# Analysis of Retrofitting Possibilities for Old Historical Buildings on the Dalhousie Campus

Prepared for: ENVS3502 - The Campus as a Living Laboratory

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## EXECUTIVE SUMMARY

This research project outlines the need for an expansion upon Dalhousie University's Green Building Policy to include energy efficient upgrades to older infrastructure on campus such as the Henry Hicks Academic Administration building. Through data analyses and extrapolation from quantitative data, priority-based recommendations are made in order to determine which retrofit options are most feasible for the Henry Hicks building. Baseline consumption data for heating, electricity, and water, combined with informations from informal interviews with Facilities Management are used as a basis for highlighting these target areas. Using a literature review, parameters for the various types of retrofitting areas are also discussed and justified for deployment in the Henry Hicks.

The historic and iconic Henry Hicks building is roughly 63 years old and is selected as the case study for the focus of our research. The Henry Hicks is riddled with leaky windows, gaps between main doors, and excessive waste from water fixtures. Therefore, retrofit options in the areas of water consumption and heating are selected as priority areas for Dalhousie University. Our findings suggest that the retrofit of windows can reduce the heating utility bill for the Henry Hicks by 20% to 30% annually. Furthermore, standardized installation of low-flow water fixtures for two appliances, toilets and faucets, can facilitate a reduction in water consumption by 30% to 40% annually. Among the priority areas, a solar energy system for hot water heating, insulation, re-pointing of stonework and smart-meters also have the potential to significantly minimize the resource use and waste associated with the Henry Hicks building.

## 1. INTRODUCTION

Currently, buildings around the world account for over 40% of global energy use, producing approximately one third of global greenhouse gas emissions. It is also well known that low carbon emissions are one of the key factors that contributes to sustainable urban development and effectively tackles climate change. (Yung & Chan, 2012) Historical buildings in particular, make up a significant portion of the entire building stock all over the world and it is not possible to preserve them as they are because of their inefficient energy consumption (Yung & Chan, 2012). Although the construction of new buildings is costly, it also requires significant raw materials, energy, and also generates high carbon emissions**.** Instead, the adaptive retrofitting of historical buildings is a form of sustainable urban regeneration, which extends the buildings life and avoids demolition waste (Yung & Chan, 2012). Historical building conservation is a multidimensional way to increase building energy efficiency and reduce greenhouse gas emissions (Iyer-Raniga & Wong, 2012). Adaptive retrofitting not only extends the life cycle and cost efficiency of historical buildings, it also conserves significant heritage values attached to them. (Yung & Chan, 2012) The adaptive retrofitting of historical buildings represents an effective strategy to combat climate change while preserving important cultural value and remaining cost effective.

### 1.1 Study Context

The adaptive retrofit of a historical building is essential as a decrease in energy and water consumption, which would result in the use of fewer resources. This initiative would address anthropogenic climate change and minimize the utilization of precious resources such as water, as well as decreasing fossil fuel emissions associated with building operations. Anthropogenic climate change has resulted from increased industrialization, made possible by excessive fossil fuel use and therefore associated greenhouse gas emissions (GHG) into the Earth's atmosphere. Fossil fuel use and waste (i.e. water and energy) is rapidly increasing across the world, with buildings playing a progressively larger role (Rosenzwig, et al. 2008). Supply difficulties, exhaustion of energy resources and increasingly intense environmental impacts are becoming a prominent concern surrounding the continued and increased use of non-renewable fuels (Pérez-Lombard, et al. 2008). Continued development using fossil fuels has caused an increase in associated GHG emissions with the concentration of carbon dioxide ($CO_2$) increasing from 280ppmv (parts per million by volume) in the pre-industrial era to 400 ppmv as of mid-2013 (Harvey, 2013). If we continue on this current destructive path, carbon concentrations are projected to reach between 600-1200 ppmv by the year 2100 (Harvey, 2013). The IPCC Working Group II Fourth Assessment Report concluded that the global assessment of data from 1970 displayed anthropogenic warming as the most likely (66-90%) cause of harmful effects seen on biological and physical systems. Therefore, significantly reducing the amount GHG emissions and resource waste associated with historical building operations is necessary in order to prevent further damage to environment.

The knowledge of our impacts as humans on the environment has become more thoroughly understood, increasing individuals concern for the environment while spurring the movement towards sustainability. Reduction of GHG emissions is a major component of this movement and is essential for maintaining and mitigating damages. The global contribution toward energy consumption and ultimately GHG emissions from buildings is now exceeding other major sectors including both the industrial and transportation (Pérez-Lombard, et al. 2008). This consistent increase has resulted in buildings being responsible for 20-40% of carbon emissions in developed countries (Pérez-Lombard, et al. 2008). More specifically, buildings in the United States contribute to 38.1% of total national $CO_2$ emissions (U.S. Environmental Protection Agency, 2012). Population growth, increased demand for varied buildings services, increased time spent inside buildings, accompanied by a disregard for nature have all contributed to the increase in building emissions (Pérez-Lombard, et al. 2008). This makes the environmental performance of buildings of particular importance to reduction and mitigation of climate change. Buildings have been increasingly designed to realize dramatic reductions in energy required for heating in many countries (Harvey, 2013).

## 1.2 Green Buildings

In a recent study which analyzed 150 energy efficient buildings, 50% saw their initial cost premium for implementation or construction being paid back by energy and water savings in 5 or less years (Issa et al. 2010). Another study which reviewed 30 different schools across the United States concluded that energy savings made up 36% of the whole life cost; those savings were three times larger than the initial cost which was invested into making the buildings more efficient (Issa et al. 2010). Although this might not always be the case, retrofits usually result in reduced energy use, which is correlated with a reduced expenditure on supply resources. The benefits reaped could be an asset for Dalhousie and the saved money could be reinvested in continued retrofitting, for old, inefficient buildings.

Retrofitting of museum buildings, in particular the Delphi and Ljubjana in Europe, represent a successful initiative for reducing fossil fuel use and associated GHG emissions, while still maintaining the unique integrity of the buildings and exhibits. Although the Henry Hicks is distinctive, the results and comparison is still applicable. The Henry Hicks and museum building types are both large in size, have a varying occupancy, and are well known (Zannis, 2006). Improvements of microclimate were made through use of shading, planting, use of water surfaces and insulation and glazing upgrades, which all contributing to the reduction of thermal losses for the museums (Zannis, 2006). Insulation of heating recovery modules, use of ceiling fans, night ventilation for cooling, high-efficiency luminaires, lighting mechanisms, and daylight compensation were implemented to reduce energy consumption (Zannis, 2006). Control strategies, ventilation and other innovations were also made (Zannis, 2006). The results varied across the different museums but all saw a reduction in energy. Energy conservation resulted in a reduction by 97.3 % for heating, 68.6% for cooling, 59.3% for lighting and other electrical by 34.8% with a grand total of 77.2% energy conserved for the Delphi museum (Zannis, 2006). The Kristinehamn Museum, which was part of the same study, saw a reduction as a result of retrofits, but to a lesser degree with energy consumption reduced by 39.2%

in total (Zannis, 2006). These varying results are likely due to different features, which uniquely characterize the buildings and the applicability of potential retrofits, and initial inefficiencies levels present. Although this particular study did not focus on water consumption, reduction of water use has been documented in many environments by simply switching to more energy efficient fixtures (Harvey, 2013).

In the UK a study was conducted to test how retrofits for increased efficiency can benefit protected buildings of historical significance. This project was conducted in a unique way and differently from ours, but still provides evidence for success. The Royal Standard House (1923) was used and on-site work was conducted to collect qualitative and quantitative data regarding thermal and visual comfort of occupants, in addition to a personal review of energy use (Rodrigues & Kacel, 2013). A simulation matrix was created for a number of different cases with varying parameters. The study concluded that 50% of reduction on energy use could be achieved with no associated impacts on the external character and very minimal impacts internally (Rodrigues & Kacel, 2013). This is particularly important, as it provides evidence of success even for historical buildings, which often come with additional challenges.

