932	135K - 185K	23.3%
Pathway 8	-189,522	-161,094	-217,950	160K - 218K	27.3%
Pathway 9	49,706	42,250	57,162	43K - 58K	7.1%

Steam	in GJ	Low	High	Range	
Baseline	13,293				
Pathway 1	-1,595	-1,356	-1,834	1.4K - 1.8K	12.0%
Pathway 2	-4,260	-3,621	-4,899	3.6K - 4.9K	32.0%
Pathway 3	-8,002	-6,802	-9,203	6.8K - 9.2K	60.2%
Pathway 4	-12,872	-10,941	-14,803	10.9K - 14.8K	96.8%
Pathway 5	-3,800	-3,230	-4,370	3.2K - 4.4K	28.6%
Pathway 6	-3,800	-3,230	-4,370	3.2K - 4.4K	28.6%
Pathway 7	-4,260	-3,621	-4,899	3.6K-4.9K	32.0%
Pathway 8	-8,002	-6,802	-9,203	6.8K-9.2K	60.2%
Pathway 9	-12,872	-10,941	-14,803	10.9K-14.8K	96.8%

Appendix G

Financial Analysis

Financial Analysis - UKC

Discount Rate	Inflation Factor
2.5%	3.0%

	Pathway 1			Pathway 2			Pathway 3		
Year	Investment	Savings	Present Value	Investment	Savings	Present Value	Investment	Savings	Present Value
0	-$684,000			-$684,000			-$684,000		
1		$50,194	$48,970	-$525,000	$50,194	$48,970	-$525,000	$50,194	$48,970
2		$51,700	$49,209	-$729,000	$91,397	$86,993	-$729,000	$91,397	$86,993
3		$53,251	$49,449		$160,155	$148,720	-$3,270,000	$160,155	$148,720
4		$54,849	$49,690		$164,960	$149,446		$285,297	$258,465
5		$56,494	$49,933		$169,909	$150,175		$293,855	$259,725
6		$58,189	$50,176		$175,006	$150,907		$302,671	$260,992
7		$59,935	$50,421		$180,256	$151,643		$311,751	$262,265
8		$61,733	$50,667		$185,664	$152,383		$321,104	$263,545
9		$63,585	$50,914		$191,234	$153,126		$330,737	$264,830
10		$65,492	$51,162		$196,971	$153,873		$340,659	$266,122
11		$67,457	$51,412		$202,880	$154,624		$350,879	$267,420
12		$69,481	$51,663		$208,966	$155,378		$361,405	$268,725
13		$71,565	$51,915		$215,235	$156,136		$372,247	$270,036
14		$73,712	$52,168		$221,692	$156,898		$383,415	$271,353
15		$75,923	$52,422		$228,343	$157,663		$394,917	$272,677
16		$78,201	$52,678		$235,193	$158,432		$406,765	$274,007
17		$80,547	$52,935		$242,249	$159,205		$418,968	$275,343
18		$82,964	$53,193		$249,517	$159,982		$431,537	$276,687
19		$85,452	$53,453		$257,002	$160,762		$444,483	$278,036
20		$88,016	$53,714		$264,712	$161,546		$457,817	$279,393
21		$90,656	$53,976		$272,654	$162,334		$471,552	$280,755
22		$93,376	$54,239		$280,833	$163,126		$485,698	$282,125
23		$96,177	$54,504		$289,258	$163,922		$500,269	$283,501
24		$99,063	$54,769		$297,936	$164,721		$515,277	$284,884
25		$102,035	$55,037		$306,874	$165,525		$530,736	$286,274
SUM	-$684,000			-$1,938,000			-$5,208,000		
NPV			$614,668			$1,693,984			$1,065,004
IRR			8.2%			7.6%			4.1%

	Pathway 4			Pathway 5			Pathway 6		
Year	Investment	Savings	Present Value	Investment	Savings	Present Value	Investment	Savings	Present Value
0	-$684,000			-$684,000			-$684,000		
1	-$525,000	$50,194	$48,970	-$264,000	$50,194	$48,970	-$264,000	$50,194	$48,970
2	-$729,000	$91,397	$86,993	-$465,000	$64,094	$61,006		$120,758	$114,939
3	-$3,270,000	$160,155	$148,720		$136,509	$126,762		$124,380	$115,500
4	-$2,400,000	$285,297	$258,465		$140,604	$127,381		$128,112	$116,063
5		$421,396	$372,453		$144,822	$128,002		$131,955	$116,629
6		$434,038	$374,269		$149,167	$128,626		$135,914	$117,198
7		$447,059	$376,095		$153,642	$129,254		$139,991	$117,770
8		$460,471	$377,930		$158,251	$129,884		$144,191	$118,344
9		$474,285	$379,773		$162,999	$130,518		$148,517	$118,922
10		$488,513	$381,626		$167,889	$131,155		$152,972	$119,502
11		$503,169	$383,487		$172,926	$131,794		$157,561	$120,085
12		$518,264	$385,358		$178,113	$132,437		$162,288	$120,670
13		$533,812	$387,238		$183,457	$133,083		$167,157	$121,259
14		$549,826	$389,127		$188,960	$133,732		$172,172	$121,850
15		$566,321	$391,025		$194,629	$134,385		$177,337	$122,445
16		$583,310	$392,932		$200,468	$135,040		$182,657	$123,042
17		$600,810	$394,849		$206,482	$135,699		$188,137	$123,642
18		$618,834	$396,775		$212,677	$136,361		$193,781	$124,246
19		$637,399	$398,711		$219,057	$137,026		$199,594	$124,852
20		$656,521	$400,656		$225,629	$137,695		$205,582	$125,461
21		$676,217	$402,610		$232,398	$138,366		$211,749	$126,073
22		$696,503	$404,574		$239,370	$139,041		$218,102	$126,688
23		$717,398	$406,548		$246,551	$139,720		$224,645	$127,306
24		$738,920	$408,531		$253,947	$140,401		$231,384	$127,927
25		$761,088	$410,524		$261,566	$141,086		$238,326	$128,551
SUM	-$7,608,000			-$1,413,000			-$948,000		
NPV			$1,162,916			$1,661,643			$1,953,981
IRR			3.7%			8.8%			12.6%

