DEVELOPING AN EVALUATION PROTOCOL FOR THE TORONTO PUBLIC LIBRARY (TPL) SYSTEM THROUGH THE APPLICATION OF A BUILDING PERFORMANCE EVALUATION (BPE) OF A BRANCH LIBRARY TO INFORM ITS RETROFIT STRATEGY

by Rosemary Martin

Bachelor of Science, Toxicology

University of Toronto, 1990

A Major Research Project

presented to Ryerson University

in partial fulfillment of the requirements

for the degree of Master of Building Science

in the program of Building Science

Toronto, Ontario, Canada, 2019

Author's Declaration

I hereby declare that I am the sole author of this MRP. This is a true copy of the MRP, including any required final revisions.

I authorize Ryerson University to lend this MRP to other institutions or individuals for the purpose of scholarly research,

I further authorize Ryerson University to reproduce this MRP by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

I understand that my MRP may be made electronically available to the public.

DEVELOPING AN EVALUATION PROTOCOL FOR THE TORONTO PUBLIC LIBRARY (TPL) SYSTEM THROUGH THE APPLICATION OF A BUILDING PERFORMANCE EVALUATION (BPE) OF A BRANCH LIBRARY TO INFORM ITS RETROFIT STRATEGY

Rosemary Martin

Master of Building Science,

Ryerson University, 2019

Abstract

Buildings play a significant role in our economy and society. Substantial capital is invested in buildings, and they are the locales where a large portion (e.g., work, cultural, religious, social and personal activities) of our lives are conducted. Despite the significant monetary and temporal investments in buildings, building performance evaluations (BPEs) are not standard practice. From BPEs that have been conducted, important findings have been identified. Significant gaps frequently exist between the design intent of buildings and their measured performance (e.g., energy and water consumption) and user satisfaction (e.g., thermal comfort, lighting, noise). Environmental (e.g., resource consumption) and economic drivers (e.g., productivity, operational costs) are spurring the growth of BPEs. A BPE was conducted of the Weston Public Library (WPL) with the intent of informing a retrofit strategy and developing a protocol for conducting BPEs in the Toronto Public Library (TPL) system.

Acknowledgements

I would like to acknowledge and thank Dr. Mark Gorgolewski for his guidance and assistance to undertake and complete this research. I appreciate the time you spent with me on this project given your considerable workload during the past term.

I would like to acknowledge and thank Mr. Greg Labbé, who was instrumental in conducting airtightness testing and infrared thermography activities and teaching me how to operate monitoring equipment for the indoor environment quality and indoor air quality assessments.

I would like to thank Mr. Anthony Martin for volunteering to help with the preparatory and restoration activities for the airtightness testing on a cold January night.

Finally, I would like to thank the Toronto Public Library staff for allowing me to undertake research at the Weston Public Library. Without your approval and co-operation, this research would have never taken place.

Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction

Buildings play a significant role in our economy and society. Substantial capital is invested in buildings, and they are the locales where a large portion of our lives (e.g., work, cultural, religious, social and personal activities) are conducted. Despite the significant monetary and temporal investments in buildings, building performance evaluations (BPEs) are not standard practice (Sharpe, 2013).

From BPEs that have been conducted, important findings have been identified. Significant gaps frequently exist between the design intent of buildings and their measured performance (e.g., energy and water consumption) and user satisfaction (e.g., thermal comfort, lighting, noise) (Loftness, V., Aziz, A., Choi, J.H., Kampschroer, K., Powell, K., Atkinson, M. & Heerwagen, J., 2009). The performance gap can result from numerous factors, including the building design and technology, and the differences between assumed and actual patterns of building operations and management, occupancy and use of building controls (Cole, R. J., Robinson, J., Brown, Z., & O'Shea, M., 2008). As a result of the performance gap (Brown and Cole, 2009) and market growth of green buildings (Cole et al., 2008), the use of BPEs is increasing (Cole et al., 2008).

Environmental and economic drivers also are spurring this development. In 2015, buildings in the commercial, institutional and public administration sectors used 17% of all energy consumed in Ontario (Environmental Commissioner of Ontario, 2017). Reducing utility consumption and associated carbon emissions in buildings is critical to adhere to the International Panel on Climate Change (IPCC)’s plan for limiting climate change. Knowing how a building is performing in relation to energy consumption and carbon emissions is essential. Increasing evidence shows an important connection between job performance and numerous physical attributes (e.g., thermal comfort, lighting, noise) of the workplace (Baird, G., Gray, J., Isaacs, N., Kernohan, D & McIndoe, G., 1996 xxiii). Organizational costs are substantial if employees perform below their complete capabilities because their workplace does not entirely meet their needs (Baird et al.,1996, xxiii).

A BPE is a rigorous and systematic approach comprising various activities including research, measurement, benchmarking, evaluation and feedback that occur during every phase of a building’s lifecycle: planning, programming, design, construction, occupancy, and reuse/recycling (Mallory-Hill, S. Preiser, W.F.E., & Watson, C., 2012). A BPE concentrates on the relationship between design and technical performance of buildings concerning human behaviour, requirements and desires (Mallory-Hill et al., 2012). The purpose of a BPE is to determine if a building works for the individuals that use, occupy or otherwise are affected by it (Mallory-Hill et al., 2012). An evaluation can be used to identify and remedy deficiencies in an individual building (Mallory-Hill et al., 2012). Furthermore, it can be used as a source of information to improve the planning, programming, design and management of future buildings (Mallory-Hill et al., 2012) and retrofits of existing buildings. Ultimately, the overall goal of integrating evaluative processes into the design and management of buildings is to advance improved decision-making and enhance building performance (Mallory-Hill et al., 2012).

1.1 Research Objectives

The research objectives were to acquire a better understanding of the building performance of libraries in the TPL, and to answer the following questions: What are the key operational and occupancy criteria for conducting a BPE of a library branch? What are the necessary activities for conducting BPEs in the TPL System?

2. Literature Review

A limited literature review using keywords, (i.e., building performance evaluation, BPE, post occupancy evaluation (POE), heritage building, historic building, and library) alone or in combination was conducted using Google Scholar and the Ryerson University Library and Archives. Results from this review produced numerous references which were analyzed to determine relevance to the research topic. Once references were identified as relevant to the research topic, their bibliographies were reviewed for additional sources of information. The results of the literature review are presented from an historic perspective identifying landmark research and the evolution of the BPE discipline. Finally, BPEs of several libraries are presented. Unique occupancy and operational aspects of libraries affecting BPEs, were identified.

2.1 BPEs

BPEs evolved from POEs. Victor Hsia of the University of Utah and Sim van der Rijn of the University of California, Berkeley conducted one of the first systematic evaluations of a building's performance from an occupant's perspective in the late 1960s (Preiser, 2005). This POE, although not identified as such at the time, was conducted on university dormitories (Preiser, 2005). In 1968, the Building Performance Research Unit was established at the University of Strathclyde in Glasgow, UK (Bordass, B. & Leaman, A., 2009). In 1972, Tom Markus et al. published landmark research from this institution in *Building Performance* (Leaman, A., Stevenson, F., & Bordass, B., 2010). This book presented a model process for the rigorous and systematic evaluation of buildings concerning behavioural, environmental, and technical aspects ((Mallory-Hill et al., 2012). In 1975, the first publication using the term "POE" in its title was authored by Herb McLaughlin from KMD Architecture and published in the *American Institute Architects Journal* (Preiser, 2005). This article reviewed the results of POEs conducted in hospitals in California and Utah (Preiser, 2005).

Dr. J. Zeisel wrote one of the first books on evaluating building performance in 1984, *Inquiry by Design: Tools for Environment-Behaviour Research.* (Leaman et al., 2010). The first POE textbook, *Post Occupancy Evaluation*, was authored by Preiser, Rabinowitz and White in 1988 (Preiser, 2005). The following year, a companion volume entitled *Building Evaluation*, was released (Preiser, 2005). The initial POE framework described in *Post Occupancy Evaluation* identified three categories of effort, levels of complexity and data gathering techniques: indicative, investigative and diagnostic (Preiser, 2005). The three POE stages with three steps in each comprised: 1) Planning: exploration and feasibility, research planning and resource planning; 2) Conducting: setting up data collection processes, monitoring and overseeing data collection processes, and analyzing findings; and 3) Applying: reporting results, recommending actions, and reviewing outcomes (Preiser, 2005). Performance criteria were categorized into three groups: people, settings and relational concepts (Preiser, 2005). In retrospect, this framework was incomplete and simplistic. (Preiser, 2005)

Dr. Preiser and Dr. Ulrich Schramm collaborated to develop an integrated model of BPE in the mid 1990s (Preiser, 2005). This framework focuses on the entire lifecycle of the building and identifies six internal review processes: 1) market/needs analysis, 2) effectiveness review, 3) program review, 4) design review, 5) commissioning, and 6) POE. This framework advocated for using knowledge acquired from conducting these reviews into the next building cycle (Preiser, 2005). Figure 1 illustrates this model.

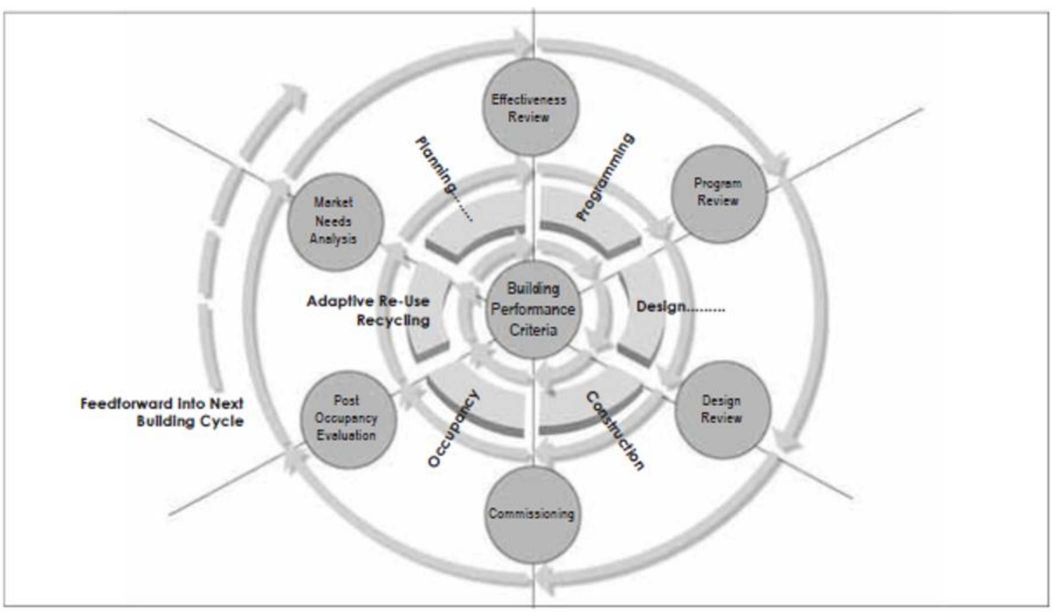


Figure 1 – Integrated BPE (Preiser & Nasar, 2008)

Building performance criteria were established from this framework (Preiser, 2005). They addressed issues such as:

- The cultural, psychological and social elements of buildings,
- Health, safety, and security, and
- Building codes, functionality and building operation manuals. (Preiser, 2005).

In 1997, Preiser and Schramm published this BPE model in *Time Saver Standards for Architectural Design Data* (Preiser, 2005).

In 2005, *Assessing Building Performance* was published resulting from the efforts of the International Building Performance Evaluation consortium. This book presented numerous international case studies of BPEs (Preiser, 2005).

The Post-occupancy Review of Buildings and their Engineering (PROBE) studies began in 1995 as a joint venture between several parties: the UK government, the Chartered Institute of Building Services Engineer (CIBSE), the *Building Services Journal* and a research team (Enright, 2002). The PROBE methodology comprised a comprehensive and systematic method of evaluating sixteen new commercial and public buildings, two to three years old, that had been well received by the design community (Enright, 2002). It incorporated site visits, a review of 14 main subjects including occupant satisfaction, management perceptions, utility consumption, operation and management, and benchmark comparison (Enright, 2002). The results of the PROBE studies were featured in a special issue of *Building Research & Information* in 2001. (Leaman et al. 2010). The PROBE studies established a global precedent by disclosing detailed performance analysis of identified buildings in the public realm (Enright, 2002). The PROBE studies showed that a formal process of feedback from the design team and the occupants on significant parameters can help substantially improve building design and operations (Enright, 2002).

From the PROBE investigations, Cohen, R., Ruyssevelt, P., Standeven, M., Bordass, W. and Leaman, A. (1999, p.2), as cited by Cole et al. (2008), identified the need for designers and suppliers to support occupants with suitable, understandable systems with user-friendly control interfaces, which supply pertinent and immediate feedback on performance. This finding underscored the importance of three variables - occupants, controls and immediate feedback – which contribute to building performance.

Economic and operational factors have shifted the primary focus of BPEs from solely technical performance metrics (e.g., energy and water consumption, GHG emissions) to encompass and reinforce the importance of occupants in building performance. Occupant salaries are the largest costs related to commercial buildings (Baird et al., 1996). In office buildings labour costs per square meter are significantly higher compared to energy costs per square metre.

(Coleman, S.; Touchie, M.; Robinson, J.; & Peters, T., 2018). Occupants and users can play a critical role in identifying and correcting operational problems providing that the building systems are easily accessible and understandable and the occupants are willing to use them (Cole et al., 2008). Introducing the concept of “interactive adaptivity”, Cole et al. (2008) suggest that building performance is the result of interaction and adaptability between two entities, occupants and technology. Occupants determine if a building is a failure or success (Li et al., 2018.). Consequently, the occupant survey has become essential to any effective BPE conducted today (Li et al, 2018).

A notable factor contributing to the concept of “interactive adaptivity” was a change in the assumptions associated with comfort, and the practices that either impact or are impacted by them (Cole et al., 2008). Traditionally, comfort has been defined as supplying and maintaining a fixed set of acoustic, lighting and thermal conditions, frequently using automated, centralized approaches (Cole et al., 2008). Several important assumptions formed the foundation of the comfort theory, including 1) Occupants are passive recipients of conditions supplied in their environment, 2) Physiology is the primary mechanism that provides comfort, although behavioural and psychological factors may help, and 3) The indoor environmental conditions should be maintained within a relatively narrow range. (Cole et al., 2008). The “interactive adaptivity” concept proposes that occupants are not passive beings, but inhabitants, individuals who may perform an active role in the maintenance and performance of their building (Cole et al., 2008). Cole et al. (2008) posit that comfort can be achieved through a range of indoor environmental conditions which foster adaptability, interaction and resilience within the built context.

The results from the application of the National Environmental Assessment Toolkit (NEAT) in 22 federal buildings in the U.S General Services Administration emphasized the importance of combining physical measurements with occupant surveys for several reasons (Loftness et al., 2009). Occupants can act as sensors and controllers of building performance. Technologies and systems that work can be identified by connecting occupant satisfaction with environmental conditions to technical attributes of buildings. Occupant behaviour plays a key role in securing environmental gains.

Since 2010, the number of BPE-related publications has increased significantly (Li, P., Froese, T. M., & Brager, G., 2018). From these evaluations, several common findings have been identified. First, building performance is not static. As a result of changes in focus, personnel, operations, building occupancy and physical layout, building performance can deteriorate over time. For example, the Elizabeth Fry Building at the University of East Anglia had exceptionally strong performance in the 1990s; in fact, it was the best performing building in the PROBE cohort (Bordass, B. & Leaman, 2012). In 2011, a BPE of this building showed that the building performance had decreased (Bordass, B. & Leaman, A., 2012). Building performance is not a one-time activity. Failing to pay attention continuously to building performance and the management systems that contribute to its success will impact a building's performance negatively.

Second, the lack of knowledge transfer between the design and construction teams to building management hinders optimal building operations and performance (Sharpe, T., 2013, Oxford Brookes University, ND). Building performance relies not only on strong design and construction, but exemplar building operations.

Third, as mentioned earlier, a performance gap often exists between predicted and actual performance in buildings. Bordass, B., Cohen, R. and Field, J. (2004), as cited by Brown and Cole (2009), suggest that the gap between predicted and actual performance related to energy occurs because the assumptions used to predict performance are not well informed as to actual practices in the building, and the individuals who design the building rarely evaluate its performance once it is constructed. Designers need to receive feedback on the performance of a building that they have designed, so that the performance of future buildings can be improved.

To address the performance gap, Coleman et al. (2018) recently proposed a new approach comprising two steps. The first step stresses the importance of reframing the goals of a BPE. It comprises 1) establishing the goals of an evaluation on a wider sustainability perspective, acknowledging the equal relevance of both environmental and human outcomes, 2) moving beyond net zero to net positive approaches, and 3) expanding the concentration on individual buildings to include neighbourhood-scale built environment systems (Coleman et al., 2018). Subsequent to the reframing step, the second step encompasses the integration of qualitative and quantitative elements of BPEs over time to manage both environmental and human outcomes (Coleman et al., 2018).

As a consequence of this binary approach, a simple conceptual framework was developed for conducting BPEs (Coleman et al., 2018). This model supports the identification of three performance gaps: 1) Prediction gaps - predicted compared to actual resource consumption (e.g., modelled and measured energy and water usage), 2) Expectation gaps - expectations related to the performance of sustainable buildings compared to the real lived experience of the building occupants (e.g., pre- and post-occupancy evaluations), and 3) Outcome gaps - measured performance compared to lived experience (e.g., thermal comfort measurements and survey results) (Coleman et al., 2018). Figure 2 depicts the framework.

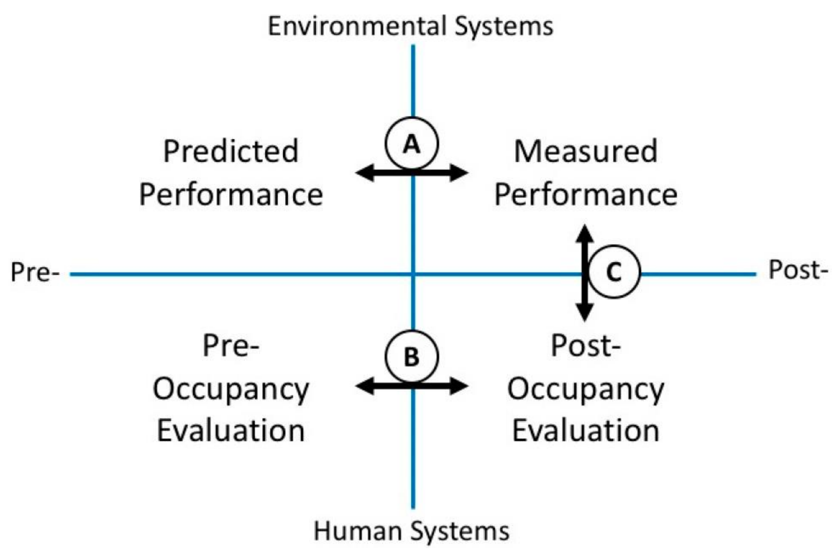


Figure 2 – Conceptual Framework for Conducting BPEs (Coleman et al., 2018)

The researchers emphasize that understanding the prediction gap requires a knowledge of institutional practices related to building design, construction and commissioning, occupant behaviour, and buildings in use (Coleman et al., 2018). To better understand the prediction gap, future research is required to analyze the type of tools and methods used to collect building performance data, what types of data to collect, who collects this data, and how the results are interpreted (Coleman et al., 2018).

When BPEs are undertaken, they typically are conducted of new buildings to evaluate performance post construction (Foster, J. A., Foster, S. A., Sharpe, T. R., & Poston, A., 2016). Two recent BPE case studies illustrate examples of customizing BPEs to address retrofits. Both studies implemented BPEs with narrow scopes. A BPE was conducted of a 19th century heritage building, used originally as a blacksmith shop, in rural Scotland, and repurposed as a visitor centre (Foster et al., 2016). The purpose of the BPE of the visitor centre was to inform a retrofit strategy to improve energy efficiency (Foster et al., 2016). The BPE comprised airtightness testing, infrared thermography scans, in-situ U-value measurements, monitoring of temperature, relative humidity (RH), and carbon dioxide (CO_2) levels, and energy metering. The data collected from the BPE informed the retrofit strategy and identified areas of significant energy loss. U-value measurements showed that heat loss was less than expected through the stone walls, and more than anticipated through the ceiling (Foster et al., 2016). The identification of thermal losses in the building enclosure permitted the architects to reduce insulation thickness in the stone walls minimizing costs in this area while offsetting increased insulation values in the ceiling (Foster et al., 2016). Following the implementation of the retrofit strategy, a post-retrofit BPE was conducted. The results showed improvements in the building enclosure, occupant comfort and energy efficiency (Foster et al., 2016).

Mackintosh Environmental Architecture Research Unit and John Gilbert Architects developed “Hab-Lab”, a service that provides BPEs of social housing that has undergone or is ready for a retrofit in Scotland (Sharpe, T., Lantschner, B., & Morgan, C., 2018). The purpose of the “Hab-Lab” service was to develop a “light touch” methodology for conducting BPEs to overcome barriers with conventional BPEs (e.g., long duration, cost, disruption), tailor the BPE to the immediate needs of the client, and develop retrofit strategies (Sharpe et al., 2018). The project evaluated 20 on-site monitored flats and the retrofit of 48 properties (Sharpe et al., 2018). The BPE involved the following four categories of data collection: 1) energy monitoring, 2) building enclosure testing and systems testing (e.g., airtightness, thermography, U-value measurements, ventilation), 3) environmental monitoring (e.g., temperature, RH, CO_2), and 4) engagement with occupants, facility managers and designers (Sharpe et al., 2018). The results of two case studies reviewed showed that retrofit measures implemented based on the findings of the BPEs were successful in improving energy performance ((Sharpe et al., 2018). However, there were unintended consequences in one of the case studies (Sharpe et al., 2018). Installed insulation retrofits performed less well than predicted with higher rates of heat loss with the risk of condensation and mould growth as a result of inferior installation procedures (Sharpe et al., 2018).

Embedding BPEs as a standard practice in the building sector has the potential to transform the market in expectation and demand for better performing buildings (Cole, 2005). To achieve this transformation, numerous issues need to be addressed. BPEs can take a few weeks to a few months depending on the amount of data and level of details that is collected (Lackney & Zajfen, 2005). Several strategies could be used to support this transformation:

1. To minimize costs and maximize knowledge acquired, use a phased approach to conducting a BPE (Li et al., 2018):
2. Start by evaluating the building performance at a high level before delving into the details (Li et al., 2018).
3. To improve the interpretation of results, standardize methods (Li et al., 2018).
4. Make the BPE results understandable with visually appealing presentation formats for non-technical audiences (e.g., owners, occupants) (Li et al., 2018).
5. Encourage industry rather than academia to drive BPE development and implementation (Li et al., 2018).
6. Consider BPEs, not as a one-time activity, but as an integrated, continuous feedback mechanism to improve the building's performance (Li et al., 2018).

   Finally, and most importantly, work with the building owner, building manager, tenant and legal communities to improve transparency in building performance. Develop a solution to the dilemma that building owners face – the reluctance to furnish third-party access to actual performance data and analysis of an identified building due to potential litigation from third-parties seeking compensation for buildings that are costing more to operate than predicted.

Several research topics related to BPE have emerged recently. Analyzing BPE databases, researchers are investigating the performance of buildings from the context of human response to workplace design (e.g., green building strategies, offices with open workplans) (Li et al., 2018). Various approaches to measure occupancy accurately, which impacts the gap between predicted and actual performance (e.g., energy), are being proposed (Li et al., 2018). Discussions concerning intensity-based resource metrics are evolving from the traditional metric based on an area (e.g., ekWh/m^2) to one based on occupants (e.g., ekWh/occupant) (Li et al., 2018).

2.2 Libraries

Although Kusack, as cited by Lackney et al. (2006), identified a lack of literature, research and case studies of BPEs in libraries, they are not completely absent. Several library associations in the UK have embarked on BPEs (Enright, 2002). They include the Society of College National and University Libraries (SCONUL), focused on academic libraries, and the Library Association, focused on public libraries (Enright, 2002). The SCONUL Library Design Award is presented to a library which has advanced the approach of library planning and design (Enright, 2002). It highlights examples of best practices for a specified 5-year period. (Enright, 2002). Libraries receiving this award are subject to an evaluation of the building's functionality 18-36 months after initial occupancy. Furthermore, they must not have any significant deficiencies (Enright, 2002).

Preiser and Wang (2006) conducted BPEs in combination with geographic information systems (GIS) to develop a Facilities Master Plan for the Public Library of Cincinnati and Hamilton County in the United States. Libraries were ranked on composite scores comprising eight weighted performance indicators: building, building evaluation, site, usage, service area, staff survey, staffing output and capacity, (Preiser & Wang, 2006). Subsequent to the ranking, the libraries were categorized into groups of high, medium and low performing libraries (Preiser & Wang, 2006). Library performance also was benchmarked. The investigation resulted in the development of specific recommendations for each branch: required improvements, closure and/or consolidation with other branch libraries, or the construction of a new full service "hub" library (Preiser & Wang, 2006). This approach for developing a Facilities Master Plan was comprehensive and systematic. However, from a practical perspective, it may be too time-consuming and intensive for many library systems. Public libraries, dependent on municipal budgets, are strapped frequently for money and may not be able to justify the time, money and human resources necessary to execute such an intensive exercise.

A BPE was conducted of the Alice Turner Library in Saskatoon, Saskatchewan in 1998 (Turcato, Brown and Gorgolewski, 2015). The energy performance of the library was significantly better than Canada's Model National Energy Code in terms of lower energy consumption and costs. An addition to the library was completed in 2012 (Turcato et al., 2015), and a subsequent BPE was conducted of the library. The scope of the evaluation comprised the period from the time when the addition was completed until May 2014. The BPE methodology included an evaluation of occupancy issues, energy consumption, water consumption, economic considerations, indoor environment, site issues, and materials issues. An occupancy survey was administered. Indoor environmental quality (IEQ) and indoor air quality (IAQ) spot measurements were recorded in various locations throughout the library. Utility analysis was conducted. Water intensity and weather corrected energy usage intensity metrics were calculated. Interviews were conducted with the design team, building manager and occupants. The researchers identified a key issue with conducting a BPE of a library. Because a library does not have a standard occupancy schedule, it is very challenging to determine occupant density. Despite having occupancy visitor counts, occupancy density could not be determined since visitor duration times were not recorded.