Waltham Forest College in London, is characterized by buildings dating from the 1930's and had reduced energy costs by 25% through a retrofitting program which included double glazing, solid wall insulation, and a heat exchange system (Wall, 2013). They won the Non-domestic Retrofit Project of the Year Award in 2013, and intend to continue on this path by aiming for zero emissions, and directing culture towards sustainable energy use (Wall, 2013).

## 1.3 Dalhousie Context and Policy:

Building demolition and replacement in a majority of the world is extremely low, at less than 1% per year (Harvey, 2013). This means that most buildings standing today will still be standing in 35+ years (Harvey, 2013), which solidifies the importance of retrofitting for increased efficiency and maintenance. Historical buildings are of particular importance and are defined as having architectural, aesthetic, historical, economic, cultural, or spiritual values (Rodrigues & Kacel, 2013); these values make these buildings problematic for demolition and reconstruction for more energy efficient buildings or for conversation to LEED buildings, as for the case of Dalhousie University.

Sustainable development is becoming increasingly prominent and presents one of the most extensive challenges of the century. Numerous universities have entered the debate and have integrated sustainability into their policies (Weenen, 2000). There are various ways which universities can involve themselves in sustainable development including but not limited to management, planning, development, retrofitting, education, research, sourcing, design, and renovation (Weenen, 2000). Dalhousie University has a Green Building Policy that requires each new building to achieve, at minimum, LEED gold standard. Although Dalhousie states that green building programs for existing buildings and operations maintenance, will be explored, as they have yet to sufficiently do so or implement major retrofits. As buildings being the primary energy consumer, this renders retrofitting essential and a top priority for historical and aesthetically significant buildings, which are problematic for demolition. Retrofitting existing historical buildings provides many benefits including retention of identity, awareness, promotion of equality, reduction of environmental damage, and economic returns while also providing a cleaner environment that both students and faculty can be proud to be a part of. Additionally universities are in a unique position to address problems of sustainability with a principal goal of education (Uhl & Anderson, 2001). Not only do universities educate, but are often large, prestigious and influential institutions which have the capability of significant impacts on the environment directly, as well as influence on local and potentially global communities (Uhl & Anderson, 2001).

## 1.4 Study Rationale

Universities and others across the globe have begun to retrofit buildings to reduce waste including water, energy consumption and associated emissions. Dalhousie has an opportunity to increase their concern and stewardship for the environment as well as become a leader as a sustainable, energy efficient university. Retrofitting provides a perfect option for Dalhousie at it provides a happy median for which the environmentally concerned individual and historical preservationist may agree.

Mount Allison University in New Brunswick recently made a controversial decision in an effort to meet the future needs of the university. Mount Allison University's historic, 84-year-old "Memorial Library", was demolished in order to make way for the addition of a new Fine and Performing Arts Centre. This decision made by the university sparked uproar among alumni, architects, and heritage society activists. Gloria Jollymore, the vice-president of university advancement at Mount Allison stated, "We regret that not everyone agrees, but we are making this decision in the best interests of the university" (Posner, 2011). Although Mount Allison's decision to demolish the historic building is drastic, surely, for buildings with significant historical importance and value, there lies a middle ground before its "out with the old and in with the new".

## 1.5 Building Descriptions:

Henry Hicks:

The Henry Hicks is one of Dalhousie most recognizable iconic buildings distinguished by its striking clock tower and historical design. The building was designed within the colonial style of the other buildings on campus (University Club, Macdonald Building, Chemistry Building and Sherriff Hall), with the final construction completed on December 1st 1951 (Dalhousie University, 2006). Renovations including repairs of rotting window frames and crumbling mortar were done in 1992, lighting improvements were made in the Financial Services hallway in 2003 and basement restrooms were renovated in 2005 (Dalhousie University, 2006). The building is bright and airy and today houses classrooms, administration offices and the Office of Research Services. Old buildings like the Henry Hicks are rundown and inefficient making them an important focus in the sustainability sector. Energy related issues, evident to any student who uses the building, are not limited to leaky windows (many have plastic over them), drafts from gaps between main doors, crumbling of mortar and inefficient use of water in old sinks and toilet fixtures.

Mona Campbell:

The Mona Campbell was Dalhousie's newest and most energy efficient building as of its opening in 2010. The Mona Campbell is LEED gold certified following the regulation of Dalhousie's Green Building Policy. This building has many environmentally friendly aspects including recycling facilities, BubbleDeck concrete (requires 30% less concrete), recycling of construction and demolition waste, ethical sourcing, OptiNet sensors for air quality, low-flow fixtures, efficient lighting, solar and efficient heat pumps (Smulders , 2010). The Mona Campbell houses many classrooms, offices, large lecture halls, cyclist facility, Office of Sustainability and coffee shops, which are used by students and faculty. This building depicts an extremely energy efficient accomplishment of Dalhousie University.

## 1.6 Project Definition and Objectives

Dalhousie's Green Building Policy, which came into effect in 2010, made a commitment that any newly constructed building on Dalhousie's campus' over 10,000 $ft^2$ in size would have to meet or exceed the Leadership in Energy and Environmental Design (LEED) Gold construction standard. (Dalhousie University, 2011) Although the implementation of this ambitious building policy is set to create new, efficient and sustainable buildings, without more actively addressing the inefficient, aging, buildings already existing on campus, the effort will be ineffective. By only focusing on the creation of new sustainable buildings, a significant gap remains in the Green Building Policy. Existing buildings on campus, like the Henry Hicks for example, are already multi-use, high traffic buildings, and the longer they age under the pressure of intense use without efficiency renovations, the more unsustainable their operations will become. The inclusion of making efficiency improvements to existing buildings on campus as part of the Green Building Policy could prove to more pervasively institute a sustainable built environment.

In order to preserve the iconic character of Dalhousie's main campus, while also upholding the University's recent commitment to improving the efficiency and sustainable standards of the built environment on campus, the Green Building Policy will need to be expanded upon. This expansion of the building policy will have to include the improvement of existing buildings on campus through specifically targeted retrofitting projects, rather than simply demolishing them.

The Henry Hicks building on Dalhousie's Studley Campus, is arguably the most iconic building associated with the university. Despite undergoing some limited renovations projects during its 63-year existence, there has been little effort to improve the working efficiency of the facilities within the building. By using the Henry Hicks building as the focus of this research project, we hope to be able to ascertain what retrofitting projects would be most applicable to the historical Henry Hicks building to expand the scope upon the existing Green Building Policy.

Through analyzing monitoring data taken from the Henry Hicks building over the past four years, we extrapolated what areas were in most need of improvement in the building. Furthermore, by conducting a comparative analysis between the monitoring data taken from the Henry Hicks and data from the Mona Campbell building, the only LEED Gold certified building on Dalhousie’s Campus, we were able to specify in more detail what retrofitting strategies would be best suited for the University to engage with and employ in the Henry Hicks Building. Lastly, knowledge was gathered through personal observation and in meetings with Facilities Management.

Through these analyses we were able to answer questions surrounding the issues of what areas are most in need of attention from a retrofitting project such as heating or water facilities, what the best strategies to implement those projects are, and what benefits, if any at all, could we potentially achieve from instituting those changes to the Henry Hicks building. More specifically we aimed to answer our research question: What retrofitting projects would be most effective for the historical Henry Hicks building to reduce energy use and water consumption (increase efficiency) within the building to expand the scope upon the existing Green Building Policy?

Through completion of our research, to we aim to better inform University administrators and Facilities Management on what retrofitting projects would be best suited to improve the efficiency and sustainable operations of the Henry Hicks in future endeavors. The answers to this question will hopefully help Dalhousie realize the potential they have to jump on the opportunity to become a leading University in sustainability. Perhaps our research will even influence the university to adopt an expanded building policy that will focus more on the sustainable improvement of existing buildings on campus.

