THESIS (Chapter 2/2)

LINKING A COMPREHENSIVE SURVEY OF BUILDING SATISFACTION

AND ADAPTIVE BEHAVIOR TO GREEN BUILDING DESIGN

Abstract

A survey of the faculty, staff, and student body of the Yale School of Forestry and Environmental Studies is used to explore the impact of a green building on occupant satisfaction, work, and time impact. By comparing differences between occupants who can self-select into LEED Platinum Kroon Hall to those randomly assigned to it, this paper sheds light on discrepancies in the green built environment literature. The self-selecting student subgroup receive a statistically significant benefit from the green building while the faculty and staff assigned to it, akin to random assignment in an experimental design, report being no more satisfied than their counterparts elsewhere on average. One possible cause is that self-selection improves satisfaction and welfare when the buildings of an organization are heterogeneous. Another is that ‘green’ ‘vanity architecture’- structures built to impress visitors, have left the permanent staff of green buildings no better off than traditional structures.

Keywords: LEED, comfort survey, green building, vanity architecture, quasi-experimental

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I, Zachary Turk, conducted the statistical analysis and composition of this study. The survey questions were developed by Matthew Kotchen (thesis advisor) and James Ball (fellow student), and the survey instrument was implemented by James Ball. I am grateful for their substantial contributions and feedback on this work as well as the feedback of Anthony Leiserowitz (thesis co-advisor).

**Linking a Comprehensive Survey of Building Satisfaction**

**and Adaptive Behavior to Green Building Design**

# Introduction

This study explores the concern that, when taken to extremes, green buildings tradeoff comfort for energy efficiency to such an extent that it adversely effects productivity. In such extremum, building occupants may engage in adaptive behavior that undermines energy efficiency goals. The study analyzes whether tradeoffs occur between energy efficiency, or greenness, and user satisfaction in modern green buildings through a survey and situation akin to a natural experiment. It also reports whether members of the workforce in green buildings adapt and undermine energy efficiency goals. The analysis uses feedback from comparable residents of green and traditional buildings. As an additional feature, the feedback is differentiated by whether the respondent can self-select into the green building or was assigned to it- a quasi-experimental setting mimicking a randomized controlled trial (RCT). In this way, the study also informs on discrepancies in the green building literature.

For this work, a survey of the entire student and faculty body at the Yale School of Forestry and Environmental Studies (F&ES) in New Haven, Connecticut is conducted. This is a particularly appropriate population for study for three reasons. First, F&ES members are spread about evenly between a fairly standard set of university buildings built and renovated over the last century, and Kroon Hall which is one of the “greenest” buildings in the United States. Controlling for any differences between users of Kroon Hall and the standard, or baseline set of buildings may approximate a treatment effect on resident comfort and productivity from the green building.

Second, the population is identifiable as students, who primarily use public spaces, versus faculty and staff who use offices. This has several possible interpretations. As students are inherently transient (or should be at least), the comparison may be thought of as short run versus long run effects of a green building on satisfaction. Turnover rates of faculty and staff are particularly small at F&ES, allowing this interpretation. It may also be thought of as a comparison of office architecture versus those prepared for the public. This can be thought of in terms of a ‘green’ ‘vanity architecture’- emphasis on design to impress visitors to a building with grandeur and greenness, at the expensive of underwhelming the long-term building inhabitants- the staff.

Importantly, there is also a difference in being able to self-select into and out of the green space for students- not an option for faculty, staff, and those in research roles. It enables a more rigorous quasi-random experimental argument for the faculty and staff group, while contrasting against the student group who choose the environment best suited to them, potentially impacting satisfaction. The reality is that each of these factors is likely important to some extent. They also make comparison of faculty to students more complicated and so much of the study instead compares faculty to faculty and students to students in the green building to their conventional building counterparts.

A third reason is the general characteristics of the population of survey. F&ES is a graduate school with a significant number of young professionals and early to mid-career researchers and staff. The findings then inform on the interests and preferences of the U.S., office-bound workforce of the coming decades. This adds substantially to the external validity of the study- it informs on the effects of green infrastructure on exactly the subset of the U.S. workforce that will be expected to work in such buildings in coming decades.

In what follows, a review of the green and general building satisfaction literature is presented. A detailed methodological discussion is the followed by statistical analysis results, discussion, and conclusion. The main body focuses on the results of questions on thermal comfort and adaptation strategies while an appendix presents extended tables of results across nine additional categories on building satisfaction, preferences, and work impacts.

# Literature review

Building satisfaction surveys as well as laboratory and other experiments occur throughout the built environment literature. Frontczak and Wargocki (2011) provides a good introduction to the general literature identifying factors impacting comfort. From their meta-analysis, comfort is particularly sensitive to gender and age and so these are included as controls in this study. They also find that thermal comfort can substantially impact other factors, e.g. when a space is thermally uncomfortable, occupants also find noise levels and other distractions more irritating. Frontczak and Wargocki (2011) is not green building specific, it also reviews studies where the subjects are transient and where they are assigned without discussing this important difference. They compare the results without considering the self-selection issue and so find sometimes conflicting results.

