BOSTON COLLEGE CO_2 LEVELS AND AIR POLLUTION AT MAJOR BOSTON UNIVERSITIES

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ENVS4943.01: Environmental Seminar
Group 01: Assessing Outdoor Air Quality

03 May 2018

ABSTRACT

Background: Exposure to high levels of specific pollutants has been linked to numerous health complications including asthma, pneumonia, myocardial infarction, lower lung function, and lowered cognitive functioning.[1] Understanding the emissions of these pollutants from universities as well as their ambient air makeup would elucidate whether or not their students are being exposed to potentially harmful gases on their campuses. In this study, we sought to determine whether Boston College's emissions are lower or higher than comparable universities in Boston and around the nation and what ambient pollutant levels are like around Boston College's Chestnut Hill Campus. Emission and population data was obtained for several universities and used to calculate emissions in a comparable metric; comparisons were then made between the schools. A CO2 meter was utilized to take ambient CO2 levels at five locations, both indoors and outdoors, over two weeks; this data was used to determine problem areas around Boston College's campus.

Results: Boston College has lower emissions per student FTE than two other Boston Universities, but when compared to schools across Massachusetts and the nation Boston College is slightly below average. Boston College does have a higher emission level per square footage than many comparable schools. The outdoor locations on Boston College's Chestnut Hill Campus have similar levels of CO2, but the indoor location, O'Neill Library, has significantly ($p = .000$) higher levels, and they vary greatly.

Conclusions: Boston College has low emissions compared to peers in terms of student population, but it has only moderate emission levels when compared to peers in terms of campus square footage. Boston College's outdoor ambient CO2 levels are consistent and normal, but levels inside O'neill Library are high and approaching levels that begin to reduce cognition.

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INTRODUCTION

Air pollutants pose a hazard to public health and can lead to a myriad of different illnesses and ailments, including asthma, pneumonia, myocardial infarction, and lower lung functioning.[1]It is recognized among the scientific community that there are associations between higher levels of exposure to air pollutants and serious health effects. Since the 1970's, when the federal government signed the Clean Air Act, air quality has steadily improved. The 1970 Clean Air Act required the federal government to limit emissions from mobile and stationary sources, expanding the reach of the federal government on issues of air pollution.[2] It curbed the emissions of pollutants such as carbon monoxide, sulfur dioxide, and nitrogen oxides, leading to a 40% reduction in sulfur dioxide, a 50% reduction in carbon monoxide, and a 30% reduction in nitrogen oxides in national average emissions.[3] Then, in 1977 and 1990, the federal government passed the Clean Air Amendments, which further restricted air emissions.[4]The 1990 Clean Air Amendments aimed to address toxic air emissions, alongside other issues such as the depletion of the ozone, acid rain, and urban area pollution.[5]In 2010, the EPA estimated that the implementation of this amendment led to the prevention of 160,000 deaths due to toxic air emissions.[6]

While these acts since their inception have led to the reduction by 70% of the six pollutants regulated by the EPA: nitrogen dioxide, ozone, sulfur dioxide, particulate matter, air pollutants continue to threaten public health.[7]The severity of the public health effects from exposure to pollutants has been underscored in countless scholarly articles, which link air pollutants to asthma, lower lung functioning, pneumonia, myocardial infarction, and other grave health effects, and suggest that even low levels of exposure to pollutants adversely impact those exposed. Studies suggest that long-term exposure to pollutants, even in compliance with current air quality standards, can lead to premature death.[8]With the average adult intaking over 3,000 gallons a day of air and children intaking even more air per pound of body weight, these negative health effects associated with pollutants represent a valid source of concern.[9]

As a result of these concerns, this study intends to examine the pollutants Boston College currently measures and the university's overall emissions, which may be impacting the health of its students. Expanding on this, Boston College's current emissions were compared to other universities, including Harvard University and Boston University, to highlight areas where we differ and could improve.

This study aims to answer two research questions:

1. Are Boston College's emissions lower or higher than other comparable universities?
2. What are ambient pollutant levels like around Boston College's campus and where can improvements be made?

LITERATURE REVIEW

Extensive literature exists on the connections between pollutants and health effects, here we will describe a few pertinent to this study.

