Exploring Classroom Temperatures: An Analysis of Student Preferences and Energy Usage

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Contents

1 Introduction

Over 32% of Boston College's energy bill is spent on natural gas and oil, which is used to heat classrooms and dormitories throughout campus. In a previous study done in 2018, which evaluated the Boston College work order system, it was determined that while students were, in fact, dissatis ed with the room temperatures in the buildings at Boston College "it was not personally bad enough to warrant a work order" (Kang et al., 2018). However, it has been three years since this study was conducted and a common problem that is still often voiced by students at BC is that classrooms are either too cold or too warm. Hence, our research aims to evaluate Boston College's energy usage in classrooms in Fulton Hall, Gasson Hall, and Stokes Hall (North and South) by determining if there is a signi cant over-heating or over-cooling problem in Boston College classrooms. Furthermore, rather than focusing on modifying the work order system, our main goal is to determine whether or not the HVAC system used at BC needs to be changed and/or modi ed to support both the preferences of students at Boston College as well as improve the energy usage in classrooms. To further assess this problem our study focused mainly on the following four research questions:

1. What is the relationship between changes in the outside temperature and the temperature, taken from our device, in Boston College buildings? Is there variability across buildings?

2. What are students' preferences on the room temperature? Are they being over/under heated?

3. Does gender in uence student comfort levels?

if they were previously renovated because \indoor climate in classrooms is largely in uenced by windows" (Mohelnikova et al., 2020). Consequently, our team began to question whether there was any signi cant relationship between the temperatures of previously renovated and/or newer buildings at Boston College. Hence, the buildings at BC proved to be the perfect subject for our research as the campus provides both newer buildings like Stokes Hall, which was built in 2011, and older buildings that have been previously renovated like Fulton Hall and Gasson Hall.

According to the U.S Department of Energy's Buildings Energy Data Book, one of the main sources of energy consumption in buildings are from the use of Heating, Ventilation and Air Conditioning (HVAC) systems that utilize around 43% of the total energy consumption in buildings in the U.S. ("Residential Sector Energy Consumption," 2012). As such, there has been previous research that focused on HVAC systems in o ce buildings. In this speci c study, one of the main aspects that were identi ed was that "the diversity in occupants' thermal comfort preferences is usually overlooked in the operations of centralized-HVAC buildings and room temperatures are maintained within a narrow temperature range" (Aryal & Becerik-Gerber, 2018). Hence, this study sought to understand the di erences between personal comfort levels and the temperatures that o ce buildings were being set to. Once the di erences were determined, the researchers discovered that if the buildings were changed to be set at the occupants' personal comfort levels as opposed to the building level set point, there were energy savings up to 6.5%. Additionally, occupant preferences led to an average satisfaction of 63%, compared to average satisfaction of about 38% for the control case using the building level setpoint (Aryal & Becerik-Gerber, 2018). As such, the results of their study found that adhering to the personal preference of its occupants is considered a key factor in improving energy consumption.

Furthermore, while researching the relationship between personal preferences and temperature, there were also various case studies that included other social factors in correlation with personal temperature preference. For example, the topic of gender in relation to temperature preference seemed to be a popular area of study. One of the studies that peaked our interest was titled, The in uence of acclimatization, age and gender-related di erences on thermal perception in university buildings: Case studies in Scotland and England. This study used numerous methods including questionnaire surveys and high tech indoor environment measurement tools like Black-bulb thermometers, Anemometers, Relative humidity probes, and TRH USB loggers to determine whether gender and age had any in uence on thermal perception (Jowkar et al., 2020). As such, the results of the study proved that although age didn't really a ect person's temperature preference, the study did prove that thermal perceptions of females di ered from men in a way that females seemed to feel colder

than males in university classrooms and thus, women generally displayed cooler sensations and warmer preferences as opposed to men in university classrooms (Jowkar et al., 2020). In particular, the methods used in this study was a major in uence concerning our decision to use student questionnaires and thermostats in our study.