A rather interesting study by Kingma and van Marken Lichtenbelt (2015) further emphasizes the role that gender plays, focusing on thermal comfort. They advocate for a better model of thermal demand that represents the actual occupants of buildings. Citing evidence that women prefer warmer temperatures on average, they argue that buildings are typically set to match standards based on male metabolic rates and that these are fundamentally different from most women’s. In a context of comparing green to conventional buildings, men and women may be impacted differently if a green building is too hot (initially favoring women) or too cold (not impacting men as much initially).

As an example of the green building literature, the Center for the Built Environment conducted a large analysis of green versus conventional building comfort (Center for the Built Environment, 2006). Of the 181 buildings included in the survey, 21 were either LEED certified or owner designated as “green”. Light on statistical analysis and relying on a comparison of means instead, they find green buildings better in some categories (thermal comfort, air quality) but not in other such as acoustical quality. And like much of the literature, they survey building occupants without any identifying information about whether they are able to self-select in or out of buildings (short of resigning from their professions and dropping out of the study). This seems to be a recurring theme in the literature- a lack of comparison and inclusion of both assigned and transitive occupants.

Holmgren, Kabanshi, and Sorqvist (2017) is an example of a more rigorous approach to questions of building comfort and green labels. They conduct a small laboratory experiment where labelling of a laboratory workspace as having a “low carbon footprint” is interacted with temperature. They find that environmentally concerned participants tend to like the low carbon, or green, labeled space more (no surprise). They are also willing to tolerate higher temperatures in the green space (give higher acceptability scores) relative to otherwise same non-green spaces- but within limits. Beyond some range of acceptability, temperature appears to then take precedence over green preferences. An unfortunate limitation on this sort of research is that it only measures a short-term situation- the green effect they find may dissipate with long term, repeat exposure to only mildly uncomfortable spaces consistent with most building occupant behavior.

As a final example, Paul and Taylor (2008) study a mix of one green and two conventional buildings on university campuses with a similar variety of questions to the survey utilized here. However, Paul and Taylor didn’t analyze the impact on more transient students and only sampled university employees who are assigned space. While this places their study on the more stringently designed side of the green building environmental research spectrum, it is limited in comparison to what can be said in the present work. Still, they find similar results for our assigned subgroup- little to no difference in satisfaction from being placed in a green building. It appears, if green buildings do have some advantage for occupants, it comes from being able to self-select into the right environment rather than being placed orthogonally to preferences.

Finally, green buildings have other value than building comfort. Kok and Quigley (2013) note substantial energy savings potential relative to matched conventional buildings. Unfortunately, these savings are found to be well incorporated into the rents of green space and so is less of a direct remunerative advantage to occupants even if good for the environment.

# Methodology

This section outlines the study methodology in four parts. First, the general research environment- the buildings that occupants use who are included in the study. Then, the population surveyed is outlined and contrasted to the general population. The survey design is then highlighted and finally the statistical approach utilized is outlined in greater depth. Due to the complication of including two intrinsically different groups in this study, the empirical approach is taken with great care.

Research Environment

Yale F&ES owns a variety of valuable resources. In addition to reputations for excellence in research and teaching and several thousand acres of productive Connecticut and adjoining forests, it owns and occupies six buildings on campus. These buildings, built between 1878 and 2009 and continually updated, have a contrasting characteristic that provides a rich environment for research on the impact of green buildings on productivity and satisfaction. An extensive survey of F&ES building users was conducted recently to estimate a green building effect, if any, and key drivers of satisfaction and productivity caused by such a built difference.

The set of buildings in comparison is particularly novel due to the inclusion of Yale University’s greenest building- Kroon Hall. Designed in 2005 by Hopkins Architects, Kroon Hall was intended to be at the very forefront of sustainability and environmental innovation. After its construction, it was awarded the US Green Building Council’s (USGBC) highest certification for green building- LEED Platinum. The certification is based on points received by implementing a checklist of green features. For Kroon Hall, these features include geothermal wells, adiabatic cooling, exotic air handlers, high efficiency heat pumps, and a 100-kilowatt photovoltaic system. In total, Kroon received 97 points on the LEED checklist, far more than the 80 points needed to receive Platinum certification

