A Post Occupancy Evaluation (POE) Framework for Certified Sustainable Higher Education (HE) Residence Halls

by

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Table of Contents

Table of Figures

Table of Tables

Abstract

Numerous higher education (HE) institutions in the United States (US) have created sustainability agendas, including construction of sustainable buildings. More than 200 US HE institutions, have at least one Leadership in Energy and Environmental Design (LEED) certified building on their campus (Princeton Review 2012). With the growing student population and need to house them, residence hall construction is rising nationwide. A profile of newly constructed building types shows residence halls hold the largest median area (Princeton Review 2012). In an effort to assess if sustainable residence halls are performing sustainably, a series of post occupancy evaluation (POE) indicators were selected. POE indicators were chosen through a review of widely adopted sustainability rating systems, scientific literature and student occupant feedback. The selected indicators address a range of parameters including: water and energy consumption, occupant thermal comfort, occupant consumption behavior and education, noise insulation (indoor and outdoor), and Facilities Management (FM) operational feedback. Furthermore, specific indicators such as building energy management systems (BEMS), building automation control systems (BACS) and artificial intelligence (AI) agents were examined. The proposed POE indicator framework data was collected from various key stakeholders including: designers, HE FM departments, residential life personnel, and student occupants. The dataset includes: actual temperature (T) and relative humidity (RH) measurements of a LEED-Gold residence hall, actual water (9 residence halls) and energy consumption (4 residence halls) data, and feedback from designers, HE FM departments and 593 student occupants (LEED and non-LEED residence halls). The proposed POE indicator framework triangulates quantitative and qualitative data, via investigative and diagnostic techniques; creating a comprehensive building performance picture, vis-à-vis technical and non-technical parameters.

KEYWORDS: Post Occupancy Evaluation, Residence Halls, Student Occupant Feedback Techniques, Sustainable Performance Indicators, Sustainability Rating Systems, LEED, Water and Energy Benchmarking, Residence Hall Water Consumption Tendencies, Occupant Thermal Comfort Parameters.

1. Introduction

1.1 Background

The United States (US) buildings sector is the largest contributor of resource consumption and depletion, accounting for more than 30% of greenhouse gas emissions and 41% of primary energy use (US-DOE 2013). Examining the largest sector contributing to construction spending in the US, the private sector led with non-residential spending exceeding 309 billion in 2014 (US Census 2014). Within the private non-residential sector, HE institutions contributed over 15 billion in construction in place dollars (US Census 2014). HE residence halls held the largest median area of newly constructed facilities on HE campuses (Princeton Review 2012) and contributed to the second highest construction spending preceded only by instructional space (US Census 2014). Based on the Princeton Review, a widely used reference source for college selection and marketing; more than 60% (200 out of 332) of US HE institutional owners created sustainability agendas. HE agendas generally require Leadership in Energy and Environmental Design (LEED) certification of new facilities, having at least one LEED certified building on their campus (Princeton Review 2012). Overall 658 million gross square meters equating to 44,000 buildings are LEED certified in the US (USGBC 2014). In the European Union (EU), similar to US in terms of gross domestic product (GDP) (IMF 2014), only 74 million gross square meters of buildings are LEED certified, accounting for over 1,700 buildings (USGBC 2014). However, US average power consumption per person is 200% higher than EU member states (US-DOE 2014, CIA 2014). The vast differential between certified and non-certified buildings in the US and EU, with opposing consumption results highlights other factors such as: consumption culture, energy policy and taxation may have more pronounced impacts on overall resource consumption versus sustainability certification alone (EU EEA 2013, US-DOE 2014).

The implementation of sustainability rating systems such as LEED is due to: heightened level of awareness, need for sustainable solutions to improve energy and water resource use efficiencies, lower life cycle costs, facility operation improvement and increased marketability (Princeton Review 2012, USGBC 2014). To address these aspirations a majority of US facilities owners adopted LEED certification. LEED provides guidance on sustainable strategies allowing owners to attain varied levels of modelled (expected) sustainable behavior. However, LEED does not require post occupancy evaluations (POEs) to verify expected outcomes with actual outcomes, nor does it require or account for occupant feedback. For this scope, POE indicators are necessary to ensure buildings are performing sustainably in actuality. A POE framework of indicators provides a post occupancy tool to measure building performance. POEs indicate: if certified buildings meet design intent, if design assumptions are valid in practice, if occupants are satisfied with their indoor conditions and how they are interacting with designed sustainability strategies. POEs aim to answer two questions: how is the building working, and if the actual performance reaches its expectations (Leaman 2003, Bordass et al. 2010).

Assumptions made by designers dictate the post occupancy state, but rarely re-examined for accuracy and applicability in practice (Bordass et al. 2010). Building performance is repeatedly not monitored and correction measures rarely implemented (Brown et al. 2010). Researchers indicate a lack of POEs perpetuate energy and water waste and potential occupant dissatisfaction (Bordass et al. 2004, Bordass et al. 2010). POEs provide owners numerous benefits including: (1) aide communication between stakeholders (architects/engineers (A/E), occupants), (2) create mechanisms for quality monitoring, providing knowledge when buildings do not meet design intent; (3) provide data and knowledge for future designs and key decisions; (4) support development of policy for design and planning guides; (5) hasten the learning process within organizations by building on successes and not repeat failures, and (6) provide insight on occupant interaction with efficiency strategies implemented (Brown et al. 2010, Bordass et al. 2010). Even though POEs provide numerous benefits to owners, uncertainty in the selection of indicators and feedback techniques inhibit their adoption (Bordass et al. 2001, Cicelsky et al. 2009). Split incentives and industry fragmentation also hinder POE implementation (Bordass 2000, Hadjri and Crozier 2009, Riley et al. 2010). With the current increase in performance specifications in addition to prescriptive ones, it is evident POEs are becoming critical in the design and operations process. Another indicator POEs are gaining momentum may be found in LEED version 2009 reporting requirement of water and energy for 5-years post occupancy. Yet POEs are not implemented widely due to barriers such as a 'one-size fits all POE' approach not existing and being discouraged. Given POEs must be tailored to specific building typologies and applications, unique POEs need to be developed for varied building typologies (Turpin-Brooks and Viccars, 2006, Bordass et al. 2006, Hadjri and Crozier 2009, Riley et al. 2010, Leaman and Stevenson 2010).

LEED has added to their minimum program requirements with energy and water reporting, but it is still unclear how this data will be analyzed and shared with the design and facility operations community. Additionally, simply reporting water and energy consumption does not paint a comprehensive building performance picture without occupant feedback. LEED certification is based on a proposed design case (PDC) promising improved performance compared to a baseline design case (BDC), but actual performance is never recorded or compared and demographic behavioral tendencies and feedback is not solicited. Given LEED certified buildings are not re-examined in post occupancy, it is clear an informational gap exists on their actual performance. To ensure LEED is delivering on its promises, a comprehensive POE framework is needed to verify actual sustainability of strategies in practice.

Researchers indicate the biggest unknown variable in resource consumption is occupant behavior (Barr 2003, Bamberg 2003, Hand et al. 2003, Randolph and Troy 2008) and find it has the largest potential to ensure sustainability in practice (Barr 2003, Hurlimann 2006, EU EEA 2013, US-DOE 2014). Researchers also highlighted occupant resource consumption varies depending on: culture, gender and socioeconomics (Vickers 2001, Balling et. al 2007, Randolph and Troy 2008, Schleich and Hillenbrand 2009, Vinz

2009, Elliott 2013, Berardi 2013). Given these parameters impact consumption, variables such as gender and non-US (EU) consumption metrics are examined. The purpose for comparison between US and EU metrics lies in that they are developed countries with similar GDP (IMF 2014), yet differing energy policies (US-DOE 2014, EU EEA 2013) and societal structures on the topic of sustainability. US and EU members are individualistic societies, yet differ vastly on the implementation of energy policies. In the US energy policies are individualistic since society is less accepting of government taxation and policy implementation, however in EU societies there is a collective acceptance of such measures to ensure energy security for current and future generations. Generational justice in energy policies is far more pronounced in EU policies and taxation structures than in the US (US-DOE 2014, EU EEA 2013). Comparing US and EU energy consumption benchmarks provide a snapshot of actual consumption culture given energy policies.

Given behavior is a large component in attaining sustainability and biggest unknown variable (EU EEA 2013, US-DOE 2014); POEs facilitate the knowledge gap through occupant feedback mechanisms. POEs shed light on the human interaction with efficiency strategies and provide insights as to whether sustainability strategies are actually realized in practice (Leaman and Stevenson 2010). POEs capture this information to inform current and future designs; ensuring repeat errors in design assumptions are avoided, corrected, and accurate consumption projections are used for target performance metrics. The target performance metrics should be compared to benchmark values, to compare the level of sustainability attained. Identifying accurate benchmarks for HE institutions is a challenge, given US and non-US water and energy reporting agencies do not isolate all building typologies within their datasets. For example, various educational buildings within their datasets are not further sub-divided into their end uses (i.e. lecture space, residence hall, athletics facility, etc.). The lack of specificity of HE facilities' actual energy and water information, and lack of occupant feedback result in the inability to benchmark HE facilities accurately.

Assessing HE facilities with largest use finds students spend majority of their time in their residence halls (Bonnet et al. 2002) and in climate controlled environments (Bonnet et al. 2002, Kats 2010). Given the vast amount of time students spend in residence halls and that they hold the largest median area of newly constructed facilities (Princeton Review 2012), they have been selected for the development and application of the POE framework presented herein. It must be noted the largest contributor of construction spending in 2014 was the overall (non-academic) residential sector, however it is not the target of this research. The overall sector poses varied data collection challenges such as data accessibility, which cannot be overcome given the timeframe and resources of this research. However, the next step for graduating students is entering this sector as they start their professional lives (Harvard University 2012). Based on a recent joint study over 60% of individuals under the age of 35 enter the residential market (Harvard University 2012, NAR 2014). With their entry into this sector, their behaviors will carry over. Documenting and impacting student occupant consumption behaviors and tendencies during their college years, can provide an invaluable opportunity to shift unsustainable behaviors into sustainable ones prior to their 'real-world' entry. College years are critical as HE institutions are responsible for student intellectual growth, and grass root development of positive habits to reduce environmental impact on our planet. College years provide an opportunity to create positive change. It is prudent to gain insight as to how student occupants interact with the built environment to validate design assumptions, informing the design and operations process. These insights can be gained through in-depth POE analyses, providing an honest investigation of occupant interactions and potentially erroneous designs.

1.2 Research Objective

The objective of this research is to create a comprehensive POE framework for LEED certified HE residence halls. The student resident demographic is critical in investigating resource consumption and closing the knowledge gap on this typology and promised sustainability of LEED certification. Even though HE construction dollars in place are not the largest at only 5% of non-residential development, it has been selected due to the following reasons: (1) HE requirements of LEED certifying all their new facilities, (2) lack of available water and energy consumption data on this typology, (3) specialized student demographic in their formidable educational years, (4) HE's ability to create 'living lab' environments to promote sustainability awareness and sustainable behaviors, (5) HE's lifetime ownership of their facilities and continual ability to implement behavioral change through education of current and future generations of students, (6) HE responsibility to society to form rational thinkers with sustainable habits which contribute positively to society, and (7) given they fall within the largest category of individuals who will enter the residential market (Harvard University 2012, NAR 2014).

1.3 Methodology and Research Limitations

The selection of POE indicators in this research is based on: (1) level of importance in widely adopted sustainability rating systems, scientific studies and papers, (2) applicability in post occupancy phase, higher education context, reduction in water and energy consumption, promotion of sustainable HE and student behaviors and occupant thermal comfort, and (3) survey results highlighting main areas of concern from actual feedback from occupants (n=593). The selected indicators address a range of topics including: water and energy consumption, occupant thermal comfort, occupant consumption behavior and education, noise insulation (indoor and outdoor), and facilities management (FM) operational feedback. Specific indicators such as building energy management systems (BEMS), building automation control systems (BACS) and artificial intelligence (AI) agents are also examined to identify if such system benefits have been realized. Based on the selection criteria discussed a total of 12 POE indicators were selected.

There are various types of POEs including: (1) indicative: general inspection of building performance by experienced personnel, (2) investigative: in-depth study of building performance, surveys and interviews of stakeholders, and comparison of findings to similar facilities, and (3) diagnostic: sophisticated data collection and analysis, physical measurements, surveys and interviews of stakeholders (Turpin-Brooks and Viccars, 2006). The proposed POE framework employed investigative and diagnostic data collection techniques to test the applicability of the POE framework in practice. The methodology employed for the collection of the 12 indicators included qualitative and quantitative methods such as actual metering/billing data, LEED submitted documentation for proposed design cases, surveys, interviews, and actual physical measurements.

Various methods of data collection and different stakeholders were needed in the data collection process for this research, solicited feedback and quantitative data was gathered from designers, HE FM departments, residential life personnel, and student occupants. The methodology captured actual metering information, actual building logging, and surveys. Combining quantitative and qualitative data collection techniques provides a holistic performance picture, triangulating findings uncovering stakeholder specific perspectives and behaviors which impact sustainability in practice.

The dataset includes: actual temperature (T) and relative humidity (RH) measurements of a LEED-Gold residence hall for a period of one month, actual water (9 residence halls) and energy consumption (4 residence halls) data from utility billing, comparisons of water and energy consumption to US and EU metrics due to their similarity gross domestic product (IMF 2012), and feedback from designers, HE FM departments and over 590 student occupants (LEED and non-LEED residence halls).

This research is limited to HE certified sustainable residence halls, and does not encompass: varied age and socioeconomic occupant demographics, varied building typologies and all US geographies. Residence halls used in this POE framework for data collection were not sub-metered, therefore high specificity of energy and water end-uses and exact consumption per person metrics were not generated. Behavioral experimentation analyzing methods which reduce energy and water consumption was not carried out given the resource limitations of this research.

1.4 Thesis Content

This thesis report is structured according to the following sections: (2) Literature Review, (3) POE Framework Methodology, (4) Results, (5) Summary of Findings and (6) POE Framework Conclusions and Recommendations.

The literature review portion of the report examines various notable scientific publications and widely adopted sustainability rating systems; reviewed for the selection of the most applicable POE indicators in the proposed HE POE framework. It is subdivided into the following sections: (2.1) Sustainability Rating System Studies, (2.2) Stakeholders and Building Performance, (2.3) POEs-General Applications, (2.4) POEs-Higher Education (HE) Applications, (2.5) POE Indicator Specific Studies and (2.6) Literature Review Overview.

The POE framework methodology section of the thesis outlines the detailed methodology of quantitative and qualitative techniques used to collect data pertaining to specific POE indicators selected. It also provides details of the buildings in the dataset. It is subdivided into the following sections: (3.1) POE Indicator Selection Methodology Summary and Stakeholders, (3.2) Selected POE Indicators and Data Collection Methods (POE Indicators 1-12), and (3.3) Selected Residence Halls (LEED and Non-LEED). In the case of POE Indictor 1 (Water), additional non-LEED residence halls were also analyzed. The details of the additional residence halls may be found in the Water Study (section 4.1) portion of the results.

The results section provides an outline of the detailed methodology and findings of each of the selected and executed (data collected) POE indicators. This section is arranged as follows: (4.1) Water Study (POE Indicator 1), (4.2) Energy Study (POE Indicator 2, 3, and 4), (4.3) Thermal Logging Study (POE Indicator 6), (4.4) Student Survey (POE Indicator 7, 8, 10, and 12), (4.5) Facilities Management Feedback (POE Indicator 5, 7, 8, 9, 10, and 11), and (4.6) Design Firm Surveys.

The results of all indicators are further summarized in: Section 5-Summary of Findings. This section is structured as follows: (5.1) Summary of Indicator 1, (5.2) Summary of Indicators 2, 3, and 4, (5.3) Summary of Indicators 6, 7, and 8, (5.4) Summary of Indicator 10, (5.5) Summary of Indicator 12, (5.6) Summary of FM Feedback (Indicators 5, 7, 8, 9, 10, and 11, (5.7) Summary of Designer Feedback, and (5.8) Stakeholder Specific Recommendations.

Lastly, notable deductions in the findings are presented in Section 6-POE Framework Conclusions. This section explores the implications of the proposed POE framework findings' notable results, highlighting steps which must be undertaken to ensure sustainability of resources for current and future generations.

1.5 Conclusions

The proposed POE framework provides a simple yet comprehensive method using quantitative and qualitative techniques to measure: (1) whether LEED certified residence halls deliver on their promised performance, (2) if differences between LEED and non-LEED certified residence halls exists, and (3) if other pronounced variables such as behavior play a role in sustainability in practice. Given the knowledge gap on this typology, the application of the proposed POE framework also identified energy and water consumption of this specific building type and demographic specific areas of concern.

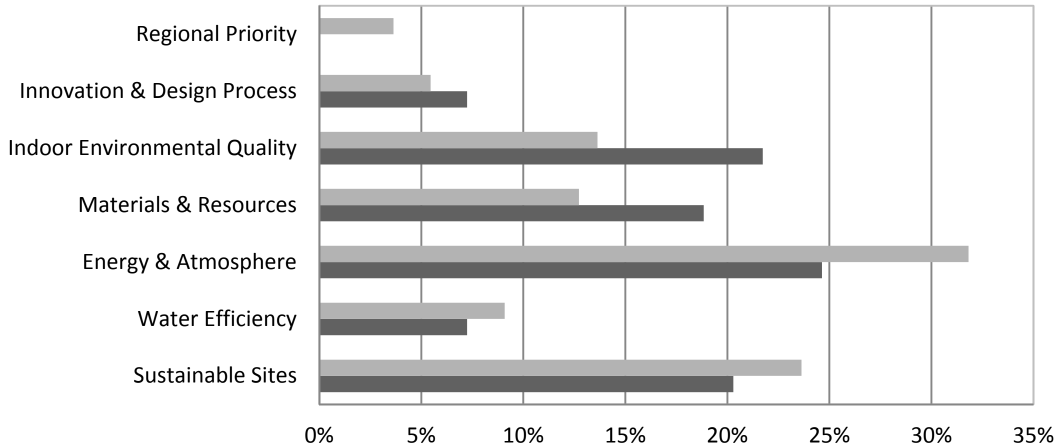
2. Literature Review

The following sections provide a detailed review of existing literature on sustainable building certification, stakeholders and building performance, POEs in general applications, POEs in HE applications, indicator specific POEs and an overview of studies and findings as pertaining to the HE residence hall POE indicator framework. This body of scientific work is the driving force behind strategies implemented to attain sustainability and provides concepts and applications which offer sustainable solutions. It is the basis for the selection of the POE indicator framework proposed herein.

2.1 Sustainability Rating System Studies

In the effort to answer sustainability requests on HE campuses, practitioners of the construction community have adopted the guidance of many sustainability-rating systems including: LEED (USGBC 2009), BRE Environmental Assessment Method (BREEAM 2008), Comprehensive Assessment System for Built Environment Efficiency (CASBEE 2010), Living Building Challenge (LBC-ILFI 2012), and Green Globes (2012). These various rating systems provide guidance on designing sustainably by focusing on various parameters including: sustainable site selection, energy efficiency, indoor environmental quality, and water efficiency. In comparing the various rating systems it must be noted they fall into two categories (1) point systems, and (2) performance systems.

LEED, BREEAM, CASBEE, and Green Globes are based on a point system. However, LBC is based on actual post occupancy performance and attainment of zero-net water and zero-net energy. New rating systems such as Deutsche Gessellschaft fur Nachhaltiges Bauen (DGNB 2013), are currently under development. DGNB promises a more comprehensive approach by incorporating: economic, sociocultural, functional, technology, processes, and site quality components (DGNB 2013). A note to be made about DGNB is there are no prerequisites, and no one category holds more weight. Per Figure 1 it is evident LEED places the highest importance on energy efficiency.



	Sustainable Sites	Water Efficiency	Energy & Atmospher e	Materials & Resources	Indoor Environme ntal Quality	Innovation & Design Process	Regional Priority
LEED NC-2009 PERCENT OF TOTAL	24%	9%	32%	13%	14%	5%	4%
LEED NC-VERSION 2.2 PERCENT OF TOTAL	20%	7%	25%	19%	22%	7%	0%

Figure 1-Percent of Total per LEED Category

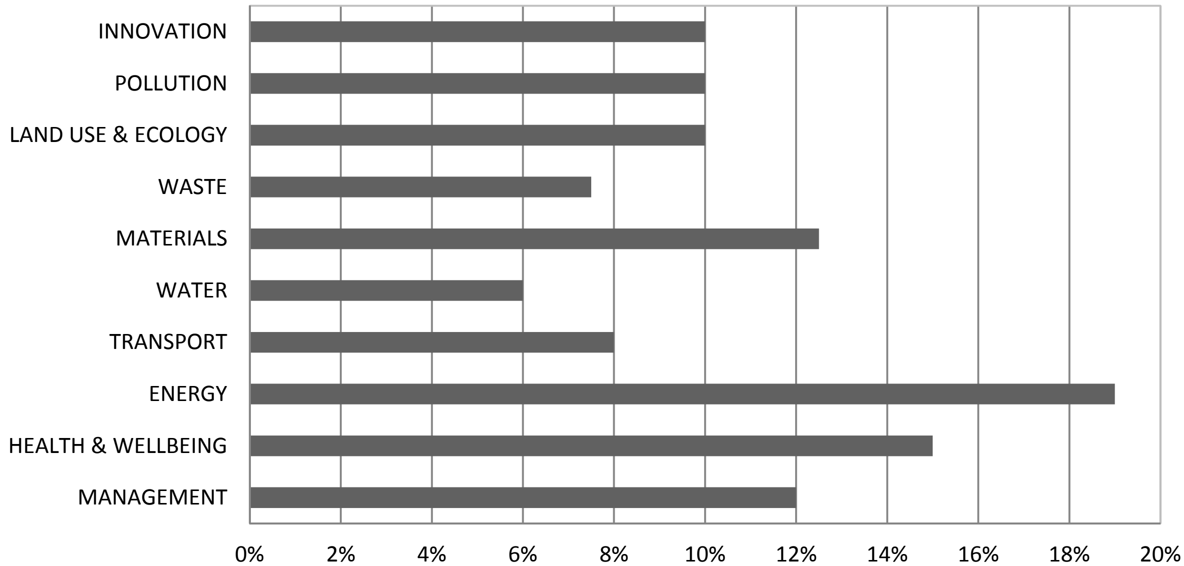
Figure 1 and Table 1 also outline the various percentage and point distributions per LEED New Construction (NC)-Version 2.2 and LEED NC-2009. This shows that even through the transitions between versions, the energy category still holds the most weight.

Table 1-LEED Point Distribution per Category

Category	LEED NC*-Version 2.2 (possible points)	LEED NC-2009 (possible points)
Energy and Atmosphere (EA)	17	35
Sustainable Sites (SS)	14	26
Indoor Environmental Quality (IEQ)	15	15
Water Efficiency (WE)	5	10
Materials and Resources (MR)	13	14
Innovation and Design Process (ID)	5	6
Regional Priority (RP)	Points unavailable in version	4

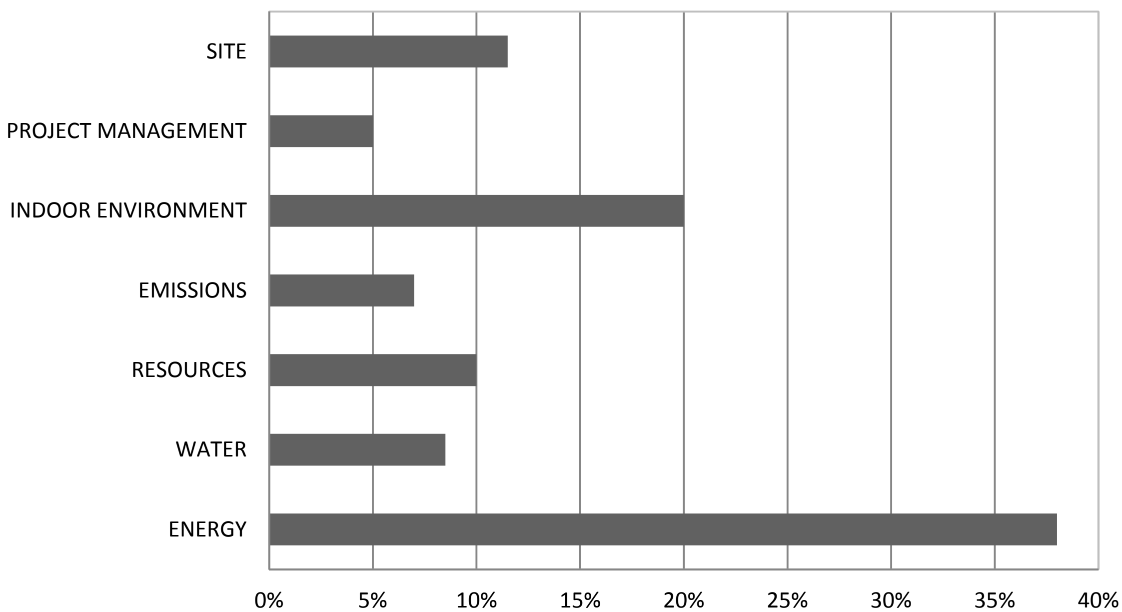
* NC=New Construction

BREEAM, CASBEE and Green Globes also place the highest importance on energy efficiency as outlined per Figures 2, 3, and 4.



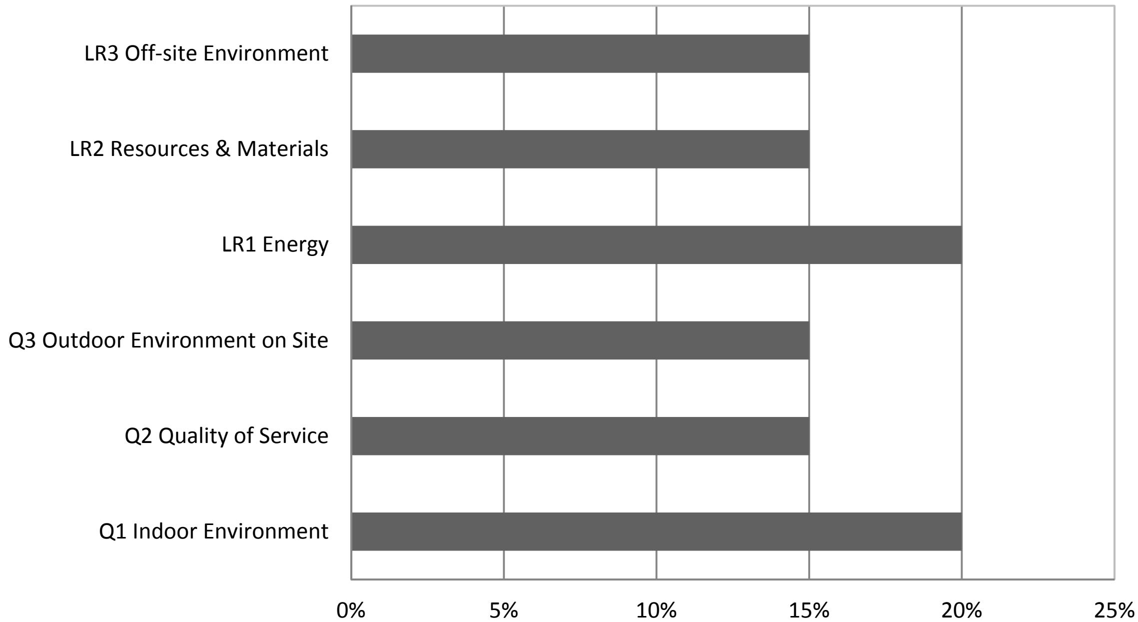
	MANAGEMENT	HEALTH & WELLBEING	ENERGY	TRANSPORT	WATER	MATERIALS	WASTE	LAND USE & ECOLOGY	POLLUTION	INNOVATION
% of Total	12%	15%	19%	8%	6%	12.50%	7.50%	10%	10%	10%

Figure 2-Percent of Total per BREEAM Category



	ENERGY	WATER	RESOURCES	EMISSIONS	INDOOR ENVIRONMENT	PROJECT MANAGEMENT	SITE
% OF TOTAL	38.00%	8.50%	10.00%	7.00%	20.00%	5.00%	11.50%

Figure 3-Percent of Total per Green Globes Category



	Q1 Indoor Environment	Q2 Quality of Service	Q3 Outdoor Environment on Site	LR1 Energy	LR2 Resources & Materials	LR3 Off-site Environment
% of Total Weight Distribution	20.00%	15.00%	15.00%	20.00%	15.00%	15.00%

Figure 4-Percent of Total per CASBEE Category

LEED, BREEAM, Green Globes and CASBEE place the highest importance on energy efficiency at: 32%, 19%, 38% and 20% respectively, yet none mandate occupant feedback. It must be noted sole focus on energy efficiency is not a comprehensive measure of sustainable performance and is a limiting view (Sinopli 2009). Buildings are far too complex and need to be investigated in a wider context (Sinopli 2009, Berardi 2012).

Given the wider context, in performance based certification system LBC, 'living' certification is only possible if zero-net energy and zero-net water is achieved. LBC requirements are so rigorous very few owners pursue it, due to cost and regulation challenges. In recent years the International Living Futures Institute (ILFI) developers of LBC performance certification system, have published guidance on meeting regulatory challenges and advocated building code changes (LBC-ILFI 2012). DGNB (DGNB 2013) has to yet to be fully developed but based on information provided on their website, every category shall have equal importance.

Table 2 outlines categories within the various rating systems, applicable in the POE framework.

Table 2- POE Applicable categories and percent of points possible from total points per rating system

Category	LEED NC* 2009	LEED Version 2.2	BREEAM	Green Globes	CASBEE
Energy and Atmosphere	32%	25%	19%	38%	20%
Indoor Environmental Quality Health and Wellbeing	14%	22%	15%	20%	20%
Water Efficiency	9%	7%	6%	8.5%	2.5% (Under Resources & Materials)
Total POE** Indicator Significance	**55%**	**54%**	**40%**	**66.5%**	**42.5%**

* NC=New Construction
**POE=Post Occupancy Evaluation

Examining rating system parameters (energy, water, and indoor environmental quality) applicable in the occupancy phase of sustainable buildings, it is clear a major portion of the design indicators are impacted. On average more than 50% is impacted among the rating systems (LEED NC-2009, BREEAM, Green Globes and CASBEE). This percentage only fortifies the criticality of POEs in closing the performance gap. As evident the rating systems are also unbalanced. Further inspecting downfalls of an unbalanced weighting, researcher Zhou (2011) cautions inherent weighting of LEED categories, may misrepresent unsustainable buildings for sustainable ones.

Pacheco, Ordóñez and Martínez (2012) reviewed various parameters with potential impact on overall energy efficiency of buildings including: building shape, orientation, envelope, shading devices, passive systems and glazing. They found sustainable design strategies can reduce overall energy demand for heating and cooling, however suggest larger benefits are reaped if buildings are viewed life cycle terms. They indicate a more energy efficient design does not automatically translate into more economical or environmentally conscious design.

Given current design processes are not informed through POEs on actual building performance, design assumption validity comes into question. Arguments made by researchers (Sinopli 2009, Zhou 2011, Pacheco, Ordóñez and Martínez 2012, Berardi 2012) higlight the need to inform the design process. Only through POEs with actual building performance data, can sustainability rating systems be improved and sustainable practices promoted. POEs facilitate benchmarking and uncover sustainable design strategies which work and those that do not (Leaman 2003, Bordass et al. 2004, Bordass et al. 2010).

Given majority of weight is given to energy efficiency categories within varied rating systems a review of modeling software is warranted. Zhao and Magoulès (2012) reviewed various techniques, which include complex artificial intelligence agents to simplified engineering models. In most cases to accurately model energy performance, historical performance data is required. Table 3 outlines their findings of methods, model complexity, ease of use, running speed, required inputs and model accuracy.

Table 3- Comparative Analysis of Commonly used Energy Modeling Methods (Zhao and Magoulès 2012)

Methods	Model Complexity	Easy to Use	Running Speed	Required Inputs	Model Accuracy
Elaborate Engineering	Fairly High	No	Low	Detailed	Fairly High
Simplified Engineering	High	Yes	High	Simplified	High
Statistical	Fair	Yes	Fairly High	Historical Data	Fair
Artificial Intelligence Neural Networks (ANNs)	High	No	High	Historical Data	High
Support Vector Machines (SVMs)	Fairly High	No	Low	Historical Data	Fairly High

Naturally to create historical databases, POEs are required to collect and benchmark information. Zhao and Magoulès (2012) highlight POEs can translate into rich and robust databases, informing the design process. It must be noted 80% of methods require detailed building knowledge, and 60% require historical data. These are large percentages indicating POEs can have a large influence on the energy modeling design process. These findings support the suggestions of Kelly, Crawford-Brown and Pollitt (2012) indicating a dire need to develop robust building performance assessment tools.

They argue building performance evaluation tools are critical in estimating and recommending cost effective improvements for energy efficiency, and overall lowering of emissions. Based on their study of UK residential dwellings, they found implementation of energy efficient strategies are hindered by the large performance gap. They state the first step in achieving future emissions targets is ensuring robust measurement, and certification procedures.

Berardi (2012) also mirrors the sentiments of researchers, indicating the dire need for a holistic multi-dimensional approach to building assessment (Leaman 2003, Bordass et al. 2004, Sinopli 2009, Bordass et al., 2010, Zhou 2011, Kelly, Crawford-Brown and Pollitt 2012). Figure 5 outlines the heavy tilt in energy efficiency categories between various rating systems from his study. Berardi highlights eventhough such importance is given to the energy efficiency category within BREEAM, LEED, CASBEE, Green Globes, SBTool, SBC-ITACA; the rating systems do not mandate verification of modeled energy targets. This statement ties back to the performance gap previously discussed (Leaman 2003, Bordass et al. 2004, Sinopli 2009, Bordass et al. 2010).

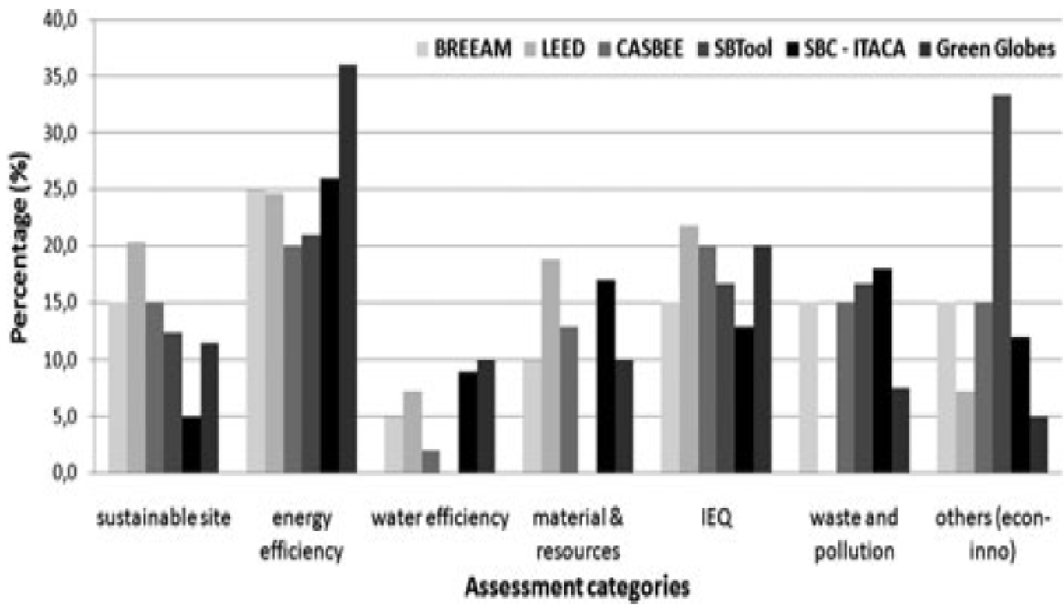


Figure 5-Sustainability Rating Assessment Categories (Berardi, 2012)

Turner (2006) studied 11 sustainable buildings, examining indoor water and energy consumption. In terms of energy consumption results were favorable, however only half the buildings did well in terms of indoor water use (compared to LEED Sustainable Design Case). Turner notes baseline cases are based on possibly inaccurate assumptions therefore a need exists to verify models. Turner also indicates further studies to establish benchmarks is direly required. These findings and suggestions echo researchers, magnifying the need to close current performance gaps through POE implementation.

Sawyer, Wilde and Turpin-Brooks (2008) implemented a POE case study of two identical office buildings, one with BREEAM certification and one without. They found the certified building did not result in reduced energy consumption. The certified building when compared to ECON 19 (ECON 19, 2003) targets actually performed as a conventional building. The performance gap would have never surfaced, if not for the POE process. Occupant surveys also brought to light shared problems including: overheating, poor ventilation and a lack of air movement. This work highlights the weighting problem within rating systems; and that simply attaining certification does not translate into better performance. These findings also echo previously discussed research on unbalanced rating systems and their inherent shortfalls.

In a comparative study between LEED and non-LEED office buildings by Newsham, Mancini and Birt (2009), it was found on average LEED buildings used 18%-39% less energy per floor area than their conventional counterparts. However 28%-35% of LEED buildings used more energy than their non-LEED counterparts. The researchers also found certification level had negligible correlation to energy performance of the certified buildings.

In a rebuttal paper by researcher Scofield (2009), he notes that Newsham, Mancini and Birt (2009) misrepresented data by not comparing source energy, therefore showing favorable results. Scofield highlights that researchers used site energy (on site) as compared to source energy (off-site) data, tipping the results in favor of LEED buildings. Scofield also emphasizes majority of LEED-certified offices do use less energy than their non-LEED counterparts, however only when large office buildings are taken out of the sample size. When LEED offices are compared collectively a negative impact on overall consumption is seen, as large LEED office buildings consume most of the energy. Therefore LEED offices (aggregate of large and small) are not using less energy than their non-LEED counterparts.