Hassanain and Mudhei (2006) conducted a POE of an academic and research library King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia. Their methodology comprised several activities: 1) conducting a literature review related to performance requirements of academic and research libraries, 2) conducting a walk-through of the library, 3) developing and administering a user survey addressing functional and technical elements affecting library performance, 4) analyzing the results of the user survey, and 5) preparing an action plan to improve library performance. This approach was limited in scope in many aspects. The investigation did not include physical testing of key parameters (e.g., lighting, noise, IAQ, airtightness, thermal performance of building enclosure). Resource consumption and benchmarking were not considered as part of the evaluation. The usefulness of analyzing user perceptions is limited when there is no actual data to corroborate or contradict perceptions with reality. Furthermore, developing action plans to improve library performance based on perceptions without verifying these beliefs without real data could be ineffective and costly.

BPEs were conducted of the Palm Desert Joint Library in Los Angeles, California and Salt Lake City Public Library. These BPEs comprised staff interviews, occupant and visitor surveys and site visits, including documentation of environmental conditions (Lackney, J.A. & Zajfen, P., 2005). The BPE of the Palm Desert Joint Library showed that contemporary library designs incorporating natural daylight spaces, high ceilings and open floor plans can produce various occupant comfort issues, (e.g., thermal, air flow, acoustics, glare) and that they require attention during the design process (Lackney, J.A. & Zajfen, P. ,2005). The BPE of the Salt Lake City Library demonstrated the tension between the expectations of the library environment – should it provide an atmosphere of quiet refuge for passive activities such as research and study or does it offer a forum where active events such as discussion and community lectures can occur (Lackney, J.A. & Zajfen, P. ,2005).

2.3 Summary

During the last 50 years BPEs have evolved from asking occupants for their feedback on a building's functionality to evaluating numerous parameters dealing with actual and predicted performance, technology, occupant behaviours, IAQ, IEQ, and sustainability. Despite the wealth of information that can be acquired from a BPE, it remains a tool primarily within the realm of academia that is used infrequently in the building industry. Several factors contribute to this situation. They include 1) a building industry where continuous improvement is not embedded in its business and operational practices, 2) a lack of standardization for conducting and reporting on the results from a BPE, 3) perceived potential disruption to occupants and operations, 4) time, labour and cost implications, and 5) liability concerns resulting from identifying deficiencies.

Libraries present several unique operational and occupancy aspects compared to conventional commercial buildings. First, there are contrarian views of suitable library environments. Should a library be a quiet refuge for study, research and reflection? Or should it act as a forum for dialogue and community engagement? Should it accommodate both, and if so, how do you successfully manage active and passive activities that occur concurrently and/or in close proximity of each other? Second, library occupants are categorized into one of two categories, staff or library visitor. The former is an occupant who works in the library for a fixed period of time. Whereas, the latter is a transient occupant, who may spend a brief or extended period at the library. Third, library visitors do not have defined schedules. Consequently, it is difficult to predict occupant density or schedule accurately. Fourth, library visitors span an expansive range of ages, from toddlers, children, teens, adults to seniors

3. Methodology

3.1. Task 1 – Developing a Draft Protocol for Conducting a BPE

A BPE typically evaluates a building's performance from three perspectives at minimum: 1) Occupants – How well does the building meet the requirements of the occupants?, 2) Resources – How efficient is the building in terms of energy and water consumption?, and 3) Finances – Is the building economically viable (e.g., value for money, return on investment)? (Leaman et al., 2010). Considering these three perspectives, a three-step process was used to develop a draft protocol. Step 1 involved the identification of research that was most relevant to the research objectives and provided a suite of activities to conduct a BPE. Step 2 comprised the evaluation of these activities from numerous view points. Step 3 refined the list of activities for evaluating libraries in the TPL system and tested this protocol by conducting a BPE at the WPL. Figure 3 illustrates the process flow.

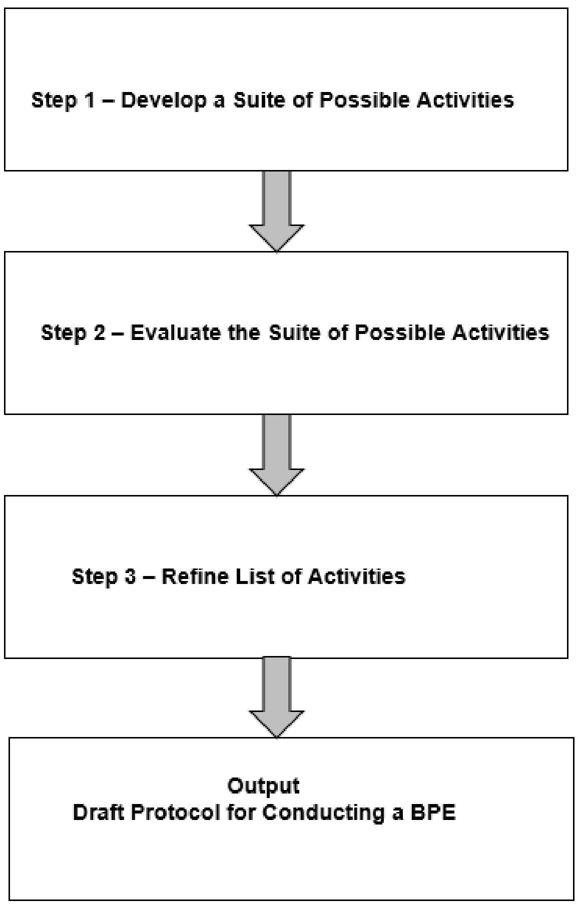


Figure 3 – Process Flow Chart for Developing a Draft Protocol for Conducting a BPE

The development of the BPE was based on one particular research paper (Leaman et al., 2010) and four case studies examined in the literature review. This collection of research was selected to form the foundation from which to develop a draft protocol because the research paper outlined the various practices and principles for undertaking BPEs; two of the case studies focused on BPEs in conjunction with retrofits; and the remaining two case studies were BPEs of libraries. From this body of research, a suite of possible activities to develop a draft BPE was identified (Step 1). Table 1 lists these various activities. Unique operational issues (e.g., noise, lighting) and occupancy issues (i.e., an undefined occupancy schedule, an inability to capture occupant density, types of occupants: staff and visitors) also were considered in the development of this draft protocol.

Table 1 – BPE Activities

Research	BPE Activities
Leaman et al. (2010)	• Documentary review • Site visit • Occupant survey • Audit of energy consumption
Lackney, J.A. & Zajfen, P. (2005).	• Occupant and visitor surveys • Site visits • Documentation of environmental conditions
Turcato et al. (2015)	• Energy and water consumption • Economic considerations • Indoor environment quality • Indoor air quality • Site issues • Material issues • Occupancy survey • Water and energy intensity • Utility analysis • Interviews with design team, building manager and occupants
Foster et al. (2016)	• Airtightness • Thermography scans • U-value measurements • Temperature, RH, and CO_2 monitoring • Energy metering
Sharpe et al. (2018)	• Energy monitoring • Airtightness testing • Thermography • U-value measurements • Ventilation balancing and flow measurements • Heat systems checks • Temperature, RH, CO_2 monitoring • Engagement with occupants, facility managers and designers

Several factors were used to evaluate the activities in Table 1 (Step 2). First, the primary goals of preparing a protocol, to 1) develop a protocol that could be used to measure library performance systematically across the TPL system, 2) benchmark a library's performance prior to a retrofit and 3) inform its retrofit strategy, were considered. Second, factors affecting library performance were taken into account. Third, since human and environmental aspects are inherent in evaluating building performance, a combination of parameters related to human comfort, productivity and resource consumption were selected. Fourth, activities and parameters that had industry standards or templates (e.g., occupancy survey, thermal comfort) were chosen. Fifth, practical and temporal implications, such as readily available equipment and a reasonable time frame to complete the assessment, were considered.

Several activities listed in Table 1 were eliminated from inclusion in the draft protocol because of the aforementioned factors (Step 2 continued). Library visitor surveys were suggested to TPL management as a means to evaluate occupant satisfaction; however, TPL management did not want to pursue this activity. Consequently, library visitors did not participate in the occupant survey. Investigations, such as in situ U-value measurements of the building enclosure and HVAC assessments (e.g., conducting ventilation balancing, heat system checks and flow measurements) were not included in the draft protocol. These activities were excluded because the purpose of the draft protocol was to identify major building performance issues. In situ measurements and HVAC assessments were considered secondary activities to be undertaken in the event that the building enclosure or energy performance were identified as sub-optimal. Given the age of the original building and addition, it was not possible to interview the designers. Due to time constraints, economic data, site issues and material issues, other than building enclosure properties related to thermal conductance and resistance, were not considered

As a result, the original suite of activities was refined to a list of activities comprising the draft protocol (Step 3). This draft protocol encompassed the collection of qualitative and quantitative data from various sources. It comprised five tasks: 1) conducting physical testing, 2) administering an occupancy survey, 3) interviewing facility and branch management staff, 4) analyzing utility data, and 5) conducting a lighting power density (LPD) assessment. This draft protocol was piloted at the WPL from January 2019 to April 2019 and subsequently refined following its implementation.

3.2. Task 2 – Conducting Physical Testing

Various physical testing was conducted in accordance to specific standards:

1. Airtightness testing
2. Infrared thermography
3. IEQ (i.e., temperature, RH, noise and lighting)
4. IAQ (i.e., CO_2, carbon monoxide (CO), particulate matter, 2.5 microns, ($PM_{2.5}$) and particulate matter,10 microns, (PM_{10}), and volatile organic compounds (VOCs)

Air leakage is unplanned and unintentional airflow through a building enclosure (BC Housing et al., 2017). For air to flow, two conditions must be present: the existence of a continuous path between two points and a pressure difference between the two paths. The primary sources of these pressure differentials are HVAC systems, stack effect and wind (BC Housing et al., 2017). Airtightness is an important building performance parameter since it can impact thermal performance, IEQ, IAQ, occupant comfort and durability. Normalized air leakage rate by enclosure area rather than floor area permits comparison with performance requirements and benchmarks (BC Housing et al., 2017). It is the most frequently used metric for whole-building airtightness.

Airtightness testing of the building was conducted in general accordance with *ASTM E779-10 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. The objectives of the test were to 1) measure quantitatively the airtightness of the building enclosure, expressed in ACH_{75} and Equivalent Leakage Area (EqLA), and 2) quantify the extent of holes and unintentional openings in the building enclosure using infrared thermography based *on ASTM E1186-17 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*. Conducting an airtightness test of the enclosure requires the formation of a pressure boundary through the creation of a single-zone condition (BC Housing, BC Hydro & City of Vancouver, 2017). To form this boundary, HVAC systems were shut down by Facility Operations staff, exterior openings (e.g., bathroom vents, exhaust grilles, mechanical penetrations, library drop box) were sealed and interior doors were propped opened. Boundary conditions (e.g., temperature, windspeed, pressure) were recorded during the testing. Facility Operations staff deactivated the building alarm system for the airtightness testing to proceed.

Two high-powered blower door fans were installed in the emergency exit door opening located on the east side of the building and baseline conditions recorded. The testing was conducted manually under extreme pressure differences induced by pressurization and depressurization. To provide consistency, verify accuracy and allow extrapolation of the results, the quantity of airflow through the fan was measured at many pressure differences (BC Housing et al., 2017), approximately at +/- 60 Pa, +/- 55 Pa, +/- 50 Pa, +/- 45 Pa, +/- 40 Pa, +/- 35 Pa, +/- 30 Pa, +/- 30 Pa, +/- 25 Pa, and +/- 20 Pa (Note: ASTM E-779-10 requires pressurization at 75 Pa. However, this condition was not achieved because only two fans were available during the testing and the air intake on the roof top unit (RTU) could not be sealed completely). The Tectite software was used to record the readings. Using conservation of mass, the air leakage rate was calculated by equating the flow through the fans to the flow through the building enclosure (BC Housing et al., 2017). The volume and surface area of the building enclosure was estimated from a combination of physical measurements on site and architectural drawings.

Infrared thermography is frequently used in conjunction with airtightness testing. It can be used to evaluate the thermal properties of the building enclosure, the detection of thermal bridges and areas of excessive heat loss, air leakage, damaged or missing insulation, and sources of moisture (Kylili, A., Fokaides, P.A.; Christou, P., & Kalogirou, S. A., 2014).

Infrared thermography images were taken during the airtightness testing to identify the infiltration and exfiltration pathways visually. Once the maximum pressure was achieved during pressurization, the building was scanned both from the interior and the exterior using the infrared thermography camera to obtain a baseline reading of building enclosure details and identify hot spots or thermal anomalies (BC Housing et al., 2107). The resulting images visually showed the heated indoor air exfiltrating through the holes and gaps in the building enclosure and heating the surrounding enclosure (BC Housing et al., 2017). Once the maximum pressure was achieved during depressurization, the building was scanned again both from the interior and exterior using the infrared thermography camera to obtain building enclosure details to identify the location and severity of air leakage through the building enclosure (BC Housing et al., 2017). The resulting images visually depicted the cold outdoor air infiltrating through the holes and gaps in the building enclosure and cooling the surrounding enclosure (BC Housing et al., 2017). The photos taken during pressurization and depressurization were corrected to display an identical temperature range to allow comparison between the two images and to differentiate between air leakage and thermal bridges (BC Housing et al., 2017). (Note: Sites that show differences in thermal anomalies between pressurization and depressurization frequently are associated with air leakage (BC Housing et al., 2017)).

Once the pressurization and depressurization measurements were completed and infrared thermography images taken, the temporary sealing materials on exterior openings were removed and the interior doors that were propped open closed and the building alarm system re-activated.

Because IEQ and IAQ parameters play a significant role in occupant comfort (e.g., temperature, RH), health and safety (e.g., C0, particulates, VOC) and productivity (e.g., CO_2, lighting, noise) these parameters were measured. Spot measurements of IEQ and IAQ parameters were collected at 17 sampling locations (Note: Sixteen sampling locations were identified originally. The Branch Head 2 Office was not part of the initial sampling strategy because the researcher was informed that it was a storage room. However, during the testing period, she was told that the space was an office that was used infrequently). With the exception of lighting levels, physical measurements were recorded for approximately five minutes at each location to provide a composite average comprising measurements taken at one second intervals. Lighting levels were measured at the height where an individual would be working or reading (e.g., 90 cm at the reading table in the Adult Zone and desks in the workroom, 120 – 150 cm at library stacks). During site visits to record IEQ and IAQ measurements, observations of the building conditions and performance were noted. Figure 4 illustrates the sampling locations on the building plan and Table 2 lists the sampling locations

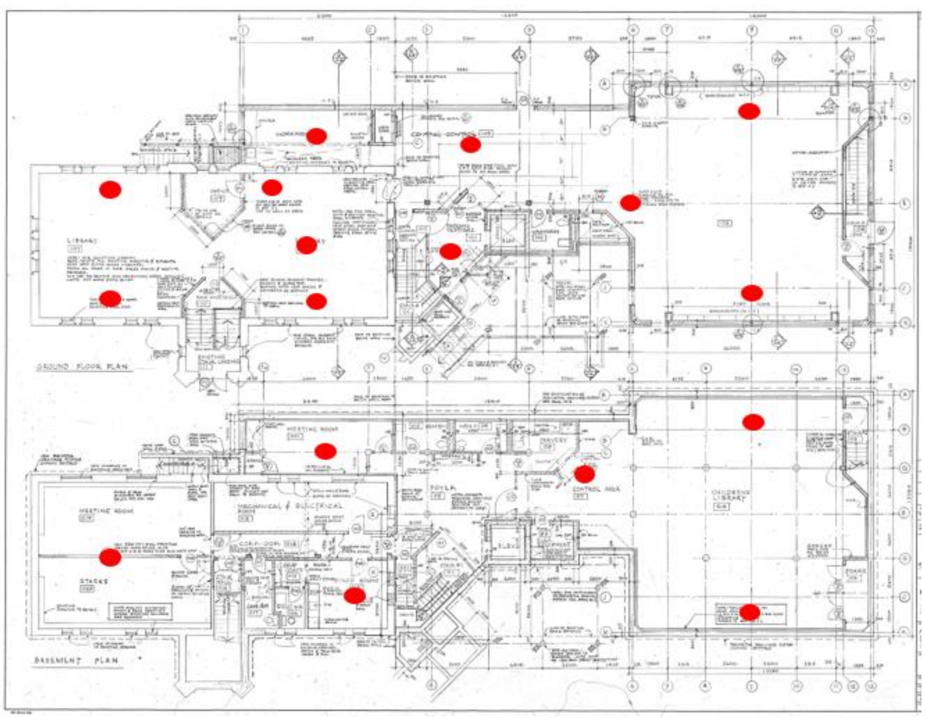


Figure 4 – Sampling Location on Building Plan (Dunlop, Farrow & Aitken, 1980)

Table 2 – Sampling Locations

Locations	
Entrance vestibule	Teen zone - south library stack
Circulation desk	Teen zone - north library stack
Workroom	Teen zone - computer station
Adult zone - south library stack	Children zone - south library stack
Adult zone - north library stack	Children zone - north library stack
Adult zone - south work stations	Children zone - information station
Adult zone - north work stations	Staff room
Adult zone - reading tables	Program meeting room
Branch Head 2 office	

Table 3 provides a list of the calibrated equipment used to conduct the physical testing.

Table 3 – List of Calibrated Equipment

Test	Equipment	Manufacturer/ Model	Serial Number	Accuracy	Calibration Date
ATT	Fan	Minneapolis Model 3	333633, 33636	Airflow $\pm$ 2%	June 2018
	Manometer	TEC DG-1000	1886, 1889	Air pressure $\pm$ 5%	June 2018
IRT	Camera	Fluke Ti450 Pro	18060323	Spatial resolution - 1.3 mRad	Not available
			18060236		Not available
Noise	Sound level meter	CESVA CS160	T228338	Noise $\pm$ 0.5 dB	September 2008
IAQ/IEQ	Environmental monitor	3M™ EVM	EML 120024	Temperature $\pm$ 1.1°C	Not available
				RH $\pm$ 5%	Not available
				CO + 2%	October 2014
				CO_2 + 12%	October 2015
				$PM_{2.5}$ $\pm$ 15%	Not available
				PM_{10} $\pm$ 15%	Not available
				VOCs $\pm$ 2%	Not available
Lighting	Light level meter	Extech HD 450	160612291	$\pm$ 0.5% + 10 digits	Not available

3.3. Task 3 – Administering an Occupancy Survey

An occupancy survey was distributed to library staff to investigate their level of satisfaction with environmental conditions in the building. The purpose of the occupant survey was to obtain quantitative and qualitative feedback from the branch staff on various subjects, and to compare the results with the physical testing conducted in Task 2.

An existing survey, based on various published surveys (e.g., PROBE, The Centre for the Built Environment and International Initiative for Sustainable Built Environment (iiSBE)) and originally approved by the University's Ethics Review Board for previous research at Ryerson University, was modified to meet the needs of the TPL. The revised survey was submitted to the University's Ethics Review Board for approval, which was secured subsequent to the review.

The survey, attached with a consent form, was administered to branch staff in a paper format during the period from February 15 to February 23, 2019. Appendix 1 provides the consent form and occupant survey. The intent of the consent form was to communicate the purpose of the survey, the manner in which anonymity and confidentiality would be maintained, and the option to withdraw from participating in the survey at any time. The survey comprised a series of questions concerning thermal comfort, air quality, lighting, noise control and acoustic quality, and productivity. The occupant survey was sent to the entire employee population of nine individuals, comprising six full-time staff: one Branch Head, one Librarian, one Senior Librarian Assistant, one Librarian Assistant, and two Public Services Assistants, and three part-time staff: one Public Services Assistant, and two Pages. The survey contained two categories of questions. The first category asked occupants to rate a particular parameter (e.g., lighting) on a seven-point Likert rating scale, with one identified as the lowest rating and seven identified as the highest rating. The second category of questions asked the occupants if a particular parameter "enhanced" or "interfered" with their ability to get their job done. These two questions were used to measure the level of occupant satisfaction.

3.4. Task 4 – Interviewing Facility and Branch Staff

Telephone interviews and in-person interviews were conducted with the Manager, Facility Operations, and the Branch Head Two and Librarian of the WPL, respectively. The purpose of the interviews was to 1) understand how the building is operated, maintained, and performing, 2) identify recent renovations and any issues of concern, and 3) obtain a perspective on the level of occupant satisfaction with the building.

3.5. Task 5 – Analyzing Utility Data

Analyzing utility data was an important task for evaluating the building's performance from a resource and efficiency perspective. TPL management provided 2015-2017 electricity, natural gas and water consumption data, based on metered utility consumption recorded on utility bills, to the researcher. Natural gas consumption was complete for the three-year period. Metered electricity consumption was missing for January 2015 and December 2017. The missing electricity consumption was estimated using the monthly averages for the latter and previous years, respectively. Water consumption was missing for July 2015, February 2016, January to April 2017, inclusively, June to September 2017, inclusively, and November 2017. The missing water consumption was estimated using the respective monthly averages for the 2015-2017 period. This data was used to calculate the annual breakdown of energy by type of fuel, and to compare annual energy and water performance (i.e., total consumption) over time.

2013 to 2016 energy data on public libraries was downloaded from Ontario's database, Energy Use and Greenhouse Gas Emissions for the Broader Public Sector (Government of Ontario, ND). The annual energy intensities, (i.e., eWh/HDD (heating degree days) (°C)/m^2) of the WPL were compared to annual TPL network and province-wide public library energy intensities in this dataset. (Note: The researcher did not calculate the energy intensities, HDDs or areas. The government database discloses the energy intensity accounting for area and HDD.)

TPL management provided 2013 to 2017 annual visitor data for the WPL, and 2015 to 2017 employee data for the WPL to the researcher. This data, in combination with the data from Ontario's Energy Use and Greenhouse Gas Emissions for the Broader Public Sector Database, was used to determine annual energy intensities (i.e., eWh/HDD(°C)/visitor, eWh/HDD(°C)/ full-time employee equivalency (FTE)).

An annual water intensity (m^3/m^2) was calculated from the utility dataset provided by TPL management. Using the annual visitor and employee data in combination with this utility dataset, annual water intensities (i.e., m^3/visitor, m^3/ FTE) were calculated.

3.6. Task 6 – Conducting a LPD Assessment

Lighting is an important parameter to evaluate for three reasons. Areas that have dim lighting or are over lit can produce eye strain and decrease occupant satisfaction. Ineffective lighting can reduce staff productivity. Furthermore, inefficient lighting consumes more energy than necessary. LPD is the maximum lighting per unit area according to a space function of a building classification (ASHRAE, 2013). A LPD assessment was conducted of the interior lighting by counting the number of fixtures and lamps and estimating wattages to provide a LPD estimate.

3.7. Task 7 – Revising the Draft Protocol for Conducting a BPE

Based on the findings and learnings from the BPE of the WPL, the draft protocol for conducting a BPE in the TPL System was revised.

4. Building Description

The TPL has categorized their libraries into three tiers: Tier 1, neighbourhood libraries, Tier 2, district libraries and Tier 3, reference and research libraries (Ernst and Young LLP, 2019). The TPL comprises 81 neighbourhood libraries, 17 district libraries and 2 research and reference libraries. (Ernst and Young LLP, 2019). The age of the building stock in the TPL system varies from libraries that have been constructed within the last 5 years to others that were built more than a century ago (Ernst and Young LLP, 2019). The weighted average age of the portfolio is 44 years (Ernst and Young LLP, 2019). Seventy-six percent of the libraries in the TPL system are over 31 years old; which is 14% higher than the national library ratio (Ernst and Young LLP, 2019, Canadian Infrastructure, 2016). Sixty-two branches or 70% of the portfolio were built before 1980 (Ernst and Young LLP, 2019). Since the age of library branches varies widely, the construction methods and materials also are diverse.

The WPL, located at 2 King Street in Toronto, Ontario, is a Tier 1, neighbourhood library. Compared to the average neighbourhood library, it is approximately 47% or 357 m^2 (3,833 ft^2) larger, serves a smaller residential catchment (18,000 versus 23,000), and is considerably older than the 44-year average weighted age of the TPL portfolio (Ernst and Young LLP, 2019)

The WPL was constructed with a grant from the Carnegie Corporation of New York and opened in 1914 (Toronto Public Library, 2018). Peter White from Lindsay and Brydon, Architects, a Weston resident, was the principal architect of the building. (Toronto Public Library 2018). The library, a single-storey structure with a full basement, was designed in a simple Arts-and Crafts-style library (Toronto Public Library, 2018). It was embellished with Art Nouveau mosaic panels, fabricated by Italian Mosaic & Marble Company of Canada Ltd., and stained-glass windows, manufactured by Robert McClausland Limited (Toronto Public Library, 2018). The windows are named after famous literary authors (Toronto Public Library, 2018). In 1978, the Borough of York designated the building “to be of historic and architectural value or interest” under the

Ontario Heritage Act (Toronto Public Library, 2018). Figures 5 and 6 show exterior images of the 1914 building.