The key source of identifying variation on the green building effect in this study is a comparison of satisfaction, work impact, etc. ratings of Kroon Hall users to those who primarily use the other five buildings at Yale F&ES. These other buildings are relatively standard institutional structures. While some are aged, they have undergone sufficient renovation over the years that they also remain comparable to most U.S. office spaces, at least on the interior. In the following econometric model, the replies from occupants of these buildings, which constitute roughly half of the FES faculty, staff, and student body, are grouped together to form a baseline. Despite differences in age and design, the five structures are also comparatively similar relative to Kroon Hall. For context, the six structures occupied in this study are outlined in detail:

Kroon Hall at 195 Prospect Street was completed in 2009. It’s the largest structure at F&ES at 52,635 square feet and is a four-story structure. In addition to LEED status, it is known for its imposing natural wood and concrete design and open floor plan. Kroon Hall contains the college dean and several faculty and staff offices. A large auditorium, classrooms, and student spaces are distributed throughout as are three research centers. This structure is serviced by central heat and cooling and utilizes an integrated open plenum ventilation system for distribution with several hundred floor-mount low flow vents. Heating and cooling is also aided by guided occupant response- a system informs occupants when windows should be opened or closed to assist the central system based on a comparison to the outdoor environment.

Sage Hall at 205 Prospect Street is F&ES’s next largest building. Built in 1924 and composed of 27,698 square feet, it houses several faculty, staff, and student researchers. It also houses a large auditorium, classrooms, lounges, computing lab, and a couple research centers. Heating and air conditioning are accomplished by a mix of radiators, window units, and wall systems as space allows and conditions warrant. While perhaps not the most efficient system from a central planner perspective, it allows a great deal more tailoring to the occupant.

Greeley Memorial Laboratory, 370 Prospect St., built in 1959, 24,246 square feet. Houses faculty, staff, one classroom, and 10 labs. Separate Greenhouse (4,278 GSF).

Marsh Hall at 360 Prospect Street was built in 1878 but updates as necessary. It is 13,048 square feet in the form of a multistory Victorian home. Marsh houses faculty, staff, and one seminar room as well as two research centers.

301 Prospect St., built in 1907, 12,932 square feet. Houses faculty, staff, and one 1 seminar room. Also houses the Hixon Center for Urban Ecology, the Urban Resources Initiative, the Environmental Leadership Training Initiative, the Tropical Resources Institute and the Yale Sustainable Food Project.

380 Edwards St., built in 1907, 10,475 square feet. Houses faculty, staff, and 1 seminar room. Also houses the Center for Industrial Ecology, and the Journal of Industrial Ecology.

Survey population and response rate

The opportunity to contribute to the survey used in this analysis was extended to the entire population of Yale F&ES using an online survey collection platform. Of the F&ES population of 602 at the time, which included students, faculty, staff, and visiting researchers, a response rate of 53.7-percent was achieved with gentle prodding. The response rate was similar between the faculty and staff at 55.0-percent, and the students and visiting researchers at 52.4-percent. The response rate was also similar along gender lines, at 51.2-percent and 49.7-percent for women and men, respectively. Nevertheless, the survey data is weighted for responsiveness along these forms of affiliation and gender using nonresponse and post-stratification weights following standard survey methodologies. This is considered necessary as the former is expected to substantially impact how respondents interact with the building and the latter is an important factor in comfort according to the literature (i.e. Kingma and Lichtenbelt, 2015). Table 1 presents survey weighted summary statistics of the data.

Survey weighting is undertaken to ensure the survey accurately represents the survey population rather than the general population. This supports internal validity rather than attempting to address external validity concerns. The results are generally found at a high level of statistical significance, however. The student subpopulation at F&ES surveyed has already entered the workforce as well and so this study at a minimum still informs on at least some share of the general workforce. The limited scope of the survey means complex stratification or clustering techniques are also not needed- a single strata and a cluster of one is applicable. The simple weighting strategy follows standard conventions: Weight(Final,i)=Weight(Selection,i)\*Weight(Nonresponse,i)\*Weight(Poststratification,i) where Weight(Selection,i)=1 in our survey due to full sampling of the population, Weight(Nonresponse,i) is the inverse of the response rate for key response categories of faculty and staff versus student body, and Weight(Poststratification,i) is used to account for small proportional differences in gender response rates relative to the F&ES population (Heeringa, West, & Berglund; 2010). While the use of strata is known to reduce standard errors, and clustering and weighting increase standard errors, only weighting is applied in this survey. The standard errors are then equal or greater than would be derived in a perfect survey and the statistical significance of results are a lower bound. Finally, due to the simple survey design, Taylor series linearization, the generally accepted default, is retained in computing sampling variance.