	Pathway 7			Pathway 8			Pathway 9		
Year	Investment	Savings	Present Value	Investment	Savings	Present Value	Investment	Savings	Present Value
0	-$684,000			-$684,000			-$684,000		
1	-$525,000	$50,194	$48,970	-$525,000	$50,194	$48,970	-$525,000	$50,194	$48,970
2	-$264,000	$52,319	$49,798	-$264,000	$52,319	$49,798	-$264,000	$52,319	$49,798
3		$148,027	$137,457	-$3,270,000	$148,027	$137,457	-$3,270,000	$148,027	$137,457
4		$152,467	$138,128		$272,804	$247,147	-$2,400,000	$396,630	$359,327
5		$157,041	$138,802		$280,988	$248,353		$408,529	$361,080
6		$161,753	$139,479		$289,418	$249,564		$420,784	$362,841
7		$166,605	$140,159		$298,100	$250,781		$433,408	$364,611
8		$171,603	$140,843		$307,043	$252,005		$446,410	$366,390
9		$176,751	$141,530		$316,255	$253,234		$459,802	$368,177
10		$182,054	$142,220		$325,742	$254,469		$473,597	$369,973
11		$187,516	$142,914		$335,514	$255,711		$487,804	$371,778
12		$193,141	$143,611		$345,580	$256,958		$502,439	$373,591
13		$198,935	$144,312		$355,947	$258,211		$517,512	$375,414
14		$204,903	$145,016		$366,626	$259,471		$533,037	$377,245
15		$211,050	$145,723		$377,624	$260,737		$549,028	$379,085
16		$217,382	$146,434		$388,953	$262,009		$565,499	$380,934
17		$223,903	$147,148		$400,622	$263,287		$582,464	$382,792
18		$230,621	$147,866		$412,640	$264,571		$599,938	$384,660
19		$237,539	$148,587		$425,020	$265,862		$617,936	$386,536
20		$244,665	$149,312		$437,770	$267,158		$636,474	$388,422
21		$252,005	$150,041		$450,903	$268,462		$655,568	$390,316
22		$259,565	$150,772		$464,430	$269,771		$675,235	$392,220
23		$267,352	$151,508		$478,363	$271,087		$695,492	$394,134
24		$275,373	$152,247		$492,714	$272,410		$716,357	$396,056
25		$283,634	$152,990		$507,496	$273,738		$737,848	$397,988
SUM	-$1,473,000			-$4,743,000			-$7,143,000		
NPV			$1,830,127			$1,207,495			$1,412,974
IRR			8.9%			4.4%			4.1%

Summary

	NPV	IRR
Pathway 1	$614,668	8.2%
Pathway 2	$1,693,984	7.6%
Pathway 3	$1,065,004	4.1%
Pathway 4	$1,162,916	3.7%
Pathway 5	$1,661,643	8.8%
Pathway 6	$1,953,981	12.6%
Pathway 7	$1,830,127	8.9%
Pathway 8	$1,207,495	4.4%
Pathway 9	$1,412,974	4.1%

	Cost Averages:
EMCS	$684,000
HVAC	$525,000
Envelope	$264,000
Solar	$465,000
Steam to HW	$3,270,000
Geothermal Ene	$2,400,000

Appendix H

Benchmarking and Analysis

Benchmarking and Analysis

This section provides an overview of the EEMs analyzed in this report. For each measure, estimates of the annual savings in each of the following were determined:

- Electricity consumption;
- Steam consumption;
- Total energy cost; and
- GHG emissions

GHG emission reductions were calculated based on the results from the energy model. The following table lists the GHG emission factors used as relevant in Nova Scotia.

Table 22: Emission Factors – Electricity & Natural Gas

Energy Source	CO2e Emission Factor
Electricity	629.7 gCO2e / kWh
Steam (Natural Gas)	48.75 kgCO2e / GJ or 1.912 kgCO2e / m^3

The energy modeling results have been categorized into nine pathways as highlighted in the decision tree. Each pathway was compared for factors including carbon reduction, cost savings, and energy savings - allowing the university options to explore different efficiency measures combinations and technologies.

Table 23: EEM Pathway Summary

	# EEMs	Energy Efficiency Measures Implemented
Pathway 1	2	EMCS Upgrades & Lighting Controls
Pathway 2	5	Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Upgrades
Pathway 3	6	Steam to Hydronic Conversions, Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Upgrades
Pathway 4	7	GSHP, Steam to Hydronic Conversions, Solar Energy, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Upgrades
Pathway 5	4	Solar Energy, Building Envelope Upgrades, EMCS & Lighting Upgrades
Pathway 6	3	Building Envelope Upgrades, EMCS & Lighting Upgrades
Pathway 7	4	Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Upgrades
Pathway 8	5	Steam to Hydronic Conversions, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Upgrades
Pathway 9	6	GSHP, Steam to Hydronic Conversions, Building Envelope Upgrades, HVAC Upgrades, EMCS & Lighting Upgrades

A carbon offset is a credit for emissions reductions given to one party that can be sold to another party to compensate for its emissions. Carbon offsets can be bought from organizations & projects that reduce the amount of greenhouse gasses emitted into the atmosphere. Carbon offset will be considered in the analysis to reach the goal of carbon neutrality, and will be set at an average cost of $30/tonne per CO_2e. Generally, CSA Standard-Certified Canadian Offsets are currently at an average cost of $20-30/tonne of CO_2e, but are expected to rise sevenfold by 2030 as regulations aim to limit the average global temperature increase in accordance with the Paris Agreement. However, there are many concerns with an over-reliance on offsets, and they often enable polluters to continue business as usual.

Table 24: Pathways Performance Table

	Baseline	Pathway #1	Pathway #2	Pathway #3	Pathway #4
Electricity (kWh)	695,251	653,536	428,571	400,729	639,957
Steam (lbs)	10,553,015	9,286,653	7,170,896	4,200,198	334,311
GHG Emissions (tCO_2e)	5,026	4,686	3,139	2,781	1,594
Utility Rate at $0.0105 /kWh	$73,494	$69,085	$45,304	$42,361	$67,649
Steam Rate at $35/1000lb	$369,356	$325,033	$250,981	$147,007	$11,701
Total Savings		$48,732	$146,565	$253,482	$363,500
Capital Costs		$680,000	$1,940,000	$5,210,000	$7,610,000
Simple Payback (Yrs)		14.0	13.2	20.6	20.9
Carbon Offsets ($)	$150,781	$140,568	$94,172	$83,440	$47,826

