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PSU Green Building Internship Final Report, 2018: Karl Miller Center Post-Occupancy Study

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Karl Miller Center Post-Occupancy Performance Study

PSU Living Lab Program - Green Building Internship

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TABLE OF CONTENTS

ABSTRACT

In this report, both occupant comfort perception-based data, collected via surveys, and building performance-based data, collected via sensors, are utilized to conduct a post-occupancy evaluation of Portland State University's (PSU) new Karl Miller Center (KMC), formerly known as the School of Business Administration. The KMC was completed in September 2017 and is on track to earn LEED Platinum certification, primarily for the passive ventilation strategies incorporated into its design. The environmental factors studied in this report are air and concrete slab temperatures, CO_2 levels, and airflow. The personal factors studied in this report are clothing levels (clo), gender identity, thermal comfort levels, and classroom preference. The performance-based data for the passively ventilated pavilion will be compared to that of the renovated side of the building which has an HVAC system. The perception-based survey data will be examined in order to identify trends between comfort levels within classrooms that are mechanically cooled and classrooms that are passively cooled.

**This study was conducted as part of Portland State University's Living Lab Program, with funding from the Institute for Sustainable Solutions, and support from the School of Architecture's BUILT Lab and Capital Projects & Construction.*

KEY CONCEPTS + TERMS

Perception-Based Comfort Data - the attitudes, understanding, and feelings of an occupant associated with the five senses, used to expressed one's level of comfort. This data was collected via hard copy, one page, anonymous occupant surveys with multiple choice + short answer response options.

Performance-Based Comfort Data - this type of quantitative data includes indoor and outdoor air temperature (IAT and OAT), indoor CO_2 levels, and concrete slab temperatures of classroom floor slabs. All data was collected via sensors: campus-monitored SIEMENS sensors, intern-monitored Onset HOBO sensors, and a handheld Raytek MiniTemp infrared thermometer.

ASHRAE Standard 55 - this industry-preferred standard specifies the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority (80%) of the occupants within the space.

Standard 55 Section 5.4 - *Criteria for occupant-controlled naturally conditioned spaces:*

- The spaces have operable windows open to the outdoors and readily adjustable by occupants.
- There is no mechanical cooling system installed. No heating system is operating.
- Occupants are engaged in near-sedentary physical activities, with metabolic rates ranging from 1.0 to 1.3 met.
- Occupants are free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as wide as 0.5-1.0 clo.
- The prevailing mean outdoor temperature is greater than 50F and less than 92.3F.
- Increased airspeed adjustment is required (i.e. fans).

Air Change per Hour (ACH) - How many times the air in a closed space is replaced per hour.

Factors that Affect Thermal Comfort - Activity level/metabolic rate (met), clothing insulation (clo), air temperature, radiant temperature, air speed, humidity.

Clo - A unit used to express the thermal insulation provided by clothing garments; 1 clo = 0.155 $m^2 \cdot °C/W$ (0.88 $ft^2 \cdot h \cdot °F/Btu$). Per ASHRAE Standard 55, occupant comfort surveys must use the ASHRAE 7-point thermal sensation scale/clo levels for occupants to choose from.

Met - Metabolic Rate and is the energy produced per unit skin surface area of an average person seated at rest.

Space Type - This study focuses on classroom environments, thus, it can be assumed that occupants are engaged in near-sedentary physical activities, with metabolic rates ranging from 1.0 to 1.3 met.

Renovated Side - The Southern half of the building. Mechanically cooled, HVAC.

Pavilion Side - The Northern half of the building. Passively cooled, natural ventilation, automated window system, fans.

Passive Cooling Strategies and Terms -

- **Air Handling Unit (AHU)** - A system consisting of a duct and fans that transport conditioned/heated air to a designated space in the building.

- **Dedicated Outdoor Air System (DOAS) -** A system consisting of a duct and fans that transport fresh air to a designated space in the building.

- **Stack Effect** - A convection effect caused by temperature or vapor pressure difference between indoor and outdoor environments, leading to warm air flowing upwards and out of a building while colder air flows into the lower levels of a building through openings.[1]

- **Night Flush/Purge** (goal is to cool the indoor air temperature to 68 F) - The utilization of the stack effect principle to promote cool air entering the building to exit warmer air out of the building during the night. This is so classrooms can return to the optimal temperature by the morning to be reoccupied.

- **Building Automation System (BAS)/Apogee -** A software that provides users access to the automated systems and controls of the building as well as live indoor atmospheric conditions.

- **Automated Systems** (windows, exhaust fans, ventilation fans, atrium dampers) - The KMC Pavilion uses automated electronic equipment to facilitate passive ventilation during both day and night.

- **Automated/Automatic Windows -** The windows can be operated manually during the day, and at night when the building is unoccupied, the system automatically keeps the windows open for the duration of the night

- **Exhaust Fans -** Three exhaust fans are located on the roof to allow for better cross-ventilation through the classrooms.

- **Atrium Dampers -** Two dampers located in the atrium and roof for the purpose of cross-ventilation of the building. Normal operation is usually opened at night to allow for night flush.

- **Ventilation Fans -** Overhead fans installed in Pavilion classrooms can be manually turned on to simulate airflow within the spaces.

- **Concrete Slab Heat Release** - the concrete slabs in the Pavilion classrooms absorb heat during the day and radiate that heat back out into the classrooms during the night, which can counteract night flush if the classrooms get too hot during the day. The goal is to cool the slabs to 70 degrees Fahrenheit by morning time.

[1] https://gharpedia.com/stack-effect/

PURPOSE OF STUDY

This post-occupancy study aims to determine if the mechanical and passive design strategies in PSU's Karl Miller Center are functioning properly to provide appropriate levels of thermal comfort to occupants. The data collected during this study will also be compared with the design intent as stated by the project design team in order to determine the extent to which the Karl Miller Center is performing as intended. Key focuses will include drawing correlations between outdoor temperature and indoor environmental conditions related to CO_2 levels, indoor air temperature, and concrete slab temperatures.

Figure 1: The Researchers Jocelyn (left) and Omar (right) and Their Supervisor Quinn (middle).

LIMITATIONS

- The night flush code algorithm was still under calibration during and after data collection.

- The original plan was to install ten HOBO sensors in focus classrooms, however, not all sensors operated as desired. Two of the sensors did not collect any information because they were intended to be used as data loggers if connected to reading instruments.

- There were no official classes held in the Pavillion classrooms all summer. Thus, in order to compare occupant comfort between the Pavilion and the Renovated rooms, Pavilion side survey data was used from a previous study conducted during the fall 2017 term (Lattin 2018), and Renovated side survey data was collected during the Summer 2018 Term as part of this study. As the weather is quite different per season, direct comparisons cannot be made due to differing environmental conditions.

- Ideally would have hoped that more instructors would participate in the surveying. In total, twenty-one instructors were emailed and only nine instructors agreed to participate.

- Ideally would have wanted to survey additional classes later in the evening (17:00 or later) to get feedback on the conditions and comfort levels during that period of time.

- No access to utility bills as early as when the building opened to calculate the actual EUI. The only period of time that utility bills were available and overlap is April - July 2018, therefore, the EUI was calculated as an extrapolation.

- The gateway that translated between the BAS and the automatic windows was not functioning properly, causing miscommunication between the night flush system and window operations which resulted in some windows randomly closing during night flush despite being commanded to stay open.

PRECEDENT LITERATURE REVIEWS

- Kyhetica Lattin's Undergraduate Honors Thesis - An Indoor Environmental Quality Assessment: *The Study of Naturally Ventilated University Classrooms Within a Mixed-Mode Ventilated Building. 2018.*
- ASHRAE Standard 55, 62
- Behnisch Design Intent
- SRG + Behnisch Concept Design Booklet IIA (April 18, 2014)
- SRG + Behnisch Land Use Review Presentation III (Aug 6, 2015)
- Previous Green Building Summer interns' air quality report
- BUILT Lab RBDI posters[2]

[2] http://www.builtpdx.org

KMC DESIGN INTENT + DESIGN FEATURES

The Karl Miller Center project was a collaboration between PSU, Behnisch Architekten, SRG Partnership, Skanska, and PAE. The building can be divided into three main sections: the all-new five-story passively ventilated classroom pavilion, the central glass atrium which provides both occupant and air circulation, and the five-story renovated side, which includes a conventional HVAC system and was an existing building on site at the start of the project. Thus, the KMC can be called a mixed-mode ventilated building as it uses both mechanical and natural/passive ventilation. The air temperature in the renovated side of the building is controlled and regulated by a setpoint of 75F which is remotely adjustable by FPM through SIEMENS Apogee. The pavilion is designed to provide adequate thermal comfort for temperatures up to 78F due to increased air movement via electric fans and operable exterior windows. Per ASHRAE 55, all indoor rooms that are categorized under educational buildings (classrooms) are recommended to have 5 ACH. This is achieved in the renovated classrooms via the HVAC system, while the pavilion classrooms are equipped with the DOAS which provides fresh outside air.

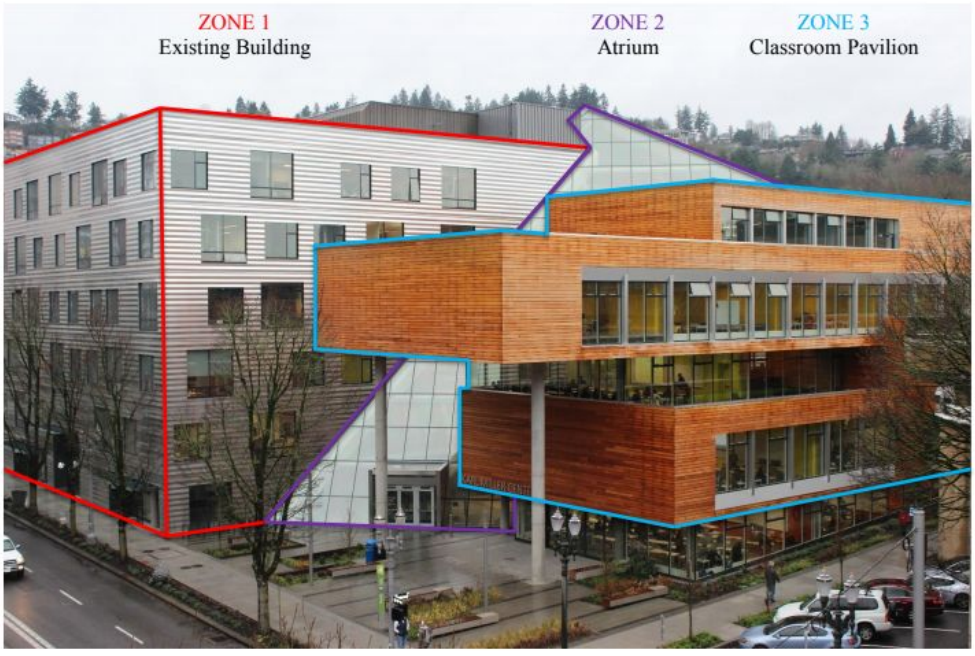


Figure 2: The Three Different Building Zones Outlined. *Source: (Lattin 2018)*

The design team assumed that the regular school year is from October 1st to April 3rd and that the summer term is from May 1st to August 15th. With the passive ventilation system designed, Behnisch/PAE calculated that there should only be 35 overheating hours above 83F operative

temperature during the regular school year. They also calculated that if there are fully occupied pavilion classrooms during the summer term (May 1 - August 15), there will be an additional 100 overheating-degree hours per year. However, the regular school year is actually from September 25th to June 12th, which resulted in a ten-week discrepancy regarding normal building occupation times. This most likely had a large impact on the passive ventilation calculations.

RESEARCH DESIGN + METHODS

RESEARCH GOALS

1. Identify trends between the location, count, and reason for complaints. The work order complaints spreadsheet will be provided by Facilities and Property Management (FPM).

2. Use student survey responses to compare location preference between and thermal perception in Renovated classrooms versus Pavilion classrooms. Use Lattin's survey data collected in the Fall term 2017 for Pavilion classrooms. Survey responses in Renovated classrooms will be collected during this study.

3. Identify survey trends between gender and thermal comfort levels. Use student responses from survey questions 2, 4 and 5.

4. Compare occupant comfort levels with indoor air temperature and CO_2 levels in surveyed classrooms. Compare occupant comfort levels in Interior and Perimeter Renovated classrooms. Use student surveys and SIEMENS sensor data from Renovated classrooms. The Interior classrooms studied are KMC 245 and 275. The Perimeter classrooms studied are KMC 255, 470 and 560.

5. Correlate total population comfort levels with thermal perception. Use student responses from survey questions 4 and 5.

6. Determine the effectiveness of the night flush procedure in Pavilion classrooms. Track concrete slab temperatures every morning and every evening in each Pavilion classroom using a handheld infrared thermometer.

7. Determine summer course suitability in Pavilion classrooms. The Pavilion includes fifteen classrooms over 5 floors. Assume that 75F is the comfort threshold for indoor air temperature. Indoor air temperature will be collected via SIEMENS sensors. Using Excel, tally the number of days that Indoor air temperature exceeds 75F.

8. Compare Indoor Air Temperature and CO_2 levels between Renovated and Pavilion classrooms.

PROJECT DESIGN

Two types of data will be collected during this study: performance-based data collected by sensors and occupant comfort perception-based data collected via surveys. The performance data includes air temperatures, concrete slab temperatures in the Pavilion classrooms, and indoor CO_2 levels in both Renovated and Pavilion classrooms. Outdoor Air Temperature (OAT) is provided by The National Oceanic and Atmospheric Administration's (NOAA) online weather database[3]. The concrete slab temperatures will be measured using a handheld Raytek MiniTemp Infrared Thermometer. Indoor Air Temperature (IAT) and indoor CO_2 levels (PPM) are collected by wall mounted SIEMENS sensors installed in each Renovated and Pavilion classroom. Additional wall mounted Onset HOBO Data Loggers provided by the BUILT Lab will be used to verify the IAT and CO_2 readings taken by the SIEMENS sensors in ten target classrooms. Refer to Appendix A for photographs of the sensors used.

The occupant comfort data will be gathered by distributing a one-page, hard copy, anonymous seven-question survey to students taking summer classes in the KMC. The survey asks questions regarding clothing level (clo), thermal comfort levels, and preference between Renovated and Pavilion classrooms. Summer classes were not held in the Pavilion as the automated systems are still being fine-tuned. Thus, the survey data only includes responses from students taking courses in the Renovated classrooms. Previous Pavilion classroom survey data collected in the Fall of 2017 will be used as supplemental data (Lattin 2018). Both the performance-based data and the perception-based data will be stored in Excel and then translated into graphs and charts in order to identify correlations between outdoor environmental conditions and indoor environmental conditions, or between indoor environmental conditions and occupant comfort levels.

[3] https://www.ncdc.noaa.gov/cdo-web/search

PROCEDURES (Sensors, Concrete Slab Study, Surveys)

The Performance-based data was collected using three different procedures. First, Noel Mingo, PSU Facilities Energy and Utilities Manager, began remotely tracking IAT, CO_2, and airflows with the installed SIEMENS sensors in seven Renovated and all fifteen Pavilion classrooms. The Renovated classrooms that were tracked were: KMC 245, 255, 275, 350, 405, 470 and 560. The Pavilion classrooms that were tracked were: KMC 180, 185, 190, 285, 290, 295, 380, 385, 390, 480, 485, 490, 495, 580, and 590. Additionally, 10 priority classrooms were selected to also be monitored by HOBO sensors in order to verify the accuracy of the SIEMENS sensors. These classrooms were selected based off of highest observed plenum obstruction (Appendix B) and highest count of work order complaints received by FPM. Per the FPM work order complaints spreadsheet, KMC Rooms 190, 255, 295, 350, 380, 405, 460, 495, 560, 580 were identified as focus rooms. These sensors were installed closer to the ceiling in each room and left to record data for two weeks *(July 16th - July 30th).* The HOBO sensors were uninstalled and the collected data was trended into Excel and graphed against OAT and the SIEMENS (Appendix C) for a selected test classroom (KMC 190).

Concrete slab temperatures were manually collected every weekday at approximately 9:00 am and 4:00 pm for all fifteen Pavilion classrooms as well as in the West and East atriums from 07/05/18 to 08/27/18. The slab data was manually put into an Excel spreadsheet and then graphed with OAT in order to identify patterns of slab behavior, especially during extremely hot days (Appendix D). The plenums in each Pavilion classroom were examined in order to identify if rooms with greater plenum obstructions (Appendix B), which leads to less air flow and cross-ventilation, had higher slab temperatures since night flush wouldn't be at optimum performance.

The occupant survey and consent form (Appendix E) was distributed to students in Renovated classrooms at various times of the day throughout the summer term (June 25th - Aug 19th). Two methods of survey distribution were employed. The primary method involved emailing specific instructors who were teaching courses during times of the day and in certain classrooms that were identified as priorities for surveying and asking them if they would be willing to allow their students to participate in a brief survey during class time. It was decided that the optimal time to

survey students was either in the middle of class time or at the end of class so that students' metabolic rates would be close to resting rather than heightened as they are at the beginning of class time. Some instructors declined to participate, stating that there simply was not enough time to distribute surveys during their class time. The secondary survey method was to stand outside focus classrooms and hand out surveys to students as they exited their classrooms. This method did not prove to be very effective as most students were uninterested in filling out a voluntary survey.

DATA RESULTS + ANALYSIS

PERFORMANCE DATA ANALYSIS

Additional installed HOBO sensors in ten classes confirm that the current SIEMENS sensors are accurate. On average, the HOBOs recorded 1.6F warmer than the SIEMENS sensors, a possible explanation to this is that the HOBOs were placed closer to the ceiling whereas the SIEMENS sensors were placed at waist level (Appendix A, Figure A5). In regards to stack effect inside the KMC, the Pavilion classrooms increased in slab temperature by about 1F per floor when the outdoor air temperature exceeded 85F - 95F (Appendix D). The Renovated classrooms did not show any evidence of stack effect, most likely due to the controlled air conditions provided by the HVAC. The concrete slabs in the Pavilion are targeted to cool down to 70F during night flush.

EUI

One of the objectives of designing a building that utilizes passive cooling is to conserve energy. The EUI, a measurement widely used in the industry, calculates a building's energy use per gross square foot per year. This value determines a building's efficiency based on its gross square footage. Below is a study that compares the KMC's current EUI with its EUI prior to renovation when it was known as the School of Business Administration (SBA).

Prior to renovation in the fall of 2017, the SBA had an EUI of approximately **63 kBtu/gsf/year.** (Appendix G) The remodeled KMC was designed to have the lowest EUI on campus, at **25 kBtu/gsf/year.** The period between 04/03/18 and 07/22/2018 was extrapolated for a year and the EUI was calculated to be **24 kBtu/gsf/year.**

It is important to note that this EUI value was extrapolated based on a four-month measurement from April - July 2018 due to an insufficient record of energy utility bills that were available. As of July 2018, the building with the lowest EUI at PSU is the Helen Gordon Child Development Center at 40 kBtu/gsf/year. The KMC exceeded its target goal of 25 kBtu/gsf/year, it overperformed to be of the lowest EUI building on campus. This achievement provides a benchmark for future PSU buildings. As of September 2018, there are two buildings on campus that are under construction which are comparable to the KMC. The existing and under renovation Neuberger Hall proposed for LEED is ~56 kBtu/gsf/yr. The upcoming Fourth and Montgomery Building is ~26 kBtu/gsf/yr (this number includes a solar renewable energy source that provides for the building). To compare the KMC to these buildings, it performs the best even without a renewable energy source. However, the purpose of a building definitely impacts its EUI. Neuberger hall is more energy demanding due to its nature of holding multiple departments. Thus, greater energy is used to compensate for the greater demand of the building.

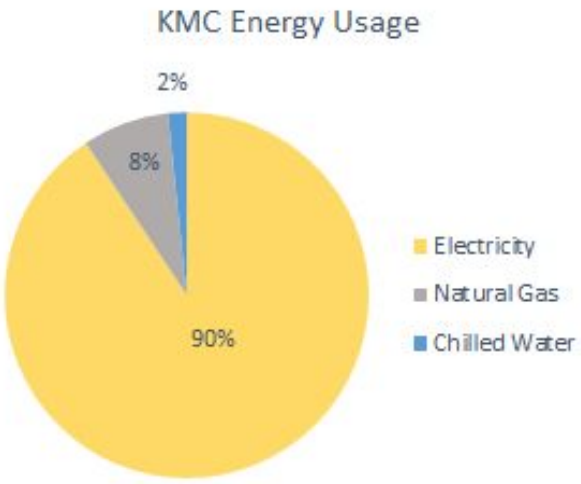


Figure 3: Energy Usage Distribution For The KMC.

PERCEPTION DATA ANALYSIS

The perception-based data was collected purely through student surveying. The paper survey responses were logged into Excel using a survey key that translated responses into single letter or number codes. These Excel sheets were then used to generate various pie charts, bar graphs, sunburst diagrams and conclusions related to thermal comfort (Appendix E). Some of the survey questions and multiple choice responses were based on ASHRAE Standard 55. For example, ASHRAE Standard 55 states that a thermal comfort question asked on a survey must include seven different thermal comfort levels: Cold, Cool, Slightly Cool, Neutral, Slightly Warm, Warm and Hot. Along with asking this question, the survey also asked occupants to circle their general comfort level with five options: Very Uncomfortable, Uncomfortable, Neutral, Comfortable and Very Comfortable. The correlations between these two different yet inherently related thermal comfort ratings are very interesting. Various other conclusions can be drawn between comfort levels and indoor environmental conditions. Below are the conclusions for each of the eight research goals.