Additionally, the correlation between personal preferences and performance was also an aspect that we decided to research more on. Although our project did not speci - cally focus on this area of study, which would have required us to gain IRB approval, it was important to gain some insight on how temperatures in a building could a ect a person's performance in an environment. For example, an excellent study conducted in Denmark ti- tled, The E ects of Moderately Raised Classroom Temperatures and Classroom Ventilation Rate on the Performance of Schoolwork by Children, showed that reducing air temperatures in classrooms from 77F to 68 F increased test scores in language and numerical based tasks as well as proved that students performed better when air ow through the classroom was in- creased (Haverinen-Shaughnessy & Shaughnessy, 2015). Furthermore, another study we also looked at also analyzed the e ects of ventilation and temperature on student performance. Particularly, the main discovery of this study was that higher temperatures aren't ideal for students in a learning environment and that increased ventilation rates and decreased indoor temperatures led to better testing scores (Haverinen-Shaughnessy & Shaughnessy, 2015). The information provided from these two studies proved helpful in interpreting our data since, while our survey did not in any way ask any details on a student's performance in class, there were comments from students which voiced that high temperatures made them feel uncomfortable and thus, a ected their performance in class by making them \sleepy" and/or \distracted."

2 Methods

In order to study the perception and impact of temperature on students in classrooms across Boston College's campus, we needed to know which classrooms are in use and which classrooms are used the most often. We began by reaching out to Boston College Student Services

classroom at the time. It would be very helpful if the students could complete the quiz every day that they are in the classroom during this week.

The temperature was monitored in the selected classrooms for the entire week that the thermometers were installed. We also monitored the outside temperature but didn't change the questions on the survey depending if it was a particularly hot or cold day throughout our study.

2.2 Survey

In order to collect data from the students in the selected classrooms, we created a survey