Table 25: Pathways Performance Table Continued

	Pathway #5	Pathway #6	Pathway #7	Pathway #8	Pathway #9
Electricity (kWh)	512,198	617,198	533,571	505,729	744,957
Steam (lbs)	7,536,594	7,536,594	7,170,896	4,200,198	334,311
GHG Emissions (tCO2e)	3,793	4,454	3,800	3,443	2,255
Utility Rate at $0.0105 /kWh	$54,144	$65,243	$56,403	$53,460	$78,749
Steam Rate at $35/1000lb	$263,781	$263,781	$250,981	$147,007	$11,701
Total Savings	$124,925	$113,826	$135,465	$242,383	$352,400
Capital Costs	$1,410,000	$950,000	$1,470,000	$4,740,000	$7,140,000
Simple Payback (Yrs)	11.3	8.3	10.9	19.6	20.3
Carbon Offsets ($)	$113,777	$133,612	$114,008	$103,275	$67,662

The following table highlights the carbon reductions identified for each pathway. A column indicating the carbon offsets required for carbon neutrality is also included at $30 per tonne of CO2e. Note that the costs for carbon offsets are expected to rise in the coming years, which could triple in cost as government regulations become more stringent (e.g. carbon tax).

Table 26: GHG Emissions Table

GHG Emissions	Total Emissions (tCO2e)	% Remaining	% Reduced	Carbon Offsets to Net Zero ($)
Baseline	5,026			$150,781
Pathway 1	4,686	93.2	6.8	$140,568
Pathway 2	3,139	62.5	37.5	$94,172
Pathway 3	2,781	55.3	44.7	$83,440
Pathway 4	1,594	31.7	68.3	$47,826
Pathway 5	3,793	75.5	24.5	$113,777

Pathway 6	4,454	88.6	11.4	$133,612
Pathway 7	3,800	75.6	24.4	$114,008
Pathway 8	3,443	68.5	31.5	$103,275
Pathway 9	2,255	44.9	55.1	$67,662

Electricity usage for each pathway has been identified in the table below. As previously mentioned, Nova Scotia power is transitioning from fossil fuels to generate electricity to renewable sources, and is expected to reach 80% renewable by 2030. This entails immediate reductions in electricity usage which could have great impacts on overall GHG emissions.

Table 27: Electricity Consumption Table

Electricity	Total kWh	% Remaining	% Reduced
Baseline	695,251		
Pathway 1	653,536	94.0	6.0
Pathway 2	428,571	61.6	38.4
Pathway 3	400,729	57.6	42.4
Pathway 4	639,957	92.0	8.0
Pathway 5	512,198	73.7	26.3
Pathway 6	617,198	88.8	11.2
Pathway 7	533,571	76.7	23.3
Pathway 8	505,729	72.7	27.3
Pathway 9	744,957	107.1	-7.1

The steam usage reductions has been accounted for in each measure, and highlighted in the table below.

Table 28: Steam Consumption Table

Electricity	Steam (GJ)	Steam (lbs)	% Remaining	% Reduced
Baseline	13,293	10,553,015		
Pathway 1	11,698	9,286,653	88.0	12.0
Pathway 2	9,033	7,170,896	68.0	32.0
Pathway 3	5,291	4,200,198	39.8	60.2
Pathway 4	421	334,311	3.2	96.8
Pathway 5	9,494	7,536,594	71.4	28.6
Pathway 6	9,494	7,536,594	71.4	28.6
Pathway 7	9,033	7,170,896	68.0	32.0
Pathway 8	5,291	4,200,198	39.8	60.2

Pathway 9	421	334,311	3.2	96.8

Financial calculations have been estimated for each pathway, namely the energy savings, simple payback, IRR and NPV rates. The financial figures completed were at a high-level of preliminary analysis and do not include factors such as salvage value, maintenance costs and the current and rising inflation rates. The purpose of analysis is to give insights on various financial metrics to help compare each path. Please note that "Discount rate" used was (2.5%) and the "Inflation rate" assumed was (3%) over a 25 year period.

Table 29: Energy & Cost Savings Table

	Electricity (kWh)	Steam (lbs)	Carbon Reductions (tCO2e)	Electricity Savings	Steam Savings	Total Savings
Baseline	695,251	10,553,015				
Pathway #1	653,536	9,286,653	-340	-$4,410	-$44,323	-$48,732
Pathway #2	428,571	7,170,896	-1,887	-$28,191	-$118,374	-$146,565
Pathway #3	400,729	4,200,198	-2,245	-$31,134	-$222,349	-$253,482
Pathway #4	639,957	334,311	-3,432	-$5,845	-$357,655	-$363,500
Pathway #5	512,198	7,536,594	-1,233	-$19,350	-$105,575	-$124,925
Pathway #6	617,198	7,536,594	-572	-$8,251	-$105,575	-$113,826
Pathway #7	533,571	7,170,896	-1,226	-$17,091	-$118,374	-$135,465
Pathway #8	505,729	4,200,198	-1,584	-$20,034	-$222,349	-$242,383
Pathway #9	744,957	334,311	-2,771	$5,254	-$357,655	-$352,400

Simple Payback, NPV, and IRR*:

Table 30: Payback, NPV, and IRR Table

	Simple Payback (yrs)	NPV	IRR
Pathway 1	14.0	$614,668	8.2%
Pathway 2	13.2	$1,693,984	7.6%
Pathway 3	20.6	$1,065,004	4.1%
Pathway 4	20.9	$1,162,916	3.7%
Pathway 5	11.3	$1,661,643	8.8%
Pathway 6	8.3	$1,953,981	12.6%
Pathway 7	10.9	$1,830,127	8.9%
Pathway 8	19.6	$1,207,495	4.4%
Pathway 9	20.3	$1,412,974	4.1%

**This analysis completed was high level and excludes factors such as maintenance costs, refurbishment costs, and salvage value.*

The annual consumption & emissions data is highlighted in the figures below for each pathway.