Figure 5 **–** Original Building Facing West

Figure 6 **–** Original Building Facing South

The original building has undergone two major renovations (Toronto Public Library, 2018). In 1962 Dunlop, Wardell, Matsui, Aitken Architects redesigned the circulation desk and foyer, and added a suspended acoustic ceiling and fluorescent lighting to the main room. (Toronto Public Library, 2018). In 1981 the library was closed for a renovation and Dunlop, Farrow & Aiken Architects undertook an expansion compatible with the original design. The footprint was enlarged from 400 m^2 (4,300 ft^2) to 1,111 m^2 (11, 944 ft^2) (Toronto Public Library, 2018*).* Figures 7 and 8 show exterior images of the 1981 addition*.*

Figure 7 **–** 1981 Addition Facing East

Figure 8 **–** 1981 Addition Facing South

The original 1914 building is supported by solid masonry walls (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014) having an estimated RSI-value of 0.41 (R-2.3). This section of the building has an asphalted hip roof with two brick chimneys (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014). The leaded stain glass windows are protected by pre-finished aluminum framed glazing on the exterior (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014) having an estimated U-value of 2.6 $W/m^2 \cdot K$ (0.5 $BTU/hr \cdot ft^2 \cdot °F$)

(Culp, T.D., Widder, S.H., & Cort, K.A., 2015). A wood door provides an emergency exit on the south orientation (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014).

The 1981 addition comprises a steel frame supported by a poured-in-place concrete wall (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014). The building enclosure consists of brick cladding and a concrete block back-up (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014). The wall has an RSI-value of 1.76 (R-10) (Exergy Associates Ltd, 2018). The windows are double pane, insulated glazing units (IGUs) with pre-finished aluminum frames with an RSI value of 0.35 (R-2) (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014, Exergy Associates Ltd, 2018). A protruding display window is located adjacent to the main entrance (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014). The entrance comprises a pre-finished aluminum door with glazing panels. Two types of roofing were installed on the addition: a built-up roof on the west orientation, and a raised shingled hip roof on the east orientation. (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014). The roof has an estimated RSI -value of 3.2 (R-20) (Exergy Associates Ltd, 2018). Two sloped skylights are located in the built-up roof section connecting the addition to the original building (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014). The skylights have ongoing water leaks (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014)

Figure 9 provides a plan of the building. Figure 10 illustrates the library zones: 1) Adult Zone, identified in red, (Main Floor – Original Building) 2) Circulation Zone, identified in purple, (Main Floor – Addition) 3) Teen Zone, identified in orange, (Main Floor- Addition), 4) Children's Zone, identified in blue (Basement - Addition), and 5) Program Meeting Room, Staff Room, Library Branch Head 2 Office and Mechanical Room, identified in pink (Basement – Original Building and Addition). Figures 11 to 14 show images of the first four zones.

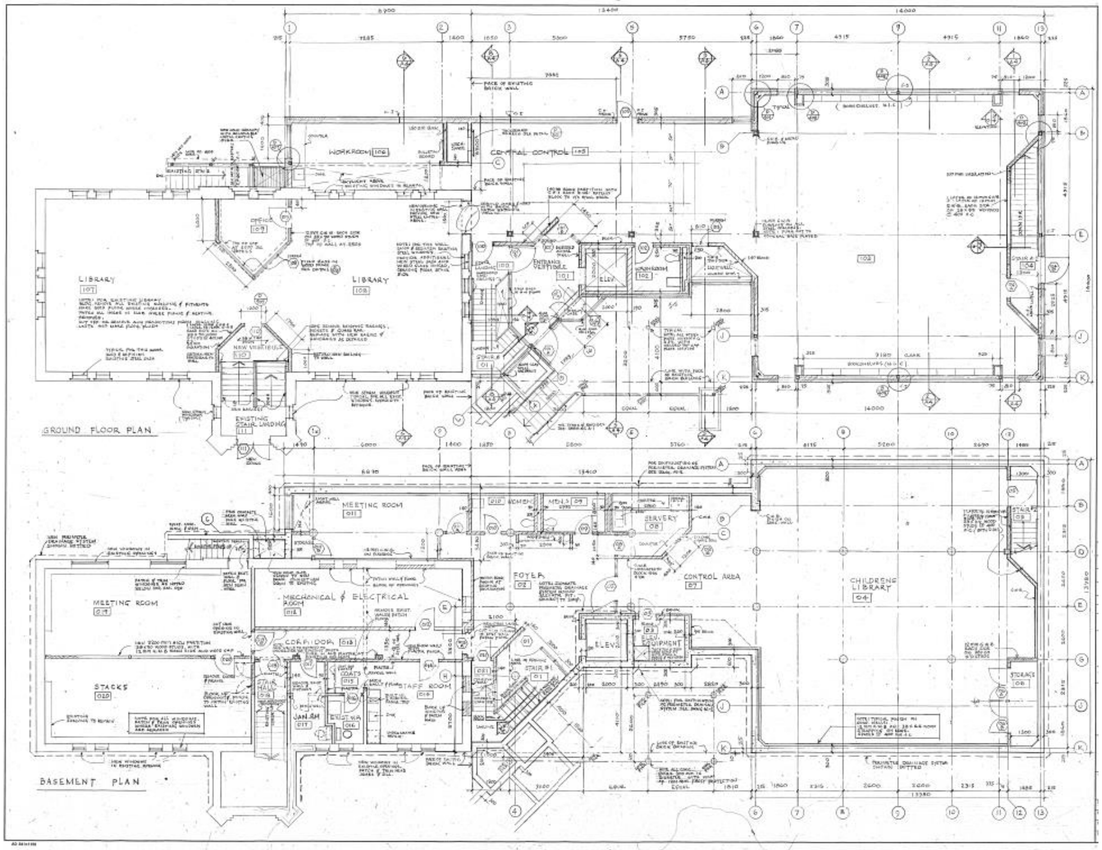


Figure 9 – Building Plan (Dunlop et al., 1980)

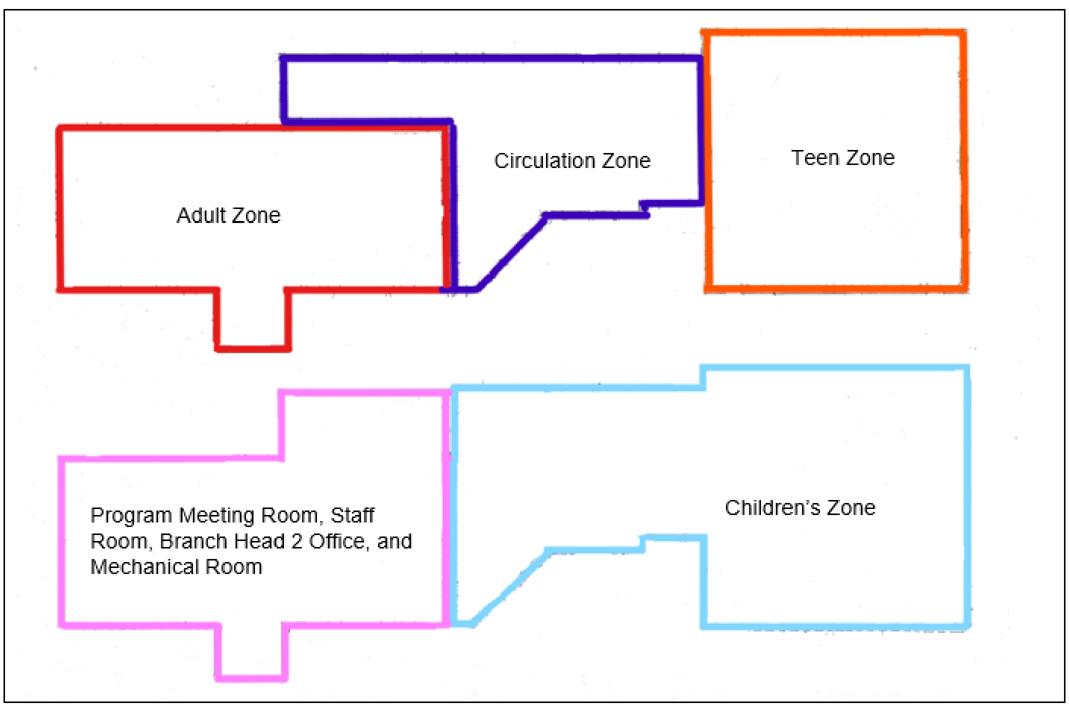


Figure 10 – Library Zones

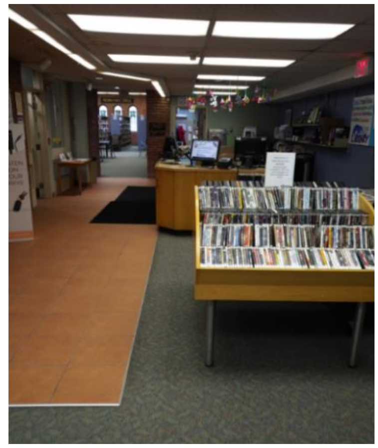


Figure 11 –

Adult Zone Figure 12 –

Circulation Desk

Figure 13 – Teen Zone

Figure 14 – Children's Zone

The mechanical systems were replaced recently. An 81 kW (23-ton) Carrier RTU, with a heating output of 76/95 kW (260,000 /324,000 BTU/hr) was installed to replace a chiller and distribute heating, cooling and humidification throughout the building in 2017. Two natural gas-fired hydronic boilers, with maximum input ratings of 117 kW (399,000 BTU/hr), with an output capacity of 108 kW (367,000 BTU/hr) were installed in the fourth quarter of 2018 to provide heating to the building. A 175 L electric self-contained hot water heater situated in the basement mechanical room provides domestic hot water (Stantec Consulting Ltd. & Pretium Andersen Toronto Inc., 2014). The building is equipped with a building automation system (BAS) that regulates the heating, cooling and ventilation (Exergy Associates Ltd, 2018).

Interior lighting primarily comprises linear fluorescent lamps, various halogen fixtures, including track lighting, and screw-in compact fluorescent (CFL) and mercury vapour lamps (Exergy

Associates Ltd, 2018). High intensity discharge (HID) fixtures and screw-in CFLs provide exterior lighting (Exergy Associates Ltd, 2018)

The WPL is open from 10:00 am to 6:00 pm on Mondays, 12:30 pm to 8:30 pm on Tuesdays and Thursdays, 10:00 am to 6:00 pm on Wednesdays and Fridays, 9:00 am to 5:00 pm on Saturdays, and 1:30 pm to 5:00 pm on Sundays, excluding summer months.

5. Results

5.1 Developing a Draft Protocol for Conducting a BPE

The draft protocol was used to conduct a BPE of the WPL from January 2019 to April 2019

5.2 Physical Testing

Airtightness testing and infrared thermography scans were conducted on January 16, 2019. Figure 15 shows the blower door setup. Figures 16 to 18 illustrate examples of sealed openings in the building enclosure.

Figure 15 – Blower Door Set Up

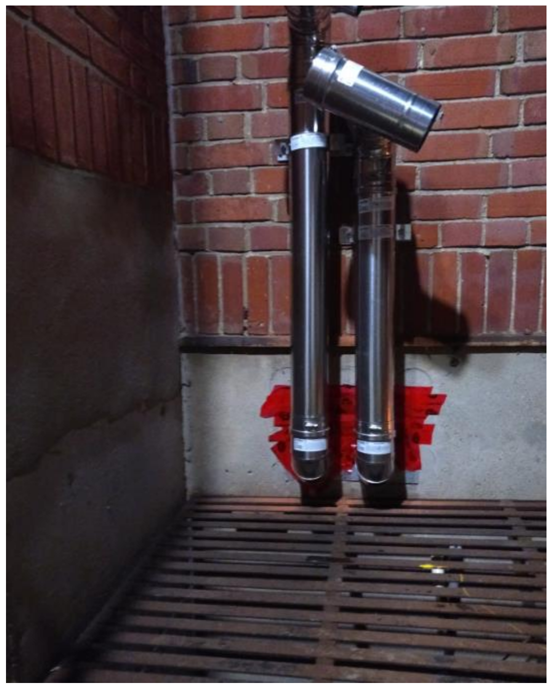


Figure 16 – Sealed Mechanical Penetrations

Figure 17 – Sealed Air Intake Grille

Figure 18 – Sealed Library Drop Box

Table 4 provides a list of boundary conditions experienced during the airtightness testing.

Table 4 – List of Boundary Conditions

Date	Start Time	End Time	Average Outdoor Temperature (°C)	Average Indoor Temperature (°C)	Average Relative Humidity (%)	Atmospheric Pressure (kPa)	Wind Velocity (km/h)	Wind Direction
01/16/19	18:00	23:00	-9.9	20	56	100.6	17	N-NW

Table 5 shows the results of the pressurization and depressurization.

Table 5 – Results of Pressurization and Depressurization

Point	Pressurization		Depressurization	
	Building Pressure (Pa)	Total Flow (lps)	Building Pressure (Pa)	Total Flow (lps)
1	56	4,913	59	4,965
2	50	4,666	56	4,845
3	47	4,570	51	4,539
4	47	4,338	43	4,088
5	43	4,171	39	3,750
6	35	3,737	34	3,410
7	30	3,375	27	2,939
8	27	3,195	21	2,389
9	22	2,939	NMR	NMR
10	18	2,598	NMR	NMR

Figure 19 shows a graph of air-flow versus the corrected pressure differences for pressurization and depressurization created by the Tectite Express 5.0 software. To calculate the flow exponent (n) and the air leakage coefficient (C), the power law airflow equation was used. The air leakage coefficient was corrected to standard conditions, (i.e., air density and dynamic viscosity) and the equivalent air leakage areas (A) for pressurization and depressurization tests were determined. Equation 1 describes this relationship:

$$Q = C(\Delta P)^n$$

Where

Q = air flow rate (m^3/s)
C = air leakage coefficient
ΔP= pressure difference between interior and exterior air (Pa)
n = flow exponent

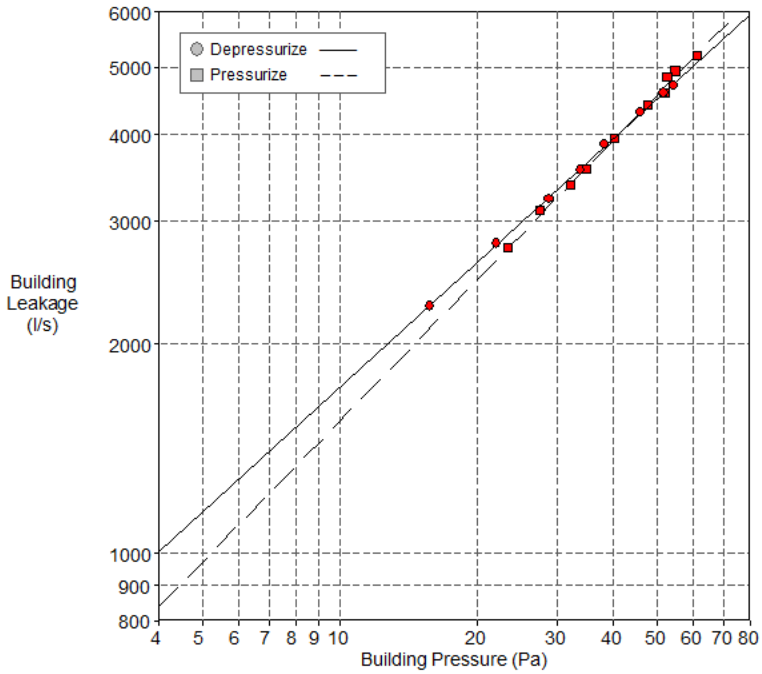


Figure 19 – Log-Log Graph of Pressurization and Depressurization

Tables 6 to 8 show the results of the airtightness testing quantified by Tectite Express 5.0.

Table 6 – Airflow @ 75 Pa

Airflow @ 75 Pascals	Depressurization	Pressurization	Average
L/s 75	5727 (+/- 0.4%)	5972 (+/- 1.0%)	5849
ACH75	5.95	6.2	6.08
Surface Area (L/s·m^2)	2.8708	2.9932	2. 9320

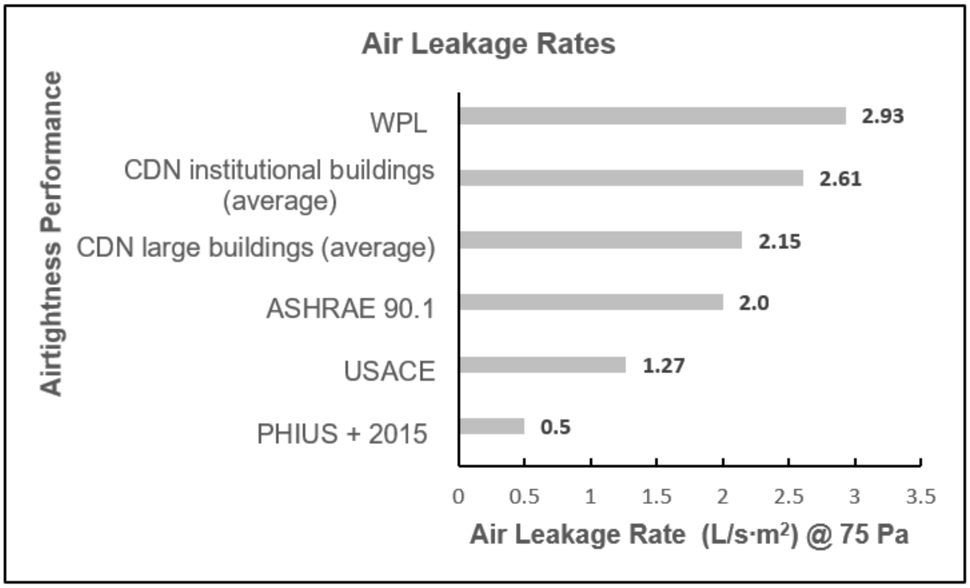
Table 7 – Leakage Areas

Leakage Areas	Depressurization	Pressurization	Average
Canadian EqLA @ 10 Pa (in^2)	1077.1 (+/- 0.9%)	964.6 (+/- 2.8%)	1020.9
Surface Area (in^2/m^2)	0.5399	0.4835	0.5117
LBL ELA @ 4 Pa (in^2)	603.7 (+/-1.4%)	504.5 (+/-4.5%)	554.1
Surface Area (in^2/m^2)	0.3026	0.2529	0.2777

Table 8 – Building Leakage Curve

Building Leakage Curve	Depressurization	Pressurization
Flow Coefficient (C)	440.6 (+/- 2.03%)	331.6 (+/- 7.0%)
Exponent (n)	0.594 (+/- 0.006)	0.670 (+/- 0.18)
Correlation Coefficient	0.99968	0.99701

Figure 20 compares the air leakage rate of the WPL to performance standards and average leakage rates according to building type.



Source (BC Housing et al., 2017, RDH, 2015)

Figure 20 – Comparative Air Leakage Rates

Thermography identifies thermal anomalies in the building enclosure (e.g., thermal bridges, exfiltration/infiltration, incorrectly installed services). Figures 21 and 22 show thermal bridges through the steel studs in the basement of the Program Meeting Room during pressurization and depressurization, respectively.

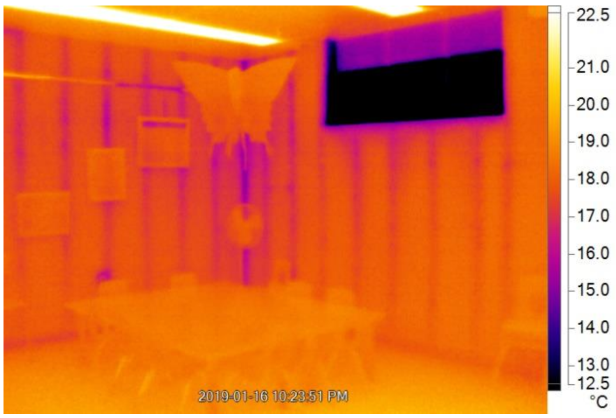


Figure 21 – Program Meeting Room, Pressurization

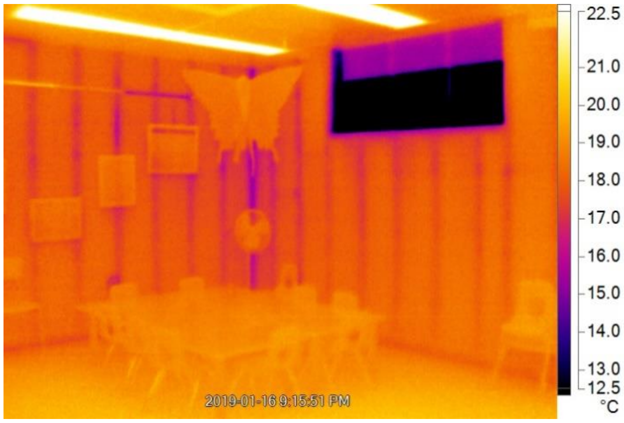


Figure 22 – Program Meeting Room, Depressurization

Figures 23 and 24 illustrate air leakage through the emergency exit from the Adult Zone during pressurization and depressurization, respectively.

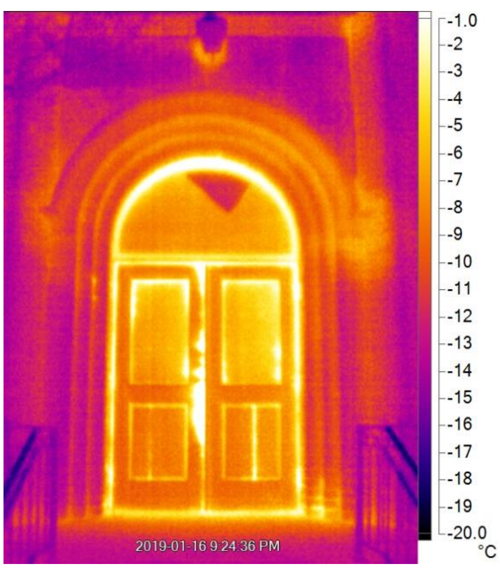


Figure 23 – Emergency Exit, Pressurization

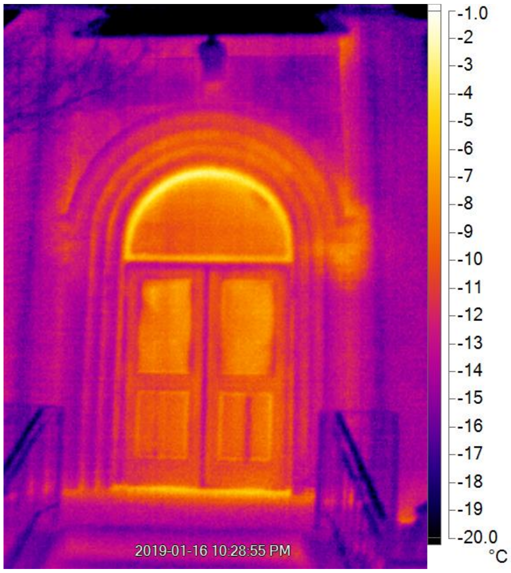


Figure 24 – Emergency Exit, Depressurization

Figures 25 and 26 show thermal losses through the slab edge, soffit and window in the Teen Zone Facing Southeast during pressurization and depressurization, respectively. Table 9 presents a list of thermography images and highlights areas of concern. Appendix 2 shows the remaining thermography images.

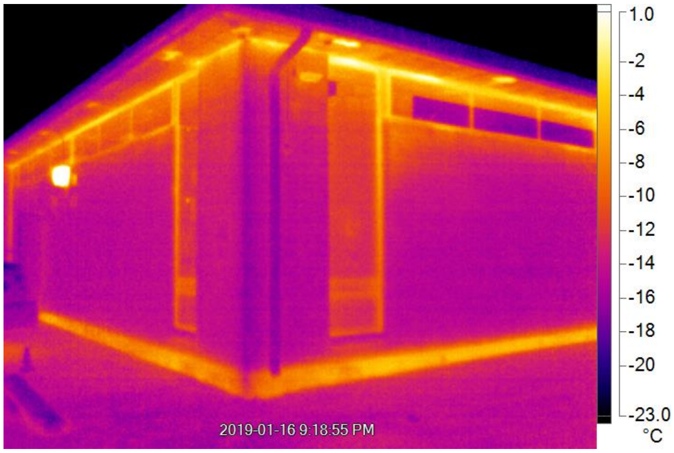


Figure 25 – Teen Zone, Pressurization

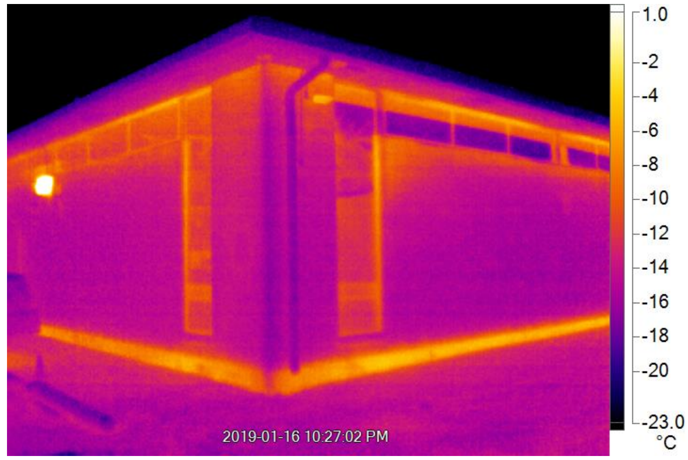


Figure 26 – Teen Zone, Depressurization

Table 9 – List of Thermography Images

Appendix 2 – Image Reference	Location/Description	Comments
1, 2	Main Floor, Teen Zone, Ceiling Cove	Thermal losses through interface between wall and ceiling/roof
3, 4	Main Floor, Adult Zone, Ceiling Cove	Thermal losses through interface between wall and ceiling/roof
5,6	Main Floor, Circulation Desk, Door	Air leakage through door frame
7, 8	Basement, Mechanical Room, Combustion Exhaust Stack	Air leakage around combustion exhaust stack
9, 10	Exterior, Window Facing South	Thermal losses at window frame and slab edges
11, 12	Main Entrance Door	Air leakage through door frame and drop box. Thermal losses at slab edge.
13, 14	Roof, Air Handling Unit (AHU)	Air leakage through AHU
15, 16	Main Floor, Adult Zone, Roof Hatch	Air leakage through roof hatch

Spot measurements of IEQ and IAQ parameters, with the exception of lighting and noise levels, were collected at 17 sampling locations in the library during a six-day period, from February 21 to 23, and from March 16 to 18, 2019. Measurements were taken from approximately 3 pm to 5 pm on February 21, and 2:30 pm to 4:30 pm on February 22 and February 23. During the March sampling, measurements were recorded from approximately 2:00 pm to 4:00 pm daily. The researcher noticed lingering odours and stale air occasionally and high noise levels frequently when sampling the IEQ and IAQ parameters. Figures 27 to 30 show examples of several sampling locations.