Based on variances found between researchers' results, it is evident measuring sustainability is complex. It should be more inclusive of indicators beyond the simple inclusion of energy and water indicators. Sustainable building performance requires the measurement of many indicators, and involvement of many stakeholders. From the review of the varied sustainability-rating systems and work of researchers mentioned above, it is clear categories holding the most importance (energy and water efficiency, indoor environmental quality) are influenced by occupants. Current rating systems and practices do not mandate any type of POEs and stakeholder feedback. To minimize energy and water consumption and promote sustainable practices these groups of stakeholders must be included.

Many researchers higlight advantages and disadvantages of various design strategies, however their collective outcomes indicate promotion of sustainable buildings requires a comprehensive life cycle POE approach. Researchers state holistic methods for sustainable building performance evaluation, must be inclusive of stakeholders. Such knowledge-building mechanisms (POEs) will inform the design process; ensuring design mistakes are not repeated and performance gaps are closed (Leaman 2003, Bordass et al. 2004, Bordass et al. 2010). Given importance of stakeholders in promoting sustainability, the next section elaborates on their impact.

2.2 Stakeholders and Building Performance

Forbes (2002) indicates POEs identify the extent design intent has been met, through involvement of occupants and facilities management. The feedback of these stakeholders provides a holistic understanding of building performance. Documenting 'lessons learned' and 'best practices' can improve future designs, by informing the design process and industry at large.

Lutzkendorf and Lorenz (2005) discuss the importance of incorporating building performance in the valuation of sustainable buildings. They indicate the trend of viewing buildings as commodities is changing, and an emphasis is being placed on building characteristics. Building performance is increasingly being used in the determination of worth and market value. They highlight social and environmental considerations are beginning to gain momentum, in addition to the economic return of sustainable buildings.

The researchers also stress social, environmental and economic characteristics can provide a more in depth analysis about the performance of a building. These statements mirror the deductions of Forbes (2002): to truly understand building performance occupants must be involved in the process. Gupta and Chandiwala (2010) and Stevenson and Rijal (2010) also stress Forbes and Lutzkendorf and Lorenz suggestions. They indicate POEs are critical in improving future designs through occupant feedback.

Sawyer, Wilde and Turpin-Brooks (2008) note POEs must be documented and incorporated in future designs to change the 'status quo'. Their POE indicated that the sustainable building was underperforming and did not meet occupant needs. Returning to the idea of building valuation in Lutzkendorf and Lorenz's work (2005), the value of the sustainable building would be lowered. Based on Forbes' work these results would inform the design process.

Cicelsky et al. (2009) note demand to lower energy consumption and simultaneously improve occupant comfort can be conflicting requirements. This requires a delicate balance, only attainable through POEs involving occupants and facilities personnel.

Stevenson and Leaman (2010) discuss various studies showing a lowering of occupant energy consumption with feedback mechanisms. They note taking control away from occupants may result in adverse behaviors, such as increased energy consumption. They emphasize the human element is the biggest variable in energy use predictions. Cultural and normative behavior must be accounted for in relation to thermal comfort and energy consumption. Researchers indicate POEs are necessary to inform the design process and identify course correction measures. Only then can energy consumption and occupant behavior be altered. POEs should also focus on 'interactive adaptivity' as to why occupants consume and behave the way they do. Behavioral consumption differential is also documented in a study carried out by Gram-Hanssen (2010).

Gram-Hanssen's study (2010) showed occupants of similar homes often consumed three or more times as much energy for heating as compared to their neighbors. Stevenson and Leaman recommend empowering occupants with information on how to curb consumption and also potential carbon taxes to ensure vested interest.

Streimikiene and Volochovic (2011) highlight the importance of occupant behavior on consumption. In a review of various studies they indicate the differential in consumption can be explained partly by weather, wealth, culture and behavior. A couple of salient consumption examples provided indicate 21% of residential energy use in UK residences in 1998 and 51% in Sweden were related to dishwasher use. Cultural preferences showed cold water use in China for clothes washing, while typically hot water is used in Europe. They indicate substantial differences exist among countries in how lighting is used, and what room temperatures are considered comfortable. The researchers state user behavior is reliant on information, motivation and responsibility. They discuss the importance of educating occupants and putting consumption awareness programs in place to motivate conservational behavior. Occupant education is also supported by many arguments in the 'The Sustainable University' (Sterling et al. 2013). Although their review was geared towards household applications, the need for consumption awareness and occupant education is applicable in numerous contexts.

Zalejska-Jonsson (2012) highlights occupants of sustainable apartments are more aware of their energy and water consumption. Occupants are more prone to behave in an environmentally friendly manner. In a survey of occupants in a sustainable apartment building 50% of occupants believed they spent less on energy and water. Occupants believed it was due to increased awareness highlighted by individual metering. The two major behavioral changes of occupants in sustainable buildings were: (1) change of clothing habits and (2) increased awareness of energy and water consumption. Figure 6 outlines the perceived effect of individual metering on occupants' energy and water consumption.

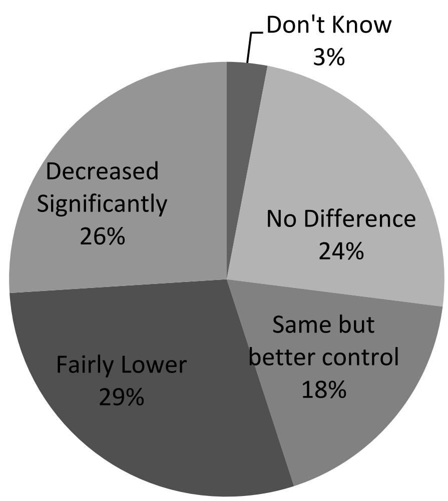


Figure 6-Effect of Individual Metering on Energy & Water Consumption in Low Energy Households in Sweden (Zalejska-Jonsson, 2012)

In Zalejska-Jonsson's study, the point of contention for both types of dwellings conventional and low-energy was ventilation. The cooking fumes spread through the ventilation system to neighboring apartments. Occupants of low-energy dwellings also complained about dry air, exhaust fans problems and low suction; related to airtight building construction. Per Figure 6, 55% of respondents perceived a sense of conservation in energy and water consumption. This highlights informing occupants is critical in minimizing consumption, and promoting sustainable behaviors. It is only through such POEs we can appreciate occupants' impact and adaptability to their environment.

From the work of the various researchers it is evident POE Indicators provide a comprehensive tool to measure sustainable building performance. Parameters such as meeting design intent, and occupant satisfaction can only be addressed through POE implementation and stakeholder feedback. Even though POE Indicators provide numerous benefits to industry at large, they have yet to be adopted by industry practitioners. This lack of adoption has been due to poor categorization and uncertainty in indicators to be selected (Lavy et al. 2010). The considerable uncertainty as to what the feedback techniques are, how they should be used, and what value they add are current barriers to POE adoption (Bordass et al. 2001).

To further explore POE benefits, the next section provides insight into the added value POEs bring to the design and operations process. The section examines real world research opportunities which can positively impact designers, FM personnel and occupants.

2.3 POEs-General Applications

Bordass (2000) notes the reasons for a lack of POE adoption have been due to split incentives, and industry fragmentation. Initial cost estimating of projects have an immense impact on their sustainability and acceptability of associated costs. Estimators know little about building services; therefore undermining the sustainability potential of the design process. Estimators tend to lock designers in unrealistic projected building costs. Designs will be far more holistic if the entire life of the building, and all its associated costs are reviewed. The added value and benefits buildings bring to their users must be accounted for by incorporating economic, human and environmental parameters.

Bordass, Leaman and Ruyssevelt (2001) state even though clients are interested in POEs it is not routine practice. The considerable uncertainty as to what the POE process is composed of is a hindrance in its adoption. Data collection should not be the only consideration, the correct and effective analysis of feedback is also important. An obstacle to this, is current weak data and knowledge management in design firms.

Zimmerman and Martin (2001) state POE analysis can give practitioners a competitive edge. The facility delivery process does not recognize the concept of continual improvement or any on-going involvement, on the part of the designers, and architecture/engineering/construction (A/E/C) professionals. As a result the A/E/C industry does not invest in research and development (R&D). In 1988 R&D was below 0.4% and by comparison the automotive and oil industries spent 1.9% to 2.9% respectively. Since only scholars in social design and academia are versed on the topic of POEs, the gap between intent and reality has yet to be bridged. The researchers also stress the findings of Bordass (2000) on industry fragmentation as a major factor in the lack of POE adoption. They indicate owners and occupiers are unaware of their influential position to change the 'status quo'.

Preiser (2002) highlights the need for continual building performance evaluation and indicated POEs are different from other evaluation methods. POEs focus on technical and non-technical parameters providing a holistic performance picture. The author stresses sharing of knowledge is required to ensure designers do not repeat mistakes and understand their designs in practice.

Lackney and Zajfen (2005) highlight the many benefits of POEs listing them as follows: (1) aiding in communication amongst stakeholders (A/E/C and occupants), (2) creating mechanisms for quality monitoring, providing owners with the knowledge when buildings do not meet design intent, (3) supporting the fine-tuning, settling in, and renovation of existing settings, (4) providing data and knowledge for future designs and decisions, (5) supporting development of policy as reflected in design and planning guides, and (6) hastening the learning process within organizations by allowing decision-makers to learn and build on successes and not repeat failures. Researchers indicate the key to changing building design 'status quo' is in POEs.

Augenbroe and Park (2005) stress the importance of measuring building performance addressing key performance aspects such as: energy, lighting, thermal comfort, maintenance and indoor air quality. They stress a large gap between modeled and actual performance exists. The key to closing this gap, is in the investigation of actual conditions post construction. Decreasing the gap between the two is an important target for the building industry to become more client driven. They indicate industry needs to provide better overall value to increase customer satisfaction. In order to do so two dialogues must take place: (1) architectural and engineering parties need to meet the functional needs of occupants and client expectations, and (2) facility managers must meet occupant expectations and needs through proper maintenance and management practices. As can be seen to carry out these important conversations POEs are required to close the knowledge gap and increase A/E/C's understanding of their designs in practice.

Fowler (2005) emphasizes the lack of performance measured data, hampers the adoption of sustainable design and construction. This lack minimizes the savings realized, as stakeholders are simply unaware of the information. Based on the lack of building performance information the Department of Energy Office of Energy Efficiency and Renewable Energy's (EERE) Federal Energy Management Program (FEMP), initiatied the Building Cost and Performance Data Project looking specifically at office buildings. Fowler's research identified no protocol was in place to measure office building performance. Therefore a framework was developed, to create the business case to build green office buildings.

Turpin-Brooks and Viccars (2006) discuss the importance of developing robust and effective POEs as part of a sustainable approach to workplaces. They state POEs are effective in addressing client satisfaction, and user needs as part of sustainability assessments. They highlight the importance of POEs in creating holistic methods for sustainability assessment, through occupant inclusion. One of their key findings was the importance of understanding how occupants interact with the building. This interaction plays a key role in energy consumption, and perceptions of thermal comfort. Another noteworthy recommendation is a 'one-size fits all POE' does not exist.

Bordass, Leaman and Eley (2006) mimic the statements of Turpin-Brooks and Viccars in that a 'one-size fits all POE' does not exist and should be discouraged. They discuss the importance of feedback from various stages of the building process (design, construction, and operations) in quality assurance and performance measurement. They state a major reason for the lack of POE adoption, is due to designer performance accountability fears. They point out techniques adopted can be in the form of physical monitoring, surveys, and observations. They also caution to implement inexpensive and simplistic POE techniques, to ease adoption by professionals.

Woods (2008) also outlines a lack of clarity and consensus on the methods of performance measurement are a hindrance to POE adoption. To account for how well a building is actually performing, a benchmarking strategy must be in place. Woods states there should be objective methods in place for measuring and evaluating building performance. Such methods should be based on the assumption that a building functions as a system.

Steemers and Yun (2009) studied the US data on residential energy consumption, they found climate and building characteristics alone were not sufficient determinants of energy demand. Occupant behavior and socio-economic parameters were also important components in the equation of energy consumption and sustainability. The first parameter impacting consumption was climate, followed by occupant behavior and their ability to control their indoor environment. Occupant needs can only be understood if POEs are undertaken, documented and shared. Their study showed older housing stock built in the 1940s, performed far better than ones in 1980s. This was due to the fact that by default 1940s homes had passive strategies, not offering centralized heating/cooling. The researchers state POEs and benchmarking are critical in understanding building performance, and developing insight into sustainability measures.

Cicelsky et al. (2009) also highlight the importance of POEs as a required step towards sustainability by the inclusion of occupant feedback. The authors point out buildings are a large cost investment, but rarely re-visited to ensure design intent is met and occupants are satisfied. A lack of systematic benchmarking methods has resulted in haphazard processes, failing to promote sustainability. Without POE implementation every building is a prototype.

The Soft Landings Framework (2013) developed by the Usable Buildings Trust and BSRIA further highlights the need for the adoption of POEs. This framework is geared towards new construction, refurbishment and alteration. It allows for the smooth transition of projects into occupancy, from the early inception of projects. Soft Landings addresses many problem areas typically uncovered by POEs, but early on when lessons can be incorporated in the design. By increasing performance cognizance the Soft Landings process helps in setting realistic target goals and responsibilities, at the very early stages of projects. In this framework feedback is received early on, hence it is incorporated into design to ensure repeat failures do not occur. Such feedback mechanisms ensure client and occupant satisfaction, and inform designers and industry at large.

Hadjiri and Crozier (2009) discuss the benefits of POEs in improving facilities management processes. Industry fragmentation, split incentives amongst stakeholders, and a lack of consensus on POEs have inhibited their adoption. They indicate POEs can be a diagnostic tool for the evaluation of building performance considering technical and non-technical factors. These factors influence design and operations of facilities. They also stress the impossibility of attempting to reconcile all POE approaches into a single methodology. They suggest a portfolio of contextualized techniques should be created. They caution against lengthy cumbersome POE processes, as they will likely not be adopted. These suggestions mirror recommendations made by previous researchers (Bordass, Leaman and Eley 2006, Turpin-Brooks and Viccars 2006).

Guerra-Santin and Itard (2010) also discuss the influence of occupants on energy consumption. They studied a residential application in Netherlands showing the type of heating/cooling system selected had an influence on occupant consumption behavior. Their study is another fortification in that inclusion of occupant feedback and behavior is critical in understanding interactions with the building and systems. They implemented POEs using surveys and questionnaires to understand technical and non-technical aspects of the user experience. Another finding showed programmable thermostats resulted in more hours of heating and cooling versus manual ones. Such findings can only be incorporated in future designs if POEs are carried out, documented and shared. In this case temperature controls turned out to be very important in the use of heating/cooling and ventilation systems. Such insights can only be achieved through POEs, identifying what works and what doesn't in practice.

Brown et al. (2010) contend sustainable buildings and user experiences are complex shaped by technical and non-technical aspects. Their study reviewed the relationship of sustainable building design and workplace practices in comparison to organizational culture in shaping design and operations. One of their key findings was sustainable design decisions alone are not the answer to sustainable practices. The end-occupants have to be involved in the process as they contribute to sustainability by the way they impact their space. They also highlight sustainable designs may not be well suited for all types of occupants. They stress the question must be posed whether the occupant will be best served by a sustainable building. They also indicate the need to involve various stakeholders such as owners, facilities managers and occupants to document varied case studies for future use in 'best practices' and 'lessons learned'.

Masoso (2010) studied waste energy consumption during non-occupied periods of six buildings. The study highlights the importance of tracking, measurement and ongoing building performance awareness; as they are the key to lowering energy consumption and promoting sustainability. This study provided examples of occupant impact on reducing energy consumption. In the study performed the energy used during non-working hours was 56% more than when the building was being officially used 44%. This large consumption was in part due to minor behavioral trends such as: leaving lights and equipment on, and poor HVAC zoning and controls. This work highlights the importance of the occupant in sustainability and impact of design decisions (easy controls, appropriate HVAC zoning etc…). The researcher stresses much focus is placed on energy efficiency, however serious attention must be given to occupant behavior and feedback. The researcher also compared the average energy consumption of the buildings 172 kWh/m^2 to international benchmarks, noting that the buildings compared fairly. However, with the knowledge that over 50% of the energy was wasted, international benchmarks should be questioned.

Ornstein and Ono (2010) indicate POE studies have been carried worldwide in both the private and public sector, but have rarely led to 'lessons learned' and design changes. The lack of systematic POE use by A/E/C members has led to a situation where mistakes are repeated and every building is a prototype. The lack of documentation and adoption of POEs has led to stagnation in potential innovative design strategies.

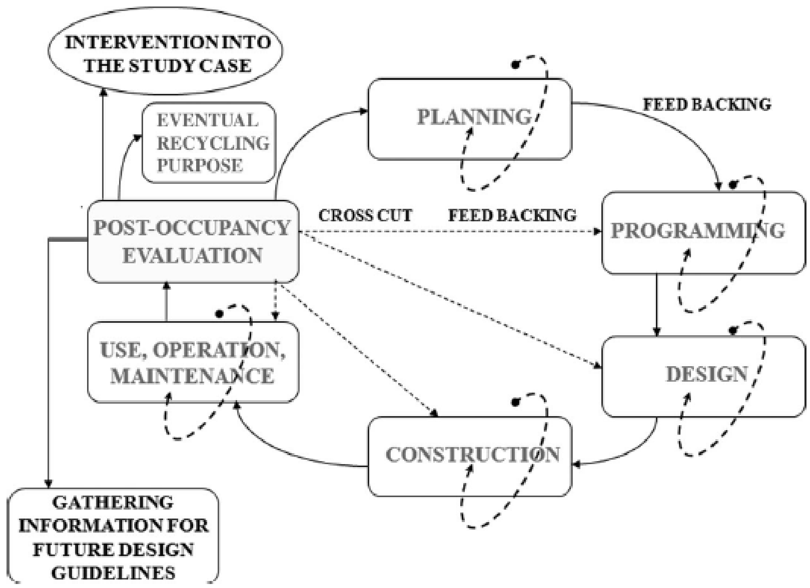


Figure 7-POEs on production, use, management/operation and maintenance cycles (Ornstein and Ono, 2010)

Figure 7 outlines the potential information loop and 'lessons learned' opportunities through POEs. They highlight the importance of calibrating qualitative and quantitative POE techniques to ensure they are: easy to read, watch and interpret by decision makers. Researchers point out the housing sector is the most significant construction sector, however little work has been done in developing quality indicators and references. They also note POEs are not widespread among private entities, therefore improvement opportunities are constantly missed.

Bordass, Leaman and Stevenson (2010) outline the importance of real world research in impacting the design and operations phases of building projects. They stress lack of published and accessible POE results, make the process more difficult and confusing. Researchers point out including too many parameters to be tracked and collected, can make the POE process cumbersome and difficult to analyze. Collecting pertinent data is the key in ensuring ease of data collection and analysis. Feedback is currently not an integral part of design and construction, it is not mandated nor contractually obligated. POEs are multi-disciplinary by nature dealing with many topics from human behavior to hard metrics. Therefore the process requires a comprehensive approach accounting for various technical and non-technical parameters.

Zhun (2011) discusses the impact of occupant behavior on building energy consumption. Zhun indicates several factors influence building energy consumption, however the leading one is occupant behavior. In order to promote sustainable practices occupants and facilities personnel must be involved in the process to make sustainability a reality.

Deuble and de Dear (2012) studied occupant comfort in mixed-mode buildings by comparing feedback from over 1000 respondents using ASHRAE 55 standard Fanger's PMV-PPD method. Their results did not conform to PMV-PPD predictions and occupant thermal perceptions were affected by the buildings mode of operation instead of the indoor climatic conditions. The researchers stress the inadequacy of the PMV-PPD method and bring to question its validity. They indicate actual performance data can lead to changes in design practices as it allows benchmarking and comparative analysis with modeled assumptions.

As can be seen from the deductions of various researchers above, the key to building performance measurement is the implementation of POEs; and involvement of all stakeholders. As noted above detailed POEs are composed of: walkthroughs, surveys, questionnaires, thermal measurements, and consumption data from metering. The triangulation of data through involvement of various key stakeholders such as designers, owners, facilities managers and occupants is critical. To get the full performance picture and promote sustainable practices occupants are pivotal, this group has always been excluded from any type of data gathering processes in building projects. Simply collecting energy and water consumption data is not sufficient, as its only part of the picture.

Based on the findings of various researchers POEs must be a simple yet comprehensive. They encompass technical and non-technical components. Researchers caution against a 'one-size fits all POE', stressing the need to contextualize POEs. This indicates POEs must be tailored to each building typology. In developing a POE process contextualized for certified sustainable HE residence halls, further studies specializing in this area have been explored in the next section.

2.4 POEs-Higher Education (HE) Applications

Researchers Bonnet et al. (2002) studied various sustainability parameters on the campus of University of Bordeaux. They defined a methodology for auditing energy and water consumption. Their results were ratio-based in terms of water consumed in cubic meters per square meter, and kilowatt-hours per year per square meter for electricity. The campus buildings analyzed included: library, administrative, lecturing, catering, research, and student housing. The study did not specify the number of occupants in the student housing, instead the ratio information was provided on a per room basis.

Since researchers did not specify the number of occupants, water and energy consumption per person cannot be isolated in the student housing facilities. Also using the information on a per room basis is problematic, as a description of the facilities was not provided. Several key findings include: student housing held the second largest floor area on their campus (21%), was the second largest consumer of water resources (35%), and third largest consumer of electricity (16%). Water and electricity end-uses within student housing were not further subdivided to profile student consumption tendencies. Although the work of Bonnet et al. (2002) provides insight into energy and water consumption of their campus, it is not comprehensive and does not include thermal comfort parameters or student occupant feedback.

Hassanain (2008) carried out a POE on non-LEED student housing facilities on the campus of King Fahd University of Petroleum and Minerals in Saudi Arabia. POE was done on one building housing a total of 72 students. 28 students responded to an administered survey (20% response rate). It must be noted based on LEED guidelines 30% response rate is recommended, and POE research expert Adrian Leaman indicates 50% to 100%. Hassanain created a user survey addressing technical and functional performance elements. However did not triangulate data through the collection of actual utility consumption or involve facilities personnel. The survey posed vague questions to which requires further clarification. For example one of the questions: “overall perception of the thermal environment in the building” is not location specific within the building and does not define which parameter of thermal comfort is being questioned. Vague questions related to indoor air quality and thermal comfort, small sample size along with a lack of stakeholder feedback; weaken the study as issues of study robustness come into question. It must be noted the survey was designed with bias, respondents were forced to make a selection of strongly satisfied, satisfied, dissatisfied or strongly dissatisfied. Since the scale forces a response the results may not be a true representation of the occupant experience. The author concludes emphasizing the survey is generic and with proper customization it may be applicable to other student housing facilities. Although this study lacks robustness, it highlights organized and robust methods are direly needed to carry out POEs in HE student residence hall applications.

Paul and Taylor (2008) studied satisfaction perceptions of occupants in a university workplace setting. The study covered two conventional buildings and one green building. They found there was no significant difference between the buildings in terms of occupant thermal comfort. In fact occupants of the green building were more prone to feel hot, translating into a poorer working environment. This study highlights the importance of POEs in informing the design process, to ensure occupants are indeed satisfied with indoor thermal conditions.

Dahlan et al. (2009) carried out a study of only female occupants in Malaysia and found that their major concerns in order of importance were: thermal comfort, acoustical comfort and visual comfort. The study was of a naturally ventilated student housing with ceiling fans. They also found outdoor conditions have an influence on occupants' perception of indoor thermal comfort. This finding is in agreement with previous research by de Dear and Brager (2002). Their study also found that the female occupants were more sensitive to temperature as a parameter of their indoor thermal comfort. Temperature sensitivity amongst women versus men is well documented in review papers by Karjalainen (2012) and Wang (2006).

Brown and Cole (2009) examined the influence of knowledge on occupant behavior studying green and non-green academic (departmental) buildings on a university campus. Using POE techniques they found even though availability and use of personal controls was higher in the green building, the absence of timely feedback, and poor comprehension led to sub-optimal comfort conditions. Their findings indicate occupants need to learn more about how buildings work and how comfort is provided. They argue in order for green buildings to perform effectively, there needs to be a shift in the conceptualization of occupants from passive recipients to active participants. The researchers discuss the shift in higher occupant controls in green buildings due to their inclination to adopt passive strategies. They also discuss two prevalent gaps in green buildings today relating to: (1) predicted versus actual performance gap of buildings (performance gap), (2) the gap between assumed and actual comfort. In their POE study they found users of green buildings used far more space heaters, fans and plug-in lamps than conventional non-green building occupants. The results of their POE analysis indicate occupant needs were not met in the green building, highlighting the performance gap. They suggest designers need to pay more attention to design and communication of thermal comfort systems in buildings to minimize waste.

Riley et al. (2010) discuss POEs in the past have focused on commercial and residential buildings rather than higher educational facilities. They mirror the sentiments of previously mentioned studies on the lack of adoption of POEs, due to split incentives amongst industry professionals. They indicate there are various methods to measure performance and no one defined approach exists; suggesting methods should be selected based on the unique needs and objectives of those conducting the evaluation. The researchers recommend methods be used which provide: easily comparable data, require minimal time of respondents, offer value in terms of quality and content, relevant to the situation, reliable, and address factors related to the needs activities and goals of the building users. Researchers recommend use of the PROBE POEs (Usable Building Trust, 2013). It must be noted PROBE POEs are geared towards non-domestic applications, however student mentality is also non-domestic as they are short-term occupants.

Further analyzing HE POE research Hassanain et al. (2010) outline indicators for faculty housing developments on campuses. They argue since housing developments on HE campuses are a major investment, performance evaluation should be undertaken to ensure quality of life and place are not compromised. The authors highlight the importance of getting feedback from facilities managers and community at large to facilitate incorporation of high quality features. It must be noted target occupants of faculty housing are very different from the student occupant demographic and mentality. Therefore indicators applicable in faculty housing applications, do not necessarily translate in student housing POE process.

Hassanain et al. (2010) propose a framework for the evaluation of university housing facilities including: (1) walk-through investigations, (2) organization of focus groups (3) interview of campus maintenance and planning departments (4) development of a questionnaire survey (5) public hearing sessions (6) analyzing data gathered and (7) recommending a range of time phased solutions for housing improvements. The framework addresses several indicators applicable in HE student housing: 1, 2, 3, 4, 6, 7, however 5 is inapplicable as it is cumbersome and likely not to be adopted by HE owners. The researchers also developed indoor and outdoor performance requirement indicators, addressing housing unit layout, visual comfort, thermal comfort and indoor air quality, finish systems and furniture and support services/utilities. They propose collection of data through qualitative and quantitative methods, facilitating triangulation of data. However the methods of data collection and specifics of what is being collected is not outlined in their study. For example examining thermal comfort "quality of air inside the bedroom space" is a very vague indicator, leaving the door open to wide interpretation of air quality parameters to be measured or tracked. Since the study is for faculty housing and not on residence halls, certain indicators such as "Appropriateness of the number of rooms to your standards of living" or "Amount of guest space/Family living space" are not applicable. As previously mentioned the selection of indicators to be measured and tracked is critical in developing a concise yet powerful and applicable POE framework.

Yang et al. (2010) researched indicator selection collection methodology and analysis. They selected a series of performance indicators for residential applications, based on a literature research and feedback from industry experts. They initially selected over eighty indicators further refined down to seventeen. Figure 8 outlines the refined list of indicators.

Order	Categories	Indicators
1	CT1. Building design	A1. Orientation of building
2		A2. Shape of building
3		A3. Outdoor environment
4	CT2. Performance of envelope	B1. Insulation of envelope
5		B2. Airtightness of envelope
6		B3. Outdoor and indoor shadow
7	CT3. Energy efficiency of building facilities	C1. HV&AC facilities
8		C2. Lighting facilities
9		C3. Water supply facilities
10		C4. Lifts
11	CT4. Building operation and management	D1. Operation schedule of shared facilities
12		D2. Qualification of building manager
13		D3. Energy efficiency knowledge training & advertisement
14		D4. Energy consumption statistics & public awareness
15	CT5. Comfort and health	E1. **Humidity of** indoor thermal environment
16		E2. Indoor lighting and acoustic environment
17		E3. Indoor air quality

Figure 8-Refined Final Indicators post Industry Experts Feedback (Yang et al. 2010)

As can be seen from Figure 8 the refined list is more acceptable for adoption versus the 80 indicators. As researchers Leaman and Bordass point out in their various previously discussed publications, the POE process must be easy to implement. Although this provides a good framework the list of indicators requires further clarity in exactly how parameters are to be collected and analyzed. For example the "comfort and health" category can be further refined into very specific indicators to be collected and analyzed.

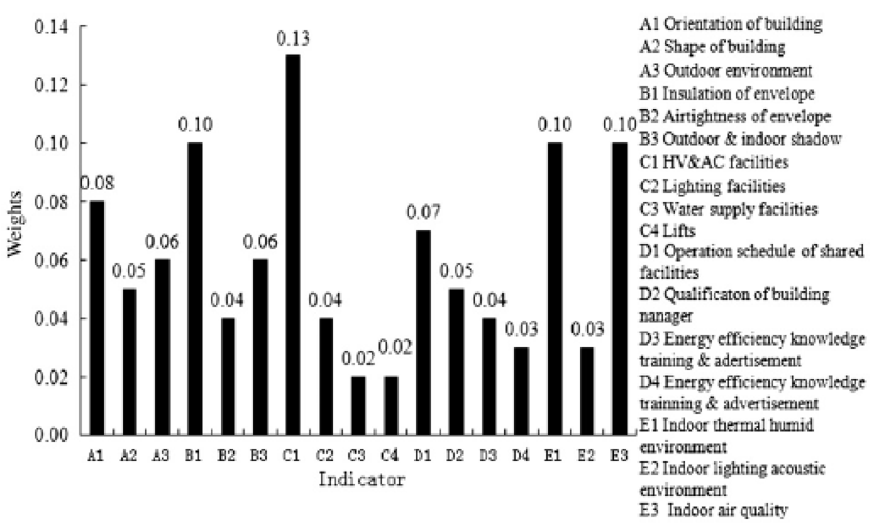


Figure 9-Weights of Indicators of Residential Building Energy Efficiency Assessment (Yang et al. 2010)

Yang et al. (2010) further developed weights for specific indicators through expert feedback. Per Figure 9 it is evident the largest weight is given to HVAC Facilities (C1), followed by a tie between Indoor thermal humid environment (E1), Indoor Air Quality (E3), Insulation of envelope (B1) and third place the orientation of the building (A1). Per Table 4 it is clear the educational component is not given high importance as it's at the bottom of the list.

Table 4-Indicators per Weighted Importance (Yang et al., 2010)

Indicator	Indicator Description	Weight
C1	HVAC Facilities	0.13
B1	Envelope Insulation	0.10
E1	Humidity of Indoor Thermal Environment	0.10
E3	Indoor Air Quality	0.10
A1	Building Orientation	0.08
D1	Operation Schedule of Shared Facilities	0.07
A3	Outdoor Environment	0.06
B3	Outdoor & Indoor Shadow	0.06
A2	Building Shape	0.05
D2	Building Manager Qualifications	0.05
B2	Envelope Airtightness	0.04
C2	Lighting Facilities	0.04
D3	Energy Efficiency Knowledge Training & Advertisement	0.04
D4	Energy Consumption Statistics & Public Awareness	0.03
E2	Indoor Lighting and Acoustic Environment	0.03
C3	Water Supply Facilities	0.02
C4	Lifts	0.02

Yang et al. (2010) outline the importance of certain indicators in the residential energy efficiency sector, however exact details as to the data to be collected and method of analysis is lacking. Their work offers a good starting point however not at the level of specificity required to actually carry out a POE in practice. A detailed refined collection and analysis methodology is required. The authors also do not discuss the various stakeholders' involvements (occupants, facilities managers, and owners), critical in a POE analysis.

Assessing indicators of highest concern to students, McGrath and Horton (2011) point out students are most concerned with disturbing noise coming from an external source (not residents of their neighboring rooms). They also highlight the benefits of POEs in improving the commissioning process, user requirements and management procedures. POEs also inform the design process and provide knowledge for design guides and regulatory processes.

Adewunmi et al. (2011) study carried out a POE of a postgraduate hostel at the University of Lagos in Nigeria. The researchers note student-housing facilities have been neglected in terms of POE studies and little research exists relating to these types of buildings. They selected 29 indicators based on a literature search, and an interview with a member of the university's hall management committee. Data was collected from facilities management and the university hostel coordinator, along with a user survey of the student occupants. The researchers selected to carry out an investigative in-depth

POE based on various indicators. Although they address some of the major categories of building performance such as: thermal, acoustic, and visual comfort, indoor air quality and fire safety. Several key indicators focused in sustainable rating systems such as: energy or water efficiency were missing from their indicator set. It is interesting to note, most student complaints were related to student out-of-pocket expenses to fix plumbing or electrical problems. Such problems do not exist in the US HE residence hall systems since student-housing costs are all inclusive; in fact student involvement in fixing damages is discouraged due to liability concerns.

Martani et al. (2012) carried out a study on two non domestic buildings on the MIT campus showing operation of heating, ventilation and air conditioning systems adhered more closely to other factors than occupancy. They were closely tied to external temperature, however there was a significant correlation between occupancy and electricity consumption. Occupancy accounted for over 60% of electricity consumption in each of the buildings studied. It must be noted researchers looked at two distinct types of buildings, a laboratory space and multi-use academic building (lecture space, offices and an open reception). The buildings were also built in different periods one in 1983 and 1970, resulting in different energy profiles. The researchers used wifi systems to track building occupancy to minimize electricity consumption. Rooms adjacent to each other communicate, to minimize wasted energy consumption by profiling occupancy trends. They suggest wifi system tracking can be used by facilities managers to accurately predict occupancy, hence intervening with building energy systems (BEMS) and improving energy efficiencies. The researchers suggest through the use of artificial intelligence (AI) systems and wifi connections, a holistic occupancy profile may be derived reducing wasted energy. However the question must be raised of how sustainable will these practices be if more control is given to systems versus occupants.

The next section explores studies related to specific indicators and their potential impact on sustainable practices. The indicator specific studies discussed in the next section include: energy efficiency, indoor thermal comfort, building automation control systems (BACS), building energy management systems (BEMS), artificial intelligence (AI), and adaptive strategies.

2.5 POE Indicator Specific Studies

Bordass (2000) indicates major components such as building airtightness and plant efficiency are widely overlooked. Owners who operate and maintain their buildings are interested in POEs, but many are also still trying to figure out how to do so. The researcher points miscommunication between designers and owners during the design process, result in poor building performance in practice. Building needs and occupant expectations must be clearly communicated. Erroneous estimations of occupant behavior by designers, compound the problem of poor performing buildings. Increased communication along with improved user profiles, through POEs can change the 'status quo'.

Mathews et al. (2001) discuss the possibilities of reducing energy consumption without jeopardizing indoor air quality through the use of automated control systems. Such systems can provide occupants a range of control options. They studied a mixed-use building composed of office space and lecture halls. They indicated a savings of 66% in yearly energy consumption by manipulating start-stop times.

Zagreus et al. (2004) point out only through POEs can we truly understand how a building performs in practice. They discuss how occupants are under-utilized in the process and therefore actual performance information is never collected. They recommend use of online surveys, which are easier to fill out, collect and analyze. The researchers indicate often designers, owners and key decision makers are hesitant to survey occupants in fear of expensive course correction measures. Split incentives and fear of litigation (Bordass 2006) between these groups obstruct POEs. However based on a study performed by Deuble and de Dear (2012) they found occupants are more willing to forgive imperfect indoor conditions in green buildings, in line with the findings of Leaman and Bordass (2007).

Abbaszadeh et al. (2006) carried out an extensive study (sample size of n=160 in the Center for the Built Environment (CBE) database versus LEED rated n=21) on indoor environmental quality of LEED and non-LEED certified office buildings. Their results show occupants of green buildings (LEED certified) were more satisfied on average with thermal comfort and air quality as compared to those in non-LEED buildings. An interesting note to be made is buildings newer than 15 years showed no statistical significance between LEED and non-LEED certified aside from the air quality category. Figure 10 and 11 outline the mean satisfaction score comparison across all CBE survey categories, and median and mean air quality satisfaction scores. Figure 12 outlines the median and mean air quality satisfaction scores as compared to new buildings only.

Mean satisfaction score	Database buildings: all (non-green)	Database buildings: age<15 (non-green)	LEED-rated / green buildings
Office Layout	0.95	1.03	0.94
Office Furnishings *	0.84	1.03	1.26
Thermal Comfort *	-0.16	0.17	0.36
Air Quality * ^	0.21	0.52	1.14
Lighting	1.12	1.16	1.08
Acoustics	-0.20	-0.01	-0.27
Cleaning and Maint…*	0.91	1.15	1.48
Overall Workspace *	0.84	1.03	1.13
Overall Building *	0.93	1.14	1.47
Number of buildings	160	35	21

* Difference b/w LEED-rated/green and the rest of CBE database is statistically significant.
^ Difference b/w LEED-rated/green and new buildings in the rest of CBE database (age<15) is statistically significant.