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| **Table 1 | Summary statistics** | | | |
| Variable | Overall | Faculty and staff | Students |
| Kroon Hall | 0.60 | 0.34 | 0.84 |
|  | (0.03) | (0.04) | (0.03) |
| Faculty & staff | 0.48 | 1 | 0 |
|  | (0.03) | - | - |
| Kroon\*Faculty & staff | 0.17 | 0.34 | 0 |
|  | (0.02) | (0.04) | - |
| Office | 0.45 | 0.90 | 0.02 |
|  | (0.03) | (0.03) | (0.01) |
| Kroon Hall\*Office | 0.15 | 0.29 | 0.01 |
|  | (0.02) | (0.04) | (0.01) |
| Age | 36.34 | 45.30 | 27.97 |
|  | (0.80) | (1.14) | (0.44) |
| Female | 0.53 | 0.57 | 0.49 |
|  | (0.03) | (0.04) | (0.04) |
| Survey weighted statistics with standard errors in parentheses. There are 323 responses in the survey, suggesting a 53.7-percent response rate. However, only 259 observations are complete to include age and gender indicators, a 43.0-percent effective response. | | | |

Survey Design

The survey was conducted throughout April 2015 and asked questions on respondent usage and satisfaction with F&ES facilities on campus, basic demographics, and a few questions of less general interest. The core survey component was a set of nine questions on the satisfaction with, and impact on productivity of building characteristics categorized as acoustics, aesthetics, air quality, sustainability features, furniture, lighting, functionality, thermal comfort, and other (with an option to write in text). For each category, respondents were asked about the importance of the category, satisfaction with the F&ES building they most use, the impact on their productivity in that building, and the impact on amount of time spent in the building. Respondents ranked each from very unimportant, very dissatisfied, greatly interfere, or a lot less time (responses=1), to very important, very satisfied, greatly enhance, or a lot more time (responses=5) as applicable. This data offers a substantial picture of respondent experiences with green Kroon Hall versus traditional buildings. In total, nine built environment characteristics are analyzed for their impact on four satisfaction and importance measures. This offers 54 data points per respondent, measured at a resolution of a scale from one to five. Respondents were also queried on how they adjust the building environment with a dichotomous choice for nine adaptation options: open and close windows, doors, raise and lower window blinds, adjust building thermostats, air vents, bring in portable heaters, fans, wear different clothing, or other (with another write-in option).

Econometric model

The econometric models attempt to identify whether there is an impact of LEED certified Kroon Hall versus the rest of the F&ES building inventory- the comparatively standard buildings, and whether adaptive behavior differs. An ordered probit model is estimated for each experience and impact category to capture to the fullest extent of the impact of the green structure. The models take the form:

|  |  |
| --- | --- |
|  | (1) |

where *i* indicators the four measures (importance, satisfaction, work impact, time impact), *j* indicators the nine building characteristics (thermal impact, acoustics, aesthetics, etc.), and subscripts for individual observations are suppressed for clarity. *Cat* indicates the ordinal response subcategory, *KroonPrimary*=1 if Kroon Hall is the respondent’s self-reported primary F&ES building, *Office*=1 if they have an office at F&ES, *Kroon\*Office* as interaction term, and *Age* and *Female* as expected. In selecting the independent variables, Frontczak & Wargocki (2011) and Kingma & Lichtenbelt (2015) emphasize age and gender are important factors influencing indoor comfort. A second version using *FacStaffOther*=1 if the respondent is faculty, staff, or has indicated a role such as visiting research fellow or postdoc rather than using *Office* results in qualitatively same results. The correlation between being faculty/staff and having an office is expectedly high- only students in particular research roles and doctoral students generally receive office assignments. The office assignment is similar to that of faculty and staff for these people- exogenously determined for the individual and thus the random assignment characteristic of office is preferred.

Equation (1) is estimated for each of our 54 *Catij* ordinal response subcategories. However, the category with the greatest energy impact potential, thermal comfort, is the focus of the analysis while the breadth of results occupies the appendix. Focusing further, the variables on the usage of Kroon Hall versus the rest of the F&ES inventory and the interaction of Kroon Hall and office assignment are of primary interest.

The next measure of building satisfaction is whether use of the green building results in a difference in efforts to modify the indoor climate by occupants. To explore this, a dependent variable indicating whether the respondent adjusts thermostats, vents, and seven other adaptive behaviors as well as a do-nothing response option are estimated in the form:

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| --- | --- |
|  | (2) |

where **X** is the vector of right hand side variables from equation (1), and *AdaptiveBehaviori* is a dichotomous choice measure of whether the respondent engages in the stated behavior. This specification is estimated by two methods. First, each behavior is taken separately using a survey weighted probit model. This indicates which sorts of behavior have the highest probability of occurring, but not about how many are engaged in by an individual on average. Second, the individual behaviors are transformed into a dependent count variable of how many behaviors are engaged in. This has the disadvantage of implicitly weighing each behavior equally while some are costlier to the building’s bottom line. The advantage is it suggests the severity of the environmental mismatch through how many adaptive behaviors are undertaken. As a final exploration, the marginal effects of the Kroon hall treatment on level of thermal comfort satisfaction are explored at the end.