Figure 27 – Children Zone, South Stack

Figure 28 – Teen Zone, North Stack

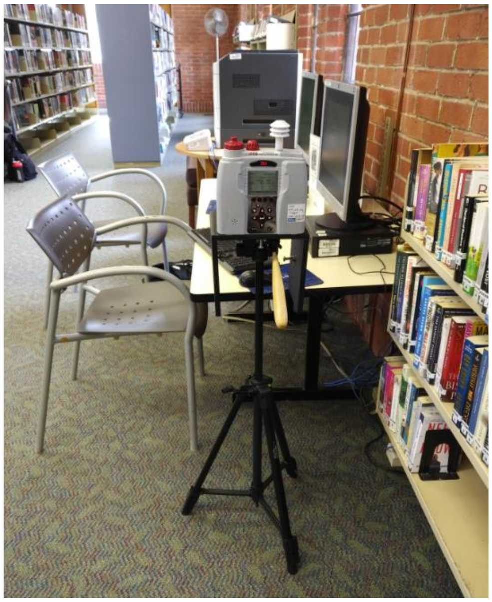


Figure 29 – Staff Room

Figure30 – Adult Zone, North Workstation

Figures 31 and 32 show the outdoor conditions, measured at the Toronto International Airport, during February 21 to 23 and March 16 to 18, 2019, respectively.

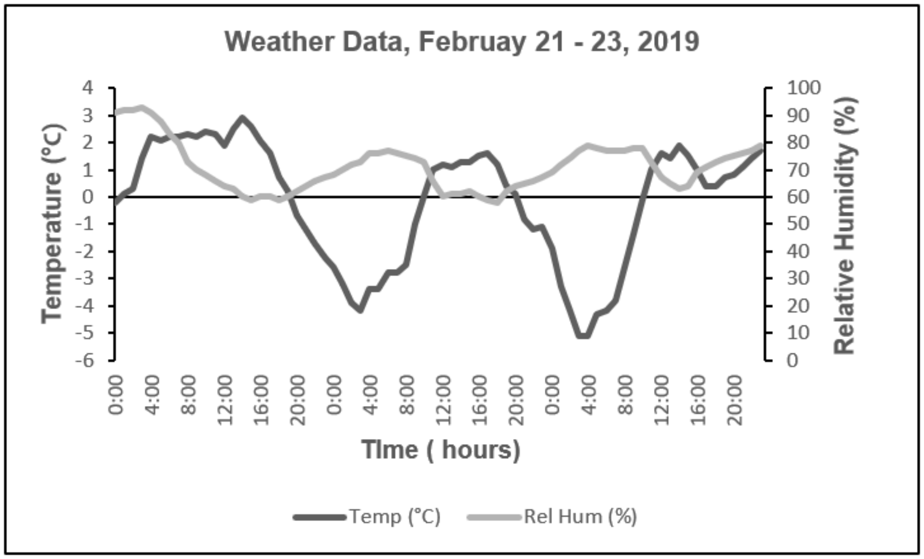


Figure 31 – Weather Data, February 21 – 23, 2019

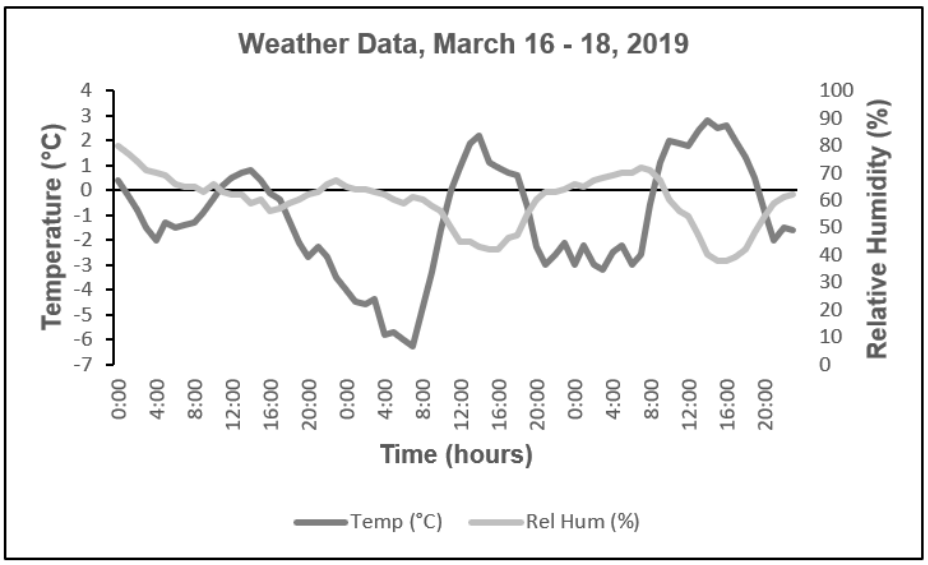


Figure 32 – Weather Data, March 16 – 18, 2019

ASHRAE 55-2013 mandates that at minimum 80% of occupants are thermally comfortable in a space, and establishes a temperature range within which these results are most likely to occur. Table 10 shows the overall thermal comfort results. The average temperature within the library complies with the mean of the temperature range identified in the ASHRAE 55-2013 standard. However, only sixty percent of spaces were in compliance with the ASHRAE 55-2013 standard. From the 40% of spaces that were not in compliance, 67% were above the upper threshold, and 33% were below the lower threshold.

Table 10 – Overall Thermal Comfort Results

Reference	Target (°C)	Minimum (°C)	Maximum (°C)	Mean (°C)	Standard Deviation (°C)	Number of Spaces in Compliance	% Spaces in Compliance
ASHRAE 55	Winter 20-24°C	19.5	28.5	22	2	58 from 97	60%

The twenty-six exceedances of the upper threshold were recorded throughout the five zones in the library on February 21 and 22, 2019. Although there was no geographical pattern to the upper threshold exceedances, there was a geographical pattern to the readings that were below the lower threshold. Twelve of the thirteen temperature readings below the lower threshold were recorded specifically, in the Adult Zone, at the entrance vestibule, and circulation desk. Furthermore, there was a temporal pattern; each day of the March testing period had readings that were below the lower threshold. Tables 11 and 12 provide the individual sampling measurements by location during February 21 to 23, 2019 and March 16 to 18, 2019, respectively.

Table 11 – Thermal Comfort Results – February 21 – 23, 2019

Location	February 21, 2019		February 22, 2019		February 23, 2019	
	Temperature (°C)	In Compliance (20-24°C)	Temperature (°C)	In Compliance (20-24°C)	Temperature (°C)	In Compliance (20-24°C)
Entrance vestibule	25.2	No	28.0	No	19.5	No
Circulation desk	23.2	Yes	27.9	No	20.6	Yes
Workroom	24.2	No	28.5	No	21.4	Yes
Adult zone - south library stack	24.9	No	27.7	No	21.1	Yes
Adult zone - north library stack	24.1	No	26.3	No	20.4	Yes
Adult zone - south work stations	24.2	No	26.1	No	20.8	Yes
Adult zone - north work stations	24.1	No	25.9	No	20.4	Yes
Adult zone - reading tables	24.3	No	27.0	No	21.1	Yes
Teen zone - south library stack	24.9	No	27.6	No	21.6	Yes
Teen zone - north library stack	25.4	No	28.1	No	22.0	Yes
Teen zone - computer station	NMR	NA	28.4	No	22.3	Yes
Children zone - south library stack	24.5	No	NMR	NA	22.5	Yes
Children zone - north library stack	23.6	Yes	24.8	No	22.7	Yes
Children zone - information station	23.6	Yes	24.7	No	23.1	Yes
Staff room	23.6	Yes	24.5	No	22.8	Yes
Program meeting room	24.5	No	24.3	No	21.5	Yes
Branch Head 2 office	NMR	NA	NMR	NA	NMR	NA

NMR = no measurement recorded
NA = not available

Table 12 – Thermal Comfort Results – March 16 –18, 2019

Location	March 16, 2019		March 17, 2019		March 18, 2019	
	Temperature (°C)	In Compliance (20-24°C)	Temperature (°C)	In Compliance (20-24°C)	Temperature (°C)	Compliance (20-24°C)
Entrance vestibule	19.5	No	19.4	No	19.1	No
Circulation desk	19.3	No	20.0	Yes	19.8	No
Workroom	20.5	Yes	20.6	Yes	20.7	Yes
Adult zone - south library stack	20.5	Yes	20.2	Yes	20.6	Yes
Adult zone - north library stack	19.9	No	19.5	No	19.9	No
Adult zone - south work stations	20.4	Yes	19.6	No	20.2	Yes
Adult zone - north work stations	20.0	Yes	19.4	No	19.9	No
Adult zone - reading tables	20.6	Yes	20.4	Yes	20.4	Yes
Teen zone - south library stack	20.5	Yes	19.8	No	20.5	Yes
Teen zone - north library stack	20.5	Yes	20.0	Yes	20.9	Yes
Teen zone - computer station	20.6	Yes	20.2	Yes	20.7	Yes
Children zone - south library stack	21.1	Yes	20.8	Yes	21.1	Yes
Children zone - north library stack	21.5	Yes	21.2	Yes	21.3	Yes
Children zone - information station	21.8	Yes	21.5	Yes	21.6	Yes
Staff room	21.9	Yes	21.5	Yes	21.7	Yes
Program meeting room	21.9	Yes	20.8	Yes	21.2	Yes
Branch Head 2 office	22.4	Yes	21.8	Yes	22.1	Yes

NMR = no measurement recorded
NA = not available

Table 13 shows the overall RH results. Fifty-one percent of the spaces were in compliance with the IAQForum guideline (IAQ Forum, ND). All spaces that were not in compliance with this guideline were below the lower RH target.

Table 13 – Overall RH Results

Reference	Target (%)	Minimum RH (%)	Maximum RH (%)	Mean RH (%)	Standard Deviation (%)	Number of Spaces in Compliance	% Spaces in Compliance
IAQForum.ca	30-50%	25	34.5	30	2	33 from 98	51%

All five zones had sampling locations that did not reach the minimal threshold. Consequently, there was no geographical pattern to these results. Although each sampling day recorded RH levels that did not meet the minimal threshold, the majority of these events happened on February 22, March 17 and March 18, 2019. Tables 14 and 15 provide the individual sampling measurements by location during February 21 to 23 and March 16 to 18, 2019, respectively.

Table 14 – RH Results – February 21 – 23, 2019

Location	February 21, 2019		February 22, 2019		February 23, 2019	
	Relative Humidity (%)	In Compliance (30-60%)	Relative Humidity (%)	In Compliance (30-60%)	Relative Humidity (%)	In Compliance (30-60%)
Entrance vestibule	27.1	No	25.3	No	32.9	Yes
Circulation desk	28.6	No	26.6	No	32.1	Yes
Workroom	29.0	No	25.7	No	31.9	Yes
Adult zone - south library stack	29.3	No	26.9	No	31.6	Yes
Adult zone - north library stack	31.3	Yes	28.2	No	32.6	Yes
Adult zone - south work stations	30.4	Yes	28.7	No	32.2	Yes
Adult zone - north work stations	30.5	Yes	28.2	No	32.3	Yes
Adult zone - reading tables	30.6	Yes	27.8	No	32.0	Yes
Teen zone - south library stack	30.6	Yes	26.8	No	31.1	Yes
Teen zone - north library stack	30.2	Yes	26.1	No	30.6	Yes
Teen zone - computer station	NMR	NA	25.9	No	30.3	Yes
Children zone - south library stack	31.5	Yes	NMR	NA	31.0	Yes
Children zone - north library stack	33.1	Yes	32.0	Yes	30.6	Yes
Children zone - information station	33.8	Yes	32.9	Yes	30.6	Yes
Staff room	31.4	Yes	28.6	No	29.3	No
Program meeting room	30.2	Yes	27.6	No	30.2	Yes
Branch Head 2 office	NMR	NA	NMR	NA	NMR	NA

NMR = no measurement recorded
NA = not available

Table 15 – RH Results – March 16 – 18, 219

Location	March 16, 2019		March 17, 2019		March 18, 2019	
	Relative Humidity (%)	In Compliance (30-60%)	Relative Humidity (%)	In Compliance (30-60%)	Relative Humidity (%)	In Compliance (30-60%)
Entrance vestibule	33.2	Yes	27.1	No	28.8	No
Circulation desk	34.1	Yes	27.3	No	30	Yes
Workroom	32.6	Yes	27.5	No	29.3	No
Adult zone - south library stack	33.8	Yes	27.3	No	29.7	No
Adult zone - north library stack	34.4	Yes	28.1	No	30.4	Yes
Adult zone - south work stations	34.4	Yes	28.2	No	30.4	Yes
Adult zone - north work stations	34.5	Yes	28.3	No	30.7	Yes
Adult zone - reading tables	33.7	Yes	27.5	No	30.2	Yes
Teen zone - south library stack	31.8	Yes	28.1	No	29	No
Teen zone - north library stack	31.8	Yes	27.3	No	28.5	No
Teen zone - computer station	31.6	Yes	27.3	No	29.3	No
Children zone - south library stack	32.6	Yes	29.5	No	29	No
Children zone - north library stack	32.3	Yes	28.7	No	28.8	No
Children zone - information station	31.8	Yes	28.9	No	29.1	No
Staff room	31.2	Yes	26.6	No	28.4	No
Program meeting room	31.5	Yes	26.7	No	27.5	No
Branch Head 2 office	29.2	No	25	No	25.6	No

NMR = no measurement recorded
NA = not available

ASHRAE 62.1-2013 stipulates a maximum allowable CO_2 value of 700 ppm above outdoor air CO_2 levels within occupied spaces. Table 16 shows the overall CO_2 results above outdoor air levels. Appendix 3 provides the individual sampling measurements by date and location. Ninety-eight percent of spaces were in compliance with this reference target. During the February 22, 2019 sampling period, the CO_2 levels at the north stack and the information station in the Children Zone exceeded the target.

Table 16 – Overall CO_2 Results Above Outdoor Air Levels

Reference	CO_2 Target (ppm)	CO_2 Minimum (ppm)	CO_2 Maximum (ppm)	CO_2 Mean (ppm)	Standard Deviation (ppm)	Number of Spaces in Compliance	% Spaces in Compliance
ASHRAE 62.1	< 700 ppm	39	778	265	133	94 from 96	98%

Table 17 illustrates the overall CO results. They were very low; 100% of spaces were below the Canadian guideline identified in the ASHRAE 62.1 standard. Appendix 4 provides the individual sampling measurements by date and location.

Table 17 – Overall CO Results

Reference	CO Target (ppm)	CO Minimum (ppm)	CO Maximum (ppm)	CO Mean (ppm)	Standard Deviation (ppm)	Number of Spaces in Compliance	% Spaces in Compliance
ASHRAE 62.1	<11 ppm	0	1	0.20	0.40	95 from 95	100%

Tables 18 and 19 show the overall particulate levels at 2.5 and 10 microns, respectively. Appendix 5 provides the individual sampling measurements by date and location. The levels were low; 100% of spaces were in compliance with the U.S. EPA guideline and National Ambient Air Quality Standards (NAAQS) Table (US EPA, 2003, US EPA, ND).

Table 18 – Overall Particulate Results – $PM_{2.5}$

Reference	$PM_{2.5}$ Target	$PM_{2.5}$ Minimum ($\mu g/m^3$)	$PM_{2.5}$ Maximum ($\mu g/m^3$)	$PM_{2.5}$ Mean ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)	Number of Spaces in Compliance	% Spaces in Compliance
U.S. EPA	< 35 $\mu g/m^3$	6	15	8	2	50 from 50	100%

Table 19 – Overall Particulate Results – PM_{10}

Reference	PM_{10} Target	PM_{10} Minimum ($\mu g/m^3$)	PM_{10} Maximum ($\mu g/m^3$)	PM_{10} Mean ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)	Number of Spaces in Compliance	% Spaces in Compliance
U.S. EPA	< 150 $\mu g/m^3$	7	30	15	5	48 from 48	100%

Table 20 shows the overall VOC levels. Appendix 6 provides the individual sampling measurements by date and location. One hundred percent of spaces sampled were in compliance with this target.

Table 20 – Overall VOC Results

Reference	VOCs Target (μg/m^3)	VOCs Minimum (μg/m^3)	VOCs Maximum (μg/m^3)	VOCs Mean (μg/m^3)	Standard Deviation (μg/m^3)	Number of Spaces in Compliance	% Spaces in Compliance
Health Canada	< 1000 μg/m^3	0	69	1	7	96 from 96	100%

Table 21 shows the overall noise results according to type of space. (The noise levels were recorded in decibels (dBA). These values were then converted into Noise Criterion Balanced (NCB) values by subtracting 5 to each dBA value to allow comparison to suitable reference standards).

Table 21 – Overall Noise Results

Reference	Type of office	Noise Target (NCB)	Noise Minimum (NCB)	Noise Mean (NCB)	Noise Maximum (NCB)	Standard Deviation (NCB)	Number of Spaces in Compliance	% Spaces in Compliance
ANSI/ASA S12.2-2008	Open plan office	40	35	46	66	5	5 from 40	13%
	Private office	35	36	48	59	7	0 from 9	0%

Thirteen percent of open plan spaces sampled complied with the ANSI S15.2-1995 standard; whereas, none of the private office spaces complied. In the open plan spaces, two of the three highest average noise levels were recorded in the Children's Zone at 48.5 and 49.4 NCB. The highest average noise level was recorded in the Program Meeting Room at 51.8 NCB. The three lowest average noise levels were recorded in the Adult Zone, North Library Stack, at 40.7 NCB, the Teen Zone, North Library Stack at 41.4 NCB, and Teen Zone, South Library Stack at 42.1 NCB. In the private office spaces, the average noise levels in the Workroom, Staff Room and Branch Head 2 Office were 41.6, 50. 4 and 51.3 NCB, respectively. Tables 22 and 23 provide the individual sampling measurements by sampling location for open plan spaces and private office spaces, respectively.

Table 22 – Noise Measurements in Open Plan Spaces

Location	March 6, 2019			March 7, 2019			March 9, 2019		
	Noise (dBA)	Noise (NCB)	Compliance (≤ 40 NCB)	Noise (dBA)	Noise (NCB)	Compliance (≤ 40 NCB)	Noise (dBA)	Noise (NCB)	In Compliance (≤ 40 NCB)
Entrance vestibule	50.7	45.7	No	52.0	47.0	No	55.3	50.3	No
Circulation desk	52.9	47.9	No	49.7	44.7	No	52.9	47.9	No
Adult zone - south library stack	46.5	41.5	No	65.5	60.5	No	41.6	36.6	Yes
Adult zone - north library stack	46.8	41.8	No	45.6	40.6	No	44.6	39.6	Yes
Adult zone - south work stations	50.1	45.1	No	53.1	48.1	No	52.5	47.5	No
Adult zone - north work stations	49.7	44.7	No	46.7	41.7	No	48.9	43.9	No
Adult zone - reading tables	47.8	42.8	No	55.3	50.3	No	53.2	48.2	No
Teen zone - south library stack	54.2	49.2	No	46.6	41.6	No	40.4	35.4	Yes
Teen zone - north library stack	50.2	45.2	No	48.9	43.9	No	40.0	35.0	Yes
Teen zone - computer station	50.6	45.6	No	56.5	51.5	No	45.0	40.0	Yes
Children zone - south library stack	50.3	45.3	No	59.6	54.6	No	50.7	45.7	No
Children zone - north library stack	49.4	44.4	No	53.5	48.5	No	46.1	41.1	No
Children zone - information station	NMR	NA	NA	58.9	53.9	No	49.8	44.8	No
Program meeting room	NMR	NA	NA	47.4	42.4	No	66.1	61.1	No

Table 23 – Noise Measurements in Private Office Spaces

Location	March 6, 2019			March 7, 2019			March 9, 2019		
	Noise (dBA)	Noise (NCB)	Compliance (≤ 40 NCB)	Noise (dBA)	Noise (NCB)	Compliance (≤ 40 NCB)	Noise (dBA)	Noise (NCB)	In Compliance (≤ 40 NCB)
Workroom	45.7	40.7	No	53.6	48.6	No	40.5	35.5	No
Staff room	51.5	46.5	No	50.6	45.6	No	64.0	59.0	No
Branch Head 2 office	56.6	51.6	No	60	55.0	No	52.4	47.4	No

In accordance with IESNA lighting standard, minimum and maximum lighting levels were measured on February 23 and March 6, 2019. Table 24 shows the lighting levels. Appendix 7 provides the individual sampling measurements by date and location. Sixty-five percent of the locations measured were within the acceptable range. The lighting levels at the reading table in the Adult Zone, the south and north library stacks in the Children Zone, and the Branch Head 2 Office exceeded the lighting standard target. The south and north library stacks in the Teen Zone were below the lighting standard target.

Table 24 – Overall Lighting Results

Reference	Lighting Target (lux)	Lighting Minimum (lux)	Lighting Maximum (lux)	Lighting Mean (lux)	Standard Deviation (lux)	Number of Spaces in Compliance	% Spaces in Compliance
IESNA lighting standard	350-750	221	1268	564	391	11 from 17	65%

5.3 Occupant Survey

The occupant survey was administered during the period from February 15 to February 23, 2019. Occupant results were pooled to maintain response confidentiality and averaged. Four staff members participated in the occupant survey yielding a response rate of 44%. The small occupant population and low participation rate limited the value of the responses. The pooled, averaged responses in each category were all in the satisfied range. Lighting received the highest satisfaction rating, followed by productivity, thermal comfort, noise and air quality. Seventy-five percent of respondents indicated that air quality and thermal comfort interfered with their ability to get their job done; whereas, the same percentage of respondents indicated that lighting enhanced their ability to get their job done. Figure 33 shows the results of the occupancy survey.

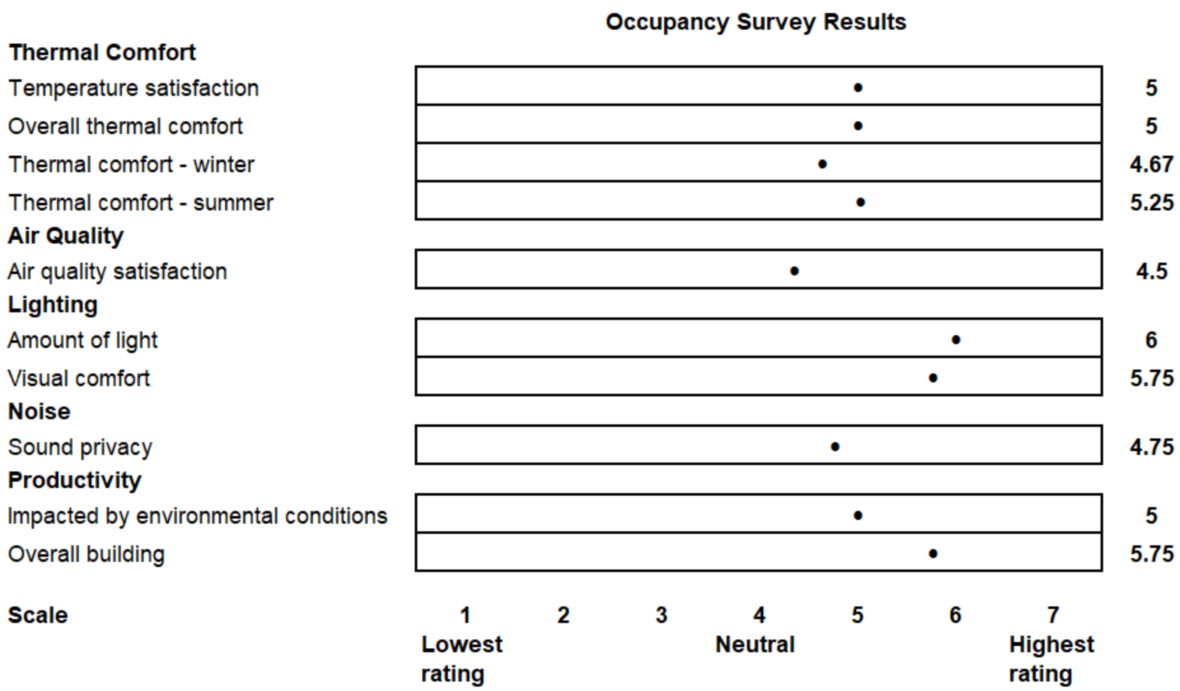


Figure 33 – Occupancy Survey Results

5.4 Interviews with Facility and Branch Staff

Interviews were conducted with the Manager, Facility Operations, Branch Head Two and Children's Librarian of the WPL. Several themes emerged from these interviews. Staff noted that generally the temperature throughout the library varies considerably on any given day or moment. Typically, the Adult Zone, the heritage section, tends to be warmer in the summer and cooler in the winter than the other sections of the library. Consequently, library staff frequently dress in layers to accommodate the thermal fluctuations in the building. Although library staff indicated that there seemed to be no pattern to when thermal comfort issues occurred, they did state that there seemed to be less thermal comfort issues during the spring and fall seasons. (Note: This statement could not be verified since thermal-related incidents are not tracked in a database). During the two previous summers, the library remained closed or was forced to close because the building was too hot on several occasions. (Note: The TPL rented temporary air conditioning units to provide cooling in the past two years. It also replaced the chiller in 2017 with an RTU to provide better cooling, and is in the process of upgrading the BAS to permit Facility Operations to handle thermal comfort issues remotely). When thermal comfort issues arise, library staff notify Facility Operations who will visit the site to adjust the thermostat, which is locked and inaccessible to library staff, and mechanical systems. Typically, the facility response time is between 10 minutes to two hours. Numerous fans and heaters are located throughout the library to address thermal comfort in the interim between the notification of a thermal comfort incident to Facility Operations and its resolution, and to accommodate personal occupant requirements. A staff member indicated that fans were used weekly in the winter and daily in the summer.