# 2 RESEARCH METHODS

## 2.1 Design and Justification

Our exploratory research project worked to uncover knowledge on efficient retrofitting projects, which can be administered to the historic and culturally identifiable buildings on Dalhousie's Studley Campus. Our systematic inquiry evolved to increase the scope of Dalhousie's current Green Building Policy so it can include increased energy efficiency for older buildings (Campus Energy Master Plan, 2012). To answer our research question we used both qualitative and quantitative data to come to our final results.

Our quantitative data was comprised of billing records from both the Henry Hicks building and the Mona Campbell building on Studley campus. This information was granted to us from the Facilities Management staff at Dalhousie and incorporates: the total amounts of water consumption in liters per billing period otherwise measured in temporal scale as one month; and the total electricity consumption in kWh per billing period. The primary billing information is recorded in two separate spreadsheets on a Microsoft excel file (Appendix 7.2).

We looked into two areas of consumption in the Henry Hicks, those being water consumption and heating. These two areas where chosen based around information provided from the Executive Summary on Campus Energy Master Plan (2012) which comprised of multiple energy audits which were performed on Dalhousie Campuses throughout 2012. The Henry Hicks was highlighted as a building in need of a lighting retrofit. A lighting retrofit was completed in 2012 by Facilities Management, therefore we were able to broaden our scope to encompass areas which have not yet been treated by Facilities Management, those being water consumption and heating. Currently during peak heating times on Studley campus the central boiler does not have the "adequate firm capacity," to support the demand. As a result, the current Campus Energy Master Plan (2012) put an 'Immediate and Short term requirements' to, "upgrade and expand campus central heating systems to support new development." To solve this problem we thought it wise to act in the most sustainable means possible to ensure efficient heating retrofits are implemented in the Hicks building in order to reduce the burden on our poor boiler conditions.

Our second avenue for retrofitting in the Henry Hicks involved water consumption. Water plays a large role in the students, faculty and administrative person’s everyday behaviour. We use water for toiletries, drinking and cleaning. With Dalhousie predicting to grow 600, 000 square feet in building space over the next five years we will consider retrofits in the Hicks building which will work to help conserve water usage with our growing population (Campus Energy Master Plan, 2012).

The next step in resolving our research question dealt with qualitative data analysis. To explore the literature surrounding retrofits possibilities, group members conducted a critical literature review. To perform this review we used the database collection on the Dalhousie libraries websites (http://libraries.dal.ca/). The review started with multiple Boolean searches, which incorporated word selections such as: conservation, water, retrofit*. Once articles were collected they were categorized as being in favour for heating or water retrofitting options. To understand how it would be possible to initiate the types of retrofits possible for the Hicks building we moved into the next stage of qualitative research, which involved informal interviews with Facilities Management.

Interviews with Facilities Management were necessary to produce validity in the large selection of retrofitting options found in our literature review. Having background on the parameters, Facilities Management helped to narrow down our options as to what was feasible in the areas of retrofits on the Dalhousie campus and in particular within the Henry Hicks. Gathering information on funds available for projects, as well as projects already scheduled to take place on the Hicks allowed us to focus knowledge towards areas of the building in need of attention. These parameters led to a categorization system for our literature review. Each article found was then placed into ‘future’ or ‘present’ categories of projects. In the present, we describe as being within the next five years. Future projects would be starting over five years from now.

By working through a literature review, quantitative base lines and information gathered from interviews, it is our hope to see development on Dalhousie campus with it’s commitment to sustainability. We see this being realized with the mitigation of GHG emissions, as well as solidifying our stance as a sustainable institution within Canada and the world.

## 2.2 Procedures

The origin of our research question stemmed out brain storming session between our newly formed group members. As a group we expressed our ideas around what we viewed as sustainable issues on campus. This led to our final research question, “What retrofitting projects would be most effective to the historical Henry Hicks building to reduce energy use and water consumption within the building and to expand the scope upon the existing Green Building Policy?” After the creation of our research question we began literature reviews to collect background information on the building we chose to incorporate in our study. By reviewing information such as, when the construction of the building took place, we are able to collect key concepts to help in the conceptualization of what types of architectural materials were originally put into the building.

Background information was used to provide comparative rational between the constructional differences between the two buildings incorporated into this project. The Henry Hicks represents older infrastructure on campus, this aspect would be the focus of our research findings for retrofitting potential. Second, the Mona Campbell was used as a reference point for high efficiency buildings on campus. The Mona Campbell was built under LEED gold certification, which ensures its international recognition as a low impact environmental building (Smulders, 2010).

To begin our analysis of the buildings, there was a need to understand baselines of consumption in the Henry Hicks building. Meaning there was a need to know how much energy, water or heat the building was currently consuming. To fill this need we began corresponding through e-mails with the director of Facilities Operations and Management who was able to provide us with a Microsoft excel spreadsheet of monthly billing data. This data incorporated: the total amounts of water consumption in liters per billing period otherwise measured in temporal scale as one month; the total electricity consumption in kWh per billing period or month (Appendix 8.2)**.**

From the numerical data on the spread sheet, members of the group were able to complete linear functions comparing the water use in liters per billing period of the Henry Hicks versus the water usage in liters per billing period for the Mona Campbell all over a temporal scale starting in 2010 and progressing through to 2013 (Base year 2010 was chosen as this was the year the Mona Campbell opened). This same exercise was then completed for heat use in the buildings (Figure 1).

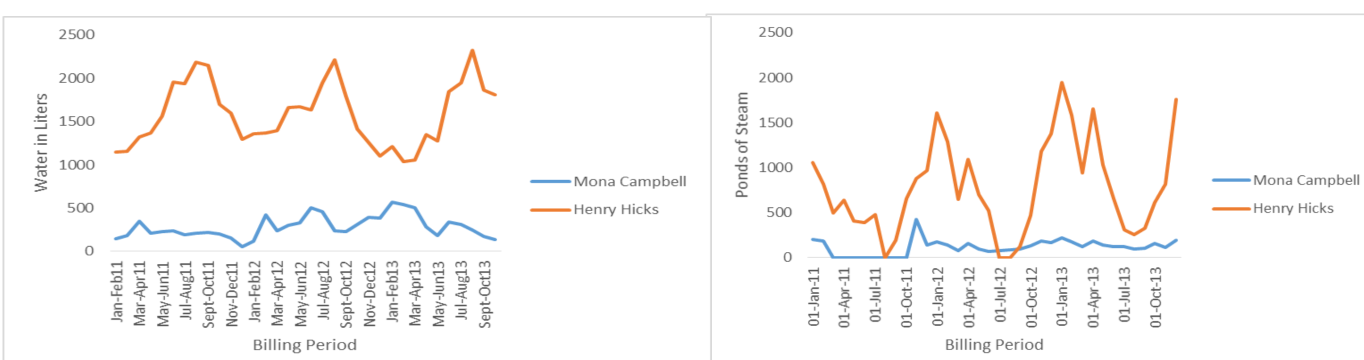


Figure 1: Comparison of consumption patterns for water and heat use in the Mona Campbell and Henry Hicks buildings. Data projected over a three year period from the beginning of 2011 until the end of 2013. Data provided from Facilities Operations and Management, Dalhousie University 2014.

This qualitative analyses made is possible for the group to build a base line of the current consumption of water and heat in the building. The members of our groups have utilized this information, throughout the duration of our project and this helped us to select which areas we would devote the majority of our time.

A literature review was then conducted in order to fill the knowledge gap between what our base lines meant, and how these base levels could be lowered to ensure more efficient use of resources in the Henry Hicks. After producing ideas of what potential project could be initiated in the Henry Hicks there was a need to understand if these projects fell under the feasibility of our Facilities Management, to ensure validity in our results.