The implementation of the Clean Air Act and Clean Air Amendments led to vast improvements in air quality within Massachusetts. Massachusetts currently meets federal standards, the National Ambient Air Quality Standard, limiting concentrations of air pollutants. Massachusetts meets the standards for carbon monoxide, lead, nitrogen dioxide, sulfur dioxide, particulate matter, and ozone.[10] However, health threats still remain even under current air quality standards. Within the city of Boston, a study emerged over a decade after the passage of the 1990 Clean Air Amendments, which demonstrated an association existed between air pollution and emergency admissions. The study examined 15,578 patients admitted to the hospital for myocardial infarction and 24,857 patients admitted for pneumonia.[11] They found that there were significant associations between black carbon and emergency admissions to the hospital due to pneumonia and smaller associations between PM2.5 and carbon monoxide and pneumonia. They also found significant association between carbon monoxide, nitrogen dioxide and PM2.5 and emergency admissions to the hospital due to myocardial infarction.[12]

Pollutants impair normal lung functioning and can threaten lung development. A study examining associations between exposure to air pollution and lung functioning in children found that childhood exposure to pollutants, even at low levels in compliance with the current emission standards, leads to reduced levels of lung functioning. This study built upon prior studies done in the 1990's, which linked pollution to lower levels of lung functioning and reduced lung growth.[13] However, taking into account the substandard air quality standards during the 1990's, this study sought to examine whether these findings held up, considering the current, stricter emission standards. The authors followed six hundred and fourteen mother-children pairs, estimating their proximity to traffic-congested roadways and their exposure to PM2.5 and black carbon. It found

that participants who lived in closer proximity to traffic-congested roadway, especially those who lived less than 100 meters away from a major roadway, suffered from lower lung functioning capacities.[14] They found associations between exposure to pollutants at birth and mid-childhood and between exposure to black carbon and PM2.5 during participant's lifetime and over the past 365 days and lower lung functioning.[15]

Exposure to specific pollutants have been linked to various diseases, one in particular is asthma.[16] They have shown a link, but this was elucidated further when researchers discovered a link between methylation of certain genes. This study examined children in the Fresno, California school district, a city already known for its poor air quality. They found that increased exposure to common pollutants like NO and PM2.5 were directly linked with an increase in methylation at certain regions of the genome. In addition, these changes at the genome level were then compared to asthma levels and they found a perfect link. Increases in these pollutants leads to increases in methylation and this study showed how this is linked to asthma development. Most importantly, the time of exposure was very short, only 90 days, indicating these gases can cause harm in shorter periods of time than previously thought.[17]

Exposure to pollutants over long periods of time has been linked with increased rates of morality. Researchers examined 60,925,443 Medicare beneficiaries and estimated their expected exposure to ozone and particulate matter based on their home addresses.[18] They directly estimated these participant's risk of death based on long-term exposure to pollutants both above and below current National Ambient Air Quality Standard. They linked participant's risk of death to additional exposure of 10 $\mu g/m^3$ PM2.5 and 10 ppb ozone. When pollutant levels were above National Ambient Air Quality Standard, they found that additional exposure of 10 $\mu g/m^3$ PM2.5 led to 7.3% increase in mortality rate. For ozone, they attributed an addition exposure of 10 ppb ozone to a 1.1% increase in mortality rate.[19] Even long-term exposure to PM2.5 and ozone at low levels, concentrations below National Ambient Air Quality Standards, led to an increased rate of mortality at a 1.136 hazard ratio for PM2.5 and 1.010 hazard ratio for ozone. This means that at the additional incremental exposures established above, PM2.5 and ozone will increase a subject's risk of morality by 13.6% and 1.0%, respectively.[20] Supporting this hypothesis, a study led by researchers at Harvard School of Public Health linked reduction in PM2.5 exposure with a higher level expectancy. From 2000 to 2007, the study examined PM2.5 levels of 545 counties in the United States and associations between PM2.5 exposure and life

expectancy.[21] Researchers analyzed PM2.5 levels measured in μg/m3 and life expectancy, along with medical history and socioeconomic factors, from 2000 to 2007 and demonstrated that with a decrease of PM2.5 levels in 2007 from 2000 levels that life expectancy increased.[22] The study estimated that a 10μg/m3 decrease in exposure to PM2.5 led to an additional 0.35 years of life. These two studies demonstrate the association between pollutants and higher rates of mortality or increased life expectancy.[23]