Based on staff interviews and physical testing results, thermal comfort is definitely an issue. The occupant survey reinforced this finding. Seventy-five percent of respondents indicated that thermal comfort interfered with their ability to get their job done. Thermal comfort in the winter received a 4.67 rating, on a scale of 0 to 7, the second lowest rating of all parameters surveyed. Occupant survey responses on temperature satisfaction and overall thermal comfort corroborated this finding. Both parameters were awarded a 5 rating.

Library staff interviews identified that air quality in terms of dust, odours, and ventilation, and noise were concerns. The occupant survey results reinforced this perception. Seventy-five percent of occupancy survey respondents indicated that the air quality interfered with their productivity. In fact, air quality was awarded the lowest rating, 4.5, of all parameters examined. However, the occupancy survey result contrasts strongly with the testing results which showed compliance rates at 98% or greater for all IAQ parameters tested.

Library staff indicated that noise can be an issue in the library, especially between different areas of the library. For example, visitors in the Teen Zone occasionally complain about noise emanating from the Children's Zone. Staff members indicated that noise reverberates in the Adult Zone. Occupant survey results reinforce this observation. Occupant survey respondents rated noise quality at 4.75, the third lowest rating of all parameters surveyed.

Based on staff interviews, lighting was generally acceptable in most zones. The occupant survey results support this perception. Seventy-five percent of occupant survey respondents indicated that the lighting enhanced their productivity. The amount of light and the visual comfort of the lighting were rated at 6 and 5.75, (out of 7) respectively, the two highest ratings for parameters surveyed. Staff stated that the Children's Zone was a dimly lit space. This perception contrasts with the measured lighting levels in this zone. The lighting levels in the south and north library stacks in the Children's Zone were 884 and 783 lux, respectively. These measurements suggest too much lighting in this zone rather than too little. The lighting level at the information desk in the Children's Zone was at the high end of the acceptable range, 744 lux.

5.5 Utility Analysis

2015 to 2017 annual natural gas, electricity and water consumption was calculated from statistics provided by the TPL. The statistics were based on monitored consumption identified on utility bills. During 2015, 2016 and 2017, annual electricity consumption ranged from 50% to 57% of the total energy consumption; whereas, natural gas consumption ranged from 43% to 50%.

Figure 34 shows the annual natural gas consumption from 2015 to 2017. Natural gas consumption in 2016 and 2017 decreased from 2015 levels by 34% and 17%, respectively. The reasons for these significant fluctuations in natural gas from year to year could not be determined conclusively. The impact of weather was explored as one possible reason. The number of HDD (°C) in 2015, 2016 and 2017 were 3766, 3462 and 3502, respectively (Environment Canada, ND). The variation between the highest and lowest figure was less than 10%. Weather would have accounted for approximately 25% of the natural gas decrease between 2015 and 2016.

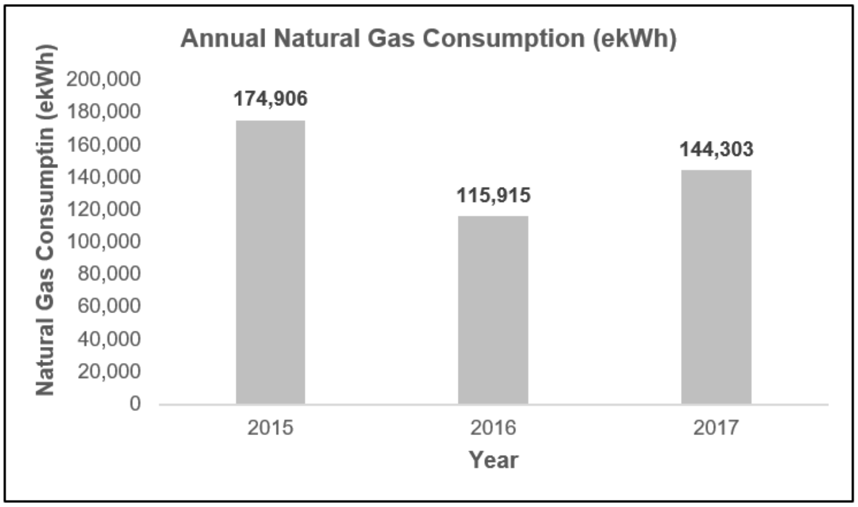


Figure 34 – Annual Natural Gas Consumption

Figures 35 illustrates the annual electricity consumption from 2015 to 2017. Electricity consumption in 2016 and 2017 decreased from 2015 levels by 12% and 14%, respectively. Similar to natural gas consumption, the reasons for the variations in electricity consumption from year to year could not be determined conclusively. The impact of weather could not account for the variation. The number of cooling degree days (CDD) (°C) in 2015, 2016 and 2017 were 351, 566 and 349, respectively (Environment Canada, ND). Based solely on the CDD, one would expect the electricity consumption to increase rather than decrease from 2015 to 2016. The changeout of the chiller to an RTU may have contributed to the decreased consumption between 2015 and 2017.

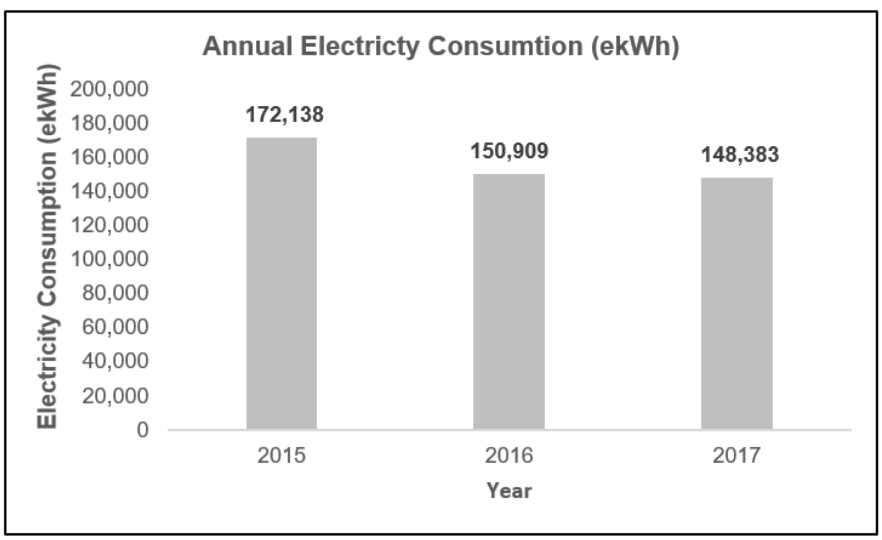


Figure 35 – Annual Electricity Consumption

Figure 36 depicts the annual water consumption from 2015 to 2017. Water consumption in 2016 and 2017 decreased from 2015 levels by 23% and 16%, respectively. Once again, no explanation could be developed to account for these differences.

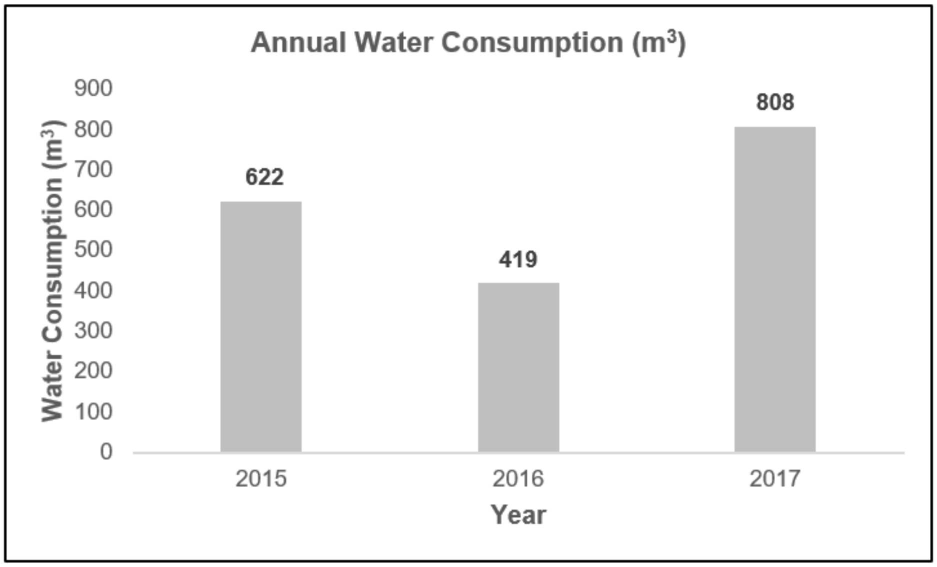


Figure 36 – Annual Water Consumption

Figure 37 illustrates 2013 to 2016 annual energy intensities, corrected for HDD, by area (i.e., eWh/HDD ((°C)/m^2) of the WPL, TPL system and Ontario public libraries. The WPL energy intensity was below the TPL average energy intensity, except for 2015. The WPL energy intensity was above the average Ontario public library energy intensity except for 2016.The energy intensity from 2015 to 2016 dropped by 52% from 0.76 to 0.36 kWh/HDD(°C)/m^2.

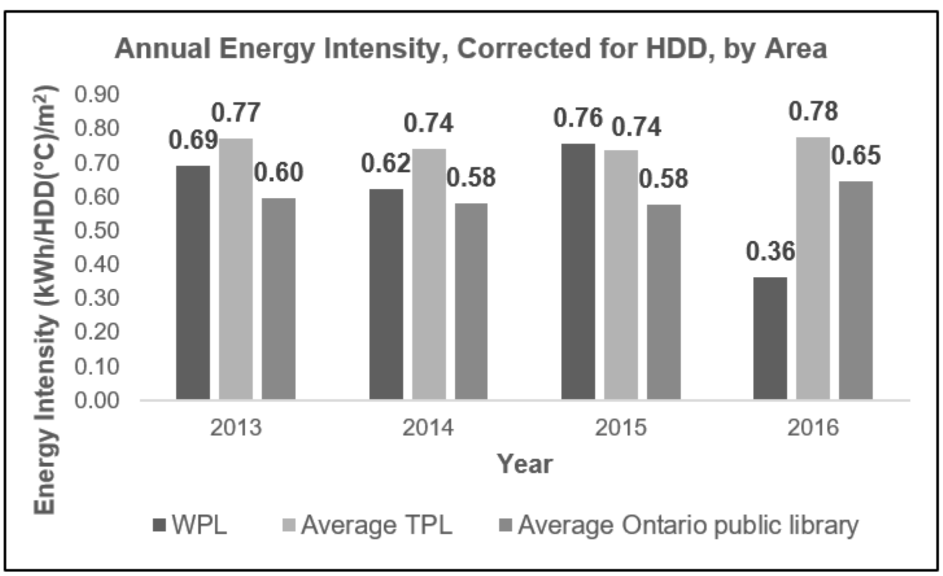


Figure 37 – Annual Energy Intensity, Corrected for HDD, by Area

Figure 38 shows the 2013 to 2016 annual energy intensities, corrected for HDD, by visitor (i.e., eWh/HDD(°C)/visitor). The results of the variation in annual energy intensity could not be explained. The 53% drop between 2015 and 2016 annual energy intensities suggest that data errors may have contributed to the decrease.

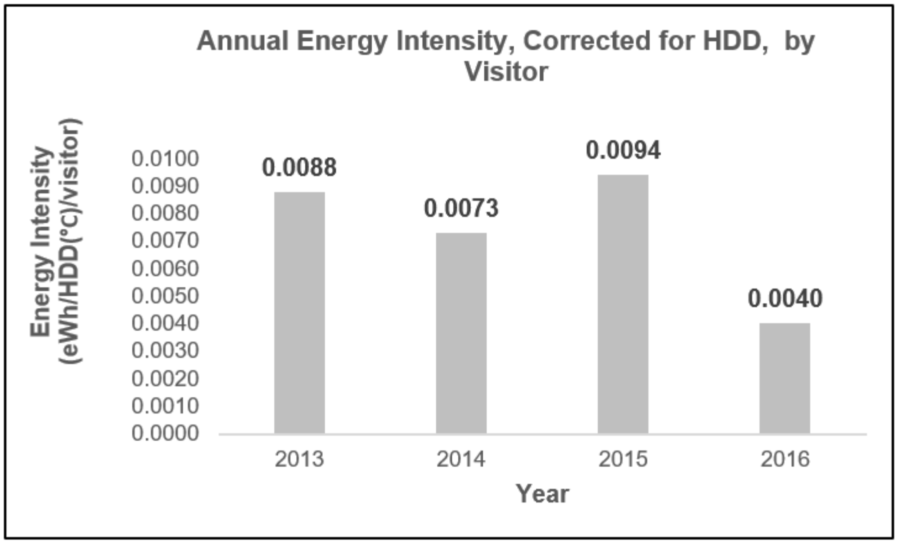


Figure 38 – Annual Energy Intensity, Corrected for HDD, by Visitor

Figure 39 shows the 2013 to 2016 annual energy intensities, corrected for HDD, by FTE (i.e., eWh/HDD(°C)/FTE). The variations in annual energy intensities by FTE mirror identically the results of the variations by area because the FTE was constant from 2013 to 2016 just as the area of the library remained constant.

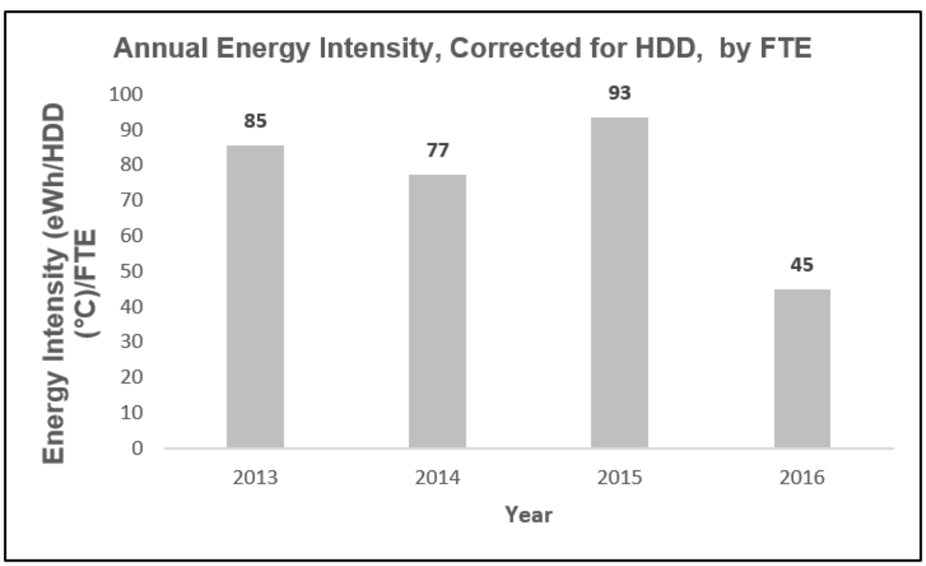


Figure 39 – Annual Energy Intensity, Corrected for HDD

Figure 40 depicts the 2015 to 2017 annual energy intensities by area (i.e., kWh/m^2). These annual energy intensities are lower than 483 kW/m^2, the 2019 Canadian energy median energy intensity for libraries (Energy Star Portfolio Manager, 2019), and higher than 226 kW/m^2, the 2018 U.S energy median energy intensity for libraries (Energy Star Portfolio Manager, 2018), respectively

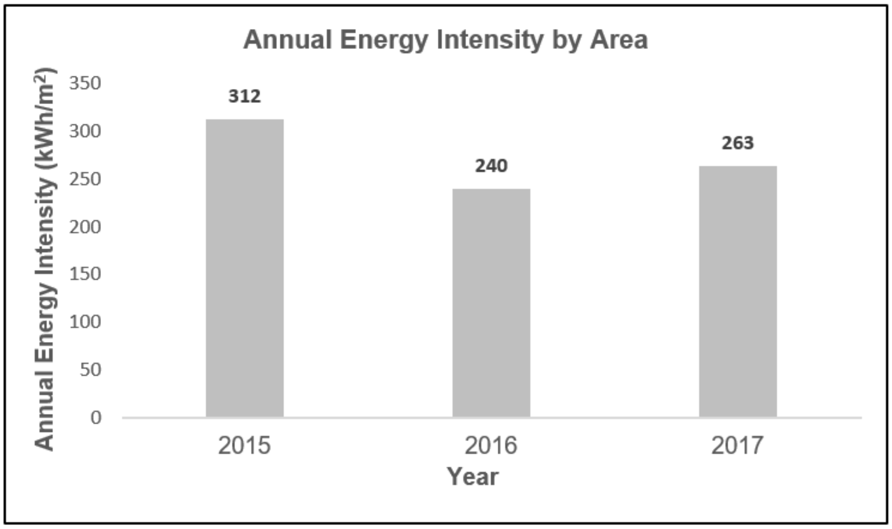


Figure 40 – Annual Energy Intensity by Area

Figure 41 presents the 2015 to 2017 annual water intensities by area (i.e., m^3/m^2). Compared to the 2015 annual water intensity, the 2016 value decreased by 32% and the 2017 value increased by 30%. The annual water intensities (m^3/m^2) were considerably higher than the annual water intensity of 0.01 m^3/m^2 in the Alice Turner Library, which researchers identified as being extremely low (Turcato et al., 2015)

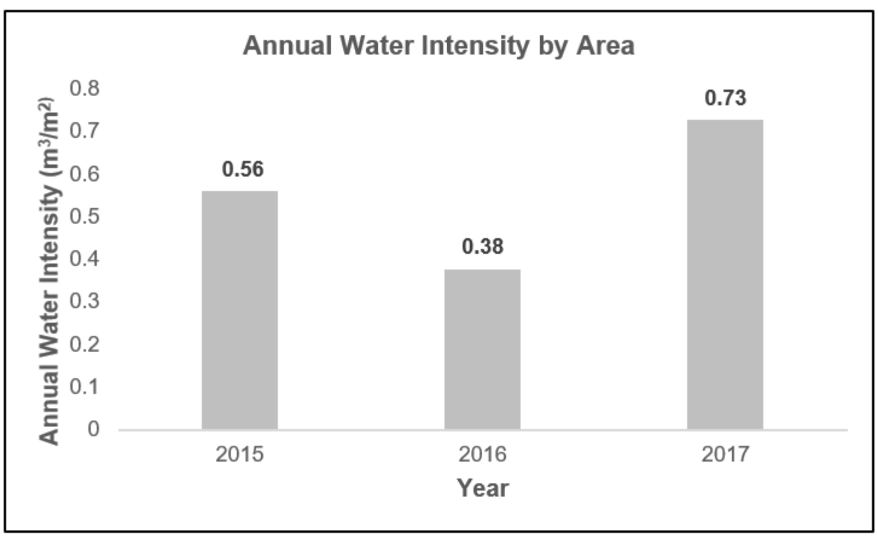


Figure 41 – Annual Water Intensity by Area

Figure 42 depicts the 2015 to 2017 annual water intensities by visitor (i.e., m^3/visitor). Compared to the 2015 annual water intensity, the 2016 value decreased by 40% and the 2017 value increased by 25%. The annual number of visitors increased by 12% in 2016 and decreased by 7% in 2017 compared to 2015 figures. These changes accounted for some of the variation in the water intensities.

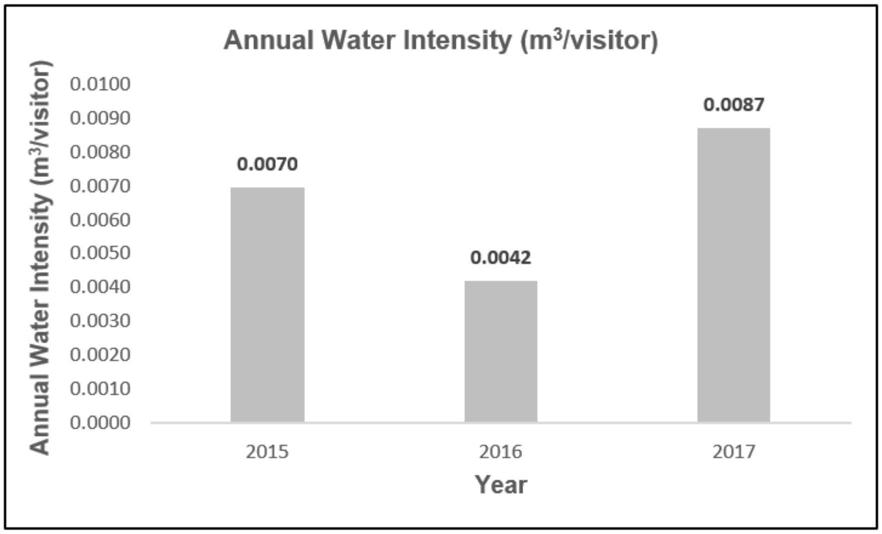


Figure 42 – Annual Water Intensity by Visitor

Figure 43 presents the 2015 to 2017 annual water intensities by FTE (i.e., m^3/FTE). Compared to the 2015 annual water intensity, the 2016 value decreased by 32% and the 2017 value increased by 30%. These variations mirror the variations in the annual water intensities by area. In both situations, the denominators of the water intensity metric did not vary. The area of the building and the number of FTE during the three-year period did not change.

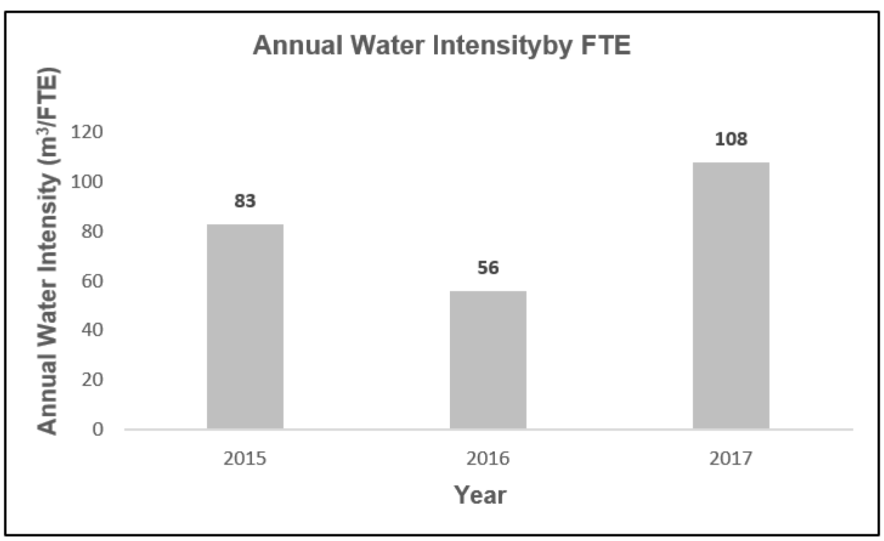


Figure 43 – Annual Water Intensity by FTE

5.6 Conducting LPD Assessment

The lighting power density was estimated at 14 W/m^2. ASHRAE 90.1 -2013 stipulates a 11.5 W/m^2 and 18.4 W/m^2 at reading tables and in stacks in libraries, respectively. Appendix 8 shows the calculations used to estimate the lighting power density. The results suggest that the LPD seems to be high given the area allocated to stacks and reading zones.

5.7 Revised Protocol for Conducting a BPE

As a result of implementing the draft protocol for conducting a BPE in the TPL system at the WPL and reviewing the *Toronto Public Library Facilities Master Plan Final Report*, the draft protocol was revised to expand the focus from occupants and resources to include a review of the Facilities Master Plan and use a phased approach for tailoring the BPE to the needs of the particular library. This phased approach for tailoring the BPE encompassed three phases: 1) conducting a review of historic data, 2) seeking feedback from key personnel (e.g., facility and library staff, library visitors and designers of the library) 3) conducting a customized suite of physical testing measures based on the outcomes from Phases 1 and 2. Although financial considerations were not considered part of the draft protocol, they were added to the revised protocol for several reasons. Without financial expenditures, library services could not be provided to the community and there would be no need for a library branch. It is important to understand how a library is performing financially. Does this library cost more to operate, deliver less program services to the community or have lower loan rates compared to its cohort (e.g., Tier 1)? Furthermore, it would be useful to know if a particular library consumes a large or a small percentage of TPL's overall operating and capital budget. These considerations could help the TPL rank its library branches according to financial performance (e.g., operating and capital costs compared to its cohort and percentage of the TPL overall budget) and impacts (e.g. volume of services provided, loan rates) and determine priority for conducting a BPE. Spending time, money and effort wisely would maximize returns on the investment of conducting a BPE. Figures 44 to 46 describe the activities, objectives and outputs from each phase of the model.

