Accounting for Nature

An Audit & Ranking of Indoor Green Spaces in Student-Use Buildings at Dalhousie University

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AUTHOR INFORMATION

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EXECUTIVE SUMMARY

Poor indoor air quality has been linked to an increase in health conditions such as asthma, lung cancers, cardiovascular disease, decreased lung function, and more. (Claudio, 2011; Dr. Daniel Rainham, personal communication, February 7, 2019). One approach to improving indoor air quality is through the use of indoor green spaces (Torpy, Zavattaro & Irga, 2017). Indoor plants help lower Carbon dioxide (CO_2) concentrations, produce oxygen, and filter harmful toxins from the air (Claudio, 2011). This paper identifies the potential to increase indoor green spaces near student study spaces on Dalhousie University's Studley Campus highly trafficked buildings. Additional green spaces would improve the air quality within these buildings and create a welcoming, positive atmosphere for students to learn in.

Audits were completed in five buildings on Dalhousie Studley Campus. The purpose of these audits was to determine the current amount of green space per study seat in the chosen buildings as well as assess the potential space for additional plants. Additionally, data was retrieved from CO_2 sensors in the buildings. Some sensors showed levels above 1000 ppm, a level at which humans can experience drowsiness (Kane International, n.d.). Furthermore, it was established that sensors in Killam were non-existent; and that the data received for the Mona Campbell building was faulty. A thorough analysis of results by way of a weighted matrix found that all buildings would benefit from green space development. However, the Killam Library was ranked as the building most in need of additional development followed by the Marion McCain Arts and Social Sciences Building.

After a thorough analysis of the data, the research team recommends the ranking provided in this report be used in future discussions with relevant parties when considering potential building improvements. Applying the findings into future endeavours aligns with campus environmental initiatives and encourages a greener future. Furthermore, it is noted that there is much room for further internal and academic studies on this topic. There is pressing need to assess the functionality of sensors currently in place in buildings on Dalhousie’ Studley campus. In addition, a cost/benefit analysis would be beneficial to understand the costs related to implementation of this studies recommendations.

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1. INTRODUCTION

1.1 Background & Literature Review

Healthy levels of carbon dioxide in indoor spaces range from 350 ppm - 1000 ppm for buildings with good airflow exchange, while the average carbon dioxide concentration in the air outside is within 250 ppm - 350 ppm (Kane International, n.d.). Although indoor carbon dioxide (CO_2) levels between 350-1000 ppm in indoor spaces are still safe, indoor air quality is not as good as it is outdoors. Thousands of chemicals are used in most everyday products, furniture, and building materials to ensure that the materials are cheap, up to consumer standards, and durable (Dr. D. Rainham, personal communication, February 5, 2019). These chemicals leach into their surroundings, constantly worsening the quality of the air indoors. In addition, poor air circulation in many buildings limits access to fresh air indoors and prevents harmful chemicals from being constantly filtered from the air. Poor indoor air quality has been linked to an increase in health conditions such as asthma, lung cancers, cardiovascular disease, decreased lung function, and more. (Claudio, 2011; Dr. D. Rainham, personal communication, February 7, 2019).

One approach to improving indoor air quality is through the use of indoor green spaces (Torpy, Zavattaro & Irga, 2017). A green space is defined as an area predominantly covered by vegetation (Morrison, 2017). For the purpose of this study, an indoor green space is defined as an area indoors with vegetation coverage of $1.5m^3$ or greater. Indoor plants help lower CO_2 concentrations, produce oxygen, and filter harmful toxins from the air (Claudio, 2011; Browning, 2016). Not only do green spaces improve indoor air quality, there have been several epidemiological studies linking an increase in exposure to nature to improvements in health, mental and social well-being, productivity, focus, and creativity (Morrison, 2017).

On average, urban residents spend 80-90% of their time indoors, thus limiting their access to fresh air and the many benefits attributed to exposure to nature (Spengler & Sexton, 1983; Dr. D. Rainham, personal communication, February 7, 2019). Indoor green spaces allow for people who spend the majority of their time indoors to have greater access to these benefits. Although there are many institutions now investing resources towards increasing green spaces, few studies have been conducted specifically focusing on indoor green spaces in academic, primarily student use, institutions. Studying the presence and effect of indoor green spaces at Dalhousie Studley campus opens the door to discussing the benefits of increasing these spaces for the betterment of the Dalhousie community.