An important link between carbon dioxide and cognitive function has also been shown; a recent study examined the impact of commonly found indoor environments on cognitive function, including CO2. Several novel observations were made. They found that increasing ventilation to outside air increased cognitive function. CO2 in particular was shown to play a larger role than previously expected; people performed best in low CO2 environments with high ventilation while they performed the worst in high CO2 environments. Importantly, they defined high CO2 as 1,400ppm and medium CO2 as 900ppm; both levels not out of the realm of everyday experience especially indoors.[24]

METHODS

The study was divided into two parts focusing on each research question. Part I was collection of data to compare Boston College with other universities. Part II was direct data collection of CO2 levels to get a glimpse into ambient air pollution levels.

Calculation of Emissions for other Schools

In order to compare emission levels between schools, a comparable metric was needed. It was decided to calculate pollutant emissions by their student full time equivalents (FTE). FTE is a common metric and is self-reported by most universities. Harvard reports full time students but not part time students, while Boston University reports both, but separately. To calculate Boston Universities FTE, the method developed by the integrated postsecondary education data system was utilized.[25] This entails multiplying the number of part-time undergraduate enrollment by .392857 and adding it to the number of part-time graduate enrollment by .382059 and then adding the sum of these numbers to the full-time students. Through this method, Boston University's FTE was calculated. Harvard does not report data on their part time students, either graduate or undergraduate, and as a result it was impossible to include these students in the student FTE total.

Most schools self-report their emission data as well. This data was collected from the desired schools off their websites and used in calculations. The metric chosen for the emission data was metric tons of carbon dioxide equivalents (MTCDE). Instead of calculating the emissions per pollutant, schools can aggregate their emissions from different greenhouse gases based on their global warming potential in terms of CO2. The data was reported in terms of MTCDE so no calculations were required.

Gross emissions per student FTE were then calculated at Harvard by dividing Harvard's greenhouse gas emissions by their FTE. Boston University's gross emissions per students were also calculated by dividing their greenhouse gas emissions by their FTE.

Calculation of Emissions for Boston College

Boston College is in the process of submitting a sustainability performance report with the Sustainability Tracking, Assessment & Rating System (STARS) which is a transparent, self-reporting framework where schools of higher education can report their sustainability results and track them over time.[26] For this process, Boston College hired the Sightlines Consulting Group which conducted an outside investigation of the emission levels and issued a report to Boston College.[27] This report contained the FTE calculations and emissions per student FTE for Boston College so these values did not need to be calculated. In addition, they conducted their own comparison of Boston College's emissions to several other comparable universities across the country, enriching the data outside of Boston comparisons.

Independent Collection of Ambient CO2 Levels

While overall emissions are easily calculated from yearly totals, it was decided to investigate overall ambient air quality outside of overall emissions. In order to do this, a device had to be obtained which could measure, in real time, the levels of pollutants in the air. Due to budget constraints, CO2 was decided upon because it is fairly common and CO2 detection meters are fairly easy to access. Boston College agreed to purchase a CO2 meter for use in this project and for further projects. The university purchased an Amprobe CO2-100 hand-held carbon dioxide meter.

CO2 levels, air temperature, and dew point were measured over a period of two weeks around campus. Readings were taken at all five locations twice a day: in the afternoon at 3pm and in the evening at 7pm. Readings were taken on three days each week: weekdays Tuesday and Wednesday plus Sunday for weekend readings. Locations were chosen to be areas of high

traffic or near buildings that are used regularly as well as in areas throughout campus. The readings were made by holding the meter at chest height upwind of the individual, so there were minimal CO2 contamination from breathe. At each time point one reading was taken at the outdoor locations, but three were taken inside of O'Neill Library because the CO2 levels observed were erratic and varied drastically. The three locations inside the library were all on the third floor in different study sections. The main five locations chosen are shown in Figure 1 and Table 1.

Table 1 - Locations and building names of the locations on Boston College's Chestnut Hill Campus where CO2 data was collected.