Figure 10- Mean Satisfaction Score Comparison across All CBE Survey Categories (Abbaszadeh et al. 2006)

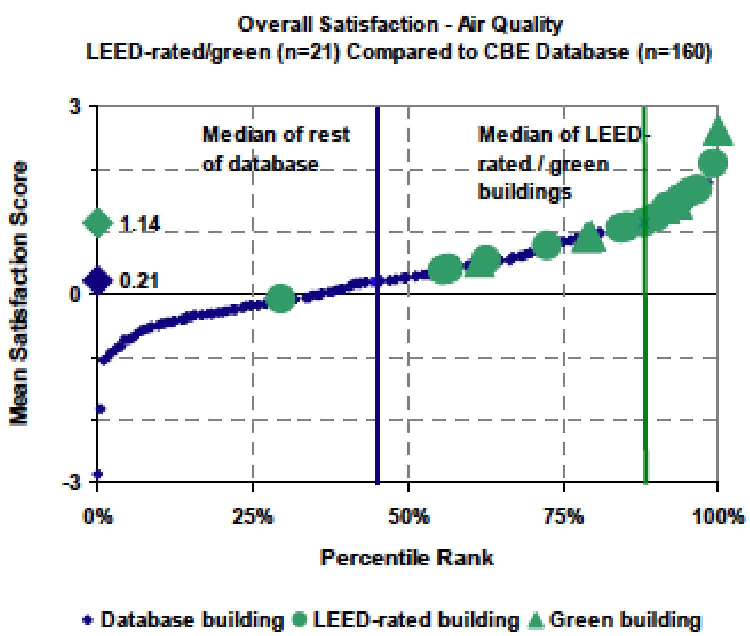


Figure 11-Median and Mean Air Quality Satisfaction Scores (Abbaszadeh et al. 2006)

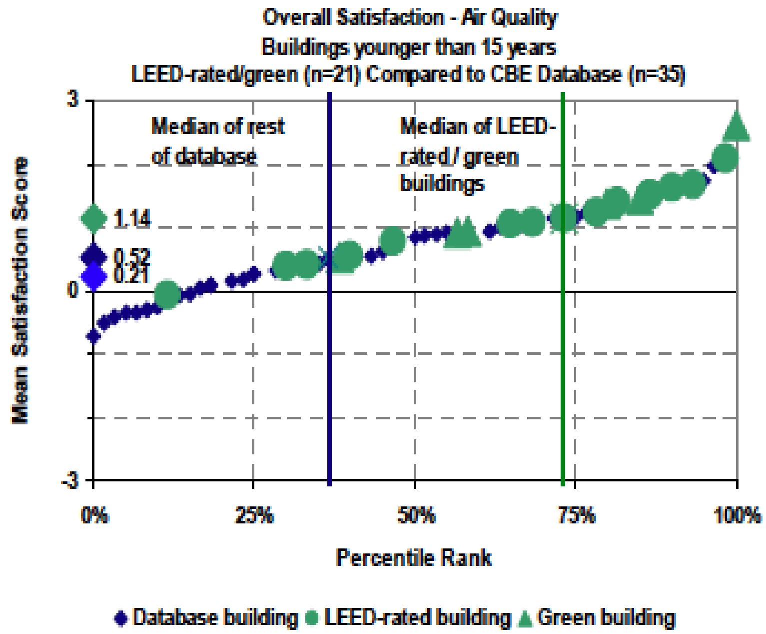


Figure 12-Median and Mean Air Quality Satisfaction Scores As Compared to New Buildings Only (Abbaszadeh et al. 2006)

Although their study was related to office buildings it is important to note their findings are critical in identifying and closing the performance gap. They highlight the gap between modeled and actual performance in sustainable buildings. These findings also stress the dire need for A/E professionals to learn from their buildings to improve their designs.

Gillespie et al. (2006) recommend tracking and metering systems. Systems including: Building Energy Management Systems (BEMS), graphical data displays, and commissioning and training of the operating personnel. They indicate the criticality of identifyng the information to be tracked early on in the design phase, when changes are easier, less expensive and have a higher chance of adoption.

Barlow and Fiala (2007) discuss the importance of adaptive comfort theories in reducing energy consumption and promoting sustainable practices in office buildings. Their key findings were that design guidelines such as the PMV models, did not accurately predict the thermal perceptions of occupants. The inability of heat balance models to fully explain surveyed responses, indicates further POEs need to be carried out. POEs would fine-tune design assumptions, and ensure occupant satisfaction. Adaptive strategies such as operable windows are simple, yet highly influential in changing energy consumption patterns; they are also the least expensive, and complicated. Their findings showed office worker respondents voted positively for active adaptive strategies such as opening windows; and manually controlled external shading for controlling solar glare and gains.

Brager and Baker (2009) carried out a POE surveying occupant satisfaction in mixed-mode buildings as compared to conventional buildings in the CBE database. Their sample was mainly office buildings, with the inclusion of several educational buildings. Their findings indicated occupants were on average more satisfied with thermal comfort conditions of mixed-mode buildings than non-mixed mode.

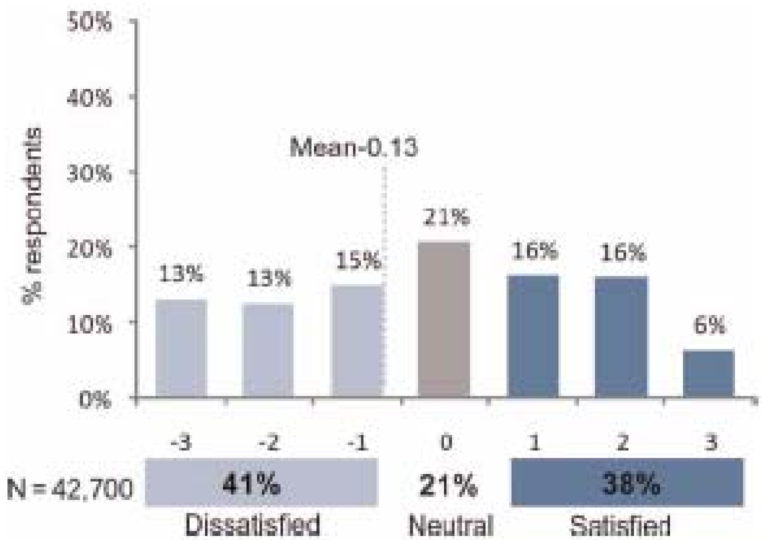


Figure 13-Thermal Satisfaction by Individual, Non-Mixed Mode Buildings (Brager and Baker 2009)

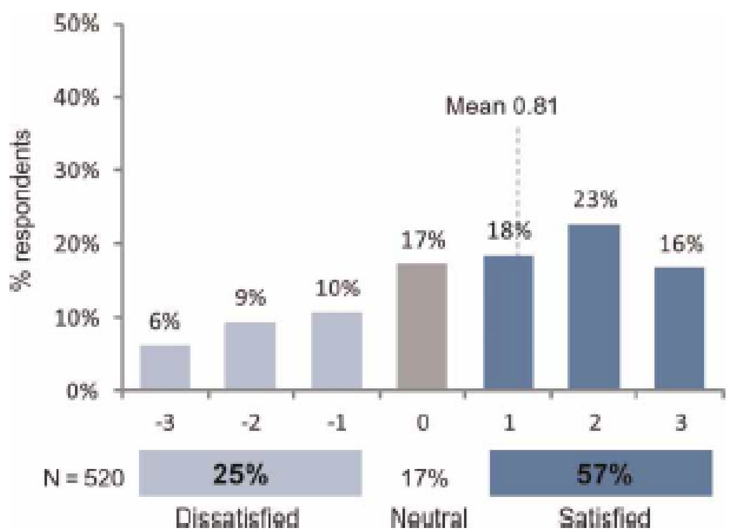


Figure 14-Thermal Satisfaction by Individual, Mixed-Mode Buildings (Brager and Baker 2009)

Even though there was an improvement in thermal satisfaction in mixed-mode buildings (sustainable strategies), the 25% dissatisfaction rate was still high. Based on Figures 13 and 14, it is evident American Society of Heating Refrigerating and Air conditioning Engineers (ASHRAE) standard 55's 80% satisfaction acceptability threshold is not met in both cases of mixed and non-mixed mode buildings.

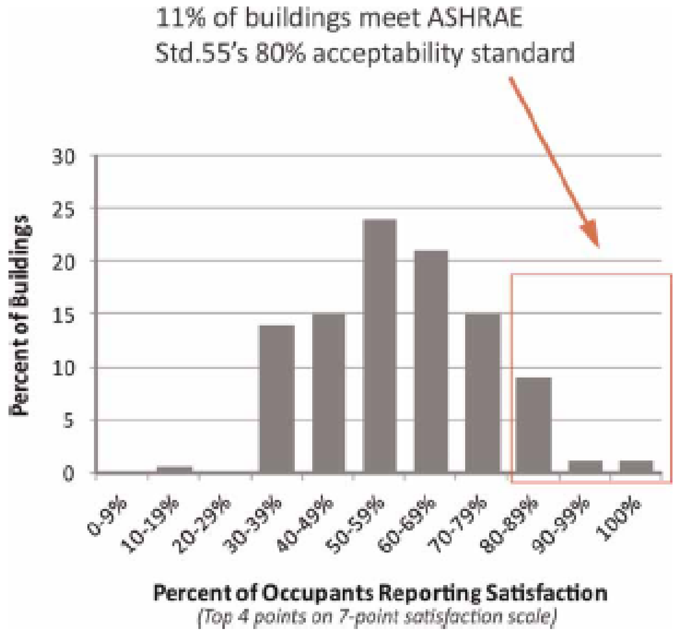


Figure 15-Thermal Satisfaction by Building (Brager and Baker 2009)

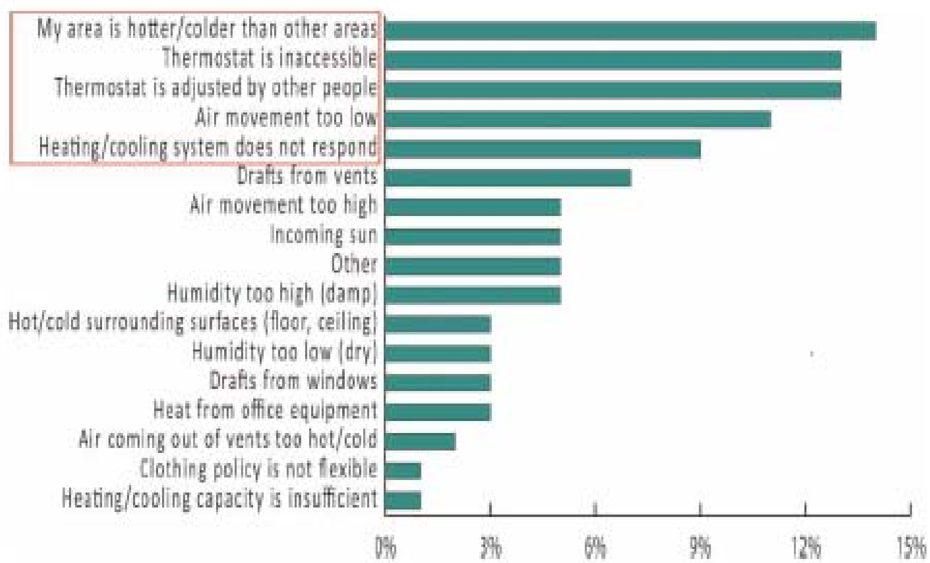


Figure 16-Top Reasons for Thermal Dissatisfaction (Brager and Baker 2009)

Per Figure 15 and 16, a large number of buildings do not provide occupants with acceptable thermal comfort conditions. This large gap between actual and modeled building conditions indicates perhaps ASHRAE standard 55 requires modification. With POEs and added case studies strong scientific arguments can be made to amend current standards and meet occupant needs. The most common thermal comfort problems were related to low air movement causing stale and smelly air, this was of particular interest since ASHRAE standards are focused on minimizing air movement and drafts. The researchers highlight the importance of POEs and occupant feedback to gain valuable insight into how buildings are actually performing in practice. They indicate to bridge the performance gap, POEs are critical to understand occupant needs their interactions with buildings.

Toftum et al. (2009) studied the energy consumption in two different types of buildings in Singapore one with active cooling and one with passive strategies. They found no significant energy consumption or significant complaints by those who experienced higher temperatures in the passive building, even though the differential between the two were vastly different. They attributed this finding to the 'forgiveness factor' previously mentioned (Leaman and Bordass 2007, Deuble and de Dear 2012). Since occupants were not used to strict climate control in the naturally ventilated space, they were not as harsh in their critique of the conditions. Their research highlights the possibility of designing more naturally ventilated or mix-mode buildings to promote sustainable practices.

Thomas and Rao (2009) also discuss the importance of POEs and impact on energy consumption. They state POEs have the power of informing A/E members of problem areas and highlighting the need for course correction. To minimize consumption and understand performance they recommend sub-metering, and calibration of BEMS systems.

Berker et al. (2011) carried out a study on the user evaluation of sustainable buildings looking at parameters such as indoor climate, mechanical operation, user attitudes and general satisfaction. They highlight ultimate performance of a building is reliant on users. They indicate simulation tools do not model reality sufficiently, therefore there is always a gap between modeled and actual performance. Simulation tools do not capture problems experienced by the occupants, POEs should be carried out to calibrate buildings based on actual performance. Occupants evaluate thermal conditions contextually, hence their feedback is critical in understanding why the building may be performing poorly.

They found eventhough studies suggest occupants of sustainable buildings are more satisfied than conventional buildings, problems and frustrations are still present in sustainable buildings. Adopting feedback mechanisms can higlight these frustrations and ensure mistakes are not repeated in future designs. They state three additional ways building evaluations may be improved: (1) inclusion of the buildings social context (user expectations) in the analysis, (2) extension of evaluations to include architectural and aesthetic qualities, and (3) an in-depth study of the training and information in the daily operation of energy-efficient buildings, and understanding in operating complicated energy systems by facilities personnel.

Choi et al. (2012) carried out a detailed survey of twenty office buildings in the US recording indoor environment parameters, and distributing user questionnaires measuring user satisfaction. Some of their key findings were: (1) significant thermal dissatisfaction between the genders during the same cooling season, (2) occupants older than age 40 were more satisfied with their thermal environment in all seasons, compared to the ones under 40, (3) occupants located in the perimeter zones were more satisfied, (4) in the past indoor environmental quality (CO, CO_2, VOCs, total particulates and relative humidity) has been treated part of thermal comfort, however significant differences in CO_2 concentrations were dependent on air velocity. The higher the air velocity the lower the CO_2, and (5) amongst the environmental qualities of office buildings thermal quality was of the highest importance to occupants and their satisfaction. Their findings are based on 50% of the respondents being dissatisfied with their thermal comfort. It must be higlighted that based on ASHRAE Standard 55, a 20% dissatisfaction rate is acceptable. Their findings fortify the findings of Abbaszadeh et al. (2006) and support the arguments that ASHRAE Standard 55 requires re-examination.

Klein et al. (2012) suggest reducing energy consumption through installation of artificial intelligent (AI) agents, to collect occupant behavioral data and create comfortable conditions. They note since we spend most of our time indoors building conditions have a greater impact on our productivity, learning, health and happiness. They proposed the architecture of a system of sensors and programs to predict behavior and adjust HVAC systems accordingly. Based on their experiment a 12% reduction in energy consumption and 5% improvement in occupant comfort were realized when compared to the baseline control case. However these are small percentages and it begs the questions can we attain such improvements through simpler methods. Perhaps we can reduce consumption through implementation of simpler and less expensive adaptive strategies. Another question their study highlights is whether facilities personnel easily understand these systems. To address some of these questions we need to first understand how facilities departments are dealing with their current levels of automation through POEs.

Yang and Wang (2013) carried out a similar study as Klein et al. (2012) focusing on the creation of a multi-agent intelligent control system to interact with occupants by responding to their requests and obtaining feedback based on their behaviors. The researchers concluded these systems are easy to configure, and new agents may be added without interfering in the operations of the whole system. However it must be noted the level of sophistication required to 'configure' and analyze these multi-agent intelligent systems may require a new breed of FM personnel.

Nguyen and Aiello (2013) studied the relationship between behavior and energy consumption. They found energy unaware behavior can add 33% to the modeled energy consumption of a building. The researchers discuss building energy and comfort management systems (BECMS), control systems used for individual buildings or groups of buildings using computers and distributed microprocessors for monitoring. Such systems intend to fulfill occupants' requirements for comfort while reducing energy consumption. Their study highlights potential energy savings of 40% in HVAC and lighting energy consumption of buildings, through installation of intelligent agents. They indicate to save energy static assumptions made in design, should not be considered. Instead the building should be viewed as dynamic system, constantly recalibrated based on how it is being used and by whom. Behavior tracking and trending is a relatively new area therefore more studies should be done on sensor architecture and behavior forecasting techniques.

An indicator widely overlooked in the context of HE institutions, but intensely stressed by authors of The Sustainable University (Sterling et al. 2013) is the education of occupants in HE applications. The authors highlight the ability of HE's in changing and molding mindsets and behavior. The education of occupants to encourage sustainable behaviors is critical. Hence the education indicator is a pertinent component of the HE contextualized POE framework. The Sustainable University (Sterling et al. 2013) highlights the need for awareness programs on HE campuses to help change and mold students into a fresh new way of thinking and eventually behavior.

Studies mentioned in this and preceding sections indicate the importance of various parameters in POEs. Occupant feedback and behavior play a defining role in sustainability in practice. The various studies highlight that a comprehensive POE must include technical and non-technical parameters allowing for triangulation of data.

It must be noted additional studies have been incorporated in the various indicator specific results sections of this report.

2.6 Literature Review Overview

LEED, BREEAM, CASBEE, LBC, and Green Globes are the most widely internationally adopted rating systems. LEED, BREEAM, CASBEE, and Green Globes are based on a point system, while LBC is based on actual post occupancy performance, and attainment of zero-net water and zero-net energy. LEED, BREEAM, Green Globes and CASBEE place the highest importance on energy efficiency at 32%, 19%, 38% and 20% respectively but do not mandate occupant feedback. It is important to note focusing on energy efficiency and water consumption as a measure of sustainability is a limiting view. But also from the review of sustainability-rating systems, it is evident the design categories holding the most importance (energy, water efficiency and indoor environmental quality) are influenced by occupants, their perceptions and behaviors in the operations phase. Occupant behavior and perceptions can have an impact of 55%, 40%, 66.5% and 42.5% on performance outcomes in LEED, BREEAM, Green Globes and CASBEE respectively yet none of these rating systems mandate POEs.

In a study comparing responses of 42,700 occupants in mechanically ventilated buildings over 40% were dissatisfied with their thermal comfort. This resulted in less than 11% of studied buildings meeting ASHRAE standard 55, which defines the range of indoor thermal environmental conditions acceptable to at least 80% of occupants (Brager and Baker 2009). Major complaints were related to discomfort with temperature, lack of thermal control over their environment and unresponsive heating ventilation and air conditioning (HVAC) equipment.

Occupant behavior and perceptions of their indoor environment have a large impact on sustainability in practice (Leaman and Stevenson 2010). If occupants are provided more control and knowledge over their environment, there is a higher chance of sustainable behaviors in practice (Stevenson and Leaman 2010). Therefore it is possible to lower occupant energy consumption with feedback mechanisms and education (Brown and Cole 2009, Stevenson and Leaman 2010, Streimikiene and Volochovic 2011, Zalejska-Jonsson 2012, Sterling et al. 2013).

Facilities management (FM) personnel are also instrumental in guaranteeing sustainability goals are met in practice. FM personnel can ensure sustainability through on-going commissioning and routine maintenance. In cases where advanced systems such as building automation control systems (BACS), building energy management systems (BEMS), and artificial intelligence (AI) systems are adopted FM personnel should be able to adjust systems to minimize energy consumption and ensure occupant thermal comfort. For example, manipulation of HVAC equipment start-stop times can provide savings in the range of 30-60% in energy consumption (Mathews et.al 2001, Nguyen and Aiello 2013). AI systems can also reduce energy consumption, through the collection of occupant behaviour to calibrate HVAC equipment. Such systems can create comfortable indoor conditions, while reducing wasteful energy consumption (Klein et. al 2012, Yang and Wang 2013, Nguyen and Aiello 2013).

Based on studies discussed above, a lack of clarity on the selection of performance indicators and methods in collecting and analyzing POE data of certified sustainable HE residence halls exists. The problem of sustainable building performance is ever more pressing since there is high variability in the results of researchers as to how well sustainable buildings are actually performing in practice. As noted in section 1.2 *'Sustainability Rating System Studies',* there is a heavy focus amongst sustainability rating systems on energy, water and indoor environmental quality measures; however none of the rating systems require POEs to ensure design intent is met, and occupant satisfaction is achieved. Researchers also highlight sustainable buildings must be viewed as a whole system.

The contributions of the researchers discussed in section 1.4 *'POEs General Applications',* highlight the benefits of POE analysis by involving the owners, facilities managers, and occupants. They discuss the power of POE analysis as a diagnostic tool for the evaluation of building performance. Researchers also caution POE methods must be simple and building typology specific. The researchers highlight industry split incentives have inhibited adoption of POE processes. However POEs are the key to improving the 'status quo', and establishing 'best practices' and 'lessons learned'.

Focusing on HE Applications of POE in section 1.5 *'POEs Higher Education Application',* the work of the various researchers dictate the need for the development of a student residence hall specific POE framework. The lack of selected performance indicators related to student residence halls and feedback methodologies, highlight the need for their development. As previously noted in the introduction student residence halls hold the largest median area of newly constructed buildings (Princeton Review 2012); therefore their importance is ever more pronounced in ensuring sustainable performance. This research bridges the performance gap between modeled performance and actual performance of LEED certified HE residence halls; by creating feedback processes for HE owners to implement. The feedback mechanisms include: occupants, facilities management personnel, residential life, actual consumption data and thermal logging. This constructs a holistic building performance picture, through the triangulation of qualitative and quantitative data between stakeholders. The POE framework proposed herein will shed light on the sustainability of LEED HE residence halls in practice.

3. POE Framework Methodology

3.1 POE Indicator Selection Methodology Summary and Stakeholders

The methodology followed for the selection of POE indicators entailed a literature review of widely adopted sustainability rating systems and published scientific studies and papers. The research covered areas including: POEs in general applications (non-residential and non-academic specific), POEs in HE applications, stakeholders and building performance, and impact of specific technologies on building performance (i.e. artificial intelligence (AI), building automation control systems (BACS) and building energy management systems (BEMS)).

Selection of POE indicators is based on: (1) level of importance in: widely adopted sustainability rating systems, scientific studies and papers, (2) applicability in: post occupancy phase, higher education context, reduction in water and energy consumption, promoting sustainable HE and student behaviors, and ensuring occupant thermal comfort, and (3) actual feedback from occupants.

The considered rating systems include: LEED (Global and US-USGBC 2009), BRE Environmental Assessment Method (United Kingdom-BREEAM 2008), Comprehensive Assessment System for Built Environment Efficiency (Japan-CASBEE 2010), Living Building Challenge (Global and US-LBC 2012), and Green Globes (Canada 2012).

Indicators impacting overall performance not addressed in sustainability rating systems, but highlighted in scientific literature were also included (i.e. occupant behaviour and education, consumption feedback mechanisms, and facilities management feedback).

Depending on the type of POE indicator, its associated data requires quantitative and/or qualitative techniques. Qualitative data collection techniques include face-to-face and online surveys, tied to likert 7-point scales and open-ended questions. Quantitative data collection methods involve the collection of actual data through billing information, meter readings, physical measurements, design documents (plans and specifications) and finalized LEED documentation.

To create a comprehensive building performance picture the involvement of key stakeholders is considered critical. Key stakeholders targeted for POE collection include designers, facilities management and residential life personnel, and occupants.

The data to be collected from designers includes design (plans and specifications), and finalized LEED documentation (baseline and design case documentation calculations/assumptions). Design documents provide the basis and assumptions for the design and detailed data on incorporated features (i.e. low flow fixtures, window sensors, increased ventilation and advanced controls). LEED documentation provides the baseline (non-sustainable) and design (sustainable) cases, to be used for comparison to actual data and benchmarking.

Facilities Management (FM) personnel provide actual consumption data through metering/billing information of water and energy, and operational feedback via a face-to-face short survey. The short survey provides insight as to whether the residence hall has met design intent in practice, highlighting key areas of concern.

Residential life personnel document student number, gender split, operational days, and any complaints or concerns reported by student occupants. To compare actual consumption data to submitted LEED documentation, it is fundamental to collect the mentioned data in order to develop accurate benchmarking metrics.

Occupant feedback provides invaluable information on the human interaction with the building. Occupants can shed light on issues related to daily use of the residence hall (i.e. faulty or hard to understand controls and thermostats, poor ventilation, leaky building envelopes, and their perceptions of thermal comfort), which can further be analyzed by actual measurements and eventually fixed to reduce waste (Cicelsky et al. 2009, Stevenson and Leaman 2010, Gram-Hanssen 2010, Streimikiene and Volochovic 2011, Sterling et al. 2013). Occupants are the least used resource; their feedback can be critical in promoting sustainability in practice. It can also highlight design features to be avoided in future designs.

3.2 Selected POE Indicators and Data Collection Methods (POE Indicators 1-12)

Based on the review of various rating systems, published scientific research discussed in previous sections and the results of the student survey, a series of POE indicators were selected. These POE indicators have the potential to reduce energy and water consumption, promote sustainable occupant behaviors, ensure occupant thermal comfort (indoor air temperature and humidity) and provide indoor sound comfort.

The selected POE indicators are: (1) water, (2) electricity and (3) gas consumption, (4) on-site renewable energy generation and use, (5) building systems commissioning, (6) monitoring of indoor air temperature and humidity, (7) occupant satisfaction with controllability of systems-temperature and humidity, (8) building controls ease of use, (9) routine preventative maintenance for HVAC systems and building enclosure, (10) education efforts by HE owners to promote sustainable occupant behaviors (Education Indicator), (11) optimization of BACS, BEMS and AI. The collection of data for indicator 11 is reliant on whether the building has implemented such advanced systems, and (12) indoor sound insulation indicator, resultant of student comments.

Indicators 1-6, 9 and 11 require the involvement of designers and FM personnel to gather actual data. Indicators 1-4 may be collected through meter readings and billing data. Data from indicators 1-4 can be used to compare actual values to finalized LEED documentation from designers, informing them if their design assumptions are valid. For example this information can highlight monthly and yearly trends in consumption and aide in forecasting resource needs. Furthermore this information can be used to stabilize consumption loads resulting in lower utility bills and contracts. It can also help in the development of course correction measures by designers and FM personnel.

Indicator 5 provides insight into the commissioning process and any HVAC problems, which may have translated into the operational phase of the residence hall. Commissioning information available through the designers and FM personnel sheds light on actual energy consumption values experienced and potential issues with indoor air quality (temperature and humidity).

Indicator 6 focuses on indoor temperature and humidity tracking and measurement, to ensure occupants are satisfied with their indoor air conditions. It may be collected through BACS if adopted or actual field measurements. Indicator 6 data can be compared to standard ASHRAE 55-2013, checking validity of the standard in practice and whether course correction measures are required.

Indicator 9 ensures residence hall envelope and HVAC systems are performing as intended. For example if window sensors have been incorporated to shut off HVAC systems when windows are open, this indicator can ensure such design features are actually delivering on their intended outcomes.

Indicator 10 requires the active involvement of residential life personnel and the HE institution as a whole, to inform occupants of sustainable behaviors. Indicator 10 can be implemented through monthly workshops, informational flyers and emails on sustainable behaviors. Such practices can be adopted to minimize consumption and promote sustainability in reality. An example is turning of the faucet while brushing teeth, and closing windows when HVAC equipment is turned on. Such minor educational efforts increase sustainability awareness and push the sustainability agenda into the forefront of issues on campus. Often comments and concerns are raised to residential life personnel first, followed by the involvement of FM personnel. Therefore collecting data from residential life personnel also allows triangulation of data between FM personnel, and occupants.

Indicator 11 addresses the customization of BACS, BEMS and AI in tracking, measuring and reducing energy consumption. Manipulation of HVAC start-stop times along with space utilization programming can be done through these systems, to minimize energy consumption and model occupant behaviour. This indicator can highlight whether these systems are being manipulated or customized. Often times when these systems are not customized they may result in wasteful consumption.

Indicator 12, indoor sound insulation, was added to the POE indicator framework due to student survey results in this study. It entails actual measurements and a student survey on whether indoor sound conditions are comfortable. This indicator examines sound travel between bedrooms, bathrooms and between floors. Given the academic setting, indoor sound travel and comfort is very important.

Table 5 outlines selected POE indicators requiring quantitative data collection methods, researched authors highlighting the specific indicator and key stakeholders to collect data from.

Table 5-POE Indicators requiring quantitative data collection methods

Selected POE Indicator	Researched Authors highlighting the Indicator	Data Collection Method	Key Stakeholders for Data Collection	Report Section
Resource Consumption: (1)*Water (2)*Electricity (3)*Gas	LEED, BREEAM, CASBEE, LBC, Green Globes Augenbroe & Park, 2005 Fowler et al., 2005 Gillespie et al., 2006 Woods, 2008	Metering/Billing Data (Monthly/Quarterly)	Designers & Facilities Management (FM) Personnel	(1)*Water Study: 4.1 (2 & 3)*Energy Study: 4.2
(4)*On-site renewable energy generation	LEED, BREEAM, CASBEE, LBC, Green Globes	Metering/Billing Data (Monthly/Quarterly)		(4)*Energy Study: 4.2.3.2
(5)*Building Systems Commissioning	LEED, BREEAM, CASBEE, LBC, Green Globes Fowler et al., 2005 Yang & Yao, 2010	Commissioning Process Documentation		(5)*FM Feedback: 4.5.2.1
(6)*Monitoring of Indoor Air Temperature and Humidity	Augenbroe and Park, 2005 Fowler et al., 2005 Warren & Taylor, 2008 Choi et al., 2012	Building Automation Controls (BACs) Readings or Actual Measurements	FM Personnel	(6)*Thermal Logging Study: 4.3
(9)*Routine preventative maintenance program for HVAC systems and building enclosure.	Mathews et al., 2001 Fowler et al., 2005 Yang & Yao, 2010 Nguyen & Aiello, 2013	Process Documentation		(9)*FM Feedback: 4.5.2.3
(11)*Use of building automation control systems (BACS), Building Energy Management Systems (BEMS), and Artificial Intelligence (AI) to reduce energy consumption.	Mathews et al., 2001 Thomas & Rao 2009 Martani et al., 2012 Klein et al., 2012 Yang & Wang, 2013 Nguyen & Aiello, 2013	Survey of facilities management and BACS, BEMS, and AI System Manipulation Experiments. (Quantitative and Qualitative)		(11)*FM Feedback: 4.5.2.1
(12)*Student Survey Resultant Indicator: Indoor Sound Insulation	Student Survey based on comments	Student Survey And Actual Measurements (Quantitative and Qualitative)	Occupants	(12)*Student Survey: 4.4.2.3.7

*Numbers in parenthesis represent POE Indicator Numbers

Indicators 7, 8 and 10, are to be collected from occupants, through incentivized online surveys using the online platform SurveyMonkey.

Indicator 12, indoor sound insulation, entails actual measurements and a student survey on whether indoor sound conditions are comfortable. Previously noise conditions between the indoor and outdoor environment was asked in the survey, however future applications of this POE framework will incorporate questions related to indoor sound travel between bedrooms, bathrooms and between floors.

Table 6 outlines selected POE indicators requiring qualitative data collection methods, researched authors highlighting the specific indicator and key stakeholders to collect data from.

Table 6-POE Indicator requiring qualitative data collection methods

Selected POE Indicator	Researched Authors highlighting the Indicator	Data Collection Method	Key Stakeholders for Data Collection	Report Section
(7)* Occupant Satisfaction with Controllability of Systems-Temperature and Humidity	Zagreus et al., 2004 Lützkendorf & Lorenz, 2005 Turpin-Brooks & Viccars, 2006 Abbaszadeh et al., 2006 Warren & Taylor, 2008 Cicelsky et al., 2009 Steemers & Yun, 2009 Gupta & Chandiwala, 2010 Stevenson & Rijal, 2010 Deuble & de Dear, 2012 Choi et al., 2012	Survey-open ended questions, yes/no questions, and 7-point likert attitude scale questions.	Designers (LEED pursuits) and Occupants	(7)* Student Survey: 3.4 (4.4.2.3.2 & 4.4.2.3.3)
(8)* Building Controls Ease of Use (thermostat)	Brager & Baker, 2009 Leaman & Stevenson, 2010 Guerra-Santin & Itard, 2010	Survey-open ended questions, yes/no questions and 7-point likert attitude scale questions.	Designers (LEED pursuits), Occupants, & FM** Personnel	(8)* Student Survey: 3.4 (4.4.2.3.4)
(10)* Occupant consumption awareness education efforts by Higher Education (HE) Institution (owner) Education Indicator	Masoso, 2010 Brown et al., 2010 Leaman & Stevenson, 2010 Gram-Hanssen, 2010 Streimikiene & Volochovic, 2011 Zhun, 2011 Berker et al., 2011 Zalejska-Jonsson, 2012 Nguyen & Aiello, 2013 Sterling et al., 2013	Student survey, Designer survey, & HE Posted Programs	Occupants, Designer, & HE Institutional Programs	(10)* Student Survey: (4.4.2.3.6) & Water Study: 4.1 (4.1.4.2.1.1, 4.1.4.3.1.1, 4.1.4.3.2.1, 4.1.4.3.3.1, 4.1.5)

*Numbers in parenthesis represent POE Indicator Numbers
**Facilities Management

3.2.1 Detailed Indicator Methodology

For detailed methodology per POE indicator please refer to the specific report sections as outlined in Tables 5 and 6.

3.3 Selected Residence Halls

Three LEED-New Construction and one non-LEED residence hall have been selected to gather data for the development of the POE framework. For the purposes of anonymity the names of the residence halls and HE institutions have been withheld. The residence halls selected for the POE framework study include EH, CSC, PS, and WT. The individual methodology sections within the specific chapters of this report, provide pertinent residence hall information.

An additional five residence halls located in the Northeast were included only for the water study portion, labeled by the acronyms MH1, MH2, MH3, HH and KH. Please refer to the water study methodology section for specific details related to the non-LEED residence halls.

3.3.1 LEED Residence Halls

Residence halls EH, CSC, and PS are LEED Gold, Gold and Silver respectively. Table 7 outlines their respective age, number of occupants, residence hall percent female gender split, location and climatic building zone designation per US-DOE.

Table 7-LEED selected residence halls

Residence Hall	Age Yrs.	# of Occupants	Gender Split (% Female)	Location	Building Zone*
EH	5	232	F=31%	Northeast	Cold
CSC	3	450	F=53%	Northeast	Mixed-Humid
PS	3	622	F=44%	West Coast	Hot-Dry

*Based on United States Department of Energy (US-DOE 2013)

3.3.1.1 Residence Hall EH

EH is a singular five-storey residence hall, with its own gas, electricity and water meter. Table 8 outlines EH's data availability date, operational days per year per its submitted LEED template, operational days per the residential life calendar, total area, conditioned area, and ASHRAE climate zone per submitted LEED documentation.

Table 8-EH residence hall data

Residence Hall	Data Available From	Operational days per year*	Operational Days (Res. Life Calendar)	Total Area (Sq. m)	Conditioned Area**	Climate Zone***
EH	July 2008 (based on billing information)	305	215	15,088	8,304	Zone 5A

*Operational days per submitted LEED documentation

**Conditioned area per LEED submitted documentation (excludes unconditioned parking garage area)

***Climate zone per LEED energy calculations

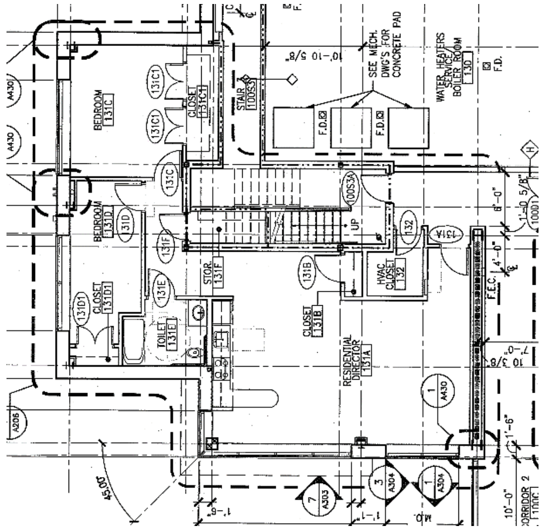


Figure 17-EH Two Bedroom Suite Layout

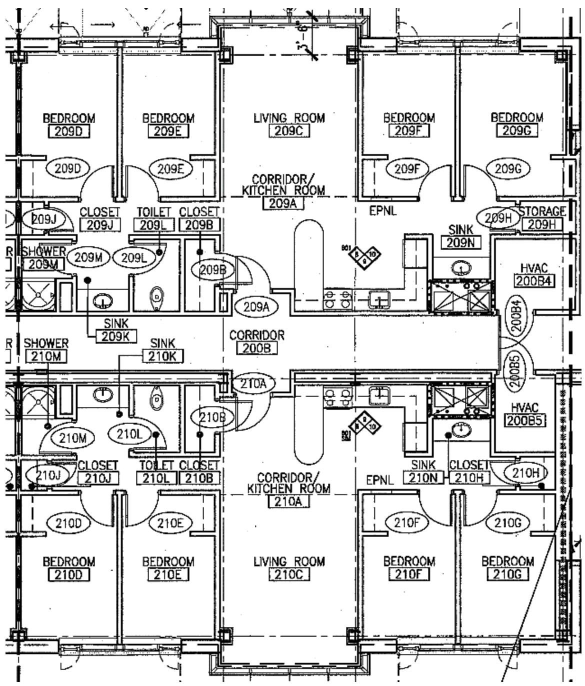


Figure 18-EH Four Student Singles Layout

EH suites are designed for four students per suite, with one thermostat per suite located in the living room. The layouts are depicted in Figures 17, and 18 respectively. The suites are equipped with a living room, kitchen, two sets of bathroom sinks and one bathroom.