RESEARCH GOAL COMPLETION

1. **Identify trends between the location, count, and reason for complaints.**

The tally tables below (Tables 1 and 2) show all of the work order complaints that FPM received from occupants in the KMC between August 2017 and July 2018. As stated by a School of Business faculty member, more complaints are made regarding comfort in the KMC, especially for Pavilion classrooms, but not all of these complaints are officially reported to FPM. In the future, it would be more helpful to officially record all complaints so that more accurate trends could be determined. Complaints that are highlighted blue represent comments that the building was “Too Cold.” Similarly, red comments are from occupants saying that the building was “Too Hot.” Yellow comments are for any other comments. In this case, the outlying comment was that one of the fans in Pavilion classroom 380 was too noisy. All of the Pavilion classrooms have high-speed fans installed in them as a passive cooling strategy.

Table 1: Number of Complaint Types as well as Date of Complaint for the Renovated Side.

KMC Renovated	Count	Type	Date
255 p	2	A/C not working. Too hot.	08/28/17
230 i	2	Too cold	12/13/17
262 p	1	Too cold	06/12/17
220 i	1	Too cold	12/11/17
245 i	2	Too hot	05/31/18
318 i	1	Too hot	11/07/17
310 i	3	Too hot	03/07/18
465 p	1	Too hot	02/01/17
405 i	1	Too hot	07/05/18
560 p	1	Too hot	05/31/18
570 p	1	Too cold	06/12/18
660C i	1	Too hot	10/11/16
610 (E through K) p	1	Too cold	12/13/17
610C p	1	Too cold	12/13/17
650 i	2	Too hot	10/10/16
605 i	1	Too hot	06/18/18
660 p	1	Too hot	02/19/18
630B p	1	Too hot	02/19/18
630C p	1	Too hot	02/20/18

Table 2: Number of Complaint Types as well as Date of Complaint for the Pavilion Side.

KMC Pavilion	Count	Type	Date
380 p	1	Noisy Fan	05/04/18
495 p	1	Too Hot	04/10/18
580 p	1	Fan not working + Too hot	05/08/18

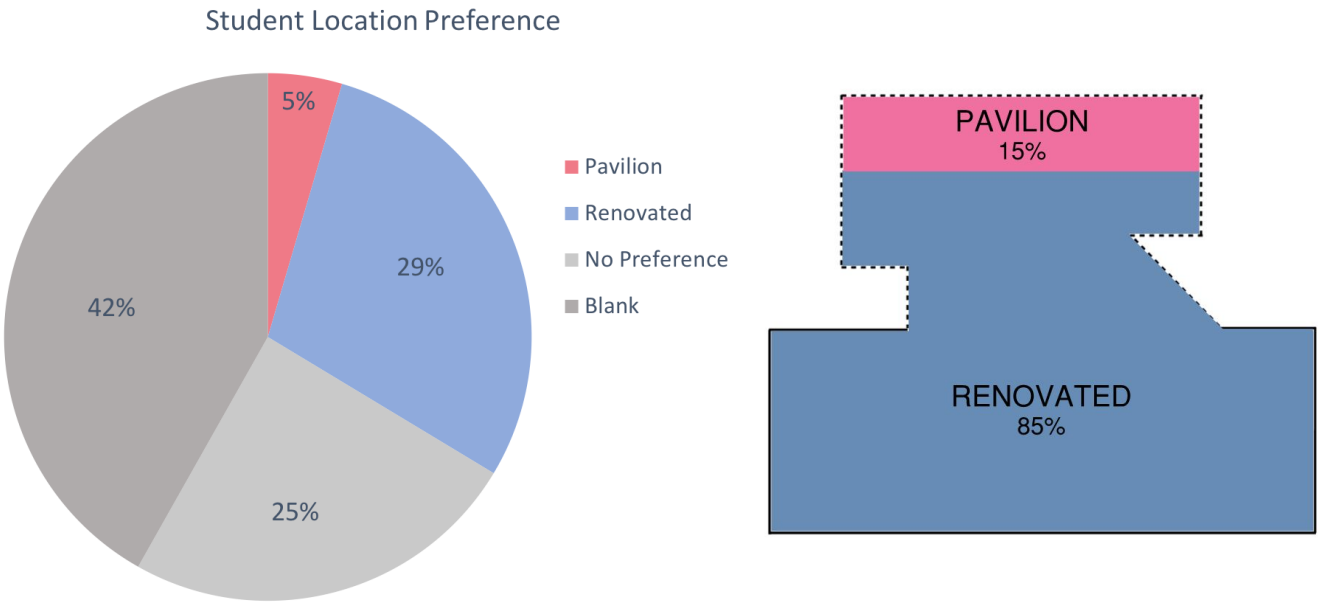
Surprisingly, only 10% of the total reported complaints were from the Pavilion side of the building. This number is much lower than expected based off of the data that was collected from both the surveys and the sensors showing that the Pavilion is often uncomfortably warm. Of the 90% of complaints that were from the Renovated side of the KMC, the complaints were split almost equally between Interior rooms and Perimeter rooms (56% Interior(i) and 44% Perimeter (p)). More of the complaints are expected to be from Interior rooms because these rooms often feel stuffier than Perimeter rooms, which all have operable windows. Overall, 71% of complaints were that the building was “Too Hot” while only 25% of complaints were that the building was “Too Cold.” Most of the “Too Hot” complaints were from the winter season, suggesting that the building may be being overheated during the winter.

Based on these observations, it is recommended that:

- During the winter, decrease the thermostat temperature by 1-2F to prevent overheating.
- During the summer, increase the thermostat temperature by 1-2F to prevent overcooling. This recommendation will be further validated in the conclusions of research goals 2, 4 and 6.

2. **Use student survey responses to compare location preference between, and thermal perception in, Renovated classrooms versus Pavilion classrooms.**

Survey responses in Renovated classrooms were collected during this study. Survey responses from Pavilion classrooms were provided by a former PSU architecture student, who conducted a similar post-occupancy study of the Karl Miller Center for an Honors thesis. Kythetica Lattin's survey data was collected during the fall term of 2017 (Lattin 2018). Figures 4 and 5 show the distribution of students' preference of location within the KMC. Figure 4 includes all survey responses. Dark grey is the percentage of students that left the question blank. Light grey shows that one-quarter of students did not have a location preference. This could either mean that they like the Renovated side and the Pavilion equally, or that they did not have enough experience in both sides of the building to have an opinion. Figure 5 compares Pavilion preference to Renovated preference.



Figures 4 and 5: Distribution Of Occupants' Preference In The KMC.

Student location preference was determined by asking survey Question 6ii - “Do you have a preference for occupying (A) or (B)?” A equals the Pavilion side and B equals the Renovated side. A surprisingly high number of students either left this question blank or stated that they did not have a location preference. This was the only survey question that had more than one or two blank responses total. As shown in Figures 4 and 5, students were 6 times more likely to prefer Renovated classrooms to Pavilion classrooms. This could be explained by taking a closer look at students’ thermal perception (Figure 6), or, in other words, how students felt temperature wise. This data comes from survey answers to Question 6i, which asked students if they notice a difference in temperature when they move from the Renovated side to the Pavilion side. This chart shows that 42% of students felt colder in the Renovated classrooms than they did in the Pavilion classrooms. This supports the observation that, in general, students prefer to feel cooler. Bear in mind that all surveyed students were occupying Renovated classrooms at the time of data collection. Thus, their recollections of the thermal conditions within the Pavilion classrooms most likely dates back to the spring 2018 term when the window night flush system was not functioning as designed.

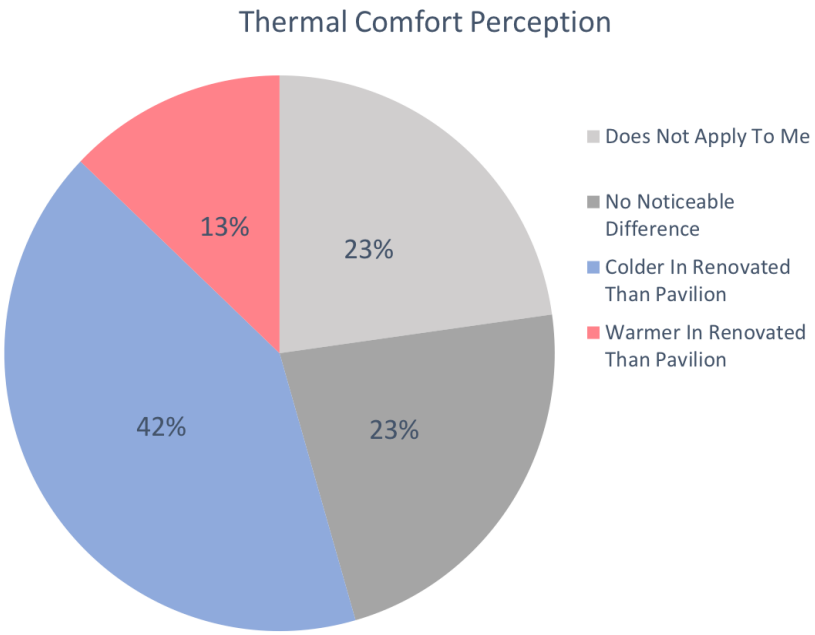


Figure 6: Thermal Comfort Perception of Occupants’ When Moving From Renovated to Pavilion.

Data compared to Pavilion survey data

Next, the Renovated side survey data (Figure 7) was compared with Lattin's Pavilion side survey data (Figure 8), specifically focusing on thermal comfort perception levels. Students had seven thermal levels to choose from based on ASHRAE's Thermal Sensation Scale: Cold, Cool, Slightly Cool, Neutral, Slightly Warm, Warm and Hot. At a glance, it looks like the distribution of various comfort levels are similar in Pavilion classrooms and Renovated classrooms. To determine which side of the building is providing greatest comfort to the most occupants, data from students who circled moderate comfort levels was isolated. This data only includes responses of: Slightly Warm, Neutral and Slightly Cool. For the Pavilion side, exactly 80% of occupants landed in the comfortable range. For the Renovated side, 82% of occupants landed in the comfortable range. ASHRAE's acceptable occupant comfort satisfaction rate is 80%. 10% dissatisfaction is assumed for local discomfort and 10% is for normal variances. Thus, it can be concluded that both sides of the building are providing the target comfort conditions.

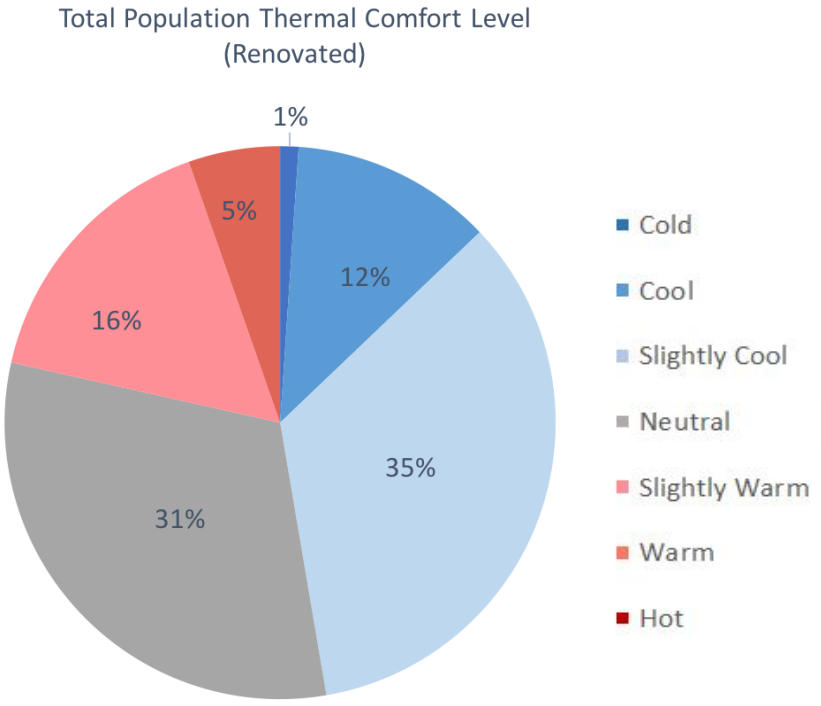


Figure 7

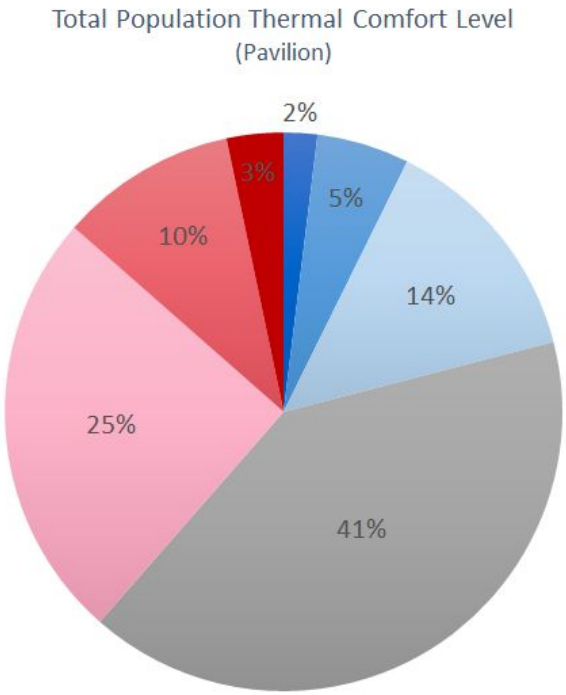


Figure 8

3. **Identify survey trends between gender and thermal comfort levels.**

Focusing on the four pie charts below (Figures 9, 10, 11, and 12), a few trends can be identified. First, regarding comfort levels for each gender, about half of surveyed men said they felt comfortable while less than a third of women said that they felt comfortable or very comfortable. Initially, the assumption was that this difference in gender comfort levels was because women generally prefer slightly warmer environments than men do, and since the Renovated classrooms tend to be cooler because they are mechanically regulated, it would be expected that women would generally feel less comfortable in these classrooms than men. According to one study, women prefer rooms at 77F while men prefer 72F.[4] All of the surveyed classrooms had indoor air temperatures of 68F - 73F, which is on the cool side even for male comfort levels. However, despite the rooms being on the cooler side, the data shows that a greater number of men felt colder than women felt. In fact, about 10% more men than women felt cool. Looking at Figures 9 and 11, more women actually felt warmer than men. Thus, a linear correlation between thermal comfort and temperature perception based on gender cannot be drawn from this data alone. What the charts show is that, overall, there is a mostly even distribution of comfort levels and temperature perception. Due to this even distribution, no recommendations can be made based on this research goal conclusion.

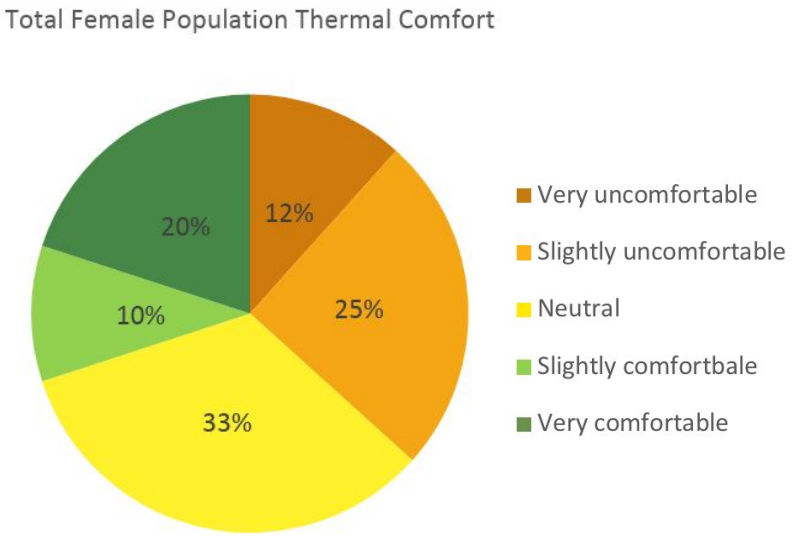


Figure 9: Distribution of Female Population Thermal Comfort

[4] https://www.nature.com/articles/nclimate2741#close

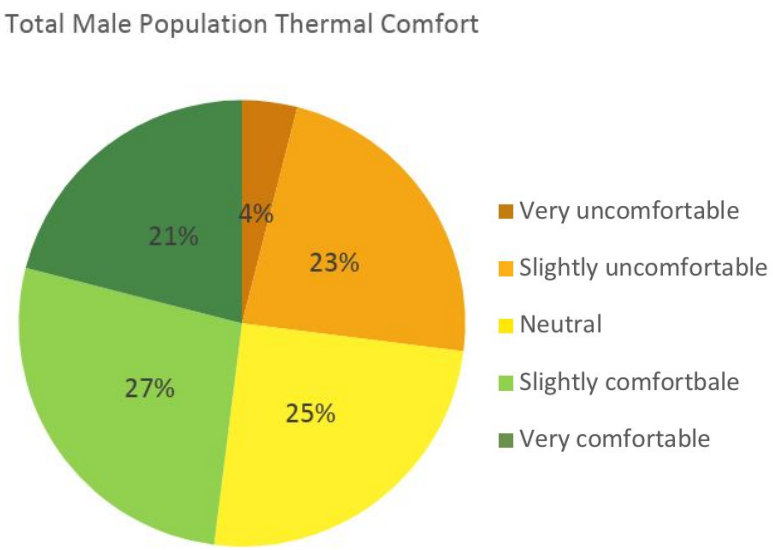


Figure 10: Distribution of Male Population Thermal Comfort

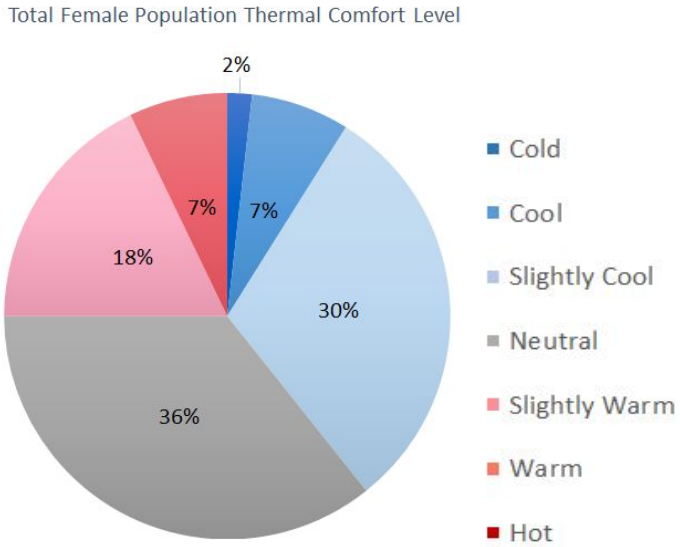


Figure 11: Distribution of Female Population Thermal Comfort Levels

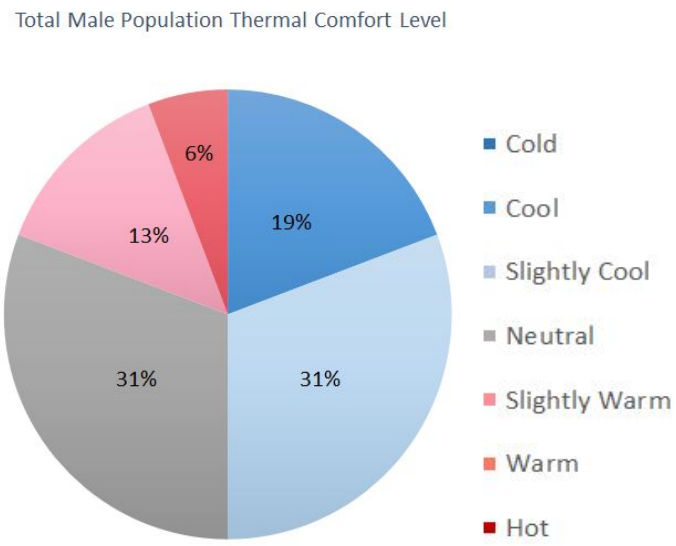


Figure 12: Distribution of Male Population Thermal Comfort Levels

4. **Compare occupant comfort levels with indoor air temperature and CO_2 levels in surveyed classrooms. Compare occupant comfort levels in Interior and Perimeter Renovated classrooms.** Use student surveys and SIEMENS sensor data from Renovated classrooms. The Interior classrooms studied are KMC 245 and 275 (boxed in blue). The Perimeter classrooms studied are KMC 255, 470 and 560. (Figure 13)

Figure 13 shows six pie charts representing the six survey sets and states the indoor environmental conditions that existed at the time when the surveys were conducted. All six of the survey sets are from students in Renovated classrooms. Based off of the data collected, neither IAT nor PPM seem to be the key deciding factors for thermal comfort. Rather, classroom location within the Renovated side of the building seems to be the deciding factor for occupant comfort levels. For example, looking at the pie charts in the blue boxes (interior classrooms), there are greater levels of discomfort compared to the other charts. This suggests that interior classrooms provide more unpleasant conditions for the occupants. A possible explanation for this may be due to a psychological effect. According to the LEED v4 for Operations & Maintenance Checklist, points could be scored for daylight and quality views. Due to the location of an interior classroom, it receives no direct sunlight as it has no operable windows. Based on the survey results, it is recommended that the air flow in KMC Room 275 be increased in order to reduce PPM and IAT due to such a high level of discomfort.