1.2 Purpose & Objectives

This study identifies the potential to increase indoor green spaces near student study spaces on Dalhousie University's Studley Campus highly trafficked buildings. The proposed green spaces would improve the air quality within these buildings and create a welcoming, positive atmosphere for students to learn in. Through use of a quantitative building audit and analysis of CO_2 levels the study addresses the question; How can Dalhousie University utilize green spaces to improve air quality in student-use buildings on Studley Campus?

2. METHODS

2.1 Study Design

A quantitative approach was used to answer the research question. The information needed was gathered through building audits performed in five buildings on Dalhousie Studley Campus. The specific buildings chosen were the Killam Memorial Library, Student Union Building (SUB), Life Science Centre (LSC), Mona Campbell Building and the Mccain Arts and Social Science Building. Note that for the LSC, the Steele Ocean Science Building and Psychology department were not included as these areas are not always available to all students. These buildings were chosen because they are heavily trafficked spaces on campus, with most having multiple spaces for students to study, get food, or hang out.

2.2 Procedure

The audits were performed by measuring the total volume of green spaces in each of the chosen buildings. For the purpose of this research project, a green space is defined as any collection of plants that takes up 1.5 cubic meters or more of space. When conducting building audits, measuring tapes were used to measure the cubic area of green spaces in close proximity to study spaces. The measurements for any green spaces which could not be reached were estimated using photographs containing objects of known measurements alongside the green spaces. The total number of study spaces within each building were counted to determine how many students are able to have access to these green spaces at a time. A study space was defined as any seat with access to a work surface in a public area of a building. This did not include lecture halls or classrooms as these rooms are not always accessible to students. In addition to measurements of existing green space, the audit included an analysis of potential areas within each building which could support plant life. Potential area for green space was measured in square meters; taking into consideration access to natural light as well as floor space.

The audit data for the Killam Library was separated into two separate parts for analysis, one of them including the atrium and the other one excluding the atrium. This is done because the atrium has 98% of the building's green space but contains only 13% of the study seats available, thus including the atrium results in inaccurate representation of the lack of green spaces within the Killam Memorial Library. The audit data that include the atrium was still shown in the report, in order to show this inaccuracy. Using the data gathered in the audits, a weighted matrix was created to rank the buildings based on three criteria (Table 1). These criteria included study seat capacity, current green space allocation, and potential for green space. A high ranking indicates a high potential for green space development, while a low ranking indicates lower potential or necessity for additional green space development. This matrix output allows further insight into which buildings have the greatest potential and need for green space development.

Additionally, data was obtained from air sensors which are installed in most of the buildings. These sensors measure CO_2 levels at specific time intervals of every 15 minutes or less. Data reading intervals varied between buildings. This data was used to assess current CO_2 levels as well as make recommendations. The Killam Memorial Library and the Mona Campbell building were not included in the conglomeration of CO_2 data. This is because the Killam Library does not have any air sensors installed, and the Mona Campbell building was found to have unreliable sensors. According to the University, the CO_2 levels of each buildings are at a safe level as Dalhousie University tries to satisfy their policy to keep CO_2 levels below 1000 ppm above ambient conditions.(J. Macdonald, personal communication, February 14, 2019). The CO_2 readings from the three buildings with valid available data were compared using a single factor ANOVA test. This test was chosen because the output determines whether there is a statistically significant difference in the CO_2 levels between multiple buildings. The CO_2 data gained from each building was used to recommend which buildings are in most need of indoor green space development with the overarching goal of improving indoor air quality.

3. RESULTS

3.1 Presentation of Results

Table 1. Weighted matrix of building rankings on Studley campus at Dalhousie University. Rankings based on the three criteria; study seat capacity, current green space allocation, and potential for green space. Data collected between March 15, 2019 and March 25, 2019.