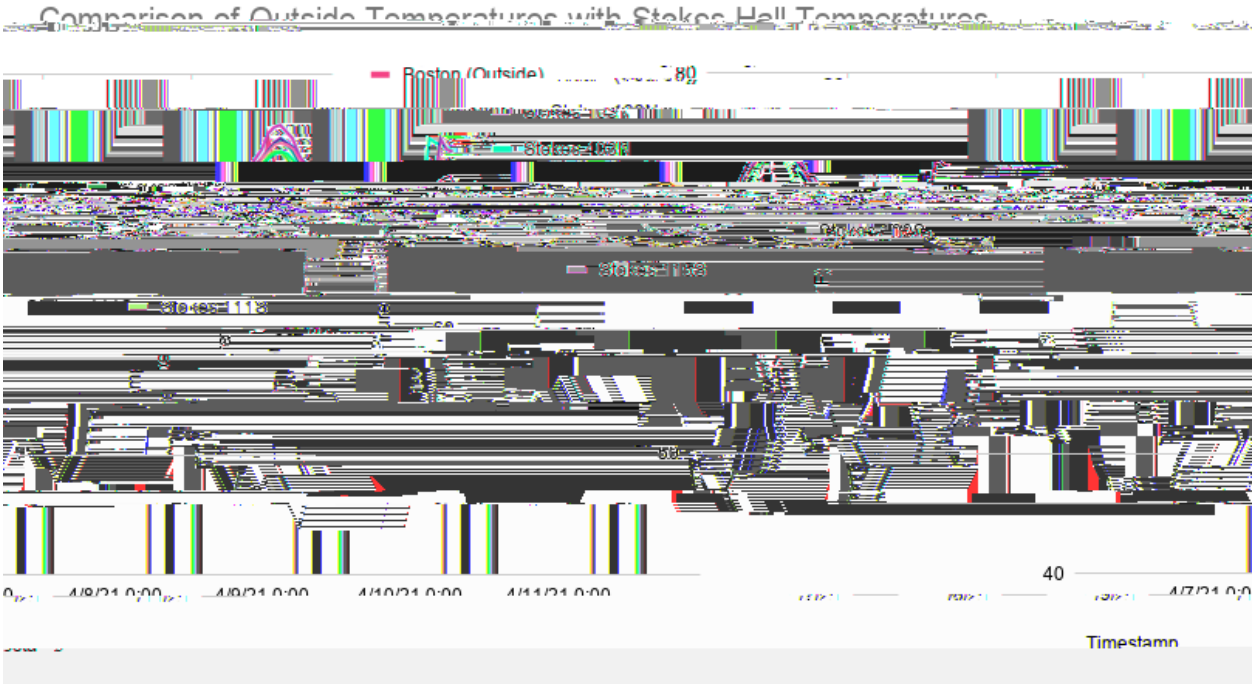
2.3 Materials

We used 10 Govee H5072 Hygrometers to gather temperature and humidity data for our study. The 10 thermometers allowed us to record the temperature in each individual room over the course of the week. At the end of each week, the hygrometers were collected from their rooms, and the data was synced. Then, they were moved to the next round of rooms to collect the next set of data.

3 Results

3.1 Oustide vs Inside Temperatures and Building Variability

What is the relationship between changes in the outside temperature and the temperature, taken from our device, in Boston College buildings? Is there variability across buildings? We can analyze the relationship between inside and outside temperature by comparing our readings from thermometers inside Boston College buildings to historical temperature data provided by Weather Underground.



to quick increases in outside temperature. On this day, the outside temperature rose up to 75 F, the high for the week. What follows this spike in outside temperature is a spike in inside temperatures. All monitored rooms in Stokes Hall reached 74 F with a high of 76 F.

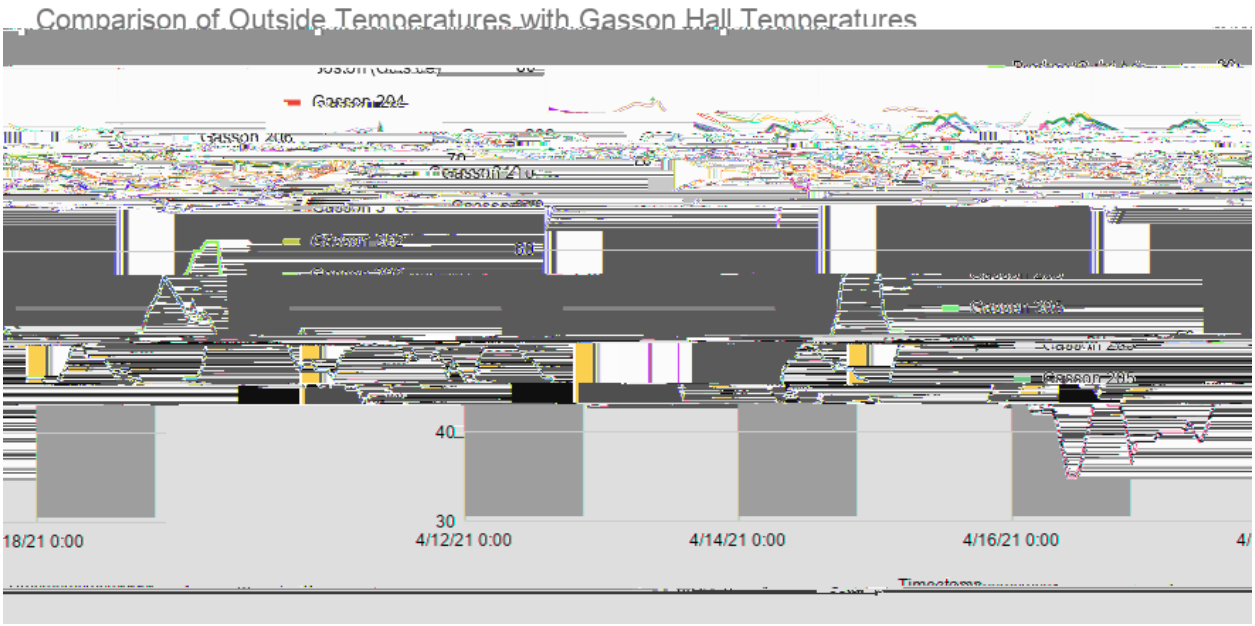


Figure 2: A graph displaying the temperature (in degrees fahrenheit) of selected rooms in Gasson Hall and the outside temperature.