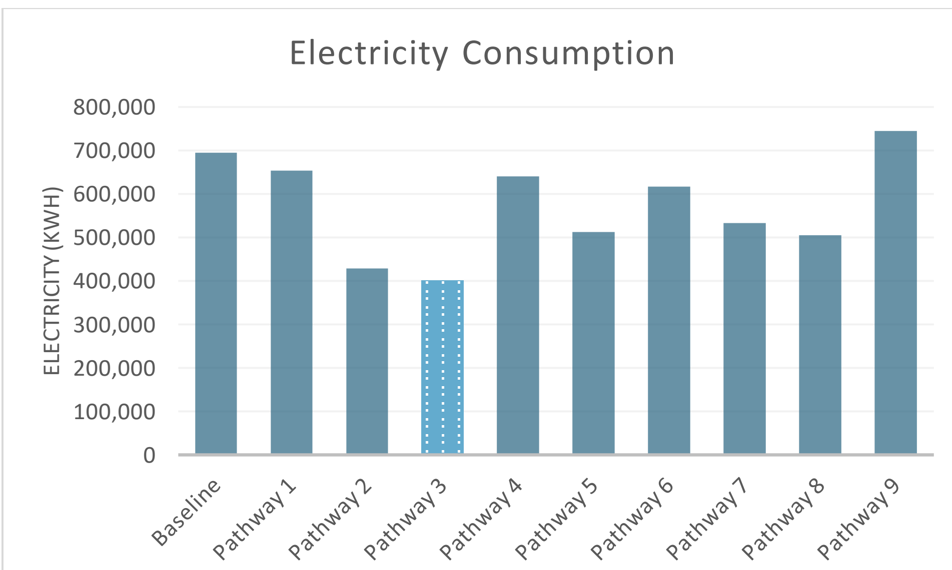


Figure 7: Annual Electricity Consumption

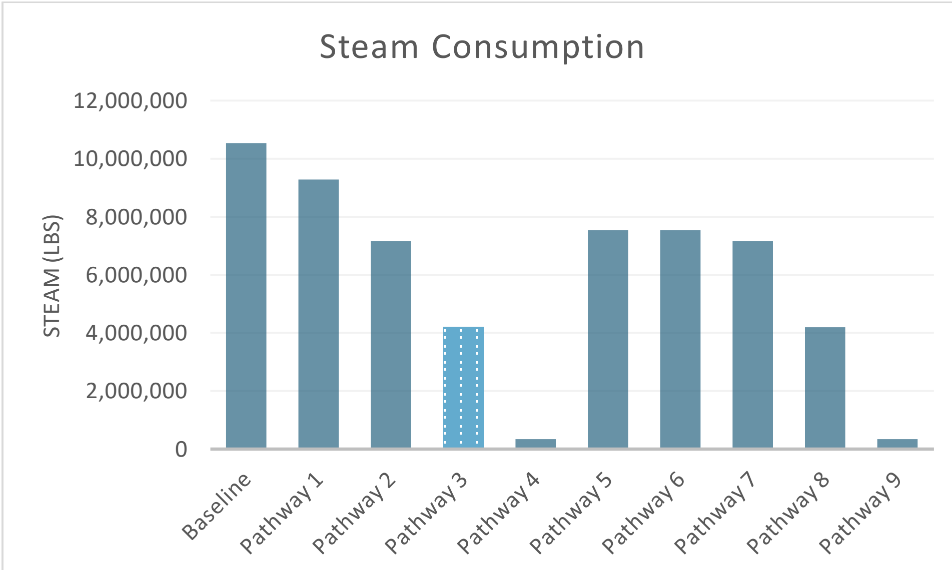


Figure 8: Annual Steam Consumption

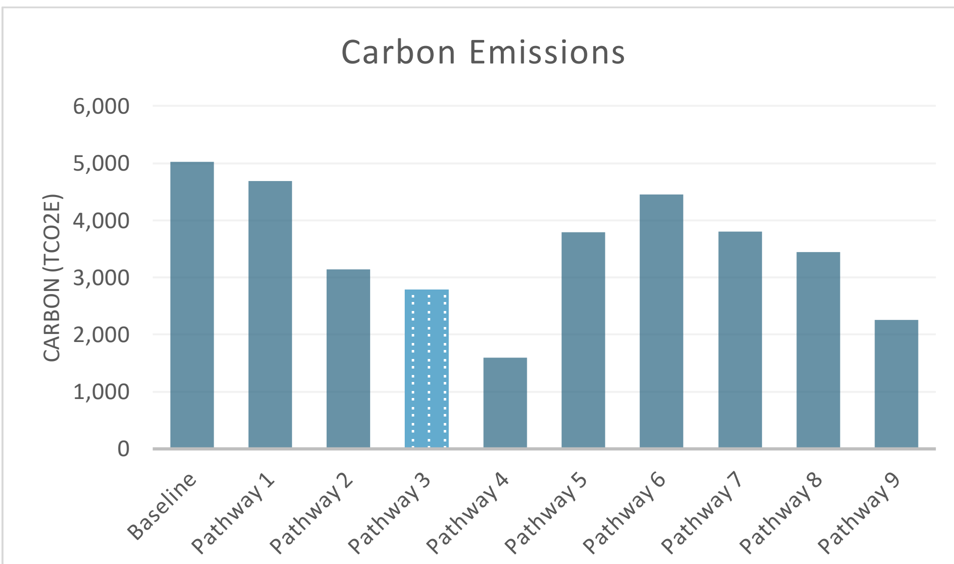


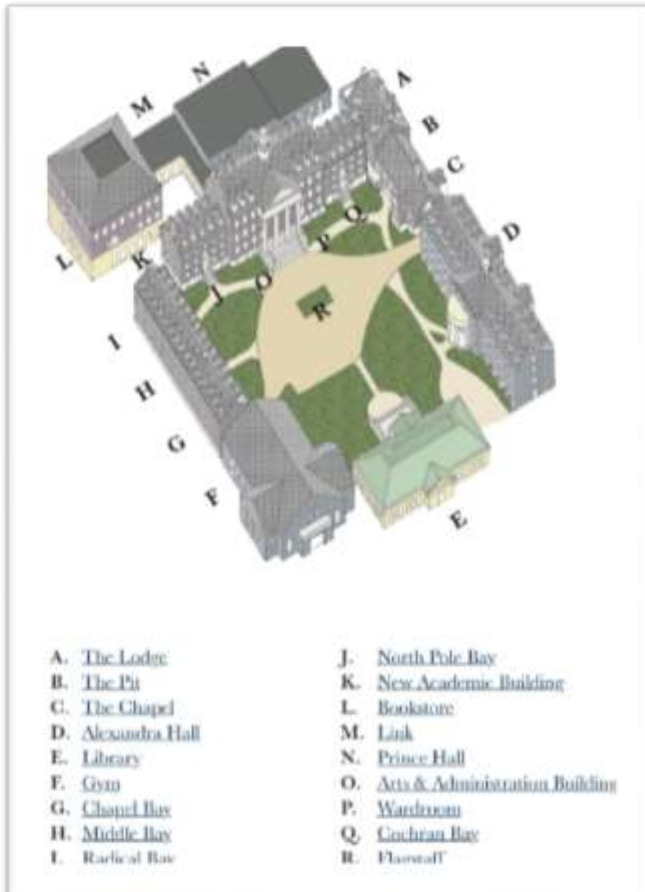
Figure 9: Annual Carbon Emissions

Appendix I

Hydronic Conversion

The University of King's College is Canada's oldest chartered university, founded by Loyalists in Windsor, Nova Scotia in 1789. Located in Halifax, Nova Scotia, since 1920, the King's of today is a small and extraordinarily lively academic community, built on an Oxford-style quadrangle and framed by the stately architecture of Andrew Cobb.