Criterion	Killam Library (Including Atrium)	Killam Library (Excluding Atrium)	Student Union Building	LSC/ Wallace McCain	McCain Arts & Social Sciences	Mona Campbell
Study Seat Capacity	6	5	4	3	2	1
Current Green Space Allocation (m^3)	2	5	3	1	6	4
Potential for Green Space (m^2)	5	6	1	3	4	2
Total Values	**13**	**16**	**8**	**7**	**12**	**7**

The buildings were ranked relative to one another based on three specified criteria of interest. A weighted matrix score of 6 indicates that the building is doing the worst in comparison to the others in terms of meeting the specified criteria. A score of 1 indicates that the building is doing the best in comparison to the others in terms of meeting the specified criteria.

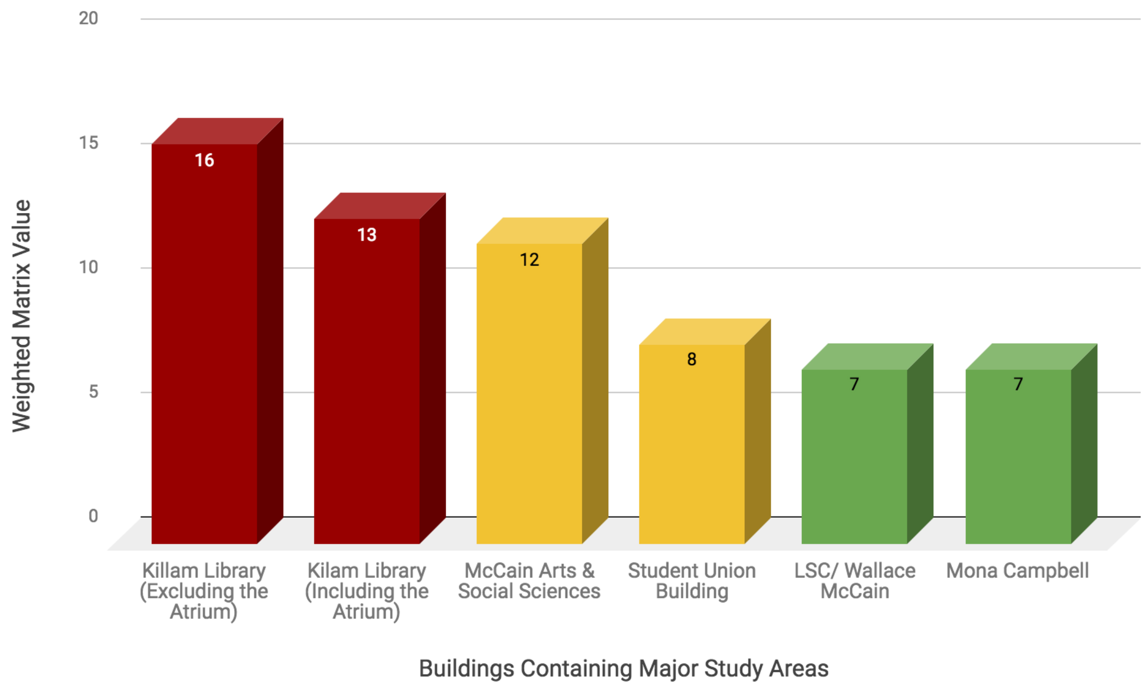

Figure 1. Weighted matrix ranking of major study areas on Studley Campus based on determined need for indoor green space development. Data collected between March 15, 2019 and March 25, 2019.

Total weighted matrix rankings show the order of need for improved indoor green spaces between the chosen buildings. Overall, the Killam Memorial Library shows the highest total score including or excluding the Atrium. The McCain Arts and Social Sciences Building ranked second highest, and the Student Union Building ranked third. The Mona Campbell Building and the LSC including the Wallace McCain Learning Commons tied for lowest total weighted matrix score.

