Acoustical Quality of the Haas School of Business

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EXECUTIVE SUMMARY

This project provides an overview and in-depth analysis of the acoustical quality of the University of California Berkeley Haas School of Business.

Preliminary Analysis

Results taken from the CBE survey revealed that 65% of occupants were dissatisfied with the acoustical quality in the building. Multiple complaints mentioned include proximity to other people, construction and traffic noise, and echoing. Given that poor acoustical quality affects adequate productivity, we were interested in exploring the causes of this issue and offering solutions to combat these negative effects.

Objectives

Our objective was to establish the methods by which to improve the acoustical quality in the Haas School of Business. We sought to investigate the key causes behind the complaints by determining whether the building is in line with ASHRAE's Performance Measurement Protocol (PMP) for Commercial Buildings in regards to acoustics. In doing so, we were be able to provide straightforward solutions to improve acoustical quality based on our findings.

Two hypotheses outline our endeavor:

1) The occupants are dissatisfied with acoustical quality because the building does not meet the PMP benchmarks regarding dB (A) ranges for background noise. In the event this proves true, we will seek structural and topical methods to bring the building to standards.
2) The occupants are dissatisfied with acoustical quality, but the building's range of background noise meets the PMP benchmarks regarding dB (A) range. In the event this proves true, we will seek behavioral and perceptive methods to bring the building to standards.

Approach

To resolve our hypotheses, we conducted a walk-through of the building to evaluate which rooms would serve as representative areas of concentration to study. These rooms consisted of private offices, public offices, and conference rooms. In choosing the rooms to take measurements, we established room criteria so as to narrow down our selection. These criteria required that we compare similar room types but with different adjacent surfaces (i.e. reflective or absorptive hallways or staircases) as well as threshold conditions (i.e. opened and closed windows and doors). Measurements were taken in the early morning, morning, afternoon, and evening depending on the availability of the rooms. These measurements refer to sound meter samplings used to compare background noise levels the pre-determined to dB(A) standards.

Results

Findings from the CBE survey illustrate that occupants in private offices are much more satisfied than occupants in open offices. Additionally, occupants in open offices are dissatisfied with shorter partitions than taller partitions. Findings from the sound meter measurements are as follows: 4 rooms measured below the ideal dB(A) range in the early morning and night; 3 rooms measured above the maximum dB(A) range when windows were open, people were talking nearby, and thermal comfort equipment (i.e. personal fans) were in use; but the majority of rooms were within their designated minimum dB(A) range.

Summary of Recommendations
As occupants primarily in shared offices have expressed their dissatisfaction with their acoustical environment, suggestions mainly apply to these inhabitants. The background noise levels for these spaces were found to be below the ideal standards set by ASHRAE. Thus, sound masking systems would allow occupants to raise the background noise level when needed. These systems are both noninvasive and less expensive than other options. Office booths may solve issues with some occupants needing space to conduct phone calls and hold interviews. However, it is unlikely that employees who must frequently do such tasks would be willing to move constantly to these spaces. Moreover, the cost of such booths is high and a booth would be needed for each shared office for maximum benefit. The current use of partitions did not solve speech privacy. Thus, converting to state-of-the-art acoustical partitions may not increase environmental satisfaction but would still be a pricey endeavor. Ideally, any of these options may be used however, as long as occupants become more satisfied with the space and less distracted by noise. A behavioral system where occupants agree to keep voice levels low would also be beneficial. Nonetheless, such a measure would not solve overall speech privacy. As for private offices, occupants only complained when people in nearby spaces conversed loudly on telephones. Therefore, a simple solution would be to instruct those people to keep their doors closed when conducting such tasks. Overall, the Haas School of Business has the ability to increase satisfaction and productivity of its occupants through acoustical means and should do so without delay.

INTRODUCTION

Description of the Building

The Haas School of Business, located on 2220 Piedmont Avenue and founded in 1898, offers six business programs to about 2,200 students (undergraduate, master, and PhD students). The building's final design was provided by Charles Moore and built in 1995. The school encompasses three distinctive wings: classroom wing (Cheit Hall), faculty wing, and student services wing. Each building ranges 4-7 floors with a combined total of 90% occupancy. This occupancy includes nearly 85 ladder-track faculty, 146 professional or visiting faculty, and 300 staff members.

Facts and figures related to the school include a gross floor area of 200,000 square feet, about 90 hours of operation per week (this value is derived from a weekly schedule of 8-10pm for seven days), and about 500 computers (this value is an estimation that includes the number of computers provided in the computer lab as well as the prediction that almost every faculty and staff person would have their own work computer).

Background on Acoustics

To provide a basic understanding of acoustics in office buildings, this section reviews previous studies. In general, sound can affect one's mood, how one think, and even the ability to hear one's self think (Vickers 2007). It can have a deep impact on productivity and stress as well. Louis Harris & Associates (1980) surveyed U.S. office workers and found that over half of those surveyed said "quiet" was important to their comfort at work while only 48% said they had quiet environments in their offices (Louis Harris & Associates 1980). In addition, Sundstrom et al (1994) reported that over 54% of occupants were being bothered "often" by one or more noise sources (Sundstrom et al 1994). As this research involved almost 2,400 office employees from 58 sites across the U.S. and Canada, the difficulties involving acoustical satisfaction are not limited to only a few locations. The study also found small but significant correlation between disturbance by noise and job satisfaction as well as hypothesized that environmental satisfaction relating to acoustics and job characteristics together affect job satisfaction. Thus, acoustics has a critical influence on occupants and not enough priority has been given to this dilemma faced by countless offices.

Energy Star Benchmarking

Using estimations on the occupancy, amount of computers, and weekly operational hours, as seen in the description of the building, Site and Source Energy Use Intensity (EUI) for the years of 2011 through 2015 were calculated. Site EUI is the amount of energy consumed by the building at its location, while Source EUI is the total amount of energy used to provide the energy consumed. This involves following the energy to its production. The Site EUI for 2011 was 40.2 kBtu/ft^2 rose steadily to 55.0 kBtu/ft^2 in 2014. In 2015, there was a sudden jump to 194.7 kBtu/ft^2. The Source EUI correspondingly rose from 135.9 kBtu/ft^2 to 329.5 kBtu/ft^2 from 2011 to 2015. The Site and Source EUI for 2015 exceeded the national medians set by Energy Star's Technical Reference of the U.S. Energy Use Intensity by Property Type. Source EUI for Haas surpassed the national median Source EUI by 25.5 kBtu/ft^2 for this year (Energy Star 2014). The large increase in EUI from 2014 to 2015 can be attributed to the recent building renovations, which require more energy use to function.