Key to the novelty of the results, the population under study is composed of two groups which are materially different in both purpose at the university and the methodological implication. One group, non-office students, can select into and out of Kroon Hall and any other F&ES building. They choose which building to spend time in and designate as their primary in the survey. This self-selection implies the coefficient on Kroon Hall alone cannot be interpreted in the context of a quasi-random experiment. It is likely that students who select Kroon Hall do so because they prefer it over the baseline options. One way to check for evidence of this is through the coefficient on Kroon Hall estimated on the importance category as in column 1 of Table 2. In a true random experiment, or setting that mimics it, the importance of any attribute should not differ between treatment and control groups yet is statistically significant for the Kroon Hall group. An exception occurs when the treatment results in the treated developing an affinity for the category being tested- the attribute becomes important after exposure. This exception cannot be tested from the survey data, unfortunately.

Fortunately, estimates on the second group in the study- those with an office at F&ES takes a different interpretation. Assignment to an office in Kroon Hall or elsewhere, whether faculty and staff or the few students who are placed through research roles is effectively randomly assigned relative to their preferences. Whether the office is in Kroon Hall or the baseline building group is entirely independent of the person. Rather, office assignment has to do with the F&ES administrative division’s location or the research center. Importantly, there is no reason to believe personnel select into or are hired by these divisions or research projects specifically because of an interest in being seated in Kroon Hall or not. Because of this independence of assignment, the treatment of Kroon Hall can be taken as a quasi-experimental assignment and discussed in a randomized controlled trial (RCT) framework for the office subgroup. This adds to the validity of the coefficients discovered- they represent the treatment of Kroon Hall on the treated, unaffected by self-selection. The resulting estimates could still indicate a statistically significant coefficient on importance of attributes, but only under the aforementioned circumstance that an affinity has developed from treatment. This is generally not found in the results to follow and therefore not at risk of undermining the claim of a quasi-experimental environment for the office subgroup.

# Results

This paper focuses on the result with perhaps the largest implication for energy use- thermal comfort. All other results are presented in the appendix.

Equation (1) is estimated using an ordered probit model of the probability of selecting between the five levels of satisfaction, impact, etc. An ordered probit is selected because it makes less restrictive assumptions about the data than the logistic alternative. Unfortunately, while more appropriate for this sort of analysis, the ordered probit model coefficients are difficult to interpret as they are a change in z-scores. The calculated marginal effects are at a specific point, holding all else at their means or other significant value. This is further complicated in an ordered probit model. The probabilities are calculated of moving between each dependent variable respondent score, from one through five, for each independent variable- a large set of results which are for the most part not particularly useful outside F&ES. Simpler, and to the point of the research, significance and sign of results indicate which groups, if any, are impacted by Kroon Hall’s green building treatment.

The results on thermal comfort importance (1), satisfaction (2), work impact (3), and time impact (4) are presented in Table 2. From the model specification, the base category in the results are primarily F&ES master’s students not based in Kroon Hall, do not have an office, and is male. They are not faculty, staff, or a doctoral student. This base category then may self-select into Kroon Hall versus other F&ES buildings in the survey and is more transient in nature. The coefficient on Kroon Hall identifies the effect of Kroon Hall on this population. The more rigorously interpretable effect of Kroon Hall on the F&ES subgroup with an office is found by linear combination of coefficients on Kroon Hall and Kroon\*Office. This is provided at the bottom of Table 2 for each column. By this specification, the faculty and staff with a Kroon Hall office are compared to those with an office elsewhere in the F&ES inventory.

From Table 2, it is clear that the student population reports a statistically significant effect of Kroon Hall on general satisfaction, work impact, and time impact. However, as cautioned in earlier sections, the negative and statistically significant coefficient on Kroon Hall in the importance category may indicate self-selection. The linear combination coefficients for office users in Kroon Hall all come up insignificant. These members of F&ES are made no better office statistically than their counterparts- an office remains an office. The comparison of these results itself may be an important takeaway- choice is an important driver of satisfaction. However, personal experience cannot reject an alternative explanation- green ‘vanity architecture’ has primarily revolutionized public spaces rather than the office environment.