Location
Outside McElroy Commons (1)
Outside O'neill Library (2)
Inside O'neill Library (3)
Outside of Corcoran Commons (4)
Outside of Cheverus Dorm (5)

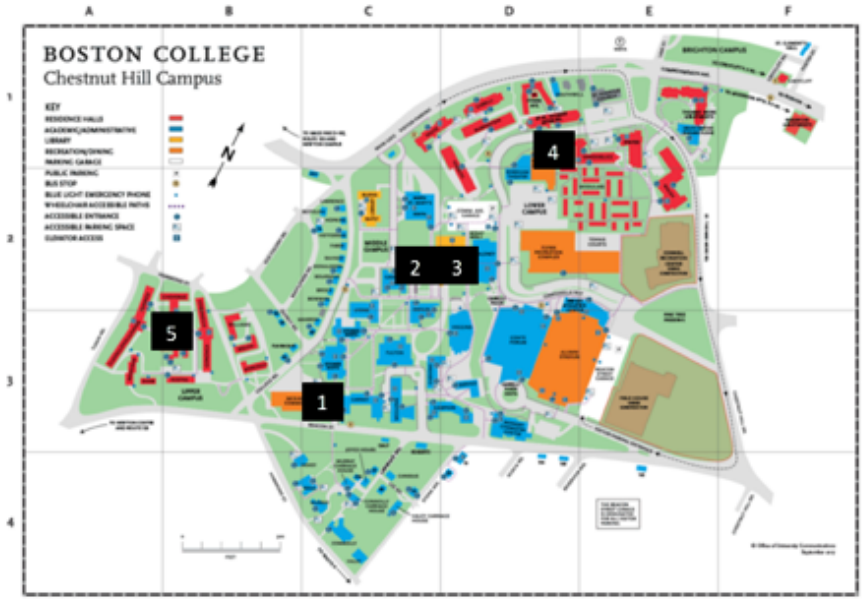


Fig. 1 - Locations of CO2 data collection on Boston College Chestnut Hill campus.[28]

Both dining halls on lower and middle campus were chosen because these are areas of extremely high traffic. O'Neill library is the largest study space on campus and frequently filled with students. Finally, Welch dormitory was chosen to get a reading from upper campus which is at a higher elevation than the rest of campus.

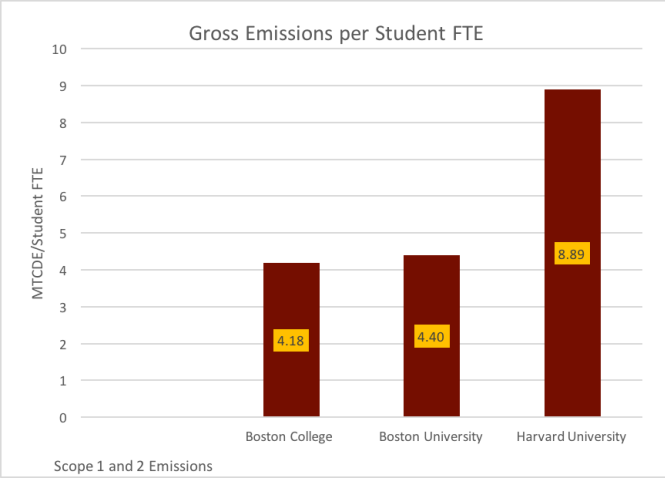
Statistical Analysis

The data obtained in the CO2 direct collection was imported and analyzed using IBM's SPSS software. Mean comparisons were run between the five different locations, the two different times of day, and the different days of the week to determine any outliers or locations that were statistically significant. Tests were run against all variables collected to control for possible effects from outside parameters.

RESULTS

Emissions of other Boston Schools and Boston College

Fig. 2 - This graph depicts the gross emissions per student FTE for Boston College and its regional peers, Harvard University and Boston University. It includes scope 1 and scope 2 emissions.