Figure 2 shows the outside temperature in comparison to the inside temperatures for 10 selected rooms in Gasson Hall. During the observation period, the lowest temperature recorded outside was 35 F while the warmest was 61 F. Inside the buildings, the lowest temperature recorded was 66 F, while the highest temperature recorded was 76 F. When compared to Figure 1, the room temperatures in Gasson are much more variable. Instead of room temperatures being consistent from day to day (except for exceptionally warm days), temperatures vary greatly.

Figure 3: A graph displaying the temperature (in degrees fahrenheit) of selected rooms in Fulton Hall and the outside temperature.

Figure 3 shows the outside temperature in comparison to the inside temperatures for the 6 selected rooms in Fulton Hall. Our temperature data shows that the lowest temperature recorded outside was 35 F, while the highest temperature recorded outside was 75. Inside the classrooms, temperatures ranged from a low of 62 to a high of 77 F. In general, the outside temperatures for the week that temperature data was being recorded in Fulton Hall were much more variable. On April 20th, and 21st, temperatures peaked in the afternoon, leading to exceedingly warm classroom temperatures. One common result found throughout all three buildings is that on days where the outside temperature is much hotter than normal, the HVAC systems in each building fail to prevent the inside temperatures from reaching 75 F or greater.

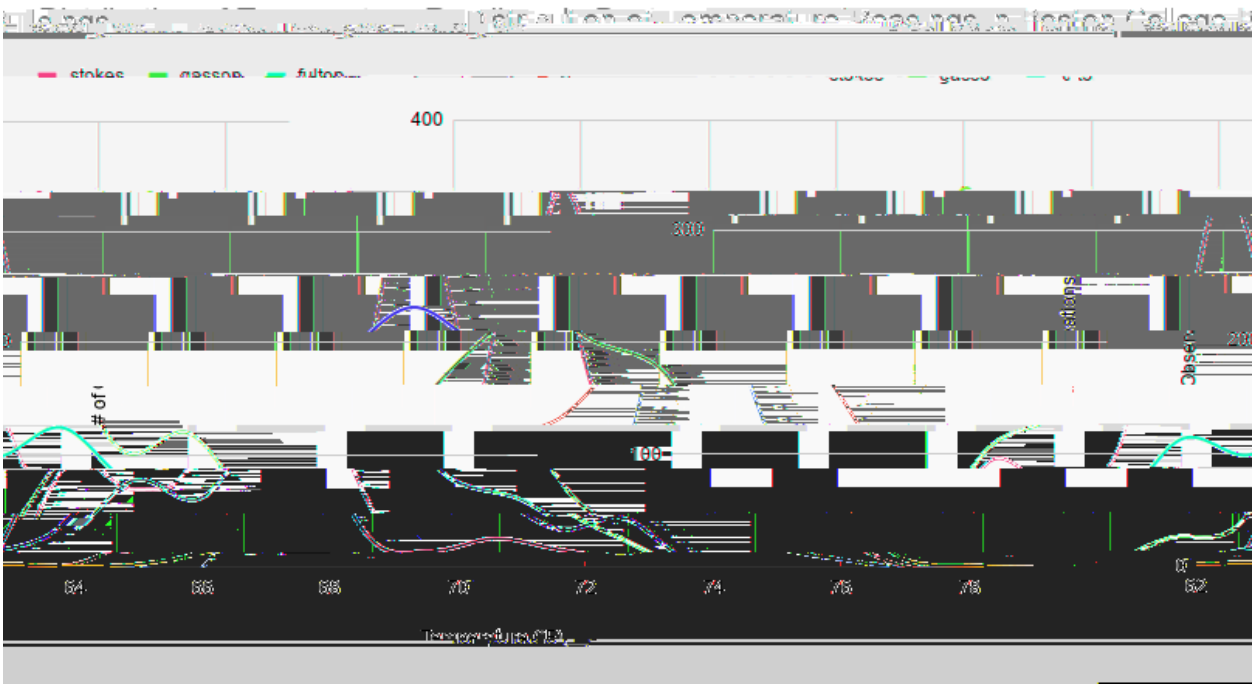


Figure 4: A graph displaying the distribution of temperature recordings in all three monitored buildings.