Our correspondent, the director of Facilities Management forwarded us the contact information for the manager of Zone 3 of the University, which is where the Henry Hicks resides. An informal interview was then conducted with the manager of Zone 3. This interview provided us with the constraints to what was possible, in the capacity of Zone 3 staff, to accomplish. On top of establishing parameters, we've gained insight from the Facilities Management perspective on the buildings on our campus. Correlating their identified areas with the chosen areas of water, and heating allowed our group to further narrow the scope in which the project would continue.

With new parameters in place on the potential retrofitting option for the Henry Hicks, the literature review continued, however, this time including search terms which correlated with current infrastructure in the Henry Hicks, such as "poor envelope". The Energy Master Plan (2012) was helpful to this stage of the research, as now there was the ability to compare what the University believed were important projects for Facilities Management to approach in the future, and what the group believed were important areas of emphasis in particular to the Hicks building.

The Facilities Management manager of Zone 3, was then able to direct the researchers towards an engineer whom worked with Facilities Management. This second informal interview increased the understanding of what parameters the group needed to work within to enhance the feasibility of the retrofits that could be implemented. This interview also brought forth projects, to be completed in the Henry Hicks building in the near future and the financial barriers, which restrict them from occurring immediately.

The final steps towards answering the research questions was then combining our final literature reviews which had been placed categorically, with the parameters provided to us from Facilities Management.

From the final collection of qualitative information surrounding retrofitting projects in the Henry Hicks the group was able to make recommendation to the University as to what retrofits would be suitable for the present and into the future. Within these final recommendations, there were still unanswered questions, which lead to pronounced areas of further research, which can continue to develop from this project.

**Method of Categorizing Articles**

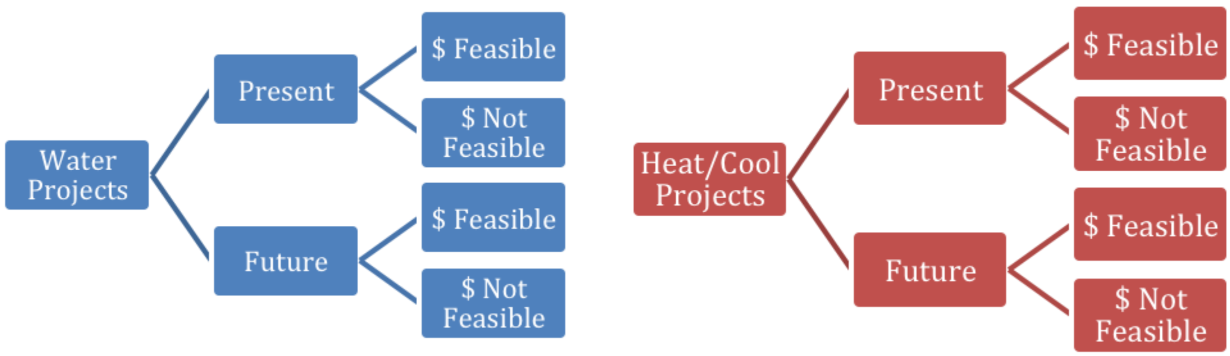


**Figure 1:** Method used to categorize articles used in the literature review and recommendations for retrofitting the Henry Hicks project. This chart demonstrates our proposed retrofitting ideas. They are divided into two categories, be it water and heating/cooling projects. They are then divided into two time frames and then they are undivided depending on their level of feasibility.

## 2.3 DISCUSSION

Our research revolved around exploring the potential for retrofitting the historic and iconic Henry Hicks building. Through completing a literature review built around identifying potential retrofitting projects, which have taken place in other institutions, we believe the generalization of these projects can be applied to other older building on campus. Specific parameters were set to increase the validity of our outcome to match the materials of the Henry Hicks; by doing so we decreased the scope and excluded any generalization to older buildings on Dalhousie campuses.

There were unforeseen limitations, which arose as the scope of the project narrowed to fit parameters set by Facilities Management on Dalhousie's Campus. The financial constraints on what projects could be actually attainable resulted in the group not only finding retrofit options which would work with the old infrastructure of the building but also fit well under the annual buildings budget of $18,000,000.00. A second parameter which limited retrofit possibilities, was knowing what Facilities Management planned to do in the near future. This knowledge influenced our research to build off of these proposed ideas instead of us focusing on new ideas. These limitations did restrict our analyses however this made our results more site specific and therefore beneficial for answering our research question.

There were specific restraints we placed on ourselves as delimitations in order to fully understand our outcomes. We chose to focus specifically on the Henry Hicks as this allowed us to be specific and target our data to fit the parameters around the iconic Henry Hicks. If it were to become a more efficient building, it would play a significant role in the ongoing transformation of Dalhousie towards being a truly sustainable institution.

We decided to work within the budget proposed by the university as this allowed the validity of our findings to match those resources in place at the university. We restricted our findings to two major areas of the building based on the highest consumption readings from our data spread sheet we received. However we were only given three consumption readings in total from the building (water, electricity and heating), which also limited the areas we could pursue for retrofits. As a group we will not be looking into energy consumption of the Henry Hicks as the energy category filters into multiple branches of the building, including some areas, which our research question covered, such as energy required for heating. Since there was a current need associated with specifically heating in the building we focused more towards looking into heating processes instead of the broader category of energy. This defined our proposal to be efficient in solving our research question within the time frame provided.

## 3 RESULTS

Through the compilation of our analysis's on both the baseline data obtained from Facilities Management, information from meetings and personal observation we come to the conclusion of main areas of which to focus our efforts: heating retention, reducing water usage, and some more extensive possibilities for reducing our impact using potential solar power and smart meters. Below in Table 1 is summary comparison of each retrofit option which we propose Dalhousie implement, or consider for implementation. This table will hopefully guide Dalhousie to retrofit options which may most suit their needs, while briefly describing the benefits and barriers to implementation. Each recommendation is talked about more extensively below.

**Table 1** Summary comparison of the effectiveness of suggest recommendations based on four different levels: low, medium, high and very high.

| **Recommendation** | **Potential for Increasing Efficiency** | **Difficulty of Implementation (level of difficulty to implement)** | **Level of Cost** | **Possibility to continually improve** |
|---|---|---|---|---|
| **Solar Power** | High | Medium | High | High |
| **Window Repair** | High | Low | Low | Low |
| **Insulation Building** | High | High | High | Low |
| **Re-pointing Stonework** | Low | Medium | Low/medium | Low |
| **Insulating Pipes** | Medium | Very High | High | Low |
| **Low-Flow Fixtures** | High | Medium-High | Medium- High | Low |
| **Future Possibilities** | | | | |
| **Smart Meters** | Low | Medium | High | Low |
| **Heat Exchanger** | Medium | Low-Medium | Medium | Low |
| **Smart Grid** | High | High | High | High |

## 3.1 Solar power on the Henry Hicks Building:

On Dalhousie campus there already exists some solar power collection. Although this is unknown to the majority of students, there are currently forty solar collectors on the roof for the Life Science Centre (LSC) (N.A., 2012). A company named Thermo Dynamics installed the panels on the roof of the LSC and they have been there since 2011. These panels seem to be well hidden on the roof of the building, but they are currently not being utilized to their full potential, as they are collecting an over abundance of energy in order to heat the water. The water is meant to heat the building, but the LSC is currently generating too much power, meaning that the surplus of energy is simply going to waste.

When looking at other potential buildings on the Studley campus, the Henry Hicks is a front-runner. It was constructed 63 years ago, and its structure and building material lack environmental sustainability. Being an older building, it would make more sense to retrofit certain aspects that could be improved on. Solar panels would be one alternative to generate power within the Henry Hicks. There are many downsides to this however, as the panels themselves are expensive to install and manage. It may also be difficult to sell the idea to the university community as not everyone would want to see a set of solar panels on the roof of one of the most historic buildings on campus. It seems as though there has already been some student lead interest in this initiative. In 2012, the Dalhousie Student Union released a project proposal called *Solar Dalhousie.* This initiative was sadly not realized, perhaps because of its lofty goals to install solar panels on the majority of the buildings on campus. One of their goals was to encourage the whole university to focus on renewable energy, even though they expected the students of the university to contribute the majority of the funds needed to realize this project. In order to install solar panels on the Henry Hicks building, it would cost over $144, 000, but if Dalhousie wants to remain accountable to its commitment to sustainability, this may be the ideal option (Collings, & et al, 2012).