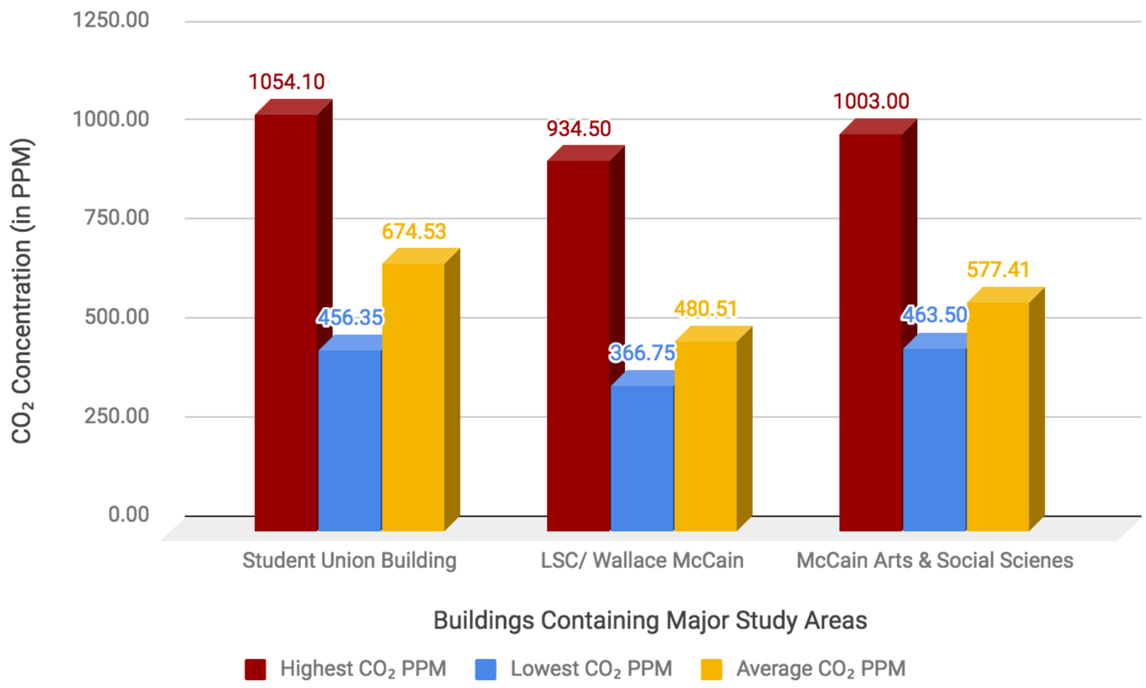

Figure 2. CO_2 Concentrations in primary student use buildings on Studley Campus, Dalhousie University. Data was collected by CO_2 sensors at intervals of 15 minutes or less in each building between February 3, 2019 and February 9, 2019 inclusive.

Average CO_2 concentrations ranged from 480.51 to 674.53 PPM in the Student Union Building, the Life Sciences Centre, and the McCain Arts and Social Sciences building between February 3, 2019 and February 9, 2019 inclusive. The Student Union Building had the highest average CO_2 concentration, and the Life Sciences Centre had the lowest average CO_2 concentration. The highest recorded CO_2 levels of 1054.103 PPM were in the Student Union Building.

Table 2 Analysis of Variance output comparing CO_2 readings between the Student Union Building, the McCain Arts and Social Sciences Building, and the Life Sciences Centre at Dalhousie University. Data was collected by CO_2 sensors in each respective building between February 3, 2019 and February 9, 2019 inclusive.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7306683.118	2	3653341.559	196.6054982	0	3.00075151
Within Groups	33261945.62	1790	18582.09253			
Total	40568628.74	1792				

The single factor Analysis of Variance (ANOVA) test shows that the mean CO_2 readings in the Student Union Building, the McCain Arts and Social Sciences Building, and the Life Sciences Centre on Dalhousie University's Studley Campus are significantly different. This is because the F value is greater than the F critical value. Thus the null hypothesis that the mean levels of CO_2 between buildings are the same is rejected.

Table 3 Two-Sample t-Test output comparing CO_2 readings between the Student Union Building and the McCain Arts and Social Sciences Building at Dalhousie University. Data was collected by CO_2 sensors in each building between February 3, 2019 and February 9, 2019 inclusive.

	SUB (ppm)	*McCain (ppm)*
Mean	674.5294705	577.4114583
Variance	21182.29522	22854.95597
Observations	455	1008
P(T<=t) two-tail	0	
t Critical two-tail	1.962585784	

At a significance level of 0.05, there was a significant difference between the CO2 readings in the Student Union Building and the McCain Arts and Social Sciences Building based on a p value of 2.0E-29.