The college is home to 1,200 students and is known nationally and internationally for its interdisciplinary programmes in the humanities and journalism. King's has a unique partnership with Dalhousie University, the largest university in the Maritimes, which gives King's students access to the resources, facilities, and classes Dalhousie offers.



King's recently embarked on the next phase of their sustainability initiatives. The goal is to reduce the greenhouse gas emissions from campus operations and reduce campus reliance on fossil fuels as energy sources, with the ambitious goal of achieving carbon neutrality for the campus at some point in the not too distant future. The conversion of the campus's steam heating infrastructure to hydronic heating is a critical step towards this goal. In addition to the operational savings directly resulting from the conversion, the project will be used as a stepping stone for King's to implement further measures towards achieving carbon neutrality. These additional measures will include supplementing campus heating and cooling requirements with a geothermal-source heat pump system, reducing heating loop temperatures throughout, and interconnecting multiple smaller mechanical systems to further centralize heating generation on the campus.

The centralized steam heating system serves about 240,000 square feet of floor area and buildings with a combined occupancy of about 1,500 people throughout the King's campus. Steam is supplied from Dalhousie University's central service as high-pressure steam into the basement of the North Pole Bay (i.e., part of the Arts & Administration building). The current steam peak consumption is about 4,200 lbs/hr with total steam consumption for the past 4-5 years typically about 10,500,000 lbs annually. A high-level overview for each of the buildings has been provided below.

Building	Description	Current Systems
Alexandra Hall, including Chapel & Pit	1969, 47,600 sq.ft., 5-storey residence	● Hydronic Heating, two (2) 1,000-MBH (estimated) steam convertors. Circulated by two (2) (duty/standby) Grundfos UPS-80 with 3-HP motors. Operates based on outdoor air temperature reset. ● A single zone valve for radiators services many rooms with a common single set-point pneumatic thermostat. No schedules.
Library	1991, 24,900 sq.ft., 2-storey library	● Two (2) 1,000-MBH steam convertors located in the basement provide hydronic heating. Circulated by two (2) (duty/standby) circulators with 2-HP motors. Pneumatic controls throughout.
Prince Hall	1961, 20,100 sq.ft., 2-Storey cafeteria	● One (1) 1,000-MBH (estimated) steam converter located in the basement provides hydronic heating for the facility's radiators. Circulated by two (2) (duty/standby) circulators with 2-HP motors. Pneumatic controls throughout. ● One (1) 1,000-MBH (estimated) steam converter located in the basement provides glycol heating water for four (4) reheat coils used to maintain the high bay area at set-point. Circulated by two (2) (duty/standby) circulators with 1-HP motors. Pneumatic controls throughout.
New Academic Building including Link	2001, 36,600 sq.ft., 4-storey classroom	● One (1) 1,305-MBH steam convertor located in the basement provides hydronic heating. Circulated by two (2) (duty/standby) circulators with unknown motor size. Electronic controls throughout, minimal scheduling or resets. ● One (1) 565-MBH steam converter located in the basement provides glycol water heating. Circulated by one (1) circulator with an unknown motor size. Electronic controls throughout, minimal scheduling or

		resets.
Gymnasium	1960, 21,900 sq.ft., 2-storey athletic	● One (1) 1,000-MBH (estimated) steam converter located in the basement provides hydronic heating for the facility's radiators. Circulated by two (2) (duty/standby, manually switched) circulators with unknown motors. Pneumatic controls throughout. Combination of fan coil units and force flows used. ● Domestic hot water is produced by an indirect hot water tank (on hydronic system) and complete with a recirculation pump. No schedules.
Arts & Administration including North Pole & Cochran Bays	1929, 42,200 sq.ft., 4-storey mixed use	● One (1) unknown steam converter located in the North Pole basement and one (1) unknown steam converter located in the Cochran Bay basement provide hydronic heating for the facility's radiation. Each is circulated by two (2) (duty/standby, manually switched) circulators with unknown motors. Pneumatic controls throughout. ● Domestic hot water is produced by an indirect hot water tank (on a hydronic system) and complete with a recirculation pump. No schedules. System recently renovated. ● Facility has a 400-ft long snow melt system along the edge of the building. No known controls associated with the system.
Tri-Bays including Radical, Middle & Chapel Bays	1929, 42,000 sq.ft., 4-storey mixed use	● Very limited information, expected to be similar to the Arts & Administration building noted above.

Generally speaking, understanding the intent is to convert the steam heating infrastructure to hydronic heating, all existing steam plant infrastructure would be demolished, including steam-to-water convertors and condensate receiver tanks. All existing steam supply and condensate return piping, equipment and infrastructure would be demolished in its entirety throughout the facility. For the most part these systems are located within mechanical service spaces or utility corridors, with a few notable exceptions (i.e., the Arts & Administration, Library, New Academic, and Chapel buildings). Wherever deemed appropriate, the existing steam supply piping could be reused, however, at this time (given that pipe integrity testing has not been completed) this was assumed to not be a viable option due largely to the age of the infrastructure as well as that high-pressure steam distribution piping doesn't lend itself well to hydronic conversion due to smaller pipe sizes (i.e., low-pressure steam supply piping can often be a straight conversion).

An energy exchange station would be installed within the basement of the North Pole Bay (i.e., where the primary service from Dalhousie University enters the campus). The energy exchange station would hydraulically isolate Dalhousie University's hydronic heating system (likely to be a medium-pressure, high-temperature system) from King's hydronic system. With hot water generated centrally, all other steam-to-water convertors throughout the campus would simply be removed and not replaced with additional heat exchangers. Where there are glycol-water heating systems, smaller heat exchangers will be installed for these sub-systems. All secondary circulators will remain installed and unchanged (i.e., the circulators currently on the load-side of the existing steam-to-water convertors). Primary loop circulators, located with the energy exchange station in the basement of the North Pole Bay, will distribute hot water throughout the campus.