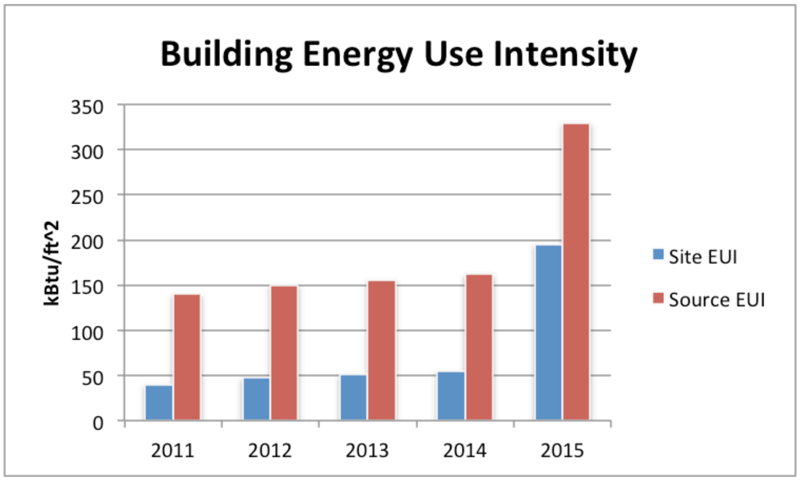
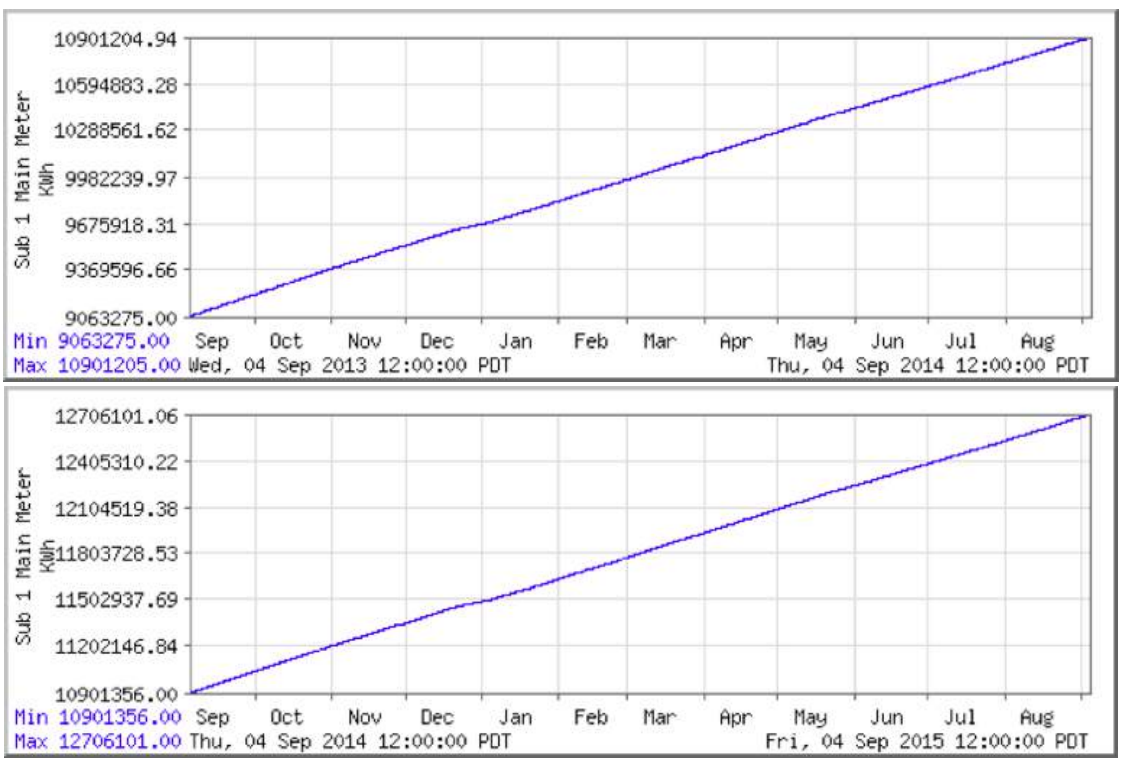


Figure 1: Site and Source Energy Use Intensity for Haas from 2011 to 2015

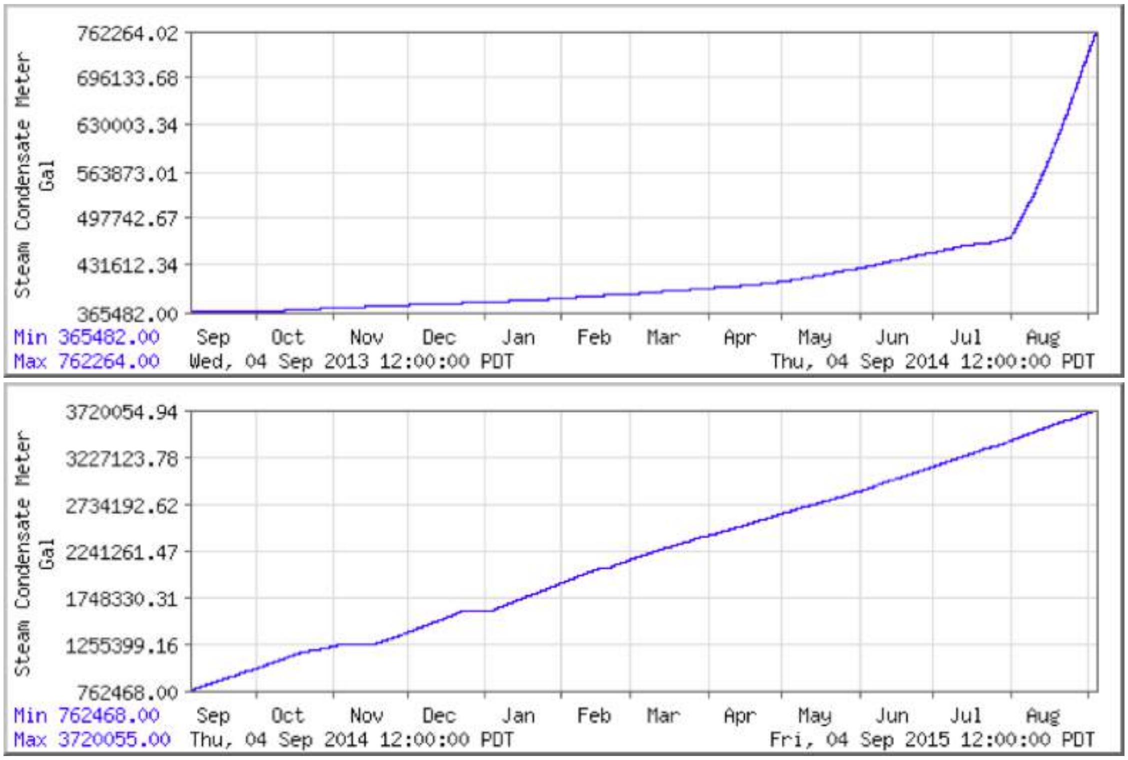
Obvius Energy Analysis

To get an overview of the Haas School of Business regarding energy consumption patterns, data from Obvius at buildingmanageronline.com was used. Several graphs were constructed for years 2013 to 2015.



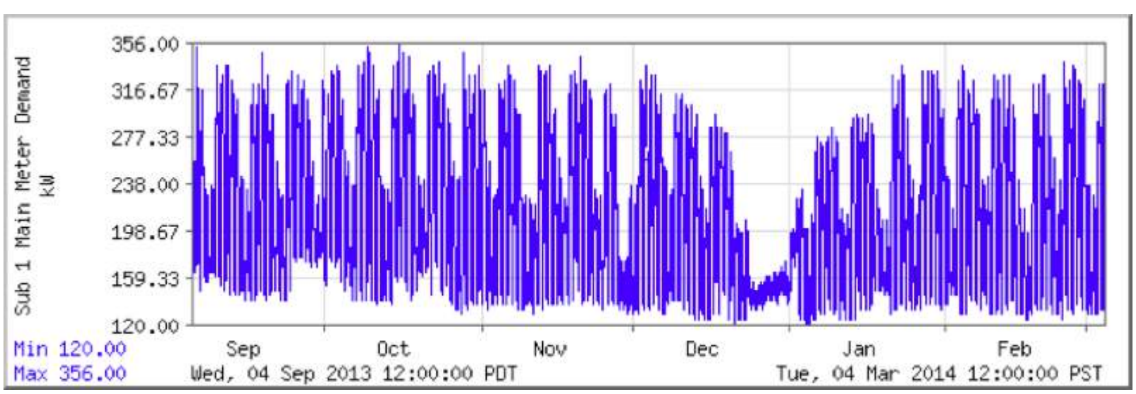
Figures 2-3: Electricity Consumption for Meter 1 at Haas, September to August, 2013 to 2015
Source: Obvius 2015