3.3.1.2 Residence Hall CSC

CSC is comprised of two seven-storey residence halls located adjacent to each other. CSC halls share one meter for their gas, electricity and water meter. Per its LEED submitted documentation, it has been grouped therefore the total area comprises both buildings. Table 9 outlines CSC's data availability date, operational days per year per its submitted

LEED template, operational days per the residential life calendar, total area, conditioned area and ASHRAE climate zone per its LEED documentation.

Table 9-CSC residence hall data

Residence Hall	Data Available From	Operational days per year*	Operational Days (Res. Life Calendar)	Total Area (Sq. m)	Conditioned Area**	Climate Zone***
CSC	June 2010 (based on billing information)	360	216	16,427	16,427	Zone 4A

*Operational days per submitted LEED documentation
**Conditioned area per LEED submitted documentation
***Climate zone per LEED energy calculations

CSC suites offer varied living arrangements including: four students per suite or two double rooms, five students with five single rooms, and six students with three double rooms. More than half the rooms are single occupancy, their layouts are depicted in Figures 19, 20, and 21 respectively.

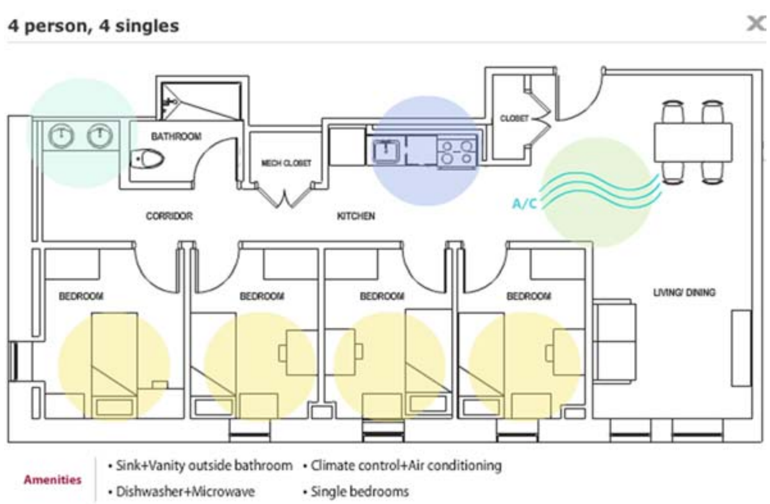


Figure 19-CSC Four Student, Four Singles Layout

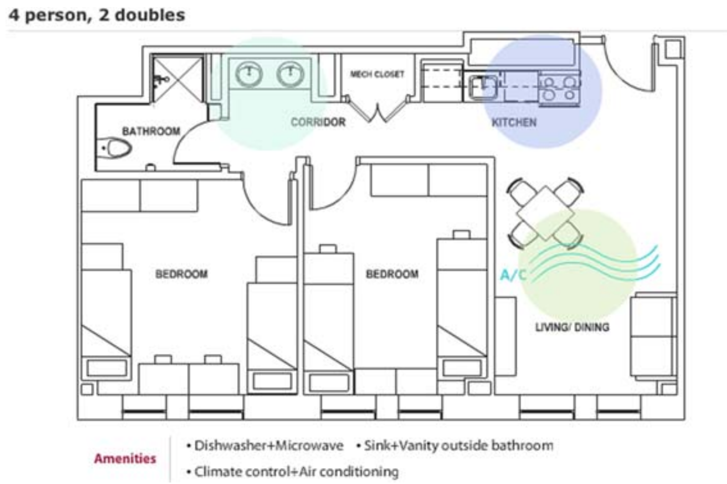


Figure 20-CSC Four Student, Two Doubles Layout

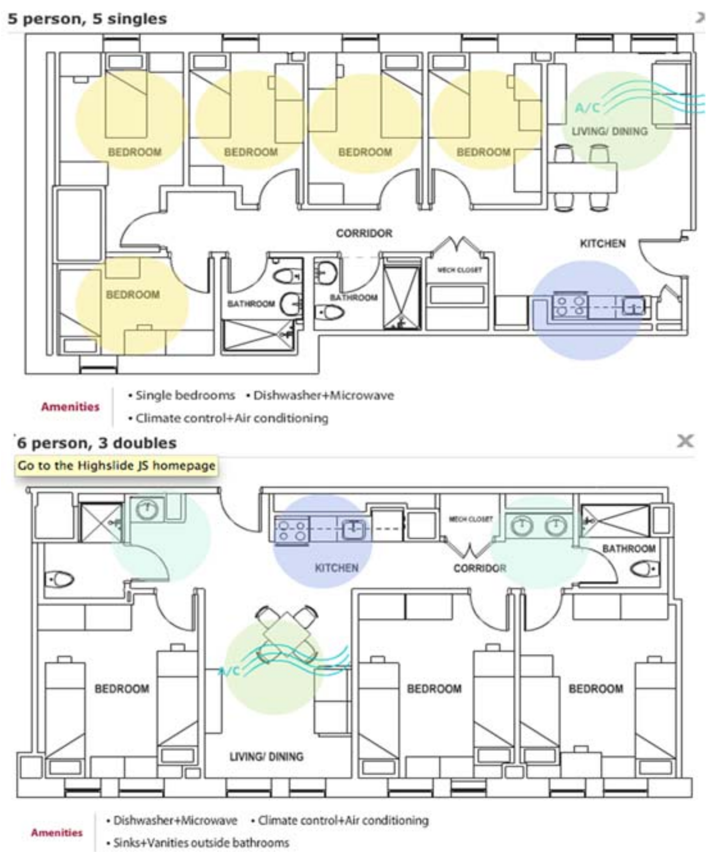


Figure 21-CSC Five Student, Five Singles and Six Student Three Doubles Layout

CSC suites are equipped with a living room, kitchen, varied sets of bathroom sinks and bathrooms. All layouts have one thermostat per suite, located in the living room.

3.3.1.3 Residence Hall PS

PS is comprised of three four-storey residence halls, which pursued LEED certification as a combined building. Table 10 outlines PS's data availability date, operational days per year per its submitted LEED template, operational days per the residential life calendar, total area, conditioned area, and ASHRAE climate zone per its LEED documentation.

Table 10-PS residence hall data

Residence Hall	Data Available From	Operational days per year*	Operational Days (Res. Life Calendar)	Total Area (Sq. m)	Conditioned Area**	Climate Zone***
PS	May 2010 (based on billing information)	250	250	21,976	20,743	Zone 9

*Operational days per submitted LEED documentation
**Conditioned area per LEED submitted documentation
***Climate zone per LEED energy calculations

PS suites offer varied living arrangements including: four and two students per suite. Their layouts are depicted in Figures 22 and 23 respectively. All layouts have one thermostat per suite, located in the living room.

Figure 22-PS Four Students per Suite Layout

Figure 23-PS Two Students per Suite Layout

PS suites are equipped with a living room, kitchen, varied sets of bathroom sinks and bathrooms. All layouts have one thermostat per suite, located in the living room.

3.3.2 Residence Hall WT

WT is non-LEED certified five-storey residence hall located on the Northeast, serving 475 students. It is 11 years old, and holds a female gender split of 18%. Table 11 outlines WT's data availability date, operational days per residential life calendar, total area, and ASHRAE climate zone designation.

Table 11-WT residence hall data

Residence Hall	Data Available From	Operational Days (Res. Life Calendar)	Total Area (Sq. m)	Climate Zone
WT	June 2009 (based on billing information)	365 Days	16,091	Zone 5A

WT suites offer varied living arrangements including: four and six students per suite. A typical floor plan is provided in Figure 24 below.

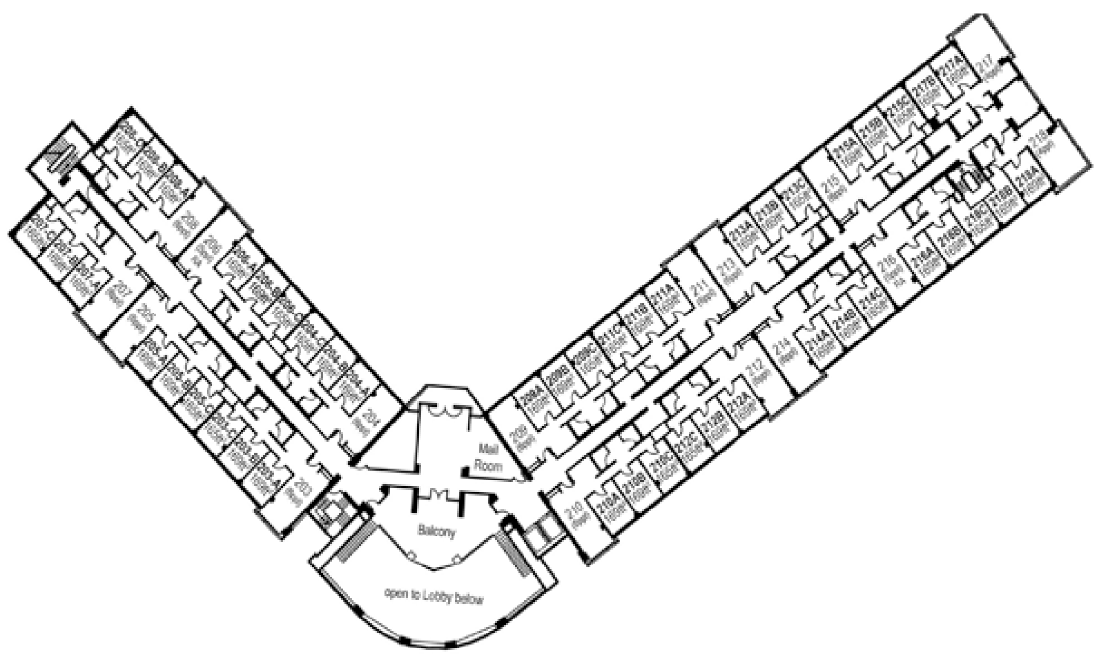


Figure 24-WT Typical Floor Plan

WT suites are equipped with a living room, kitchen, varied sets of bathroom sinks and bathrooms. All layouts have one thermostat per suite, located in the living room.

4. Results

4.1 Water Study (POE Indicator 1)

4.1.1 Introduction

In 2050, global population, water demand, and global gross domestic product should increase by 30%, 55% and 100% respectively (OECD 2012). By 2050 almost 70% of the world population is projected to live in cities, relying on public water supply (OECD 2012). As a result, future urban developments will further stress public water supply infrastructures.

Given less than 1% of the world water is fresh water and adapts to human use (ILFI 2011), future challenges of sustainable water consumption and recharge will become ever more pressing. The current state of water extraction from groundwater and freshwater sources have resulted in dramatic negative environmental impacts, such as water depletion, quality reduction, waterlogging, salinization, annual discharge reduction, and contamination of potable water sources (OECD 2012, EEA 2012). Excessive diversion of river waters has also led to lowering of ground water tables and saltwater infiltration in coastal areas (EEA 2012). These considerations require the promotion of sustainable water management and use. In particular, this study will focus on the opportunities available for student residence halls in the United States (US).

In the US, the United States Geological Survey (USGS) works in collaboration with local, state, and federal agencies to collect water-use data. USGS has several goals including: (1) analyzing source, use, and disposition of water resources at local, state, and national levels; (2) replying to water-use information requests from the public; (3) documenting water-use trends; (4) co-operating with state and local agencies on projects of special interest; (5) developing water-use databases; and (6) publishing water-use data reports outlining domestic (residential) water consumption from self-supplied (i.e. wells) and public-supplied (i.e. state agencies) sources. Domestic (residential) water-use typically includes: drinking, food preparation, washing clothes and dishes, flushing toilets, and outdoor applications include watering lawns and washing cars (USGS 2013).

In the last decade, almost every region in the US has experienced water shortages, and at least 36 US states have recently anticipated local, regional or statewide water shortages under non-drought conditions (Shi et al. 2013). Researches show that due to increases in water demand and droughts, water has not been recharged at sustainable rates (Shi et al. 2013). This points to the need to promote sustainable pathways, which consider population growth, climate change and water-use habits; to decrease risks of future water shortages and challenges in our ability to source water (The National Academies 2008, Shi et al. 2013).

From the total water withdrawn for all uses in the US, domestic water-use has an estimated value of 111.3 billion liters per day (USGS 2009). The consumption differs from 193 liters per person per day (LPD) in Maine, to 715 LPD in Nevada, with the national average at 375 LPD (USGS 2009). The Environmental Protection Agency (EPA) WaterSense program reports a similar average value of 379 LPD, of which 70% (265 LPD) is assumed for indoor purposes (EPA 2013).

Since this research is focused on water consumption in residence halls, it would be a misrepresentation to compare the residential case studies to residence halls, as they include outdoor water consumption values. A lack of uniformity in US water-use study methods and variables result in the inability to use available reports for comparisons (SIU 2002). Categorical disparities of residence halls (commercial or domestic) by USGS and United States Department of Energy (US-DOE) further complicate isolating water-use in residence halls (USGS 2009, US-DOE 2013). USGS does not explicitly categorize building types, resulting in ambiguity on whether residence halls fall under the commercial or residential dataset. Commercial water-use data was not collected by USGS in the 2000 and 2005 reports (USGS 2000, USGS 2009). However, in the 1995 report, below the commercial category, the following building typologies were identified: hotels, motels, restaurants, office buildings, 'other' commercial facilities, civilian and military institutions (USGS 1995). These building types are very different from residence halls and their water consumption values do not reflect indoor water-use purposes in residence halls. Residential values suggested by USGS seem more applicable to residence halls, although they include outdoor applications (watering lawns, gardening, and washing cars).

US-DOE categorizes residence halls under lodging, a commercial category. However, the US-DOE relies on the USGS datasets for water-use reporting per sector. Given the inconsistency between the USGS and US-DOE building categorization no explicit US data on indoor water consumption of residence halls exists.

Examining water consumption in the European Union (EU), between 60% and 80% of public supply water is used for domestic applications, of which personal hygiene and flushing account for 60% (Mudgal and Lauranson 2009). Case studies from different member states showed domestic water consumption of 168 LPD on average (Mudgal and Lauranson 2009).

The overall withdrawals in the EU are projected to decrease by almost 11% in 2020 (Floerke and Alcamo 2004). However, a major unknown variable of water use in EU is the domestic water consumption (Floerke and Alcamo 2004). Given the current increase in water consumption in urban area and the increasing effects of climate change, the Mediterranean river basins are continuing to create water stress (EEA 2012). These stresses pose threats to the availability of clean potable water, and might increase the need for more sophisticated wastewater treatment methods.

The European Community (EC) report on water-use does not explicitly categorize residence halls (Mudgal and Lauranson 2009). However, EC identifies educational buildings in the non-residential public sector, although there is a lack of water consumption data for this category.

Differences between EU and US study methodologies and building categorizations compound problems of isolating residence hall water consumption. To address this lack, this study assesses and compares the water consumption of several US residence halls. Different uses of water, such as washing dishes and clothing, flushing toilets, and showering have been taken into account (Vickers 2001, Schleich and Hillenbrand 2009).

Many factors influence water consumption such as geographical location, climate, culture, gender, and occupant behavior (Vickers 2001, Balling et. al 2007, Randolph and Troy 2008, Schleich and Hillenbrand 2009, Vinz 2009, Elliott 2013, Berardi 2013); to mitigate the effect of all these variables, the present study considers water related practices in several residence halls in the last ten years.

4.1.2 Sustainability Rating Systems and Water Efficiency Strategies

Voluntary sustainability rating systems including LEED (USGBC 2009), BRE Environmental Assessment Method (BREEAM 2008), Comprehensive Assessment System for Built Environment Efficiency (CASBEE 2010), Living Building Challenge (LBC 2012), and Green Globes (2012), recommend use of water efficient flow fixtures to minimize water demand. Guidance is also provided for the minimization of wastewater effluent into existing treatment infrastructures, by implementing onsite treatment strategies.

Some of the shared water saving strategies recommended by the rating systems and professional associations such as American Institute of Architects (AIA) and Royal Institute of British Architects (RIBA) include: low flow fixtures, dual flush toilets, ultra-low flow or waterless urinals, infrared sensors, timed automatic shut-off faucets, low water-use washing machines and dishwashers, rainwater catchment, greywater use, and on-site wastewater treatment.

On-site wastewater treatment can reduce the quantity of effluent treated in the public treatment infrastructures; reducing overall energy demands to treat, and transport effluent (AIA 2007, USGBC 2009, LBC 2012). Onsite treated water can be re-used within the building for non-potable purposes such as toilet flushing, minimizing demand from public water supply infrastructures. Various strategies might be implemented to accomplish secondary or tertiary level treatment of wastewater including anaerobic septic tanks, anoxic reactors, closed aerobic tanks with plants to filter gases, open aerobic tanks with snails, shrimp and fish, re-direction of sludge to septic tanks or composting of sludge, and redirection of polluted water to indoor wetlands for filtration (AIA 2007, ILFI 2011, LBC 2012). ‘Living machines’ are amongst the newest onsite water treatment strategies treating and filtering sewage to its natural unpolluted state (AIA 2007, ILFI 2011).

Table 12 outlines recommended water saving flow fixture efficiencies in liters per flush (LPF) for toilets and liters per minute (LPM) for showerheads, lavatory and kitchen faucets. As can be seen, difference between recommended efficiencies by rating system exist. In cases such as CASBEE and LBC, a prescriptive value is not provided and it is at the discretion of designers to select and specify the appropriate fixture technology to meet water saving target performance goals.

Table 12-Efficiencies of water saving flow fixtures

Rating system & Professional Best Practices	Toilet efficiency targets (LPF)	Shower efficiency targets (LPM)	Lavatory faucet targets (LPM)	Kitchen faucet targets (LPM)
LEED	≤ 6LPF	≤ 9.5 LPM	≤ 8.5 LPM	≤ 8.5 LPM
BREEAM	Dual Flush: ≤ 3 LPF (low) to ≤ 4.5 LPF (full)		≤ 6 LPM	2 Stage faucets with low flow for rinsing and higher flow for filling objects
CASBEE	Specific target values not provided.			
LBC	Specific target values not provided.			
Green Globes	≤ 6 LPF	≤ 9 LPM	≤ 7.5 LPM	≤ 7.5 LPM
AIA	≤ 4.9 LPF Dual Flush: ≤ 3.6 LPF (low) to ≤ 5.7 LPF (full)	≤ 6.6 LPM	≤ 3.8 LPM	≤ 7.6 LPM
RIBA	Specific target values not provided, suggested to refer to other reference sources including BREEAM.			

However, water efficient fixtures and treatment strategies alone may be insufficient to reduce consumption, as user behavior is critical in lowering overall water consumption (Stevenson and Leaman 2010). The collection of user feedback about water efficiency strategies in buildings and education on consuming less water, play a key role in realizing water efficiency strategies in practice. Active participation of users and post occupancy evaluations are significant to uphold sustainability in practice. Various researchers highlight the need to adopt education campaigns to promote more sustainable user behaviors (Stevenson and Leaman 2010, Sterling et al. 2013, Berardi 2013).

Some examples of organizations, agencies and programs promoting sustainable water practices include the Center for Neighborhood Technology (CNT), Nature's Voice-Our Choice, Water Use it Wisely, Save our Water, Stop the water while using me, and EPA WaterSense. These agencies and programs provide suggestions on water conservation and water saving strategies, and promote water efficiency through behavioral changes.

Design strategies and users are strongly linked in the process of making sustainability a reality (Stevenson and Leaman 2010, Berardi 2013, GhaffarianHoseini et al. 2013). A bridge between modeled design and actual outcome is represented by post occupancy evaluations (POEs). POEs ensure users are satisfied with their current conditions and inform future designs (Bordass et al. 2006, Stevenson and Leaman 2010, Bordass et al. 2010, Berardi 2012). Design strategy labeling can also be developed through the collection of user feedback further identifying which 'sustainable' strategies to promote or avoid in practice (Bordass et al. 2006, Berardi 2012).

4.1.3 Case Study Overview and Methodology

Three LEED and six non-LEED residence halls, varying from 3 to 62 years of age, comprise the studied dataset. The research methodology involved the collection of various specifications including: number and gender split of students served, flow fixture efficiencies, actual water meter readings, and LEED documentation pertaining to water efficiency (WE) credits in LEED certified residence halls.

Data was gathered from designers, facilities management departments and residential life offices of the various HE institutions. All residence halls are located in the US with eight in the Northeast, and one on the West Coast. For the purposes of anonymity, acronyms designate the residence halls. Table 13 provides main building data of the selected residence halls.

Table 13-Overview of residence halls (EH, CSC, PS, WT, MH1, MH2, MH3, HH, and KH)

Residence Hall	Rating	Age Yrs.	# of Users	Gender Split (% of female)	Location	Building Zone*
EH	LEED-Gold	5	232	F=31%	Northeast	Cold
CSC	LEED-Gold	3	450	F=53%	Northeast	Mixed-Humid
PS	LEED-Silver	3	622	F=44%	West Coast	Hot-Dry
WT	Non-LEED	11	475	F=18%	Northeast	Cold
MH1	Non-LEED	62	284	F=60%	Northeast	Cold
MH2	Non-LEED	52	190	F=49%	Northeast	Cold
MH3	Non-LEED	47	190	F=60%	Northeast	Cold
HH	Non-LEED	54	163	F=50%	Northeast	Cold
KH	Non-LEED	52	191	F=53%	Northeast	Cold

* Based on US-DOE 2013

Monthly actual water meter readings were collected for EH, PS, WT, MH1, MH2, MH3, HH, and KH and quarterly actual water meter readings for CSC. The average number of students served per year allowed calculating the liters per person per day (LPD) metric to compare water performance. EH, CSC, WT, MH1, MH2, MH3, HH and KH are located on the Northeast, experiencing cold to mix-humid climates; whereas PS is located on the West Coast, experiencing a hot-dry climate.

Typically, the peak water consumption occurs in summer (AWWA 1999). The weather in the US followed typical patterns in the years from 2002 to 2009, and in 2011 and 2013; reversely, in 2010, the coldest winter was experienced and in 2012 record summer heat and mildest winter was recorded (NWS 2013).

Flow fixture efficiency values were collected to highlight differences in technologies used between residence halls. Non-LEED flow fixture data was collected from the HE facilities departments, while for LEED residence halls WE documentation was collected from designers. Residence hall age was also recorded as newer ones are less likely to experience plumbing leakage related issues, and may have implemented higher efficiency fixtures.

Student feedback was also requested from four HE institutions, through the distribution of online surveys using the SurveyMonkey platform. The selected residence halls for student feedback included: EH, CSC, PS and WT. Surveys were administered through the collaboration of individual HE institution's residential life offices.

Residence EH was surveyed twice over a three year span. The first survey was administered in November of 2010 with a two week open survey window, while the second survey was administered in October of 2013 with over a three month open survey window. It must be noted that the second survey differed in question structuring to gain more detail and specificity as to the approximate minutes water is used in the shower.

All surveys were incentivized with a $50 sweepstakes per residence hall, facilitated through the SurveyMonkey Sweepstakes tool and in compliance with U.S. Federal Sweepstakes Laws. In the case of PS two $50 prizes were distributed. Weekly reminders were emailed to students via residential life personnel, to encourage participation in the survey. The email reminders included information related to: response rates to date, target response rates, purpose for taking the survey, and sender contact information in case of questions.

The survey collection dates differed due to academic institution and residential life schedules. In some cases residential life personnel also requested a delay in the distribution of this survey, due to their own internal student surveys. The survey collection periods are indicated in Table 14 along with total number of occupants, survey response rates, and gender split.

The response rate per HE institution differed with an average response rate of 34% for all institutions. The overall response rate was shy of ASHRAE 55-2013 requirements by 1%. Based on ASHRAE 55-2013 section 7.3.1. "Surveys of Occupant Responses to Environment" if more than 45 occupants have been selected a minimum of 35% response rate must be achieved. In an alternate study carried out by GreenerU hired by Brown University to carry out a Dorm Energy Efficiency Project (DEEP) a 25% response rate was achieved, indicating meeting the 35% ASHRAE response rate is a challenge even for industry professionals.

Table 14-Student survey details (EH, CSC, PS, and WT)

Residence Hall	Total # of Occupants	Survey Respondents 'n'	Survey Response Rate	Res. Hall Gender Split (% of female)	Survey Collection Dates
EH	232	82	35%	F=31%	10/21/2013 – 01/16/2014
CSC	450	162	36%	F=53%	10/21/2013 – 11/20/2013
PS	622	201	32%	F=44%	11/24/2013 – 01/06/2014
WT	475	148	31%	F=18%	10/21/2013 – 01/16/2014

The student survey was subdivided into several sections, and questions were developed based on parameters included in the LEED rating system and scientific literature within this report. Table 15 outlines the various vote collection methods employed per survey question related to this study.

Table 15-Survey vote/response collection methodology

Student Survey Question	Vote Collection Method
% Showering daily, twice a day, and every other day	Multiple choice selection with provisions for additional comments
Approximate minutes water is run when taking a shower.	Multiple choice selection with provisions for additional comments
Approximate number of toilet flushes per day	Multiple choice selection with provisions for additional comments
Frequency of thinking about water consumption	6 Point Likert Scale: 1= never, and 6=always
% Indicating presence of conservation awareness programs on campus/res. hall	Yes/No with provisions for additional comments
% Indicating participation in conservation awareness programs on campus/res. hall	Yes/No with provisions for additional comments
% Participation in Awareness programs on campus/residence hall	Yes/No with provisions for additional comments
% Indicating a change in their energy and water consumption behavior from awareness programs	Yes/No with provisions for additional comments

Statistical Package for Social Sciences (SPSS) version 19 was used to analyze the survey responses collected. Multi-variable linear regression was carried out for the various survey questions using single-tailed significance testing, both in stepwise and non-stepwise methods to identify independent variables with the largest impact on dependent variables. Collinearity was examined through the examination of variance inflation factors and scatterplots (graphing regression standardized predicted values and regression standardized residual values). This examination ensured no one variable's impact has been misrepresented in the findings. The strength of each independent variable was observed in relation to its beta coefficient, t-distribution and significance test. The beta coefficient represents the estimate of average number of standard deviation (SD) changes in the criterion that will result in a change in one SD of the dependent variable. The lower the beta coefficient of an independent variable the weaker is the variable's role in the regression model. Values from the t-distribution and significance test provide for the constant and regression coefficients. They further indicate the strength if dependent-independent variable relationships.

When carrying out the multi-variable linear regression using SPSS the responses with missing values were not considered. The cases analyzed were based on responses with no missing values for any variable, therefore the sample size analyzed for the regressions are notated below in Table 16. The instances where variables were unanswered by respondents occurred for the following: shower duration, number of toilet flushes, behavioral impact from awareness programs, and frequency of cognizance about water consumption.

Table 16-Multi-variable linear regression sample size cases analyzed (EH, CSC, PS, and WT)

Residence Hall	Survey Respondents 'n'	SPSS Cases Analyzed 'n'
EH	82	73
CSC	162	147
PS	201	176
WT	148	131
Totals	**593**	**527**

4.1.3.1 Engineer's Metrics

The International and Uniform Plumbing Codes do not require designers to calculate total water consumption of buildings (ICC 2009, IAMPO 2009), hence engineer's metrics were developed based on two separate reports: the EC report providing European metrics (Mudgal and Lauranson 2009) and the AWWA report, providing guidance on US metrics (AWWA 1999).

The AWWA report values are based on data from over 1000 households in 12 study sites around the US. The data includes historic billing records and detailed mail surveys, broken into two sets to capture winter and summer indoor water consumption. The AWWA water end-use findings are: 70 LPD for toilet use, 57 LPD for clothes washer, 44 LPD for shower use, 41 LPD for faucet use, 36 LPD for leaks, 5 LPD for baths, 4 LPD for dishwasher, and 6 LPD for other domestic use (AWWA 1999). In calculating the comparative AWWA metric, the value applicable to residence halls was assessed to be 212 LPD (including toilet use, clothes washer, shower use, and faucet).

The EC report values are based on information collected from local case studies in different European member states, it includes feedback from stakeholders and a literature search. Findings in water using products of residential buildings include: 41 LPD toilet use, 26 LPD clothes washer, 37 LPD showers, 29 LPD faucet use, 10 LPD dishwasher, and 11 LPD outdoor use (Mudgal and Lauranson 2009). Calculating the comparative EC metric, the value applicable to residence halls was 143 LPD.

4.1.4 Results and Discussion

4.1.4.1 Average Overall (LEED and Non-LEED) Actual Water Consumption

As indicated in Table 17, the overall range of actual LEED and non-LEED residence hall water consumption fell between 85 and 175 LPD, with an average of 144 LPD and a SD of 34 LPD. Comparing the average consumption to the EC and AWWA engineer's metrics, the consumption was higher by almost 1% and 32% respectively.

Table 17-Average overall water consumption results in liters per person per day (LPD) per residence hall

Res. Hall	Data Range Dates	Sample Size 'n'	Actual Avg. Consumption (LPD)	Standard Deviation of Bldg. Data Set (LPD)	Comparison Actual to EC Engineer's Metric (143 LPD)	Comparison Actual to US Engineer's Metric (212 LPD)
EH	Sept. '08-June '12	46	85	52	- 41%	- 60%
WT	Jan '02-June '13	138	107	37	-25%	-50%
HH	July '07-May '12	59	110	74	-23%	-48%
MH2	July '07-June '12	60	160	104	+12%	-25%
KH	July '07-June '12	60	162	114	+13%	-24%
CSC	May '11-April '13	24	163	82	+ 14%	-23%
MH3	July '07-June '12	60	164	98	+15%	-23%
PS	July '11-May '13	23	172	107	+20%	-19%
MH1	July '07-June '12	60	175	101	+22%	-18%

Figure 25 depicts the actual water consumption of the nine residence halls in LPD in order of highest performance (lowest consumption). LEED residence hall EH is the top performer followed by non-LEED residence halls WT and HH, while LEED residence hall PS performed slightly better than the poorest performer non-LEED residence hall MH1.

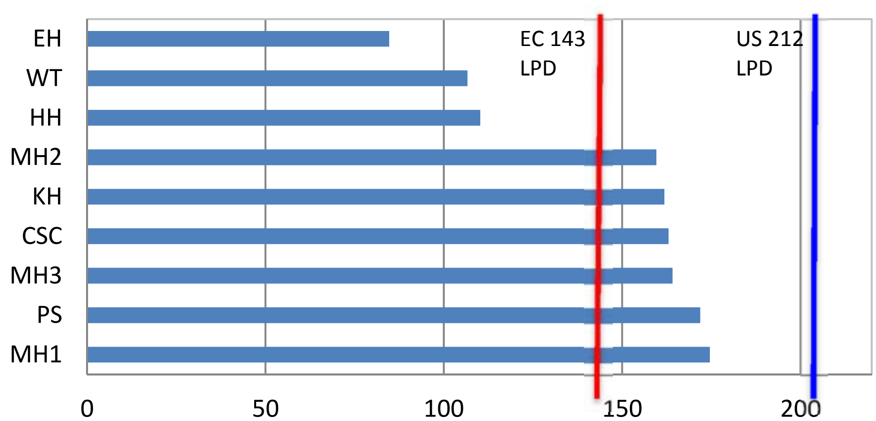


Figure 25-Actual water consumption of all residence halls in Liters per Person per Day (LPD) (compared to engineer's metrics)

4.1.4.2 Non-LEED Residence Halls

The average water consumption of non-LEED residence halls was 146 LPD with an SD of 30 LPD. Figure 26 provides a profile of the water consumption of the six non-LEED residence halls over the years. WT's average consumption was 107 LPD with an increase in consumption over the twelve years of 3%. Although the increase in consumption over the years, its average consumption was lower than engineer's metrics, by 25% and 45% respectively.

Excluding WT from the non-LEED dataset, the average consumption was 154 LPD. Comparing this average to the engineer's metrics, the consumption is higher by 8% and lower by 38% respectively. In MH1, MH2, MH3, KH, and HH, the percent net change over the five years was 3% indicating an uptick. HH and KH showed the highest variation over the years versus steadier consumption in MH1, MH2, MH3 and WT (Figure 26).

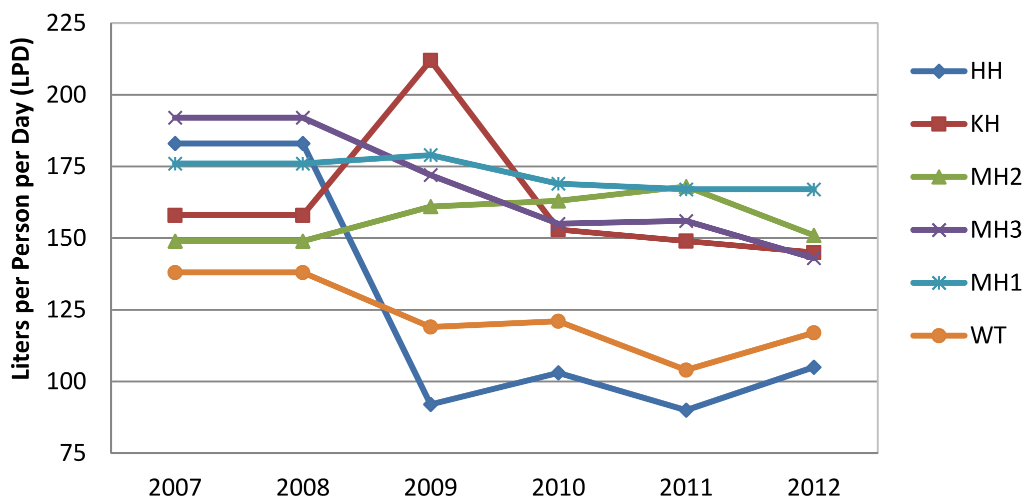


Figure 26-Actual average yearly water consumption in Liters per Person per Day (LPD) of non-LEED residence hall

As shown in Figure 26, HH and KH showed the most variation over the years versus steadier consumption in MH1, MH2, MH3 and WT. Several factors can vary consumption, including academic schedules of institutions, weather, water technologies, gender split, and occupant behavior (Vickers 2001, Schleich and Hillenbrand 2009, Vinz 2009, Kats 2010, Elliot 2013), however no single variable could be identified as the sole source of these variances. In an effort to dissect the purpose behind the variations, an exploration of the monthly consumption values is provided in Figure 27, showing the actual average monthly LPD of the six non-LEED residence halls for all the years data was collected.

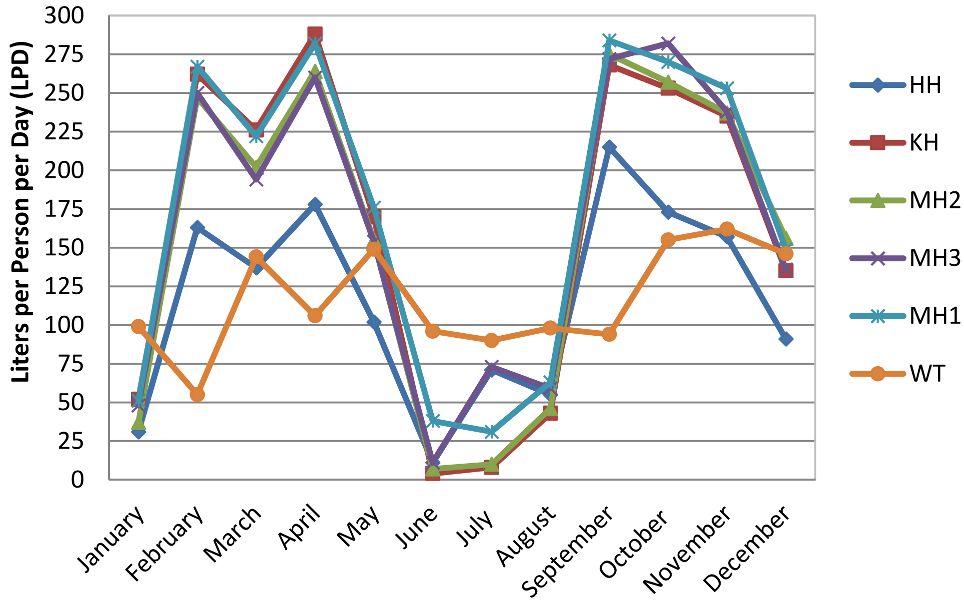


Figure 27-Actual average monthly water consumption of non-LEED residence halls in Liters per Person per Day (LPD) (from 2007 to 2012)

Per Figure 27, the months with the highest average consumption were during the Fall and Spring semesters for: MH1, MH2, MH3, KH and HH. The water consumption for the summer months (June, July and August) were the lowest, followed by January winter recess. The highest consumption periods were attributed to periods of high occupancy (returning students) and warmer months within those semesters.

WT also experienced high consumption during the Fall (September-December) and Spring (January-April) semesters, but still consumed during the summer months (June-August), given that it is in operation year round due to its summer academic requirements. MH1, MH2, MH3, KH and HH do not hold summer sessions and are closed, which is reflected in their minimal summer consumption.