Alternate heating sources for a number of kitchen appliances in Prince Hall (currently served by direct steam), humidification in the Library (currently served by a steam-to-steam humidifier), and various steam radiators within the Tri-Bay building including Radical, Middle & Chapel Bays and the Arts & Administration building, including the Centre and Cochran Bays. A small electric steam boiler will be installed for the kitchen appliances in Prince Hall, an electric humidifier will be installed to provide humidification in the Library and the steam radiators throughout will be replaced with hydronic radiators.

Typical annual steam consumption for the last 4-5 years has been 10,500,000 lbs, based on utility monitoring data. The energy simulation model developed for King's was calibrated to model 10,411,248 lbs of annual steam consumption. Based on the estimated efficiencies of Dalhousie University's central steam plant, this steam consumption has been estimated to correspond to 12,636 GJ of natural gas producing 755 tonnes of equivalent carbon dioxide ($tCO2_e$).

Converting the campus's steam heating infrastructure to hydronic heating will reduce natural gas consumption to 9,260 GJ, or by about 27%. This reduction in natural gas consumption corresponds to a reduction of greenhouse gas emissions of about 202 $tCO2_e$, to about 553 $tCO2_e$. Based on the current utility pricing agreement with Dalhousie University (i.e., about $20 per 1,000 lbs of steam), the conversion will also provide about $55,600 in annual energy savings for King's. The modelling uncertainty is about ± 15%.

A detailed Class 'D' Construction Cost Estimate was developed for the conversion of the campus's steam heating infrastructure to hydronic heating. Given that the project is at a preliminary design stage (i.e., pre-schematic design) and specific details and quantities for the project are not yet available, typically such an estimate is expected to be within ±25% of the construction project value. It's important to note that recent global events (i.e., ongoing COVID-19 recovery, the Ukraine crisis, increasing global oil prices, uncertainty in manufacturing and raw material pricing, etc.) continue to significantly impact construction costs locally and, as a result, relatively accurate cost estimating and scheduling is becoming increasingly challenging.

The construction cost has been estimated at $2.875M with an additional $600K in projects costs, including engineering, contingencies, escalation (assuming a 2023 start), and commissioning. See below for a high-level summary of the project cost estimate:

- Construction: $2,500,000
- General requirements (10%): $250,000
- Profit (5%): $125,000
- **Construction Cost Estimate: $2,875,000**
- Engineering: $250,000
- Design contingency (10%): $250,000
- Escalation/inflation (2.5%): $62,500
- Commissioning (1.5%): $37,500
- **Project Cost Estimates: $600,000**
- ***Total Project Cost Estimate: $3,475,000***

Appendix J

Detailed Cost Estimates

Line	Alexandra Hall (including Chapel and Pit) Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$7,500
03	Electronic Sensors		$15,000
04	Electronic Zone Valves		$7,500
05	Lighting Controls		$10,000
06	Field Control Devices		$10,000
07	Electrical and Wiring		$5,000
08	Programming		$10,000
09	Integration to Existing		$5,000
10	Field Testing and Verification		$5,000
11	*Construction Cost Estimate*		*$80,000*
12	Design and Development Contingency	*10 %*	$8,000
13	Construction Contingency	*10 %*	$8,000
14	Escalation / Inflation	*15 %*	$12,000
15	General Requirements	*10 %*	$8,000
16	Overhead and Profit	*5 %*	$4,000
17	Commmissioning	*2 %*	$1,600
18	**Project Total**		$121,600

	Library Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$2,500
02	Modifications and Retrofits of Existing		$2,500
03	Electronic Sensors		$5,000
04	Electronic Zone Valves		$5,000
05	Lighting Controls		$10,000
06	Field Control Devices		$2,500
07	Electrical and Wiring		$5,000
08	Programming		$2,500
09	Integration to Existing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$40,000*
12	Design and Development Contingency	*10 %*	$4,000
13	Construction Contingency	*10 %*	$4,000
14	Escalation / Inflation	*15 %*	$6,000
15	General Requirements	*10 %*	$4,000
16	Overhead and Profit	*5 %*	$2,000
17	Commmissioning	*2 %*	$800
18	**Project Total**		$60,800

	Prince Hall Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$5,000
03	Electronic Sensors		$10,000
04	Electronic Zone Valves		$5,000
05	Lighting Controls		$7,500
06	Field Control Devices		$5,000
07	Electrical and Wiring		$5,000
08	Programming		$5,000
09	Integration to Existing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$52,500*
12	Design and Development Contingency	*10 %*	$5,250
13	Construction Contingency	*10 %*	$5,250
14	Escalation / Inflation	*15 %*	$7,875
15	General Requirements	*10 %*	$5,250
16	Overhead and Profit	*5 %*	$2,625
17	Commmissioning	*2 %*	$1,050
18	**Project Total**		$79,800

	New Academic Building (including Link) Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$2,500
02	Modifications and Retrofits of Existing		$2,500
03	Electronic Sensors		$5,000
04	Electronic Zone Valves		$5,000
05	Lighting Controls		$10,000
06	Field Control Devices		$2,500
07	Electrical and Wiring		$5,000
08	Programming		$2,500
09	Integration to Existing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$40,000*
12	Design and Development Contingency	*10 %*	$4,000
13	Construction Contingency	*10 %*	$4,000
14	Escalation / Inflation	*15 %*	$6,000
15	General Requirements	*10 %*	$4,000
16	Overhead and Profit	*5 %*	$2,000
17	Commmissioning	*2 %*	$800
18	**Project Total**		$60,800

	Gymnasium Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$2,500
02	Modifications and Retrofits of Existing		$2,500
03	Electronic Sensors		$5,000
04	Electronic Zone Valves		$5,000
05	Lighting Controls		$10,000
06	Field Control Devices		$2,500
07	Electrical and Wiring		$5,000
08	Programming		$2,500
09	Integration to Existing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$40,000*
12	Design and Development Contingency	*10 %*	$4,000
13	Construction Contingency	*10 %*	$4,000
14	Escalation / Inflation	*15 %*	$6,000
15	General Requirements	*10 %*	$4,000
16	Overhead and Profit	*5 %*	$2,000
17	Commmissioning	*2 %*	$800
18	**Project Total**		$60,800