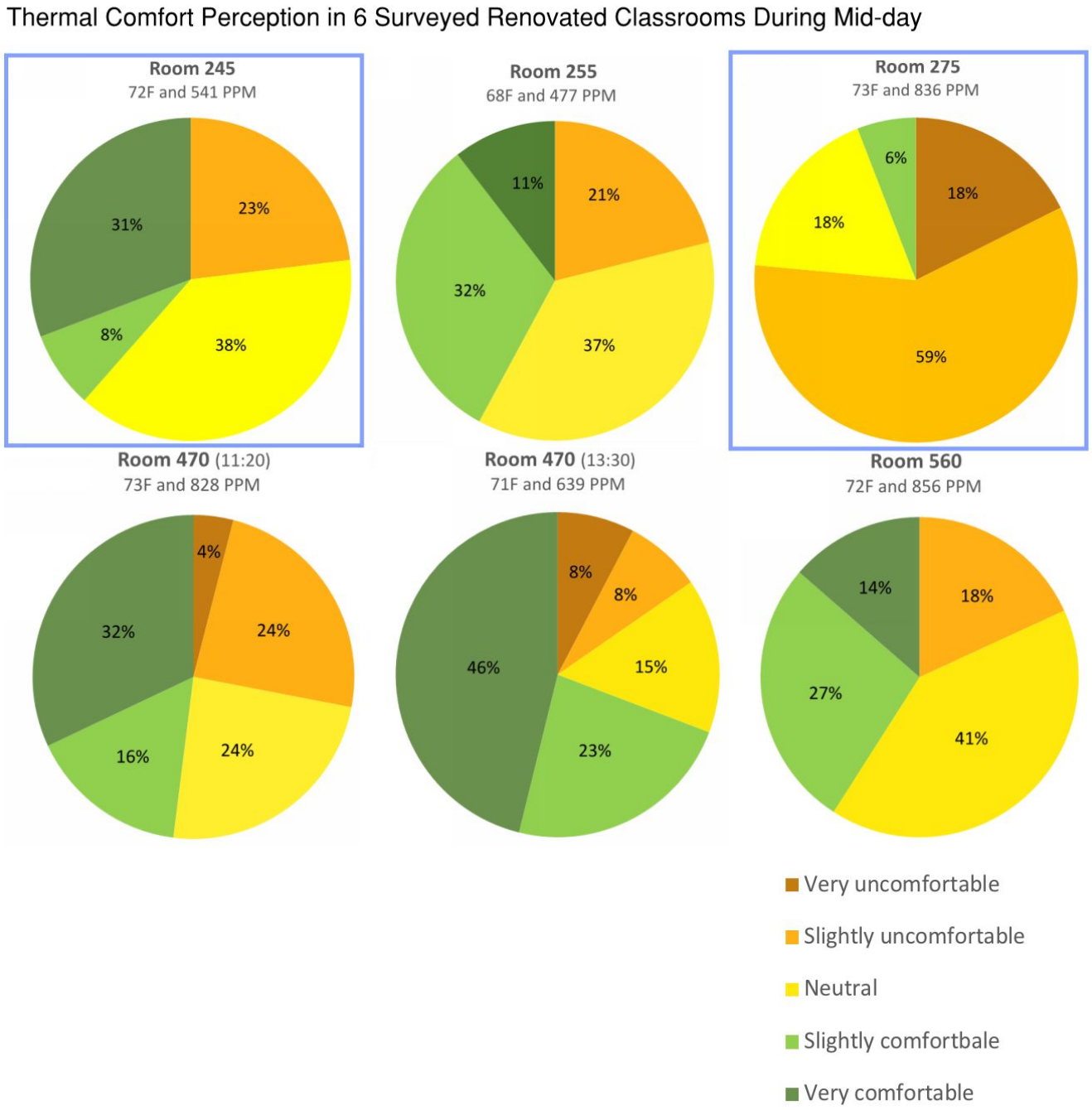

Thermal Comfort Perception in 6 Surveyed Renovated Classrooms During Mid-day
Room 245
72F and 541 PPM
23%
38%
8%
31%
Room 255
68F and 477 PPM
21%
37%
32%
11%
Room 275
73F and 836 PPM
18%
59%
18%
6%
Room 470 (11:20)
73F and 828 PPM
4%
24%
24%
16%
32%
Room 470 (13:30)
71F and 639 PPM
8%
8%
15%
23%
46%
Room 560
72F and 856 PPM
18%
41%
27%
14%
Very uncomfortable
Slightly uncomfortable
Neutral
Slightly comfortbale
Very comfortable

Figure 13

5. **Correlate total population comfort levels with thermal perception.** Use student responses from survey questions 4 and 5.

ASHRAE Standard 55 requires that post-occupancy studies that ask occupants about their thermal comfort level must provide a 7 point 'Thermal Sensation Scale' as the answer options: Cold, Cool, Slightly Cool, Neutral, Slightly Warm, Warm and Hot. Along with this question, the survey distributed during this study also includes a question that asks, "Overall, how thermally comfortable are you in this room?" and then provides five more general answers: Very Uncomfortable, Uncomfortable, Neutral, Comfortable and Very Comfortable. The researchers asked both of these questions about the same topic because they not only wanted to determine thermal comfort level using the above ASHRAE question, but also to identify potential thermal sensations that most students felt 'Comfortable' at.

Figure 14 is a sunburst diagram, which is essentially a two-tiered pie chart. Appendix H Figure H1 represents the same data but in a different visual format. The IAT range for this sunburst diagram is between 68F and 73F. As shown above, most students that circled thermally Neutral also circled that they felt Neutral temperature-wise. In total, 70% of students felt Neutral, Comfortable, or Very Comfortable. 64% of those students also said they felt on the neutral to cooler part of the temperature spectrum. This supports the conclusion that students prefer to feel Slightly Cool or Cool while in the classroom setting. Of the 25% of people that felt uncomfortable, 52% of students that said they either felt Uncomfortable or Very Uncomfortable also circled thermally Slightly Warm or Warm. This supports a conclusion that overheating causes greater discomfort than overcooling does.

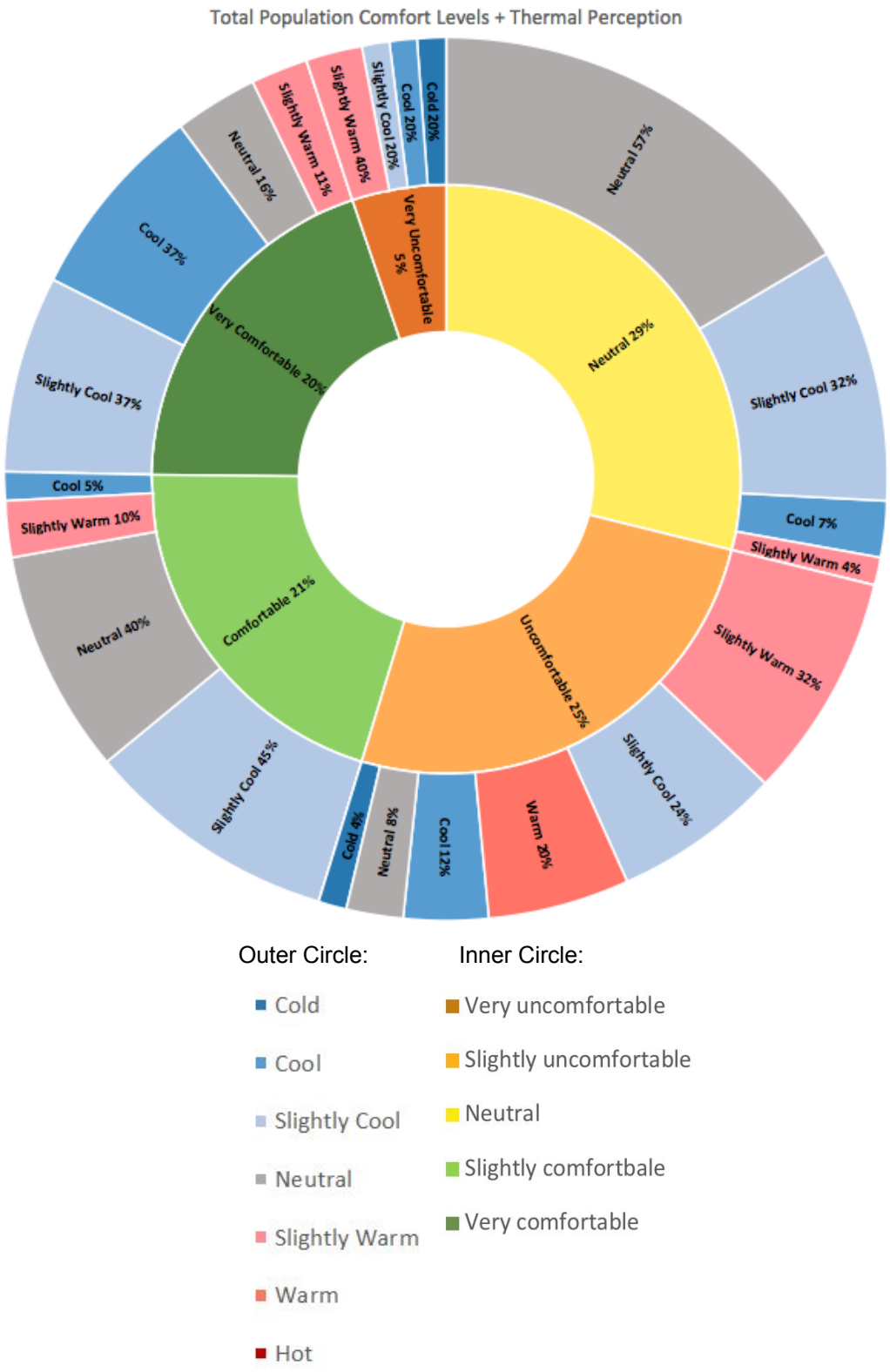


Figure 14: Sunburst Diagram That Displays Thermal Comforts and Thermal Comfort Levels.

6. **Determine the effectiveness of the night flush procedure in Pavilion classrooms.** Track concrete slab temperatures every morning and every evening in each Pavilion classroom using a handheld infrared thermometer.

The data supporting that night flush is effective is shown in table 3. The Apogee night flush reports showed that night flush began to execute as designed on the night of 08/08/2018. One way to establish the effectiveness of night flush in the Pavilion was to compare the decrease in concrete temperature overnight between two separate nights. In order to make this a fair comparison, two dates with similar outdoor air temperatures were selected (approx. 1% different). The average decrease in concrete slab temperatures (of every Pavilion room) was compared. It was found that prior to 08/08/2018 (when night flush was not operating as designed) the average decrease in slab temperature was 0.94F. After successful night flush, the average decrease in slab temperature was 1.62F. This 72% difference suggests that night flush does have an impact on the concrete slab temperatures.

Table 3: Concrete Slab Temperatures Before and After Successful Night Purge

	7/16/18 4pm to 7/17/18 9am	8/9/18 4:30pm to 8/10/18 9am
Outside Air Temperature From Previous Evening to Next Morning (F)	95 to 69	94 to 70
Average Decrease in Pavilion Slab Temperatures (F)	0.94	1.62
Percent Change	72%	

Another factor that could have made this research goal better attainable was to have occupancy within certain classrooms. The presence of people in a space provides valuable information regarding met per person and the heat added when occupied. This information could then be cross-referenced with before and after successful night flush to better support or disagree with the effectiveness of night flush.

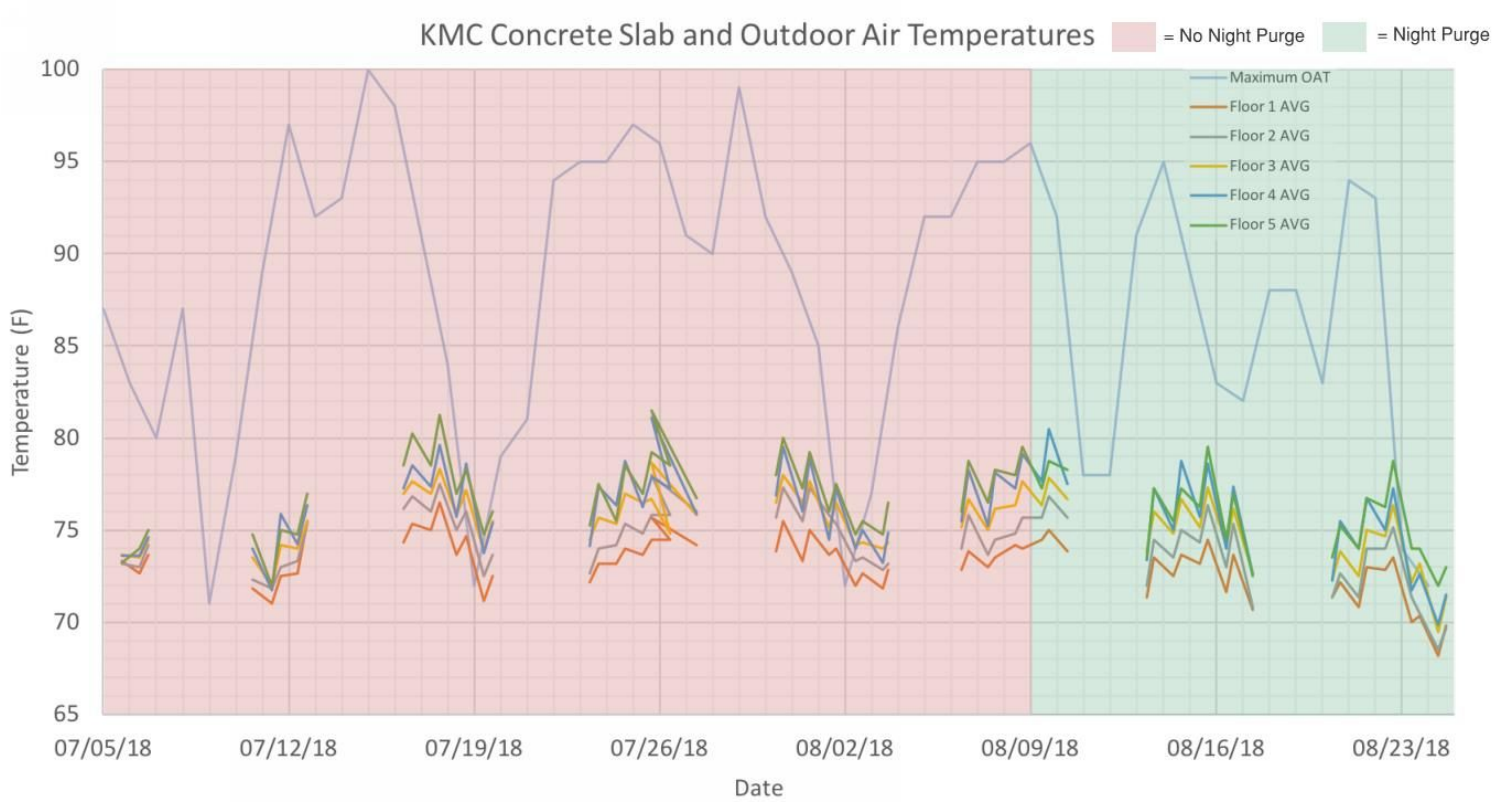


Figure 15: Maximum Oat Per Day Vs Floor Average Concrete Slab Temperatures Of The Pavilion Side Over Time.

Figure 15 shows the relationship between the indoor conditions of the Pavilion and the maximum OAT per day. As expected, as the OAT increases, concrete slab temperatures also increase. The opposite trend can also be recognized if OAT decreases. To focus more on the night flush effectiveness, the red region, in general, sees higher concrete slab temperatures than the green region. Although this difference may not be very great, it is enough supporting data to claim that night flush has an effect on concrete slab temperatures. Additionally, the stack effect in the KMC is apparent and follows the principles of physics. Heat within a closed space will elevate to the top (in this case, floor 5) which leaves the lower floors cooler in temperature. The graph shows that as OAT increases, the difference in floor averages also increases. This is also true for vice versa.

7. **Determine summer course suitability in Pavilion classrooms.** ***(75F = IAT comfort threshold)*** *(15 classes total)*

Summer course suitability is determined using two different methods. First, overheating days, defined as days when a classroom exceeds 75F at any point in time, were identified from 5/21/18 to 08/15/18 (Table 4). The second method focused on the hours of the day between 6 am - 11:45 pm during which the average IAT was below 75F. This method is more accurate because it is time-dependent and displays the hours of suitability (Appendix I, Table I1). The designed comfort temperature threshold is intended to be 78F, but since there was not consistent student occupation within the Pavilion classrooms this summer, it is assumed that the rooms would be 3 degrees warmer than recorded if students were present.

The first floor is the most comfortable temperature-wise in the Pavilion during warmer months. In terms of overheating hours, no classroom on the first floor averaged a temperature greater than 75F by the time of day average (Appendix I, Table I1) in intervals of 15 minutes. The highest temperature recorded in room 180 during spring term was 78F and it only reached this temperature twice over a period of 30 days. 185 only overheated once during the entire summer. Based on overheating days, it is not recommended that summer classes should be held in 190 because there was a total of 31 overheating days (above 75F). A possible explanation for this observation is the obstruction in the plenums which inhibits cross-ventilation. Appendix B Figure B4 displays sketches of the plenum of room 190. It was found that the area that air can pass through is 17.5 in^2. This area is much smaller than other classrooms. Even during the summer when the room was unoccupied, multiple overheating days occurred. It is anticipated that the overheating in room 190 is caused by over-obstructions in the plenum, which leads to insufficient cross-ventilation. The engineers at PAE are investigating the obstruction and believe the acoustic boot in the plenum is the major obstruction. PAE recommended that this boot should be resized. This remodel should greatly improve the natural ventilation in this classroom, however, cannot be guaranteed. Additionally, 190 has a high amount of glazing on its East facade and thus has a greater heat gain in the morning. 180 and 185 never get direct sunlight because their exterior facades are on the North side of the building.

In total, only two classrooms have been identified as semi-occupiable by overheating days and both are on the second floor of the Pavilion: KMC 285 and 295 (Figure 16). 285 had 22 overheating days and 295 had 21 overheating days. When it was unoccupied, 295 was, on average, 1F cooler than 285 and it also had less overheating days than 285. 295 never exceeded 77F during the summer, and 285 never exceeded 78F; 285 and 295 temperature graphs are included in Appendix F, Figures F5 and F6. However, for overheating hours, the same conclusions can be made as those made for the first floor. No classroom on the second floor averaged a temperature greater than 75F for any time of day. This discrepancy could be explained by the fact that on average the rooms are cool, but, the IAT's exceeded 75F on hot days.

Based on the overheating days and hours analysis, the researchers recommend that class schedules should be determined by overheating hours for each room of interest.

Under the current operating conditions, based on overheating days, the remaining rooms (190, 290, and all classrooms on floors 3, 4 and 5) may not be suitable for summer classes as there are too many exceedance days over 75F even when unoccupied. These rooms range from 31 to 50 exceedance days. In contrast, overheating hours support otherwise, to an extent. Overheating hours suggest all classes on the 3rd, 4th, and 5th floor are semi-suitable rooms depending on the time of day. Refer to Appendix I, Table I2 for hours of suitability for all classrooms. If faculty are interested in scheduling classes that are to be held in cooler rooms (below 72F), Appendix I, Table I3 provides a less forgiving judgment of classrooms temperatures.

Appendix F, Figures F1 and F3 show temperature readings that support the recommendation of classrooms. As shown, 180 shows much cooler readings than 190. Focusing on 180, OAT was much lower in the spring term yet IAT still occasionally exceeded 75F, possibly due to heat release from occupants. For 180 in the summer term, IAT never exceeded 75F when unoccupied despite OAT being 90F+.

Figure 16: Summer Class Suitabilities by Room. (Overheating Days)

Table 4: Number of Overheating Days above 75F.

KMC Room	Count Above 75F	Notes
180	5	Coolest room. All observations were in spring term (05/24 to 06/07). No exceeding temps when unoccupied.
185	1	Data after 06/11. 1 Exceeding temp when unoccupied. No temp data for occupied times.
190	31	Warmest room. Multiple exceeding temps even when unoccupied.
285	22	Overheating days are not occupancy dependent.
290	40	Warmest room on 2nd floor.
295	21	-
380	32	Data after 07/09.
385	49	Warmest room on 3rd floor.
480	53	Warmest room on 4th floor.
485	34	-
490	47	Data after 06/11.
495	32	Data after 07/10.
580	36	Data after 07/09.
590	50	Warmest room. All time data.

Looking at the survey data analysis from An Indoor Environmental Quality Assessment, Lattin concluded that KMC 180, 285, and 480 were the most comfortable Pavilion classrooms. This conclusion mostly lines up with the conclusions drawn from looking at performance-based data in the Pavilion. 180 was identified as a highly suitable classroom to hold summer classes in, and 285 as a 'mostly' suitable classroom. Just focusing on overheating days, 480 is not a suitable classroom, but looking more specifically at suitable hours per day, 480 is suitable during the summer from 6 am - 3 pm. This partial discrepancy between Lattin's conclusion, which was based purely on occupant perception-based data, and this paper's conclusion, which was based purely on classroom performance-based data, is proof that in order to draw the most accurate conclusions, both types of data should be examined.

In order to better predict suitability times, further analysis needs to be conducted and will be continued in Fall 2018 by the researchers.

8. **Compare Indoor Air Temperature and CO_2 levels between the Renovated classrooms and the Pavilion classrooms.**

Although IAT and CO_2 levels were collected in both Pavilion and Renovated classrooms on each of the five floors, a few limitations occurred. First, there were no official summer classes in the Pavilion, so there were no detectable CO_2 fluctuations as occupancy was inconsistent. The Renovated classrooms did have students in them during most weekdays, but these rooms have HVAC so CO_2 was regulated properly. The only exception was Room 275 which saw high levels of occupant discomfort due to stuffiness and perceived warmer temperatures. The interior classrooms have no operable windows and showed slightly higher CO_2 levels compared to their Perimeter counterparts which have both HVAC and windows. IAT comparisons between the Renovated and Pavilion sides are also skewed because the automatic window system wasn't functioning properly during most of the data collection period. At seating (quiet) humans are at 1.0 Met, releasing 80 Btu/h·ft^2 to the surroundings (ASHRAE Standard 55 Chapter 5.2, Table 5.2.1.2). Since the Pavilion classrooms had little to no summer occupancy, a valid comparison could not be drawn.