Sightlines Emission Comparison

The consulting group Sightlines calculated the gross emissions per student FTE of Boston college and peer universities listed in Table 2. They also determined all of the universities gross emissions per 1000 square feet as well. They determined Boston College emits less MTCDE/student FTE than many of their peer universities, but Boston College has a relatively high emission level in terms of our square footage (Figure 4). Each universities' MTCDE/student FTE included all Scope 1, Scope 2, and Scope 3 (Figure 3) emissions in calculating their overall total.[29]

Table 2 - List of the Peer-Group Schools used in the comparison with Boston College and their corresponding abbreviations used in the following figures.[30]

University	Location	Abbreviation
American University	Washington, DC	A
Babson College	Wellesley, MA	B
Bentley University	Waltham, MA	C
Emerson College	Boston, MA	D
Loyola University Maryland	Baltimore, MA	E
Occidental College	Los Angeles, CA	F
Rensselaer Polytechnic Institute	Troy, NY	G
Tufts University	Medford, MA	H
University of Vermont	Burlington, VT	I
Wesleyan University	Middletown, CT	J

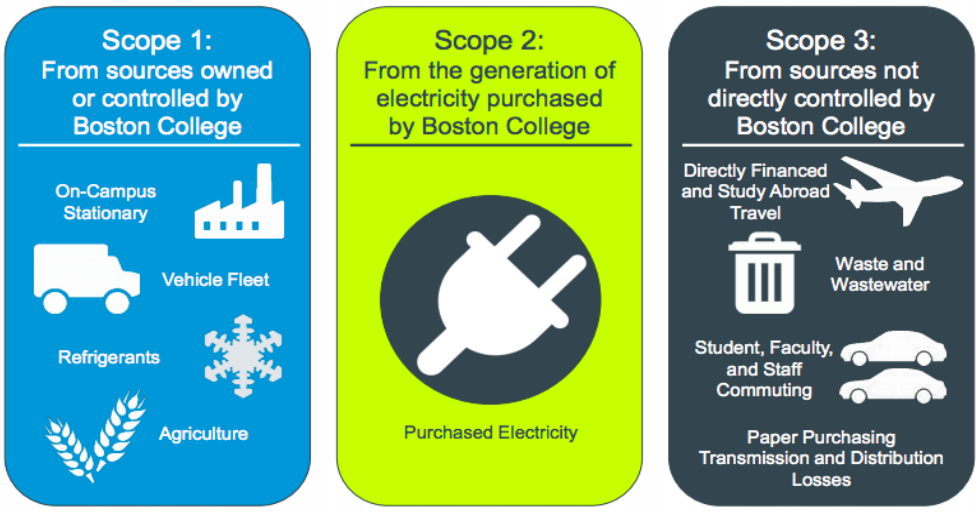


Fig. 3 - Description of the three scopes used to break down emission data in the Sightlines report provided by Boston College.[31]