An issue with the Henry Hicks is the fact that the roof of the building is slanted, which would make it difficult to install and/or hide the solar panels (Green Power Lab Inc, 2009). It does not make it impossible, but when developing renewable energy alternatives this must be taken into consideration. After speaking to Facilities Management, we realize that it would be reasonable and profitable to install solar panels on the Henry Hicks building. A short-term goal for the Henry Hicks building would be to use solar panels in order to generate exterior lighting or heating hot water. Moving forward, when funds are secured and advancements in technology are made, we believe that it would be beneficial to use solar panels to heat the water in order to regulate heat throughout the building. It would be ideal to have the lights powered by solar panels as well, but this may seem like an insurmountable goal for the time being. It may take a few years to secure the funds in order to make this possible, but in the long run anything that can be done to reduce our dependence on fossil fuels and unsustainable energy practices, while also contributing positively to Dalhousie University as a whole.

### 3.2 Sealing the Building:

Throughout our gathering of data, mainly from Facilities Management, essential retrofitting techniques for the Henry Hicks were made clear. Facilities Management indicated tightening up the building as a principle target area for retrofitting including windows, doors, repointing of stone work, and possibilities for use of different types insulation to retain heat and more efficiently run the Henry Hicks. The most significant factor relating to heating use is also the cheapest and easiest problem to solve.

#### 3.2.1 Re-pointing Stone Work

The Henry Hicks is made of a large proportion of stone, and is generally not thoroughly insulated. Much of the stonework is crumbling and no longer in ideal condition, which was made evident through our own assessment of the buildings as well as in our talks with Facilities Management. Although it was mentioned that re-pointing would be useful for tightening up the building by Facilities Management through our own observations there were no evident gaps to the exterior due to stone work decay or chipping. With that said, re-pointing the stonework is important for retaining the characteristic and condition of the building.

### 3.2.2 Windows

Windows in the Henry Hicks are old and out dated. They are about 60 years old, and are significantly over their life expectancy. According to Facilities Management, if all the windows were replaced in the Hicks, the increase in heat conservation would result in an associated reduction of 20-30% in the heating utility bill. The Henry Hicks is characterized by its many single-paned, numerous, large windows which makes replacing all of them an expensive endeavor. Retention and upgrade versus replacement has been a controversial issue and studies in the UK have indicated that replacing historic windows, with more modern sealed glazing units is very expensive, short-lived and the least effective, although the most popular improvement for reducing energy consumption in heritage homes (Sims and Powter, 2006). When properly repaired and retrofitted, old windows can usually be made to perform at a level comparable to new windows. It is often a good choice as older windows are built in a specific style, with old growth timber, and exceptional attention paid to construction details (Turner, 2006).

A series of 'retrofit' or more accurately, restoration techniques should be implemented for the Henry Hicks windows. This would allow for the retention of their historical character, while also improving the overall efficiency of the building. This provides an ideal project for Dalhousie University as it limits extensive monetary resources, which may not be available in the University's retrofit budget. First, it is essential to determine the best approach. This would consist of carefully assessing the condition and performance of all windows within the Henry Hicks. This would require documentation on the condition of each window, gaps to the external environment, missing hardware, broken glass, as well as other quantitative and qualitative data. Documentation would consist of notes and drawings, which would indicate areas of decay, or other gaps (Turner, 2006). Once this is complete, making windows air tight is the most effective and least expensive step, and may include replacing broken glass, hardware, window locks, resetting panes using linseed oil based glazing putty and glazing points for example (Turner, 2006). Painting the sash and putty lines to make a tight seal may also reduce air and moisture infiltration, while weather-stripping products made of high quality metal, such as copper, could represent an important investment (Turner, 2006). Lastly the windows in the Henry Hicks buildings are all single-paned, which often results in the feeling of cold and draught. Adding an additional pane to the exterior or interior can mitigate this relatively cheaply. This will ensure that the innermost pane of glass is air tight. This may not be ideal for the Henry Hicks as many of the windows are made up of many separate panes, but is an idea to consider beyond the essential weatherproofing and restoration of current windows.

Using our baseline data provided by Facilities Management and the estimated reduction of 20-30% in energy usage if all windows were replaced we can estimate the amount of energy that would be saved by this potential retrofit. Although we do not suggest replacing all the windows, our recommendation will make the windows nearly as efficient as a complete replacement. For the year of 2010, the total amount of electricity was 419451.2 kWh, which is associated with a reduction of 83890.24 - 125834.36 kWh per year for the Henry Hicks. This is purely estimation as the specific reduction of replacing windows is uncertain. Additionally, consumption was based on meter which serves multiple buildings, so an estimate for use per month was based on total GSF serviced.

### 3.2.3 Insulation

Due to the Henry Hicks' colonial buildings style and stone work, there is minimal insulation within in the inside of the building. Although this may be extremely beneficial in reducing energy loss, it is not feasible unless major renovations are undertaken, as the building is made of stone and concrete. This project would likely be too extensive, expensive, and likely degrade the historical character of the building. We propose that insulation be installed when and if major reconstruction of the interior of the building takes place.

## 3.3 Pipes

The hot water in the Henry Hicks building is heated using instantaneous water heaters, which use steam as a means of energy to heat the supply load. Water often has to travel long distances, according to the Facilities Management team. This is a particular concern, as currently none of the hot water pipes are insulated, thus they permit energy loses throughout the building. A simple solution would be to apply insulation to all pipes, which would increase efficiency and reduce the probability of pipes freezing, cracking and bursting. The expense associated with applying preformed insulation for hot water pipes is usually disproportionally high, due to the amount of manual labour involved (cutting, trimming, strapping) (Bauer, 1969). Due to Dalhousie's limited budget for retrofits, this is not currently feasible. Instead we propose that this project be done alongside other retrofits and restorations projects undertaken in nearby areas. Completing the project in intervals maybe provide a more feasible financial strategy and would provide lasting benefits.

Another option to preformed insulation is foam insulation application. Polyurethane, a popular foam insulation, may be applied by means of spray to pipes or vessels that need insulation (Bauer, 1969). The use of these spray foams is associated with reduced cost for application due to a reduction in labor costs (Bauer, 1969). However, the thickness of insulation, which may be satisfactory, is limited to less than 3 inches and needs an additional vapor barrier application, which can be expensive (Bauer, 1969). Common vapor barriers include biturnastics of bituplastics and cannot be handled without damage to the insulation system (pipes + insulation + vapor barrier) (Bauer, 1969). The two options both have the advantages and drawbacks but it provides options for Dalhousie to improve the efficiency of the Henry Hicks building. We propose that Dalhousie implement one of these options, although monetary expense may provide a barrier, the benefits would be consistent and long-term.

### 3.4 Low-flow Water Fixture

Another area of focus for the Henry Hicks buildings in the context of retrofitting measures relates to water conservation. Water conservation is defined as the controlled and efficient use of this resource, while acting in a systemic manner in the management of supply and demand of water (Carvalho et al., 2014). Demand management focuses on reducing consumption related to end uses, such as changing water-conserving fixtures, which is a central recommendation contained within our report to ensure that water conservation measures are addressed.