CONCLUSIONS

In conclusion, the Karl Miller Center is performing as it was intended to by the design team. The Energy Use Index proves that the KMC is over-performing, making the KMC the lowest EUI building on campus. The Renovated side of the building is maintaining a comfortable temperature range for 82% of its surveyed occupants. For the Pavilion side, 80% of occupants landed in the comfortable range (Lattin 2018). ASHRAE standards encourage designers to create indoor environmental conditions that 80% of the total population will feel comfortable in. Thus, it can be concluded that both sides of the building are providing the realistically ideal comfort conditions. In terms of occupant thermal comfort, 64% of students that said they felt neutral to comfortable in their classrooms also answered that they prefer to feel slightly cool. This supports the conclusion that students prefer to feel Slightly Cool or Cool while in the classroom setting. 50% of the students that felt uncomfortable in the Renovated rooms also circled thermally Slightly Warm or Warm. 40% of uncomfortable students circled Slightly Cool to Cold. This supports a conclusion that overheating causes slightly greater discomfort than overcooling does. Additionally, the Pavilion passive cooling procedure was vastly improved during the period of this research, and at best, classrooms cooled 4.4F overnight when Outside Air Temperatures reached above 92F during the previous day.

RECOMMENDATIONS

In regards to occupant surveying, the most beneficial time of year to conduct a survey study similar to this would be during the regular school year when classes are held in both the Renovated and Pavilion classrooms. This would allow for accurate comparisons of comfort levels between the two portions of the building to be made because outside conditions would be consistent. It is also recommended that those conducting the study individually email instructors that they hope will participate. This method resulted in greater instructor responses because it allows for more personalization and specificity in the emails/coordination. In a future post-occupancy comfort study, it would be interesting to ask a survey question regarding occupant age. Also, it would be interesting to compare age with thermal comfort levels, especially since PSU has a very wide range of student ages. It would also be interesting to compare indoor

air temperature and thermal comfort levels in east Pavilion classrooms versus west Pavilion classrooms to see if there are clear differences.

In terms of building operations, data collected during this study supports a recommendation that during the summer, the thermostat temperature should be increased by 1-2F to prevent overcooling. Similarly, during the winter, the thermostat temperature should be decreased by 1-2F to prevent overheating. Based on survey responses, it is advised that airflow should be increased in KMC Room 275 due to high levels of occupant discomfort and complaints about stuffiness/broken air conditioning.

On the Pavilion side, based on the examination of IAT and concrete slab temperatures in each of the fifteen classrooms, KMC 180 and 185 are the most ideal for holding summer classes in at all times of the day. These two rooms had very low counts of overheating days, and thus, are highly suitable. Depending on 2019 summer class performances of 180 and 185, 285 and 295 could hold summer classes at all times of the day as well. KMC 290, Floors 3, 4 and 5 are not recommended for holding summer classes in. These rooms each had 30-60 overheating days during the end of spring through the summer, when the rooms consistently had little to no occupation. Overheating is defined as reaching an indoor air temperature above the comfort threshold of 75F. Lastly, more occupant education is needed regarding the passive ventilation features in the Pavilion classrooms. Based on survey results, it is clear that a large number of SBA students do not understand that the Pavilion intentionally does not have an HVAC system. Posters should be placed inside each Pavilion classroom next to the fan/window switches with simple diagrams showing how the windows and fans operate and explaining how passive cooling works as well as its energy saving benefits.

REFLECTIONS

Potential Causes for Occupant Discomfort:

- The TUs and FSDs are not installed in the specified locations as designed. Some of the plenums in the Pavilion classrooms are obstructing airflow, which reduces the efficiency of night flush as well as natural ventilation during the day.

- The designers assumed the normal school year to be from October 1st - April 3rd, when, in reality, the normal school year is from September 25th - June 12th. This resulted in a 10-week discrepancy regarding normal building occupation times, which most likely had a big impact on the passive ventilation calculations.

- The gateway that translates between the SIEMENS sensors and the Functional Fenestrations windows wasn't functioning properly. Thus, the windows did not open as often as they were supposed to during night flush mode.

ACKNOWLEDGMENTS

We would like to thank Emily Quinton - Campus Sustainability Office Sustainability Education + Outreach Coordinator, Quinn Soifer - CPC Technical Services Manager, Mark Fujii - CPC Senior Project Manager, Noel Mingo - PSU Facilities Energy and Utilities Manager, and Jenny Mcnamara - CSO Campus Sustainability Manager for providing support and feedback throughout our internship. We would also like to thank Jen Rushen from the School of Business Administration for facilitating communications with the following SBA instructors who generously allowed us to survey their students during class time: Melanie Billings-Yun, Douglas Lowell, Stanton Heister, Joleen Kremin, Richard Howell and Kristi Yuthas (for allowing us to survey her class as well as helping us with data visualization). Last but not least, we would like to thank the BUILT Lab for providing technical support and equipment.

SOURCE LIST

- Lattin, Kyhetica. “An Indoor Environmental Quality Assessment.” *The Study of Naturally Ventilated University Classrooms Within a Mixed-Mode Ventilated Building*. 2018. doi:10.15760/honors.592.
- ASHRAE. “ASHRAE TERMINOLOGY.” 2018. https://www.ashrae.org/technical-resources/authoring-tools/terminology
- ASHRAE. “Thermal Environmental Conditions for Human Occupancy.” ANSI/ASHRAE Standard 55-2013. www.ashrae.org.
- ASHRAE. “Ventilation for Acceptable Indoor Air Quality.” ANSI/ASHRAE Standard 62.1-2016. www.ashrae.org.
- Behnisch Design Intent
- SRG + Behnisch Concept Design Booklet IIA (April 18, 2014)
- SRG + Behnisch Land Use Review Presentation III (Aug 6, 2015)
- BUILT Lab Research Based Design Initiative (RBDI) posters - http://www.builtpdx.org/
- LEED v4 for Building Operations and Maintenance: Existing Buildings. https://www.usgbc.org/resources/checklist-leed-v4-building-operations-and-maintenance

APPENDICES

APPENDIX A

Sensors Utilized For Performance-based Data Collection.

Figure A1: SIEMENS QMX3. P34/P74 Figure A2: Raytek MiniTemp MT4 Handheld Thermometer

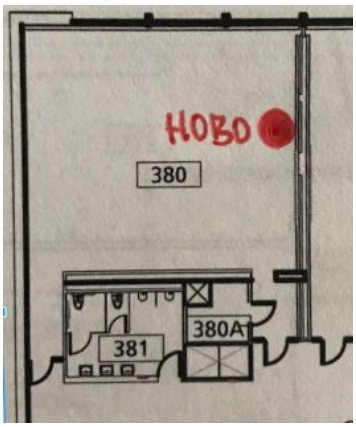


Figure A3: Onset HOBO U12 *Figures A4 And A5: Hobo Sensor Location Within Classrooms*

APPENDIX B

Detailed Plenum Sketches

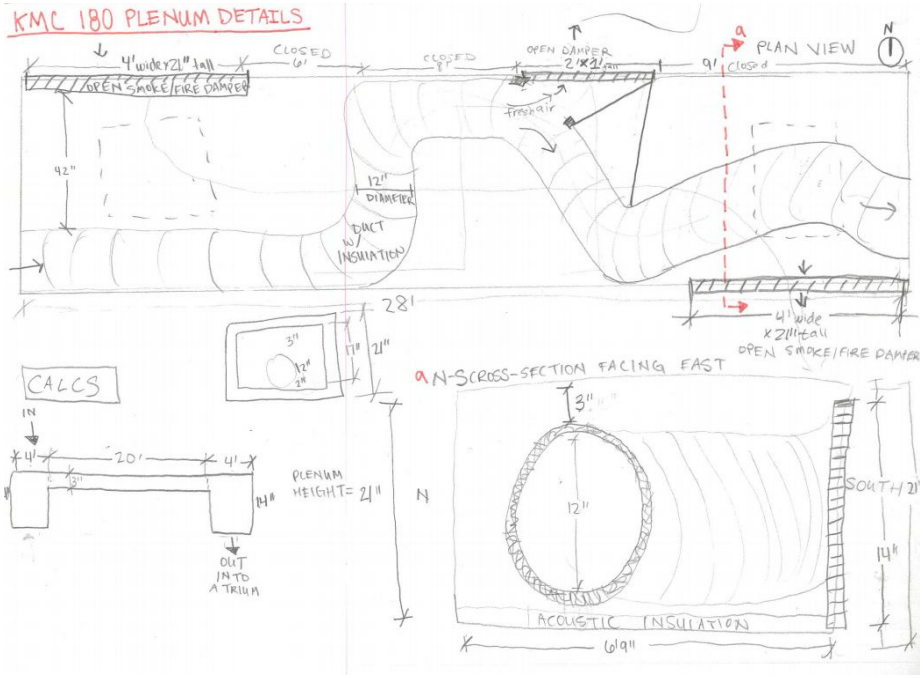


Figure B1: KMC 180 Plenum Drawing. (Western)

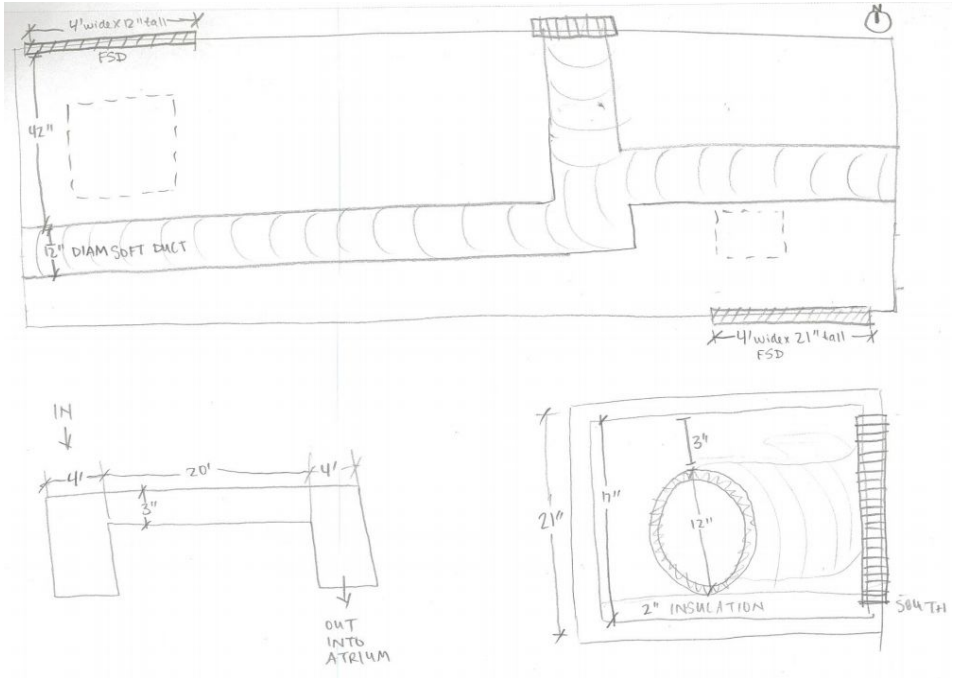


Figure B2: KMC 180 Plenum Drawing. (Eastern)

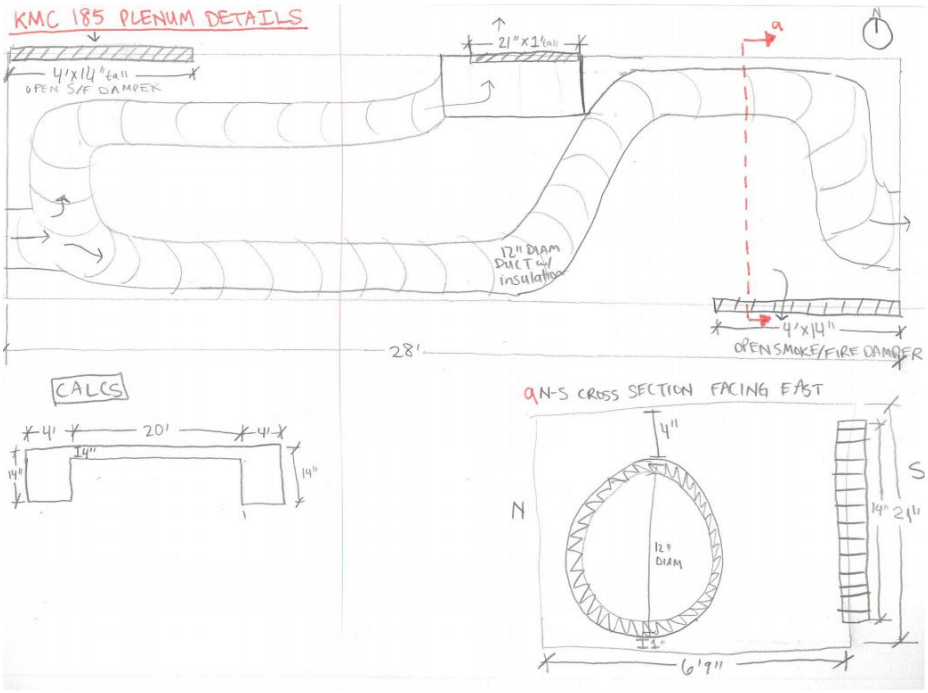


Figure B3: KMC 185 Plenum Drawing.

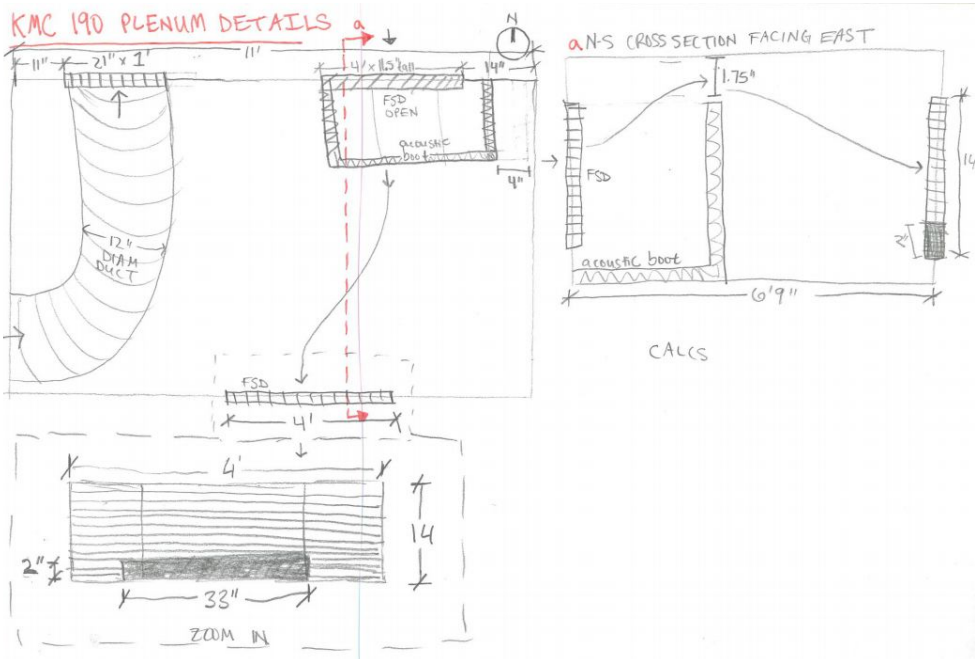


Figure B4: KMC 190 Plenum Drawing.

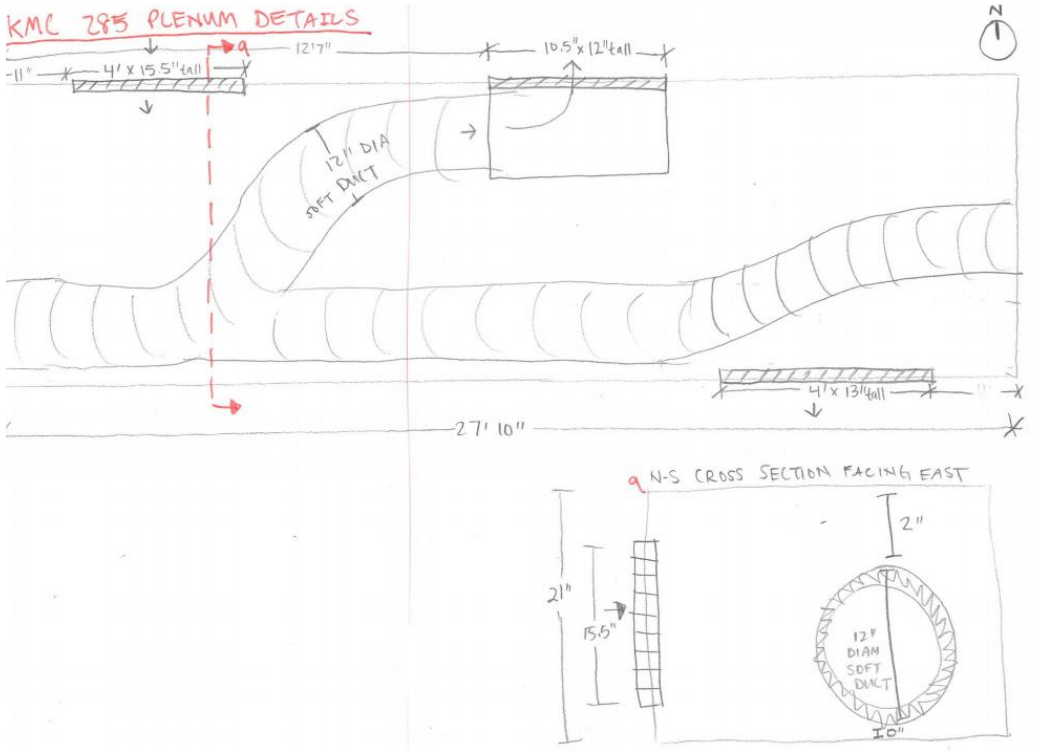


Figure B5: KMC 285 Plenum Drawing.

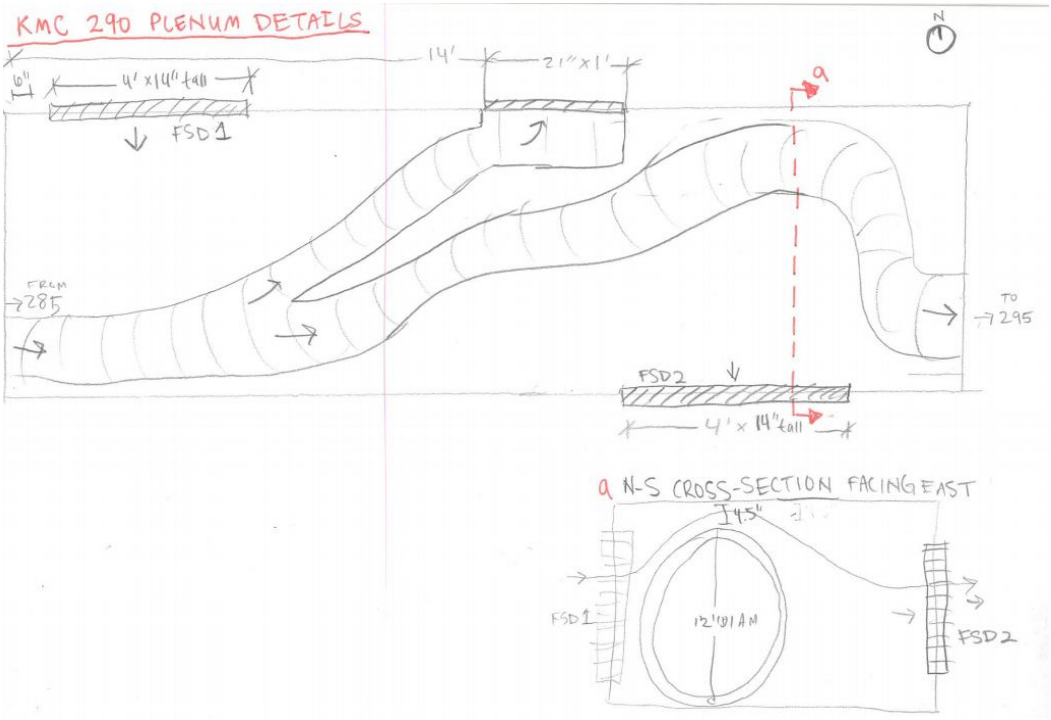


Figure B6: KMC 290 Plenum Drawing.

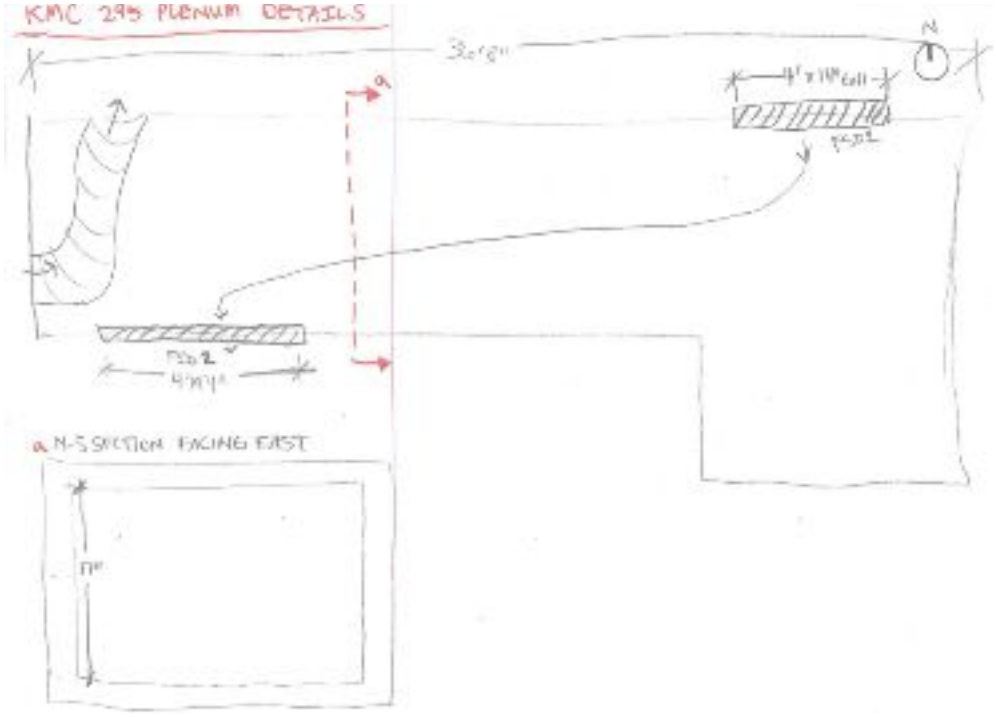


Figure B7: KMC 295 Plenum Drawing.