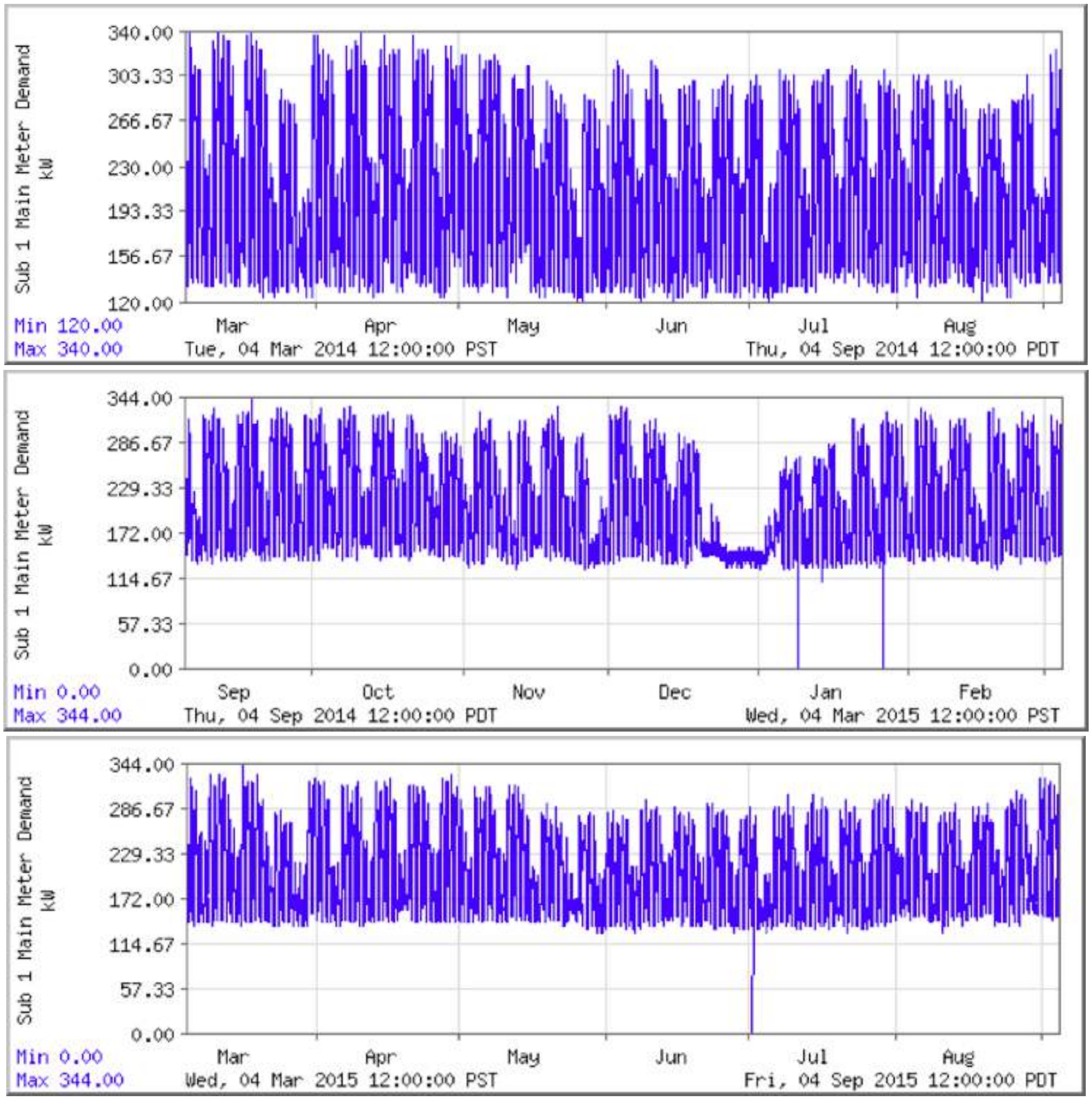
The graphs show electricity consumption of the building increased linearly over the past two years. As a long term trend, electricity consumption appears to be quite steady. In addition, Obvius had data on steam consumption, which was utilized in the following graphs.



Figures 4-5: Steam Consumption at Haas, September to August, 2013 to 2015
Source: Obvius 2015

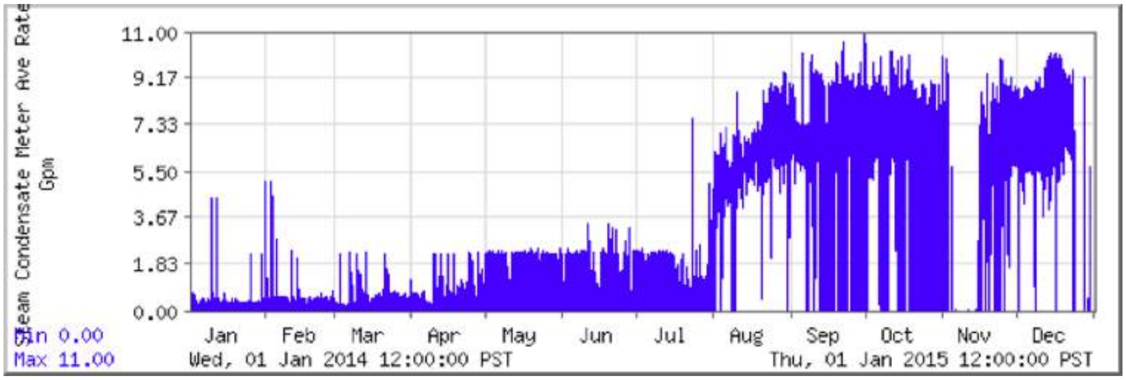
From August 2014 onwards, steam consumption in the building increased at a more rapid rate. This could be due to actual steam use but could also be due to a malfunctioning meter. Regardless, the steam consumption rose at a steady rate until April 2014, had a higher rate from May 2014 to July 2014, and then dramatically increased after this time. In addition, there were several points where steam consumption was essentially zero. These occurrences were most pronounced in November and December 2014.

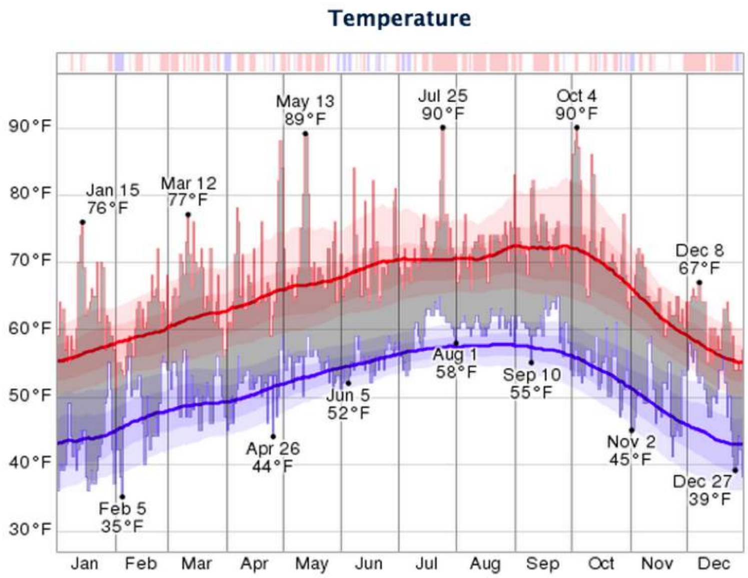




Figures 6-9: Power Demand for Meter 1 at Haas, September 2013 to August 2015
Source: Obvius 2015

To see how power use changes in the building, graphs of half year periods were produced. As is shown, there is a general background power use for the building. Power use doubles during operational hours. The data shows also that weekend use is much lower than weekday use, which can be expected as most occupants do not work during these hours. This trend is followed throughout the months. Variation from week to week and month to month is noticeable but not unusual. In addition, during winter break, the end of December to the beginning of January, power use drops to the background levels.


Steam Condensate Meter Ave Rate
Gpm
11.00
9.17
7.33
5.50
3.67
1.83
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Min 0.00
Max 11.00
Wed, 01 Jan 2014 12:00:00 PST
Thu, 01 Jan 2015 12:00:00 PST