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| **Table 2 | Thermal comfort ordered probit results** | | | | |
|  | (1) | (2) | (3) | (4) |
|  | Importance | Satisfaction | Work impact | Time impact |
| Kroon Hall | -0.672\*\* | 0.777\*\*\* | 0.560\*\* | 0.681\*\*\* |
|  | (0.336) | (0.216) | (0.217) | (0.258) |
| Kroon\*Office | 0.631 | -0.888\*\*\* | -0.595\* | -0.917\*\*\* |
|  | (0.421) | (0.311) | (0.327) | (0.342) |
| Office | -0.129 | 0.027 | -0.112 | 0.230 |
|  | (0.351) | (0.249) | (0.239) | (0.261) |
| Age | -0.006 | 0.004 | 0.008 | 0.0118\* |
|  | (0.006) | (0.007) | (0.007) | (0.007) |
| Female | 0.388\*\* | -0.009 | -0.0405 | 0.0004 |
|  | (0.155) | (0.140) | (0.133) | (0.140) |
| Observations | 258 | 255 | 254 | 248 |
| Combination: | -0.041 | -0.110 | -0.036 | -0.236 |
| Kroon+Kroon\*Office | (0.254) | (0.225) | (0.244) | (0.215) |
| Standard errors in parentheses: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1 | | | | |

To ensure reader confidence in the estimation results of Table 2, equation (1) is also estimated separately for the respondents with and without offices and the coefficients presented in Table 2a. Separate estimation reduces to:

for each of the two separate groups. It is perhaps clearer then that the Kroon Hall coefficient is interpretable as a treatment effect in the ordered probit results while controlling for age and gender differences. The coefficients in Table 2a reporting the Kroon hall treatment for non-office and office subgroups separately, are qualitatively the same to the Table 2 coefficients. Note, the *Non-office* coefficients in Table 2a correspond to the *Kroon Hall* treatment in Table 2 and the *Office* coefficients correspond to the linear combination *Kroon+Kroon\*Office*. Small differences occur, however, as estimating the model separately no longer constrains the coefficients on age and female to be the same for office and non-office members of F&ES.

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| **Table 2a | Coefficients on Kroon Hall from estimating non-office and office groups separately** | | | | |
|  | (1) | (2) | (3) | (4) |
|  | Importance | Satisfaction | Work impact | Time impact |
| Non-office | -0.692\*\* | 0.904\*\*\* | 0.659\*\*\* | 0.627\*\*\* |
|  | (0.339) | (0.228) | (0.235) | (0.240) |
| Office | -0.051 | -0.090 | -0.022 | -0.285 |
|  | (0.248) | (0.214) | (0.233) | (0.251) |
| Only the quasi-treatment coefficient on Kroon Hall is reported while age and gender coefficients are included in the estimation just as in the primary results in Table 2. Standard errors in parentheses: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1 | | | | |

This paper now analyzes how respondents adjust the building atmosphere when it doesn’t fit preferences. This question is clearly important in the context of running a building efficiently. If a significant share of residents behave in ways counter to efficient operation, it may require a different set of operating parameters where the marginal savings from reducing counter-efficient behavior meets the increase in marginal costs from operating the building less than textbook efficient. In other words, if increasing the building’s temperature such that less portable heaters are brought in during the winter results in a net decrease in operating cost, it would be more efficient to do so. Table 3 shows the results from a set of probit regressions where the dependent variable is either zero or one for whether the adaptive behavior is indicated. Column (7) on operating a portable heater may be of greatest concern from an energy saving perspective. The survey finds that across F&ES facilities, more than one in ten users brings in a space heater. However, this is highly concentrated in the office group of faculty, staff, and researchers- nearly a quarter admit to bringing a heater in to supplement office heating. The analysis finds, however, that the Kroon Hall faculty are no different from counterparts residing in other F&ES spaces in this regard. In fact only adjusting thermostats and air vents are statistically different for Kroon Hall office users and these can be explained by building design. The Kroon Hall thermostats differ from most structures in that they allow the user to only slightly modify the temperature from the building mean rather than full control. In contrast, Kroon Hall has far more vents than most buildings, several hundred dispersed across the floors.

A qualitative analysis of the text submitted in conjunction with the Other category (10) also supports general building atmosphere mismatches, not specifically at Kroon Hall but for office users in general. The majority of such responses discuss strategies to compensate for excessively hot temperatures, either from weather in the summer or from a building system mismatched with preferences. These are as extreme as leaving on hot summer days- reducing productivity, and turning on window air conditioners in the winter to offset the building heating system- a surprising waste. Obviously, this is an extremely inefficient method to compensate from a building operations standpoint. It is also likely not preferred by the respondent either. A subcategory *Do Nothing* was also offered in the survey but only 16 respondents indicated this. It indicates that nearly every user attempts to adjust F&ES building climates in at least some way. Finally, Table 3 includes a row reporting the percent of respondents who reply yes to the adaptive behavior. Despite all the negative discussion of costly adaptation strategies, it is reassuring to note a far larger share of respondents adapt by less costly means for the building operator. The largest share is found in adjusting clothing which has no impact on building energy usage.



Another perspective on adaptive behaviors is offered in Table 4. Here the dependent variable is a count of the adaptive behavior categories from Table 3. This implicitly assumes equal importance of the behaviors which is not accurate from a building efficiency perspective. The advantage, however, is to account for the number of potential adaptive behaviors engaged in by a representative individual. The model from equation (2) is then estimated with a negative binomial regression as appropriate for survey non-ordinal, count dependent variables. Note again the significance of *Office* and *Female* but not *Kroon Hall* or interaction term *Kroon\*Office*. Both office users and women are more likely to engage in a greater variety of adaptive behaviors.