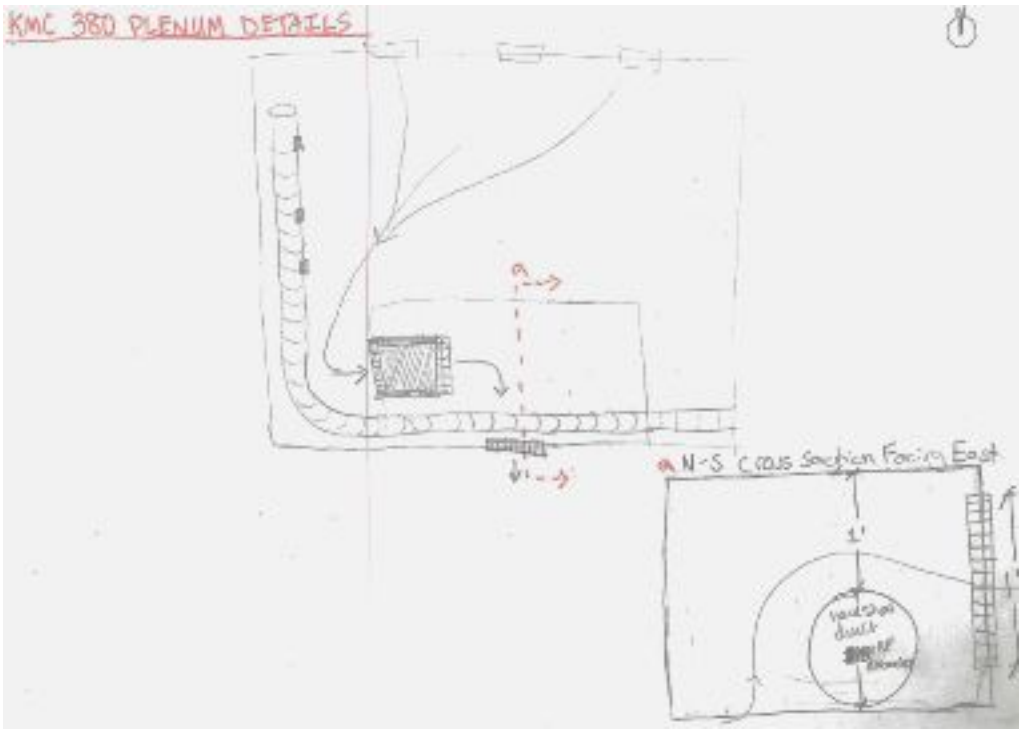


Figure B8: KMC 380 Plenum Drawing.

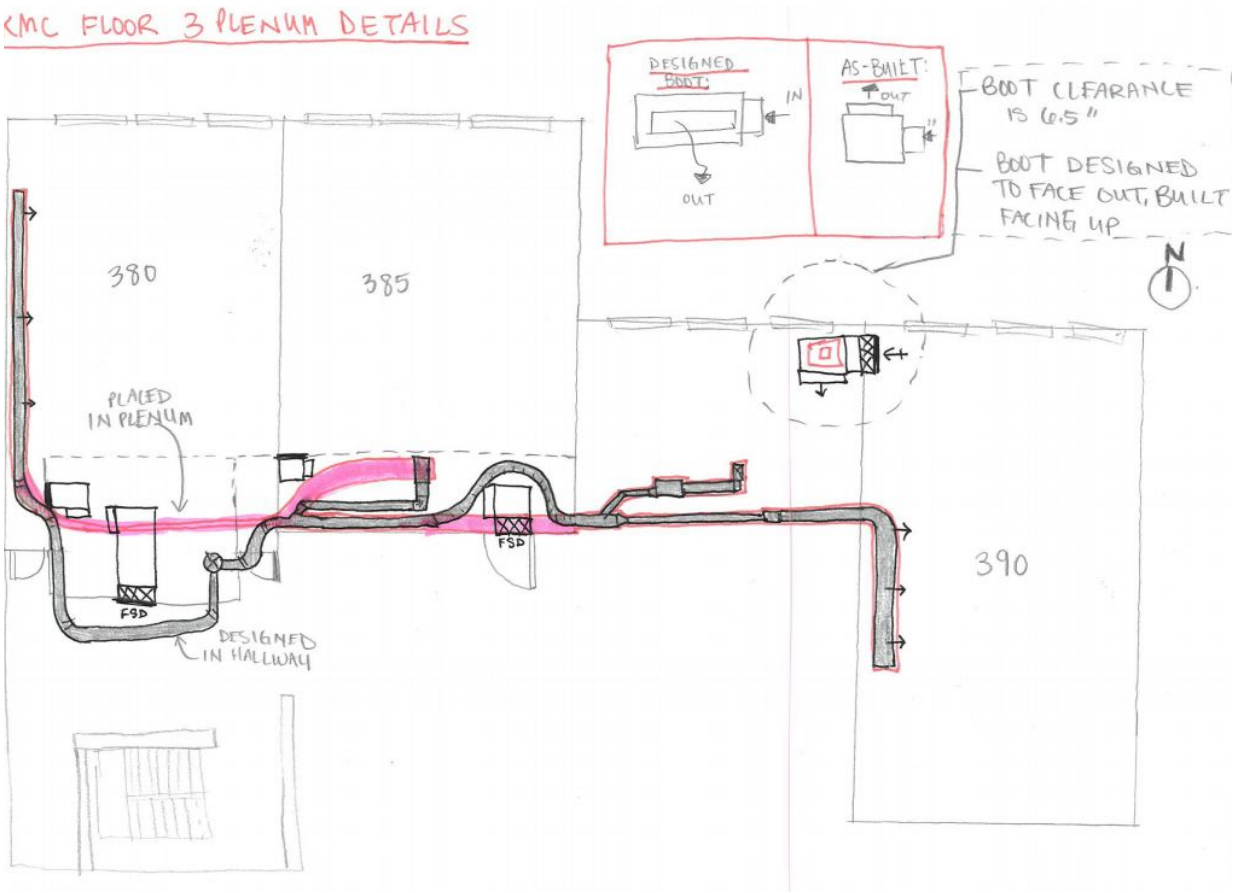


Figure B9: KMC Floor 3 Plenum Drawing.

APPENDIX C

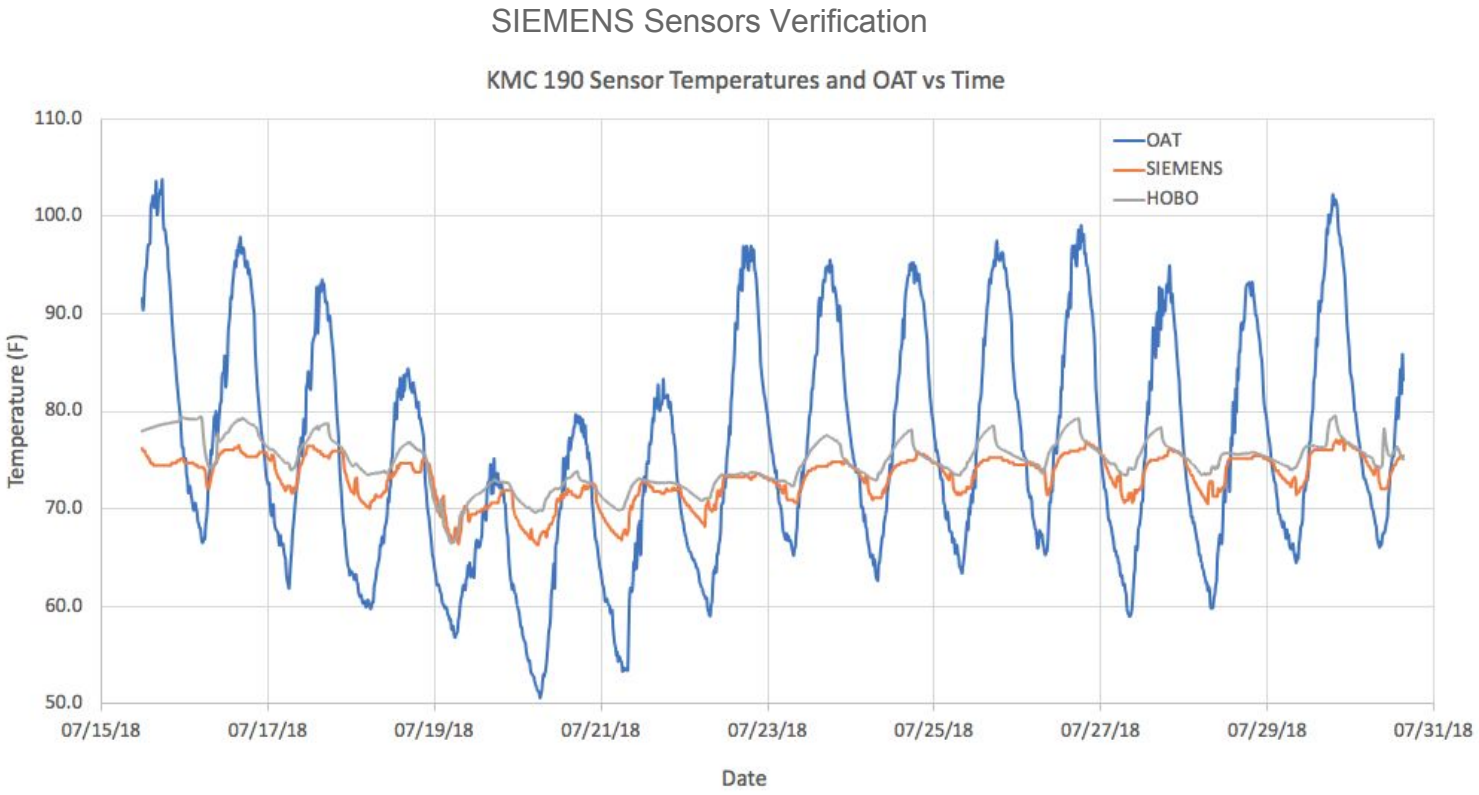


Figure C1: SIEMENS And HOBO Sensors Graphed Along With OAT vs Time.

APPENDIX D

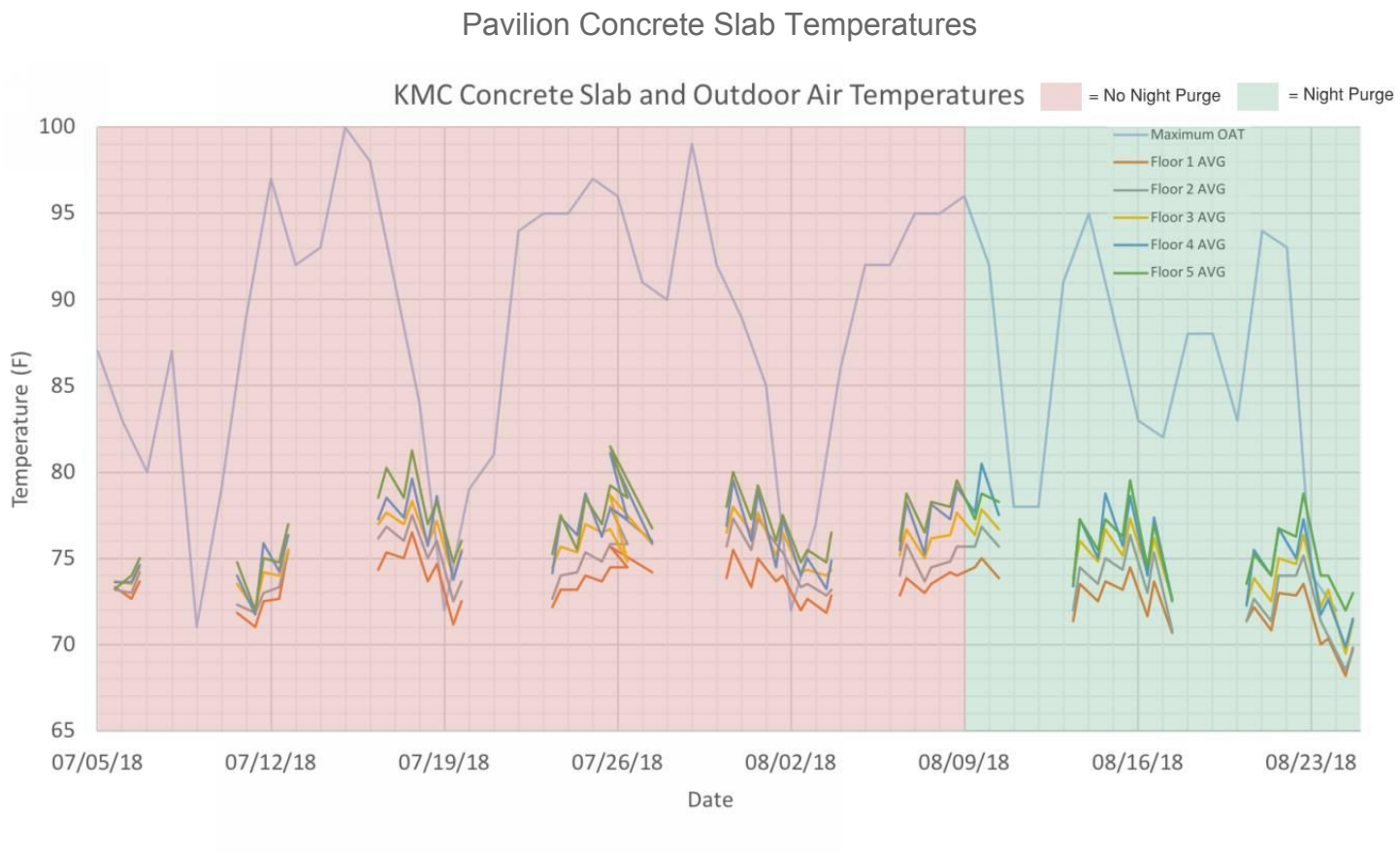


Figure D1: Concrete Slab Temperature Averages per Floor Against Maximum OAT.

APPENDIX E

Consent Form

KMC Survey Consent Form

Participant,

Taking part in this survey is completely voluntary. All survey results are anonymous. It is in your right to deny, refuse, and/or discontinue participation at any time with no penalty or loss of benefits.

This study includes research and data conducted on how the design of the Karl Miller Center's new addition and remodel affects the level of occupant comfort in the building. This study is in partnership with PSU's Institute for Sustainable Solutions Living Lab (ISS) Program, PSU Capital Projects and Construction (CPC), and the School of Architecture's Building Science Lab to Advance Teaching (BUILT).

During this project, we will analyze ventilation design performance versus occupant comfort. Our research specifically focuses on how passive architecture reduces the need for conventional HVAC systems. Passive architecture is a design strategy that uses climate, orientation, and the location of a building to optimize natural environmental conditions to improve comfort.

If you have any questions, concerns, or complaints feel free to email us:

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abusul@pdx.edu

Jocelyn Reynolds
jocelyn6@pdx.edu

If you wish to contact our supervisor with questions, concerns, or complaints about the research; questions about the subjects' rights; to obtain information or to offer input, please contact:

Capital Projects and Construction Technical Services Manager
Quinn Soifer
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Campus Sustainability Office Education and Outreach Coordinator
Emily Quinton
equinton@pdx.edu

Figure E1: The Consent Form Distributed to Occupants Along With the Survey.

Survey Data Collection

TIME:_____ SURVEY KEY DATE: _____

Karl Miller Center Comfort Survey - Summer 2018

☐ **Check this box if you choose to be a participant in this anonymous survey.** This study is being conducted as part of the Green Building Internship that is funded by the Institute for Sustainable Solutions (ISS) at PSU with support from the BUILT Lab. The purpose of this survey is strictly limited to the academic/research purposes of the internship program. Please see consent information on back. Thank you for taking the time to complete this survey.

1. Please **circle** the current time UNIFORM TIME

9am-12pm 12pm-2pm 2pm-4pm 4pm-7pm

*To ensure that we consider the needs of all our students, please consider the following **optional** question*

2. What is your gender identity? **Check** one

F ☐ Female
M ☐ Male
X ☐ Non-binary/third gender
☐ Prefer to self-describe _____

no answer = blank cell

3. Please **circle** your current clothing level

short sleeve shirt + shorts 1	short sleeve shirt + capris 2	short sleeve shirt + pants 3	long sleeve shirt + pants 4	long sleeve shirt + sweater + pants 5	jacket + sweater + long sleeve shirt + pants 6	down jacket + sweater + long sleeve shirt + pants + scarf and/or hat 7

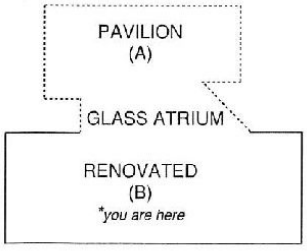
4. Overall, how thermally comfortable are you in this room? **Circle** one.

-2 Very uncomfortable | -1 Slightly uncomfortable | 0 Neutral | 1 Slightly comfortable | 2 Very comfortable

5. Please **circle** your current thermal comfort level

-3 Cold | -2 Cool | -1 Slightly cool | 0 Neutral | 1 Slightly warm | 2 Warm | 3 Hot

6. **i)** Do you notice a difference in **thermal comfort** when occupying a classroom in (B) compared to (A)?



*Please **circle** one answer:*

blank a) N/A
0 b) No
-1 c) I feel colder in B than A
1 d) I feel warmer in B than A

ii) Do you have a preference for occupying classrooms in (A) or (B)? If so, why?

NO / A / B / Blank

7. Comments regarding thermal comfort in KMC classrooms

Figure E2: The Survey Distributed to Occupants. (Key)

Table E1: KMC 255 7.18 1030

	Question								
Student	1	2	3	4	5	6i	6ii	6ii Comments	7
1	13:30	X	4	-2	-3	0	NO		Stop over cooling on warm days
2	13:30	M	1	1	-1	-1	B	Less open windows for distraction	
3	13:30	M	1	2	-1	-1	B	The classes in pavilion are always hot	
4	13:30	M	1	-1	2				
5	13:30	F	4	1	1	1	NO		
6	13:30	M	3	2	1	0			Stagnant
7	13:30	F	1	1	-1	1	NO		
8	13:30	M	1	0	-1	-1	B		
9	13:30	M	4	0	0	0	NO		
10	13:30	M	3	2	-1	-1	B	I would rather the room be cooler than warmer	
11	13:30	F		2	0	-1	B		
12	13:30	M	1	2	-2				
13	13:30	M	1	2	1	0			

Table E2: KMC 275 7.18 1400

	Question								
Student	1	2	3	4	5	6i	6ii	6ii Comments	7
1	14:00	F	1	0	1	1	B		Need A/C
2	14:00	F	3	-1	0	1	A	Cooler	Fix A/C
3	14:00	M	3	-1	1	0	NO		
4	14:00	M	3	1	0				Fix A/C, personal fan
5	14:00	F	2	-2	2	1			Fix A/C
6	14:00	M	3	-1	1	1			Stagnant air w/ high pop. = discomfort
7	14:00	M	3	-1	2	1	A	Cooler	Don Dickinson suite is too hot (fix A/C)
8	14:00	F	3	-1	2				Either too hot or too cold
9	14:00	F	4	-1	2	1			Always hot, windows are

									annoying
10	14:00	F	3	-2	1	0	B		I'm fine w/ classrooms
11	14:00	M	1	-2	-1	0	NO		
12	14:00	F	3	-1	1	0			FIR office always warm, rooms w/o fans are stuffy
13	14:00	M	3	-1	1		NO		Need A/C
14	14:00	F	3	-1	2	1	A		Fir gets very warm, have to prop doors
15	14:00	M	3	0	-2	0	NO		Fix A/C
16	14:00	F	1	-1	1	1	A		Fix A/C
17	14:00	F	2	0	-2				Usually feel cold than hot

Table E3: KMC 255 7.18 1030

	Question								
Student	1	2	3	4	5	6i	6ii	6ii Comments	7
1	10:30	M	3	2	-2				
2	10:30	M	3	-1	-2				
3	10:30	M	1	1	0	-1			Passive system makes room warmer and stuffier on hot daus
4	10:30	M	1	1	0	0			Good for winter
5	10:30	M	1	1	0	-1	B		I just like it :)
6	10:30	F	4	-1	-1	-1	B		Took a spring course in 190 and its was very very warm
7	10:30	M	4	0	-1	-1	NO		Classrooms can be cold
8	10:30	M	5	0	0	-1			
9	10:30	M	1	1	0	0			
10	10:30	F	3	-1	1	-1	NO		Not enough air flow
11	10:30	M	3	1	-1				
12	10:30	M	3	-1	-1	-1			Morning = too cold, afternoon = too hot. Why no A/C or heaters? Why no water pressure?
13	10:30	F	5	0	-1	-1			
14	10:30	F	6	0	0		NO		Can get pretty warm
15	10:30	M	4	0	-1	-1	NO	A can heat up crazy fast	