Figure 4 shows the distribution of temperatures recorded in each building. This graph shows that the temperatures recorded in Stokes Hall fall into a small range. The temperatures are almost always near 70 F. However, when it comes to the distribution of temperatures in Gasson Hall and Fulton Hall, it is much more spread out. In Stokes Hall, 73% of recorded temperatures in Stokes Hall were in the 68 to 72 F range, while only 57% and 53% of temperatures were in that range for Gasson Hall and Fulton Hall, respectively.

3.2 Student Temperature Preferences

What are students' preferences on the room temperature? Are they being over/under heated? The pie charts above show the percentage of students who felt that their classroom in Stokes,

shows that 59.5% of students felt that their classroom temperature in Fulton was just right. Similarly to Gasson, more students felt that their classroom was too hot rather than too cold. The word cloud shown in Figure 8 comes from a collection of comments that students left on the survey. The most commonly seen words in the comments appear larger in the word cloud. It is clear that many of the students feel that the temperature in Gasson is inconsistent and generally too hot.

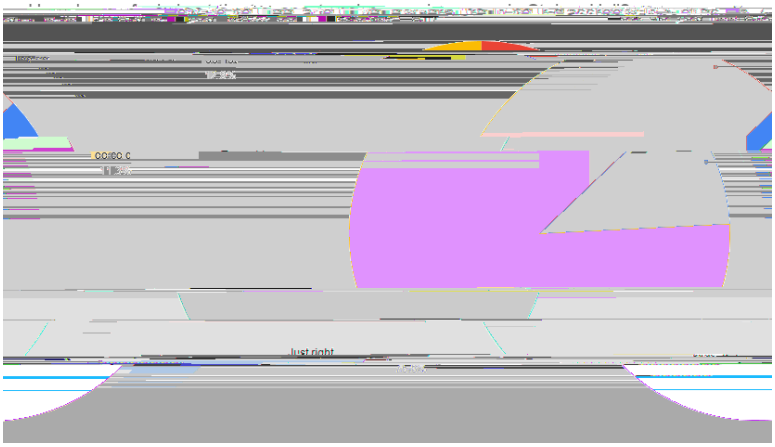


Figure 5: This gure shows the percentage of respondents that felt that their classroom in Stokes Hall was too hot, too cold, or just right.

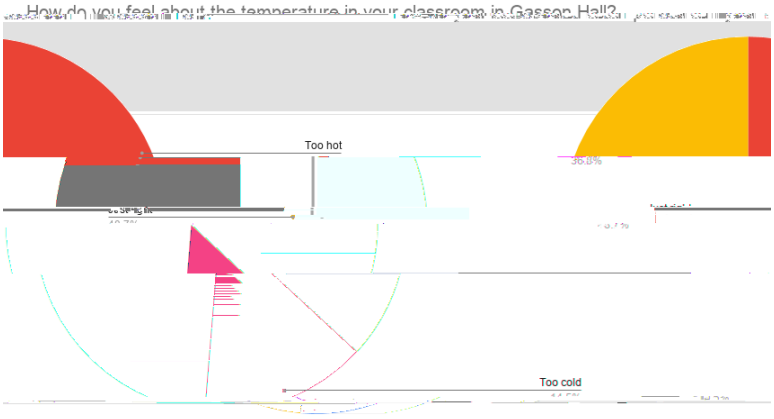


Figure 6: This gure shows the percentage of respondents that felt that their classroom in Gasson Hall was too hot, too cold, or just right.