Temperature
90°F
80°F
70°F
60°F
50°F
40°F
30°F
Jan 15
76°F
Mar 12
77°F
May 13
89°F
Jul 25
90°F
Oct 4
90°F
Dec 8
67°F
Feb 5
35°F
Apr 26
44°F
Jun 5
52°F
Aug 1
58°F
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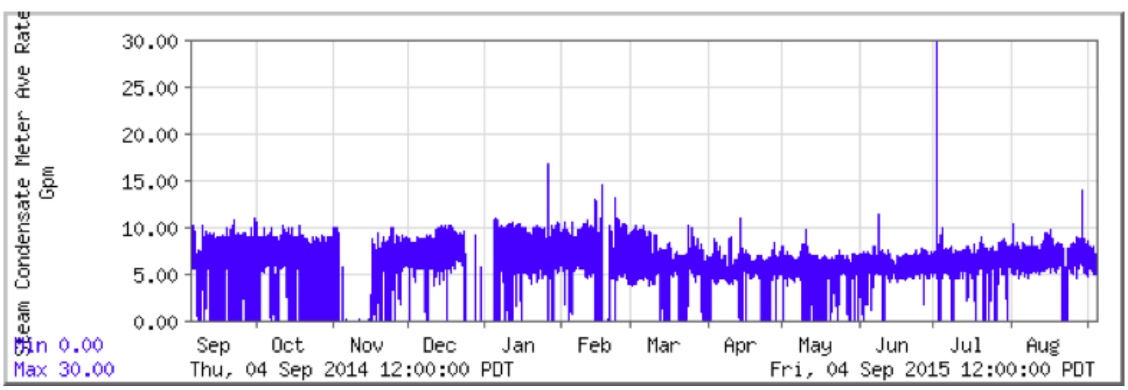
Steam Condensate Meter Ave Rate
Gpm
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Sep
Oct
Nov
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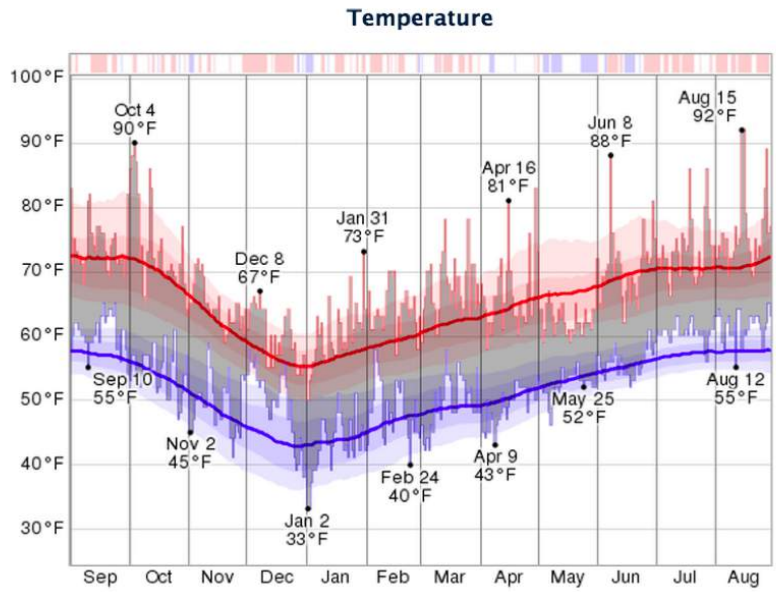
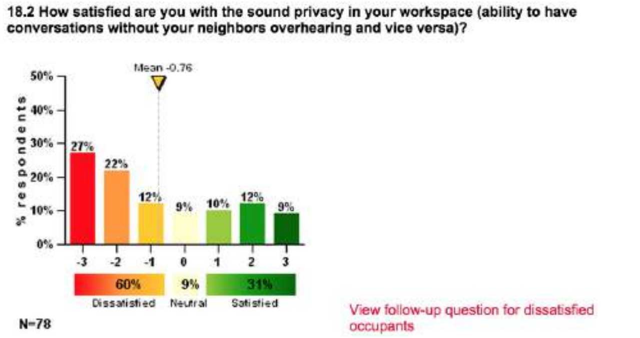
Max 30.00
Thu, 04 Sep 2014 12:00:00 PDT
Fri, 04 Sep 2015 12:00:00 PDT

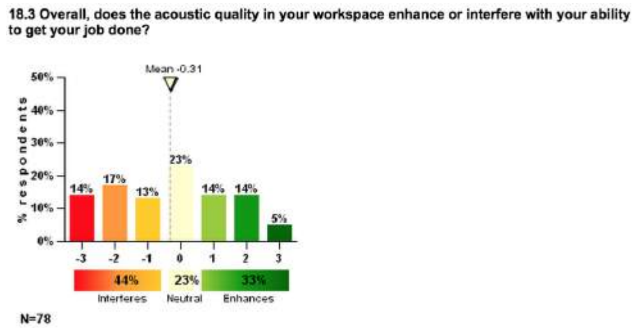


Figures 10, 12: Average Steam Use in Haas, September 2013 to September 2014, September 2014 to September 2015
Figures 11, 13: Average Outside Temperature, September 2013 to September 2014, September 2014 to September 2015
Sources: Obvius 2015, WeatherSpark 2015

A final comparison between outside air temperature and average steam use was conducted to see how weather affects steam usage in the building. The graphs show a slight correlation between the two. As the outside air temperature decreases, steam consumption increases to heat the building.

Occupant Survey Analysis





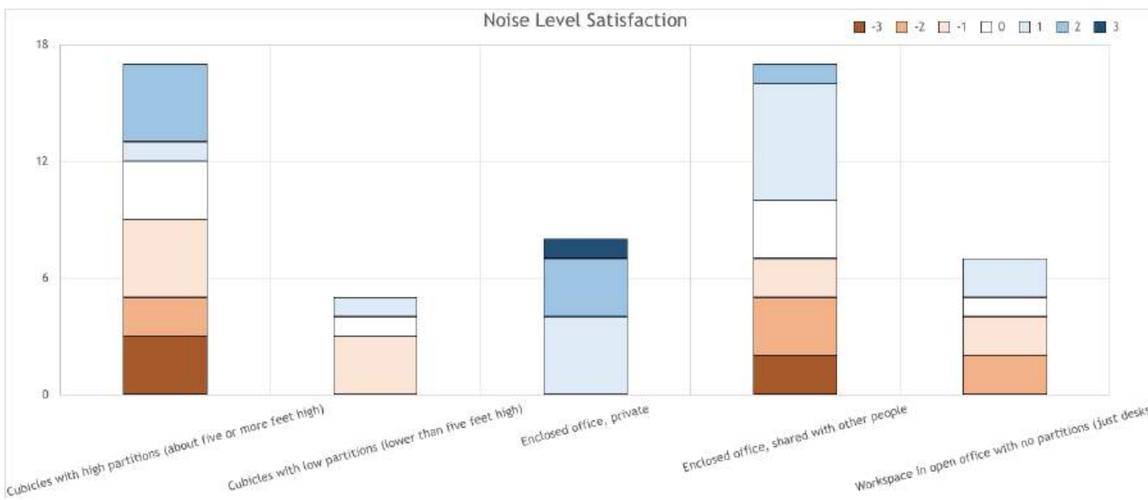
Figures 14-16: Acoustical Satisfaction for Haas School of Business
Source: CBE Survey

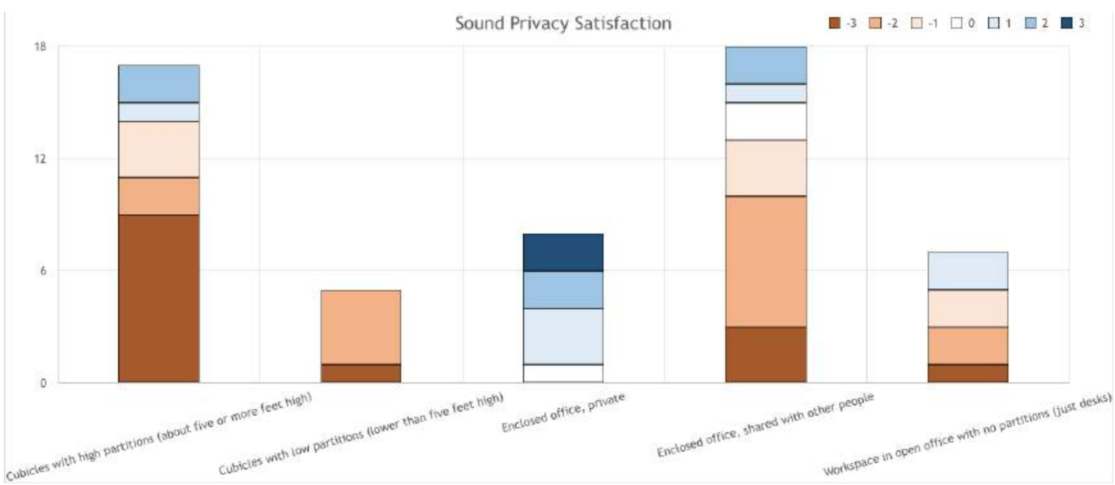
A Center for the Built Environment (CBE) survey was conducted in September 2015 to assess occupants' satisfaction of the building. All three main questions regarding acoustical quality had an average below 0 as shown in the graphs. Sound privacy had the worst average of the three with over a quarter of the occupants indicating that they were extremely dissatisfied with their workspace. Overall, acoustics had the second lowest average for all metrics of the survey. Other metrics included lighting, air quality, and thermal comfort.