	Arts and Administration Building (including North Pole, Cochran, and Wardroom) Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$7,500
03	Electronic Sensors		$15,000
04	Electronic Zone Valves		$7,500
05	Lighting Controls		$10,000
06	Field Control Devices		$10,000
07	Electrical and Wiring		$5,000
08	Programming		$10,000
09	Integration to Existing		$5,000
10	Field Testing and Verification		$5,000
11	*Construction Cost Estimate*		*$80,000*
12	Design and Development Contingency	*10 %*	$8,000
13	Construction Contingency	*10 %*	$8,000
14	Escalation / Inflation	*15 %*	$12,000
15	General Requirements	*10 %*	$8,000
16	Overhead and Profit	*5 %*	$4,000
17	Commmissioning	*2 %*	$1,600
18	**Project Total**		$121,600

	Tri-Bays (including Radical, Middle, and Chapel) Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$7,500
03	Electronic Sensors		$15,000
04	Electronic Zone Valves		$7,500
05	Lighting Controls		$10,000
06	Field Control Devices		$10,000
07	Electrical and Wiring		$5,000
08	Programming		$10,000
09	Integration to Existing		$5,000
10	Field Testing and Verification		$5,000
11	*Construction Cost Estimate*		*$80,000*
12	Design and Development Contingency	*10 %*	$8,000
13	Construction Contingency	*10 %*	$8,000
14	Escalation / Inflation	*15 %*	$12,000
15	General Requirements	*10 %*	$8,000
16	Overhead and Profit	*5 %*	$4,000
17	Commmissioning	*2 %*	$1,600
18	**Project Total**		$121,600

	Campus Central System Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$5,000
03	Electronic Sensors		$10,000
04	Electronic Zone Valves		$5,000
05	Lighting Controls		$7,500
06	Field Control Devices		$5,000
07	Electrical and Wiring		$5,000
08	Programming		$5,000
09	Integration to Existing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$52,500*
12	Design and Development Contingency	*10 %*	$5,250
13	Construction Contingency	*10 %*	$5,250
14	Escalation / Inflation	*15 %*	$7,875
15	General Requirements	*10 %*	$5,250
16	Overhead and Profit	*5 %*	$2,625
17	Commmissioning	*2 %*	$1,050
18	**Project Total**		$79,800

Measure Total	**$706,800**

	Library Heating, Ventilating, and Air Conditioning Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$5,000
03	CAV to VAV Terminal Device Replacement		$40,000
04	Ductwork Modifications		$10,000
05	Relocations of Existing Services		$10,000
06	Building Automation System Upgrades		$2,500
07	Electrical and Wiring		$2,500
08	Air Handling Unit Modifications		$2,500
09	Testing, Adjusting, and Balancing		$1,500
10	Field Testing and Verification		$1,500
11	*Construction Cost Estimate*		*$80,500*
12	Design and Development Contingency	*10 %*	$8,050
13	Construction Contingency	*10 %*	$8,050
14	Escalation / Inflation	*15 %*	$12,075
15	General Requirements	*10 %*	$8,050
16	Overhead and Profit	*5 %*	$4,025
17	Commmissioning	*2 %*	$1,610
18	**Project Total**		$122,360

	Prince Hall Heating, Ventilating, and Air Conditioning Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$5,000
03	CAV to VAV Terminal Device Replacement		$40,000
04	Ductwork Modifications		$10,000
05	Relocations of Existing Services		$10,000
06	Building Automation System Upgrades		$2,500
07	Electrical and Wiring		$2,500
08	Air Handling Unit Modifications		$2,500
09	Testing, Adjusting, and Balancing		$1,500
10	Field Testing and Verification		$1,500
11	*Construction Cost Estimate*		*$80,500*
12	Design and Development Contingency	*10 %*	$8,050
13	Construction Contingency	*10 %*	$8,050
14	Escalation / Inflation	*15 %*	$12,075
15	General Requirements	*10 %*	$8,050
16	Overhead and Profit	*5 %*	$4,025
17	Commmissioning	*2 %*	$1,610
18	**Project Total**		$122,360

	New Academic Building (including Link) Heating, Ventilating, and Air Conditioning Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$5,000
03	CAV to VAV Terminal Device Replacement		$30,000
04	Ductwork Modifications		$15,000
05	Relocations of Existing Services		$10,000
06	Building Automation System Upgrades		$5,000
07	Electrical and Wiring		$2,500
08	Air Handling Unit Modifications		$15,000
09	Testing, Adjusting, and Balancing		$1,500
10	Field Testing and Verification		$1,500
11	*Construction Cost Estimate*		*$90,500*
12	Design and Development Contingency	*10 %*	$9,050
13	Construction Contingency	*10 %*	$9,050
14	Escalation / Inflation	*15 %*	$13,575
15	General Requirements	*10 %*	$9,050
16	Overhead and Profit	*5 %*	$4,525
17	Commmissioning	*2 %*	$1,810
18	**Project Total**		$137,560

	Arts and Administration Building (including North Pole, Cochran, and Wardroom) Heating, Ventilating, and Air Conditioning Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$5,000
02	Modifications and Retrofits of Existing		$5,000
03	Air Conditioning Unit Upgrades		$65,000
04	Ductwork Modifications		$15,000
05	Relocations of Existing Services		$10,000
06	Building Automation System Upgrades		$5,000
07	Electrical and Wiring		$2,500
08	Air Handling Unit Modifications		$10,000
09	Testing, Adjusting, and Balancing		$1,500
10	Field Testing and Verification		$1,500
11	*Construction Cost Estimate*		*$120,500*
12	Design and Development Contingency	*10 %*	$12,050
13	Construction Contingency	*10 %*	$12,050
14	Escalation / Inflation	*15 %*	$18,075
15	General Requirements	*10 %*	$12,050
16	Overhead and Profit	*5 %*	$6,025
17	Commmissioning	*2 %*	$2,410
18	**Project Total**		$183,160

Measure Total		**$565,440**

	Alexandra Hall (including Chapel and Pit) Building Automation System Upgrades		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$15,000
02	Modifications and Retrofits of Existing		$5,000
03	Distribution Piping		$100,000
04	Heat Exchanger Modifications		$25,000
05	Coil and/or Radiator Replacement		$0
06	Relocations of Existing Services		$15,000
07	Building Automation System Upgrades		$25,000
08	Electrical and Wiring		$5,000
09	Testing, Adjusting, and Balancing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$195,000*
12	Design and Development Contingency	*10 %*	$19,500
13	Construction Contingency	*10 %*	$19,500
14	Escalation / Inflation	*15 %*	$29,250
15	General Requirements	*10 %*	$19,500
16	Overhead and Profit	*5 %*	$9,750
17	Commmissioning	*2 %*	$3,900
18	**Project Total**		$296,400