Table 4 Two-Sample t-Test output comparing CO2 readings between the Student Union Building and the Life Sciences Centre at Dalhousie University. Data was collected by CO2 sensors in each building between February 3, 2019 and February 9, 2019 inclusive.

	SUB (ppm)	*LSC (ppm)*
Mean	674.5294705	480.514899
Variance	21182.29522	1915.632017
Observations	455	330
P(T<=t) two-tail	0	
t Critical two-tail	1.964193971	

At a significance level of 0.05, there was a significant difference between the CO2 readings in the Student Union Building and the Life Sciences Centre based on a p value of 1.30E-102.

Table 5 Two-Sample t-Test output comparing CO2 readings between the McCain Arts and Social Sciences Building and the Life Sciences Centre at Dalhousie University. Data was collected by CO2 sensors in each building between February 3, 2019 and February 9, 2019 inclusive.

	McCain (ppm)	*LSC (ppm)*
Mean	577.4114583	480.514899
Variance	22854.95597	1915.632017
Observations	1008	330
P(T<=t) two-tail	0	
t Critical two-tail	1.961758651	

At a significance level of 0.05, there was a significant difference between the CO2 readings in the Student Union Building and the Life Sciences Centre based on a p value of 5.87E-66.

4. DISCUSSION

4.1 Summary of Research

This research project aimed to answer a specific research question: How can Dalhousie University utilize green spaces to improve air quality in student-use buildings on Studley campus? A thorough audit was conducted to determine, in a subjective ranking, what buildings on Studley campus were most urgently in need of indoor green space development in order to address the research question. This ranking was based on a series of measurable factors: study seat capacity, current green space allocation (m^3) per seat, and potential for green space development (m^2). Due to unavailable and unreliable data, indoor concentrations of carbon dioxide (CO_2) were not included in the weighted matrix responsible for determining ranking. However, the available parts-per-million (ppm) data was taken into account during the decision making process for general recommendations.

4.2 Significant Findings

The aforementioned audit found that there are some significant concerns with Dalhousie Studley campus air quality and indoor green space projects. The CO_2 levels between buildings were statistically different at a significance level of 0.05. This means that overall air quality within the audited buildings varies significantly, indicating that there is room for air quality improvement in the buildings with lowest CO_2 measurements. Through analysis of CO_2 concentration data made available courtesy of the Dalhousie Office of Sustainability, it was discovered that several of the buildings audited had recorded air quality with CO_2 concentrations over 1000 ppm. Concentrations of CO_2 over 1000 ppm are noted as "poor air quality" and can produce symptoms of drowsiness (Kane International, n.d.). There were also several issues in accessing the data itself. It was unexpectedly discovered that the Killam Library was without carbon dioxide monitors, and deduced - based on incorrect, unreliable readings - that the Mona Campbell building had unrepaired, malfunctioning monitors.

Ultimately it was ultimately concluded that the Killam Library was most in need of indoor green space development. The library received this recommendation due to its large capacity, high potential for green space development, and low current allocation of indoor green space per student. In fact, the Killam only offers 0.0768 m^3 of indoor green space per study seat, when the suggested amount of plant space necessary to classify as a green space was noted as 1.5 ft^2 by the research team. The Marion McCain Arts & Social Sciences is subsequently listed after the Killam as the next recommendation for development due to its current lack of indoor green spaces, at 0 m^2. It is then suggested that the Student Union be considered for development, as it has a high student capacity and records of extremely high CO_2 ppm concentrations. The Life Sciences Centre and the Mona Campbell simultaneously ranked last when evaluated using the weighted matrix scheme, however it should be noted that indoor green space development in the LSC is preferable over the Mona Campbell as the LSC has more potential footage which could be allocated for green space (Appendix 2).

4.3 Consideration of the Findings

These findings can be best classified as a quantitative extension of past research. This analysis takes concepts from previous publications and data, combining various sets of information into a comprehensible description of the current status of indoor green spaces on Dalhousie Studley campus. The intention of the researchers was to create an easily communicated series of data and findings in order for present issues with the development of indoor green spaces to be addressed by the relevant parties on campus.

Original background study for this research project noticed a lack of specific research on the impact of air quality on academic contexts and therefore this publication is believed to be an associated, but specifically differentiated, piece of literature within an area of study. It should stand to serve as a coordination between the scientific studies of air quality on academic performance and the specific metrics of Dalhousie University, contextualizing outside and non-specific research in order to make it applicable to Studley campus.