4.1.4.2.1 Residence Hall WT Student Survey

WT is a non-LEED residence hall, however its occupant gender split and location are very similar to EH. To further explore potential differences or similarities between behaviors a user survey was distributed. The total number of WT respondents analyzed over the collection period (10/21/2013-01/06/2014), consisted of 148 responses. This generated a 31% response rate, shy of the target ASHRAE Standard-55 35% response rate requirement by 4%. The total residence hall gender split consisted of 18% females and 82% males with a survey gender split of 23% female and 77% male. Figure 28 depicts the percent distribution of responses to the LEED and AWWA assumptions posed as related to: shower frequency and duration, and toilet flushes.

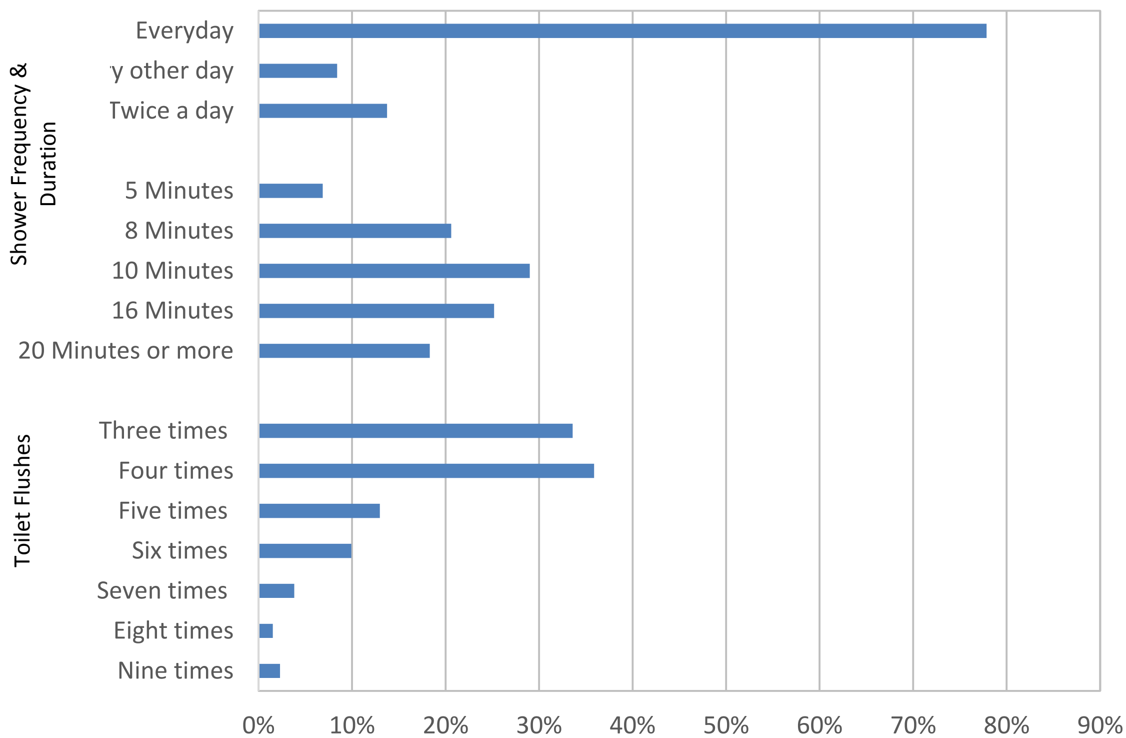


Figure 28-Occupant responses on toilet use, shower duration and shower frequency in residence hall WT

The responses indicate shower frequency and daily toilet flushes (avg. 4.29, *SD* 1.41), fall within shared thresholds of AWWA and LEED design assumptions. However the shower duration assumptions of 8 minutes, dramatically fall short. Over 73% of students take longer than 8 minute showers. On average they take 13 minute showers with an SD of 5 minutes, a 63% increase in duration from shared LEED and AWWA design assumptions.

4.1.4.2.1.1 Multi-variable Linear Regression Analysis on Student Feedback

Examining educational efforts only 40% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls with only 20% indicating participation in any such programs. From the behavioral perspective only 5% believed it had any type of impact on changing their water consumption behavior. On average they only thought about their energy and water consumption behavior 'rarely' with a *SD* ranging from 'rarely' to 'occasionally'. Table 18 outlines the student survey results, pertaining to student education on consumption conservation.

Table 18-WT Education indicator findings (n=131)

Survey Question	WT Respondent Votes n=148	WT Respondent Votes SPSS n=131
Frequency of thinking about water consumption	Avg. 3.88 SD 1.18	Avg. 3.88 SD 1.17
% Indicating presence of conservation awareness programs on campus/res. hall	40%	45%
% Indicating participation in conservation awareness programs on campus/res. hall	20%	22%
% Indicating a change in their energy and water consumption behavior from programs	5%	6%

With 60% indicating ignorance on the presence of conservation awareness programs, it is evident a vast gap for HE institutions exists to educate occupants. Given the results, frequency of thinking about water consumption, was regressed on five variables. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, approximate length of time they run the water in the shower, and if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.

The analysis did not result in any strong correlations, however the variable with the strongest positive relationship and highest significance, was tied to if their water consumption behavior changed from taking part in consumption awareness programs on campus/residence hall. This indicates students who changed their behavior were more likely to be cognizant about water consumption versus those who didn't. Table 19 outlines standardized beta coefficients and significances of variables from the analysis.

Table 19-WT standardized beta coefficients and significances in regression analysis results (n=131)

Independent Variables	Standardized Beta Coefficients	Significance
(Constant)		0.000
Gender	0.095	0.309
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	-0.004	0.968
If conservation awareness programs offered at residence hall or campus	0.059	0.517
Approximate length of time they run the water in the shower	-0.117	0.203
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	0.164	0.090
Model	**r=0.216, R square=0.047**	

Approximate length of time they ran the water in the shower, was also regressed on five variables to provide insight as to the parameters impacting consumption. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall and how frequently they think about water consumption.

The results indicate females were more likely to run the water longer in the shower than males. Table 20 outlines the strongest standardized beta coefficient and significance of the model with the most power to predict water running duration.

Table 20-WT Relationship between approximate shower duration (dependent variable) and independent variables using multiple linear regression analysis (n=131)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Gender	0.297	0.001
Model	**r=0.297, R square=0.088**	

All other variables had weaker and insignificant relationships to approximate length of time they ran the water in the shower. Table 21 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 21-WT Relationship between approximate shower duration (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=131)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
If conservation awareness programs offered at residence hall or campus	-0.011	0.897
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	-0.074	0.382
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	0.010	0.902
How frequently they think about their water consumption	-0.106	0.209

4.1.4.3 LEED Residence Halls

4.1.4.3.1 Residence Hall EH

In calculating the LEED 'green' case, designers assume a specific number of days the residence hall shall be in operation. The assumed operational days plays an important part in painting the water performance picture. Often designers assume different days, depending on the information provided by HE facilities departments typically tied to academic and use schedules. Designers of residence hall EH assumed 305 days with a LEED 'green' case consumption of 89 LPD.

Using the 305-day assumption residence hall EH resulted in the lowest average water consumption when compared to all the residence halls (LEED and non-LEED) of 85 LPD. Even though residence hall EH outperformed its counterparts in further dissecting the water consumption savings over the years, the savings are reduced by an average of 38% per year. The average yearly consumption values for 2008, 2009, 2010, 2011 and 2012 were: 133, 62, 68, 78, and 82 LPD respectively. Potential reasons behind increased consumption in 2008 and 2012, may be attributed to first year commissioning and record heat in 2012.

If consumption of the first and last years are excluded, the resultant average consumption is 69 LPD. This value is 29% lower than the 'green' case (89 LPD), however the yearly savings compared to the LEED 'green' case diminish yearly in both scenarios (85 and 69 LPD). The water consumption trends upwards, reducing the percent savings as compared to the LEED 'green' case, rendering the building less sustainable every year. EH actual consumption was less than modelled consumption by an average of 22% over the three-year period (2009-2011), but only 4% over the five-year period (2008-2012).

To further explore why a discrepancy exists between actual and LEED 'green' case consumption values, two user surveys were distributed to EH occupants via the online tool SurveyMonkey. The first user survey was distributed in November 2010 and the second in October 2013 to account for varied behavioral tendencies. The first survey resulted in 60 respondents a 26% response rate within the two week open survey window. The total number of respondents analyzed over the second collection period (10/21/2013-01/16/2014), consisted of 82 responses. This generated a 35% response rate meeting the target ASHRAE Standard-55, 35% response rate requirement. The total residence hall gender split consisted of 31% females and 69% males. In the first survey the gender question was not included, therefore the exact gender split of respondents could not be calculated; however the second survey resulted in 34% female and 66% male respondents.

Since 44% of indoor residential water end use is related to shower and toilet use (AWWA 1999), questions were developed on the shared assumptions used in LEED (USGBC 2009) and AWWA (AWWA 1999) of shower duration (8 minutes), shower frequency (1/day/occupant), and toilet flushes (5 flushes/occupant/day). Figure 29 and

30 provide the percent distribution of responses to the LEED and AWWA assumptions posed in the November 2010 and October 2013 user-survey respectively.

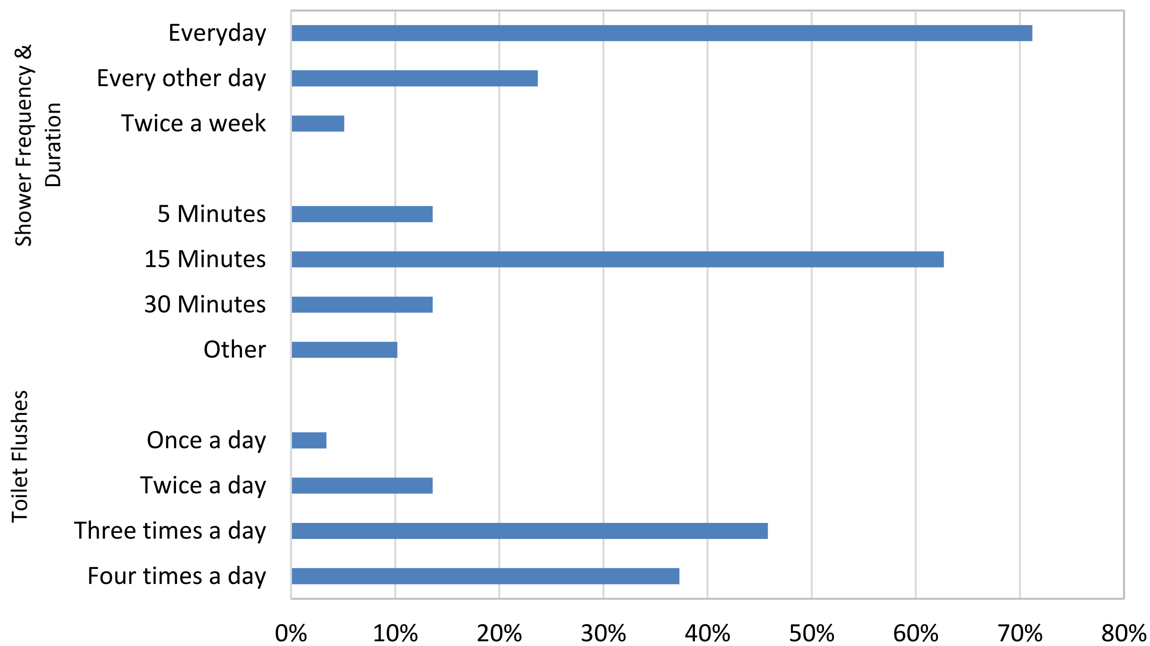


Figure 29-Occupant responses on toilet use, shower duration and shower frequency in residence hall EH (Nov. 2010 Survey)

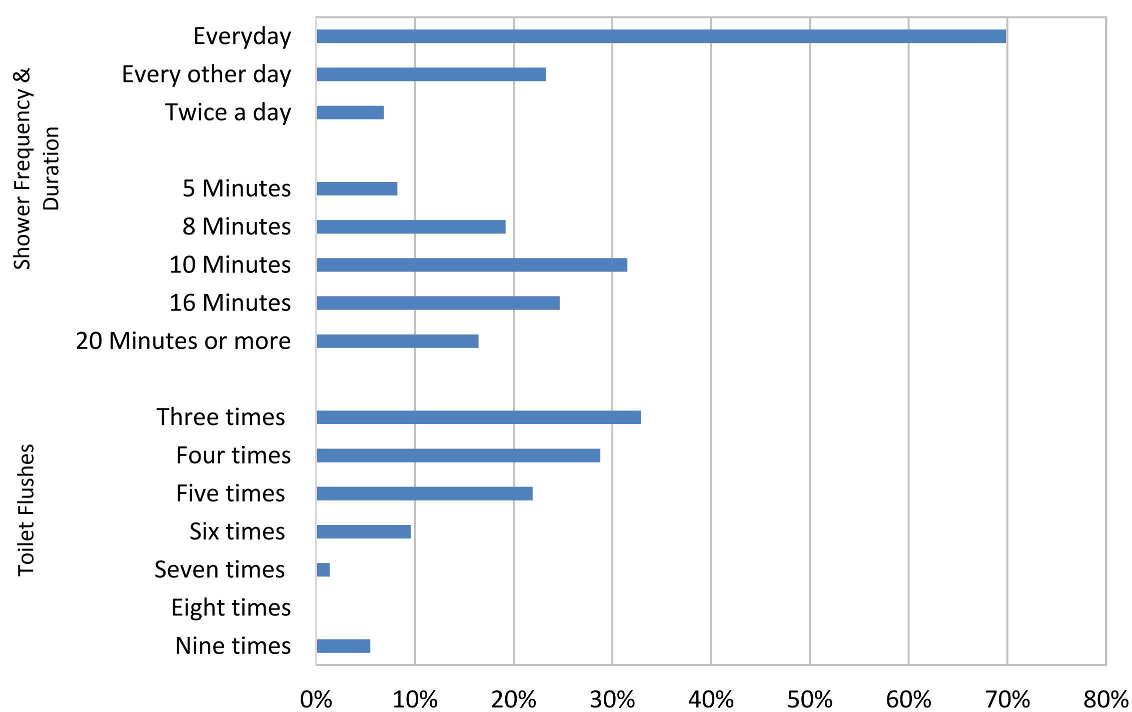


Figure 30-Occupant responses on toilet use, shower duration and shower frequency in residence hall EH (Oct. 2013 Survey)

The responses indicate shower frequency and daily toilet flushes (avg. 4.40, *SD* 1.52), fall within shared thresholds of AWWA and LEED design assumptions. However the shower duration assumptions of 8 minutes, dramatically fall short. Over 87% of respondents in the first survey indicated taking longer than 15-minute showers. The second survey indicated students on average take 13 minute showers with a *SD* of 5 minutes. Over 73% took longer than 8 minute showers, a 63% increase from the assumed LEED and AWWA value.

4.1.4.3.1.1 Multi-variable Linear Regression Analysis on Student Feedback

Examining educational efforts by HE institutions, the survey (October 2013) asked students several questions related to their cognizance about water consumption. The questions posed were related to the provision of educational programs highlighting conservation awareness programs on campus or within the residential halls, given that they inhabit LEED certified buildings.

Only 34% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls with only 11% indicating participation in any such programs. From the behavioral perspective only 1% believed it had any type of impact on changing their energy and water consumption behavior. On average they only thought about their energy and water consumption behavior ‘occasionally’ with an SD ranging from ‘very rarely’ to ‘very frequently’. Table 22 below outlines the student survey results as pertaining to student education on consumption conservation.

Table 22-EH Education indicator findings (n=73)

Survey Question	**EH Respondent Votes n=82**	**EH Respondent Votes SPSS n=73**
Frequency of thinking about water consumption	Avg. 3.79 SD 1.20	Avg. 3.79 SD 1.20
% Indicating presence of conservation awareness programs on campus/res. hall	34%	38%
% Indicating participation in conservation awareness programs on campus/res. hall	11%	12%
% Indicating a change in their energy and water consumption behavior from programs	1%	1%

With 66% indicating ignorance on the presence of conservation awareness programs it is evident a vast gap exists for HE institutions to educate occupants. This finding echoes the finding from WT discussed above. Given the results, frequency of thinking about water consumption, was regressed on five variables within the survey. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, approximate length of time they run the water in the shower, and if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.

The independent variable with the strongest correlation was found with: if they participated in any conservation awareness programs. This indicates students who participated in conservation awareness programs, were more likely to think about water consumption than those who didn't. Table 23 outlines the standardized beta coefficients and significances of the model with the most power to predict frequency of thinking about water consumption.

Table 23-EH Relationship between frequency of thinking about water consumption (dependent variable) and independent variables using multiple linear regression analysis (n=73)

Dependent Variable	Frequency of thinking about water consumption	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	0.239	0.042
Model	**r=0.239, R square=0.057**	

All other variables had weaker and insignificant relationships, with the strongest relationship and highest significance related to gender. This indicates females were more likely to think about water consumption than males. Table 24 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 24-EH Relationship between frequency of thinking about water consumption (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=73)

Dependent Variable	Frequency of thinking about water consumption	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.203	0.079
If conservation awareness programs offered at residence hall or campus	-0.011	0.924
Approximate length of time they run the water in the shower	-0.154	0.186
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	0.049	0.691

Approximate length of time they ran the water in the shower was also regressed on five variables to provide insight as to the parameters impacting consumption. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall and how frequently they think about water consumption.

This did not result in any strong relationships and significances, therefore all variables were entered into the regression using the non-stepwise enter method. Table 25 outlines the standardized beta coefficients and significances of the variables in the regression analysis results.

The variable with the strongest correlation and significance was tied to: if conservation awareness programs were offered at the residence hall. Results indicate students who said conservation awareness programs were offered, were more likely to run the water for longer than those who indicated none were offered.

Table 25-EH Relationship between approximate shower duration (dependent variable) and independent variables using multiple linear regression analysis (n=73)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Gender	0.041	0.348
If conservation awareness programs offered at residence hall or campus	0.218	0.068
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	-0.149	0.239
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	0.199	0.108
How frequently they think about their water consumption	-0.177	0.146
Model	**r=0.350, R square=0.123**	

4.1.4.3.2 Residence Hall CSC

CSC designers assumed 360 operational days, with a LEED 'green' case of 88 LPD. CSC exceeded modeled consumption by an average of 85% over the three-year period (2011-2013). The yearly consumption values for 2011, 2012, and 2013 were 147, 170, and 172 LPD respectively. Resulting in drastic percent increases in consumption as compared to the modeled case of 67% higher, 93% higher and 95% higher consumption in 2011, 2012 and 2103 respectively. As previously mentioned part of the increase may be due to record heat in 2012 throughout the US. However, drastic percent increases in consumption over the years, echo the findings of other residence halls, performing less sustainably over time.

To further explore discrepancies between actual and LEED 'green' case consumption values, a user survey was distributed to CSC occupants via the online tool SurveyMonkey. The total number of respondents analyzed over the collection period (10/21/2013 – 11/20/2013), consisted of 162 responses. This generated a 36% response rate meeting the target ASHRAE Standard-55, 35% response rate requirement by an additional 1%. The total residence hall gender split consisted of 31% females and 69% males with a survey gender split of 67% female and 33% male. Figure 31 depicts the results of the user-survey in terms of: shower frequency and duration, and toilet flushes per day.

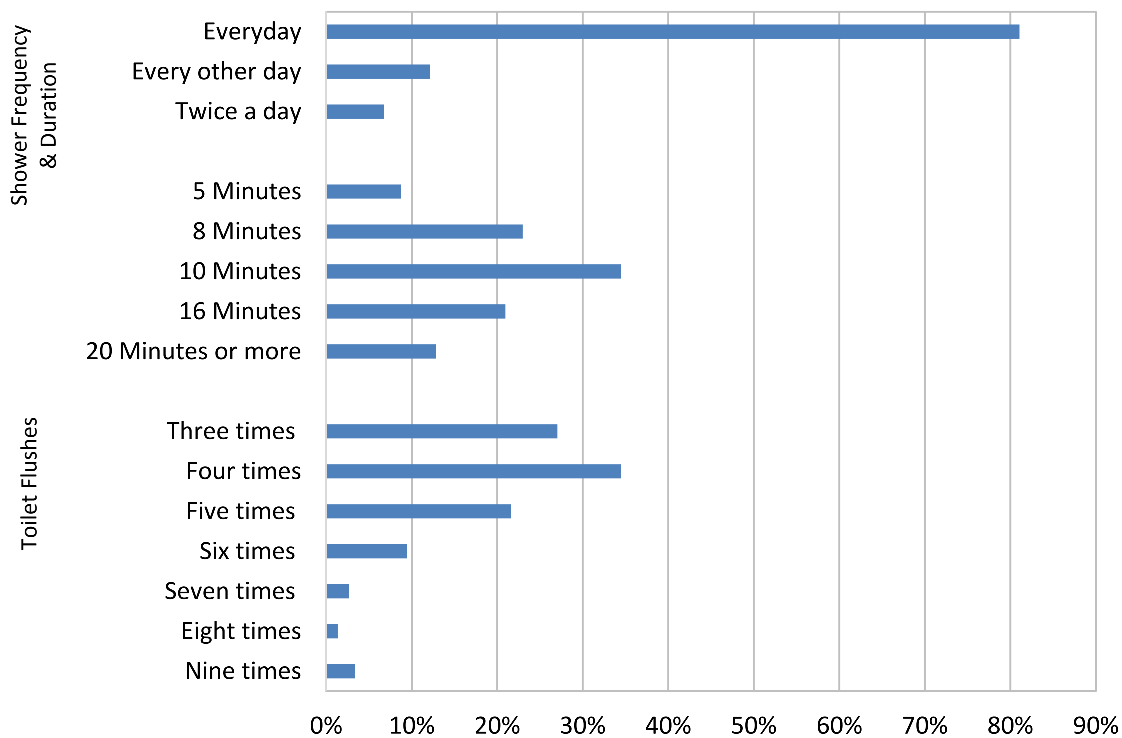


Figure 31-Occupant responses on toilet use, shower duration and shower frequency in residence hall CSC

The responses indicate shower frequency and daily toilet flushes (avg. 4.45, *SD* 1.43), fall within shared thresholds of AWWA and LEED design assumptions. However shower duration assumptions of 8 minutes, dramatically fall short. Over 68% of students take longer than 8 minute showers. On average they take 12 minute showers with an SD of 5 minutes, a 50% increase in duration from shared LEED and AWWA design assumptions.

4.1.4.3.2.1 Multi-variable Linear Regression Analysis on Student Feedback

Examining educational efforts by HE institutions, only 25% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls and 12% indicated participation in any such programs. From the behavioral perspective 0% believed it had any type of impact on changing their energy and water consumption behavior. On average they only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'very rarely' to 'very frequently'. Table 26 outlines the student survey results as pertaining to student education on consumption conservation.

Table 26-CSC Education indicator findings (n=147)

Survey Question	**CSC Respondent Votes n=162**	**CSC Respondent Votes SPSS n=147**
Frequency of thinking about water consumption	Avg. 4.05 SD 1.12	Avg. 4.05 SD 1.12
% Indicating presence of conservation awareness programs on campus/res. hall	25%	28%
% Indicating participation in conservation awareness programs on campus/res. hall	12%	14%
% Indicating a change in their energy and water consumption behavior from programs	0%	0%

With 75% indicating ignorance on the presence of conservation awareness programs it is evident a vast gap exists for HE institutions to educate occupants. This finding is echoed by residence hall WT, and EH. Given the results, frequency of thinking about water consumption, was regressed on the four variables with values within this dataset. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, and approximate length of time they run the water in the shower.

The analysis did not result in any strong relationships and significances, therefore all variables were entered into the regression using the non-stepwise enter method with the same result. Table 27 outlines the standardized beta coefficients and significances of the variables from the analysis.

Table 27-CSC standardized beta coefficients and significances in regression analysis results (n=147)

Independent Variables	Standardized Beta Coefficients	Significance
(Constant)		0.000
Gender	0.105	0.213
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	0.01	0.911
If conservation awareness programs offered at residence hall or campus	0.039	0.646
Approximate length of time they run the water in the shower	0.082	0.335
Model	**r=0.150, R square=0.023**	

Approximate length of time they ran the water in the shower was also regressed on the four variables with values, to provide insight as to the parameters impacting consumption. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, and how frequently they think about water consumption.

The analysis did not result in any strong relationships and significances, therefore all variables were entered into the regression using the non-stepwise enter method. The variable with the strongest correlation and significance was tied to gender. This indicates females were more likely to run the water for longer in the shower than males (supported by WT, and EH). Table 28 outlines the standardized beta coefficients and significances of the variables in the regression analysis results.

Table 28-CSC Relationship between approximate shower duration (dependent variable) and independent variables using multiple linear regression analysis (n=147)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Gender	0.137	0.102
If conservation awareness programs offered at residence hall or campus	-0.08	0.347
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	0.081	0.341
How frequently they think about their water consumption	0.08	0.335
Model	**r=0.198, R square=0.039**	

4.1.4.3.3 Residence Hall PS

PS designers assumed 250 operational days with a LEED 'green' case of 87 LPD. The yearly consumption values for 2011, 2012, and 2013 were 198, 146, 171 LPD respectively. Resulting in differences in consumption as compared to the modeled case of 128% higher, 68% higher and 97% higher in 2011, 2012 and 2103 respectively. Residence hall PS actual consumption exceeded modeled consumption by an average of 98% over the three-year period. It must be noted given the residence hall's location its occupants may have been better equipped to handle the heat of 2012, as consumption of PS in that year was lower than any other year.

To further explore why discrepancies exists between actual and LEED 'green' case consumption values, a user survey was distributed to PS occupants via the online tool SurveyMonkey. The total number of respondents analyzed over the collection period (11/24/2013 – 01/06/2014), consisted of 201 responses. This generated a 32% response rate shy of the target ASHRAE Standard-55, 35% response rate requirement by 3%. The total residence hall gender split consisted of 32% females and 68% males with a survey gender split of 63% female and 37% male. Figure 32 depicts the results of the user-survey in terms of: shower frequency and duration, and toilet flushes per day.

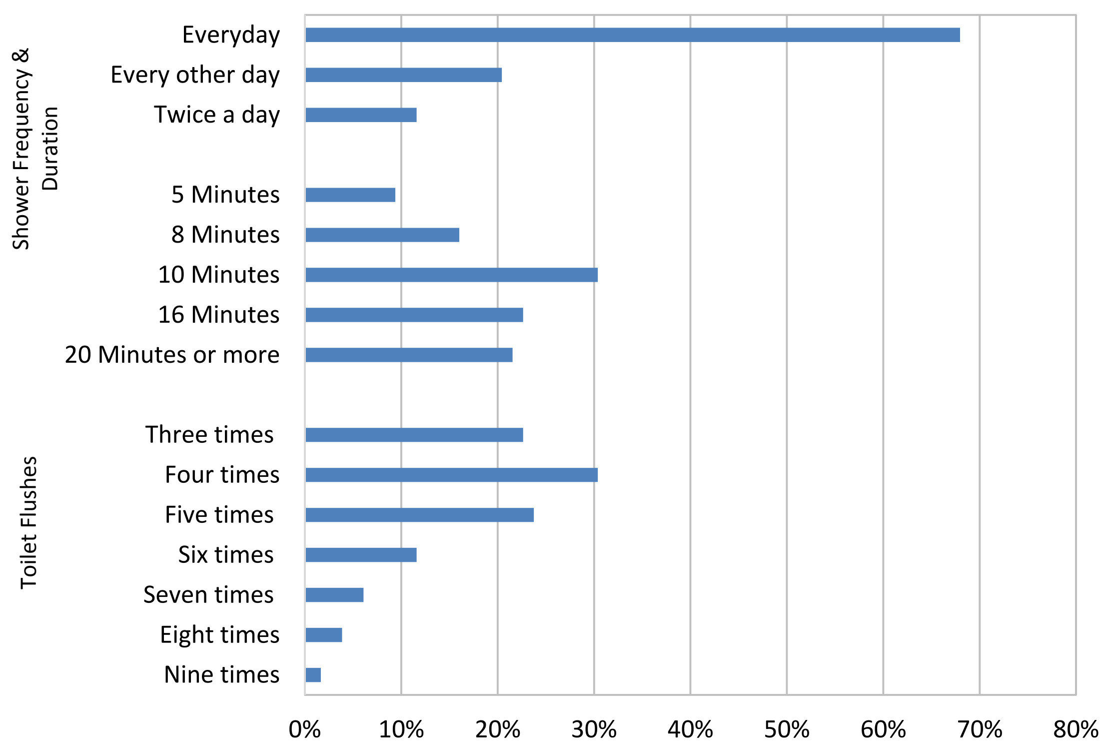


Figure 32-Occupant responses on toilet use, shower duration and shower frequency in residence hall PS

The responses indicate shower frequency and daily toilet flushes (avg. 4.70, *SD* 1.54), fall within shared thresholds of AWWA and LEED design assumptions. However the shower duration assumptions of 8 minutes, dramatically fall short. Over 75% of students take longer than 8 minute showers. On average they take 13 minute showers with an SD of 5 minutes, a 63% increase in duration from shared LEED and AWWA design assumptions.

4.1.4.3.3.1 Multi-variable Linear Regression Analysis on Student Feedback

Examining educational efforts only 42% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls with only 28% indicating participation in any such programs. From the behavioral perspective only 13% believed it had any type of impact on changing their energy and water consumption behavior. On average they only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'rarely' to 'very frequently'. Table 29 below outlines the student survey results as pertaining to student education on consumption conservation

Table 29-PS Education indicator findings (n=176)

Survey Question	PS Respondent Votes n=201	PS Respondent Votes SPSS n=176
Frequency of thinking about water consumption	Avg. 4.07 SD 1.09	Avg. 4.07 SD 1.09
% Indicating presence of conservation awareness programs on campus/res. hall	42%	46%
% Indicating participation in conservation awareness programs on campus/res. hall	28%	32%
% Indicating a change in their energy and water consumption behavior from programs	13%	15%

With 58% indicating ignorance on the presence of conservation awareness programs it is evident a vast gap exists for HE institutions to educate occupants. This finding echoes residence hall WT, EH and CSC. Given the results, frequency of thinking about water consumption, was regressed on five variables. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, approximate length of time they run the water in the shower, and if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.

The independent variables with the strongest correlations were tied to: gender and minutes they ran the water in the shower. This indicates females were more likely to think about water consumption than males. Students (male and female) who ran the water for shorter durations in the shower, were more likely to be cognizant of their water consumption. Table 30 outlines the standardized beta coefficients and significances of the model with the most power to predict frequency of thinking about water consumption.

Table 30-PS Relationship between frequency of thinking about water consumption (dependent variable) and independent variables using multiple linear regression analysis (n=176)

Dependent Variable	Frequency of thinking about water consumption	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Approximate length of time they run the water in the shower	-0.245	0.002
Gender	0.167	0.038
Model	**r=0.239, R square=0.057**	

All other variables had weaker and insignificant relationships. Table 31 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 31-PS Relationship between frequency of thinking about water consumption (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=176)

Dependent Variable	Frequency of thinking about water consumption	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	0.031	0.680
If conservation awareness programs offered at residence hall or campus	-0.039	0.597
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	0.013	0.868

Approximate length of time they ran the water in the shower was also regressed on five variables to provide insight as to the parameters that impact consumption. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall and how frequently they think about water consumption.

The variables with the strongest correlations were: gender and frequency of thinking about water consumption. This indicates females were more likely to run the water for longer in the shower than males (supported by WT, EH, and CSC). Also that students (male and female) who thought about their water consumption, were more likely to run the water for shorter durations in the shower. Table 32 outlines the standardized beta coefficient and significance of the model with the most power to predict approximate length of time they ran the water in the shower.

Table 32-PS Relationship between approximate shower duration (dependent variable) and independent variables using multiple linear regression analysis (n=176)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Gender	0.394	0.000
How frequently they think about their water consumption	-0.211	0.002
Model	**r=0.433, R square=0.188**	

All other variables had weaker and insignificant relationships, the variable with the strongest correlation within the weaker subset was tied to: whether they had taken part in any awareness programs. This indicates students who participated in awareness programs, were more likely to reduce the approximate length of time they ran the water in the shower. Table 33 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 33-PS Relationship between approximate shower duration (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=176)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
If conservation awareness programs offered at residence hall or campus	-0.029	0.669
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	-0.111	0.108
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	-0.101	0.144

4.1.4.4 Comparison of LEED and Non-LEED Residence Halls

Reviewing the age and technologies employed among the residence halls, the average age of non-LEED residence halls is 46 years with an *SD* of 18 yrs., while the average age of LEED residence halls is 4 years with an SD of 1 year. Residence halls EH, WT, CSC and PS were built in 2008, 2002, 2011, and 2011 respectively, where the 1992 and 2005 Federal Energy Policy Act (FEPA) were already in place. This act includes maximum consumption for fixtures of 9.5 liters per minute (LPM) and 6.0 liters per flush (LPF). MH1, HH, MH2, KH, and MH3 were built in 1951, 1959, 1961, 1961 and 1966 respectively, and do not comply with the 1992 or 2005 Federal Energy Policy Act.

All non-LEED residence halls and CSC used full flush toilets, while EH and PS used dual-flush toilets (low/full). Figure 33 represents the average and SD of flow fixture rates in LEED and non-LEED residence halls in LPM for lavatory, kitchen sink and shower fixtures, and in LPF for toilets.

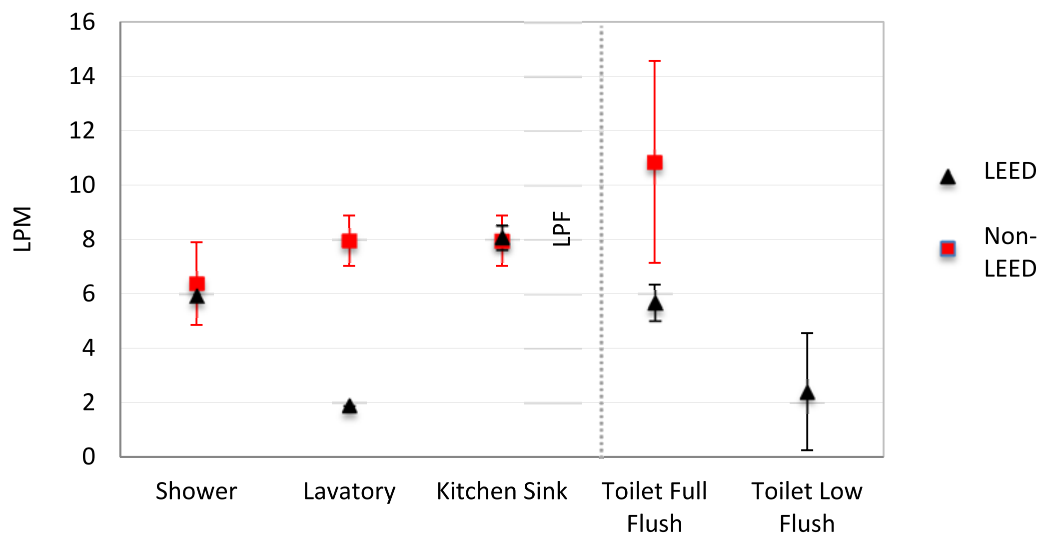


Figure 33-Average flow fixtures in liters per minute (LPM) and liters per flush (LPF) for LEED and non-LEED residence halls

Non-LEED residence halls used flow fixtures with 6.4, 7.9, and 7.9 LPM for shower, lavatory and kitchen sink respectively, with toilets using 10.9 LPF, whereas LEED ones used flow fixtures with 5.9, 1.9, and 8.1 LPM for shower, lavatory and kitchen sink respectively, with toilets using 3.6 and 5.7 LPF for low and full flush respectively.

Even though non-LEED flow fixtures were higher on average the residence halls outperformed LEED ones in terms of total LPD. This finding indicates sole reliance on technology to lower overall consumption might not be the answer. Attention must be given to occupant expectations and behaviors. For example, some respondents in the EH survey commented about their frustrations with low flow fixtures and declared they replaced low flow showerheads with higher flow fixtures, whilst others indicated taking longer showers. Similar comments were provided for low flow toilets, where respondents indicated often double and triple flushing as a single toilet low flush was not sufficient.

These results confirm the role of users as critical factors for sustainability (Stevenson and Leaman 2010, Berardi 2013, GhaffarianHoseini et al. 2013).

To further highlight whether climate impacted the consumption of the dataset, bivariate correlation analysis was carried out. The analysis tested the relationship between average monthly temperature and consumption in LPD. The analysis excluded summer months of all residence halls, except in the case of WT which has summer semesters.

The results indicate a positive correlation between average monthly temperature and LPD consumption in all residence halls except PS, however the correlations are not significant (95% or above). It must be noted in EH, HH, MH2, MH3, and MH1 the significance surpass 90%, in line with the work of previous researchers. Table 34 provides the bivariate correlation results per residence hall.

Table 34-Bivariate correlation results of average monthly temperature and liters per person per day (LPD) consumption (Residence Halls: EH, WT, HH, MH2, KH, CSC, MH3, PS, and MH1)

Res. Hall	Building Zone*	Dates of Data Range**	Bivariate Correlation Results $R_{d.f.}$ (N-2)= r, ρ
EH	Cold	Sept. '08-June '12	r (30)= 0.284, ρ<0.057
WT	Mixed-Humid	Jan '02-June '13	r (136)= 0.015, ρ<0.432
HH	Hot-Dry	July '07-May '12	r (38)= 0.237, ρ<0.070
MH2	Cold	July '07-June '12	r (38)= 0.213, ρ<0.094
KH	Cold	July '07-June '12	r (38)= 0.150, ρ<0.177
CSC	Cold	May '11-April '13	r (16)= 0.217, ρ<0.193
MH3	Cold	July '07-June '12	r (38)= 0.259, ρ<0.053
PS	Cold	July '11-May '13	r (16)= -0.079, ρ<0.378
MH1	Cold	July '07-June '12	r (38)= 0.248, ρ<0.061

*Based on United States Department of Energy (US-DOE, 2013).