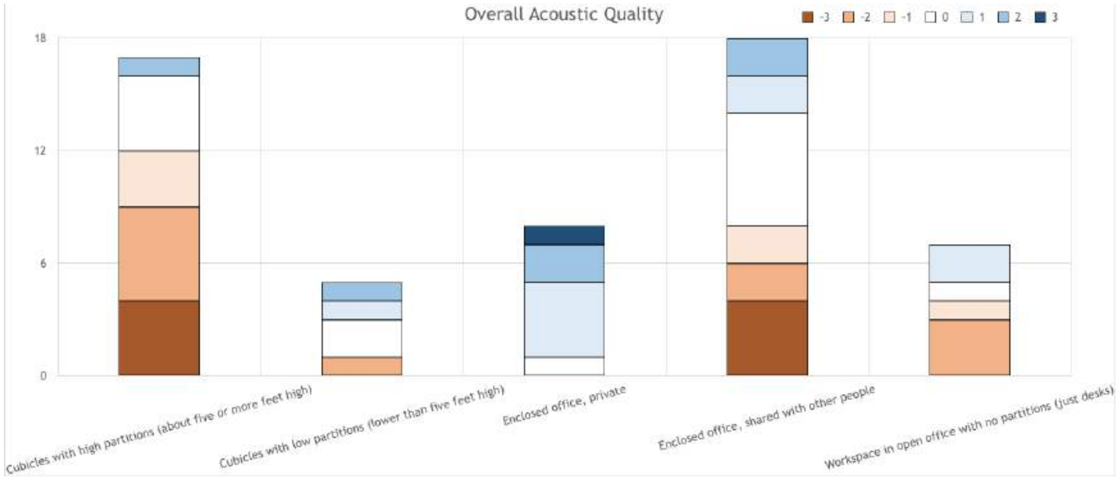
Below are some of the notable comments regarding acoustics from the survey:

- We are so close to each other, that if any of the 8 of us are on the phone, we can hear VERY clearly.
- Pipes and ventilation have been making sounds for months.
- Portable fans whirring along.
- There is no insulation in the walls, so you can clearly hear conversations in neighboring offices.
- Server room noise.
- We have a few people in the office with chronic sinus and/or coughing issues. Lots of coughing, choking, sneezing, nose blowing, etc. and it can be extremely loud at times. If there was a way to dampen the echoing of noise I'd love it!
- Outdoor traffic noise or construction noise is a matter of fact; we close the window if it's too much but then the office gets too hot and stuffy.
- Major construction noise (Maxwell Garage and new Academic building) can be a problem, so windows are often kept closed but this results in lack of air circulation.
- Noise and its subsequent distractions impact my productivity.

These comments follow a study which found that more than half of around 200 workers in an open-plan office were disturbed by noise (Boyce 1974). The main disturbances came from telephones ringing (67%), people talking (55%), air conditioning, typewriters, and office machinery, which closely aligns with the CBE survey. Beyond these comments, a considerable amount of occupants complained about speech privacy and the impact on their productivity. In addition, they mentioned their close proximity to one another and that they could hear others "even when wearing headphones and listening to music". As many of the occupants are required to "be on the phone all day", the shared space is not ideal to the say the least. Altogether, the main source of dissatisfaction acoustically was undoubtedly from this overcrowded situation. The majority of other factors had only one or two occupants comment on them. However, during the experimentation of this project, all mentioned grievances were investigated when possible.







Figures 17-19: Acoustical Satisfaction of Haas School of Business from the 4th and 5th Floor, Divided by Type of Office and Type of Partition
Source: CBE Survey

To get a better understanding of the CBE survey, acoustical satisfaction based on the type of space and partition was extracted. As shown, those in private offices are relatively pleased with the space. However, in all other spaces, people were generally dissatisfied. Occupants in cubicles with high partitions were especially unsatisfied with their sound privacy, as over half of these occupants put the lowest rating possible. Given the amount of evidence stating so, it is clear that partitions are most likely not a solution for solving the acoustical problems with the building. This agrees with an earlier study which reviewed over 20,000 respondents from 142 buildings using the CBE survey. They found that over 50% of cubicle occupants think acoustics interferes with their ability to get the job done (Jensen & Arens 2005). Similar to other reports, over 80% of cubicle occupants had a problem with colleagues talking on telephones and over 80% thought that it was a problem that others could overhear their private conversations. As high and low partitions both had issues with people talking in the surrounding offices, the authors suggested sound masking systems and covering room surfaces and partitions with sound-absorptive materials to reduce speech sound levels. Private offices or spaces was also a proposal. These solutions will be further examined in the recommendations portion of this report. As the occupant survey conducted for this study corresponded to preceding surveys, the Haas School of Business is not an isolated example of acoustical dissatisfaction.

HYPOTHESES

Even though there is a plethora of anecdotal evidence that the acoustical environment within a large portion of the Haas School of Business creates many problems and is not up to personal requirements for a workplace, the noise and sound levels in the building comply with all relevant codes and standards. In addition, grievances with the current acoustical environment are due to overcrowding resulting from poor layout and space planning rather than material and construction choices.

Two hypotheses outline our endeavor:

1) The occupants are dissatisfied with acoustical quality because the building does not meet the PMP benchmarks regarding dB (A) ranges for background noise. In the event this proves true, we will seek structural and topical methods to bring the building to standards.
2) The occupants are dissatisfied with acoustical quality, but the building's range of background noise meets the PMP benchmarks regarding dB (A) range. In the event this proves true, we will seek behavioral and perceptive methods to bring the building to standards.

APPROACH & METHODOLOGY

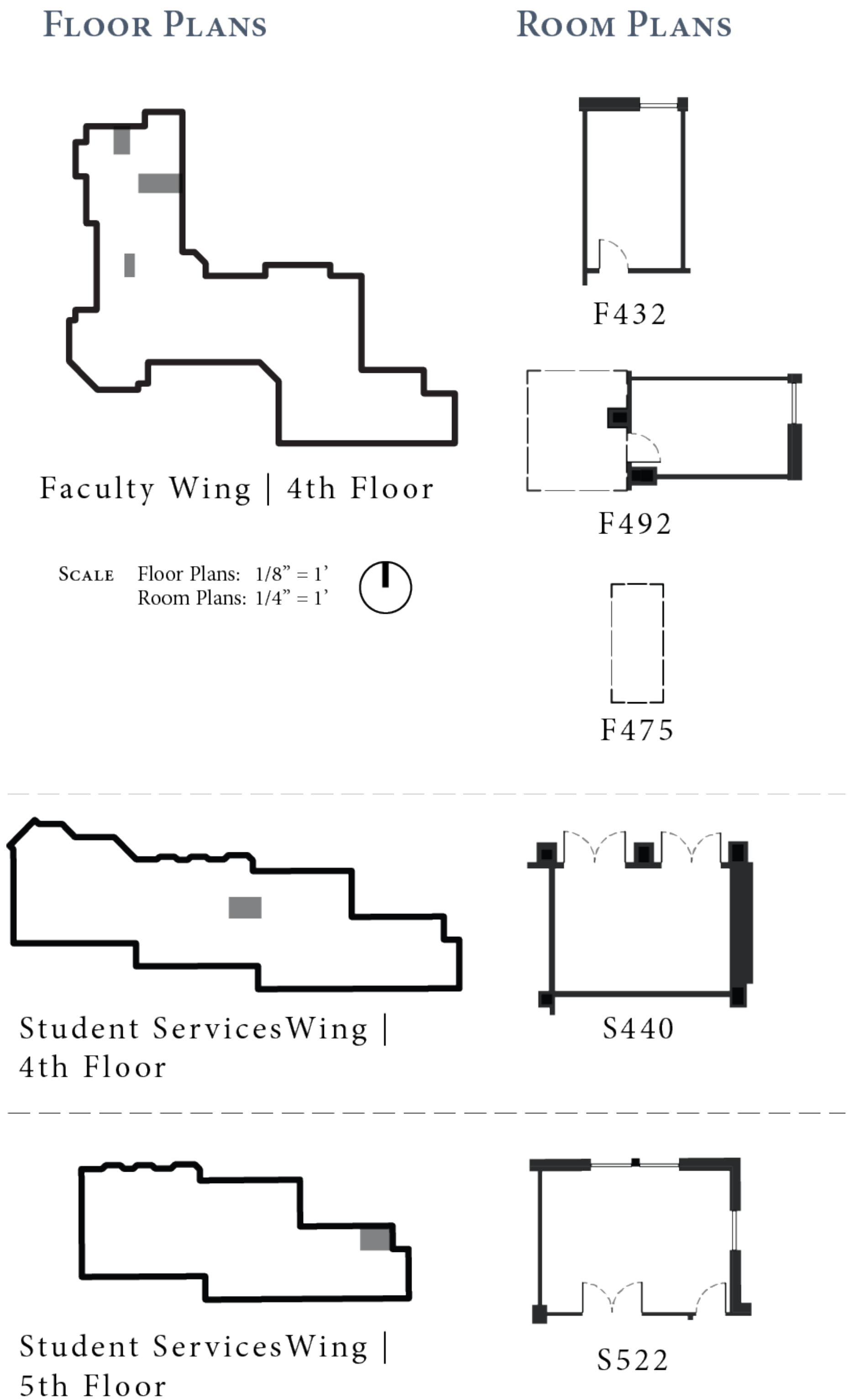
Given that the school of business has numerous uses for the spaces within each building, a variety of occupied spaces were tested to fully assess the performance of Haas. The testing areas consisted of a private office, a hallway corridor, an open office, and two conference rooms. To test the acoustical quality of each space, a sound meter was utilized, which is a measurement tool for determining noise in dB (A). Spot measurements of 30 to 60 seconds were taken. After each measurement was conducted, the values were compared to the ideal and maximum dB (A) levels from ASHRAE's Performance Measurement Protocol (PMP) benchmarks. In this manner, comparison with the CBE survey could be executed and the spaces could be compared amongst one another. Due to the location of the CBE survey respondents, the measurements were primarily performed in the faculty wing and student services wing.