4.4 Implications for Practice

The findings from this research can be used to educate students, staff, and faculty on the importance of indoor green spaces on air quality on campus. As an academic institution which prioritizes academic excellence, it is essential that primary student-use buildings positively contribute to the health and productivity of Dalhousie community members.

As previously mentioned, there are serious physiological and cognitive benefits to high quality indoor air which should be recognized and given discourse within the governance of university resource allocation. Study findings suggest it would be contradictory to leave air quality issues unaddressed while simultaneously expecting peak student performance, and that by utilizing indoor green spaces in recommended buildings, students will be better off. The results of this research should ideally be used to support the development of a reasonable quantity of indoor green spaces.

4.5 Study Limitations and Delimitations

The thoroughness of this study was limited to the availability and reliability of some secondary data sourced from professionals outside of the primary researchers. CO_2 concentration data was unavailable for one building, the Killam Library, and unreliable for another - the Mona Campbell building. Recordings from the Mona Campbell read at times as negative concentrations, which indicates that the monitors within this building may be malfunctioning as it is not possible to have negative CO_2 levels. Therefore, this data was discredited and left out of the dataset due to inaccuracy bias. External conditions that were not included in the analysis also impacted the reliability and accuracy of indoor CO2 readings. Outdoor factors such as traffic or construction could impact indoor air quality. Capacity of people in the areas where sensors were placed and proximity to doorways where ambient air could interact with sensors, was also cited as a potential interference.

Personal limitations also arose throughout the scope of the research project, which impacted the accuracy of the findings. It was the decision of the primary researchers to dictate a viable indoor green space as any plant matter that covered a minimum of 1.5 ft^3. This meant that although smaller plants may have existed within the researched areas, they were not considered significant enough to impact the findings and thus were not included in green space cubic measurements.

The decision was also made personally in regards to which buildings on Studley campus were to be included in the audit. This choice was made using the personal perceptions of the researchers; buildings were chosen based on the which were perceived to be the most important to students as study spaces. The final areas chosen are likely a result of the biases of the researchers, taking into account the buildings that were most familiar and conveniently located within the campus.

Measurement of current indoor green spaces was also measured in approximation at times, at the discretion of the researchers. Due to to the physical inaccessibility of some green spaces such as the living wall in the Student Union Building, measurements were based off of estimations made through use of photographs including objects of known height.

It can also be noted that the final ranking was subjectively ordered. Due to the limitations of scope of knowledge, it was determined that the various sets of data accumulated could not be combined into a single value - due to variances in data units and types. Therefore, a weighted matrix was utilized in order to determine a ranking. However, this method is subject to personal bias in the decisions as to which criteria were used and what values were assigned.

5. CONCLUSION

It is the belief of the research team that these findings help apply outside research on the impacts of air quality on academic performance to the local context of Studley Campus, Dalhousie University. The final ranking can be applied to future decisions from relevant parties on the dispersion of resources and budgets in regards to building improvements (Figure 1). These advancements would align with sustainability goals and campus environmental initiatives and values, leading to the overall improvement of the academic functionality of the university.

The findings of this project are that Dalhousie University should invest in the integration and development of indoor green spaces. Although these changes can come with significant fiscal costs in both initial expenses and maintenance, the benefits of improving air quality supercede these concerns.

The results of the audit also left some areas for further internal and academic study. Emphasis should be placed on understanding spikes in CO_2 concentrations and inaccurate readings, in order to assess the effectiveness of the current carbon dioxide monitoring system. This study also lends itself to internal exploration of a cost/benefit analysis to determine the economic viability of the proposed recommendations.

6. ACKNOWLEDGEMENTS

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8. APPENDIX I: ACCESS TO PECHA KUCHA

To view the original slides for our pecha kucha presentation on this topic, click here.

APPENDIX II: ACCESS TO DATA SHEETS

See the original sheets used for data collection as well as basic data and statistical analysis here.

APPENDIX III: ACCESS TO CO_2 DATA

To see the data sent from the Dalhousie University Office of Sustainability, and accompanying statistical data done by the research team, click here.