**Excludes summer months when students are not on campus except in the case of WT, since summer semesters are required as part of the academic program.

In the case of PS the number of observations in the dataset were only 18, therefore the negative correlation result may be attributed to the small sample size. In the case of WT with over 10 years of data and inclusion of the warmest months, the correlation between average monthly temperature and LPD consumption was positive yet weak. This indicates temperature has a negligible impact on consumption patterns. In order to dissect this weak correlation, the 12-month monthly temperature moving average was compared to highlight variations due to seasonality. Per Figure 34 no variations due to seasonality exist, and average temperatures were relatively steady over the 10-year period. This indicates other variables such as user consumption behavior, might be driving consumption variations. Figure 34 also provides a plot of the 12-month LPD moving average over the 10-year period. As can be seen, the consumption patterns are non-uniform and vary substantially on a yearly basis.

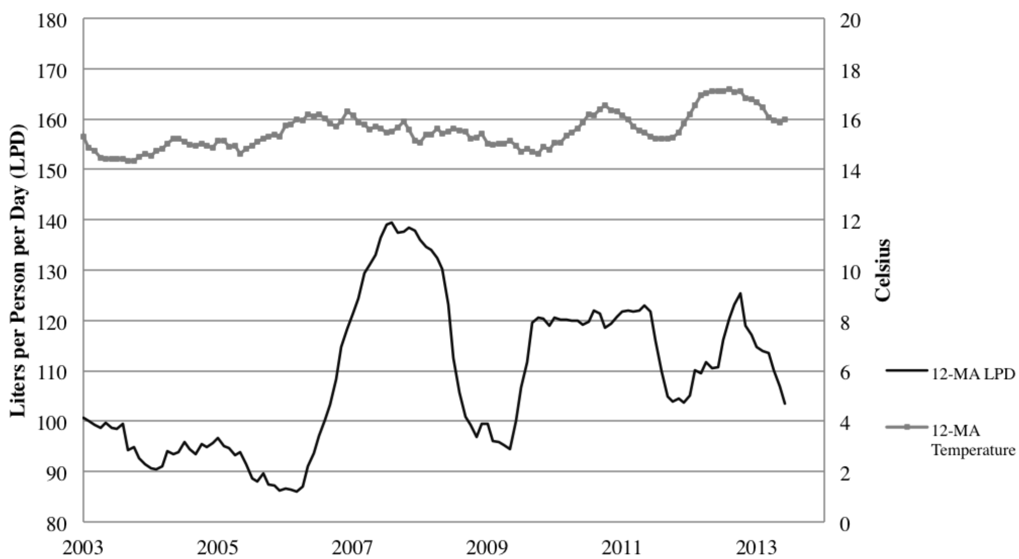


Figure 34-Twelve month Liters per Person per Day (LPD) and temperature moving averages (January 2002 to June 2013)

Examining the average water consumption of LEED residence halls between years, building EH, CSC and PS consumed 10% more, 9% more and 5% less respectively between yearly readings. However compared to their LEED 'green' cases, the average yearly consumption of EH, CSC and PS were 4% lower, 85% higher, and 98% higher respectively. These values result in an overall percent increase in consumption of 60% as compared to their LEED 'green' cases. EH and CSC are LEED-Gold while PS is LEED-Silver. Even though the LEED-Gold residence hall outperformed the LEED-Silver one, both did not provide the expected savings (Kats 2010). Moreover, LEED residence hall data indicates diminished consumption savings over time, rendering them less sustainable every year.

Non-LEED residence halls WT, MH1, MH2, MH3, KH, and HH resulted in an increase of 3% in water consumption over the years. Based on the findings, on average non-LEED residence halls outperformed LEED ones depicting steadier consumption profiles over the years.

It is interesting to note as the gender split equalized in residence halls, the consumption increased (Vinz 2009, Elliott 2013). EH and WT, highest performing, had the highest male populations at 75% on average, while MH1, MH2, MH3, KH, HH, PS and CSC had average male populations of 47%.

To provide insight into parameters impacting consumption, 'approximate length of time they ran the water in the shower' and 'frequency of thinking about their water consumption', was regressed on five variables for the various residence halls. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, and if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.

Examining dependent variable 'approximate length of time they ran the water in the shower', the results showed that in WT, CSC and PS females were more likely to run the water in the shower for longer than males. However in EH and PS it was found that females were more likely to think about water consumption than males.

In EH it was also found that students indicating conservation awareness programs were offered, were more likely to run the water for longer than those who indicated none were.

In PS students (male and female) who thought about their water consumption, were more likely to run the water for shorter durations in the shower. Also that students who participated in awareness programs were more likely to reduce the approximate length of time they ran the water in the shower. These findings support the behavioral finding from WT and cognizance PS finding (discussed below in the 'frequency of thinking about water consumption' dependent variable analysis). (1) WT indicates students who thought about their water consumption were more likely to change their consumption behavior. (2) EH indicates students who participated in conservation awareness programs, were more likely to think about water consumption.

The data from all residence halls was compiled to run a collective regression to compare the individual results. The gender split of the combined data resulted in an even 50/50 split. The results indicate females were more likely to run the water for longer in the shower than males; and students (male and female) who frequently thought about their water consumption, were more likely to run the water for shorter durations in the shower. Table 35 outlines the standardized beta coefficients and significances of the variables in the regression analysis results.

Table 35-All residence halls relationship between approximate shower duration (dependent variable) and independent variables using multiple linear regression analysis (n=527)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Gender	0.224	0.000
How frequently they think about their water consumption	-0.116	0.007
Model	**r=0.238, R square=0.057**	

All other variables had weaker and insignificant relationships to approximate length of time they ran the water in the shower. Table 36 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 36-All residence halls relationship between approximate shower duration (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=527)

Dependent Variable	Approximate length of time they ran the water in the shower	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
If conservation awareness programs offered at residence hall or campus	-0.034	0.418
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	-0.047	0.27
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	-0.028	0.519

Examining the educational component of increasing awareness amongst student occupants on consuming less water it is clear HE institutions must increase their efforts. On average 65% of student occupants indicated ignorance on the presence of conservation awareness programs on campus or within their residence halls. 18% indicated participation in said programs, and only 5% believed it had any type of impact on changing their water consumption behavior (n= 527). On average students only think about their water consumption behavior 'rarely' with an SD ranging from 'very rarely' to 'very frequently' (n=527).

Given the poor results, 'frequency of thinking about their water consumption', was regressed on five variables for each residence hall dataset and collectively. The selected independent variables included: gender, if conservation awareness programs are offered at the residence hall or campus, participation in conservation awareness programs, approximate length of time they run the water in the shower, and if consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.

Examining individual results in WT it was found students who thought about water consumption were more likely to change their consumption behavior. In EH students who participated in conservation awareness programs were more likely to think about their water consumption. A shared finding between EH and PS was that females were more likely to think about their water consumption than males.

In PS it was also found that students (male and female) who ran the water for shorter durations in the shower, were more likely to be cognizant of their water consumption. Residence hall CSC did not result in any strong variable correlations in this analysis.

The collective results of the independent variables with the strongest correlations were tied to: gender and minutes they ran the water in the shower. This indicates females were more likely to think about water consumption than males, and that students (male and female) who ran the water for shorter durations were more likely to be cognizant about their water consumption. Table 37 outlines the standardized beta coefficients and significances of the model with the most power to predict frequency of thinking about water consumption.

Table 37-All residence halls relationship between frequency of thinking about water consumption (dependent variable) and independent variables using multiple linear regression analysis (n=527)

Dependent Variable	Frequency of thinking about water consumption	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Gender	0.153	0.001
Approximate length of time they run the water in the shower	-0.119	0.007
Model	**r=0.173, R square=0.030**	

All other variables had weaker and insignificant relationships to frequency of thinking about water consumption, within this dataset. Table 38 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 38-All residence halls relationship between frequency of thinking about water consumption (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=527)

Dependent Variable	Frequency of thinking about water consumption	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Have you taken part in any consumption conservation awareness programs about water and energy consumption?	0.077	0.074
If conservation awareness programs offered at residence hall or campus	0.026	0.546
If consumption of energy and water behavior changed from taking part in consumption awareness programs on campus/residence hall.	0.073	0.091

4.1.5 Water Study Conclusions

Water related studies suggest we are consuming water at an unsustainable rate. Population growth, climate change, increased wealth, urban development and mismanagement of water systems are over stressing our already fragile water infrastructures. These issues further compound the challenges faced with sustaining this basic necessity. As a result we must engage new strategies to minimize consumption, pushing forth the idea of behavioral water conservation and not only fixture water efficiency (Bennetts and Bordass 2007, Berardi 2013). Tracking, measurement and collection of user feedback, are fundamental to understand consumption patterns. We can only develop conservation and management strategies, through an in depth understanding of qualitative and quantitative data which can be attained by implementing POEs.

In trying to gain an understanding of residence hall water-use, this study focused on identifying and comparing indoor water-use of LEED and non-LEED certified residence halls. It addressed several scopes including: identifying indoor water consumption in residence halls, comparing LEED to non-LEED residence halls, assessing LEED modeled case projections with actual water consumption, comparing actual water consumption to developed engineer's metrics and soliciting student occupant feedback on consumption tendencies and conservation awareness programs.

Evidently isolating residence hall water consumption using US-DOE, USGS, AWWA and EC data is problematic, due to differences in the categorization of residence halls between water-use studies and a lack of available data. Different classifications of residential customers by utility companies also compound the problems in collecting published data on water consumption in residence halls.

To address this gap actual consumption data was collected from nine residence halls, indicating indoor water ranges between 85 to 175 LPD. Overall average actual residence hall consumption was lower than values found in US-DOE (375 LPD), EPA (265 LPD), EC (168 LPD), AWWA US (212 LPD) and EC (143 LPD) engineer's metric. On average non-LEED residence halls consumed 4% more than LEED ones, however the LEED buildings resulted in contrasting results with a high standard deviations.

On a yearly and monthly basis, non-LEED residence halls depicted steadier consumption values with an overall 3% uptick for the entire time data was collected. On the other hand LEED residence halls showed an increase of 5% over the years and, on average, higher variations in consumption patterns. The average water consumption of EH, CSC and PS was 60% higher when compared to LEED 'green' cases. The data showed yearly decreases in savings, rendering LEED residence halls less sustainable every year. These results highlight the possibility that LEED labeling does not fully capture actual user behavior, and hence might result in unrealistic savings expectations.

It is important to highlight technology alone may not guarantee water savings. Larger reductions in water consumption need improved user attitudes and changes in occupant behaviors. Non-LEED flow fixtures used higher water values than those installed in LEED halls; however, they still outperformed LEED residence halls in terms of total LPD. These results affirm researchers' findings, in that occupants are the key to sustainability in practice (Stevenson and Leaman 2010, Berardi 2013, GhaffarianHoseini et al. 2013).

Geographical location and weather showed a positive correlation between average monthly temperature and LPD consumption in all residence halls except PS. However it must be noted the correlations were at 90% significance yet in line with the work of previous researchers (Vickers 2001, Balling et. al 2007, Schleich and Hillenbrand 2009, Berardi 2013).

This study also solicited student feedback through the distribution of online surveys to occupants of EH, CSC, PS, and WT. The survey did not pose questions related to socioeconomic factors therefore previous work of researchers on this topic could not be supported or refuted. The questions posed examined: LEED and AWWA assumption, frequency of cognizance about water consumption, presence of conservation awareness programs on campus/residence hall, participation in said programs and behavioral changes due to participation in said programs.

Shower frequency and toilet flushes per day results indicate LEED and AWWA assumptions are in line with student behaviors. Combining the results of LEED and WT residence halls, 67% of students shower daily and flush an average of 5 times a day. However examining shower duration on average students run the water in the shower for over 12 minutes with an SD of 5 minutes. This value is 50% higher than the shared shower duration assumption of LEED and AWWA. Such vast differences in assumptions (eight minutes) and actual practice (over 12 minutes) must be ameliorated, to ensure performance gaps are minimized. Such large variations in actual practice versus modeled assumptions can result in substantial gaps in water-use estimation and performance evaluations. These results confirm that occupants' attitudes and behaviors have substantial impacts in promoting sustainability in practice (Barr 2003, Bamberg 2003, Hand et al. 2003, Hurlimann 2006, Alshuwaikhat and Abubakar 2008, Randolph and Troy 2008).

Poor student survey results about consumption awareness programs, student participation and behaviors, indicates HE institutions must increase awareness and do more in educating students. Student survey results indicated high standard deviations on cognizance about water consumption and high percentages of ignorance on the presence of conservation awareness programs. Major survey findings indicate: (1) females were more likely to run water for longer in the shower; (2) students (male and female) who frequently thought about their water consumption, were more likely to run the water for shorter durations in the shower (3) females were more likely to think about water consumption than males, and (4) students (male and female) who ran the water in the shower for shorter durations, were more likely to be cognizant about their water consumption. In an alternate survey of non-LEED residential buildings questioning occupant water conservation attitudes, it was found that 31% of occupants believed there was nothing more they could do to minimize indoor water consumption (Randolph and Troy 2008). However 69% of respondents may be able to shift to sustainable behaviors through educational programs or awareness campaigns. Such results highlight that differences in attitudes and behavior have substantial impacts on sustainable practices, and development of practical policies to lower water consumption (Barr 2003, Bamberg 2003, Hand et al. 2003, Shove 2003, Hurlimann 2006, Alshuwaikhat and Abubakar 2008, Randolph and Troy 2008).

It is interesting to note as the gender differential equalized the consumption in the residence halls increased, tying to arguments made by researchers on the inequality of gender consumption (Vinz 2009, Elliott 2013). The best performing residence halls had on average 75% males, while the poorer performing residence halls held on average 47% males.

Finally, it is evident much work needs to be done given student feedback on conservation awareness programs and behavioral impacts from said programs. HE institutions have the responsibility to educate and release well-educated individuals into the world, hence should adopt sustainability into their core culture of existence. An increase in awareness efforts is required to push for student social responsibility by promoting sustainable behaviors.

4.2 Energy Study (POE Indicator 2, 3 and 4)

4.2.1 Introduction

Based on the United States Department of Energy (US-DOE) the US consumed 19% of global energy preceded only by China (US-DOE EERE 2014). The US buildings sector consumed 41% of primary energy (US-DOE EERE 2014), 44% and 36% more than the transportation and industrial sectors respectively (US-DOE EERE 2014). The dominant end uses were for space heating, space cooling and lighting, accounting for close to half of all energy consumed (US-DOE EERE 2014). The building stock also contributed 40% of total carbon dioxide emissions (US-DOE EERE 2014). In the US varied agencies provide different energy benchmarking values. The agencies selected for comparative purposes are: US-DOE Building Energy Performance Database (US-DOE BEPD), and Commercial Building Energy Consumption Survey (CBECS). The data provided by both agencies is widely used within industry, however does not explicitly isolate energy consumption in residence halls.

In the European Union (EU) the European Commission (EC) reports the energy consumption of the member states by providing reports on the regions energy indicators. Based on EU-EC Report 1725-466, nearly 40% of primary energy consumption and 36% of greenhouse gas emissions were related to buildings (EU-EC 2012). Energy consumption increased between 2009 and 2010 by 3% (EU-EC 2012). However within the EU reporting residence halls are not explicitly isolated and neither is their energy consumption benchmarking values. Given the lack of specificity on this building typology and the high consumption values of buildings it is imperative that energy consumption of residence halls are identified, measured, tracked and reduced.

This study identifies energy consumption in these specialized building typologies, by collecting actual energy consumption of residence halls in the US. The actual energy consumption values are further compared to US and EU benchmarks for comparative purposes. The US-DOE BEPD places residential and commercial building energy consumption at 20.63 kBtu/Sq.m/Month and 39.47 kBtu/Sq.m/Month respectively for buildings located on the east coast. Residential and commercial buildings on the west coast are placed at 87.01 kBtu/Sq.m/Month and 106.74 kBtu/Sq.m/Month respectively (US-DOE BEPD 2014). Data provided by CBECS identifies residence halls in the lodging typology and places energy consumption at an average of 89.07 kBtu/Sq.m/Month nationally. The European Commission (EC) places energy consumption at 11,598.40 kBtu/Month/Person. Given the agencies lack of specificity on the residence hall building typology both the residential and commercial values have been compared to identify which application residence halls more closely mimic in terms of energy consumption.

Residence halls are unique, although they are residential in nature the mentality behind their end-use falls within the commercial realm. Student residents are temporary occupants of the facility and do not have a vested interest in conserving energy. Student residents do not individually pay for their utilities and are not provided their consumption values. The cost of all their utilities is included in the overall cost of living in the residence hall, therefore awareness of energy consumption is not as significant as in a residential application. Other factors which may negatively impact residence hall energy consumption may include the student’s age bracket given they are not employed full-time. Hence, students spend more time in their residential facilities contributing to higher consumption due to higher occupancy overall percentages. Occupancy impacts consumption and typically systems are shut off when not in use. On average students spend 57% of their time in their residence halls. This value is similar to residential applications (assuming occupants have a full-time job), however student mentality differs as they do not pay their utility bills. The HE institution includes utilities as part of their own operating costs. Other factors also influence energy consumption such as geographical location, climate, culture, gender, and occupant behavior (Balling et. al 2007, Randolph and Troy 2008, Schleich and Hillenbrand 2009, Vinz 2009, Elliott 2013, Berardi 2013).

Given the impact of varied components on energy consumption and the specialized building typology, this study aims to identify energy consumption through actual energy consumption data from Leadership in Energy and Environmental Design (LEED) and non-LEED certified residence halls. Energy consumption intensities from US-DOE BEPD, CBECS, and EC, have been used to compare actual residence hall energy intensities for benchmarking purposes. Finally, a comparison between the LEED design model and actual energy consumption has been undertaken, to highlight the energy consumption behavior of the residence halls within the dataset. The results will indicate whether actual building performance has met the certification projections in actuality. The residence halls selected include three certified LEED and one non-LEED residence hall. The residence halls serve over 1750 students, of which three are located on the east coast and one on the west coast within the US.

4.2.2 Sustainability Rating Systems and Energy Efficiency Strategies

Voluntary sustainability rating systems including LEED (USGBC 2009), BRE Environmental Assessment Method (BREEAM 2008), Comprehensive Assessment System for Built Environment Efficiency (CASBEE 2010), and Green Globes (2012), require energy modeling to compare energy baseline design cases (BDC) to proposed design cases (PDC). Guidance is provided for the minimization of energy consumption through various strategies such as: massing and orientation, materials, building envelope design, and heating, ventilation and air conditioning systems.

The various rating systems also highlight the need for an integrated design process to increase communication across disciplines to optimize energy efficiency. LEED, BREEAM, Green Globes and CASBEE place the highest importance within the rating systems on energy efficiency at 32%, 19%, 38% and 20% respectively. However measurement and tracking of energy performance is not a requirement and is rarely pursued.

4.2.3 Case Study Overview and Methodology

Three LEED and one non-LEED residence hall with an average age of 5.50 years and *SD* of 3.79 years comprise the dataset. Data was gathered from designers, facilities departments and residential life offices of the various higher education (HE) institutions. The research methodology involved the collection of various specifications including: number and gender split of students served, actual energy meter readings, LEED documentation pertaining to energy efficiency (EA) credits in the LEED certified residence halls and a student survey.

LEED EA documentation collected from designers identified design assumptions of the baseline design case (BDC), and proposed green design case (PDC). Data gathered from the facilities departments of the HE institutions provided the actual case (AC), which has been compared to the PDC and various agency benchmarks (US-DOE BEPD, CBECS, EU-EC). For the purposes of anonymity, acronyms designate the residence halls.

Monthly actual energy (electricity and gas) meter readings were collected for EH, PS, WT, and CSC in kilo-watt hours and British thermal units and converted to kBtu of consumption. Due to the metrics provided by the EU-EC and US benchmarking agencies two intensity metrics were developed for this study. The number of students served per year allowed the calculation of consumed energy per month per person (kBtu/Month/Person) to compare to EU-EC values. Alternately the energy intensity used to compare US values consisted of energy per square meter per month (kBtu/Sq.m/Month). This metric was used to compare actual consumption values to CBECS, and US-DOE BEPD (residential and commercial) values.

All residence halls are located in the US with three on the east coast and one on the west coast. Residence halls EH, CSC, and WT located on the east coast, experience cold to mix-humid climates; and residence hall PS located on the west coast, experiences a hot-dry climate. Table 39 outlines their LEED rating level, age, number of students served, gender split, location and building climatic zone per US-DOE.

Table 39-Overview of residence halls in dataset (EH, CSC, PS, and WT)

Residence Hall	Rating	Age Yrs.	# of Users	Gender Split*	Location	Bldg. Zone**
EH	LEED-Gold	5	232	F=31%	East Coast	Cold
CSC	LEED-Gold	3	450	F=53%	East Coast	Mixed-Humid
PS	LEED-Silver	3	622	F=44%	West Coast	Hot-Dry
WT	Non-LEED	11	475	F=18%	East Coast	Cold

*Percent female of total residents served
** Based on US-DOE, 2013

Energy consumption was also correlated to the National Oceanic and Atmospheric Administration's Residential Energy Demand Temperature Index (NOAA-REDTI) using Statistical Package for Social Sciences (SPSS) version 19 for bivariate correlation analysis. The correlation analysis aims to identify if sensitivity to weather conditions exists within the dataset collected. Examining weather patterns within the study's data date range, the US followed typical patterns in the years from 2002 to 2009, and in 2011 and 2013; reversely, in 2010, the coldest winter was experienced and in 2012 record summer heat and mildest winter was recorded (NWS 2013).

REDTI is based on population weighted heating and cooling degree days. The seasonal changes in REDTI may provide a good indication of fluctuations in energy demand due to the high correlation (0.97) between energy use and heating degree days (NOAA, 2014). REDTI is based on data collected from 1895 till today, providing information on the impact of seasonal temperatures on residential energy demand.

A student survey was also administered, distributed via email through the collaboration of individual HE institution's residential life offices. For detailed methodology and results please refer to the 'Student Survey' section within this report.

4.2.3.1 Comparative Metrics

Metrics were identified based on EU-EC reports, US-DOE BEPD and CBECS. All sources of energy benchmarking are a result of information collected from local case studies and surveys distributed to various building owners. The values identified from both EU and US agencies may be found in Table 40 below. These values have been used to compare residence hall AC performance. Given the variation between agency energy intensities, two separate metrics, kBtu/Sq.m/Month and kBtu/Month/Person, were developed to ensure appropriate comparative unit of measures.

Table 40-Study comparative metrics

Reporting Agency	Energy Intensity Location	Energy Intensity Value	Energy Intensity Unit of Measure
US-DOE BEPD (Residential)	Northeast	20.63	kBtu/Sq.m/Month
US-DOE BEPD (Commercial)	Northeast	39.47	kBtu/Sq.m/Month
US-DOE BEPD (Residential)	West	87.01	kBtu/Sq.m/Month
US-DOE BEPD (Commercial)	West	106.74	kBtu/Sq.m/Month
CBECS	Nationwide	89.70	kBtu/Sq.m/Month
EU-EC	European Member States	11,598.40	kBtu/Month/Person

4.2.3.2 On-site Renewable Energy (POE Indicator 4)

Given EH, CSC, PS and WT did not employ any on-site renewable energy strategies, this indicator was not applicable in this dataset. It must be noted even if these strategies are employed, they must have separate metering to allow for data collection on their kWh contribution.

4.2.4 Results and Discussion

4.2.4.1 Average Overall (LEED and non-LEED) Actual Energy Consumption

As indicated in Table 41, the overall range of actual LEED and non-LEED residence hall energy consumption fell between 24 and 62 kBtu/Sq.m/Month, with an average of 47 kBtu/Sq.m/Month and an SD of 19 kBtu/Sq.m/Month.

Table 41-Actual energy consumption of residence halls (EH, CSC, PS, and WT)

Res. Hall	Date Range of Dataset	Sample Size 'N'	Actual Avg. Consumption kBtu/Sq.m/Month	Standard Deviation of Data Set
EH	G*: Jul 2008-Jan 2014 E**: Jul 2008-Jan 2014	n(G)=67 n(E)=67	40.98	8.32
CSC	G: Jun 2010-Jan 2013 E: Jun 2010-Dec 2012	n(G)=32 n(E)=31	62.37	5.30
PS	G: Jun 2011-May 2013 E: May 2010-Jun 2013	n(G)=24 n(E)=38	24.13	1.14
WT	G: Nov 2010-Mar 2014 E: Jun 2009-Feb 2014	n(G)=41 n(E)=57	62.34	20.06

*G=Gas
**E=Electricity

Figure 35 depicts actual energy consumption of the four residence halls in kBtu/Sq.m/Month in order of highest performance (lowest consumption): residence hall PS is the top performer followed by EH, WT and CSC. It must be noted consumption of WT and CSC are almost identical yet WT is a non-LEED residence hall.

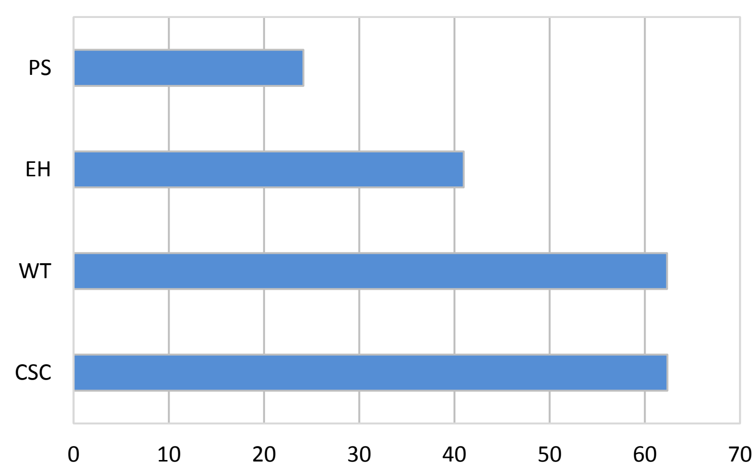


Figure 35-Actual energy consumption of LEED and Non-LEED residence halls in kBtu/Sq.m/Month

USGBC basis LEED certification on the projected energy cost reduction versus projected energy savings. This is a notable distinction as it is not a true representation of energy savings and reduces transparency of energy reduction. When dissecting savings using projected energy versus energy cost savings, there is a substantial variation between the two metrics.

In the case of PS, and CSC the energy savings are lower than noted energy cost savings entitling the residence hall to less points. However in the case of EH the projected energy savings are actually higher than the energy cost savings entitling the building to more EA points. Residence hall WT is non-LEED therefore this portion of the analysis does not apply. Figure 36 provides an overview of savings when energy cost and projected energy savings are dissected.

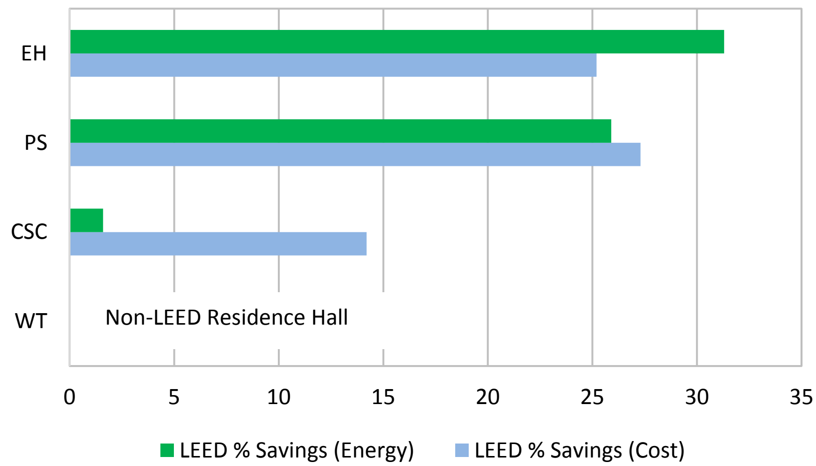


Figure 36-Comparison of LEED percent savings in terms of Cost and Energy

Table 42 provides an overview of the savings when the projected energy cost and projected energy savings are separated, as compared to LEED energy cost reduction and energy reduction.

Table 42-Energy consumption per LEED documentation (Residence Halls: EH, WT, CSC, and PS)

Res. Hall	Energy Reduction EA Credit 1* (Based on Cost)	Total Energy Reduction EA Credit 1 (Based on LEED template)	Energy Efficiency Reduction EA Credit 1 (Based on Energy Calculations)	Proposed Design Case (PDC)	Baseline Design Case (BDC)
EH	25.2% Savings	31.3% Savings	-20.3%	E=2,076,779 kWh	E=2,606,103 kWh
			-44.2%	G=4,280,317,121 Btu	G=7,664,030,656 Btu
PS	27.3% Savings	25.9% Savings	-28.6%	E=1,699,486 kWh	E=2,380,167 kWh
			-17.6%	G=2,213,608,854 Btu	G=2,686,210,745 Btu
CSC	14.2% Savings	1.6% Savings	-23.7%	E=1,687,063 kWh	E=2,211,099 kWh
			+46.9%	G=6,170,524,682 Btu	G=4,199,416,798 Btu
WT	Non-LEED Residence Hall (Not included in this analysis)				

* Extracted from submitted LEED Energy and Atmosphere (EA) documentation.

In LEED documentation electricity and gas consumption is initially individually calculated, but later combined to generate an overall metric for comparison between BDC and PDC cases. The combined value is the basis for the percent cost savings metric to attaining points. Per Table 42 electricity and gas consumption of the various residence halls are different, from the overall cost savings and energy reduction values.

4.2.4.2 LEED and Non-LEED Actual Energy Consumption Comparison to Agency Metrics

In comparing the residence halls to the various US agency metrics mixed results were found. Examining the comparison to US-DOE BEPD Residential northeast and west values, the highest performer (lowest consumer) was: PS consuming less by 72.27%, EH consuming more by 98.64%, WT at 202.18% and CSC consuming more by 202.33%.

Comparison to US-DOE BEPD Commercial values resulted in the same order of performance of PS, EH, WT, and CSC consuming less by 77.39%, and more by 3.83%, 57.94% and 58.02% respectively. The savings gap was minimized when compared to US-DOE BEPD Commercial metrics. This indicates the US-DOE BEPD commercial metric may be more representative of this building typology given the occupant mentality.

Comparing actual consumption to CBECS (89.70 kBtu/Sq.m/Month), reduced consumption was found by 73.10%, 54.31%, 30.50% and 30.47% for PS, EH, WT and CSC respectively. Table 43 outlines the various results when actual average consumption is compared to US agency metrics.

Table 43-Residence halls actual energy consumption compared to US-DOE BEPD and CBECS metrics

Res. Hall	Actual Avg. Consumption kBtu/Sq.m/Month	Standard Deviation of Data Set	Comparison of Actual to US Residential*	Comparison Actual to US Commercial**	Comparison Actual to CBECS***
EH	40.98	8.32	+98.64%	+3.83%	-54.31
WT	62.34	20.06	+202.18%	+57.94%	-30.50
CSC	62.37	5.30	+202.33%	+58.02%	-30.47
PS	24.13	1.14	-72.27%	-77.39%	-73.10

*US-DOE Building Energy Performance Database (BEPD) Residential Applications (NE=20.63 kBtu/Sq.m/Month, W=87.01 kBtu/Sq.m/Month)
**US-DOE BEPD Commercial Applications (NE=39.47 kBtu/Sq.m/Month, W=106.74 kBtu/Sq.m/Month)
***US Commercial Building Energy Consumption Survey (CBECS) (89.70 kBtu/Sq.m/Month)

In comparing residence halls to EU-EC (kBtu/Month/Person) metric the highest performer (lowest consumer) was: PS consuming less by 92.56%, and WT, CSC, EH by 81.79%, 80.37%, and 76.63% respectively.

The performance order of the residence halls differed from the area related intensity metric, highlighting potential gaps in performance reliant on benchmark unit of measures. Table 44 details the various residence hall energy intensities and their corresponding savings compared to EU-EC metrics.

Table 44-Residence halls actual energy consumption compared to EU-EC metrics

Res. Hall	Actual Avg. Consumption kBtu/Month/Person	Standard Deviation of Data Set kBtu/Month/Person	Comparison Actual to EU Metric* kBtu/Month/Person
EH	2,711.91	550.44	-76.63%
WT	2,111.91	679.69	-81.79%
CSC	2,276.64	193.30	-80.37%
PS	863.02	41.33	-92.56%

*EC Eurostat Report 2012 ISSN 1725-4566: Consumption= 11,598.40 kBtu/Month/Person

4.2.4.3 Non-LEED Residence Hall WT

Average energy consumption of non-LEED residence hall WT was 62.34 kBtu/Sq.m/Month with an SD of 20.06 kBtu/Sq.m/Month. Figure 37 provides a profile of the WT's actual electricity consumption over the five years of collected data. WT average actual consumption resulted in an overall increase of 3% in consumption over the years.

Although there was an increase in consumption over the years, the comparison to US and EU benchmarks were mixed. Favorable results were found when compared to EU-EC and CBECS data, at less than 81.79% and less than 30.50% respectively. Alternately consumption was higher by more than 202.18% and 57.94%, when compared to US-DOE BEPD residential and commercial values respectively. Table 45 and 46 provide an overview of the results found in the comparative analysis. Based on the findings residence hall WT was closer in consumption to the US-DOE BEPD commercial consumption rather than residential, and was substantially lower than the CBECS and EU-EC metrics.

Table 45-WT Comparison to US energy benchmarks

Res. Hall	Actual Avg. Consumption kBtu/Sq.m/Month	Standard Deviation of Data Set	Comparison of Actual to US Residential*	Comparison Actual to US Commercial**	Comparison Actual to CBECS***
WT	62.34	20.06	+202.18%	+57.94%	-30.50%

*USDOE Energy Performance Database Residential Applications (NE=20.63 kBtu/Sq.m/Month, W=87.01 kBtu/Sq.m/Month)
**USDOE Energy Performance Database Commercial Applications (NE=39.47 kBtu/Sq.m/Month, W=106.74 kBtu/Sq.m/Month)
***US CBECS (89.70 kBtu/Sq.m/Month)

Table 46-WT Comparison to EU energy benchmark

Res. Hall	Actual Avg. Consumption kBtu/Month/Person	Standard Deviation of Data Set kBtu/Month/Person	Comparison Actual to EU Metric* kBtu/Month/Person
WT	2,111.91	679.69	-81.79%

*EC Eurostat Report 2012 ISSN 1725-4566: Consumption= 11,598.40 kBtu/Month/Person

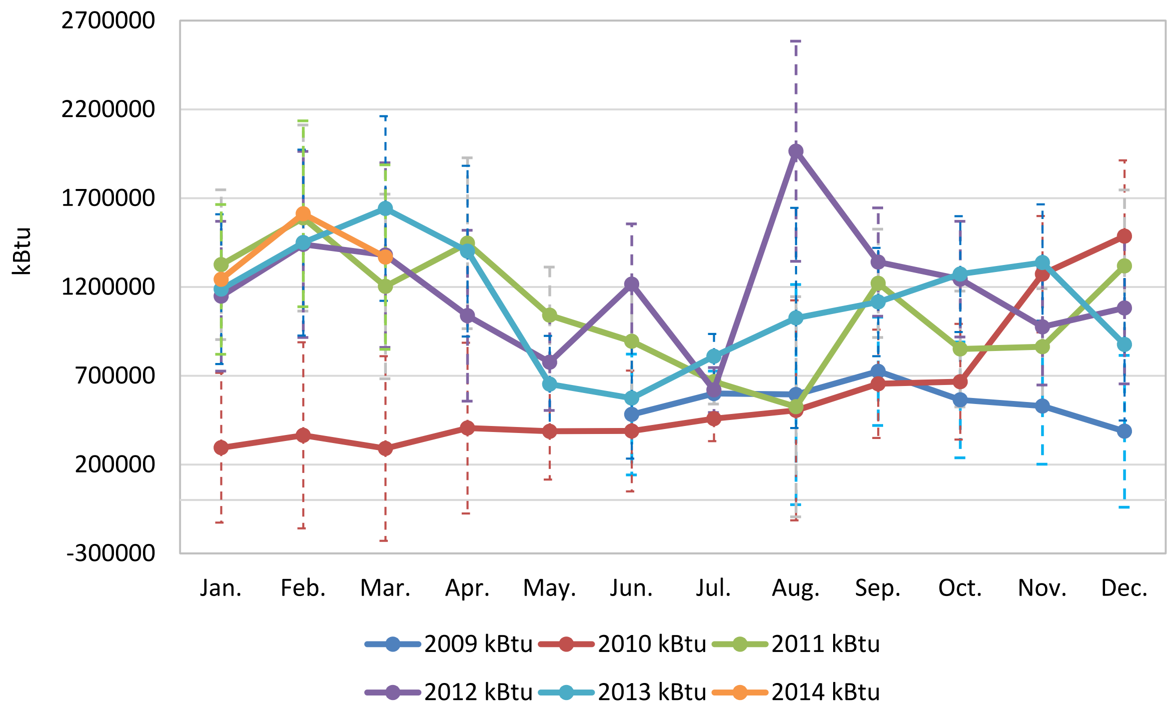


Figure 37-WT Actual energy consumption (gas and electricity-kBtu)

Examining weather patterns within the study's data date range, the US followed typical patterns in the years from 2002 to 2009, and in 2011 and 2013; reversely, in 2010, the coldest winter was experienced and in 2012 record summer heat and mildest winter was recorded (NWS 2013). WT is occupied year round given the institutions academic schedule and evident in Figure 37. The months with the highest average consumption were during the fall and spring semesters. Given the weather patterns in 2012 with record heat in the summer, the energy consumption was highest during that period evident in Figure 37. The energy consumption in the summer months (June, July and August) were lowest, followed by January winter recess. The highest consumption periods were attributed to intervals of high occupancy (returning students) and warmer months within those periods.