16	10:30	M	1	2	-2	-1	B		Rooms w/ too many windows are likely to be hot
17	10:30	F	3	0	0				Computer lab gets too cold
18	10:30	M	3	1	1				
19	10:30	F	4	0	0	-1			

Table E4: KMC 470 7.16 1120

	Question								
Student	1	2	3	4	5	6i	6ii	6ii Comments	7
1	11:20	F	4	0	-1		B	It is cool and not hot	
2	11:20	M	1	-1	1	-1	B	sweat less in B	Do not enjoy classes in KMC b/c uncomfortably hot
3	11:20	F	1	2	-1	-1	B	B is cooler	
4	11:20	M	3	-2	-2	-1	B	B is cooler	
5	11:20	M	3	2	-2		B	B is cooler	I like it
6	11:20	M	1	-1	-1	-1	B	B has A/C	Spring term night class in Pavilion was very hot, hard to concentrate
7	11:20	F	1	1	0	-1	B	B isn't too hot	I hate how hot it can be
8	11:20	M	1	0	0	-1	B	Temp is regulated	Easier to concentrate in a cooled classroom
9	11:20	F	4	-1	-1	-1	B	B feels like it has air. A is hot and stuffy in spring	
10	11:20	F	1	2	0	-1	NO		
11	11:20	F	4	0	0	-1	B		
12	11:20	F	1	2	-1	-1	NO		The automatic windows in A are annoying
13	11:20	F	4	2	-1	-1	B	B is cooler, has no sunshine, no frequent automatic window closure or open.	
14	11:20	F	1	2	-1	-1	B	Classes in A are miserably hot. Bring fans and still sweat + feel light headed.	Please do something about classes in A
15	11:20	M	3	1	-1	-1	B	B is cooler	

16	11:20	F	4	0	0	1		Prefer rooms lower in the building	Cooler would be better
17	11:20	F	3	1	-2	0			
18	11:20	M	3	-1	-1			Both are bad	Oppressively hot w/ poor circulation. The robotic windows don't provide enough air circulation.
19	11:20	M	1	0	0	-1			
20	11:20	M	3	0	0	-1	B	A is too hot	
21	11:20	M	1	2	-2	-1	B		
22	11:20	F	1	-1	1	-1	B	B is less hot	Fix A/C
23	11:20	M	3	1	-1	-1	B	B is cooler	
24	11:20	M	3	2	-2	-1	B	B is more comfortable in the summer	During summer + spring, fans aren't enough to cool pavilion
25	11:20		3	-1	-2	-1			

Table E5: KMC 560 7.18 1200

	Question								
Student	1	2	3	4	5	6i	6ii	6ii Comments	7
1	12:00	F	2	2	0		NO		Sometimes 460 is freezing
2	12:00	F	4	0	-1	-1	B	A is much warmer	It varies significantly between rooms
3	12:00	M	1	1	0	0	NO		
4	12:00	F	2	1	-1	-1			Normally pretty good. Windows can be distracting + open randomly
5	12:00	M	4	0	0	1			KMC 580 is more regulated than others
6	12:00	F	3	0	0				Pretty nice
7	12:00	M	3	0	0	0	NO		
8	12:00	F	3	2	-2	0	B		Great very comfortable
9	12:00	F	5	-1	-3	-1			Some rooms are very cold
10	12:00	F	4	0	-1	-1		Some classes are too hot	Rooms with no A/C are uncomfortable when class is full
11	12:00	F	3	-1	0	0	NO		
12	12:00	F	4	-1	-1	1	NO		

13	12:00	M	1	1	-1	-1	NO		
14	12:00	F	1	0	0	-1			
15	12:00	F	1	2	-1		NO		It's really cool I like it
16	12:00	M	1	1	-1	1	A	A has less heat	99% it's way too hot
17	12:00	M	1	0	0	-1	NO		Can get too hot & cold when using heater & A/C
18	12:00	F	3	0	0	0		There are times both feel warm and both feel fine	
19	12:00	M	1		-1	-1	NO		Some rooms are very cold, some rooms are very hot
20	12:00	F	4	-1	-2				Nice but windows in A close too often
21	12:00	F	1	1	-1	0	NO		
22	12:00	F	3	1	0				Windows are loud and shut on their own. Harrison side (south) of building gets way too hot
23	12:00	F	3	0	-1		NO		Tower mounts under the comp stick out and cause bruises + cuts

Table E6: KMC 245 7.27 9000

	Question								
Student	1	2	3	4	5	6i	6ii	6ii Comments	7
1	9:00	M	4	-1	0	0			
2	9:00	F	3	0	1	0	B		
3	9:00	F	2	-1	0	-1	B	A is warmer and windows close themselves	
4	9:00	F	4	0	0	0			Tables run away by themselves
5	9:00	F	4	2	0				
6	9:00	M	4	2	0	0			
7	9:00	F	3	2	1	0	NO		
8	9:00	F	4	0	1				

9	9:00	M	3	-1	-2	-1			
10	9:00	F	1	0	0	0	NO		
11	9:00	F	1	2	0				
12	9:00	F	4	0	-1				Group study room are congested and no air flow. Classrooms are good.
13	9:00	M	3	1	2	0			

APPENDIX F

Outdoor Air Temperatures Vs Indoor Air Temperatures

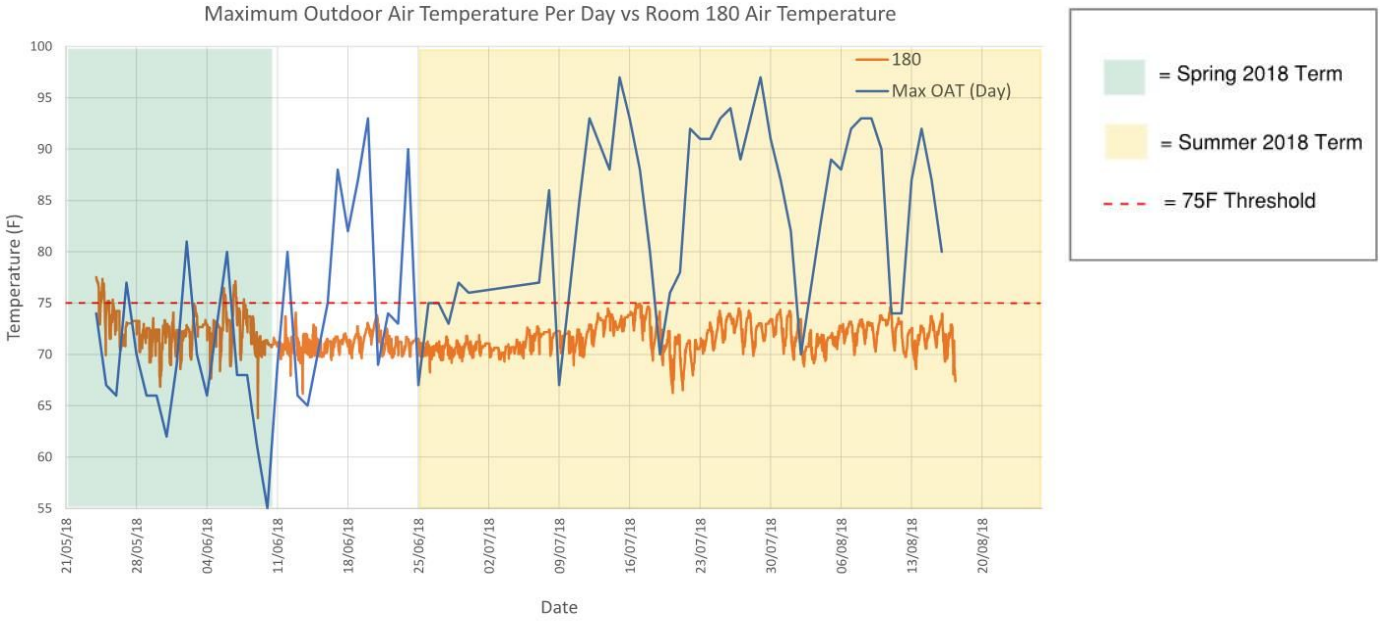


Figure F1: OAT Vs IAT For KMC 180.

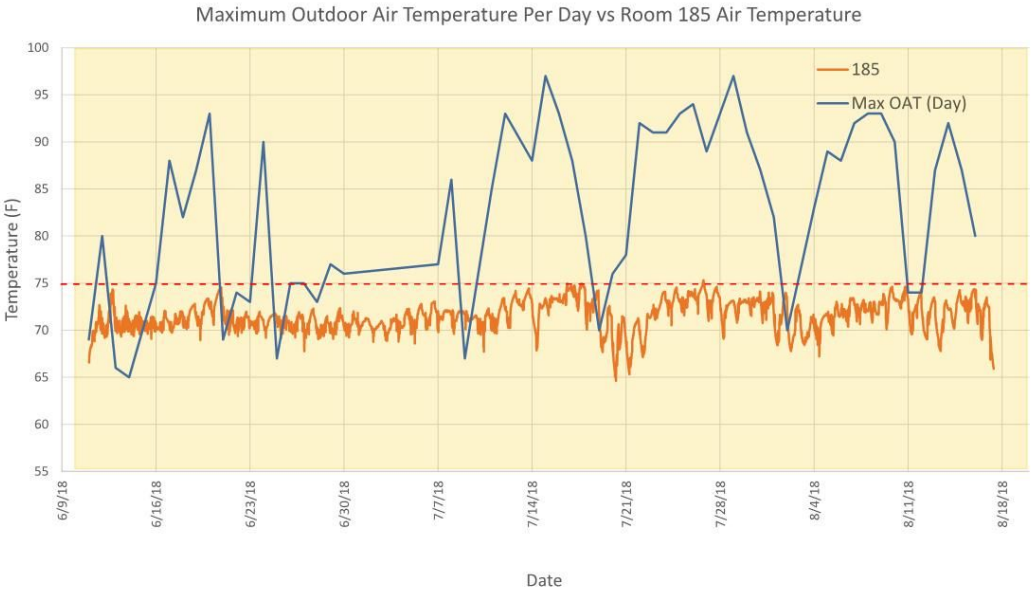


Figure F2: OAT Vs IAT For KMC 185.

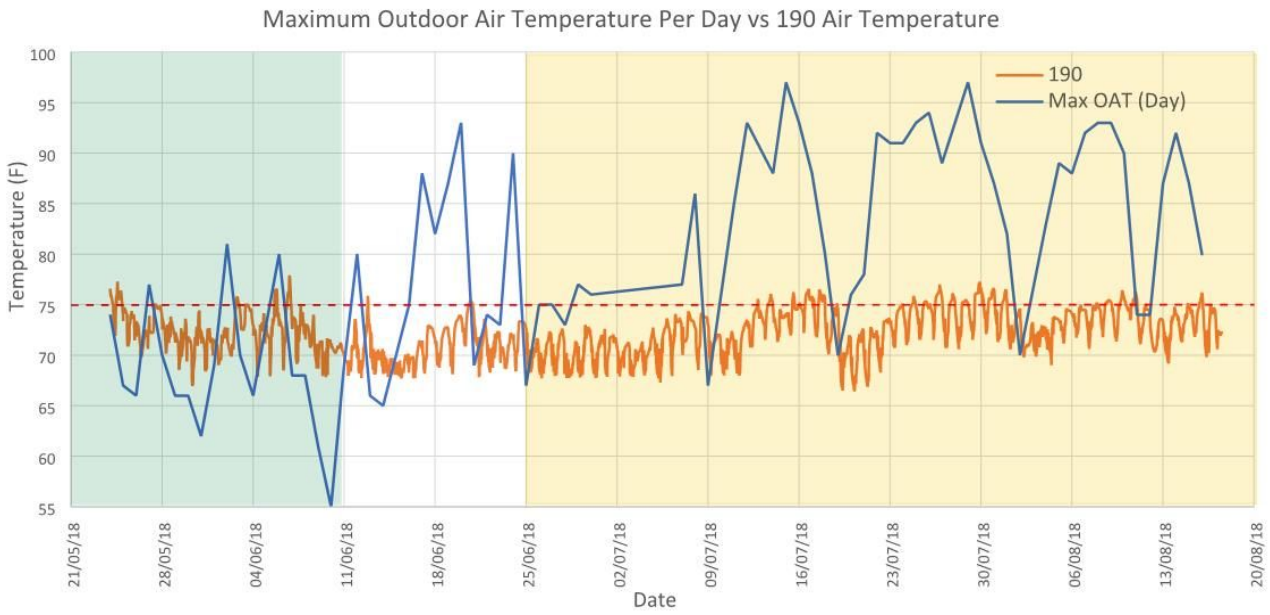


Figure F3: OAT Vs IAT For KMC 190.

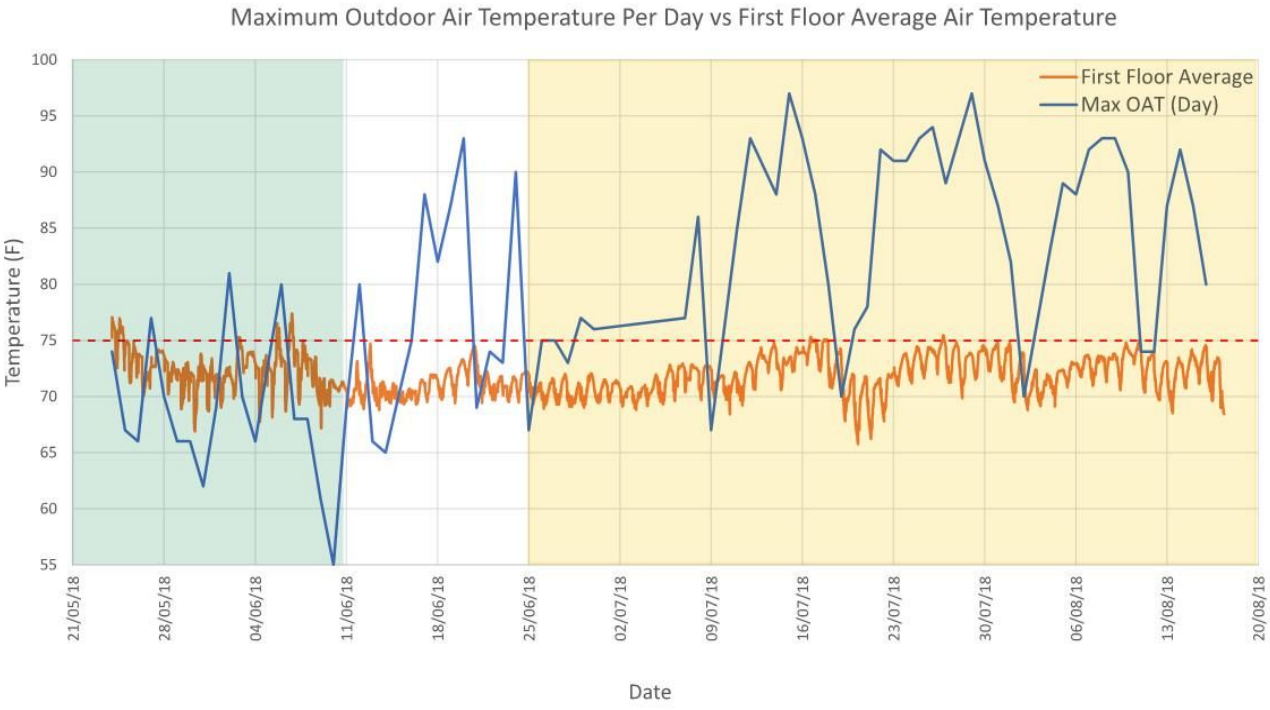


Figure F4: OAT Vs IAT For The First Floor Averaged.

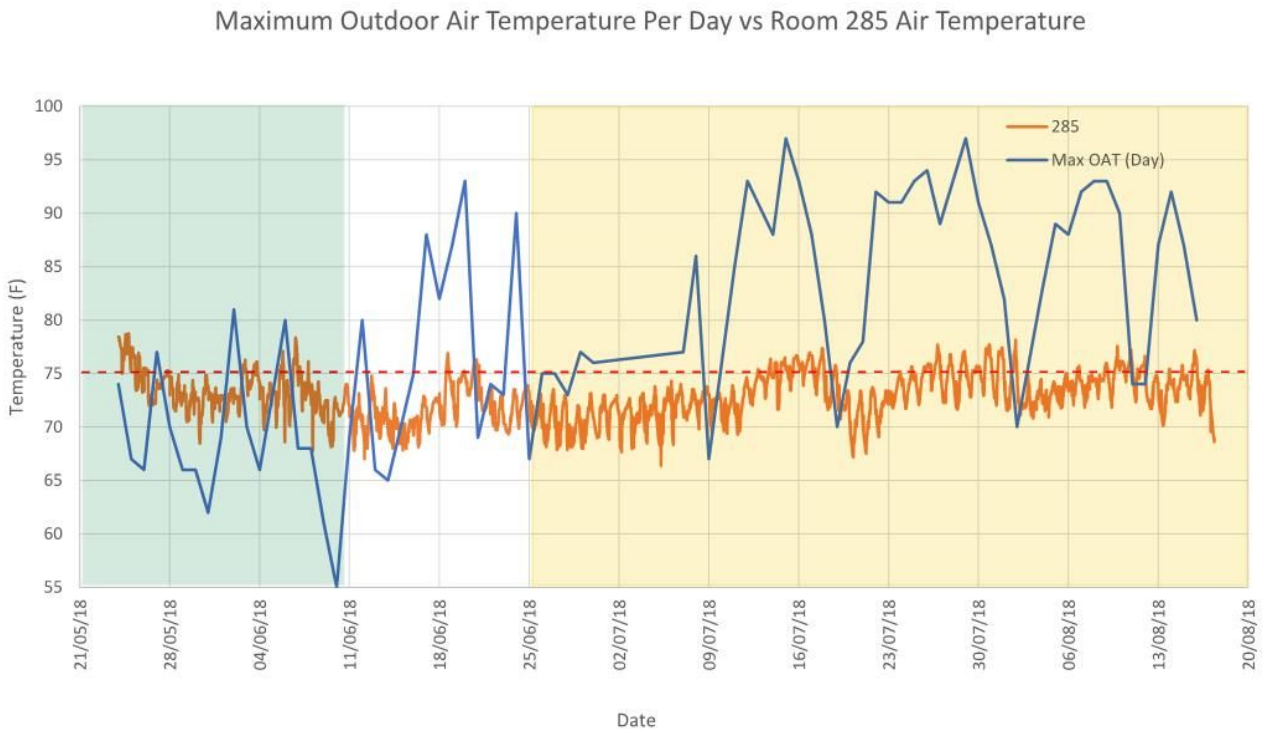


Figure F5: OAT Vs IAT For KMC 285.

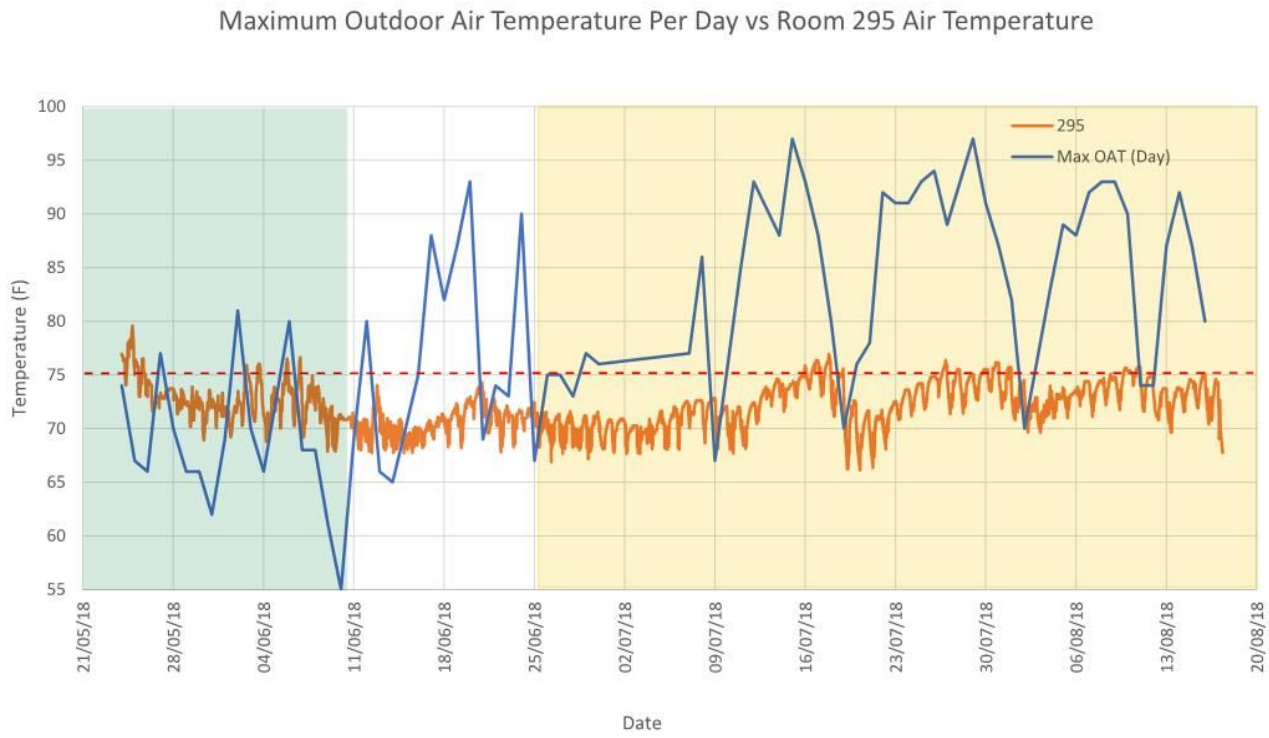


Figure F6: OAT Vs IAT For KMC 295.