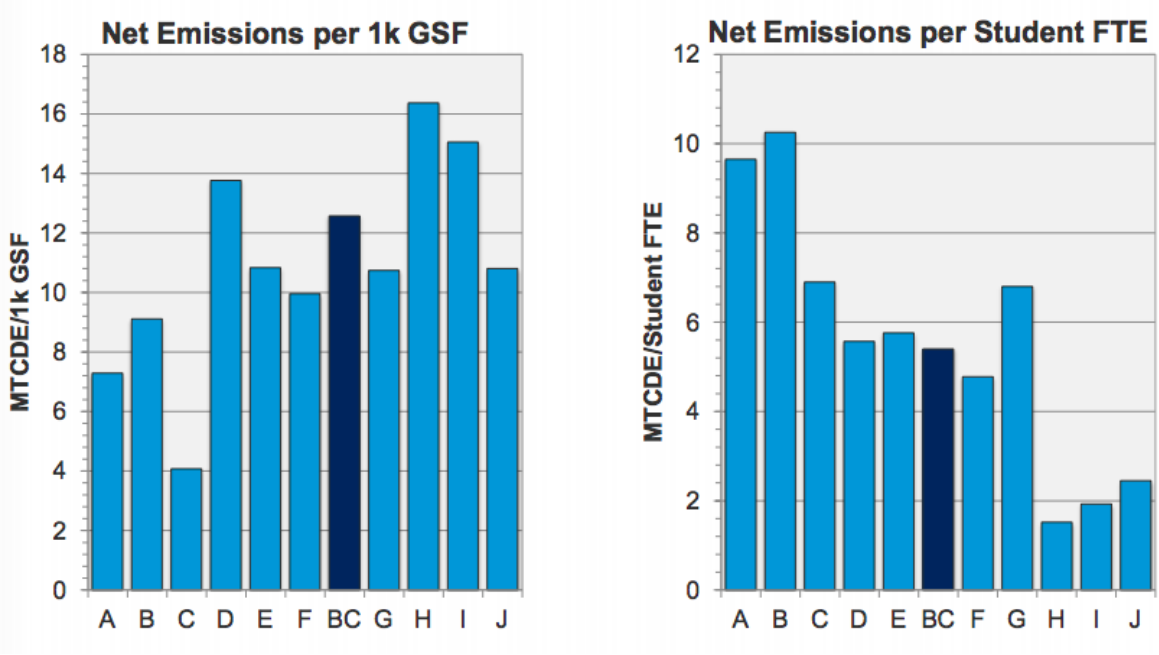


Fig. 4 - Boston College's net emissions (dark blue) compared with net emissions from peer-group schools (light blues) both in terms of square footage and per student FTE.[32]

Boston College CO2 Levels

The average CO2 levels from all readings were accumulated and calculated for each location with its standard deviation.

Table 4 - Mean CO2 levels at five locations on Boston College's Chestnut Hill campus.

Location	Mean CO2 (ppm)	Std. Deviation
Outside McElroy Commons (1)	402.1875	10.01478
Outside O'neill Library (2)	400.8125	9.47431
Inside O'neill Library (3)	741.8636	88.36383
Outside of Corcoran Commons (4)	398.8750	9.99917
Outside of Cheverus Dorm (5)	399.8667	13.58501

An ANOVA analysis between the four outdoor locations showed that there is no statistically significant difference between them in terms of their CO2 levels.

Table 5 - Two-Tailed ANOVA analysis on the differences in CO2 levels between the four tested OUTDOOR locations on Boston College's Chestnut Hill campus.

	Sum of Squares	Degrees of Freedom	F Value	P Value
Between Groups	95.197	3	.270	.847
Within Groups	6934.358	59		
Total	7029.556	62		

It was shown that the only statistically significant location was location (3), inside O'neill Library, while the four outdoor locations were too similar.

Table 6 - Two-Tailed ANOVA analysis on the differences in CO2 levels between outdoor and indoor locations tested on Boston College's Chestnut Hill campus.

	Sum of Squares	Degrees of Freedom	F Value	P Value
Between Groups	3019944.759	4	224.721	.000
Within Groups	342685.540	102		
Total	3362630.299	106		

DISCUSSION

The first part of this study sought to determine whether Boston College's emissions are lower or higher than comparable universities across the nation and Boston.

In order to determine this, the MTCDE per student FTE was calculated for Boston College, Boston University, and Harvard University and are shown in Figure 2. Based on the bar graph, it is easy to conclude that Boston College is at least keeping steady with Boston University while it is far ahead of Harvard. This indicates that Boston College has already worked to reduce their emissions which is also evident by their mission plan.[33]

In addition to comparing Boston College to schools in Boston, the sightlines report provided an excellent analysis of Boston College in terms of other Massachusetts schools and others across the nation (Table 2). As was found in the analysis of Boston schools, the Sightline's report indicated that Boston College is keeping up with peers in terms of MTCDE per student FTE. Fortunately, the report breaks down emissions in terms of another factor: square footage. When the emissions are analyzed in this way, Boston College appears be one of the higher emitters of pollutants. If emissions were just looked at in terms of student FTE, Boston College might appear on track, but the analysis in terms of square footage shows that the school still has some work to do in order to compete with peers.[34] Recommendations will be made at the conclusion of the report regarding areas Boston College can improve.

The first part of this study is only half the story, the second part of this study sought to determine what ambient pollutant levels are actually like around different areas of Boston College's campus. Boston College might be average in terms of overall emissions, but ambient air quality on campus isn't entirely accounted for by this measure. Most emission analyses are done backwards; they take the yearly emissions divided by the population which is accurate, but doesn't account for daily levels or direct measurement in different areas.[35] Emissions could be steady, but a nearby source of pollutants could easily impact the local air quality. Therefore, the CO2 meter was obtained and used to make these direct observations.

The initial goal was to identify an area on campus that maintained higher CO2 levels, but all of the outdoor locations tested were incredibly consistent around 400ppm each (Table 4). The only significant result was the readings taken inside O'Neill Library. Two important findings were observed. Not only was the level statistically different from the other four outdoor locations, the average was 250ppm higher than the outdoor locations. The second finding was the incredibly large variation of CO2 concentrations in the indoor space. The standard deviation for the library location was very large at 88 and shows just how varied the readings were.