Phase 1 – Review Historic Data

Activities	Objective	Output
• Review TPL's Facilities Master Plan	• Understand TPL's long-term plan for this library	• Identification of library's "project investment typology" – revitalization, expansion, relocation, reconstruction, business as usual
• Conduct financial analysis of annual operational, maintenance and capital (e.g., in-kind replacement of equipment) costs from previous 3-5 years and benchmarking	• Quantify annual operational, maintenance and capital costs on an absolute and intensity basis (i.e., by area, total number of operational hours) and benchmark against TPL average (overall and tier appropriate) • Identify top 3-5 facility performance costs	• Understand financial performance of library • List of top 3-5 facility performance costs
• Conduct utility analysis from previous 3-5 years and benchmarking	• Quantify annual utility consumption and costs on absolute and intensity basis (e.g. by area, total number of operational hours, visitors, FTE). • Determine quartile performance of library compared to TPL average (overall and tier appropriate) of each utility resource	• Understand utility costs and consumption • Determine if utility consumption is a performance issue (i.e., third or fourth quartile) in this library and warrants further investigation in BPE
• Review facility incidents from previous 3-5 years and compile summary	• Identify top 3 – 5 building performance issues	• List of library-specific issues to investigate in BPE
• Conduct facility site review.	• Become familiar with the library's physical layout, mechanical systems, operations and condition	• Perspective on facility conditions, layout and state of operations and maintenance practices

↓

Output

1. Identification of potential performance issues from a resource and financial perspective

Figure 44 **–** Phase 1 **–** Protocol for Conducting a BPE in the TPL System

Phase 2 – Seek Feedback from Key Personnel

Activities	Objectives	Output
• Administer occupant survey to staff	• Obtain staff perspective on building performance, (e.g., strengths and weaknesses of the building, trends, anomalies)	• List of library-specific issues to investigate in BPE from staff perspective
• Administer occupant survey to library visitors	• Obtain "customer perspective" on building performance, (e.g., strengths and weaknesses of the building, trends, anomalies) ideally from different age groups (i.e., children, teens, adults, seniors)	• List of library-specific issues to investigate in BPE from "customer perspective"
• Conduct interviews with key personnel (e.g., facility staff, library staff, designers of library)	• Understand original design intent, history of library from previous 3-5 years and future plans • Explore/probe issues that have been identified in Phase 1	• In-depth understanding of facility history, maintenance and operations, capital projects and future plans • Understanding of performance issues and identification of trends and contradictions in evidence (e.g., comparisons between facility incident summary, utility analysis, occupant survey results, interviews with key personnel).

Outputs

1. Identification of potential performance issues from the perspective of key personnel

2. Refined list of performance issues, from the perspectives of resources, finances and occupants, to investigate during BPE

Figure 45 - Phase 2 – Protocol for Conducting a BPE in the TPL System

Phase 3 – Conduct Customized Suite of Physical Testing Measures

Activities	Objectives	Output
• Conduct airtightness testing	• Quantify airtightness of building enclosure	• Air leakage rate ($l/s{\cdot}m^2$)
• Conduct infrared thermography	• Identify thermal bridges, areas of concern (e.g., excessive heat loss, and air leakage)	• Thermal images of areas of possible concern
• Measure in situ U-values	• Quantify heat loss through various building enclosure elements	• U-value measurements ($W/m^2{\cdot}K$) of building enclosure components (e.g., roof, walls, windows)
• Measure lighting, plug and thermal loads through sub-metering	• Quantify percentage of electricity allocated to each type of load	• Electricity profile by type of load
• Conduct LPD assessment	• Determine if LPD conforms to standard	• LPD levels (W/m^2)
• Conduct HVAC assessment (e.g., ventilation balancing, heat system checks and flow measurements)	• Determine if HVAC system is optimized.	• Ventilation and flow rates
• Conduct IEQ testing	• Determine if IEQ parameters meet reference target/standards	• Temperature, RH, noise and lighting results (e.g., range, mean, median, maximum, compliance rates)
• Conduct IAQ testing	• Determine if IAQ parameters meet reference target/standards	• CO_2, CO, $PM_{2.5}$, PM_{10}, VOC results (e.g., range, mean, median, maximum, compliance rates)

Outputs

1. "Snapshot" of building performance based on indicators and metrics related to occupants, resources and finances
2. Performance issues that are important to improve or remedy during a retrofit.
3. Baseline to measure success following a retrofit.

Figure 46 - Phase 3 – Protocol for Conducting a BPE in the TPL System

6. Discussion

6.1 Protocol for Conducting a BPE

The protocol for conducting a BPE in the TPL system was revised to include a review of the Facilities Master Plan, financial analysis and a phased approach. Before embarking on a BPE of a library, it is important to understand its “project investment typology”. Does the TPL plan to operate this branch in a business as usual manner? Or is it targeted for revitalization, expansion, reconstruction or relocation? If it is targeted for revitalization, expansion or business as usual, it may be useful to conduct a BPE. Obviously, if it is targeted for reconstruction or relocation, it would be prudent to reallocate the funds required to undertake a BPE to the design, construction and relocation of the library.

Buildings and their performance exist within the context of occupants, resources and financial considerations. Integrating financial analysis into a BPE is necessary to ensure that resources, both financial and human, are spent effectively both within the context of the BPE, but more importantly within the context of the overall financial situation of the particular library under evaluation and the TPL system in general. Failing to account for economic factors in a BPE has the potential to render the protocol an isolated activity siloed from the actual operation and management of the building and the TPL system.

The proposed financial analysis comprises quantifying operational, maintenance and capital costs on an absolute and intensity basis (e.g., by area, total number of operational hours) and benchmarking these results against the overall TPL average and tier appropriate average. In addition, the analysis would include the identification of the top three to five facility performance costs (e.g., routine HVAC maintenance, HVAC service calls, natural gas consumption, electricity consumption, water consumption, cleaning services, pest management). The results of this analysis would provide a perspective on the financial performance of the library, and could be used to justify proceeding with a BPE and/or tailoring the BPE activities to address significant performance costs.

The objective of the protocol is to begin the evaluation at a high level and to tailor the evaluation protocol to performance issues identified through financial analysis, utility analysis, benchmarking, an occupancy survey and interviews with key personnel. Depending on the results of Phase 1 and Phase 2, Phase 3 activities would be structured to address the issues identified in the previous phases. This approach limits the scope of a BPE to relevant performance issues for a particular library and presents a trade off. A limited scope BPE may miss performance issues if a comprehensive suite of activities is not implemented in Phase 3.

To reduce costs associated with implementing this protocol, TPL staff could complete Phase 1 activities. Because of the sensitive and technical nature of the Phase 2 and 3 activities, the services of a consulting firm are likely required for activities in these latter phases. The implementation of this protocol would provide the TPL with a “snapshot” of a library’s building performance, so that an appropriate retrofit strategy could be developed. It also would provide the TPL with a systematic and consistent method of evaluating building performance. Furthermore, it would allow comparison between pre- and post-retrofit performance and quantification of improvements, ultimately measuring the success of a retrofit.

For example, if a library had a high energy intensity (i.e., eWh/HDD(°C)/m^2) relative to its peers (e.g., fourth quarter performance), airtightness testing, infrared thermography scans, sub-metering of thermal, lighting, process and plug loads, an HVAC assessment, and a LPD assessment should be conducted. Occupant surveys and IEQ and IAQ measurements also should be conducted. On the other hand, if a library had a low energy intensity relative to its peers (e.g., first quarter performance), airtightness testing, infrared thermography scans, sub-metering, an HVAC assessment and a LPD assessment would not be required as part of the BPE.

A BPE could be a complementary evaluation completed during the same quarter when a building condition assessment (BCA) is undertaken. Ideally, it would be completed prior to a BCA, so that the evaluation team conducting the BCA possibly could identify the source of a building performance issue (e.g., water leak resulting in mould). A BCA evaluates the conditions of a building in relation to maintenance and service life. It is often conducted prior to the purchase of a building or for capital planning purposes. A BCA, however, does not measure a building’s performance. The individual materials, components, equipment, services or systems of a building could be in excellent condition; nevertheless, the building’s performance could be substandard (e.g., efficient HVAC system with a BAS improperly programmed to match the occupancy schedule). A building is more than just a physical asset comprised of materials and equipment. It is designed to provide functional requirements to occupants. Occupants determine if a building is a success or a failure. Without evaluating the actual building performance from the perspectives of occupants, resources and finances using real data, one does not know how the building is truly performing. Furthermore, one does not know if the capital spent to maintain or upgrade the material, component, equipment, services or systems, actually improved, worsened, or had no impact on the building performance.

Implementing a BCA and BCE within a short time of each other would allow the TPL to develop a database of physical conditions and building performance of libraries over time. Ideally, this database would be tied to financial data (i.e., operational and capital expenditures). This database could be analyzed to determine if certain building performance trends were correlated with particular building conditions (e.g., age of building, building typology, construction methods). Controls are important mechanisms for reducing resource consumption by tailoring functional services to occupant needs and density. If CO_2 sensors were installed in the building and the data logged permanently or during a BPE, it could be combined with visitor count data to identify periods when the library is more intensively or less intensively used. It may be useful to explore a methodology for combining CO_2 levels with occupant counts to generate occupant density. (Note: This is a preliminary concept that has not been identified, researched and tested in the field). The occupant density then could be factored into energy and water metrics and used to evaluate and benchmark performance. This database also could be used to track pre- and post-BPEs to determine the effectiveness of the retrofits. Furthermore, it could be used to inform the design and build of future libraries.

6.2 BPE of WPL

WPL had substantial air leakage, i.e., 2.93 $l/s \cdot m^2$ @ 75Pa. The air leakage results were not unanticipated given the age and method of construction of the original building and addition. The air leakage rate was approximately 50% more leaky than the 2 $L/s \cdot m^2$ target, specified in the ASHRAE 90.1 standard, and recommended by the National Research Council of Canada, (Straube, ND). In fact, the building is higher than the average airtightness of large buildings (2.15 $L/s \cdot m^2$ @ 75 Pa) and institutional buildings (i.e., government and university buildings) (2.61 $L/s \cdot m^2$ @ 75 Pa) in a recently compiled Canadian database (RDH, 2015). Obviously, WPL failed to meet the high-performance building standards established by the U.S. Army Corps of Engineers (USACE), (e.g., 1.27 $L/s \cdot m^2$ @ 75 Pa) and the Passive House Institute U.S. (0.5

L/s·m^2 @ 75 Pa) (RDH, 2015). (Note: The Ontario Building Code does not specific an airtightness performance target).

The flow exponent (n), identified as the slope of the log-log graph, of a building enclosure is typically 0.65 (RDH, 2015). During pressurization and depressurization, the value of the flow exponent was 0.594 and 0.670, respectively, generating an average n of 0.63. A flow exponent value near 0.5 would indicate that the flow was turbulent; whereas a flow exponent value near 1.0 would suggest that the flow was laminar (RDH, 2015). Turbulent flow typically constitutes flow generated by high pressure differences or through large openings and shallow and broad cracks (Burnett and Straube, 2005, p. 273). Laminar flow tends to comprise air flow produced by small pressure differences, or through smaller openings, cracks and pores (Burnett and Straube, 2005, p.273). Because the flow was between 0.5 and 1.0, the results suggest that the flow was neither solely turbulent nor laminar but a mixture of the two.

Numerous thermography images showed that there was considerable air leakage from the building. Air leakage was evident in typical interface locations (e.g., ceiling/roof to wall, window openings) and building penetrations (AHU, combustion exhaust stacks). Thermal bridges were visible in the steel studs and corners of the basement walls and at the slab edge. Although not seen by thermography imaging, air leakage through the bricks and mortar is likely another key source of unintentional airflow. Given the age of the original building and the addition and method of construction, the air leakage and thermography results were not unanticipated.

Several factors may have influenced the airtightness testing. Due to the inability to seal the RTU and generate sufficient pressure with the two fans, the test was not conducted at the required pressure of 75 Pa. The estimated air leakage result is based on the pressures recorded by the Tectite Express 5.0 software during pressurization and depressurization. The potential uneven distribution of pressure across the building enclosure (RDH, 2015) and the variability of the pressure can influence the accuracy of the results. The *ASTM E779-10 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization* requires a minimal temperature differential between indoors and outdoors and low wind-pressure differential. The airtightness testing was conducted when the temperature difference was approximately 30°C, and the average wind speed was 17 km/h with frequent bursts of wind gust. The ideal season to conduct airtightness testing is during the shoulder seasons when temperatures are moderate and the temperature difference between indoors and outdoors is less extreme. The standard also stipulates that the testing must take place on the leeward and windward sides. The airtightness test was completed only on the leeward side, the east side, of the building. Finally, the surface area of the building was estimated from building drawings and physical measurements on site.

ASHRAE 55-2013 stipulates that an occupant survey must have a response rate of 80% when the occupant population is under 20 occupants. Because the occupant survey response rate survey yielded a response rate of 44% with four occupants participating from a pool of nine, the value of the responses was limited. Several factors may have influenced the occupancy survey results. For example, occupant survey respondents rated thermal comfort in the summer higher than thermal comfort in winter despite the fact that the library was closed on several occasions during the previous two summers due to high temperatures. Prior experience in other libraries may have influenced responses. Working history at WPL also may have affected survey results. An occupant who has worked at the library over many months or years may have become accustomed to temperature variability over time; whereas, an occupant who has worked at the library for a short time may have a higher level of dissatisfaction.

Library staff stated that there was no pattern to when thermal comfort issues occurred. The weather data during the testing periods supported the staff's assessment. The temperature range during the two testing periods were very similar: from -5.1°C to 2.9°C during February 21 to 23, 2019, and -6.3°C to 2.8°C during March 16 to 18, 2019. However, the temperature within the library was considerably different.

Forty-nine percent of the RH measurements were below the 30% minimum threshold. The measurements below the minimum threshold were recorded on each day during the February and March testing period and throughout the five zones in the library. There was no spatial pattern to the distribution. Since all RH measurements were recorded during mid-afternoon on the six days of testing, a temporal pattern, if it existed, could not be determined. Low RH levels are common in buildings during the winter. Increased humidification is required to avoid occupant discomfort and the transfer of static charges between occupants and equipment.

Ninety-eight percent of spaces were in compliance with the reference target for CO_2 levels (i.e., <700 ppm above outdoor CO_2 levels). The average CO_2 level was 265 ppm above outdoor CO_2 levels, which averaged 495 ppm. These results suggest that the mechanical system provides adequate ventilation in the majority of spaces. However, the CO_2 levels at the north stack and the information station in the Children Zone exceeded the target on February 22, 2019 This exceedance was likely due to the large number of individuals in this zone when the measurements were recorded. These findings also highlight an operational challenge with libraries. Since the occupant density in a library is not fixed, it is difficult to provide building services consistently without over ventilating or under ventilating spaces. Underventilation of spaces reduces occupant comfort and productivity. Overventilation increases occupant discomfort and energy consumption. The installation of CO_2 sensors connected to the ventilation system may solve both problems.

All spaces were in compliance with CO, $PM_{2.5}$ and PM_{10}, and VOC requirements. These results are not unexpected considering that the building does not have any substantial sources of pollution (e.g., cooking, tobacco smoke, defective or unvented combustion equipment, new furnishings). One sample from 19 showed a 1 ppm CO level, a low reading. Given the health hazard with higher CO levels, further investigation into the source of this parameter is warranted. It would be advisable to confirm that there is no backdraft from the boiler exhaust into the building, and that the air intake cannot be contaminated with combustion gases.

According to the physical testing results, it appears that the air quality in the building is very good. However, this finding was not supported by library staff perceptions. Staff interviews identified air quality as an issue. Air quality was awarded a 4.75 rating, the lowest rating of all parameters surveyed. The lingering odours and stale air that the researcher noticed while on site and the low RH levels may have contributed to the staff's perception of poor air quality.

Lighting is a significant design consideration in libraries (Hassanain, M.A. & Mudhei, A.A., 2006). It influences perception of space, productivity and occupant comfort (Hassanain, M.A. & Mudhei, A.A., 2006). Natural light exposure requires a fine balancing act between its positive and negative aspects – reducing energy consumption required for lighting, improving occupant mood and productivity, avoiding glare, and preventing deterioration of library materials. Environmental conditions must be controlled to protect the library collection and provide occupants with a comfortable, pleasant environment (Hassanain, M.A. & Mudhei, A.A., 2006).

Artificial lighting supplies the majority of lighting in the WPL. Since the window-to-wall ratio is small, a sizable portion of the glazing is located at the ceiling perimeter, and 50% of the floor area is below grade, natural daylighting contributes minimally to the overall lighting levels.

Although occupants can use blinds to control lighting levels in certain areas, there are no lighting controls (e.g., blinds) on the windows at the ceiling perimeter, entrance vestibule, or in the Adult Zone

Lighting was awarded the highest level of satisfaction among the parameters surveyed. However, staff interviews identified that the Children Zone was dimly lit. In contrast to staff perceptions, lighting levels measured in the Children Zone were 744, 783 and 884 lux. The IESNA reference standard is 350 to 750 lux. These results indicate that the one of the three locations were lit adequately and two were over lit. Staff observations underscore the fact that human perception of lighting can contradict actual measurements. Staff perceptions of the lighting may be the result of other environmental factors, such as the below-grade location of the Children Zone, possible uneven lighting levels throughout the zone, the lack of views to the outside, the smaller windows, and a reduced fraction of daylighting contributing to lighting levels, influencing their perception of the lighting.

Wrightson and Wrightson (1999) as cited by Hassanain, M.A. and Mudhei, A.A., 2006, identified several acoustical problems that may result during library operations. Intrusive noise can be generated from another activity or location. Communication can be challenging in overlay reverberant spaces, where sound bounces around the room (e.g., ceiling, walls, floor) without being absorbed, during occupied and unoccupied scenarios. Speech privacy can be absent. Noise had the second lowest rating in the occupant survey. Of all parameters measured physically, noise had the lowest percentage of compliance. Only 13% of open plan spaces and none of private office spaces complied with the ANSI S15.2-1995 noise standard. The occupant survey responses corroborated these results. Staff interviews also confirmed that noise was an issue in the library, particularly in the Adult Zone where noise seemed to reverberate considerably.

Internal noise sources (e.g., library guests and equipment) rather than external noise sources seemed to be contributing factors to the noise levels in the library. The researcher noted that on several occasions, one could hear the voices of the library visitors seated in the Adult Zone at the circulation desk. Staff also indicated that occasionally, library guests in the Teen Zone would complain about the noise emanating from the Children's Zone. It was unclear if the noise transmission path was through the floor/ceiling interface between the two zones, or if the noise travelled from the basement through the stairwell to reach the main floor. In certain areas, it was clearly evident that the noise was emanating from equipment located within the building. For example, the mechanical equipment located in the room adjacent to and the location of a server stack in the Branch Head 2 Office generated noise within this office. The photocopier in the Teen Zone also was a source of noise. Because of the many hard surfaces and high ceilings in the library, the open plan concept, the open stairwell between the main floor and basement levels, and the lack of complete physical separation between spaces or acoustical isolation between equipment and human receptors, these results were not unexpected.

Numerous variables may have influenced the IEQ and IAQ testing results: 1) occupancy, 2) occupant density, 3) type of activities undertaken at time of testing, 4) time of day when testing occurred, 5) duration of testing, 6) season when testing was completed, and 7) weather. Occupancy may have affected parameters, such as CO_2, temperature, RH, and noise levels, particularly in private spaces, i.e., workroom, staff room and Branch Head 2 Office. During testing in these private spaces, the occupancy varied. During the collection of several tests, private spaces were occupied; on other occasions, they were not. Furthermore, the occupancy varied during the testing period. Occupancy density also may have impacted the aforementioned parameters. Group activities in a zone may have affected the results. For example, group activities in the Children's Zone likely increased CO_2, temperature, RH, and noise levels. The time of day when physical measurements were taken may have influenced the results. This factor definitely would have impacted lighting results. Lighting levels were measured on February 23, 2019 during the morning, when it was cloudy, and March 9, 2019 during the early afternoon, when it was sunny and clear. Lighting levels measured in the evening would have been lower, particularly, in locations where daylighting contributed to lighting levels. All measurements, with the exception of lighting, were taken over a 5-minute interval to provide a composite average. The results of a longer interval period may have been quite different from the 5-minute spot measurements taken, which provide "snapshots" of performance (Sharpe et al., 2018) and are frequently used to identify potential areas of concern. The season may have affected the results. Testing during winter, spring/fall, and summer likely would have unique temperature and RH results given outdoor condition variability (relatively cold, dry winters versus temperate shoulder seasons versus hot, humid summers). Extreme diurnal temperature fluctuations before and during testing likely would have affected the results considering the absence of BAS controls to manage these changes remotely.

The results of the WPL energy breakdown, (i.e., 50-57% electricity and 43-50% natural gas) closely mirror the TPL energy breakdown, (i.e., 60% electricity and 40% natural gas) (City of Toronto, 2014, p 414).

Energy intensities, based on the data from the Broader Public Sector Database, corrected for HDD by area, visitor and FTE showed a downward trend from 2013 to 2016, with the exception of 2015. Because the library must provide a minimum level of service (i.e., adequate heating or cooling and lighting) with a base energy load to function regardless of number of visitors present, the more important energy metric to evaluate energy performance is eWh/HDD(°C)/m^2. The energy intensity by FTE was not a useful metric because the FTE remained constant during this period.

Energy intensities, based on metered utility consumption, by area decreased in 2016 from 2015, but increased again in 2017. Although energy intensity by area is a common metric used to evaluate building performance and improve operations, the preferred metric is energy intensity, corrected for HDD, by area. Since the Ontario Broader Public Sector Disclosure Database exists and corrects for HDD, the TPL can benchmark the performance of its individual libraries and its system to a large database.

Several factors may have contributed to the general downward trend in energy intensities. Since the Energy Use and Greenhouse Gas Emissions for the Broader Public Sector Regulation came into force as of July 1, 2013, improvements in data collection may have occurred over time resulting in more accurate submissions to the provincial government. The regulation required the development of an energy and conservation demand management plan, prepared on behalf of the TPL by the City of Toronto, in July 2014. If the gas or electricity meters were changed during the reporting period, consumption may have decreased because of greater accuracy with the new metering device compared to the previous metering equipment rather than actual energy reductions. Furthermore, the annual number of visitors increased from 2013 to 2016 contributing to the lower energy intensity by visitor. These four factors may have contributed to decreased energy consumption.

Despite identifying four factors that may have contributed to changes in energy consumption over time, it is critical for the TPL to investigate and uncover the probable causes of the fluctuations between energy consumption and energy intensities over time and between the two datasets (i.e., Ontario Broader Public Sector Disclosure Database and metered energy consumption). Between 2015 and 2016, energy intensities based on the Ontario Broader Public Sector Disclosure Database decreased by 52% and the number of HDD decreased by 8% (3766 versus 3462). Taking into account HDD, the energy intensity based on the Ontario Broader Public Sector Disclosure Database decreased by 44%. However, according to the metered energy consumption from utility bills for this period, the electricity and natural gas consumption decreased by 12% and 34%, respectively. In 2016, electricity and natural gas represented 57% and 43% of the overall energy consumption, respectively. Consequently, overall energy consumption decreased by 21% approximately. Since the square footage of the building remained constant between 2015 and 2016, the resulting energy intensity (kWh/m^2) from metered utility data also decreased by 21%. Obviously, there is a significant discrepancy between a 44% reduction in energy intensity calculated from the Ontario Broader Public Sector Disclosure Database and a 21% reduction in energy intensity calculated from the metered utility data.

Water intensities were calculated by area, number of visitors and FTE. Although these metrics provided data; it was difficult to interpret the data from the perspective of building performance. These figures could not be compared to a benchmark based on a large population of Canadian libraries because the researcher was not able to locate one. The annual water intensity by area of the WPL was compared to the water intensity of the Alice Turner Library. However, the researchers at the Alice Turner Library identified that the water intensity was extremely low and the rationale for its low number was inexplicable.

Utility analysis and benchmarking is essential from a facility management perspective. First and foremost, it connects the “invisible” (i.e., resource consumption) to the “visible” (i.e., money spent). Second, simply examining utility bills can identify issues with incorrect billing and resource inefficiencies. Third, benchmarking utility performance permits performance to be tracked over time and against an appropriate cohort. Fourth, it provides a method of comparing pre and post performance when operational or capital changes are made to the building. Fifth, it prevents improvements to building performance from slipping over time without notice. Finally, embedding these practices into facility management ensures the development of institutional knowledge of the building and protects against the loss of this building knowledge when organizational and personnel changes occur.

Given the area allocated to stacks and reading zones, the LPD assessment results suggest that the LPD appears to be near the maximum permissible lighting per unit area. This finding identifies a possible opportunity to retrofit the existing lighting with high efficiency lighting (e.g., LED) and lighting controls (e.g., occupancy and daylight sensors) to reduce energy consumption. In fact, the energy audit conducted in October 2018 estimated that a LED retrofit would reduce demand by 8.2 kW, save $3,500 annually, cost $35,000 and have a simple payback of 10 years approximately (Exergy Associates Ltd, 2018). Due to the long-life span of LED technology, LED lighting requires less frequent replacements compared to compact fluorescent lighting resulting in less disruptions to occupants (Exergy Associates Ltd, 2018).

7. Conclusions

A BPE is a rigorous systematic approach for evaluating building performance. Through the development of a draft protocol for conducting a BPE in the TPL system and its implementation at the WPL, building performance issues were identified at the WPL, and more importantly, the protocol for conducting a BPE was revised.

The draft protocol evaluated the building performance of WPL quantitatively and qualitatively from the perspectives of occupants and resource consumption. Physical testing activities of the BPE showed that air leakage, thermal comfort and noise were the major environmental and occupant issues. Generally, levels of carbon dioxide, carbon monoxide, particulates and VOCs were within acceptable ranges. The BPE also demonstrated a disconnect between physical testing results and human perception in the case of air quality and lighting. Without input from the occupants, we really can't gauge a building's performance.

Implementing the draft protocol at the WPL generated several learnings to improve the protocol. First, understanding the library's "project investment typology" within the context of the Facilities Master Plan is critical. What does the TPL plan to do with this library? How could a BPE support or further inform the Facilities Master Plan? Second, incorporating financial considerations is essential because it is a parameter of building performance. If a library has a poor financial performance, a BPE could be used to identify possible issues (e.g., air leakage through exit doors) that may be easily rectified (e.g., create an enclosed vestibule with the installation of an interior door) to reduce operational costs Third, using a three-phased approach could focus the BPE on areas of concern rather than all possible areas of building performance. Segregating the activities in the first phase and allowing TPL staff to conduct the activities in this phase possibly may reduce the costs of conducting a BPE.