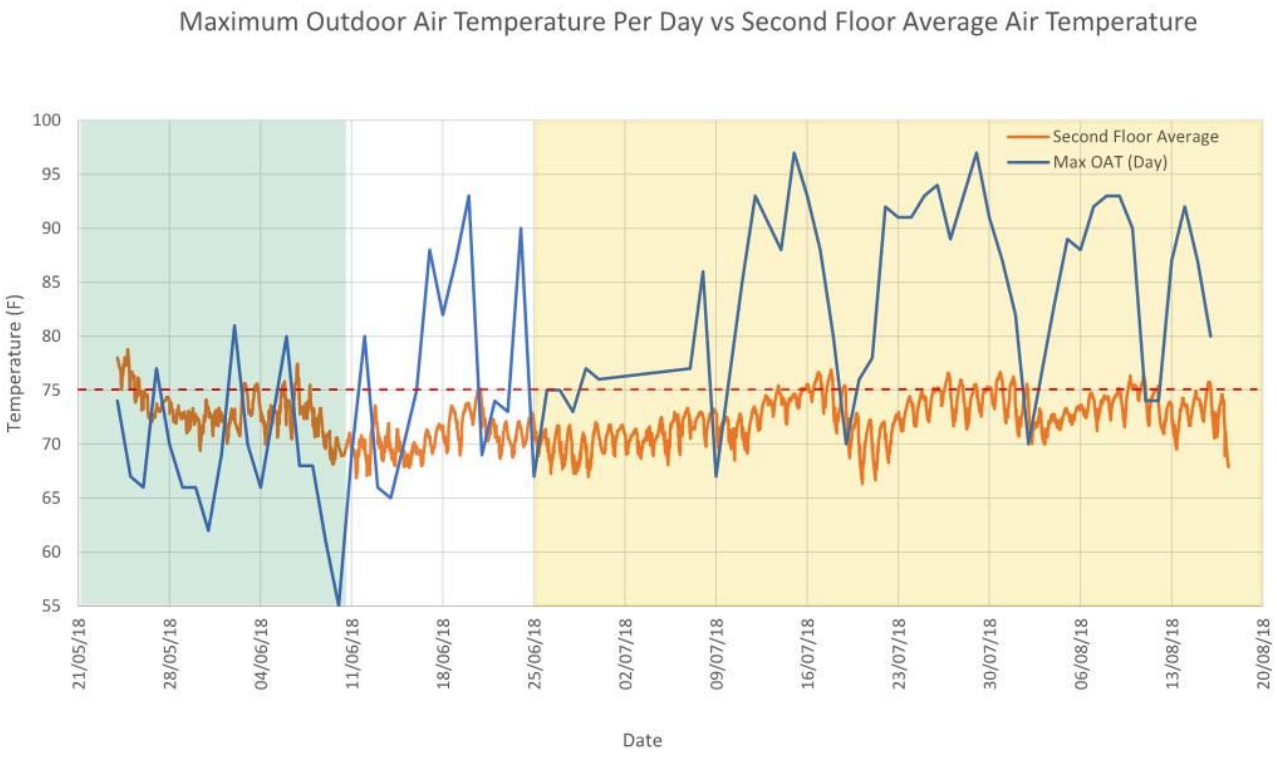


Figure F7: OAT Vs IAT For The Second Floor Averaged.

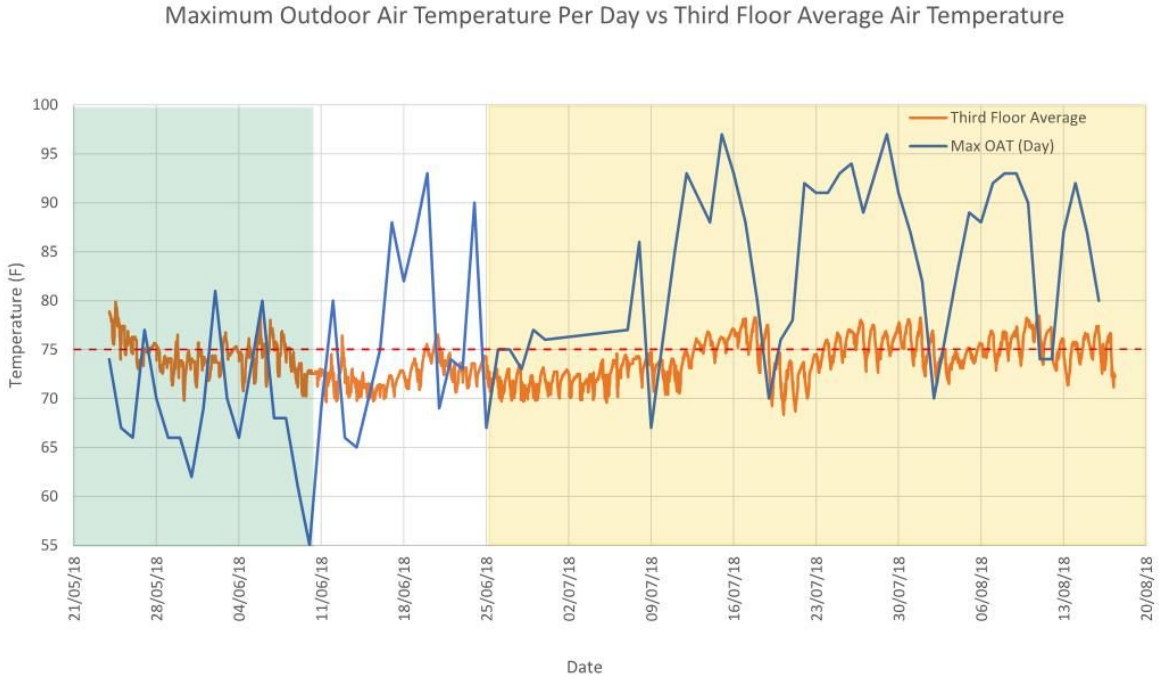


Figure F8: OAT Vs IAT For The Third Floor Averaged.

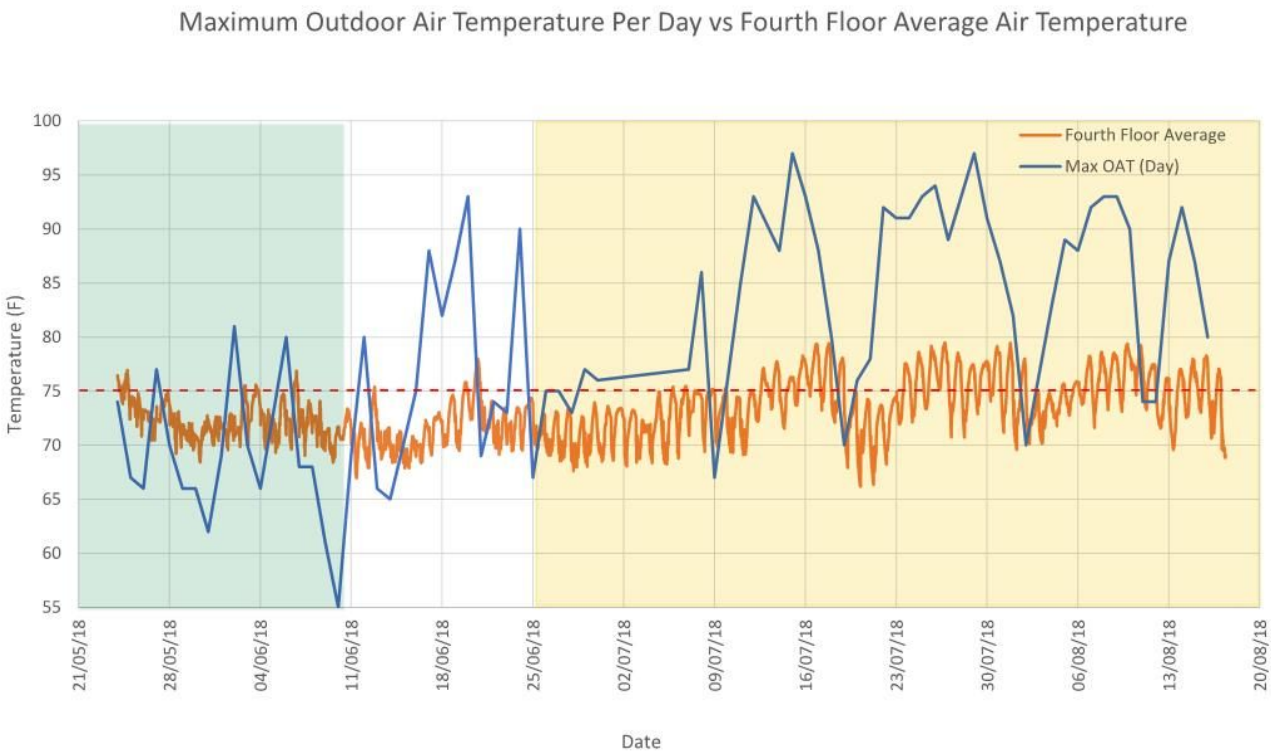


Figure F9: OAT Vs IAT For The Fourth Floor Averaged.

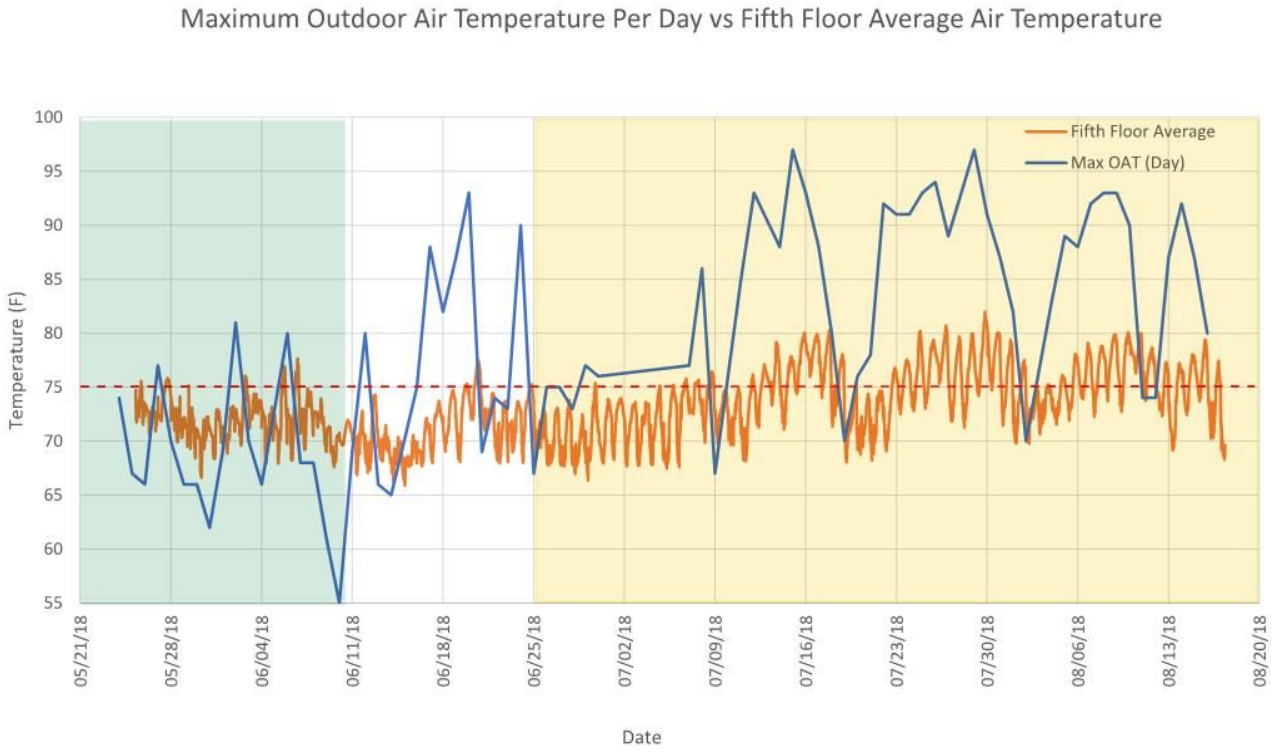


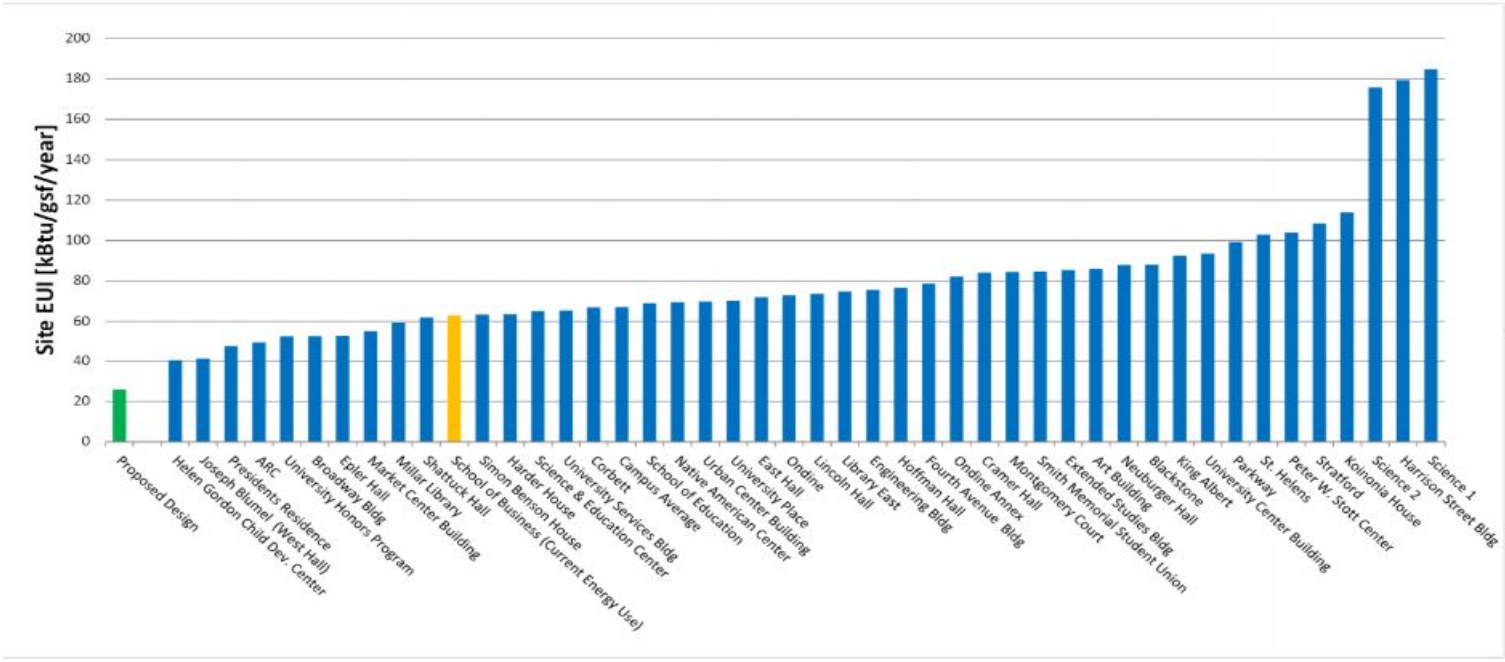
Figure F10: OAT Vs IAT For The Fifth Floor Averaged.

APPENDIX G

Energy Use Index

PORTLAND STATE UNIVERSITY | SCHOOL OF BUSINESS ADMINISTRATION
Renovation and Expansion

Benchmarking with other PSU buildings



SRG | BEHNISCH ARCHITEKTEN | PAE | TRANSSOLAR

2

Figure G1: School of Business and KMC EUI's Compared to All PSU Buildings.

APPENDIX H

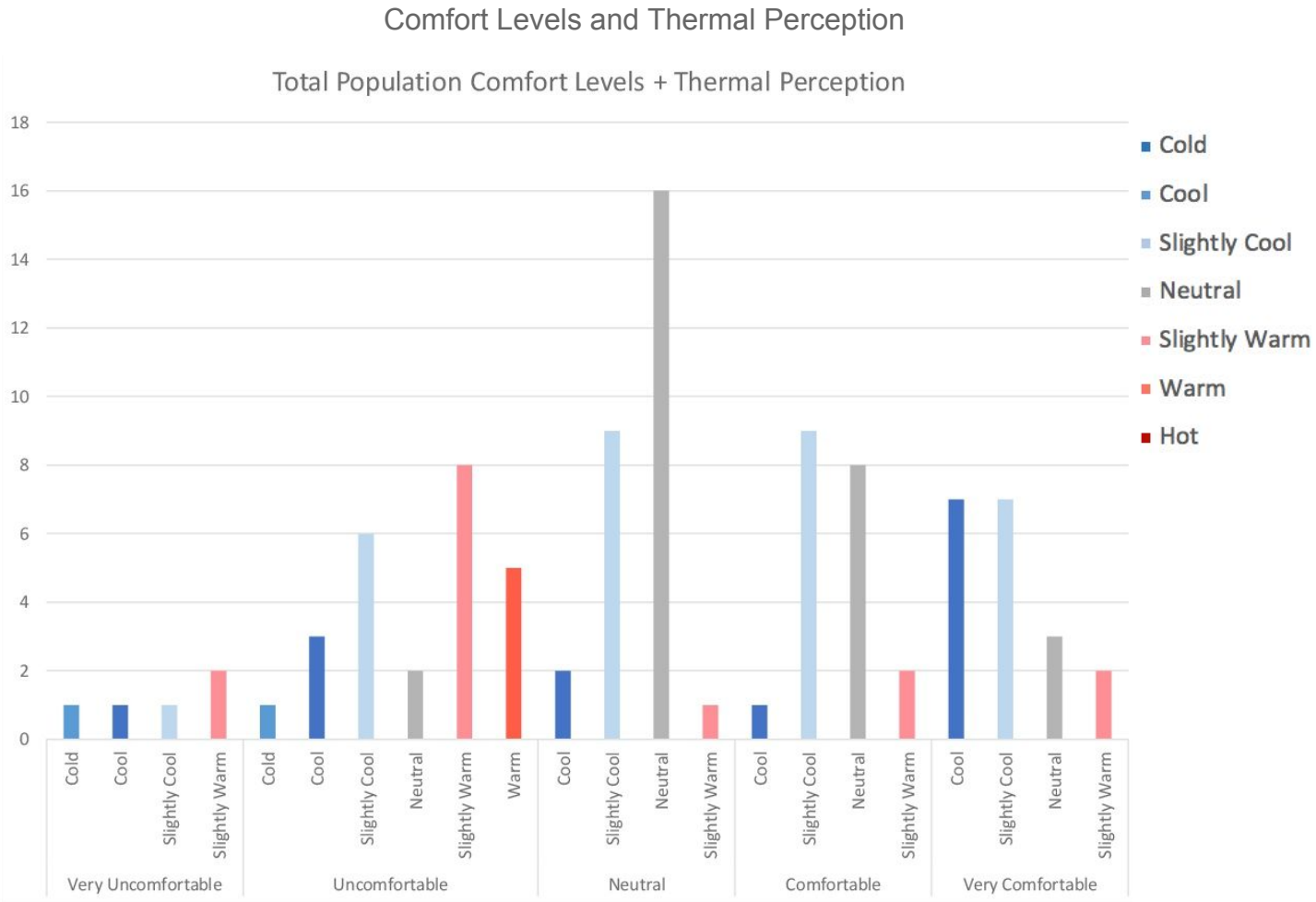


Figure H1: Bar Graph That Represents The Total Population Comfort Levels And The Occupants' Thermal Perception.