Room Types / Applications		Ideal L_{eq} (dBA)	Maximum L_{eq} (dBA)
Outdoor Ambient	Intrusion from transportation vehicle noise	40	50
	Noise Exposure of neighboring property from operation of building equipment through louvers and from outdoor equipment.	45 at the property line	Local Ordinance
Apartments and condominiums		30	40
Hotels/Motels	Individual rooms or suites	30	40
	Meeting/banquets rooms	30	40
	Corridors and lobbies	40	50
	Service/support areas	40	50
Office Buildings	Executive and private offices	30	40
	Conference rooms	30	40
	Teleconference rooms	25	30
	Open-plan offices without sound masking	35	45
	Open-plan offices with sound masking	35	40
	Corridors and lobbies	40	50
Courtrooms	Unamplified speech	30	40
	Amplified speech	35	45

ACOUSTICS PERFORMANCE BENCHMARKS

Table 1: Acoustics Performance Benchmarks Based on Room Type and Application
Source: ASHRAE, USGBC, CIBSE 2010

RESULTS



Figures 20-24: Floor and Room Plans for Examined Rooms

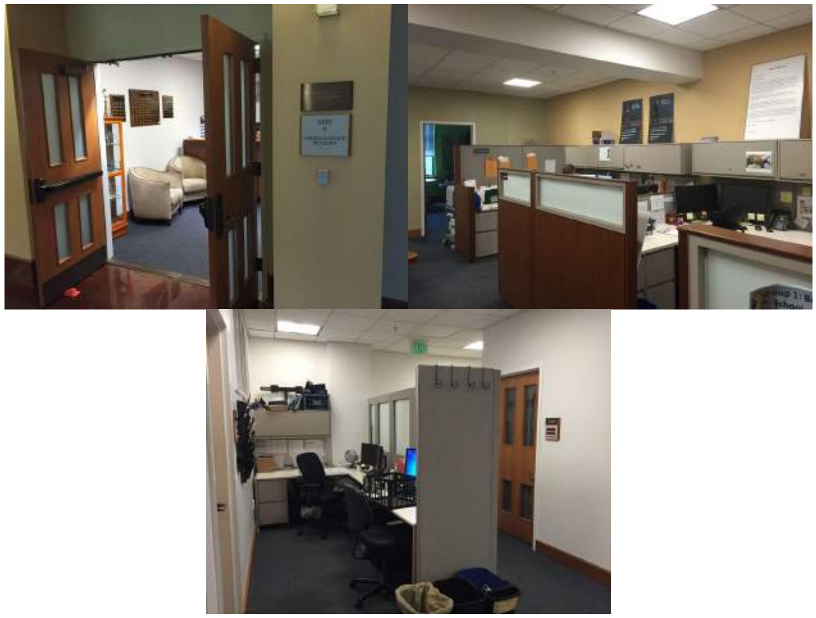
Room Number	Type of Room	Condition	Time of Day	Minimum (dB(A))	Maximum (dB(A))
F432	Conference Room	Construction, Windows Open	Afternoon	48.6	59.9
F432	Conference Room	Construction, Windows Closed	Afternoon	36.5	46.4
F432	Conference Room	No Construction, Windows Open, Traffic	Night	42.6	51.0
F432	Conference Room	No Construction, Windows Closed, Traffic	Night	34.0	48.7
F475	Hallway		Early Morning	27.6	56.7
F475	Hallway		Morning	36.9	66.4
F475	Hallway		Afternoon	39.3	50.3
F492	Private Office	Door Open	Early Morning	29.7	58.2
F492	Private Office	Door Closed	Early Morning	27.4	50.0
F492	Private Office	People In Close By Rooms Talking	Afternoon	43.0	50.7
F492	Private Office	No Talking	Afternoon	31.8	51.9
S440	Open Office	Door Closed, No Talking	Morning	37.6	47.8
S440	Open Office	Door Closed, Talking 10 ft. Away	Morning	43.7	69.7
S440	Open Office	Door Closed, No Talking	Afternoon	43.5	57.1
S440	Open Office	Door Closed, No Talking	Night	27.2	57.6
S522	Conference Room	Windows Closed, No Fan	Early Morning	21.8	58.9
S522	Conference Room	Windows Open, No Fan	Early Morning	32.9	62.0
S522	Conference Room	Windows Open, Fan On	Early Morning	38.0	61.1
S522	Conference Room	Windows Closed, Fan On	Early Morning	37.7	56.0
S522	Conference Room	Windows Closed, No Fan	Morning	37.8	60.6
S522	Conference Room	Windows Open, No Fan	Morning	40.9	50.2
S522	Conference Room	Windows Open, Fan On	Morning	46.4	50.5
S522	Conference Room	Windows Closed, Fan On	Morning	48.5	50.7

Table 2: Measured Minimum and Maximum dB (A) Levels in Haas
Note: Yellow indicates the measured value was below ASHRAE ideal levels from standards and red indicates measured value was above maximum ASHRAE standards.

The private office, room F492, was in the faculty wing as indicated by the F. The room had a surface area of about 100 square feet, contained one desk with one computer, and had one operable window. The floors were carpeted and the ceilings had square panels, which did not absorb sound well. The first set of tests for the private office was taken during the early morning to detect the true background noise levels. Tests taken from within the office with the door open and closed were conducted. The minimum noise as indicated by the sound meter with the door open was 29.7 dB (A) and 27.4 dB (A) with the door closed. From the PMP table, the minimum dB (A) background noise level in the office space with the door closed was below the ideal level. The same private office was tested during other time of the day to see how the room functions during operational hours. Of these measurements, background noise level did not exceed the PMP standards except for when people were talking in nearby rooms with their door slightly open. This occurred in the afternoon and the minimum noise level in this case was 43.0 dB (A). Thus, it is now not surprising that occupants complained in the CBE survey about this situation.

Picture 1: Hallway in Front of F475
Source: Kwan, J.

In the same region of the faculty wing, the hallway outside of room F475 was also examined. The hallway was about 6 feet wide with carpet floors and was surrounded by private offices. The walls and ceiling were highly reflective in terms of acoustics. Similar to the private office, background noise levels were low during the early morning and reached 27.6 dB (A). At other times of the day, the background noise levels were acceptable by the ASHRAE standards.



Pictures 2-4: Open Office S440; Entrance (Top Left), Work Stations within S440 (Top Right), Work Station Attached to S440 in the Back (Bottom)
Source: Kwan, J. and O'Laughlin, P.

The open office, S440, was located in the student service wing of the building. This office connected to several other offices in the area. These connected offices had a total surface area of about 1000 square feet, encompassed over 15 working stations, each with a desk and a computer, and had a variety of different sized office partition panels with translucent windows for light access. S440 itself had a surface area of about 300 to 400 square feet, about 4 occupants, and low partitions. The walls in this area were sound reflective, the ceilings had weak sound absorbing panels, and the floors had carpet which matched those of the private office. All tests shown were made with the office door closed as the occupants in this space preferred this atmosphere. An additional test involving the office next door, S450, showed that opening doors resulted in a higher background noise level. However, this allowed for more echoing and distractions that could not be shown through sound meter measurements. Tests from S440 showed that during the day, background noise levels fell within the range specified by ASHRAE. However, at night, the background noise level dropped to 27.2 dB (A). Unlike the private offices, low background noise for open offices and offices in general can be detrimental to productivity, as unexpected noises can distract occupants tremendously. Recommendations on how to solve this situation follows this section of the report.