7.1 Limitations

Although the research produced several key findings, it is critical to understand the limitations of the research. The draft protocol was applied to one library in the TPL system. WPL, built in 1914, is much older than the average age (i.e., 44 years) of the TPL portfolio. Furthermore, it is categorized as a Tier 1 library, a neighbourhood library, and is larger than the typical Tier 1 library in the TPL system. Financial analysis, a critical component when evaluating building performance, was not part of the BPE implemented at WPL. The physical testing was limited to 5-minute average composite samples at 17 sampling locations conducted during the winter, primarily in the afternoon. The participation in the occupant survey was low at 44% and restricted to one type of occupant, the staff only rather than staff and library visitors. Since staff had limited permanent controls (e.g., blinds on lower level windows in the Teen Zone, windows in the Staff Room, windows in the Program Meeting Room, no accessibility to adjust the thermostat, eight lighting zones with "on/off" capability, "on/off" switches at the entrance to the Staff Room, Program Meeting Room, Branch Head 2 Office) to modify their physical environment, the issue of "interactive adaptivity" was not explored. Understanding these limitations provides TPL with a "snapshot of performance" of the WPL rather than a comprehensive evaluation of its building performance. Neither the cost implications of conducting a BPE using primarily external resources nor the benefits extracted from the BPE results were addressed and quantified. All of these factors restrict the application of the research findings broadly. Applying the findings to other types of libraries, e.g., district or research and reference libraries or smaller neighbourhood libraries, indiscriminately would be inappropriate.

Certain activities (e.g., in situ U-value testing, sub-metering electrical loads, financial analysis, HVAC assessment) identified in the revised protocol were not tested at the WPL. Therefore, it is unknown if there are any implementation issues with the suggested activities. Other activities (e.g., trend summary of facility incidents) may not be able to be executed immediately due to the absence of an accessible, central repository of data. These limitations may restrict how the revised protocol could be implemented in the TPL system.

7.2 Recommendations related to WPL and TPL System

Despite these limitations with the research, numerous recommendations were made to improve building performance of the WPL and TPL system. They include:

1. Determining the source of CO in the building.
2. Investigating and implementing approaches to mitigate noise levels.
3. Investigating and implementing approaches to improve lighting, particular in the Children Zone.
4. Retrofitting the existing lighting to high-efficiency lighting (e.g., LED technology) and controls (e.g., occupancy and daylighting sensors, zones) to reduce energy consumption.

5. Purchasing and implementing direct digital control (DDC) for the HVAC system. (Note: The TPL has developed specifications for a DDC and is in the process of tendering them. It is anticipated that this system will be installed and operational by the end of 2019).
6. Improving the airtightness of the building enclosure if retrofit proceeds.
7. Creating an enclosed vestibule at the main entrance by installing an interior door at the entrance to the circulation desk.
8. Developing a database to track facility incidents at all libraries. This tool would allow facility management to analyze data and identify issues and trends, and possibly improve operational performance.
9. Investigating the natural gas, electricity and water consumption and intensity variations from metered utility consumption to determine the possible sources of the fluctuations.
10. Investigating the energy consumption and intensity variations from the Broader Public Sector Disclosure Database to determine the possible sources of the variations.
11. Compiling monthly reports on natural gas, electricity and water consumption for each library in the TPL system from metered utility consumption, and benchmarking the performance to the appropriate TPL tier average (i.e., neighbourhood, district, or research and reference library) and intensity metric.
12. Distributing these monthly reports to various stakeholders, including library branch and facility staff and management as part of performance management.
13. Compiling, analyzing and reporting on the individual annual results of each library in the TPL system from the Broader Public Sector Database and benchmarking the performance to the appropriate TPL tier average (i.e., neighbourhood, district, or research and reference library) and intensity metric.
14. Distributing the annual results to various stakeholders, including library branch and facility staff and management as part of performance management.
15. Using benchmarking results from utility consumption and the Broader Public Sector Database to provide a ranking of performance that management could use to prioritize efforts to reduce utility consumption and operational costs through operational and occupant changes and possible retrofits. Implementing some or all of these activities would enhance TPL’s knowledge about the actual building performance of their portfolio. Incorporating these results into Facilities Master Plan would be useful.
16. Consulting with library branch staff and visitors to inform the design and retrofit strategy of libraries.

7.3 Recommendations related to Protocol for Conducting a BPE

In addition to the recommendations for the WPL and TPL system, three recommendations were made to improve the protocol for conducting a BPE. It would be useful to apply the proposed methodology for conducting a financial analysis as part of a BPE. Questions that would need to be answered are:1) Is the data readily available? 2) Can comparisons be made between the library and its tier cohort? 3) Are area and number of operational hours appropriate intensity metrics or other metrics such as, number of visitors, number of FTE, or number of items loaned, a better intensity metric? The development of a methodology to account for occupant density and duration would be advantageous. Identifying the appropriate intensity metric(s) (e.g., area, number of operational hours, number of hours of program activities) for each type of resource (i.e., natural gas, electricity, water) consumed also would be beneficial to benchmark performance.

7.4 Future Research

Future research could pursue several different paths. The protocol could be applied to a sub-set of libraries that have similar building characteristics (e.g., libraries that were built using masonry brick prior to 1920 and have undergone additions/renovations) to determine similarities and differences in building performance among this cohort. A BPE could be undertaken prior to a BCA evaluation as a pilot to determine the benefits and challenges with this approach. The methodology used to develop the *Toronto Public Library Facilities Master Plan. Final Report* could be reviewed to determine how the results of a BPE could be integrated into the Facilities Master Plan and capital planning process.

As a result of implementing the draft BPE at the WPL, the proposed evaluation protocol for conducting a BPE in the TPL System was revised. The scope of the protocol was expanded to include a review of the Facilities Master Plan and financial analysis, and restructured to allow a phased approach for implementing the BPE. The fundamental activities of the revised protocol for conducting a BPE included a phased approach: 1) a thorough review of historic data (e.g., financial performance, utility performance, facility incidents, facility conditions), 2) an understanding of building performance issues from the perspective of key personnel including facility and library staff, library visitors, and designers of the library, and 3) the implementation of a customized suite of activities tailored to address the issues identified in the first two phases.. This approach allows the TPL to adapt the BPE according to identified building performance issues rather than pursuing activities that will unlikely uncover new issues.

A BPE comprising physical testing, utility analysis and benchmarking, interviews with key staff, an occupant survey, an HVAC assessment, and LPD assessment could provide an assessment of how well a building is performing. In addition, the results from this exercise could be used to design a retrofit strategy to improve building performance. A subsequent BPE could asses quantitatively and qualitatively the effectiveness of the retrofit. Without this data, facility owners and managers do not know if the capital invested in retrofits is actually improving the building's performance. Incorporating BPEs as a standard practice in the building sector would provide facility owners and managers with data to determine if they are getting value for money, embed a continuous improvement philosophy in the sector and transform the marketplace. Buildings consume vast economic and environmental resources during the construction and operation of them. We, as owners, managers, occupants, and members of the general public, should know if they are meeting the functional needs of the occupants, performing as designed, minimizing resource consumption, and providing value for the capital invested in them.

Appendices

Appendix 1 – Occupant Survey

Weston Public Library

Informed Consent Form

Please read this form and ask any questions before providing your consent.

The purpose of this survey is to understand the building performance of Weston Public Library from the occupant's perspective. This project is being conducted by Rosemary Martin, a Masters student in Ryerson University's Building Science Program. The work is supervised by Dr. Mark Gorgolewski in Ryerson's Department of Architectural Science. It comprises a critical component in her major research project (MRP), evaluating the building performance of the Weston Public Library. The Toronto Public Library has approved this project.

To participate in this survey, you must first provide your consent at the bottom of this form. Participation in this survey is voluntary and your choice of whether or not to participate will not influence your future relations with Ryerson University, or the Toronto Public Library. You are free to skip questions that make you uncomfortable or to withdraw your consent and stop your participation at any time. You may not gain any direct personal benefit from participating in this survey. The Toronto Public Library will not be made aware of who has or has not participated in the survey.

The occupant surveys will be kept on file until Rosemary completes her MRP. After this time, the surveys will be destroyed. Only Rosemary Martin will have access to the completed surveys. The participants and their responses will be kept strictly confidential. Results from individual occupant surveys will be pooled together to provide overall results. Again, you will not be directly identified in any of the survey reporting that results from this project. We are cognizant that our assessment of your library can have implications beyond your organization, and we will work with you and the Toronto Public Library to ensure that all reporting is agreed upon before being published.

Please contact Rosemary Martin if you have any questions about the survey.
Email: r10martin@ryerson.ca. Telephone: 647-XXX-XXXX

If you have questions regarding your rights as a human subject and participant in this survey, you may contact the Ryerson University Research Ethics Board for information. Research Ethics Board, c/o Office of the Vice President, Research and Innovation, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3. Telephone: 416-979-5042

General Consent

By signing below you are indicating that you have read the information in this agreement and have had the opportunity to ask any questions. You agree to participate in the survey and have been informed that you can change your mind and withdraw your consent to participate at any time. By consenting you are not giving up any of your legal rights. This consent form will not be used to identify you in any way.

____

Name of Participant (Please print)

____

Signature of Participant

____

Date (Month/day/year)

Occupant Survey – Weston Public Library

Instructions – Please mark an "X" in the box that best describes your response using a seven-point rating scale:

□ 1	□ 2	□ 3	□ 4	□ 5	□ 6	□ 7
Lowest rating			Neutral		Highest rating	

Thermal Comfort

1. How satisfied are you with the temperature in your workspace?
□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

2. Please rate the overall thermal comfort in your workspace.
□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

3. Please rate the overall thermal comfort in your workspace during warm or hot weather.
□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

4. Please rate the overall thermal comfort in your workspace during cool or cold weather.
□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

5. Overall, does your thermal comfort in your workspace enhance or interfere with your ability to get your job done?
□ Enhance □ Interfere

Air Quality

6. How satisfied are you with the air quality in your workspace (that is, stuffy/stale air, cleanliness, odours)?
□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

7. Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?
□ Enhance □ Interfere

[1]Sources: The Center for the Built Environment (CBE), Berkeley: Occupant IEQ Survey; Questionnaire Survey on Factors Influencing Comfort with Indoor Environmental Quality in Danish Housing - Monika Frontczak*, Rune Vinther Andersen, Pawel Wargocki; International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Building 402, 2800 Kgs. Lyngby, Denmark, The New Family Intake Center project; LEED Indoor Environmental Quality Credit 7.2: Thermal Comfort Verification

Lighting

8. How satisfied are you with the amount of light in your workspace?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

9. How satisfied are you with the visual comfort of the lighting (for example, glare, reflections, contrast)?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

10. Overall, does the lighting quality enhance or interfere with your ability to get your job done?
☐ Enhance ☐ Interfere

Noise Control and Acoustic Quality

11. How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa)?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

Productivity

12. Please estimate how your productivity is decreased or increased by the environmental conditions in this building (for example, thermal, lighting, acoustics, cleanliness):
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

13. How satisfied are you with the building overall?
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7

14. Any additional comments or recommendations about your personal workspace or building overall?

____

____

____

____

____

15. Would you like to discuss your responses further?
☐ Yes ☐ No

Appendix 2 – Thermographic Images

Location: Main Floor, Teen Zone, Ceiling Cove

Image 1
Condition: Pressurization

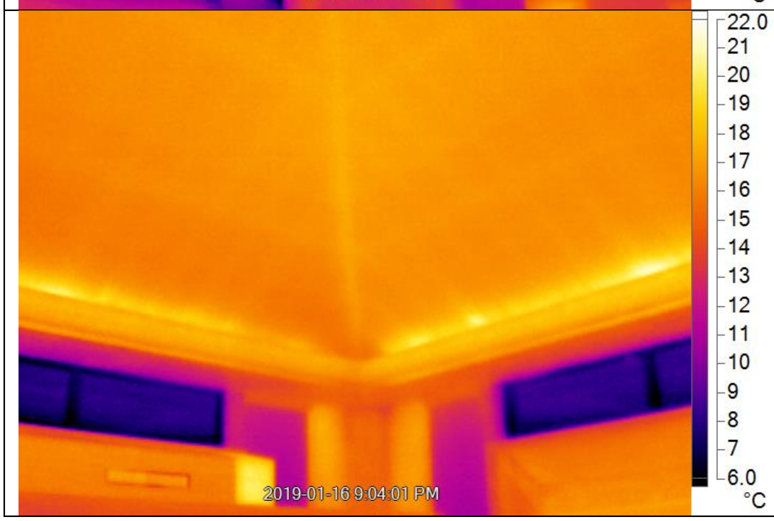
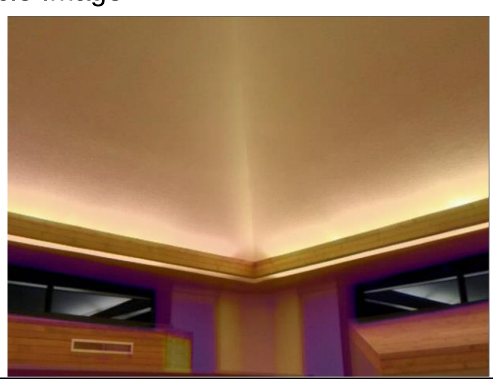
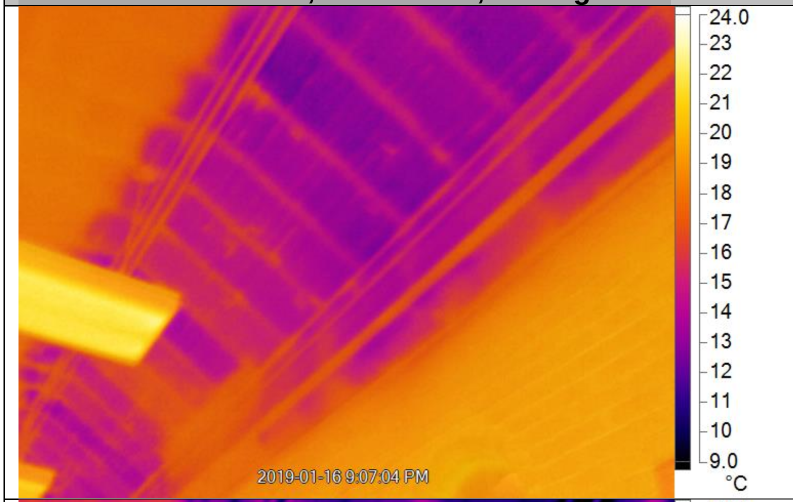
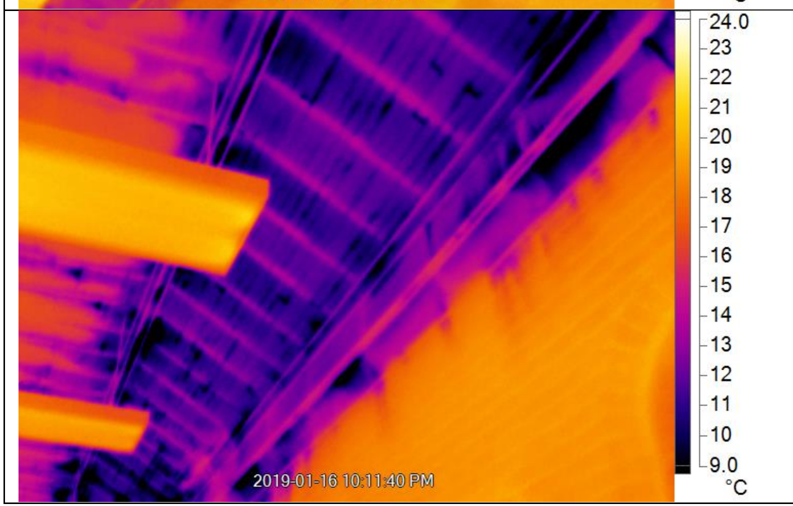


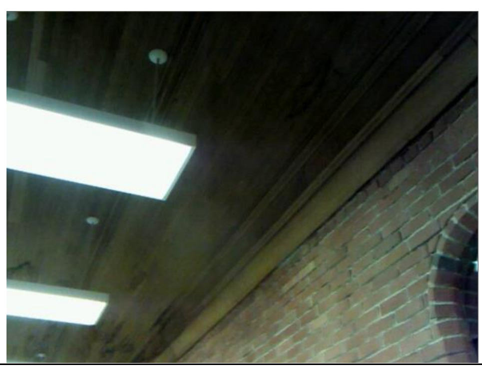
Image 2
Condition: Depressurization

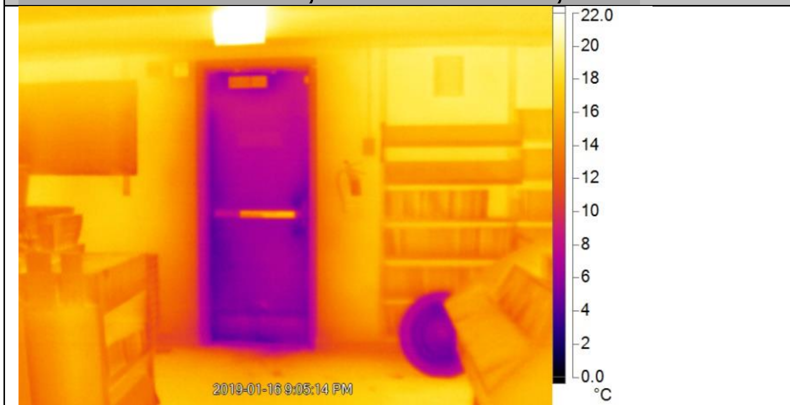
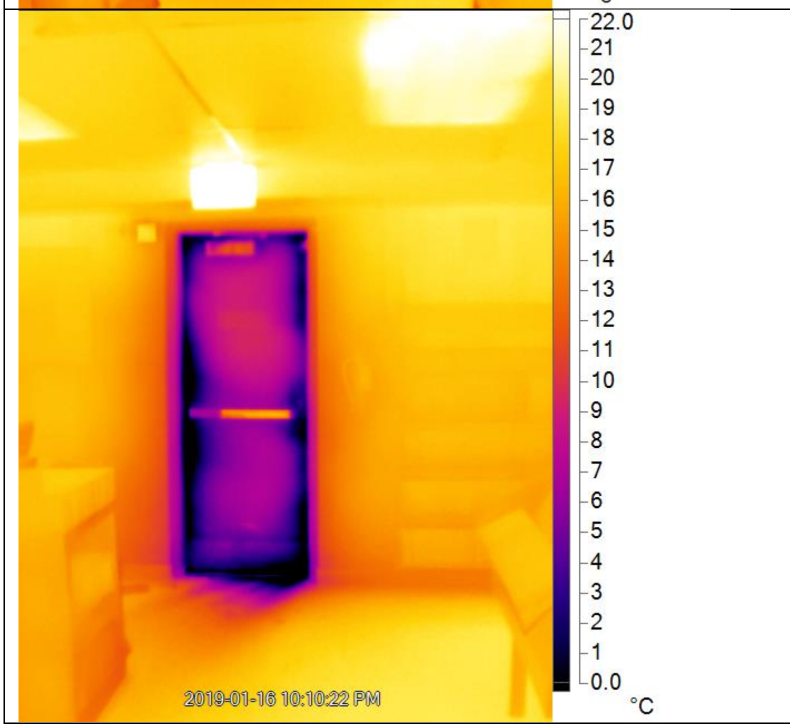
Notes: Thermal losses through interface between wall and ceiling/roof.

Visible Image

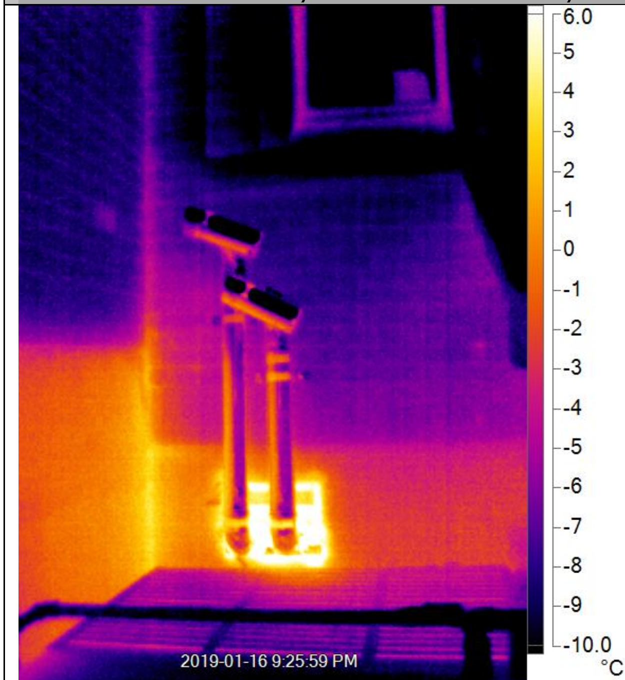
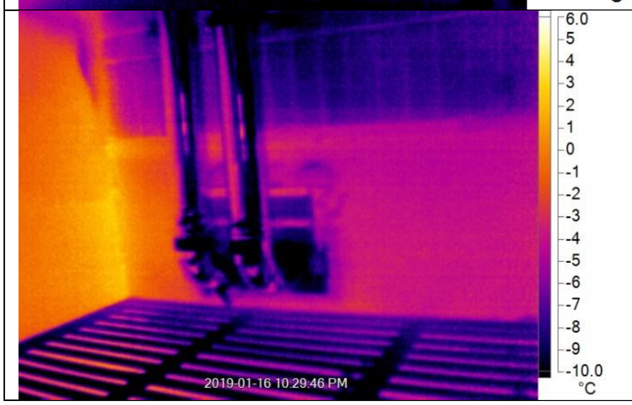


Location: Main Floor, Adult Zone, Ceiling Cove	
	**Image 3** **Condition:** Pressurization
	**Image 4** **Condition:** Depressurization

Notes: Thermal losses through interface between wall and ceiling	Visible Image 

Location: Main Floor, Circulation Desk, Door	
	**Image 5** **Condition**: Pressurization
	**Image 6** **Condition:** Depressurization

Notes: Air leakage through door frame	Visible image 

Location: Basement, Mechanical Room, Combustion Exhaust Stack	
	**Image 7** **Condition:** Pressurization
	**Image 8** **Condition:** Depressurization

Notes: Air leakage surrounding combustion exhaust stacks	Visible image 

Location: Exterior, Window Facing South	
	**Image 9** **Condition: Pressurization**
	**Image 10** **Condition:** Depressurization

Notes: Thermal losses through window frame and at slab edge	Visible image 

Location: Main Entrance

Image 11
Condition: Pressurization

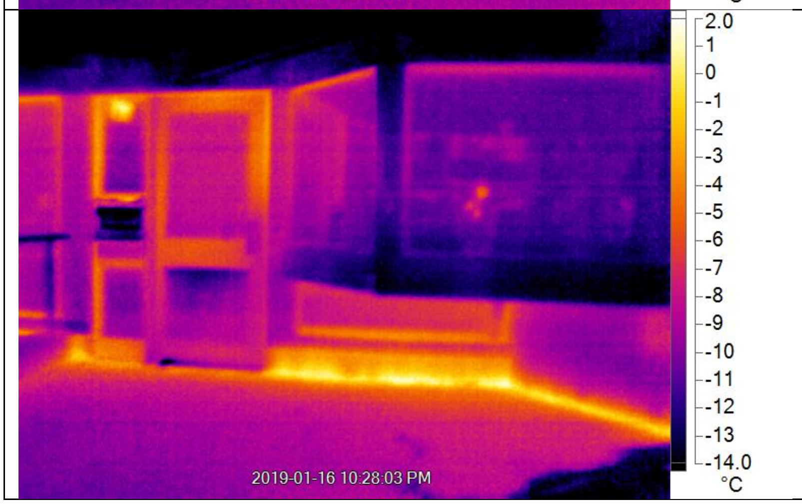
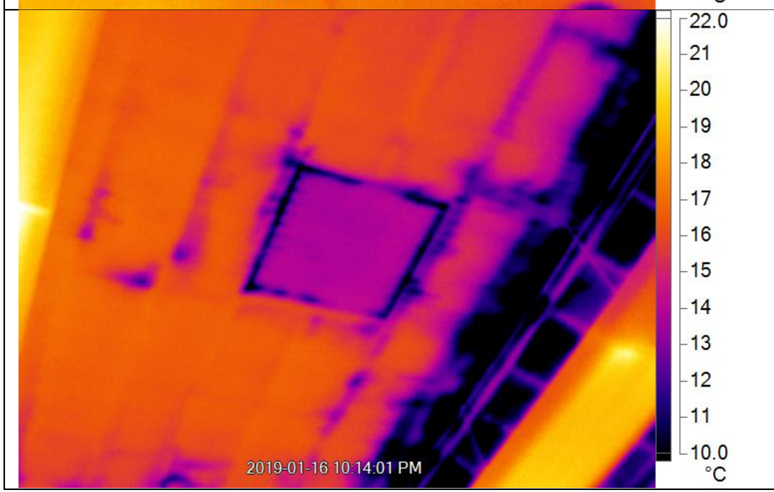


Image 12
Condition: Depressurization

Notes: Air leakage through main door frame and drop box. Thermal losses along slab edge.	Visible image 

Location: Roof, Air-Handling Unit (AHU)	
	**Image 13** **Condition:** Pressurization
	**Image14** **Condition:** Depressurization

Notes: Air leakage through AHU	Visible image None available

Location: Adult Zone, Roof Hatch	
	**Image 15** **Condition:** Pressurization
	**Image 16** **Condition:** Depressurization