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| **Table 4 | Count of adaptive behavior** | | |
| Variable | nbreg | nbreg IRR |
| Kroon Hall | -0.127 | 0.881 |
|  | (0.124) | (0.109) |
| Kroon\*Office | 0.103 | 1.109 |
|  | (0.153) | (0.170) |
| Office | 0.401\*\*\* | 1.493\*\*\* |
|  | (0.124) | (0.186) |
| Age | 0.004 | 1.004 |
|  | (0.003) | (0.003) |
| Female | 0.165\*\*\* | 1.180\*\*\* |
|  | (0.061) | (0.072) |
| Constant | 0.738\*\*\* | 2.091\*\*\* |
|  | (0.158) | (0.330) |
| Combination: | -0.021 | - |
| Kroon+Kroon\*Office | (0.087) | - |
| 259 observations. Standard errors in parentheses: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1. F-statistic of 19.88. | | |

Figure 1 attempts to display the identifying variation, or lack of, graphically. The 2-by-2 matrix of office and Kroon Hall statuses are graphed separately. The share of respondents indicating each count of adaptive behavior is compared. Generally shares of office workers select the same count of adaptive behaviors, and similarly so for non-office members of F&ES, regardless of building.

|  |  |
| --- | --- |
|  | |
| **Figure 1 | Respondent engagement in adaptive behavior** |

The remaining results are relevant to Yale F&ES rather than the general population. First, what are the probabilities of selecting each satisfaction level for different groups in Kroon? Margins on satisfaction with thermal comfort are calculated for the Kroon Hall subgroup, combined and by subcategory. We see that students- those without offices, are more likely to select higher satisfaction levels for thermal comfort. However, both students and faculty of Kroon Hall are select a level of 4 which was labeled in the survey as somewhat satisfied most often.

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| --- | --- | --- | --- |
| **Table 5 | Ordered probit margins on satisfaction with thermal comfort** | | | |
|  | (1) | (2) | (3) |
| Response scale | Pr(Overall Sat\_level) | Pr(Sat\_level| Kroon Students) | Pr(Sat\_level| Kroon office) |
| 1 | 0.081 | 0.037 | 0.092 |
| 2 | 0.242 | 0.174 | 0.273 |
| 3 | 0.137 | 0.124 | 0.148 |
| 4 | 0.366 | 0.411 | 0.356 |
| 5 | 0.174 | 0.254 | 0.131 |
| Scale of 1 being the lowest to 5 being the highest satisfaction: Standard errors not shown- all significant at the 1% level. The potential responses are: 1=Very dissatisfied, 2=Somewhat dissatisfied, 3=Neutral, 4=Somewhat satisfied, 5=Very satisfied | | | |

I then ask, is the experience different for the non-office users/students in Kroon Hall versus other F&ES buildings? And similarly, is it different for faculty and staff in Kroon Hall versus elsewhere? Table 6 presents instead changes in the margins from the Kroon Hall treatment for each group. Here we see a student in Kroon hall is 11-percent less likely to be very dissatisfied and 25-percent more like to be very satisfied than students in other F&ES buildings at a one-percent or better level of statistical significance. Unfortunately, within Kroon we also see that having an office decreases the probability of being very satisfied and increases the probability of being dissatisfied relative to other office users at F&ES though statistically insignificant at any acceptable level.

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| --- | --- | --- |
| **Table 6 | Changes in margins on satisfaction with thermal comfort** | | |
|  | (1) | (2) |
| Response scale | Effect of Kroon Hall on students | Effect of Kroon Hall on office holders |
| 1 | -0.116 | 0.088 |
| 2 | -0.196 | 0.062 |
| 3 | -0.046 | -0.009 |
| 4 | 0.109 | -0.090 |
| 5 | 0.25 | -0.052 |
| Scale of 1 being the lowest to 5 being the highest satisfaction.  Standard errors not shown- For column (1) all significant at the 1% level and for column (2) none are statistically significant. The potential responses are: 1=Very dissatisfied, 2=Somewhat dissatisfied, 3=Neutral, 4=Somewhat satisfied, 5=Very satisfied | | |

# Discussion & Conclusion

This chapter provides three important results for the general audience. First, carefully defining the population surveyed in green to conventional building comparisons informs on the context of results. A survey that only collects on the stationary, assigned inhabitants of a green building does not inform on the experience of visitors and vice versa. Second, self-selecting plays an important role in building satisfaction. Organizations that use buildings of differing character may be best served by letting their characters select and trade spaces. And third, green vanity architecture works- for those served by spaces where the architect has focused their work.