The male washroom located on the second floor was used as a case study to assess possible water conservation recommendations in the Henry Hicks building. This case was compared to the washroom technological specifications in the Mona Campbell building. At the present time, the toilets in the Henry Hicks building have efficiency ratings of approximately 13.2 litres per flush, whereas the dual flush toilets located in the Mona Campbell building washrooms range from 4.2 and 6 litres per flush (Dalhousie University, 2014) depending on the end use. Therefore, this represents the potential to reduce water consumption associated with toilet use by approximately 55% throughout the Henry Hicks building, after a retrofit using the Mona Campbell building as a technological baseline. The two options for the user to choose between two flushing options represent an effective technological design that promotes the awareness and achievement of water conservation. Ehrenfeld (2008) mentions the idea of *presencing* as being an interruption, whereby the ordinary use of equipment becomes obtrusive. In the case of dual flush toilets, *presencing* is initiated as the user chooses a flushing option, depending on excretion, while also being made aware of the larger context of water conservation.

We were not able to define the efficiency ratings for the faucets in male washroom on the second floor. However, the faucets in the Mona Campbell building have ratings of approximately 1.9 litres per minute and are defined as low-flow (Dalhousie University, 2014). A significant amount of water can be saved in public restrooms faucets when sensors are installed (Jahrling, 2005). Furthermore, based on a comparison of manual and sensor operated faucets that both flow with approximately 8.3 litres per minute (~2.2 gallons per minute), following the United States Food and Drug Administration Food Code hand-washing procedure, there would be an average savings of roughly 4 litres per washing (~1.057 gallons). This highlights the importance of sensor-operated faucets as playing a key role in promoting water conservation beyond simply a lower flow rate. “An even greater source of water savings to control operating costs is sensor-operated faucets with 0.5-gpm aerators” (p. 28). Besides reducing water consumption, an added benefit of sensor-operated faucets is improved hygiene as “…after using a public restroom, a person’s hand can carry a bacterial population of 200 million,” (p. 29).

Therefore, improved water conservation can be facilitated by focusing on the replacement of low-flow toilets and faucets, which could drastically reduce water consumption in the Henry Hicks building, especially when contrasted with the Mona Campbell building. The current water metering system on the Henry Hicks building serves multiple buildings, therefore the total consumption in litres is an estimate. Using the consumption estimate provided by Facilities Management, the Henry Hicks building used roughly 18814 litres of water in 2012. Low-flow fixtures can save between 30-40% of the water consumed (Barclay, 2014). Using a 30-40% reduction in water consumption, a low-flow retrofit for the fixtures mentioned above could result in roughly 11288-13170 litres of water saved.

## 3.5 Future Projects

We suggest that Dalhousie retrofitting for the Henry Hicks does not stop here. The above recommendation for implementation is only suggested. Sealing the building and upgrading water fixtures are essential and should be done despite other ideas, as they are extremely important to increasing efficiency. Furthermore, sealing the buildings is necessary before future retrofits for example, heat exchangers and renewable energy integration is even thought about. Insulating the pipes will be beneficial but is not likely feasible to do all at once due to monetary and time constraints. In addition to these main recommendations we propose that the University looks in to additional options that both extend upon heating and water conservation and explore issues beyond this scope. Smart grids and heat exchanger system are two great options.

### 3.5.1 Smart Meters

Reducing water consumption begins with better monitoring of water consumption rates. Aggregated water consumption rates make it difficult to determine specific water facilities' fixtures consumption rates. Smart water meters allow for almost instantaneous monitoring of water flows, and rates that are disaggregated to allow for data relating to specific fixtures (Srinivasan et al. 2011). Smart water meters would allow for more specific data to be collected to on the rates of water consumption in the Henry Hicks building. The use of these monitors in the Hicks answers to the need to understand, model and predict water consumption, as it is vital in determining potable water savings, daily demand patterns and actual end use water consumption. By expanding the availability of information, Facilities Management will be provided with conditions for conscious, participatory decision-making in terms of consumption. Furthermore, careful monitoring of a building's water consumption is essential if the best results are to be realized (Barclay, 2014). Although, the implementation of smart meters could prove beneficial in terms of water use management, its cost to benefit rate may not be worth it for the school to invest in. Perhaps an in-situ experiment to test the effectiveness a smart metering system would be feasible for Henry Hicks building

### 3.5.2 Heat Exchanger System

In our meetings with Facilities Management, the need for a replacement of air ventilation system was mentioned as being beneficial for increasing energy efficiency if implemented after the envelope of the building had been proper sealed. Heat exchangers have two capabilities, heating and cooling. More specifically the Fujitsu Halcyon system takes advantage of the climate dependent on time of season (Fujitsu, 2010). These systems eliminate need for basement or attic located evaporating unit by using copper tubing that pumps refrigerant directly to the wall mounted blower inside (Fujitsu, 2010), remarkably reversing in winter, absorbing heat from the outside air and moving it indoors to heat the buildings (Fujitsu, 2010). Installation is relatively simple, and uses only a 3-4 inch opening in the wall to connect the indoor and outdoor units (Fujitsu, 2010). Due to the ductless stem of the Halcyon they lose less than 5% vs. 40% for traditional forced-air stems increasing efficiency (Fujitsu, 2010). Additionally the Halcyon stem allows for individual zoning, allowing you to heat the areas you want and not the ones that are unoccupied (Fujitsu, 2010). The minimal sleek design of the system would, if at all, only minimally impact the character of the infrastructure that is essential for historical buildings. This is just an example of a potential retrofit for the heating system within the Henry Hicks that may be an ideal option. Due to time constraints and availability of information we were unable to assess the current ventilation system and other aspects of the building which may impede or make certain ventilation or heating systems more effective than others. We suggest that ideas such as the Halycon system be explored more thoroughly along with the current system in the Henry Hicks so that the most efficiency, applicable system can be implemented.

### 3.5.3 Smart Grid

The need for Dalhousie to integrate renewable energy not only for the historical buildings such as the Henry Hicks, is essential and should be a priority. New technologies can provide more energy efficient options for how energy is used and what energy is used. Smart grids are an example of a new technology, which is becoming prominent particularly in the United States (U.S. Department of Energy, n.d.). Our current electrical grid is outdated and often delivers excess forms of electrical waste and with the smart grid providing as two-way communication system and sensing along the transmissions lines, is a more efficient technology (General Electric Company, 2009). The smart gird combats this waste by providing the utilities with information so that only exactly what is needed is delivered.

In addition to the smart grids inherent increase in energy efficiency it allows for the integration of renewable energies; due to the current grid variability and dependency on weather and natural pattern, it has much difficulty accommodating renewable energy sources (U.S. Department of Energy, n.d.). The smart grid is capable of managing the congestion of the electrical grid and unpredictability of renewable energy sources such as wind and solar (General Electric Company, 2009). Most importantly it allows for individual control of their own power generation (on site), increasing the potential for Dalhousie University to adopt and integrate more onsite renewable energy sources (General Electric Company, 2009).

This is an extremely extensive and expensive project due to the complexity of the smart grid alone. Installation could be a lengthy process but once completed the time intensity of monitoring and maintenance is greatly reduced (U.S. Department of Energy, n.d.). In the future we recommend that Dalhousie seriously consider implementation of extensive onsite energy sources, particularly solar, for all buildings on campus, which could benefit. The use of the smart grid may be essential in integrating renewable energy forms in to the systems while also inherently reducing energy use do to its 'smart' technology. Further research is needed for all buildings on campus to form a plan, which could feasibly implement renewable energy. This must be a priority of Dalhousie, in order to maintain its loud proclamation to its commitment to sustainability.