Pictures 5-6: Conference Room S522 (Left), Conference Room F432 (Right)
Source: Kwan, J. and O'Laughlin, P.

The last type of space measured was conference rooms. Conference room S522 was selected because the room has multiple operable windows which face Piedmont Ave. and could serve as a proxy for those rooms which have occupants dissatisfied with traffic noise. The other conference room, F432, was chosen as it faced the construction of a new building. This new building is also for the Haas School of Business and will actually help alleviate some of the acoustical issues with the original building when some occupants move to this area. Both conference rooms had carpet floors, sound reflective walls, and ceiling panels which did not absorb sound well. Room S522 was tested at multiple hours a day with several scenarios involving the fan and the windows. It is interesting that in the early morning, the background noise level was below the ASHRAE ideal levels. However, once the fan was turned on in this space, the background level was adequate. In addition, when fan level was on later in the morning, the background noise level was too high for ASHRAE standards, reaching 46.4 dB (A) and 48.5 dB (A) with the window close and open. In this case, it was not the traffic that was the main factor but the usage of the fan for thermal comfort. During most times of the year, this would not be a problem as the outside temperatures allow for satisfactory indoor temperature. Heat waves could pose an issue however, as occupants have complained about thermal comfort in the space in the CBE survey. As for room F432, when the window was open at night and in the afternoon, background noise levels exceeded the maximum levels set by the PMP. Unlike room S522, room F432 has issues regarding both construction and traffic. To solve these possible noise distractions, thermal comfort and indoor air quality for the occupants must be resolved to prevent them from needing to open the windows.

As for other acoustical issues, no cracks nor damages were found in partitions or foundations that would indicate improper sound insulation. The HVAC system did not appear to be an issue and the server rooms that were located did not have any noticeable acoustic problems. Portable fans were seen in numerous spaces; however, these did not raise background noise level significantly and were mainly heard only when close by. Overall, the main source of complaints which warrants further investigation is the proximity of occupants in offices, both closed and open, not including private offices.

(A) Noise Level (dba)	(C) Sound Isolation (dba)	(D) Found Backgroun d Noise (dba)	(B) Speech Privacy (dba)		Typica l Values (dba)
Low Voice - 54	35	27.2	-8.2	(C) Estimated Noise Reduction for 70" Tall Office Screens	16
Normal Voice - 60	35	27.2	-2.2	(C) Estimated Noise Reduction for Partition Built to Ceiling Grid	35
Raised Voice - 66	35	27.2	3.8	(C) Partition from Slab to Slab	45
Loud Voice - 72	35	27.2	9.8	(C) Double Stud Partition	63
Low Voice - 54	16	27.2	10.8	(D) Typical Background Noise for Open Offices	45
Normal Voice - 60	16	27.2	16.8	(B) Unacceptable Speech Privacy	0 or More
Raised Voice - 66	16	27.2	22.8	(B) Marginal Speech Privacy	-3
Loud Voice - 72	16	27.2	28.8	(B) Normal Speech Privacy	-9

Table 3: Young's Method for Open Office S440

To test the office space beyond the ASHRAE standards, a simple calculation for speech privacy based on research conducted by Young (1965) was used (Young 1965). The procedure uses basic math to predict speech privacy.

$$A - C - D = B$$

A - Speech Level, B - Degree of Speech Privacy, C - Sound Isolation, D - Background Noise

The estimated speech levels and sound isolation values came from a report on acoustical performance measurement protocols for commercial buildings (Salter & Lawrence 2012). As the office examined had areas with high partitions and areas without partitions, two values for sound isolation were utilized. The background noise was taken from actual measurements from the space. The tables demonstrate that office S440 does not have adequate speech privacy. Only when considering those with partitions speaking with a normal or low voice does the space perform respectively. As indicated in the occupant survey, numerous occupants must make phone calls and conduct interviews for their work. Thus, it is unreasonable to assume that voice levels stay at a normal level. As this is with the assumption that the space has high partitions, other solutions may be more practical and achievable.

RECOMMENDATIONS

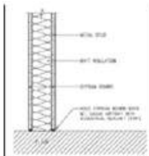
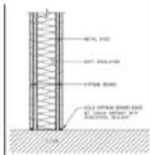
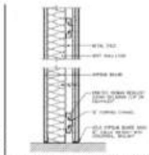
CONSTRUCTION	Baseline Partition	 Partition Type #1	 Partition Type #2	 Partition Type #3	Sound absorbing wall panel	Lay-in acoustical tile ceiling in 2x4 grid	Lay-in acoustical tile ceiling in 2x4 grid	Sound masking system
DESCRIPTION	12' high 20 gauge studs slab to slab, 24" o/c, 5/8" gypsum board each side, Level 4 finish, painted. Baseline partition is not sound rated.	Same as Baseline Partition plus R-11 fiberglass insulation, in stud cavity. Wall penetrations and perimeter sealed with acoustical caulking. Low voltage devices placed in outlet boxes. All electrical outlets sealed with outlet box pads. STC 40	Same as Partition Type #1 plus one layer of 5/8" gypsum board added on each side. STC 45	Same as Partition Type #2 except only one layer of gypsum board on one side and 1 3/8" resilient channels isolating gypsum board on the other side. STC 53	NRC 0.8 minimum	Celotex BET-197 NRC 0.55	Capaul Nubby NRC 0.9	Logison
COST	$154.30/lineal foot $12.86/sq. ft.	15% more than Baseline Partition $176.69/lineal foot $14.73/sq. ft.	31% more than Partition Type #1 50% more than Baseline Partition $231.66/lineal foot $19.30/sq. ft.	3% less than Partition Type #2 45% more than Baseline Partition $224.56/lineal foot $18.71/sq. ft.	$22.30/sq.ft. installed	$5.42/sq. ft. Installation of grid and tile, not including lights, sprinklers, etc.	$6.97/sq. ft. 28% more than standard acoustical tile ceiling	$1.81 per sq. ft. installed

Table 4: Costs of Acoustical Solutions
Source: GSA 2011

Considering acoustics affects occupants year round, resolving such issues should be prompt and of high-priority. As a preface, Young (1999) reported that 70% of office workers say that a reduction in noise would increase their productivity (Young 1999). Furthermore, as sound levels increase, the complexity of tasks one can perform generally decreases (Kiellberg et al 1996). However, it is not just the sound levels that interfere with people's productivity but also the type of noises. People are generally more distracted by sounds they consider unnecessary such as idle talk compared to those they perceive as inevitable (Vickers 2007). Speech is also considered the most annoying and distracting type of office noise. Banbury and Berry (1998) tested subjects with and without irrelevant speech in the background and found that test performance dropped by two-thirds when irrelevant speech was present (Banbury & Berry 1998). Irrelevant speech was particularly disruptive for processes involving memory including problem solving and reasoning. As Haas occupants unquestionably have such tasks and must also endure others' speech, acoustical solutions must take into account sound levels, speech intelligibility, and sources of noise to ensure realistic gains in satisfaction.

Of the possible solutions, providing private spaces for each individual is highly unlikely for the building. Occupant levels are already beyond the intended amounts and there are difficulties finding adequate space even in shared rooms. If this solution was however to become viable both financially and physically in the future, it would be the preferred method to generating acoustical satisfaction as those with private offices are undeniably the most content.

A behavioral system in which occupants agree to keep voice levels low at certain times of the day is in essence the low cost resolution. Signs on walls and such could serve as reminders that speech might interfere with others. However, this would be difficult to implement as the job requirements for many of the occupants involve making phone calls and interviewing. Furthermore, conversational distractions will occur every so often due to human nature (Vickers 2007). In addition, speech privacy, one of the most prominent source of dissatisfaction, would not be solved with this option.

As the spaces had sound-reflective surfaces, another solution is to replace such surfaces with sound-absorptive materials. These surfaces include partitions, ceilings, and hard floors. As seen in the GSA table, these solutions are relatively expensive as will be further explored in an economic analysis. This type of solution would also involve invasive construction, especially in regards to modifying the ceilings and floors. Moreover, each space would have to be redesigned based on what was added. This is not the preferred option but should be kept in mind for when new buildings are constructed.