In running a bivariate correlation analysis, on the combined consumption of electricity and gas, gauging the impact of weather and month on the dataset; it was found that the REDTI index showed a statistically insignificant and weak inverse relationship. However month was more of a factor in consumption, with a strong statistically significant relationship. The bivariate correlation indicates consumption is tied to student behavior, rather than solely the weather. Table 47 outlines the results of the bivariate correlation analysis.

Table 47-WT Bivariate correlation (Month and REDTI)

Res. Hall	NOAA Zone*	Dates of Data Range	Month-Bivariate Correlation Results** $R_{d.f.}$ (N-2)= r, ρ	REDTI-Bivariate Correlation Results*** $R_{d.f.}$ (N-2)= r, ρ
WT	Northeast	Jun 2009-Mar 2014	r (55)= 0.546****, ρ<0.000	r (55)= -0.163 , ρ<0.114

*Based on National Oceanic and Atmospheric Administration (NOAA) Zone Designation
**Correlation between Consumption and Month
***Correlations between Consumption and NOAA Residential Energy Demand Temperature Index (REDTI)
****Correlation is significant at the 0.01 Level (1-tailed)

4.2.4.3.1 WT Student Survey Results

Please refer to the 'Student Survey' section within this report, for a detailed analysis of student responses on: frequency of thinking about energy consumption, and HE institutional education efforts on consumption conservation awareness programs.

4.2.4.4 LEED Residence Halls

4.2.4.4.1 Residence Hall EH

In calculating the LEED PDC, designers assume a specific number of days the residence hall will be in operation. The assumption is generally based on information provided by owner's facilities departments per academic schedules and expected occupancy. The number of days the building is in operation plays a significant role in the energy consumption metric as it can either reduce or increase actual savings.

Designers of EH assumed 305 days, and estimated a PDC of 947,215 kBtu/month. Using the 305-day value, EH resulted in the second lowest average energy consumption; when compared to all residence halls (LEED and non-LEED). The average monthly consumption and percent savings from PDC are outlined in Table 48.

Table 48-EH energy consumption and percent savings to PDC

	PDC kBtu/m	2008 kBtu/m	2009 kBtu/m	2010 kBtu/m	2011 kBtu/m	2012 kBtu/m	2013 kBtu/m
EC*	947,215	479,810	579,837	572,202	595,265	581,494	637,761
EC SD	N/A	302,161	266,267	251,189	211,316	200,323	233,807
EC % Change	N/A	N/A	+20.85%	-1.32%	4.03%	-2.31%	9.68%
EC +/- to PDC**	N/A	N/A	-38.79%	-39.59%	-37.16%	-38.61%	-32.67%

*EC=Energy Consumption
**Energy reduction cost savings per LEED documentation= -25.2% and total energy reduction based on LEED documentation= -31.3%

Although EH performed well, in dissecting average monthly energy consumption over the years an increase in consumption of 6.18% was found. If consumption of the first (2008) and last year (2014) with partial data are excluded, the average consumption is 593,312 kBtu/month with an SD of 26,203 kBtu/month. This value is 37.36% lower than the 'green' PDC case, showing higher savings than designer modeled energy savings of 31.3% and energy cost savings of 25.2%.

Although there was an increase in consumption over the years, the comparison to US and EU benchmarks were mixed. Favorable results were found when compared to EU-EC and CBECS data, at less than 76.63% and 54.31% respectively. Alternately consumption was higher by 98.64% and 3.83%, when compared to US-DOE BEPD residential and commercial values respectively. Table 49 and 50 provide an overview of the results found in the comparative analysis. Based on the findings EH was closer in consumption to US-DOE BEPD commercial consumption versus residential, and was substantially lower than the CBECS and EU-EC metrics.

Table 49-EH Comparison to US energy benchmarks

Res. Hall	Actual Avg. Consumption kBtu/Sq.m/Month	Standard Deviation of Data Set	Comparison of Actual to US Residential*	Comparison Actual to US Commercial**	Comparison Actual to CBECS***
EH	40.98	8.32	+98.64%	+3.83%	-54.31

*USDOE Energy Performance Database Residential Applications (NE=20.63 kBtu/Sq.m/Month, W=87.01 kBtu/Sq.m/Month)
**USDOE Energy Performance Database Commercial Applications (NE=39.47 kBtu/Sq.m/Month, W=106.74 kBtu/Sq.m/Month)
***US CBECS (89.70 kBtu/Sq.m/Month)

Table 50-EH Comparison to EU energy benchmark

Res. Hall	Actual Avg. Consumption kBtu/Month/Person	Standard Deviation of Data Set kBtu/Month/Person	Comparison Actual to EU Metric* kBtu/Month/Person
EH	2,711.91	550.44	-76.63%

*EC Eurostat Report 2012 ISSN 1725-4566: Consumption= 11,598.40 kBtu/Month/Person

In running a bivariate correlation analysis, on the combined actual consumption of electricity and gas gauging the impact of weather and month on the dataset; it was found that both REDTI and month held weak statistically insignificant relationships. The bivariate correlation indicated student consumption was neither tied to month nor heating degree days in this case. Given students occupy EH during the fall and spring semesters, with light summer occupancy this result is not surprising. Table 51 outlines the results of the bivariate correlation analysis.

Table 51-EH Bivariate correlation (Month and REDTI)

Res. Hall	NOAA Zone*	Dates of Data Range	Month-Bivariate Correlation Results** $R_{d.f.}$ (N-2)= r, ρ	REDTI-Bivariate Correlation Results*** $R_{d.f.}$ (N-2)= r, ρ
EH	Northeast	Jul 2008-Jan 2014	r (65)= 0.096, ρ<0.219	r (65)= 0.158, ρ<0.100

*Based on National Oceanic and Atmospheric Administration (NOAA) Zone Designation
**Correlation between Consumption and Month
***Correlations between Consumption and NOAA Residential Energy Demand Temperature Index (REDTI)

The months with the highest average energy consumption were during the fall and spring semesters. Energy consumption in the summer months (June, July and August) were the lowest, followed by January winter recess. The highest consumption periods were attributed to intervals of high occupancy (returning students) and cooler months within those periods. Since EH does not house full occupancy during summer months, minimal consumption was experienced. Figure 38 illustrates EH's actual energy consumption over the years.

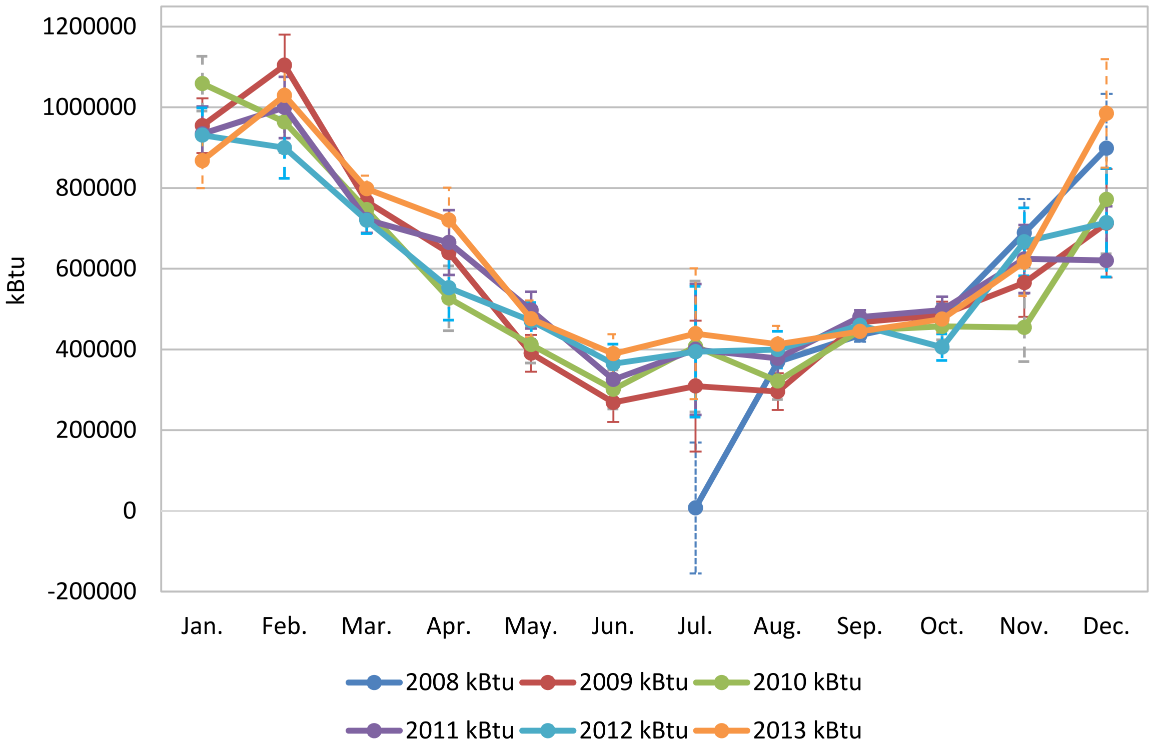


Figure 38-EH Actual energy consumption (gas and electricity-kBtu)

4.2.4.4.1.1 EH Student Survey Results

Please refer to the 'Student Survey' section within this report for a detailed analysis of student responses on: frequency of thinking about energy consumption, and HE institutional education efforts on consumption conservation awareness programs.

4.2.4.4.2 Residence Hall CSC

CSC designers assumed 360 operational days, with a LEED PDC of 993,919 kBtu/month. The average consumption was 1,024,486 kBtu/month with an SD of 86,985 kBtu/month. Residence hall CSC resulted in the poorest average energy performance when compared to all residence halls (LEED and non-LEED). The average monthly consumption and percent change from 2010 to 2013 are outlined in Table 52.

Table 52-CSC energy consumption and percent savings to PDC

	PDC kBtu/m	2010 kBtu/m	2011 kBtu/m	2012 kBtu/m	2013 KBtu/m
EC*	993,919	982,154	1,135,053	1,046,735	934,004
EC SD	N/A	790,161	257,515	168,078	N/A
% Change	N/A	N/A	+15.57%	-7.78%	N/A
EC +/- to PDC**	N/A	-1.18%	+14.20%	+5.31%	N/A

*EC=Energy Consumption
**Energy reduction cost savings per LEED documentation= -14.2% and total energy reduction based on LEED documentation= -1.6%

CSC underperformed compared to its counterparts, further dissecting the energy consumption over the years an increase of 3.89% was seen in consumption. The average consumption was 1,054,647 kBtu/month with an SD of 405,251 kBtu/month. This value is 6.11% higher than the PDC monthly consumption projection.

Although there was an increase in consumption over the years, the comparison to US and EU benchmarks were mixed. Favorable results were found when compared to EU-EC and CBECS data, at less than 80.37% and 30.47% respectively. Alternately consumption was higher by 202.33% and 58.02%, when compared to US-DOE BEPD residential and commercial values respectively. Table 53 and 54 outline the results found in the comparative analysis. Based on the findings CSC was closer in consumption to US-DOE BEPD commercial consumption than residential; and substantially lower than CBECS, and EU-EC metrics.

Table 53-CSC Comparison to US energy benchmarks

Res. Hall	Actual Avg. Consumption kBtu/Sq.m/Month	Standard Deviation of Data Set	Comparison of Actual to US Residential*	Comparison Actual to US Commercial**	Comparison Actual to CBECS***
CSC	62.37	5.30	+202.33%	+58.02%	-30.47

*USDOE Energy Performance Database Residential Applications (NE=20.63 kBtu/Sq.m/Month, W=87.01 kBtu/Sq.m/Month)
**USDOE Energy Performance Database Commercial Applications (NE=39.47 kBtu/Sq.m/Month, W=106.74 kBtu/Sq.m/Month)
***US CBECS (89.70 kBtu/Sq.m/Month)

Table 54-CSC Comparison to EU energy benchmark

Res. Hall	Actual Avg. Consumption kBtu/Month/Person	Standard Deviation of Data Set kBtu/Month/Person	Comparison Actual to EU Metric* kBtu/Month/Person
CSC	2,276.64	193.30	-80.37%

*EC Eurostat Report 2012 ISSN 1725-4566: Consumption= 11,598.40 kBtu/Month/Person

In running bivariate correlation on the combined actual consumption of electricity and gas; gauging the impact of weather and month on the dataset; it was found that REDTI held a strong yet statistically insignificant relationship, and month held a weak statistically insignificant relationship. The bivariate correlation indicates student consumption is neither tied to month nor heating degree days in this case. Table 55 outlines the results of the bivariate correlation analysis.

Table 55-CSC Bivariate correlation (Month and REDTI)

Res. Hall	NOAA Zone*	Dates of Data Range	Month-Bivariate Correlation Results** $R_{d.f.}$ (N-2)= r, ρ	REDTI-Bivariate Correlation Results*** $R_{d.f.}$ (N-2)= r, ρ
CSC	Northeast	Jun 2010-Jan 2013	r (30)= 0.099, ρ<0.295	r (30)= 0.91, ρ<0.309

*Based on National Oceanic and Atmospheric Administration (NOAA) Zone Designation
**Correlation of Consumption and Month
***Correlations of Consumption and NOAA Residential Energy Demand Temperature Index (REDTI)

The months with the highest average energy consumption were during the fall and spring semesters. The energy consumption in the summer months (June, July and August) were the lowest, followed by January winter recess. The highest consumption periods were attributed to time periods of high occupancy (returning students) and cooler months within those time periods. Even though CSC does not house students during the summer months it was lightly occupied; resulting in steady consumption over the summer periods, excluding its first year of operation. Figure 39 outlines actual energy consumption over the years data was collected.

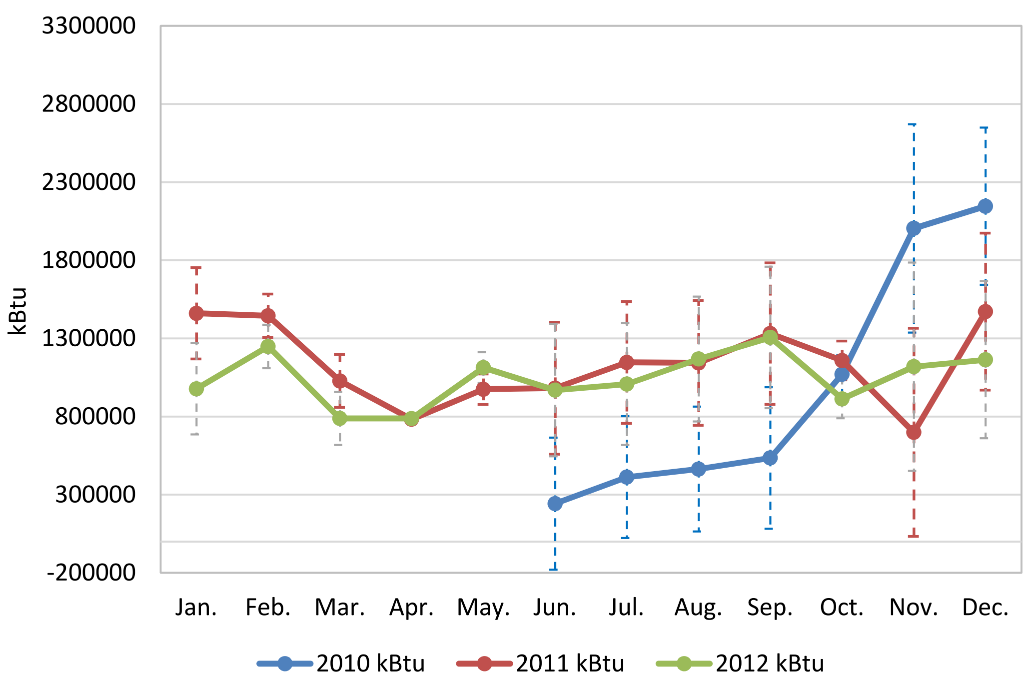


Figure 39-CSC Actual energy consumption (gas and electricity-kBtu)

4.2.4.4.2.1 CSC Student Survey Results

Please refer to the 'Student Survey' section within this report for a detailed analysis of student responses on: frequency of thinking about energy consumption, and HE institutional education efforts on consumption conservation awareness programs.

4.2.4.4.3 Residence Hall PS

PS designers assumed 250 operational days with a LEED PDC case of 667,708 kBtu/month. The average consumption was 454,699 kBtu/month with an SD of 201,632 kBtu/month. PS was the best performer (lowest consumer) amongst the compared residence halls (LEED and non-LEED). The average monthly consumption and percent change from 2010 to 2013 are outlined in Table 56.

Table 56-PS energy consumption and percent savings to PDC

	PDC kBtu/m	2010 kBtu/m	2011 kBtu/m	2012 kBtu/m	2013 KBtu/m
EC*	667,708	572,876	507,226	476,712	261,984
EC SD	N/A	347,666	90,980	103,561	264,322
% Change	N/A	N/A	-11.46%	-6.02%	-45.04%
EC +/- to PDC**	N/A	-14.20%	-24.03%%	-28.60%	-60.76%

*EC=Energy Consumption
**Energy reduction cost savings per LEED documentation= -27.3% and total energy reduction based on LEED documentation= -25.9%

PS outperformed all its counterparts, further dissecting its energy consumption over the years, an average decrease in consumption of 20.84% was seen. The average consumption was 454,699 kBtu/month with an SD of 201,632 kBtu/month. This value is 31.90% lower than the PDC monthly consumption projection. The comparison to US and EU benchmarks were all favorable showing savings of above 70% in all comparisons to US benchmark values; and savings over 90% when compared to the EU-EC value. Table 57 and 58 provide an overview of the results found in the comparative analysis. Based on the findings, CSC was closer in consumption to US-DOE BEPD commercial consumption than residential; and was substantially lower than CBECS, and EU-EC metrics.

Table 57-PS Comparison to US energy benchmarks

Res. Hall	Actual Avg. Consumption kBtu/Sq.m/Month	Standard Deviation of Data Set	Comparison of Actual to US Residential*	Comparison Actual to US Commercial**	Comparison Actual to CBECS***
PS	24.13	1.14	-72.27%	-77.39%	-73.10

*USDOE Energy Performance Database Residential Applications (NE=20.63 kBtu/Sq.m/Month, W=87.01 kBtu/Sq.m/Month)
**USDOE Energy Performance Database Commercial Applications (NE=39.47 kBtu/Sq.m/Month, W=106.74 kBtu/Sq.m/Month)
***US CBECS (89.70 kBtu/Sq.m/Month)

Table 58-PS Comparison to EU energy benchmark

Res. Hall	Actual Avg. Consumption kBtu/Month/Person	Standard Deviation of Data Set kBtu/Month/Person	Comparison Actual to EU Metric* kBtu/Month/Person
PS	863.02	41.33	-92.56%

*EC Eurostat Report 2012 ISSN 1725-4566: Consumption= 11,598.40 kBtu/Month/Person

In running a bivariate correlation analysis, on the combined actual consumption of electricity and gas, to gauge the impact of weather and month on the dataset it was found that both REDTI and month held weak statistically insignificant relationships. The bivariate correlation indicated student consumption was neither tied to month nor heating degree days. Table 59 outlines the results of the bivariate correlation analysis for both month and the REDTI index.

Table 59-PS Bivariate correlation (Month and REDTI)

Res. Hall	NOAA Zone*	Dates of Data Range	Month-Bivariate Correlation Results** R $_{d.f.}$ (N-2)= r, ρ	REDTI-Bivariate Correlation Results*** R $_{d.f.}$ (N-2)= r, ρ
PS	West	Jun 2011-Jun 2013	r (36)= -0.129 , ρ<0.220	r (36)= 0.098, ρ<0.279

*Based on National Oceanic and Atmospheric Administration (NOAA) Zone Designation
**Correlation of Consumption and Month
***Correlations of Consumption and NOAA Residential Energy Demand Temperature Index (REDTI)

The period with the highest average energy consumption was during the spring semester, while consumption in the fall semester held steady. The energy consumption for the summer months (June, July and August) were the lowest, followed by January winter recess. The highest consumption periods were attributed to the cooler months within the occupied intervals (returning students). Even though residence hall CSC does not house students during the summer months it was lightly occupied, resulting in steady consumption over the summer periods excluding its first year of operation. Figure 40 illustrates the actual energy consumption over the years data was collected.

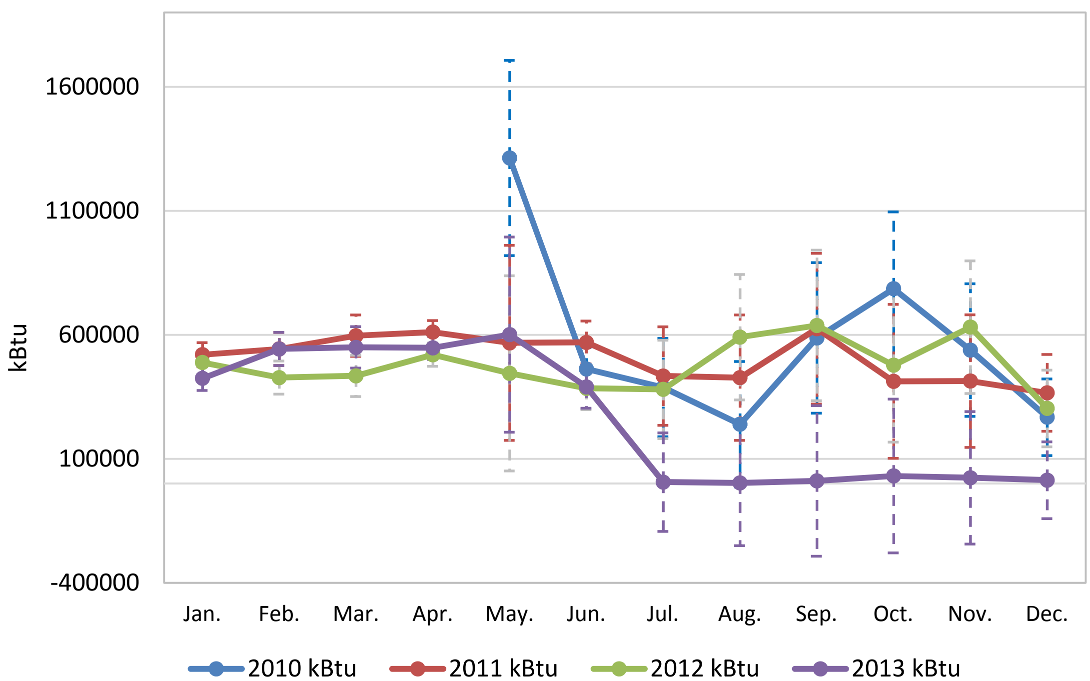


Figure 40-PS Actual energy consumption (gas and electricity-kBtu)

4.2.4.4.3.1 PS Student Survey Results

Please refer to the 'Student Survey' section within this report for a detailed analysis of student responses on: frequency of thinking about energy consumption, and HE institutional education efforts on consumption conservation awareness programs.

4.2.4.5 Comparison of LEED and Non-LEED Residence Halls

Assessing the age of the residence halls, the non-LEED residence hall is 11 years, while the average age of LEED residence halls is 3.67 years with an SD of 1.15 years. WT, EH, CSC and PS were built in 2002, 2008, 2011, and 2011 respectively.

Average energy consumption of EH, CSC, and PS (between yearly readings) resulted in consumption of: 6.18% more, 3.89% more and 20.84% less respectively between yearly readings. However compared to their LEED 'green' PDC cases, average yearly consumption of EH, CSC and PS were: 37.35% lower, 6.11% higher, and 31.90% lower respectively. These values result in an overall percent decrease in consumption of 21.05% as compared to their LEED 'green' PDC cases, but did not provide expected savings (Kats 2010).

EH and CSC are LEED-Gold while PS is LEED-Silver. In terms of energy consumption LEED-Silver residence hall PS outperformed its LEED-Gold counterparts. Although overall savings were realized, yearly savings were not steady. It must be noted variations between yearly consumption, minimize the ability of accurate consumption projections. Table 60 outlines the percent change over the years in the LEED dataset, as can be seen the percent change varies considerably. Typically facilities departments secure energy pricing based on their predictions of energy demand; therefore, stabilizing consumption is key to minimizing operating costs and attaining competitive energy pricing.

Table 60-LEED residence hall yearly energy consumption percent change (EH, CSC, and PS)

	2009 kBtu/m	2010 kBtu/m	2011 kBtu/m	2012 kBtu/m	2013 kBtu/m	Average % Change
EH % Change	+20.85%	-1.32%	+4.03%	-2.31%	+9.68%	+6.18%
CSC % Change	N/A	N/A	+15.57%	-7.78%	N/A	+3.89%
PS % Change	N/A	N/A	-11.46%	-6.02%	-45.04%	-20.84

To highlight whether climate impacted the consumption patterns of the dataset, bivariate correlation analysis was carried out. The analysis tested the relationship between month, REDTI index and monthly energy consumption. The results indicated weak correlations between month, REDTI and energy consumption except in the case of WT. In the case of WT consumption was highly correlated and significant (95% or above) to the month only. This indicates in the case of this dataset and specific building typology, heated degree days cannot aide in projecting energy consumption. Table 61 outlines the bivariate correlation results of actual monthly energy consumption to month and REDTI index. Other variables such as user consumption behavior, may be the driving force behind consumption variations. These results confirm the role of users as critical factors for sustainability in practice (Stevenson and Leaman 2010, Berardi 2013, GhaffarianHoseini et al. 2013).

Table 61-All residence halls bivariate correlation results (Month and REDTI)

Res. Hall	NOAA Zone*	Dates of Data Range	Month-Bivariate Correlation Results** R $_{d.f.}$ (N-2)= r, ρ	REDTI-Bivariate Correlation Results*** R $_{d.f.}$ (N-2)= r, ρ
EH	Northeast	Jul 2008-Jan 2014	r (65)= 0.096, ρ<0.219	r (65)= 0.158, ρ<0.100
WT	Northeast	Jun 2009-Mar 2014	r (55)= 0.546****, ρ<0.000	r (55)= -0.163 , ρ<0.114
CSC	Northeast	Jun 2010-Jan 2013	r (30)= 0.099, ρ<0.295	r (30)= 0.91, ρ<0.309
PS	West	Jun 2011-Jun 2013	r (36)= -0.129 , ρ<0.220	r (36)= 0.098, ρ<0.279

*Based on National Oceanic and Atmospheric Administration (NOAA) Zone Designation
**Correlation of Consumption and Month
***Correlations of Consumption and NOAA Residential Energy Demand Temperature Index (REDTI)
****Correlation is significant at the 0.01 Level (1-tailed)

Looking at gender inequity in energy consumption, patterns of increased or decreased consumption were not found. However this may be due to the limited dataset, in order to further examine the findings of researchers on this topic further study is required (Vinz 2009, Elliott 2013).

4.2.5 Energy Study Conclusions

Energy related studies suggest we are consuming energy at an unsustainable rate. Population growth, climate change, increased wealth, and urban development are resulting in increased energy consumption. These issues further compound the challenges faced with sustaining energy consumption. As a result we must engage new strategies to minimize energy consumption, pushing forth the idea of behavioral energy conservation and not only engineered energy efficiency measures (Bennetts and Bordass 2007, Berardi 2013). Tracking, measurement and user feedback collection methods, are fundamental to understanding consumption patterns and designing accordingly. Conservation and management strategies can only be developed effectively, with in-depth insight of qualitative and quantitative parameters through POEs.

In attempting to gain an understanding of HE residence hall energy-use, this study focused on identifying and comparing indoor energy use via three LEED and one non-LEED certified residence hall. It addressed several scopes including: identifying indoor energy consumption in HE residence halls, comparing results of LEED to non-LEED residence halls, assessing LEED modeled case projections with actual energy consumption, and comparing actual energy consumption to US and EU benchmark metrics.

Evidently isolating energy consumption of residence halls using US-DOE BEPD, CBECS, and EU-EC data is problematic due to differences in residence hall categorization between energy use studies and lack of available data. Different classifications of residence halls by agencies, compound the problem of collecting published data on energy consumption in residence halls. Also the vast gap between agency benchmark values, poses a problem in accurate residence hall energy consumption comparisons.

To address this gap actual consumption data was collected from four residence halls, indicating an indoor energy consumption range of 24 to 62 kBtu/Sq.m/Month. Overall actual residence hall consumption resulted in mixed savings as compared to values found in US-DOE BEPD residential (NE=20.63 kBtu/ Sq.m /Month, W=87.01 kBtu/ Sq.m /Month), US-DOE BEPD commercial (NE=39.47 kBtu/ Sq.m /Month, W=106.74 kBtu/ Sq.m /Month), CBECS (89.70 kBtu/ Sq.m /Month), and EU-EC (11,598.40 kBtu/ Sq.m /Person). The non-LEED residence hall consumed 47% more than average LEED residence hall consumption (42.49 kBtu/ Sq.m /Month), with the highest *SD* value of 20.06 kBtu/ Sq.m /Month. Showing even though LEED residence halls were not consistent in their savings, overall they were more sustainable and resulted in less variation than non-LEED residence hall WT.

On a yearly and monthly basis, the non-LEED had an overall 3% uptick in energy consumption for the entire time data was collected, and resulted in a higher SD. On the other hand LEED residence halls showed a decrease of 14.43% over the years and, on average, lower SD in consumption patterns. The average energy consumption of EH, CSC and PS was 21.05% lower when compared to LEED 'green' PDC cases. The combined data showed yearly decreases in energy consumption, rendering LEED residence halls more sustainable than the non-LEED residence hall. However in isolating the residence halls on the east coast from that on the west coast an increase in consumption of 3.20% is seen. These mixed results highlight the possibility that LEED labeling does not fully capture actual user behavior, and might result in unsustainable overall energy reduction expectations.

LEED documentation combines electricity and gas modeled consumption, and uses the combined value as a basis for the cost savings metric; this process minimizes the transparency of actual energy savings. If true energy reduction is to be gained in post occupancy, this metric should be reverted to its original components; ensuring transparency in energy consumption.

Increased transparency allows for reductions through accurate measurement and tracking potentials versus compounded metrics. The compounded metric dilutes actual savings and energy consumption reduction values. It is noteworthy to highlight if LEED was based on actual performance versus anticipated modeled energy cost savings, residence hall CSC would lose points while EH and PS would be entitled to more points.

Based on the results of actual energy consumption comparisons to US and EU benchmarks, it is apparent large gaps exist in benchmarking data. US-DOE BEPD (residential and commercial), CBECS and EU-EC benchmark values are highly varied, making comparisons difficult. Also given the agencies do not isolate this building typology, therefore the specialized demographic is not well represented for comparative purposes.

Gaps found in this study's comparison to agency benchmarks, may be the casualty of the building typology challenge. Residential applications may not best represent HE residence hall occupant mentality. In fact results showed better performance when compared to commercial building applications. Isolation of this building typology by various agencies will result in a benchmark truly representative, therefore more reflective benchmark comparison percentages.

Finally this study's findings on gender and consumption, did not support or refute the work of researchers on the topic of gender inequity in energy consumption (Vinz 2009, Elliott 2013). PS and EH (highest performing) had female populations at 38% on average, while WT and CSC had average female populations of 36%. Additional studies should be carried out using student feedback and quantitative metered data to assess behavioral and gender related consumption tendencies.

4.3 Thermal Logging Study (POE Indicator 6)

4.3.1 Research Methodology

4.3.1.1 Description of Selected Residence Hall

The student residence hall built in 2008 is a LEED Gold new construction, located in Worcester Massachusetts 42° 16'N 71° 48'W, in Zone 5 of the ASHRAE climate zone designation. Worcester is located in the heart of Massachusetts, 65 kilometers west of Boston. It is at an elevation 146 meters above sea level, resulting in an atmospheric pressure of 99.6 kPa. Climatic data for the city of Worcester was collected from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC). The recorded average outdoor monthly temperature and relative humidity for the study period was 3.84°C with an SD of 6.30°C and 70.92% with an SD of 22.06% respectively. The recorded average minimum temperature and relative humidity were: -10.60° C and 17.00% respectively. The recorded average maximum temperature and relative humidity were: 18.00° C and 100% respectively.

The residence hall houses a total of 228 students, with 31% female and 69% male population. A total of fourteen suites were selected for the purposes of this study. All suites with the exception of one were a four student single room and living room configuration, whilst one was a two bedroom with a living room configuration housing one staff member. Typically students may live in the residence hall for a maximum of two years, as it is only available to upperclassmen. The two-bedroom suite has been inhabited by the staff member for a total of five years. The floor plans of the suites logged may be found in Figures 41 and 42 below:

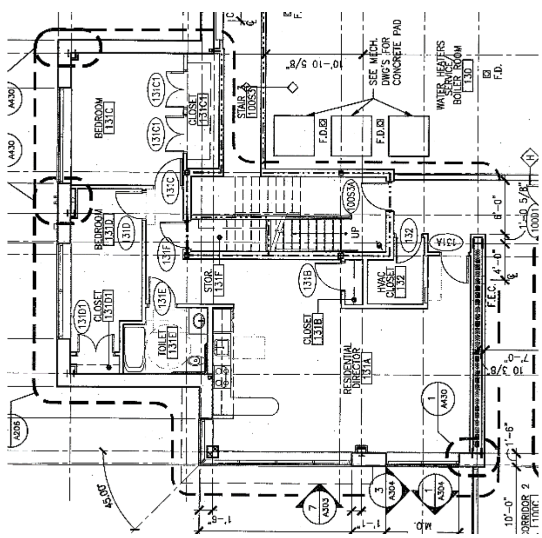


Figure 41-EH Two Bedroom Suite Layout

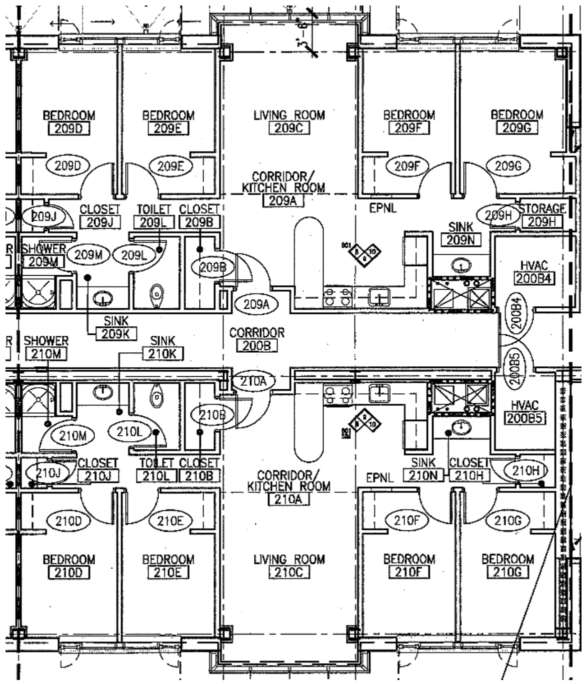


Figure 42-EH Four Student Singles Layout

The suites are located both in the North and South quadrants of the building, resulting in 53 occupants, responsible for the heating and cooling of the entire suite. Individual rooms within the suites do not have thermostats. The living room windows also do not open, only windows within the student rooms have the capability of opening. Table 62 outlines their various locations within the building envelope.

Table 62-Location of logged suites within Residence Hall EH and number of occupants

Suite Designations	Suite Floor	Quadrant Location	Number of Occupants
Suite 66	First	North	1
Suite 207	Second	South West	4
Suites 208,210	Second	South East	8
Suite 209	Second	North West	4
Suite 307	Third	South West	4
Suite 308	Third	South East	4
Suite 407	Fourth	South West	4
Suite 408	Fourth	South East	4
Suite 409	Fourth	North West	4
Suite 410	Fourth	North East	4
Suite 507	Fifth	South West	4
Suite 508	Fifth	South East	4
Suite 509	Fifth	North West	4

4.3.1.2 Logging Study Methodology

The logging study was conducted from October 30th 2013 till December 3rd 2013, resulting in a 35 day study period of the residence hall's indoor dry-bulb temperature and relative humidity conditions. The loggers recorded data at 2-minute intervals, generating a total sample size of 24,206 temperature and relative humidity data points. Table 63 outlines the weekly logging timetable, exact times data was downloaded, and loggers reset.

Table 63-Weekly logging timetable

Logging Study Week	Data Collected From	Data Collected Till	n-sample size
Week 1	10/30/2013, 18:00	11/08/2013, 15:24	6,403
Week 2	11/08/2013, 16:48	11/15/2013, 14:04	4,959
Week 3	11/15/2013, 16:20	11/22/2013, 14:14	4,978
Week 4	11/22/2013, 16:04	12/03/2013, 14:16	7,866

Table 64-HOBO U12 Measurement range and accuracy

Instrument	Measurement Range	Measurement Accuracy
HOBO U12-Temperature	-20°C to 70° C	±0.35°C from 0° C to 50°C
HOBO U12-Relative Humidity	5% to 95%	±2.5% from 10% to 90%

Sixty six HOBO-U12 loggers were installed for the purposes of this study. A total 53 students' conditions were logged, representative of 23.25% of the total residence hall population. The HOBO-U12 loggers measured indoor dry-bulb temperature, and relative humidity. Table 64 outlines the instruments measurement thresholds and compliance with ASHRAE Standard 55-2013 section 7.3.4 "Physical Measurement Device Criteria". The loggers were positioned following ASHRAE 55-2013 standard section 7.3.2 "Physical Measurement Positions within the Building".