Notes: Air leakage through roof hatch	Visible image 

Appendix 3 – CO_2 Measurements

Location	February 21, 2019				February 22, 2019				February 23, 2019			
	CO_2 (ppm)	OA CO_2 (ppm)	Δ CO_2 (ppm)	In Compliance (<700 ppm)	CO_2 (ppm)	OA CO_2 (ppm)	Δ CO_2 (ppm)	In Compliance (<700 ppm)	CO_2 (ppm)	OA CO_2 (ppm)	Δ CO_2 (ppm)	In Compliance (<700 ppm)
Entrance vestibule	599	515	84	Yes	684	495	189	Yes	665	495	170	Yes
Circulation desk	618	515	103	Yes	777	495	282	Yes	735	495	240	Yes
Workroom	663	515	148	Yes	695	495	200	Yes	821	495	326	Yes
Adult zone - south library stack	719	515	204	Yes	748	495	253	Yes	763	495	268	Yes
Adult zone - north library stack	756	515	241	Yes	767	495	272	Yes	NMR	495	NA	NA
Adult zone - south work stations	790	515	275	Yes	788	495	293	Yes	766	495	271	Yes
Adult zone - north work stations	775	515	260	Yes	781	495	286	Yes	761	495	266	Yes
Adult zone - reading tables	794	515	279	Yes	781	495	286	Yes	776	495	281	Yes
Teen zone - south library stack	950	515	435	Yes	745	495	250	Yes	772	495	277	Yes
Teen zone - north library stack	920	515	405	Yes	735	495	240	Yes	771	495	276	Yes
Teen zone - computer station	NMR	515	NA	NA	734	495	239	Yes	772	495	277	Yes
Children zone - south library stack	992	515	477	Yes	NMR	495	NA	NA	825	495	330	Yes
Children zone - north library stack	1105	515	590	Yes	1201	495	706	No	831	495	336	Yes
Children zone - information station	1152	515	637	Yes	1273	495	778	No	880	495	385	Yes
Staff room	844	515	329	Yes	723	495	228	Yes	628	495	133	Yes
Program meeting room	688	515	173	Yes	683	495	188	Yes	611	495	116	Yes
Branch Head 2 office	NMR	515	NA	NA	NMR	495	NA	NA	NMR	495	NA	NA

NMR = no measurement recorded
NA = not available
OA = outside air

Location	March 16, 2019				March 17, 2019				March 18, 2019			
	CO_2 (ppm)	OA CO_2 (ppm)	Δ CO_2 (ppm)	In Compliance (<700 ppm)	CO_2 (ppm)	OA CO_2 (ppm)	Δ CO_2 (ppm)	In Compliance (<700 ppm)	CO_2 (ppm)	OA CO_2 (ppm)	Δ CO_2 (ppm)	In Compliance (<700 ppm)
Entrance vestibule	724	497	227	Yes	553	495	58.25	Yes	651	495	156.25	Yes
Circulation desk	773	497	276	Yes	577	495	82.25	Yes	707	495	212.25	Yes
Workroom	768	497	271	Yes	575	495	80.25	Yes	697	495	202.25	Yes
Adult zone - south library stack	884	497	387	Yes	534	495	39.25	Yes	784	495	289.25	Yes
Adult zone - north library stack	899	497	402	Yes	549	495	54.25	Yes	782	495	287.25	Yes
Adult zone - south work stations	907	497	410	Yes	573	495	78.25	Yes	806	495	311.25	Yes
Adult zone - north work stations	982	497	485	Yes	569	495	74.25	Yes	806	495	311.25	Yes
Adult zone - reading tables	950	497	453	Yes	601	495	106.25	Yes	820	495	325.25	Yes
Teen zone - south library stack	795	497	298	Yes	748	495	253.25	Yes	743	495	248.25	Yes
Teen zone - north library stack	775	497	278	Yes	592	495	97.25	Yes	777	495	282.25	Yes
Teen zone - computer station	794	497	297	Yes	619	495	124.25	Yes	801	495	306.25	Yes
Children zone - south library stack	802	497	305	Yes	756	495	261.25	Yes	740	495	245.25	Yes
Children zone - north library stack	843	497	346	Yes	758	495	263.25	Yes	767	495	272.25	Yes
Children zone - information station	814	497	317	Yes	818	495	323.25	Yes	823	495	328.25	Yes
Staff room	776	497	279	Yes	567	495	72.25	Yes	668	495	173.25	Yes
Program meeting room	897	497	400	Yes	552	495	57.25	Yes	643	495	148.25	Yes
Branch Head 2 office	775	497	278	Yes	592	495	97.25	Yes	679	495	184.25	Yes

NMR = no measurement recorded
NA = not available
OA = outside air

Appendix 4 – CO Measurements

Location	February 21, 2019		February 22, 2019		February 23, 2019	
	CO (ppm)	In Compliance (< 11 ppm)	CO (ppm)	In Compliance (< 11 ppm)	CO (ppm)	In Compliance (< 11 ppm)
Entrance vestibule	1	Yes	0	Yes	0	Yes
Circulation desk	0	Yes	0	Yes	0	Yes
Workroom	0	Yes	0	Yes	0	Yes
Adult zone - south library stack	0	Yes	0	Yes	0	Yes
Adult zone - north library stack	0	Yes	0	Yes	NMR	NA
Adult zone - south work stations	0	Yes	0	Yes	0	Yes
Adult zone - north work stations	1	Yes	0	Yes	0	Yes
Adult zone - reading tables	1	Yes	1	Yes	0	Yes
Teen zone - south library stack	1	Yes	1	Yes	0	Yes
Teen zone - north library stack	1	Yes	1	Yes	0	Yes
Teen zone - computer station	NMR	NA	1	Yes	0	Yes
Children zone - south library stack	1	Yes	NMR	NA	1	Yes
Children zone - north library stack	1	Yes	1	Yes	0	Yes
Children zone - information station	1	Yes	1	Yes	1	Yes
Staff room	1	Yes	1	Yes	0	Yes
Program meeting room	1	Yes	0	Yes	0	Yes
Branch Head 2 office	NMR	NA	NMR	NA	NMR	NA

NMR = no measurement recorded
NA = not available

Location	March 16, 2019		March 17, 2019		March 18, 2019	
	CO (ppm)	In Compliance (< 11 ppm)	CO (ppm)	In Compliance (< 11 ppm)	CO (ppm)	In Compliance (< 11 ppm)
Entrance vestibule	0	Yes	0	Yes	0	Yes
Circulation desk	0	Yes	0	Yes	0	Yes
Workroom	0	Yes	0	Yes	0	Yes
Adult zone - south library stack	0	Yes	0	Yes	0	Yes
Adult zone - north library stack	0	Yes	0	Yes	0	Yes
Adult zone - south work stations	0	Yes	0	Yes	0	Yes
Adult zone - north work stations	0	Yes	0	Yes	0	Yes
Adult zone - reading tables	0	Yes	0	Yes	0	Yes
Teen zone - south library stack	0	Yes	0	Yes	0	Yes
Teen zone - north library stack	0	Yes	0	Yes	0	Yes
Teen zone - computer station	0	Yes	0	Yes	0	Yes
Children zone - south library stack	0	Yes	0	Yes	0	Yes
Children zone - north library stack	0	Yes	0	Yes	0	Yes
Children zone - information station	0	Yes	0	Yes	0	Yes
Staff room	0	Yes	0	Yes	0	Yes
Program meeting room	0	Yes	0	Yes	0	Yes
Branch Head 2 office	0	Yes	0	Yes	0	Yes

NMR = no measurement recorded
NA = not available

Appendix 5 – Particulate Measurements

Particulates - $PM_{2.5}$

Location	February 23, 2019		March 17, 2019		March 18, 2019	
	$PM_{2.5}$ ($\mu g/m^3$)	In Compliance (< 35 $\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	In Compliance (< 35 $\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	In Compliance (< 35 $\mu g/m^3$)
Entrance vestibule	15	Yes	9	Yes	9	Yes
Circulation desk	12	Yes	9	Yes	9	Yes
Workroom	12	Yes	9	Yes	9	Yes
Adult zone - south library stack	10	Yes	8	Yes	8	Yes
Adult zone - north library stack	9	Yes	8	Yes	8	Yes
Adult zone - south work stations	8	Yes	8	Yes	8	Yes
Adult zone - north work stations	9	Yes	8	Yes	8	Yes
Adult zone - reading tables	8	Yes	8	Yes	8	Yes
Teen zone - south library stack	8	Yes	8	Yes	7	Yes
Teen zone - north library stack	7	Yes	7	Yes	7	Yes
Teen zone - computer station	8	Yes	8	Yes	8	Yes
Children zone - south library stack	6	Yes	7	Yes	7	Yes
Children zone - north library stack	6	Yes	7	Yes	6	Yes
Children zone - information station	7	Yes	8	Yes	7	Yes
Staff room	7	Yes	7	Yes	6	Yes
Program meeting room	6	Yes	7	Yes	6	Yes
Branch Head 2 office	NMR	NA	7	Yes	6	Yes

NMR = no measurement recorded
NA = not available

Particulates - PM_{10}

Location	February 21, 2019		February 22, 2019		March 16, 2019	
	PM_{10} ($\mu g/m^3$)	In Compliance (< 150 $\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	In Compliance (< 150 $\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	In Compliance (< 150 $\mu g/m^3$)
Entrance vestibule	24	Yes	30	Yes	17	Yes
Circulation desk	19	Yes	19	Yes	21	Yes
Workroom	22	Yes	17	Yes	18	Yes
Adult zone - south library stack	14	Yes	15	Yes	18	Yes
Adult zone - north library stack	15	Yes	15	Yes	15	Yes
Adult zone - south work stations	16	Yes	14	Yes	16	Yes
Adult zone - north work stations	17	Yes	12	Yes	15	Yes
Adult zone - reading tables	15	Yes	12	Yes	15	Yes
Teen zone - south library stack	13	Yes	11	Yes	11	Yes
Teen zone - north library stack	16	Yes	11	Yes	11	Yes
Teen zone - computer station	NMR	NA	11	Yes	10	Yes
Children zone - south library stack	13	Yes	25	Yes	13	Yes
Children zone - north library stack	12	Yes	20	Yes	12	Yes
Children zone - information station	15	Yes	28	Yes	14	Yes
Staff room	10	Yes	7	Yes	10	Yes
Program meeting room	10	Yes	8	Yes	13	Yes
Branch Head 2 office	NMR	NA	NMR	NA	8	Yes

NMR = no measurement recorded
NA = not available

Appendix 6 – VOC Measurements

Location	February 21, 2019		February 22, 2019		February 23, 2019	
	VOCs ($\mu g/m^3$)	In Compliance (< 1000 $\mu g/m^3$)	VOCs ($\mu g/m^3$)	In Compliance (< 1000 $\mu g/m^3$)	VOCs ($\mu g/m^3$)	In Compliance (< 1000 $\mu g/m^3$)
Entrance vestibule	0	Yes	0	Yes	69	Yes
Circulation desk	0	Yes	0	Yes	0	Yes
Workroom	0	Yes	0	Yes	0	Yes
Adult zone - south library stack	0	Yes	0	Yes	0	Yes
Adult zone - north library stack	0	Yes	0	Yes	NMR	NA
Adult zone - south work stations	0	Yes	0	Yes	0	Yes
Adult zone - north work stations	0	Yes	0	Yes	0	Yes
Adult zone - reading tables	0	Yes	0	Yes	0	Yes
Teen zone - south library stack	0	Yes	0	Yes	0	Yes
Teen zone - north library stack	0	Yes	0	Yes	0	Yes
Teen zone - computer station	NMR	NA	0	Yes	0	Yes
Children zone - south library stack	0	Yes	NMR	NA	0	Yes
Children zone - north library stack	0	Yes	0	Yes	0	Yes
Children zone - information station	0	Yes	0	Yes	0	Yes
Staff room	0	Yes	0	Yes	0	Yes
Program meeting room	0	Yes	0	Yes	0	Yes
Branch Head 2 office	NMR	NA	NMR	NA	NMR	NA

NMR = no measurement recorded
NA = not available

Location	March 16, 2019		March 17, 2019		March 18, 2019	
	VOCs ($\mu g/m^3$)	In Compliance (< 1000 $\mu g/m^3$)	VOCs ($\mu g/m^3$)	In Compliance (< 1000 $\mu g/m^3$)	VOCs ($\mu g/m^3$)	In Compliance (< 1000 $\mu g/m^3$)
Entrance vestibule	0	Yes	0	Yes	0	Yes
Circulation desk	0	Yes	0	Yes	0	Yes
Workroom	0	Yes	0	Yes	0	Yes
Adult zone - south library stack	0	Yes	0	Yes	0	Yes
Adult zone - north library stack	0	Yes	0	Yes	0	Yes
Adult zone - south work stations	0	Yes	0	Yes	23	Yes
Adult zone - north work stations	0	Yes	0	Yes	0	Yes
Adult zone - reading tables	0	Yes	0	Yes	0	Yes
Teen zone - south library stack	0	Yes	0	Yes	0	Yes
Teen zone - north library stack	0	Yes	0	Yes	0	Yes
Teen zone - computer station	0	Yes	0	Yes	0	Yes
Children zone - south library stack	0	Yes	0	Yes	0	Yes
Children zone - north library stack	0	Yes	0	Yes	0	Yes
Children zone - information station	0	Yes	0	Yes	0	Yes
Staff room	0	Yes	0	Yes	0	Yes
Program meeting room	0	Yes	0	Yes	0	Yes
Branch Head 2 office	0	Yes	0	Yes	0	Yes

NMR = no measurement recorded
NA = not available

Appendix 7 – Lighting Measurements

Location	February 23, 2019		March 7, 2019		Average Level (Lux)	In Compliance (350-750 Lux)
	Maximum Level (Lux)	Minimum Level (Lux)	Maximum Level (Lux)	Minimum Level (Lux)		
Entrance vestibule	715	650	518	0	471	Yes
Circulation desk	421	400	443	415	420	Yes
Workroom	814	519	579	540	613	Yes
Adult zone - south library stack	315	313	497	409	384	Yes
Adult zone - north library stack	288	265	476	371	350	Yes
Adult zone - north work stations	425	422	377	365	397	Yes
Adult zone - south work stations	328	321	653	600	476	Yes
Adult zone - reading tables	788	772	776	765	775	No
Teen zone - south library stack	209	206	235	234	221	No
Teen zone - north library stack	207	204	315	290	254	No
Teen zone - computer station	369	356	543	541	452	Yes
Children zone - south library stack	915	907	865	849	884	No
Children zone - north library stack	704	700	872	855	783	No
Children zone - information desk	683	665	823	805	744	Yes
Staff room	600	583	585	580	587	Yes
Program room	451	440	565	564	505	Yes
Branch Head 2 office	776	785	1764	1747	1268	No

Appendix 8 – LPD Assessment

Location	Type of Fixture	Number of Fixtures	Number of Lamps	Watts per Lamp	Wattage (W)
Adult Zone	CFL - Slyvania T5	40	2	32	2,560
Workroom	CFL - Slyvania T5	4	2	32	256
Workroom	CFL - Slyvania T5	6	1	32	192
Circulation zone	CFL - Slyvania T5	12	2	32	768
Circulation zone	CFL - Slyvania T5	11	1	32	352
Circulation + Basement zone	Pot Halogen	8	1	200	1,600
Teen Zone	CFL - Slyvania T5	33	1	32	1,056
Basement Foyer	PAR	15	1	178	2,670
Basement Foyer	CFL - Slyvania T5	14	1	32	448
Children Zone	CFL - Slyvania T5	42	2	32	2,688
Women's Washroom	CFL - Slyvania T5	1	2	32	64
Men's Washroom	CFL - Slyvania T5	1	2	32	64
Library Branch 2	CFL - Slyvania T5	6	2	32	384
Staff Room	CFL - Slyvania T5	5	2	32	320
Staff Room Hallway	CFL - Slyvania T5	4	2	32	256
Staff Room Washroom	CFL - Slyvania T5	1	2	32	64
Program Meeting Room	CFL - Slyvania T5	24	2	32	1,536
South Emergency Exit	CFL - Slyvania T5	3	2	32	192
Boiler Room*	CFL - Slyvania T5	1	2	32	64
Electrical Room*	CFL - Slyvania T5	1	2	32	64
Main Floor Washroom *	CFL - Slyvania T5	1	2	32	64
Total Power (W)					**15,662**
Total Area (m^2)					**1,111**
LPD (W/m^2)					**14**

*estimated - did not enter room

References and Standards Used

ASHRAE. (2013). *Standard 55-2013: Thermal environmental conditions for human occupancy.*

ASHRAE. (2013). *Standard 62.1-2013: Ventilation for acceptable indoor air quality.*

ASHRAE (2013). *Standard 90.1-2013. Energy standard for buildings except low-rise buildings*.

ANSI/ASA (2008). *Standard 12.2: American national standard criteria for evaluating noise.*

ASTM International. (2010). *ASTM E779-10 Standard test method for determining air leakage rate by fan pressurization.* West Conshohocken, PA: American Society for Testing and Materials

ASTM International. (2017). *ASTM E1186-17 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems.* West Conshohocken, PA: American Society for Testing and Materials

Baird, G., Gray, J., Isaacs, N., Kernohan, D & McIndoe, G. (1996). *Building evaluation techniques*, New York: McGraw-Hill.

BC Housing, BC Hydro & City of Vancouver. (2017). *Illustrated guide achieving airtight buildings.*

Bordass, B., Cohen, R. & Field, J. (2004) Energy performance in non-domestic buildings: closing the credibility gap, in Paper presented at the Building Performance Congress 2004, Frankfurt, Germany.

Bordass, B. & Leaman, A. (2009, September 15). An overview of post-occupancy evaluation. SEDA seminar – Mainstreaming POE.

Bordass, B. & Leaman, A. (March 2012). Test of time. Charted Institution of Building Service Engineers (CIBSE) Journal, 30-36

Brown, Z., & Cole, R. J. (2009). Influence of occupants' knowledge on comfort expectations and behaviour. *Building Research & Information*, 37(3), 227-245. doi:10.1080/09613210902794135

Burnett, E.F.P., and Straube, J. (2005). *Building Science for Building Enclosures*

Canadian Infrastructure (2016). *Canadian infrastructure report card informing the future.* Retrieved on April 4, 2019 from http://canadianinfrastructure.ca/downloads/Canadian_Infrastructure_Report_2016.pdf

City of Toronto. (2014, July). Energy conservation & demand management plan (2014-2019)

Cohen, R., Ruyssevelt, P., Standeven, M., Bordass, W. & Leaman, A. (1999). Building Intelligence in Use: Lessons from the Probe Project, Usable Buildings, London, UK.

Cole, R. J. (2005). Building environmental assessment methods: Redefining intentions and roles. *Building Research & Information, 33(5)*, 455-467. doi:10.1080/09613210500219063

Cole, R. J. (2010). Green buildings and their occupants: A measure of success. *Building Research & Information, 38(5)*, 589-592. doi:10.1080/09613218.2010.484168

Cole, R. J., Robinson, J., Brown, Z., & O'Shea, M. (2008). Re-contextualizing the notion of comfort. *Building Research & Information, 36(4)*, 323-336. doi:10.1080/09613210802076328

Coleman, S.; Touchie, M.; Robinson, J.; & Peters, T. (2018). Rethinking performance gaps: A regenerative sustainability approach to built environment performance assessment. *Sustainability, 10(12)*, 4829; doi:10.3390/su10124829

Culp, T.D., Widder, S.H., & Cort, K.A. (2015, July). Thermal and optical properties of low e-storm window and panels. Retrieved on April 5, 2019 from https://labhomes.pnnl.gov/documents/PNNL_24444_Thermal_and_Optical_Properties_Low-E_Storm_Windows_Panels.pdf

Dunlop, Farrow & Aitken. (1980, September). Addition and alterations of the Weston Public Library.

Energy Star Portfolio Manager. (2018, August). Technical reference U.S. energy use intensity by property type.

Energy Star Portfolio Manager. (2019, August). Technical reference Canadian energy use intensity by property type.

Enright, S. (2002). Post-occupancy evaluation of UK library building projects: some examples of current activity. *Liber Quarterly, 12*, 26 -45

Environment Canada. (ND). Historical Daily Data Reports for 2015, 2016 and 2017.

Environmental Commissioner of Ontario. (2017). *Every joule counts Ontario's energy use and conservation year in review*. Retrieved on December 15, 2018 from http://docs.assets.eco.on.ca/reports/energy/2016-2017/Every-Joule-Counts.pdf

Ernst and Young LLP. (2019, January 2011). *Toronto Public Library Facilities Master Plan. Final Report*.

Exergy Associates Ltd. (2018). *Energy audit report Toronto Public Library*.

Fedoruk, L. E., Cole, R. J., Robinson, J. B., & Cayuela, A. (2015). Learning from failure: Understanding the anticipated–achieved building energy performance gap. *Building Research & Information, 43(6)*, 750-763. doi:10.1080/09613218.2015.1036227

Foster, J. A., Foster, S. A., Sharpe, T. R., & Poston, A. (2016). Building performance evaluation – a design approach for refurbishment of a small traditional building in Scotland. EECHB - 2016, Second International Conference on Energy Efficiency and Comfort of Historic Buildings, 217-223

Government of Ontario. (No date). Energy use and greenhouse gas emissions for the Broader Public Sector. Retrieved on January 23, 2018 from https://www.ontario.ca/data/energy-use-and-greenhouse-gas-emissions-broader-public-sector

IAQ Forum. (No date). Five common indoor air quality (IAQ) issues for building managers. Retrieved on March 7, 2019 from https://iaqforum.ca/en/five-common-indoor-air-quality-iaq-issues-for-building-managers/

Kylili, A., Fokaides, P.A.; Christou, P., & Kalogirou, S.A. (2014). Infrared (IRT) thermography applications for building diagnostics: a review. *Applied Energy, 134*, 531-549

Hassanain, M.A. & Mudhei, A.A. (2006). Post-occupancy evaluation of academic and research library facilities. *Structural Survey, 24(3),* 230-239

Health Canada. (1995). Indoor air quality in office buildings: a technical guide. Retrieved on March 7,2019 from http://publications.gc.ca/collections/Collection/H46-2-93-166Erev.pdf

Lackney, J.A. & Zajfen, P. (2005). Post-occupancy evaluation of public libraries lessons learned from three case studies. *Library Administration & Management, 19(1)*, 16-25

Leaman, A., Stevenson, F., & Bordass, B. (2010). Building evaluation: practice and principles. *Building Research & Information, 385(5)*, 564-577

Lia, P., Froeseb, T.M., & Brager, G. (2018). Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. *Building and Environment, 133* (Complete), 187-202. doi:10.1016/j.buildenv.2018.02.024

Loftness, V., Aziz, A., Choi, J.H., Kampschroer, K., Powell, K., Atkinson, M. & Heerwagen, J. (2009) The value of post-occupancy evaluation for building occupants and facility managers, *Intelligent Buildings International, 1:4*, 249-268, DOI: 10.3763/inbi.2009.SI04

Mallory-Hill, S. Preiser, W.F.E., & Watson, C. (2012). Enhancing building performance. In S. Mallory-Hill, W.F.E. Preiser, and C. Watson, Introduction to building performance evaluation: Milestones (pp.3-18), West Sussex, UK. Blackwell Publishing

Oxford Brookes University. (No date). Building performance evaluation research, testing, monitoring and post-occupancy evaluation.

Preiser, W.F.E. (2005) Building performance assessment—From POE to BPE, a personal perspective, *Architectural Science Review, 48:3*, 201-204, DOI: 10.3763/asre.2005.4826

Preiser, W.F.E., & Nasar, J.L. (2008). Assessing building performance its evolution from post-occupancy evaluation. *International Journal of Architectural Research, 2(1)*, 84-99

Preiser, W.F.E. & Wang, X. (2006). Assessing library performance with GIS and building evaluation methods. *New Library World, 107*(1224/1225), 193-217

RDH (2015). *A study of Part 3 building airtightness project no.8980.00*.

Sharpe, T. (2013). Building performance evaluation Vancouver, British Columbia In B. Dimitrijevic´ (Ed*.), Innovations for sustainable building design and refurbishment in Scotland: Outputs of CIC Start Online Project*. London: Springer.

Sharpe, T., Lantschner, B., & Morgan, C. (2018). Hab-Lab: Development of a Light Touch BPE Methodology for Retrofit. Passive and Low Energy Architecture (PLEA) Hong Kong 2018 Conference

Sharpe, T. (2019). Mainstreaming building performance evaluation for the benefit of users *Building Research & Information, 47:3*, 251-254, DOI: 10.1080/09613218.2019.1526470

Stantec Consulting Ltd. & Pretium Andersen Toronto Inc. (May 7, 2014). Property condition assessment.

Straube, J. (No date). *Airtightness tests: What are they and why do they matter?* Retrieved on March 24, 2018 from http://www.oaa.on.ca/professional%20resources/sustainable%20design/sustainable-article-details/Airtightness-Tests:-What-are-They-and-Why-Do-They-Matter--/19

Toronto Public Library. (2018). Weston branch (WE), Ward 11, Land acknowledgement statement.

Turcato, A., Brown, C., & Gorgolewski, M. (2015, February 17). *iiSBE Canada report – Alice Turner Library*.

US EPA. (2003). A standardized EPA protocol for characterizing indoor air quality in large office buildings. Washington: US Environmental Protection Agency.

US EPA (No date). National Ambient Air Quality Standards (NAAQS) Table. Retrieved on March 20, 2019 from https://www.epa.gov/criteria-air-pollutants/naaqs-table

Zeisel, J. (1984). Inquiry by design: Tools for environment-behaviour research. London, UK. Cambridge University Press

Glossary

ACH: Air changes per hour

BCA: Building condition assessment

BCE: Building performance evaluation

BTU/hr: British thermal units per hour

CDD: Cooling degree day

CDN: Canadian

CO: Carbon monoxide

CO_2: Carbon dioxide

DDC: Direct digital control

EqLA: Equivalent leakage area

ekWh; equivalent kilowatt-hours

ELA: Effective leakage area

eWh: equivalent watt-hours

FTE: full-time employee equivalence

HDD: Heating degree days

HVAC: Heating ventilation and air-conditioning

IAQ: Indoor air quality

IEQ: Indoor environmental quality

IPCC: International Panel on Climate Change

kW: kilowatts

kWh: kilowatt-hours LBL: Lawrence Berkley Laboratory

LPD: lighting power density

NEAT: National Environmental Assessment Toolkit

NMR: no measurement recorded

PHIUS: Passive House Institute US

POE: Post occupancy evaluation

PROBE: Post occupancy review of buildings and their engineering

RH: Relative humidity

RTU: Roof top unit

SCONUL: Society of College National and University Libraries

TPL: Toronto Public Library

USACE: U.S. Army Corps of Engineers

WPL: Weston Public Library