## 4 Recommendations

To begin the process we recommend a series of steps to follow, to most effectively and feasibly improve the efficiency of the Henry Hicks. The most important and initial step is an extremely thorough assessment of the building. Ideally this would be done by professionals, which would be responsible for the initial sealing of the building. This assessment would carefully comb over every room, window, door, light, toilet, and sink; windows, doors and rooms would be the priority for sealing up the buildings with the other information being used later on. Through this we would be able to ascertain specific areas, which are damaged and need repair. More specifically assessment of each window, door and room would be recorded using both notes and pictures, to demonstrate need for repair of missing hardware, broken glass, areas of decay (rotting wood, crumbling cement), and gaps to the external environment causing air infiltration. A similar process could be followed for water fixtures within the building. Once the through assessment is complete, repairs can begin. From here we propose a series of retrofits, which we believe would most effectively reduce energy use in the Henry Hicks. Sealing the building is necessary before any other retrofits may be complete, as it is essential for heat retention. All retrofit options are detailed under results section.

1) Seal buildings
    a. Most importantly seal up/repair all windows
    b. Seal up/ repair all doors
    c. Re-point stone to increase efficiency but perhaps more effectively to maintain building.
2) Upgrade Water Fixtures
    a. Toilets
    b. Sink Fixtures
3) Insulating Pipes

    a. Incrementally when other projects are being done near piping
4) Installation of Solar Panels
    a. Most easily would be used for exterior lighting—few resources needed
    b. Larger roof panels for heating water or other electrical needs

We recommend Dalhousie look into additional projects for the future to continually improve energy efficiency, such as the ones mentioned below and detailed in our results.

5) Future Projects
    a. Smart Meters
    b. Heat Exchanger
    c. Smart Grid

### 4.1 Conclusion:

Exploring potential retrofitting projects for the Henry Hicks does not end with this paper. The knowledge, which has been gained through informal interviews with FOM, is valuable information and can expanded into future projects. We suggest that new retrofitting projects look beyond the scope, which is put forward by Facilities Management as this spark innovation towards future projects on our campus. To add technologies are always changing and this can be seen as a benefit, as projects proposed for the building take years to be given the green light and progress. Therefore, looking into new technologies, which can be amended into retrofitting contracts, will add a level of intrigue and efficiency to building upgrades on campus. Further, there are more issues with the Henry Hicks which reach beyond heating and water miss use therefore there is a need to look into these projects and bring them into the forefront of the university.

## 5 Acknowledgements

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# 7 APPENDICES

## 7.1 Graphical Representation

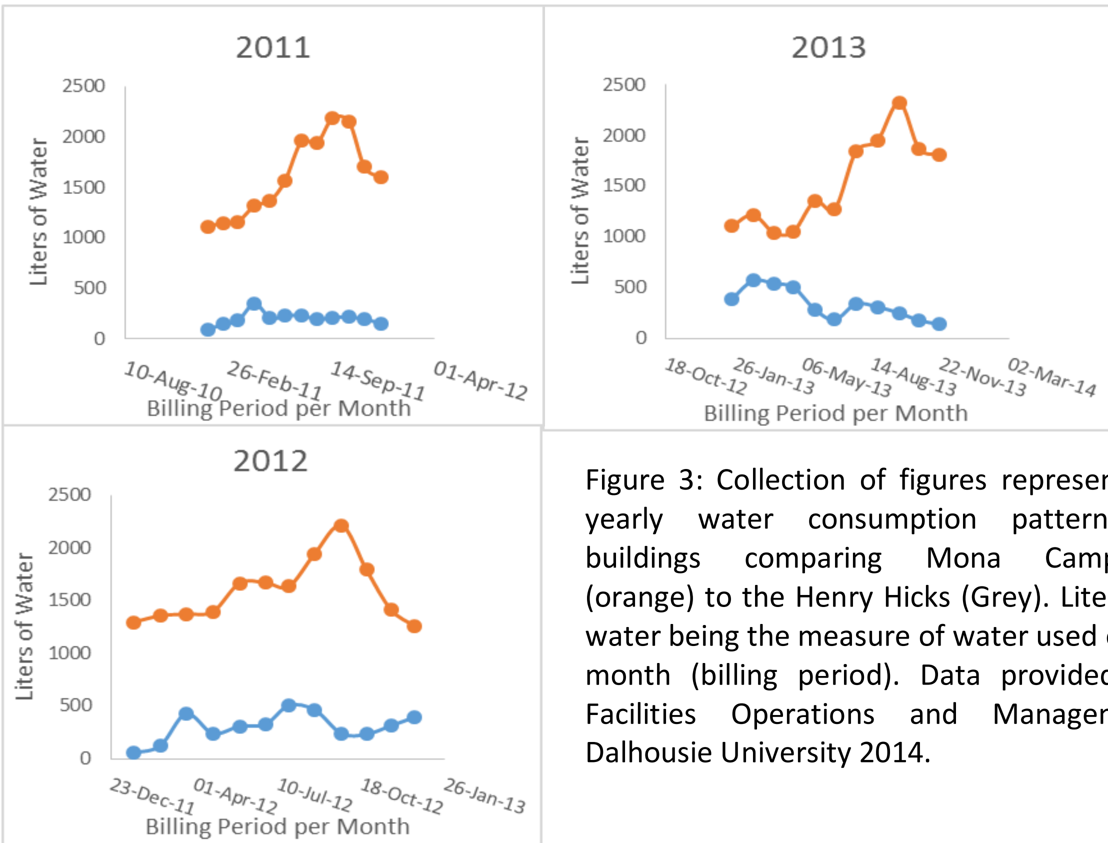


Figure 3: Collection of figures representing yearly water consumption pattern in buildings comparing Mona Campbell (orange) to the Henry Hicks (Grey). Liters of water being the measure of water used each month (billing period). Data provided by Facilities Operations and Management Dalhousie University 2014.

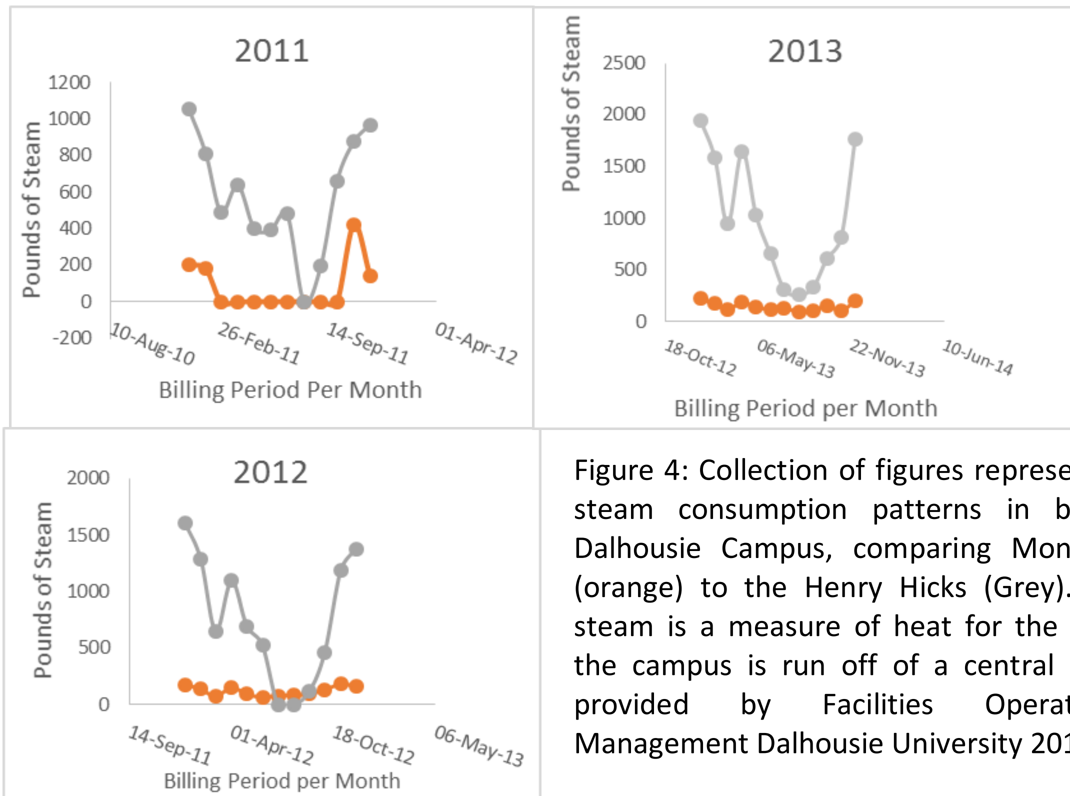


Figure 4: Collection of figures representing yearly steam consumption patterns in buildings on Dalhousie Campus, comparing Mona Campbell (orange) to the Henry Hicks (Grey). Pounds of steam is a measure of heat for the buildings as the campus is run off of a central boiler. Data provided by Facilities Operations and Management Dalhousie University 2014.