APPENDIX I

Summer Course Suitability in Pavilion Classrooms

Table I1: Average temperature by time of day (15 minute intervals) between 24/05/2018 and 17/08/2018 ***Color coding of columns determined by 75F threshold****

Time of Day	180	185	190	275	285	290	295	380	385	480	485	490	495	580	590
6:00:00	71.5	70.7	71.1	73	72.4	70.7	71.6	73.4	73.7	72.6	72.6	71.2	73.2	73.2	72.2
6:15:00	71.2	70.5	70.8	72.5	72.1	70.9	71.1	73.5	73.4	72.4	72.3	71.1	73	73	71.6
6:30:00	70.9	70.7	70.6	72.3	71.9	70.9	71	73.6	73.3	72.2	72.2	71.1	73	73	71.5
6:45:00	70.9	70.7	70.5	72.1	71.7	70.8	71	73.5	73.2	72.1	72.1	71.1	72.9	72.9	71.4
7:00:00	70.8	70.5	70.5	72	71.6	70.8	71	73.4	73.2	72	72.1	71.2	72.8	73	71.5
7:15:00	70.6	70.5	70.2	72	71.5	70.8	70.9	73.4	73	71.9	71.9	71.2	72.7	73	71.3
7:30:00	70.6	70.7	70.3	71.9	71.4	70.8	70.9	73.5	72.9	71.8	71.9	71.2	72.7	73	71.4
7:45:00	70.6	70.7	70.5	71.8	71.4	70.8	70.9	73.5	72.9	71.8	72	71.3	72.8	73.1	71.4
8:00:00	70.6	70.8	70.6	71.8	71.4	70.9	70.9	73.6	73	71.8	72.1	71.4	72.8	73.1	71.4
8:15:00	70.6	70.8	70.7	71.8	71.5	70.9	71	73.7	72.9	71.9	72.1	71.4	72.9	73.2	71.5
8:30:00	70.7	70.8	70.9	71.8	71.6	71	71	73.7	72.9	72	72.2	71.5	73	73.4	71.5
8:45:00	70.7	70.8	71	71.8	71.7	71	71.1	73.6	72.9	72	72.3	71.6	73	73.4	71.6
9:00:00	70.7	71	71.1	71.9	71.7	71.2	71.1	73.8	73	72.1	72.3	71.6	73	73.5	71.9
9:15:00	70.8	71.2	71.2	71.9	71.8	71.2	71.3	74	73	72.2	72.5	71.7	73.2	73.8	72
9:30:00	70.9	71.2	71.5	71.9	71.8	71.3	71.4	74	73.1	72.3	72.5	71.9	73.3	73.8	72.1
9:45:00	70.9	71.3	71.5	72	71.9	71.4	71.5	74	73.2	72.4	72.7	72	73.7	73.8	72.2
10:00:00	71	71.3	71.7	72	72	71.5	71.5	74.1	73.2	72.4	72.9	72	73.9	74	72.3
10:15:00	71.2	71.4	72	72.1	72.2	71.5	71.6	74.2	73.3	72.6	73	72.2	74.2	74.1	72.6
10:30:00	71.3	71.4	72.2	72	72.3	71.7	71.8	74.4	73.4	72.8	73.1	72.4	74.4	74.3	72.7

10:45:00	71.3	71.4	72.3	72.1	72.4	71.8	71.9	74.5	73.5	73	73.2	72.4	74.6	74.4	72.8
11:00:00	71.4	71.5	72.3	72.1	72.5	71.9	71.9	74.5	73.6	73.1	73.3	72.6	74.7	74.6	73
11:15:00	71.5	71.6	72.4	72	72.6	71.9	72	74.6	73.6	73.2	73.4	72.7	74.7	74.7	73.1
11:30:00	71.4	71.7	72.4	71.9	72.6	72	72.1	74.7	73.7	73.4	73.5	72.8	74.9	74.8	73.2
11:45:00	71.5	71.7	72.5	71.9	72.7	72.1	72.1	74.8	73.8	73.4	73.5	73	74.9	74.9	73.3
12:00:00	71.6	71.7	72.6	71.9	72.7	72.1	72.1	74.8	73.9	73.5	73.6	73.2	74.9	75	73.5
12:15:00	71.7	71.8	72.7	71.9	72.8	72.2	72.2	74.9	73.9	73.6	73.7	73.4	74.9	75.2	73.6
12:30:00	71.8	71.9	72.8	71.9	72.9	72.3	72.3	75	74	73.8	73.8	73.5	75	75.3	73.7
12:45:00	71.9	71.9	72.8	71.9	73	72.3	72.4	75	74.1	73.9	73.9	73.7	75.1	75.4	73.9
13:00:00	71.9	72	72.9	71.9	73.2	72.4	72.4	75.1	74.1	74.1	73.9	73.8	75.3	75.5	74
13:15:00	71.9	72	72.9	71.9	73.3	72.4	72.4	75.2	74.2	74.3	74	73.9	75.3	75.6	74.1
13:30:00	72	72.1	73	71.9	73.4	72.4	72.4	75.2	74.3	74.4	74.1	74	75.4	75.7	74.3
13:45:00	72	72.2	73	71.9	73.5	72.4	72.5	75.3	74.3	74.5	74.1	74.2	75.5	75.8	74.4
14:00:00	72.1	72.2	73	71.9	73.4	72.5	72.6	75.3	74.4	74.6	74.2	74.3	75.6	76	74.4
14:15:00	72.1	72.3	73	72	73.4	72.6	72.6	75.5	74.5	74.6	74.2	74.5	75.7	76.1	74.5
14:30:00	72.2	72.3	73.1	72	73.4	72.6	72.7	75.6	74.5	74.6	74.3	74.5	75.9	76.3	74.6
14:45:00	72.3	72.4	73.1	72	73.5	72.7	72.7	75.6	74.6	74.8	74.3	74.5	76	76.5	74.8
15:00:00	72.3	72.4	73.1	72	73.6	72.8	72.7	75.6	74.6	74.9	74.3	74.6	76	76.6	74.9
15:15:00	72.3	72.5	73.2	72.1	73.7	72.8	72.7	75.7	74.6	75	74.4	74.8	76.1	76.7	74.9
15:30:00	72.3	72.5	73.2	72.1	73.8	72.8	72.7	75.7	74.7	75.1	74.5	74.9	76.2	77	74.9
15:45:00	72.3	72.5	73.2	72.1	73.8	72.8	72.8	75.8	74.7	75.2	74.5	75	76.2	77	75
16:00:00	72.3	72.5	73.2	72.1	73.8	72.9	72.8	75.9	74.7	75.2	74.6	75.1	76.3	77.1	75.1
16:15:00	72.3	72.5	73.1	72.1	73.8	72.9	72.8	75.9	74.7	75.2	74.6	75.2	76.3	77.2	75.1
16:30:00	72.3	72.5	73.1	72.1	73.9	72.9	72.8	76	74.7	75.3	74.7	75.2	76.3	77.3	75.2
16:45:00	72.3	72.6	73.2	72	73.9	73	72.9	76	74.7	75.4	74.7	75.2	76.3	77.4	75.2
17:00:00	72.3	72.6	73.2	71.9	74	73	72.9	76.1	74.8	75.4	74.8	75.3	76.4	77.6	75.3

17:15:00	72.4	72.6	73.2	72	74	73	72.9	76.1	74.8	75.5	74.8	75.3	76.4	77.6	75.2
17:30:00	72.4	72.6	73.3	72	74.2	73	72.9	76.1	74.9	75.5	74.9	75.2	76.4	77.7	75.3
17:45:00	72.6	72.5	73.4	72.1	74.3	73.1	73	76.1	75	75.6	75	75.2	76.5	77.9	75.4
18:00:00	72.7	72.5	73.5	72.1	74.4	73.2	73	76.1	75.1	75.7	75.1	75.1	76.5	77.9	75.4
18:15:00	72.7	72.5	73.6	72.1	74.4	73.1	73.1	76.2	75.1	75.6	75.1	75.1	76.5	78	75.4
18:30:00	72.7	72.5	73.6	72.1	74.5	73.2	73.1	76.2	75.1	75.6	75.1	75	76.5	78.1	75.4
18:45:00	72.7	72.5	73.7	72.1	74.5	73.1	73.1	76.2	75.1	75.6	75.1	75	76.5	78.1	75.4
19:00:00	72.7	72.5	73.7	72.1	74.5	73.2	73.1	76.3	75.1	75.5	75.1	75	76.5	78.1	75.3
19:15:00	72.7	72.5	73.6	72.2	74.4	73.1	73.1	76.3	75.1	75.5	75.2	75	76.5	78	75.2
19:30:00	72.6	72.5	73.6	72.2	74.3	73.1	73.1	76.3	75.1	75.4	75.2	74.9	76.4	78	75.2
19:45:00	72.6	72.4	73.6	72.2	74.2	73	73.1	76.3	75.1	75.4	75.1	74.8	76.4	78	75.1
20:00:00	72.6	72.4	73.6	72.2	74.2	73	73.1	76.2	75.1	75.4	75.1	74.8	76.4	78	75
20:15:00	72.5	72.3	73.5	72.3	74.1	73	73.1	76.2	75	75.4	75.1	74.7	76.3	78	74.9
20:30:00	72.5	72.3	73.4	72.3	74	73	73	76.2	75	75.3	75	74.6	76.3	77.9	74.8
20:45:00	72.4	72.3	73.3	72.3	73.9	72.9	73	76.2	74.9	75.2	74.9	74.6	76.3	77.8	74.7
21:00:00	72.3	72.2	73.2	72.3	73.8	72.9	73	76.2	74.9	75.1	74.9	74.5	76.2	77.7	74.6
21:15:00	72.3	72.2	73.1	72.3	73.6	72.8	72.9	76	74.8	75	74.8	74.3	76.2	77.6	74.4
21:30:00	72.3	72.1	73	72.3	73.6	72.7	72.9	76	74.8	74.9	74.7	74.2	76.1	77.5	74.4
21:45:00	72.3	71.9	72.9	72.6	73.5	72.5	72.8	75.7	74.7	74.7	74.5	73.7	75.7	77	74.1
22:00:00	72.3	71.8	72.9	72.8	73.4	72.4	72.7	75.6	74.7	74.6	74.4	73.5	75.6	76.7	73.8
22:15:00	72.2	71.7	72.7	72.9	73.3	72.3	72.7	75.4	74.6	74.5	74.2	73.3	75.3	76.3	73.7
22:30:00	72	71.7	72.6	72.9	73.1	72.3	72.5	75.2	74.5	74.3	74	73.1	75.1	76	73.5
22:45:00	72	71.5	72.5	73	73	72.2	72.4	75.1	74.4	74	73.8	72.8	75	75.8	73.3
23:00:00	72	71.5	72.4	73	72.9	72.1	72.3	74.9	74.3	73.9	73.7	72.6	74.9	75.6	73.2
23:15:00	71.9	71.4	72.3	73.1	72.9	72	72.3	74.8	74.2	73.8	73.6	72.5	74.7	75.4	73
23:30:00	71.9	71.4	72.1	73.1	72.9	71.9	72.2	74.7	74.2	73.7	73.4	72.4	74.6	75.2	72.9

23:45:00	71.9	71.3	72	73.1	72.8	71.9	72.1	74.6	74.2	73.6	73.3	72.3	74.5	75	72.9
Grand Total	71.8	71.8	72.5	72.2	73.1	72.2	72.3	75.1	74.2	74	73.8	73.5	75.1	75.8	73.7

*Table I2: Range(s) of Suitable Times per Pavilion Classroom **(75F Threshold)***

Room	Suitable Times
180	6:00 - 23:45
185	6:00 - 23:45
190	6:00 - 23:45
275	6:00 - 23:45
285	6:00 - 23:45
290	6:00 - 23:45
295	6:00 - 23:45
380	6:00 - 13:00 and 23:00 - 23:45
385	6:00 - 18:00 and 20:15 - 23:45
480	6:00 - 15:30 and 21:15 - 23:45
485	6:00 - 18:00 and 20:30 - 23:45
490	6:00 - 16:00 and 18:30 - 23:45
495	6:00 - 12:45 and 22:45 - 23:45
580	6:00 - 11:45
590	6:00 - 16:00 and 20:00 - 23:45
	Note: The threshold value used to determine class suitability was 75F.

Table I3: Average temperature by time of day (15 minute intervals) between 24/05/2018 and 17/08/2018 ****Color coding of columns determined by 72F threshold****

Time of Day	180	185	190	275	285	290	295	380	385	480	485	490	495	580	590
6:00:00	71.5	70.7	71.1	73	72.4	70.7	71.6	73.4	73.7	72.6	72.6	71.2	73.2	73.2	72.2
6:15:00	71.2	70.5	70.8	72.5	72.1	70.9	71.1	73.5	73.4	72.4	72.3	71.1	73	73	71.6
6:30:00	70.9	70.7	70.6	72.3	71.9	70.9	71	73.6	73.3	72.2	72.2	71.1	73	73	71.5
6:45:00	70.9	70.7	70.5	72.1	71.7	70.8	71	73.5	73.2	72.1	72.1	71.1	72.9	72.9	71.4
7:00:00	70.8	70.5	70.5	72	71.6	70.8	71	73.4	73.2	72	72.1	71.2	72.8	73	71.5
7:15:00	70.6	70.5	70.2	72	71.5	70.8	70.9	73.4	73	71.9	71.9	71.2	72.7	73	71.3
7:30:00	70.6	70.7	70.3	71.9	71.4	70.8	70.9	73.5	72.9	71.8	71.9	71.2	72.7	73	71.4
7:45:00	70.6	70.7	70.5	71.8	71.4	70.8	70.9	73.5	72.9	71.8	72	71.3	72.8	73.1	71.4
8:00:00	70.6	70.8	70.6	71.8	71.4	70.9	70.9	73.6	73	71.8	72.1	71.4	72.8	73.1	71.4
8:15:00	70.6	70.8	70.7	71.8	71.5	70.9	71	73.7	72.9	71.9	72.1	71.4	72.9	73.2	71.5
8:30:00	70.7	70.8	70.9	71.8	71.6	71	71	73.7	72.9	72	72.2	71.5	73	73.4	71.5
8:45:00	70.7	70.8	71	71.8	71.7	71	71.1	73.6	72.9	72	72.3	71.6	73	73.4	71.6
9:00:00	70.7	71	71.1	71.9	71.7	71.2	71.1	73.8	73	72.1	72.3	71.6	73	73.5	71.9
9:15:00	70.8	71.2	71.2	71.9	71.8	71.2	71.3	74	73	72.2	72.5	71.7	73.2	73.8	72
9:30:00	70.9	71.2	71.5	71.9	71.8	71.3	71.4	74	73.1	72.3	72.5	71.9	73.3	73.8	72.1
9:45:00	70.9	71.3	71.5	72	71.9	71.4	71.5	74	73.2	72.4	72.7	72	73.7	73.8	72.2
10:00:00	71	71.3	71.7	72	72	71.5	71.5	74.1	73.2	72.4	72.9	72	73.9	74	72.3
10:15:00	71.2	71.4	72	72.1	72.2	71.5	71.6	74.2	73.3	72.6	73	72.2	74.2	74.1	72.6
10:30:00	71.3	71.4	72.2	72	72.3	71.7	71.8	74.4	73.4	72.8	73.1	72.4	74.4	74.3	72.7
10:45:00	71.3	71.4	72.3	72.1	72.4	71.8	71.9	74.5	73.5	73	73.2	72.4	74.6	74.4	72.8
11:00:00	71.4	71.5	72.3	72.1	72.5	71.9	71.9	74.5	73.6	73.1	73.3	72.6	74.7	74.6	73
11:15:00	71.5	71.6	72.4	72	72.6	71.9	72	74.6	73.6	73.2	73.4	72.7	74.7	74.7	73.1
11:30:00	71.4	71.7	72.4	71.9	72.6	72	72.1	74.7	73.7	73.4	73.5	72.8	74.9	74.8	73.2

11:45:00	71.5	71.7	72.5	71.9	72.7	72.1	72.1	74.8	73.8	73.4	73.5	73	74.9	74.9	73.3
12:00:00	71.6	71.7	72.6	71.9	72.7	72.1	72.1	74.8	73.9	73.5	73.6	73.2	74.9	75	73.5
12:15:00	71.7	71.8	72.7	71.9	72.8	72.2	72.2	74.9	73.9	73.6	73.7	73.4	74.9	75.2	73.6
12:30:00	71.8	71.9	72.8	71.9	72.9	72.3	72.3	75	74	73.8	73.8	73.5	75	75.3	73.7
12:45:00	71.9	71.9	72.8	71.9	73	72.3	72.4	75	74.1	73.9	73.9	73.7	75.1	75.4	73.9
13:00:00	71.9	72	72.9	71.9	73.2	72.4	72.4	75.1	74.1	74.1	73.9	73.8	75.3	75.5	74
13:15:00	71.9	72	72.9	71.9	73.3	72.4	72.4	75.2	74.2	74.3	74	73.9	75.3	75.6	74.1
13:30:00	72	72.1	73	71.9	73.4	72.4	72.4	75.2	74.3	74.4	74.1	74	75.4	75.7	74.3
13:45:00	72	72.2	73	71.9	73.5	72.4	72.5	75.3	74.3	74.5	74.1	74.2	75.5	75.8	74.4
14:00:00	72.1	72.2	73	71.9	73.4	72.5	72.6	75.3	74.4	74.6	74.2	74.3	75.6	76	74.4
14:15:00	72.1	72.3	73	72	73.4	72.6	72.6	75.5	74.5	74.6	74.2	74.5	75.7	76.1	74.5
14:30:00	72.2	72.3	73.1	72	73.4	72.6	72.7	75.6	74.5	74.6	74.3	74.5	75.9	76.3	74.6
14:45:00	72.3	72.4	73.1	72	73.5	72.7	72.7	75.6	74.6	74.8	74.3	74.5	76	76.5	74.8
15:00:00	72.3	72.4	73.1	72	73.6	72.8	72.7	75.6	74.6	74.9	74.3	74.6	76	76.6	74.9
15:15:00	72.3	72.5	73.2	72.1	73.7	72.8	72.7	75.7	74.6	75	74.4	74.8	76.1	76.7	74.9
15:30:00	72.3	72.5	73.2	72.1	73.8	72.8	72.7	75.7	74.7	75.1	74.5	74.9	76.2	77	74.9
15:45:00	72.3	72.5	73.2	72.1	73.8	72.8	72.8	75.8	74.7	75.2	74.5	75	76.2	77	75
16:00:00	72.3	72.5	73.2	72.1	73.8	72.9	72.8	75.9	74.7	75.2	74.6	75.1	76.3	77.1	75.1
16:15:00	72.3	72.5	73.1	72.1	73.8	72.9	72.8	75.9	74.7	75.2	74.6	75.2	76.3	77.2	75.1
16:30:00	72.3	72.5	73.1	72.1	73.9	72.9	72.8	76	74.7	75.3	74.7	75.2	76.3	77.3	75.2
16:45:00	72.3	72.6	73.2	72	73.9	73	72.9	76	74.7	75.4	74.7	75.2	76.3	77.4	75.2
17:00:00	72.3	72.6	73.2	71.9	74	73	72.9	76.1	74.8	75.4	74.8	75.3	76.4	77.6	75.3
17:15:00	72.4	72.6	73.2	72	74	73	72.9	76.1	74.8	75.5	74.8	75.3	76.4	77.6	75.2
17:30:00	72.4	72.6	73.3	72	74.2	73	72.9	76.1	74.9	75.5	74.9	75.2	76.4	77.7	75.3
17:45:00	72.6	72.5	73.4	72.1	74.3	73.1	73	76.1	75	75.6	75	75.2	76.5	77.9	75.4
18:00:00	72.7	72.5	73.5	72.1	74.4	73.2	73	76.1	75.1	75.7	75.1	75.1	76.5	77.9	75.4

18:15:00	72.7	72.5	73.6	72.1	74.4	73.1	73.1	76.2	75.1	75.6	75.1	75.1	76.5	78	75.4
18:30:00	72.7	72.5	73.6	72.1	74.5	73.2	73.1	76.2	75.1	75.6	75.1	75	76.5	78.1	75.4
18:45:00	72.7	72.5	73.7	72.1	74.5	73.1	73.1	76.2	75.1	75.6	75.1	75	76.5	78.1	75.4
19:00:00	72.7	72.5	73.7	72.1	74.5	73.2	73.1	76.3	75.1	75.5	75.1	75	76.5	78.1	75.3
19:15:00	72.7	72.5	73.6	72.2	74.4	73.1	73.1	76.3	75.1	75.5	75.2	75	76.5	78	75.2
19:30:00	72.6	72.5	73.6	72.2	74.3	73.1	73.1	76.3	75.1	75.4	75.2	74.9	76.4	78	75.2
19:45:00	72.6	72.4	73.6	72.2	74.2	73	73.1	76.3	75.1	75.4	75.1	74.8	76.4	78	75.1
20:00:00	72.6	72.4	73.6	72.2	74.2	73	73.1	76.2	75.1	75.4	75.1	74.8	76.4	78	75
20:15:00	72.5	72.3	73.5	72.3	74.1	73	73.1	76.2	75	75.4	75.1	74.7	76.3	78	74.9
20:30:00	72.5	72.3	73.4	72.3	74	73	73	76.2	75	75.3	75	74.6	76.3	77.9	74.8
20:45:00	72.4	72.3	73.3	72.3	73.9	72.9	73	76.2	74.9	75.2	74.9	74.6	76.3	77.8	74.7
21:00:00	72.3	72.2	73.2	72.3	73.8	72.9	73	76.2	74.9	75.1	74.9	74.5	76.2	77.7	74.6
21:15:00	72.3	72.2	73.1	72.3	73.6	72.8	72.9	76	74.8	75	74.8	74.3	76.2	77.6	74.4
21:30:00	72.3	72.1	73	72.3	73.6	72.7	72.9	76	74.8	74.9	74.7	74.2	76.1	77.5	74.4
21:45:00	72.3	71.9	72.9	72.6	73.5	72.5	72.8	75.7	74.7	74.7	74.5	73.7	75.7	77	74.1
22:00:00	72.3	71.8	72.9	72.8	73.4	72.4	72.7	75.6	74.7	74.6	74.4	73.5	75.6	76.7	73.8
22:15:00	72.2	71.7	72.7	72.9	73.3	72.3	72.7	75.4	74.6	74.5	74.2	73.3	75.3	76.3	73.7
22:30:00	72	71.7	72.6	72.9	73.1	72.3	72.5	75.2	74.5	74.3	74	73.1	75.1	76	73.5
22:45:00	72	71.5	72.5	73	73	72.2	72.4	75.1	74.4	74	73.8	72.8	75	75.8	73.3
23:00:00	72	71.5	72.4	73	72.9	72.1	72.3	74.9	74.3	73.9	73.7	72.6	74.9	75.6	73.2
23:15:00	71.9	71.4	72.3	73.1	72.9	72	72.3	74.8	74.2	73.8	73.6	72.5	74.7	75.4	73
23:30:00	71.9	71.4	72.1	73.1	72.9	71.9	72.2	74.7	74.2	73.7	73.4	72.4	74.6	75.2	72.9
23:45:00	71.9	71.3	72	73.1	72.8	71.9	72.1	74.6	74.2	73.6	73.3	72.3	74.5	75	72.9
Grand Total	71.8	71.8	72.5	72.2	73.1	72.2	72.3	75.1	74.2	74	73.8	73.5	75.1	75.8	73.7

Table I3: Range(s) of Suitable Times per Pavilion Classroom ***(72F Threshold)***

Room	Suitable Times
180	6:00 - 14:00 and 22:30 - 23:45
185	6:00 - 23:45
190	6:00 - 10:15
275	-
285	7:00 - 10:00
290	6:00 - 11:00
295	6:00 - 11:15
380	-
385	-
480	-
485	-
490	6:00 - 10:00
495	-
580	-
590	6:00 - 9:15
	Note: The threshold value used to determine class suitability was 72F.