By surveying both building users who can self-select and those who are assigned to green versus conventional buildings, this study sheds light on a glaring discrepancy in the green building literature. Studies generally survey transient users of green buildings, those assigned to a green versus non-green building, or all users of a space without distinguishing between the two. Their results then mirror these differences under examination. We contribute a unique feature of differentiation and reconcile the results from other studies in the process. We find one group consistently prefers the green building in our study- the more transient users. In contrast, users who are effectively randomly assigned, permanent users, are indifferent between the green and non-green buildings on average. This is an important contribution on its own.

In addition to indicating a resolution to disagreement in the literature, this study suggests allowing self-selection may enhance satisfaction. This is particularly relevant in an organization like Yale F&ES that has buildings of differing attributes. A reorganization scheme allowing faculty and staff to trade spaces may enhance satisfaction. The alternative that a green vanity architecture emphasis is to blame must be considered. It may be the case instead that Kroon Hall only excels in public spaces by design. It was no doubt designed to impress and has done so for visitors. It seems to be having less of a positive impact on the faculty and staff, however.

Regardless of cause, a marked discrepancy in the satisfaction effect of green Kroon Hall exist. The Yale F&ES subgroup assigned to offices are no better off on average by assignment to Kroon Hall. In comparison, the student body who may self-select into Kroon Hall are markedly more satisfied across measures. LEED Platinum certified Kroon Hall has certainly performed by certain measures- it is efficient and impresses visitors by demonstrating that a green structure can also be elegant. It appears to have missed the mark on improving the office setting, however, indicating an area to emphasize greater efforts on in future green building design.

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# Appendix

Table (A1) is a set of regression results using responses on importance of building characteristics. Column (1) is an OLS regression on the averaged response across the importance subcategories of each respondent. It suggests significant contextual data is lost if we only ask for an overall importance, admitting this averaged score is different from a single, overall satisfaction response. However, unlike in the tables that follow, no clear pattern across subcategories emerges. One interesting question to consider, do students self-select into Kroon Hall based on least and most important features to them? Note in column (2) the large probit coefficient on aesthetics for KroonPrimary relative to all other coefficients in the table and is significant at all levels. Contextually, Kroon Hall is known for aesthetic appeal. Note for those with Kroon offices, who cannot self-select, the nearly equal, negative coefficient does not refute the student self-selection hypothesis. Although less significant, at only the 10% level, we consider whether this is also the case with thermal comfort, selecting out of Kroon Hall. Specifically, would this be more significant if we differentiate between KroonPrimary male and female users? Noting the 1% level of significance for Female, we ran an auxiliary regression including an interaction term KroonPrimary\*Female which resulted in both Female and KroonPrimary\*Female becoming insignificant while remaining jointly significant (F-test) at the 5% level suggesting over specification of the model. Unfortunately this auxiliary regression neither supports nor refutes a self-selection hypothesis then. Finally, since we also find aesthetics, air quality, and sustainability features statistically significant for female respondents and acoustics positively related with age, this may suggest a greater need to focus on their preferences in these areas when planning and operating facilities.

Moving from ex post importance to satisfaction analysis, table (A2) presents ordered probit regressions on satisfaction responses for F&ES facilities. Consistently significant, students who primarily use Kroon Hall claim a higher level of satisfaction across all subcategories at the 1% level of significance. This would be a significant architectural achievement for a LEED certified structure as the literature cites dissatisfaction in many of these categories for many green buildings across the nation. However this may not be as momentous when the competition is considered- the baseline category is a set of historic and near-historic structures with reportedly testy and ad hoc heating and cooling systems. The building satisfaction picture is not as rosy for Faculty, Staff, and resident researchers of Kroon Hall, across all columns (with five of eight significantly) the coefficients on KroonOffice carry a negative sign, partially or fully offsetting KroonPrimary. This suggests if resources are used to improve the operation of Kroon, the question of what is behind these lower levels of building satisfaction for office space users needs to be understood. Tables (A3) & (A4) on the work and time impact of building spaces tells the same story- students are more satisfied, receive a work benefit, and prefer to spend more time in Kroon Hall due to its environment while the faculty receive less or even a penalty from placement in Kroon.









Several other questions were included in the survey but not used in this study. The survey collected time and special usage data. Respondents were asked to select blocks of time when they use the building on each day of the week divided into: 7am-noon, noon-5pm, and 5pm-10pm, 21 blocks in total. They were also asked whether the building is used when classes are out of session. A spatial map of each floor of Kroon Hall, was also provided to identify where respondents prefer to spend time. In total, the building is divided into 47 spaces across four floors. The survey also collected on seven categories exploring information demand about Kroon Hall, four on the medium through which respondents prefer to receive information, and three write-ins using single word descriptors of Kroon Hall.