## 7.2 Spread Sheets

Table 1: Quantitative spread sheets for billing information on Heat, and Water Consumptions on the Mona Campbell and Henry Hicks buildings. This data was used in the creation of Figures 1 through 4.

| Bldg ID | Description | Meter Number | Bill Period | Consumption | Unit |
|---|---|---|---|---|---|
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jan-11 | 202.506 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Feb-11 | 179.991 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Mar-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Apr-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-May-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jun-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jul-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Aug-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Sep-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Oct-11 | 0 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Nov-11 | 423.53 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Dec-11 | 138.425 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jan-12 | 177.498 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Feb-12 | 139.449 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Mar-12 | 73.421 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Apr-12 | 152.931 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-May-12 | 94.14 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jun-12 | 67.782 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jul-12 | 81.318 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Aug-12 | 85.922 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Sep-12 | 97.144 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Oct-12 | 131.533 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Nov-12 | 183.951 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Dec-12 | 164.322 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jan-13 | 219.331 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Feb-13 | 171.009 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Mar-13 | 118.837 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Apr-13 | 184.423 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-May-13 | 140.415 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jun-13 | 117.448 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Jul-13 | 124.823 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Aug-13 | 97.973 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Sep-13 | 101.573 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Oct-13 | 153.487 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Nov-13 | 109.554 | LBS |
| D110 | MONA CAMPBELL BUILDING | SD110-01-01 | 01-Dec-13 | 195.284 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jan-11 | 1054.42 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Feb-11 | 812.18 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Mar-11 | 491.46 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Apr-11 | 638.62 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-May-11 | 403.63 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jun-11 | 391.02 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jul-11 | 479.97 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Aug-11 | 0 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Sep-11 | 194.49 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Oct-11 | 660 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Nov-11 | 876.75 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Dec-11 | 969.9 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jan-12 | 1608.56 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Feb-12 | 1284.82 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Mar-12 | 647.58 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Apr-12 | 1096.31 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-May-12 | 697.98 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jun-12 | 523.65 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jul-12 | 0.5 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Aug-12 | 0 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Sep-12 | 120.52 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Oct-12 | 466.16 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Nov-12 | 1185.72 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Dec-12 | 1381.44 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jan-13 | 1948.5 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Feb-13 | 1584.73 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Mar-13 | 941.44 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Apr-13 | 1651.07 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-May-13 | 1030.53 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jun-13 | 654.79 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Jul-13 | 309.19 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Aug-13 | 256.72 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Sep-13 | 327.28 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Oct-13 | 608.99 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Nov-13 | 813.55 | LBS |
| C300 | HENRY HICKS ACADEMI | SC300-01-01 | 01-Dec-13 | 1764.3 | LBS |

Table 2: Quantitative spread sheets for billing information on Heat, and Water Consumptions on the Mona Campbell and Henry Hicks buildings. This data was used in the creation of Figures 1 through 4.

| Bldg ID | Description | Meter Number | Bill Period Start | Bill Period End | Consumption | Unit |
|---|---|---|---|---|---|---|
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 17-Dec-10 | 17-Jan-11 | 92 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 18-Jan-11 | 16-Feb-11 | 145 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 17-Feb-11 | 17-Mar-11 | 183 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 18-Mar-11 | 18-Apr-11 | 350 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 19-Apr-11 | 18-May-11 | 207 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 19-May-11 | 16-Jun-11 | 227 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 17-Jun-11 | 18-Jul-11 | 235 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 19-Jul-11 | 17-Aug-11 | 192 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 18-Aug-11 | 16-Sep-11 | 214 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 17-Sep-11 | 18-Oct-11 | 217 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 19-Oct-11 | 17-Nov-11 | 198 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 18-Nov-11 | 19-Dec-11 | 154 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 20-Dec-11 | 19-Jan-12 | 53 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 20-Jan-12 | 20-Feb-12 | 123 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 21-Feb-12 | 22-Mar-12 | 426 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Mar-12 | 23-Apr-12 | 240 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 24-Apr-12 | 25-May-12 | 307 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 26-May-12 | 25-Jun-12 | 326 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 26-Jun-12 | 23-Jul-12 | 504 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 24-Jul-12 | 23-Aug-12 | 463 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 24-Aug-12 | 24-Sep-12 | 238 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 25-Sep-12 | 24-Oct-12 | 231 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 25-Oct-12 | 22-Nov-12 | 312 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Nov-12 | 21-Dec-12 | 394 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 22-Dec-12 | 22-Jan-13 | 387 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Jan-13 | 22-Feb-13 | 569 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Feb-13 | 25-Mar-13 | 538 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 26-Mar-13 | 22-Apr-13 | 503 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Apr-13 | 23-May-13 | 283 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 24-May-13 | 21-Jun-13 | 184 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 22-Jun-13 | 22-Jul-13 | 338 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Jul-13 | 22-Aug-13 | 310 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Aug-13 | 23-Sep-13 | 249 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 24-Sep-13 | 22-Oct-13 | 176 | L |
| D110 | MONA CAMPBELL BUILDING | WD110-01 | 23-Oct-13 | 21-Nov-13 | 139 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 17-Dec-10 | 17-Jan-11 | 0 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 18-Jan-11 | 16-Feb-11 | 1148.66 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 17-Feb-11 | 17-Mar-11 | 1161.3 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 18-Mar-11 | 18-Apr-11 | 1320.09 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 19-Apr-11 | 18-May-11 | 1366.7 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 19-May-11 | 16-Jun-11 | 1564.2 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 17-Jun-11 | 18-Jul-11 | 1956.83 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 19-Jul-11 | 17-Aug-11 | 1935.5 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 18-Aug-11 | 16-Sep-11 | 2184.35 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 17-Sep-11 | 18-Oct-11 | 2151.17 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 19-Oct-11 | 17-Nov-11 | 1700.08 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 18-Nov-11 | 19-Dec-11 | 1597.38 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 20-Dec-11 | 19-Jan-12 | 1294.81 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 20-Jan-12 | 20-Feb-12 | 1355.64 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 26-Jun-12 | 23-Jul-12 | 1634.51 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 24-Jul-12 | 23-Aug-12 | 1944.19 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 24-Aug-12 | 24-Sep-12 | 2212.79 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 25-Sep-12 | 24-Oct-12 | 1790.93 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 25-Oct-12 | 22-Nov-12 | 1415.68 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 23-Nov-12 | 21-Dec-12 | 1254.52 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 22-Dec-12 | 22-Jan-13 | 1105.21 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 23-Jan-13 | 22-Feb-13 | 1216.6 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 23-Feb-13 | 25-Mar-13 | 1037.27 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 26-Mar-13 | 22-Apr-13 | 1053.86 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 23-Apr-13 | 23-May-13 | 1354.06 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 24-May-13 | 21-Jun-13 | 1273.48 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 22-Jun-13 | 22-Jul-13 | 1843.07 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 23-Jul-13 | 22-Aug-13 | 1945.77 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 23-Aug-13 | 23-Sep-13 | 2323.39 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 24-Sep-13 | 22-Oct-13 | 1869.14 | L |
| C300 | HENRY HICKS ACADEMI | WC300-01 | 23-Oct-13 | 21-Nov-13 | 1809.89 | L |