While the finding that CO2 is higher indoors is not new, the levels observed caused concern. Just two standard deviations from the mean the mean in either direction the levels range from 566ppm to 918ppm. The lower values are nothing of concern, but 918ppm is approaching the levels found in the cognitive function study that impacted cognitive function.[36] This finding is of crucial importance as the readings were taken in the main library on campus; it is a location almost exclusively used for high cognitive function, yet it maintains areas of high CO2. As an

area devoted to such, the high levels observed need to be investigated further to determine the problematic areas.

Finally, Boston college is at least at the same level of comparative universities for emissions, yet the ambient air levels of CO2 measured indoors are still too high. This shows how the university could be on the right track for reducing emissions, but environmental factors or even infrastructure are affecting the everyday levels. This importantly shows the difference between emissions and ambient air quality, something Boston College may not have considered.

Limitations:

This study has several limitations. The FTE calculation for Harvard was incomplete and only accounted for full time students, while the FTE for Boston College and Boston University included both full time and part time. This would reduce Harvard's MTCDE/student FTE, but their levels were so high its extremely unlikely it would bring their levels within range of Boston College or Boston University.

Another limitation was the direct measurement. CO2 was chosen because it was the cheapest to measure and has negative impacts on cognition, but the truly harmful diseases are linked to more dangerous gases like NO or particles like PM2.5 which were not measured. A full picture including direct measurement of multiple gases would contribute to a fuller picture of air quality around campus.

Conclusions:

Despite the limitations of the study, several important conclusions were drawn.

Part I

1) Boston College has low emissions compared to peers in terms of their student population.
2) Boston College has moderate emissions compared to peers in terms of square footage, there is still work to be done.

Part II

3) Boston College outdoor ambient CO2 is consistent and of normal levels for the area.
4) Boston College ambient CO2 in O'Neill Library is high and could be impacting the cognition levels of studying students.

RECOMMENDATIONS

This study recommends greater monitoring of dangerous emissions in high traffic locations, as pollutants have been linked to dangerous health issues like asthma over short time periods and there is minimal knowledge regarding their levels on Boston College's campus. Boston College could also benefit from greater monitoring of indoor pollutant levels, as CO2 was found to be much higher indoors and can impact cognitive function, so Boston College should be more aware of these levels in densely populated locations around campus. Within its library, Boston College could implement a HVAC system in O'Neill that brings in outside air when CO2 levels are at levels close to impacting cognitive functioning. This is a plausible option, as Boston College currently utilizes this method in Robsham and Corcoran Commons.

Greater effort by Boston area schools to be leaders in this field and reduce their emissions to protect the overall health of Boston citizens will also play a key role in the reduction of emissions. CO2 was shown to be consistent throughout the campus showing how these gases diffuse in our environment. The cities emissions affect the air we breathe and our emissions affect the rest of the city.[37] With other universities such as Harvard University and Boston University planning on enacting more aggressive emission reduction policies through climate action plans, Boston College must also push aggressive emission reductions if it hopes to remain competitive with its peer. Under its climate action plan, Harvard University pledges to become fossil-free by 2050 by incorporating sustainability into every facet of its operations.[38] Boston University proactively reduced its emissions by 25% six years ahead of its original 2016 deadline, despite a 14% campus growth.[39] Boston College should strive for similar standards to remain a leader in the field of sustainability.

This study agrees with the sightlines recommendations that to further reduce emissions, BC should work on their inefficient areas and outdated buildings. Our emissions are greatly impacted by student and faculty travel, so this is an area where the campus could improve to offset their total emissions. Boston College could neutralize its emissions from students studying abroad or faculty attending meetings elsewhere in the United States by carbon offsetting. In this system, Boston College would donate money that would reduce the impact of all the flights taken by faculty and students by reducing their carbon footprint.

APPENDICES

Additional information can be found in the Sightlines consulting report provided by Boston College. Please use the link below to access.https://stars.aashe.org/media/secure/729/7/650/5888/Boston%20College%20GHG%20Report%20FY2016.pdf

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