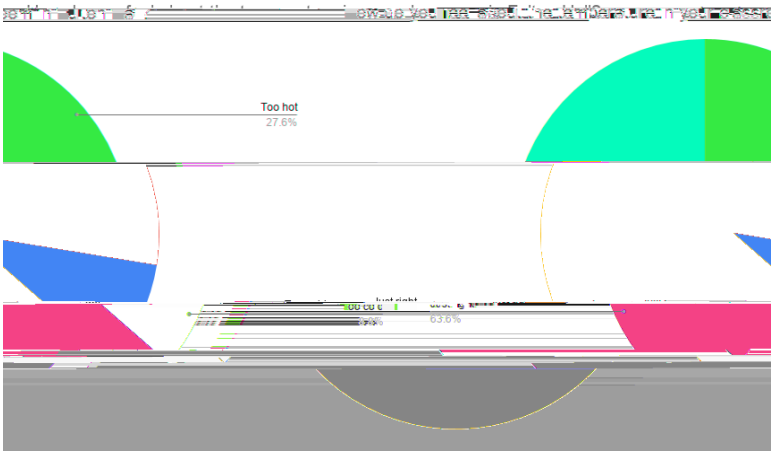


Figure 7: This gure shows the percentage of respondents that felt that their classroom in Fulton Hall was too hot, too cold, or just right.

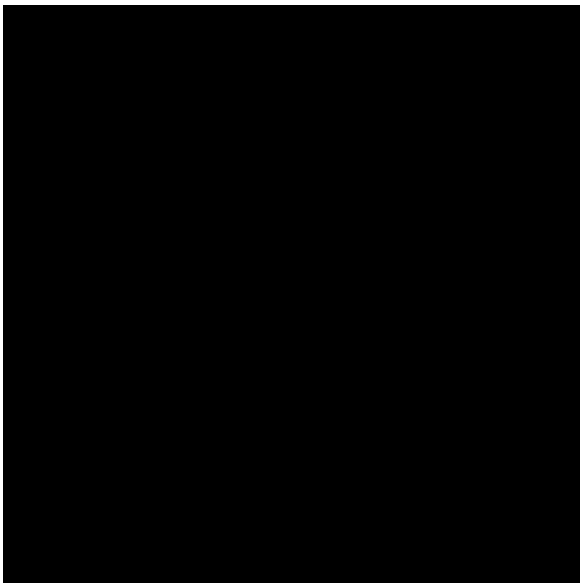


Figure 8: A word cloud of student temperature sentiments, made using comments left by participants.

3.3 Gender

4 Discussion

From Figures 5, 6, and 7, it is clear that the classroom temperatures in Gasson are the least satisfactory to students. A majority of the students who responded to the survey felt that their classroom was either too hot or too cold. In Fulton, the majority of students did say that the temperature felt just right but a high percentage of the respondents still felt that the classroom was too hot. The classrooms in Gasson do not regulate the temperature in the same way that the classrooms in Stokes do. One student left a comment that demonstrated that they picked up on this di erence, \The newer buildings are usually good. In the older buildings I am always hot." Overall, the temperature of classrooms in Gasson and Fulton are incredibly inconsistent. Stokes, a new building, does not have the same problems with temperature regulations as shown in the Figure 4. Additionally, gender seems to play a huge role in overall perception of temperature. Because, more women than men said they tend to lean cold, more women than men also tended to say that their classroom was too cold. It is therefore important to note that the classroom cannot be concluded to be scienti cally too cold or too hot since the perception of temperature is related, in some way, to gender. In regards to temperature and its relationship to academic performance, we cannot conclude anything with the results of our study. Although we received many comments from students who said they felt they were less productive in a hot environment, we did not measure their test scores. A study that could be done as a follow up to ours would be to measure the students' test scores while recording the indoor temperature of the classrooms that they took the exam in.

4.1 Recommendations

One issue in the classroom buildings that we found to be fairly consistent was the uctuation of the indoor temperatures in accordance with the uctuations of the outdoor temperature. On days where the temperature spiked outdoors, it also rose indoors. This phenomenon

Furthermore, we would also like to recommend that the Boston College Facilities team adopt more transparency in terms of providing the student body with speci c information regarding the thermostat policy and thermostat use in Boston College classrooms. For instance, unfortunately we were unable to get any information on the exact tempera-

References

[1] Aryal, A., & Becerik-Gerber, B. (2018). Energy consequences of Comfort-driven temperature setpoints in o ce buildings. Energy and Buildings, 177, 33{46. https://doi.org/10.1016/j.enbuild.2018.08.013