The optimal solution appears to be a sound masking system for its practicality and price. The installation takes less than a day and the interference with employee space is limited. In fact, several studies have highlighted the benefits of such systems. Navai and Veitch (2003) found small positive contributions to acoustic satisfaction for sound masking in open-plan offices (Navai & Veitch 2003). However, the dB(A) levels used for those systems were above current standards as the environments investigated were loud to begin with. Thus, the small gains are still positive. Other studies have also reported that sound masking systems produced productivity gains of 8% to 38%, stress reductions of up to 27%, and job satisfaction increase of 125% to 174% (Lewis et al 2003). As will be used in the economic analysis, Hongisto (2008) found that a sound masking system saved occupants in a Finnish open-office 8 minutes per day of productivity (Hongisto 2008). Therefore, the potential is high for sound masking systems.

The impacts of sound masking systems examined holistically further show why it is the preferred option. For one, providing background noise reduces the amount of distractions and increases the ability of focus on tasks and improves short-term memory (Lewis et al 2003). Although the system uses electricity to provide the background noise, overall building energy use may not increase. Occupants may finish their work faster and turn off their computers, lights, etc. sooner, which would decrease electricity use. The amount of energy used by these systems is low and is unlikely to influence overall building use extensively. Also, the system noise level can be adjusted as the amount of occupants and the arrangement of each space changes, thereby satisfying occupants as the office evolves. As a sound masking system increases speech privacy by definition, occupants would have more freedom to conduct phone calls and hold meetings in their spaces, which would undoubtedly decrease stress. Overall, sound masking systems are feasible for the offices in Haas and should be installed where occupants are most dissatisfied.

A final option that is currently gaining momentum in several countries is supplying the office spaces with indoor phone booths. Unlike the image that initially comes to mind, these are modernized spaces for conducting phone calls or interviews. All aspects of the booth including the door, the walls, the roof and the floor are specified acoustically to give the user privacy. However, the two main drawbacks of these booths are the costs of each and the space that each booth will occupy. As Haas is already space-constrained, phone booths are not the most favorable solution.

Economic Analysis

	Net Present Value ($)	Installation ($)	Electricity ($/yr)	Annual Productivity Gains ($/yr)
Sound Masking System	-1815.12	841.5	100.00	-533.33
Partitions	-385.72	6628.5		-933.33
Office Booth	-14.22	7000		-933.33

Table 5: Net Present Value of Three Potential Solutions

The net present values of three different solutions are shown in Table 5. The discount rate for all three was set at 7%. For the sound masking system and the partition options, the initial costs were based on estimates from the General Services Administration (GSA 2011). Partition Type #1 with a price of $14.73/sq. ft. was chosen as it is specified acoustically and is at a lower price. The area used for both solutions was 450 sq. ft. The plans for open office S440 indicated that the space had 300 sq. ft.; however, when in the space, it was apparent that the office was connected to other offices through a hallway in the back, which also included a private office and several cubicles. Therefore, the space was increased as a precaution. The lifetime of the sound masking system was assumed to be five years as the warranty for one sound masking system was three years (Atlas Sound 2015). The system would normally be expected to last over five years. For the sake of comparison between the options, a second sound masking system was bought at the beginning of the sixth year as the first system "expired". In reality, one sound masking system would last throughout this period. Regardless, the net present value still illustrated that the sound masking system is the most viable option financially. Cost of electricity came from assuming that the entire system would use 200 W for 8 hours a day at a rate of $0.25/kWh, which is a high estimate for California. As for other costs, manufacturers have stated that no maintenance would be required during the lifetime of the system (Lencore Acoustics 2007). Maintenance was not incorporated for the partitions either as once they are installed, the partitions are assumed not to be modified. The annual productivity gains for all three options was based on results of a study on saving 8 minutes per day of productivity for a sound masking system (Hongisto 2008). In that study, 14 minutes per day were wasted per day due to excessive noise. Thus, it was assumed that the partitions and the office booth eliminated all of these distractions. Using this saved productivity of workers, the amount of annual gain was calculated by multiplying by the amount of workdays in a year (5 days/week and 50 work weeks/year), the number of occupants (4 people), and the hourly wages of those workers ($20/hour). The number of occupants in the space was taken from the amount of workers present when conducting the experiment and the hourly wages is an underestimation from the salary rates of the university (Berkeley Human Resources 2015). The office booth installation estimate originates from an advertisement catalog (Framery 2015), where the booth itself costs over $6,200. This does not include the seat and accessories, which could easily add up to over $2,000. A middle range estimate of $7,000 was therefore used. The only maintenance required for the booth would be cleaning, which would be provided by the janitorial services of the building and would not add into this estimate.

The final results show that the sound masking system is clearly the best solution available. Negative values indicate that the option results in financial gains in the long run. Even with the assumption that the productivity gains of occupants would be smaller for the sound masking system, the high capital costs of new partitions or an office booth make these options less desirable.

	1 Minute/Day, 4 Occupants	8 Minutes/Day, 8 Occupants	15 Minutes/Day, 8 Occupants	Range
Projected Savings ($/week)	6.67	53.33	200.00	3 - 400
	Capital	Electricity	Total	Range
Projected Costs ($/week)	4.00	1.60	5.60	2.2 - 17

Table 6: Sound Masking System Estimates

A sensitivity analysis shows the range of possible savings due to the sound masking system. Variables including the amount of saved time, hourly wages, number of occupants, capital costs, electricity prices, room size, lifetime of the system, and system power requirements were all varied to see their impact on the viability of the system. It was shown that even with low estimates of projected time savings, a sound masking system could still be implemented.

Finally, a closing financial argument for any of the options is the amount of time and money spent on turnover. A study at the beginning of the millennium denoted that the cost of turnover for a hotel was $1,000 per position for entry-level roles and rose to over $10,000 for front-office associates in some cities (Hinkin & Tracey 2000). Although the hiring situations between hotels and the school of business are not identical, the same complications with turnover are still present where turnover is costly due to the time it takes to learn a new job, the productivity lost when someone unfamiliar with the tasks is replaced with a seasoned employee, and the lost work of peers and supervisors disrupted by the slack they must pick up while the new hire learns the job. The cost of turnover as a percentage of annual wage was 27-30% for the hotels examined. Even if the turnover rate of Haas is much lower, by retaining one additional employee through increasing job and environmental satisfaction, any of the options for increasing acoustical quality would be compensated.

CONCLUSION

Through investigation, it was found that first hypothesis was correct in stating that the rooms measured comply with basic performance standards, where the background noise level is for the most part below the maximum benchmarks. The few cases in which these standards were not met originated from outside sources, i.e. traffic and construction. This is easily solved by closing the windows; however, this solution may not be a panacea for when temperatures inside the building are high and indoor air quality is lacking. As for where the grievances in the acoustical environment come from, this study found that it is possible to blame overcrowding from poor layout and space planning. Yet, another main source is that the background levels are too low, as was discovered from measurements in the early morning and night. Thus, as the building is already past the original capacity and despite a new building under construction, overcrowding may occur in the future, our recommendation is to add sound masking systems to increase acoustical quality. This solution requires little encroachment on the occupants' space and could be implemented at any time. A test system could initially be implemented where occupants are most dissatisfied and scaling could occur based on this trial run. As for other solutions, both partitions and office booths were observed to have high capital costs and should only be implemented when occupants request the desire for such solutions. As the CBE survey illustrated, partitions may not solve speech privacy. Although it is likely that the partitions installed thus far are not optimal acoustically, state-of-the-art partitions would involve an even higher capital cost and would thus be the last choice. Therefore, in the order of most appropriate, the Haas School of Business should implement sound masking systems, office booths, or partitions to solve the acoustical dissatisfaction of which numerous occupants have.

CONTRIBUTIONS

Jeffrey

- Summary of Recommendations for Executive Summary
- Background on Acoustics
- Occupant Survey Analysis
- Sound Data Collection
- Results (Young's Method)
- Economic Analysis
- Recommendations
- Conclusions
- References
- Pictures of Building

Peter

- Sound Data Collection
- Pictures of Room Interiors
- Obvius Energy Analysis
- Energy Star Benchmarking
- Approach/Methodology
- Room Descriptions
- References

Arami

- Designed poster board layout
- Designed floor and room plans
- Executive Summary
- Description of the Building
- Hypotheses
- Paper formatting
- Researched building performance measurements
- Researched standards and codes

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