	Library Hydronic Conversion		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$15,000
02	Modifications and Retrofits of Existing		$5,000
03	Distribution Piping		$100,000
04	Heat Exchanger Modifications		$25,000
05	Coil and/or Radiator Replacement		$0
06	Relocations of Existing Services		$15,000
07	Building Automation System Upgrades		$25,000
08	Electrical and Wiring		$5,000
09	Testing, Adjusting, and Balancing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$195,000*
12	Design and Development Contingency	*10 %*	$19,500
13	Construction Contingency	*10 %*	$19,500
14	Escalation / Inflation	*15 %*	$29,250
15	General Requirements	*10 %*	$19,500
16	Overhead and Profit	*5 %*	$9,750
17	Commmissioning	*2 %*	$3,900
18	**Project Total**		$296,400

	Prince Hall Hydronic Conversion		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$15,000
02	Modifications and Retrofits of Existing		$5,000
03	Distribution Piping		$100,000
04	Heat Exchanger Modifications		$25,000
05	Coil and/or Radiator Replacement		$0
06	Relocations of Existing Services		$15,000
07	Building Automation System Upgrades		$25,000
08	Electrical and Wiring		$5,000
09	Testing, Adjusting, and Balancing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$195,000*
12	Design and Development Contingency	*10 %*	$19,500
13	Construction Contingency	*10 %*	$19,500
14	Escalation / Inflation	*15 %*	$29,250
15	General Requirements	*10 %*	$19,500
16	Overhead and Profit	*5 %*	$9,750
17	Commmissioning	*2 %*	$3,900
18	**Project Total**		$296,400

	New Academic Building (including Link) Hydronic Conversion		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$15,000
02	Modifications and Retrofits of Existing		$5,000
03	Distribution Piping		$185,000
04	Heat Exchanger Modifications		$25,000
05	Coil and/or Radiator Replacement		$0
06	Relocations of Existing Services		$15,000
07	Building Automation System Upgrades		$25,000
08	Electrical and Wiring		$5,000
09	Testing, Adjusting, and Balancing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$280,000*
12	Design and Development Contingency	*10 %*	$28,000
13	Construction Contingency	*10 %*	$28,000
14	Escalation / Inflation	*15 %*	$42,000
15	General Requirements	*10 %*	$28,000
16	Overhead and Profit	*5 %*	$14,000
17	Commmissioning	*2 %*	$5,600
18	**Project Total**		$425,600

	Gymnasium Hydronic Conversion		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$15,000
02	Modifications and Retrofits of Existing		$5,000
03	Distribution Piping		$80,000
04	Heat Exchanger Modifications		$20,000
05	Coil and/or Radiator Replacement		$0
06	Relocations of Existing Services		$15,000
07	Building Automation System Upgrades		$20,000
08	Electrical and Wiring		$5,000
09	Testing, Adjusting, and Balancing		$2,500
10	Field Testing and Verification		$2,500
11	*Construction Cost Estimate*		*$165,000*
12	Design and Development Contingency	*10 %*	$16,500
13	Construction Contingency	*10 %*	$16,500
14	Escalation / Inflation	*15 %*	$24,750
15	General Requirements	*10 %*	$16,500
16	Overhead and Profit	*5 %*	$8,250
17	Commmissioning	*2 %*	$3,300
18	**Project Total**		$250,800

	Arts and Administration Building (including North Pole, Cochran, and Wardroom) Hydronic Conversion		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$30,000
02	Modifications and Retrofits of Existing		$20,000
03	Distribution Piping		$90,000
04	Heat Exchanger Modifications		$40,000
05	Coil and/or Radiator Replacement		$80,000
06	Relocations of Existing Services		$20,000
07	Building Automation System Upgrades		$40,000
08	Electrical and Wiring		$10,000
09	Testing, Adjusting, and Balancing		$5,000
10	Field Testing and Verification		$5,000
11	*Construction Cost Estimate*		*$340,000*
12	Design and Development Contingency	*10 %*	$34,000
13	Construction Contingency	*10 %*	$34,000
14	Escalation / Inflation	*15 %*	$51,000
15	General Requirements	*10 %*	$34,000
16	Overhead and Profit	*5 %*	$17,000
17	Commmissioning	*2 %*	$6,800
18	**Project Total**		$516,800

	Tri-Bays (including Radical, Middle, and Chapel) Hydronic Conversion		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$30,000
02	Modifications and Retrofits of Existing		$20,000
03	Distribution Piping		$90,000
04	Heat Exchanger Modifications		$40,000
05	Coil and/or Radiator Replacement		$105,000
06	Relocations of Existing Services		$20,000
07	Building Automation System Upgrades		$40,000
08	Electrical and Wiring		$10,000
09	Testing, Adjusting, and Balancing		$5,000
10	Field Testing and Verification		$5,000
11	*Construction Cost Estimate*		*$365,000*
12	Design and Development Contingency	*10 %*	$36,500
13	Construction Contingency	*10 %*	$36,500
14	Escalation / Inflation	*15 %*	$54,750
15	General Requirements	*10 %*	$36,500
16	Overhead and Profit	*5 %*	$18,250
17	Commmissioning	*2 %*	$7,300
18	**Project Total**		$554,800

	Campus Central System Hydronic Conversion		
Line	*Cost Element*		*Sub-Total*
01	Selective Demolition		$40,000
02	Modifications and Retrofits of Existing		$25,000
03	Distribution Piping		$95,000
04	Heat Exchanger Modifications		$175,000
05	Miscellaneous Supplemental Steam Boilers		$80,000
06	Relocations of Existing Services		$15,000
07	Building Automation System Upgrades		$40,000
08	Electrical and Wiring		$10,000
09	Testing, Adjusting, and Balancing		$5,000
10	Field Testing and Verification		$5,000
11	*Construction Cost Estimate*		*$490,000*
12	Design and Development Contingency	*10 %*	$49,000
13	Construction Contingency	*10 %*	$49,000
14	Escalation / Inflation	*15 %*	$73,500
15	General Requirements	*10 %*	$49,000
16	Overhead and Profit	*5 %*	$24,500
17	Commmissioning	*2 %*	$9,800
18	**Project Total**		$744,800

Measure Total	**$3,382,000**