4.3.1.3 Student Survey Methodology

Student occupant feedback was assessed through the use of terminology and sample survey provided within the ASHRAE 55-2004 and 2013 standard. The survey covered topics of metabolic unit (MET unit), clothing insulation factor, drafts, air ventilation, indoor temperature, and indoor humidity. Questions related to adaptive strategies were not provided to the students, these questions should be included in future POE analysis.

Votes for perceived indoor temperature were based on a seven-point Likert scale, with 1 indicating cold, 4 neutral and 7 hot conditions. Votes for perceived indoor relative humidity were based on a seven-point Likert scale, with 1 indicating too dry, 4 neutral and 7 too moist/humid. Votes for satisfaction with indoor temperature and indoor relative humidity were based on a seven-point Likert scale, with 1 indicating very dissatisfied, 4 neutral and 7 very satisfied. The survey seven-point thermal sensation scale was developed using ASHRAE 55-2013 standard's designations as found in section 7.3.1.2 "Point in Time Surveys".

The surveys were administered to all students personally at the end of every week when the logger data was downloaded. Depending on whether the students were present in their residence hall suites, they were requested to fill out the survey. The response rate per week varied depending on students' presence and participation. The overall responses rate over the four week period was 36.32%, in line with the requirements of ASHRAE 55-2013 for survey response rates. Based on ASHRAE 55-2013 section 7.3.1. "Surveys of Occupant Responses to Environment", if more than 45 occupants have been selected a minimum of 35% response rate must be achieved. This study achieved a higher response rate by 1.32%. The dates student surveys were administered are outlined in Table 65.

Table 65-Dates student surveys administered and response rates

Logging Study Week	Survey Administered	n-sample size	Response Rate
Week 1	11/08/2013	23	43.40%
Week 2	11/15/2013	17	32.07%
Week 3	11/22/2013	22	41.51%
Week 4	12/03/2013	15	28.30%
All Weeks		**77**	**36.32%**

Student occupants were approached based on whether they inhabited the series of suites logged. The suites were located on various floors to ensure a random sample was logged. The date, time, suite number, student room number within suites, floor level and room orientation were noted on each occupant's survey, later utilized as filters for the data gathered.

Statistical Package for Social Sciences (SPSS) version 19, was used to analyze the data. Multi-variable linear regression was carried out for the various survey questions using single tailed significance testing both in stepwise and non-stepwise (enter) approaches to identify independent variables with the largest impact on dependent variables. Collinearity was also examined through the examination of variance inflation factors (VIF), scatterplots graphing regression standardized predicted values and regression standardized residual values; ensuring that no one variable's impact has been misrepresented in the findings.

The logged data has been plotted on the ASHRAE comfort zone Psychrometric charts. The graphs capture whether or not the building has provided comfortable conditions during the study period. The Psychrometric chart indicates the operative temperature in degree Celsius, humidity ratio and comfort within the 1.0 clothing and 0.5 clothing insulation factor zones.

4.3.2 Results

4.3.2.1 Student Survey Results

The total number of survey responses analyzed over the four week period, in the suites logged, consisted of 77 responses. The gender split of respondents was 99% male and 1% female. Given that the same units were surveyed each week, the respondents were from the same pool of logged units. Their weekly responses were individually analyzed and reported singularly as point in time surveys. Table 66 details the number of respondents per suite location, weekly response rates and cumulative achieved response rate.

Table 66-Respondent weekly response rates

Suite	**Suite Floor**	**Quadrant Location***	**Total # of Occupants in Suite**	**Week 1 Responses** 11/08/2013	**Week 2 Responses** 11/15/2013	**Week 3 Responses** 11/22/2013	**Week 4 Responses** 12/03/2013
66	First	N	1	1	1	1	1
207	Second	SW	4	2	2	1	2
208,210	Second	SE	8	2	2	2	1
209	Second	NW	4	3	1	1	2
307	Third	SW	4	1	0	2	0
308	Third	SE	4	1	1	1	2
407	Fourth	SW	4	2	1	3	2
408	Fourth	SE	4	1	4	3	1
409	Fourth	NW	4	2	2	2	1
410	Fourth	NE	4	1	0	0	2
507	Fifth	SW	4	2	0	1	0
508	Fifth	SE	4	4	2	4	1
509	Fifth	NW	4	1	1	1	0
Total Survey Responses				**23**	**17**	**22**	**15**
Weekly Response Rate				**43.40%**	**32.07%**	**41.51%**	**28.30%**
Cumulative Average Response Rate				**36.32%**			

*N=North, NE=North East, NW=North West, S=South, SE=South East, SW=South West

On average students spend 63% of their time in the residence hall of which 74% is spent in their bedrooms. 35% indicated that the air in their area is stale/not fresh and 10% indicated a draft. 55% were satisfied with their level of control over changing the temperature, and 74% indicated thermostat controls were easy to use. The weekly student responses are outlined Table 67.

Table 67-Student survey results per week

Survey Question	**Week 1 Responses** 11/08/2013	**Week 2 Responses** 11/15/2013	**Week 3 Responses** 11/22/2013	**Week 4 Responses** 12/03/2013	**Week 1-4**
Time Spent in residence hall	61.00%	65.00%	64.00%	63.00%	63.00%
Stand.dev. Time in residence hall	17.00%	13.00%	13.00%	16.00%	14.00%
Time Spent Near a window	73.91%	70.59%	81.82%	66.67%	74.03%
Air in their area is stale (stuffy, not fresh)	34.78%	41.18%	27.27%	40.00%	35.06%
There is a draft in the area they spent most of their time	4.35%	17.65%	13.64%	6.67%	10.39%
Satisfied with the level of control over changing temperature	47.83%	47.06%	63.64%	66.67%	54.55%
Thermostat Controls are easy to use	82.61%	64.71%	72.73%	80.00%	74.03%

4.3.2.2 Temperature (T)-Survey Results and Logged Data

The temperature range students are allowed within their suites, is regulated between 20°C to 22°C. Therefore the distribution of the indoor temperatures logged was normal, as it was within the confines of this range. Given this restriction the logged data could not show the preferred temperatures students may set their indoor environments to, if they were afforded the freedom of unregulated thermostats.

The student clothing insulation factor increased over the duration of the study by an average of 6% reflective of the decrease in outside temperature from October to December. However the SD increased by an average of 159%, indicating a large variation between occupant clothing preferences. The results indicate the higher spectrum of their clothing insulation factor (0.96) falls shy of ASHRAE standard 55-2013, 1-clothing zone; while the lower range (0.5) falls within its 0.5-clothing zone. Table 68 outlines the student survey results as related to perception and satisfaction with indoor air temperature, clothing insulation factor and typical activity level (MET unit).

Table 68-Student survey results (temperature, clothing insulation factor, activity level)

Survey Question	Week 1 Responses 11/08/2013	Week 2 Responses 11/15/2013	Week 3 Responses 11/22/2013	Week 4 Responses 12/03/2013	Week 1-4
Perceived Temperature	3.65	3.65	3.59	3.93	3.69
Stand.dev. Perceived Temperature	1.11	0.79	0.80	0.96	0.92
Level of Satisfaction with Temperature	4.48	4.65	4.50	4.27	4.48
Stand.dev. Level of Satisfaction with Temperature	1.31	1.37	1.37	1.28	1.31
Average Clothing Insulation Factor	0.66	0.72	0.76	0.78	0.73
Stand.dev. Clothing insulation factor	0.10	0.27	0.27	0.24	0.23
Typical Activity Level (MET unit)	1.02	1.07	1.06	1.01	1.04
Stand.dev. Typical Activity Level (MET unit)	0.17	0.28	0.22	0.21	0.22

In regressing temperature satisfaction on all other variables asked within the survey, the two variables with the strongest relationships were: indoor humidity satisfaction and clothing insulation factor. Clothing insulation factor held a negative strong relationship. The higher their clothing insulation factor the less likely they were to be satisfied with indoor temperature. This indicates students preferred to wear less clothing and if they had to wear more clothing they more dissatisfied with their indoor temperature conditions. The satisfaction with indoor air humidity held a positive strong relationship. The more satisfied they were with their indoor air humidity the more likely they were to be satisfied with their indoor air temperature conditions. Table 69 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air temperature in the area students spend most of their time.

Table 69-EH Relationship between indoor temperature satisfaction (dependent variable) and humidity satisfaction and clothing factor (independent variables) using multiple linear regression analysis (n=77)

Dependent Variable	Level of Satisfaction with Indoor Temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Level of Satisfaction with Indoor Air Humidity	0.390	0.000
Clothing Insulation Factor	-0.286	0.008
Model	**r=0.454, R square=0.206**	

Table 70 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 70-EH Relationship between indoor temperature satisfaction and independent variables excluded from multiple linear regression analysis model (n=77)

Dependent Variable	Level of Satisfaction with Indoor Temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Average time spent in residence hall	-0.061	0.558
On Floor where they spent most of the time	0.171	0.110
Whether they spent most of their time near a window	0.118	0.274
If the air was stale (stuffy, not fresh)	0.080	0.443
If there was a draft in their space	-0.172	0.127
If they were satisfied with the level of control over changing the temperature	0.145	0.173
Typical Activity Level (MET unit)	-0.112	0.319
Recorded Indoor Temperature	-0.187	0.076
Recorded Indoor Relative Humidity	-0.083	0.431

In regressing perceived indoor temperature, the variables with the strongest relationships were: clothing insulation factor, perceived indoor air humidity, draft in their space and level of satisfaction with indoor temperature.

The results indicate an increase in clothing insulation factor, did not translate into the perception of warmer indoor temperature conditions. Students who perceived their indoor conditions as drier, were more likely to perceive indoor temperature conditions as warmer. Students who felt a draft in their space were more likely to perceive their indoor air temperature as colder. Students who were more satisfied with their indoor temperature, were more likely to feel warmer. Table 71 outlines the standardized beta coefficient and significance of the model with the most power to predict perception of indoor air temperature in the area students spend most of their time.

Table 71-Relationship between perception of indoor temperature and independent variables using multiple linear regression analysis (n=77)

Dependent Variable	Perception of Indoor Temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Clothing Insulation Factor	-0.392	0.000
Perceived Indoor Air Humidity	0.269	0.012
If there was a draft in their space	-0.245	0.016
Level of Satisfaction with Indoor Temperature	0.211	0.043
Model	**r=0.543, R square=0.295**	

Table 72 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 72-Relationship between perception of indoor temperature and independent variables excluded from the multiple linear regression model (n=77)

Dependent Variable	Perception of Indoor Temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Average time spent in residence hall	-0.018	0.860
On Floor where they spent most of the time	0.107	0.348
Whether they spent most of their time near a window	0.025	0.813
Level of Satisfaction with Indoor Air Humidity	-0.018	0.892
If the air was stale (stuffy, not fresh)	-0.103	0.317
If they were satisfied with the level of control over changing the temperature	-0.024	0.820
Typical Activity Level (MET unit)	-0.152	0.156

Given the results assessing the average clothing insulation factor, on average students clothing factor was 0.73, shy of the 1.0 ASHRAE clothing zone by 0.23 (equivalent to a thin long sleeve sweater per ASHRAE 55-2013-Table 5.2.2.2B 'Garment Insulation'). The logged data may be found on the ASHRAE Psychrometric graphs in Appendix C-Thermal Logging Study Weekly Logged Temperature and Relative Humidity. As evident, logged data fell within the 1.0 clothing insulation zone and beyond. This indicates the conditions within the building are cool based on student clothing insulation factors.

The findings from the logged data are in agreement with the responses of students indicating perceived temperature at 3.69 with an SD of 0.92. Placing average perception of indoor temperature at 'slightly cool' and in the range of 'cool' to 'neutral'. However the indoor satisfaction with temperature ranked at 4.48 with an SD of 1.33, indicating 'neutral' on average and in the range of 'slightly dissatisfied' to 'slightly satisfied'. Even though the logged data indicates cool conditions the satisfaction with indoor temperature resulted in 'neutral' hence non-negative. This finding supports arguments made by researchers that occupants of sustainable buildings are more likely to forgive imperfect thermal conditions (Steemers and Yun 2009, Stevenson and Leaman 2010, Gram-Hanssen 2010).

To further explore variations in the clothing insulation factor, given it is the strongest variable impacting perception and satisfaction of indoor temperature; the data was further dissected into North and South suites. Table 73 outlines the findings from the student surveys and logged data per North and South suite locations.

Table 73-North and South suites survey and logged data findings

Description	North Suites Responses	South Suites Responses
Average Clothing Insulation Factor	0.77	0.71
Stand.dev. Clothing Insulation Factor	0.22	0.23
Perceived Temperature	3.50	3.77
Stand.dev. Perceived Temperature	1.22	0.75
Level of Satisfaction with Temperature	4.13	4.64
Stand.dev. Level of Satisfaction with Temperature	1.33	1.29
Perceived Humidity	3.79	3.79
Stand.dev. Perceived Humidity	0.41	0.72
Level of Satisfaction with Humidity	4.50	4.40
Stand.dev. Level of Satisfaction with Humidity	0.88	1.01
Air in their area is stale (stuffy, not fresh)	50.00%	28.00%
There is a draft in the area they spent most of their time	17.00%	8.00%
Satisfied with the level of control over changing temperature	21.00%	70.00%
Typical Activity Level (MET unit)	1.10	1.01
Stand.dev. Typical Activity Level (MET unit)	0.25	0.20
Minimum Temperature °C	20.90°C	20.20°C
Maximum Temperature °C	25.00°C	23.90°C
Average Temperature °C	22.40°C	22.20°C
Stand.dev. Temperature °C	1.00°C	0.80°C
Minimum Relative Humidity %	22.30%	20.60%
Maximum Relative Humidity %	39.40%	40.70%
Average Relative Humidity %	29.10%	29.40%
Stand.dev. Relative Humidity %	5.60%	5.80%

The clothing factor in the North suites was higher at 0.77 versus the South suites at 0.73. This variation may be due to the sun path and solar gains in the southern suites. It must be noted that the difference between their activity levels was minimal, South suites were less active (avg. 1.01) than North suites (avg. 1.10).

Students in the South suites were also more satisfied with their level of control over changing temperature than those in North suites. Over 85% of South suite students indicated thermostat controls were easy to use versus 50% in the North suites. Students' perception of their indoor temperature was warmer in the South suites, and on average more satisfied than those in the North suites. The perception of indoor temperature was cooler in the North suites and students were less satisfied with their indoor temperature conditions, even though their recorded indoor temperatures were higher than the South suites. The perception and satisfaction with indoor air humidity was constant between the North and South suites; however, the South suites depicted a larger SD. This variation in the SD may be the result of warmer spaces due to the sun path. Figures 43 and 44 show the indoor recorded temperatures over the weeks and their corresponding clothing insulation factor.

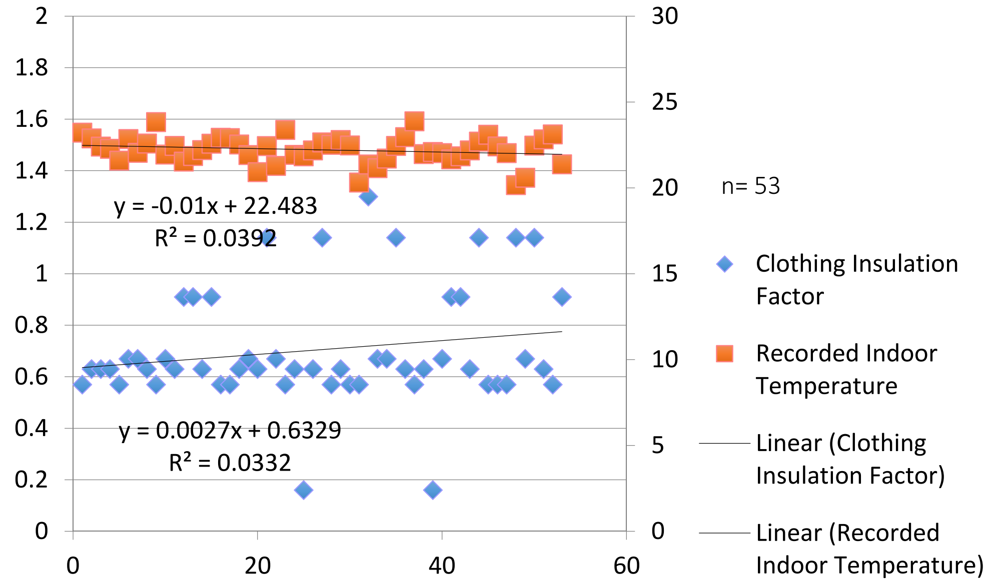


Figure 43-South Suites clothing insulation factor and recorded indoor temperature (All Weeks)

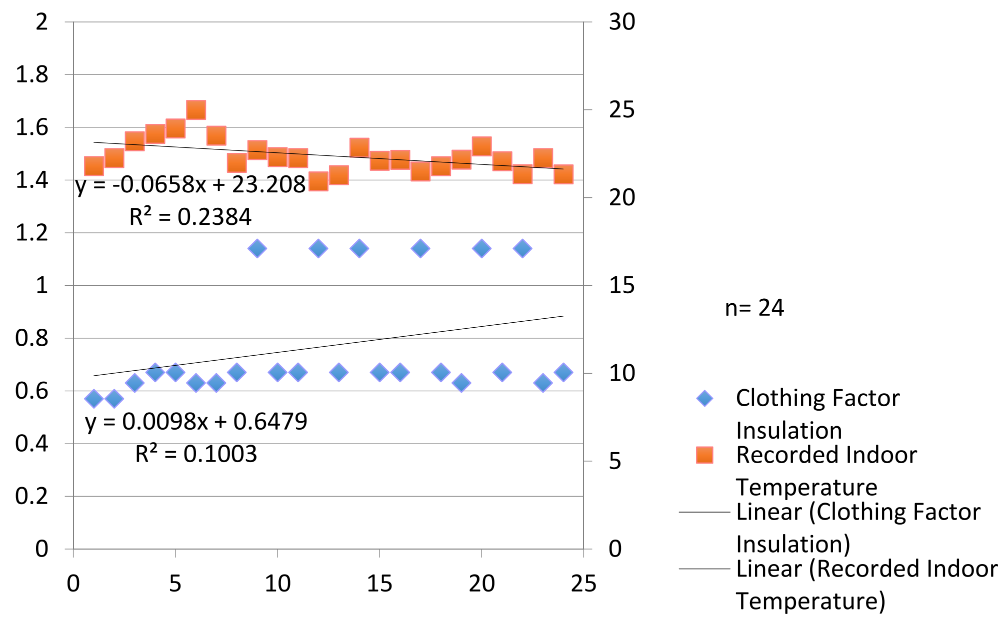


Figure 44-North Suites clothing insulation factor and recorded indoor temperature (All Weeks)

4.3.2.3 Relative Humidity (RH)-Survey Results and Logged Data

On average students spent 63% of their time indoors in their residential units and 74% in their bedrooms. It is evident students spend majority of their time in their residential units and bedrooms, clearly such environments should be healthy and comfortable. In an alternate study it was found on average students perform 30% of their academic work in their residential environments (Innis and Shaw 1997).

ASHRAE standard 55-2013 does not provide guidance on survey questions related to indoor humidity. In the sample survey provided within ASHRAE 55-2013 no direct indoor humidity questions are posed to occupants. Given the existing scientific literature on the importance of indoor humidity on healthy environments, this study incorporated direct humidity questions on surveys with ample space for student comments.

Examining student perception of indoor air humidity the results showed an average of 3.79 with an SD of 0.64. Placing average perception of indoor air humidity at 'dry' and in the range of 'dry' to 'neutral'. The indoor air humidity satisfaction ranked at 4.43 with an SD of 0.97, placing it at 'neutral' and in the range of 'slightly dissatisfied' to 'satisfied'. Table 74 outlines the weekly survey results as related to the perception and satisfaction with indoor air. Even though there was a large SD in their perceptions of indoor air humidity, the logged data indicates indoor conditions were indeed too dry and below acceptable (30%) levels.

Table 74-Student survey results on indoor air humidity satisfaction and perception

Survey Question	**Week 1 Responses** 11/08/2013	**Week 2 Responses** 11/15/2013	**Week 3 Responses** 11/22/2013	**Week 4 Responses** 12/03/2013	**Week 1-4**
Perceived Humidity	3.83	3.71	3.68	4.00	3.79
Stand.dev. Perceived Humidity	0.58	0.85	0.72	0.00	0.64
Level of Satisfaction with Humidity	4.43	4.41	4.41	4.47	4.43
Stand.dev. Level of Satisfaction with Humidity	0.90	1.12	1.05	0.83	0.97
Air in their area is stale (stuffy, not fresh)	34.78%	41.18%	27.27%	40.00%	35.06%
There is a draft in the area they spent most of their time	4.35%	17.65%	13.64%	6.67%	10.39%

In regressing level of satisfaction with indoor air humidity on all other variables with in the survey, the strongest positive relationships were found with: perception of indoor air humidity, level of satisfaction with indoor air temperature, draft conditions, and whether the air in their space was stale/not fresh.

Table 75 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air humidity in the area students spend most of their time. This indicates as conditions became more humid, students were more likely to be satisfied with their indoor air humidity. As their satisfaction with indoor temperature increased they were more likely to be satisfied with their indoor air humidity as well. In terms of ventilation students who felt a draft in their area were more likely to be satisfied with their indoor humidity conditions versus those who did not.

Students who said their air was stuffy were more likely to be satisfied with their indoor air humidity conditions versus those who did not.

Table 75-Relationship between indoor air humidity satisfaction (dependent variable) and independent variables using multiple linear regression analysis (n=77)

Dependent Variable	Level of Satisfaction with Indoor Air Humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Perception of Indoor Air Humidity	0.454	0.000
Level of Satisfaction with Indoor Temperature	0.350	0.000
Draft in the area they spend most of their time	0.373	0.000
If the air in the area they spend most of their time is stale (stuffy, not fresh)	0.231	0.009
Model	**r=0.704, R Square=0.495**	

Table 76 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 76-Relationship between indoor air humidity satisfaction (dependent variable) and independent variables excluded from multiple linear regression analysis model (n=77)

Dependent Variable	Level of Satisfaction with Indoor Air Humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Average time spent in residence hall	0.023	0.797
On Floor where they spent most of the time	-0.010	0.920
If they spend most of their time in their bedroom	-0.018	0.834
Whether they spent most of their time near a window	0.001	0.990
Their perception of Indoor Temperature	-0.082	0.377
If they were satisfied with the level of control over changing the temperature	0.066	0.453
Clothing Insulation Factor	0.105	0.248
Their Typical Activity Level (MET units)	-0.116	0.186
Recorded Indoor Temperature	0.071	0.409
Recorded Indoor Humidity	0.024	0.779

In regressing perceived indoor air humidity, on all other variables, the strongest relationships were found with: level of satisfaction with indoor air humidity, clothing insulation factor, the floor they spent most of their time and their perception of indoor temperature.

This indicates the more satisfied students were with indoor air humidity the more humid they perceived their conditions. The higher student clothing factor the more humid they perceived their environment. Students on the lower floors perceived the indoor air humidity to be drier. The warmer students perceived their indoor air temperature, the more humid they perceived their indoor air humidity conditions. Table 77 outlines the standardized beta coefficient and significance of the model with the most power to predict perception of indoor air humidity in the area students spend most of their time.

Table 77-Relationship between perception of indoor air humidity (dependent variable) and independent variables using multiple linear regression analysis (n=77)

Dependent Variable	Perception of Indoor Air Humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.001
Level of satisfaction with indoor air humidity	0.450	0.000
Clothing insulation factor	0.369	0.001
On Floor where they spent most of the time	-0.265	0.007
Their perception of Indoor Temperature	0.229	0.025
Model	**r=0.620, R Square=0.384**	

Table 78 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 78-Relationship between perception of indoor air humidity (dependent variable) and independent variables excluded from multiple linear regression analysis model (n=77)

Dependent Variable	Perception of Indoor Air Humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Average time spent in residence hall	0.147	0.120
If they spend most of their time in their bedroom	-0.004	0.968
Whether they spent most of their time near a window	-0.098	0.323
Level of Satisfaction with Indoor Temperature	-0.103	0.348
If the air in the area they spend most of their time is stale (stuffy, not fresh)	0.143	0.142
Draft in the area they spend most of their time	0.086	0.431
If they were satisfied with the level of control over changing the temperature	0.050	0.606
Their Typical Activity Level (MET units)	0.129	0.205
Recorded Indoor Temperature	0.121	0.203
Recorded Indoor Humidity	0.097	0.316

4.3.2.4 Logged Data and Student Feedback on Thermal Comfort Parameters

Examining student comments many complaints were received about very low humidity levels, resulting in negative health impacts such as dry eyes, sore throats and nose bleeds. Given the feedback on low humidity and stuffy/stale air the next sections detail the logged data and its health impacts. Detailed student comments related to their indoor thermal conditions may be found in Appendix D-Thermal Logging Student Comments. The comments provided by students were divided into three categories: positive, negative and neutral comments.

Table 79 outlines the various comment types indicated on the surveys per week. Students provided comments on various thermal comfort parameters such as controllability of systems, indoor air temperature and humidity. Their temperature controls related comments indicated frustration over their ability to change the temperature beyond the permitted range provided to them by the facilities department (20° C to 22°C). 84% of students voiced negative feedback over the lack of control while, 66% indicated improper ventilation in their apartments and very low humidity levels. 55% indicated satisfaction with the level of control over changing the temperature, while 74% indicated thermostat controls were easy to use. However it must be noted, in many instances students indicated it was easy to use because it simply does not work at all.

Table 79-Weekly comment percentages on humidity, ventilation and thermostat controls

Type of Comment	Week 1 Responses 11/08/2013	Week 2 Responses 11/15/2013	Week 3 Responses 11/22/2013	Week 4 Responses 12/03/2013	Week 1-4
Positive Humidity and Ventilation	20%	0%	0%	0%	5%
Negative Humidity and Ventilation	80%	80%	71%	100%	66%
Neutral Humidity and Ventilation	0%	20%	29%	0%	29%
Total Comments related to Humidity and Ventilation	***22%***	***29%***	***32%***	***27%***	***28%***
Positive Thermostat Comments	9%	0%	0%	0%	2%
Negative Thermostat Comments	82%	89%	82%	75%	84%
Neutral Thermostat Comments	9%	11%	18%	25%	14%
Total Comments related to Thermostat	***48%***	***53%***	***50%***	***27%***	***45%***

As related to ventilation, upon visual inspection it was found that when students cook localized smog is formed in their living room areas. This results in the activation of their smoke alarms. As a workaround students wrap ceiling smoke detectors with plastic bags, tape and secure it with a hanger to the ceiling. Although this is a temporary fix it is also a danger in the event of a fire. Figure 45 provides a work around devised by students to avoid the activation of smoke detectors in their common living area.

Figure 45-Smoke detector workaround devised by students due to poor ventilation and localized smog (Residence Hall-EH)

In assessing student satisfaction with indoor air humidity and temperature, the logged data was split into various time ranges to identify if any trends in humidity and temperature exist. The time range graphs were developed looking at the hours between 8 AM to 4 PM, 4 PM to 12 AM and 12 AM to 8 AM. The graphs are represented on the ASHRAE Psychrometric graphs outlining the various comfort zones according to their clothing factors, found in Appendix B-Thermal Logging Study Time Range Analysis of Low Relative Humidity (RH≤30%).

The split of the logged data into various time ranges did not identify any one trend in low or high temperature or RH. The logged data (T & RH) were scattered during the three distinct time ranges, indicating that time did not play a role in the indoor thermal conditions experienced by student occupants. It must be noted, the logging period encompasses data from the four days which represented the Thanksgiving holiday. The holidays were not excluded from the analysis, as the residence hall was fully operational and open to students. Table 80 outlines the percent of the sample data that fell under the 30% RH threshold, indicating that on average the building underperformed 63% of the time it was logged.

Table 80-Time range breakout of data per Relative Humidity (RH) thresholds (RH<30% & RH>30%)

Time Range	% of Sample RH ≥ 30%	% of Sample RH ≤ 30%	Min RH	Max RH	Min T (C)	Max T (C)
8:00 AM TO 4:00 PM	39.61%	60.39%	15.60%	58.00%	20.3	23.8
4:00 PM TO 12:00 AM	34.95%	65.05%	16.50%	52.10%	20.4	24.0
12:00 AM TO 8:00 AM	36.21%	63.79%	15.90%	55.60%	20.4	23.5

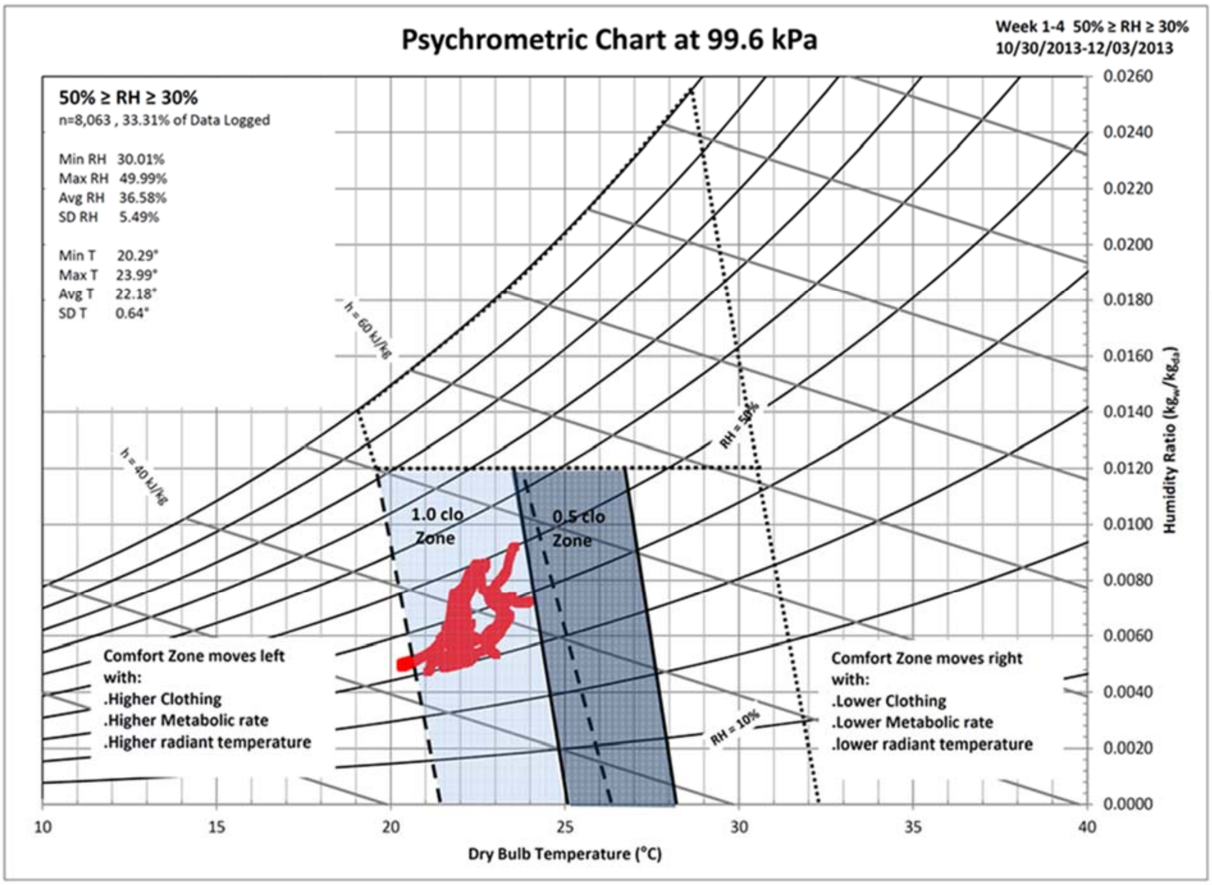


Figure 46- Acceptable Indoor Relative Humidity (RH) Range (50% ≥ RH ≥ 30%)

Figure 46 outlines the data which fell within the acceptable RH range, majority of the points logged fell within the 1.0 clothing insulation zone, although the average student clothing insulation factor was 0.73 with an SD of 0.23, indicating indoor conditions are not as warm as they should be. Student responses also indicate indoor conditions were not warm enough, both through their comments and perception of indoor temperature of 3.69 and *SD* of 0.23.

Figure 47 depicts the logged data which fell above the 30% RH conditions, as can be seen the residence hall only experienced these type of conditions for 4% of the time.

Although it represents a short duration of time and may be negligible; high humidity levels can lead to adverse health effects, if proper ventilation is not provided. On average 66% of students complained about poor ventilation within their spaces. This is an indication the ventilation system should be re-evaluated to ensure poor ventilation is not sustained which could lead to hazardous health conditions.

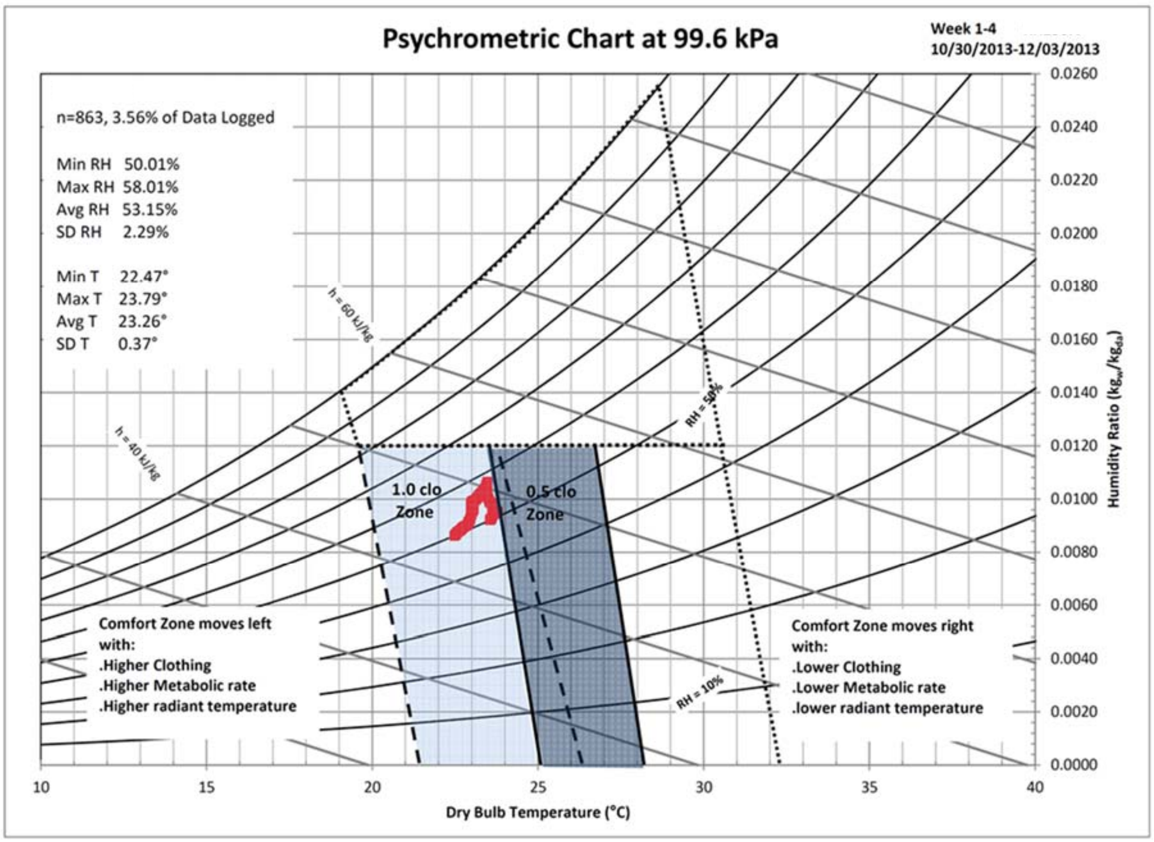


Figure 47-High Indoor Humidity (Relative Humidity RH ≥ 30%)

As can be seen in Figure 48 the majority of the logged data fell within the conditions of unacceptable indoor RH (below 30%). Over 63% of the time students were exposed to unhealthy indoor conditions.

Medical investigations of the adverse health effects of low humidity and poor ventilation on students were not examined, as it is beyond the scope of this study. However researchers indicate the nose is capable in increasing the relative humidity to 100% in the nasopharynx, even when it is exposed to cold and dry air (0°C and RH<10%) (Wolkoff and Kjaergaard 2007). At the same time the nose is able to increase temperature to a reasonable level even in cool indoor environments as low as 18°C (Wolkoff and Kjaergaard 2007).

On the other hand the eyes' pre-corneal tear film (PTF) appear to be more susceptible to low RH, particularly during computer/electronics use (Wolkoff et al. 2005). Research indicates that an increase in RH correlates with a more stable PTF and therefore more protection against loss of water by evaporation in the eye (Wolkoff et al. 2006). Lower temperature and higher RH leads to a more stable PTF minimizing adverse health impacts (Paschides et al. 1998, Kjaegaard et al. 2004). It must be noted there may be potential to save in energy costs by reducing temperature requirements but increasing RH within the building (Wan et al. 2009).

Studies on office buildings have shown associations between low RH (5%-30%) and increased prevalence of perceived dry air and sensory irritation of the eyes and upper airways and increasing RH by intervention resulted in fewer complaints (Backman and Haghighat 1999, Reinikainen et al. 1992, 1997, Reinikainen and Jaakola 2001, 2003, Nordstrom et al. 1994, Norback et al. 2000, Sato et al. 2003). The observed associations were more dominant at room temperatures exceeding 22°C and more common during the heating season (Mizoue et al. 2004).

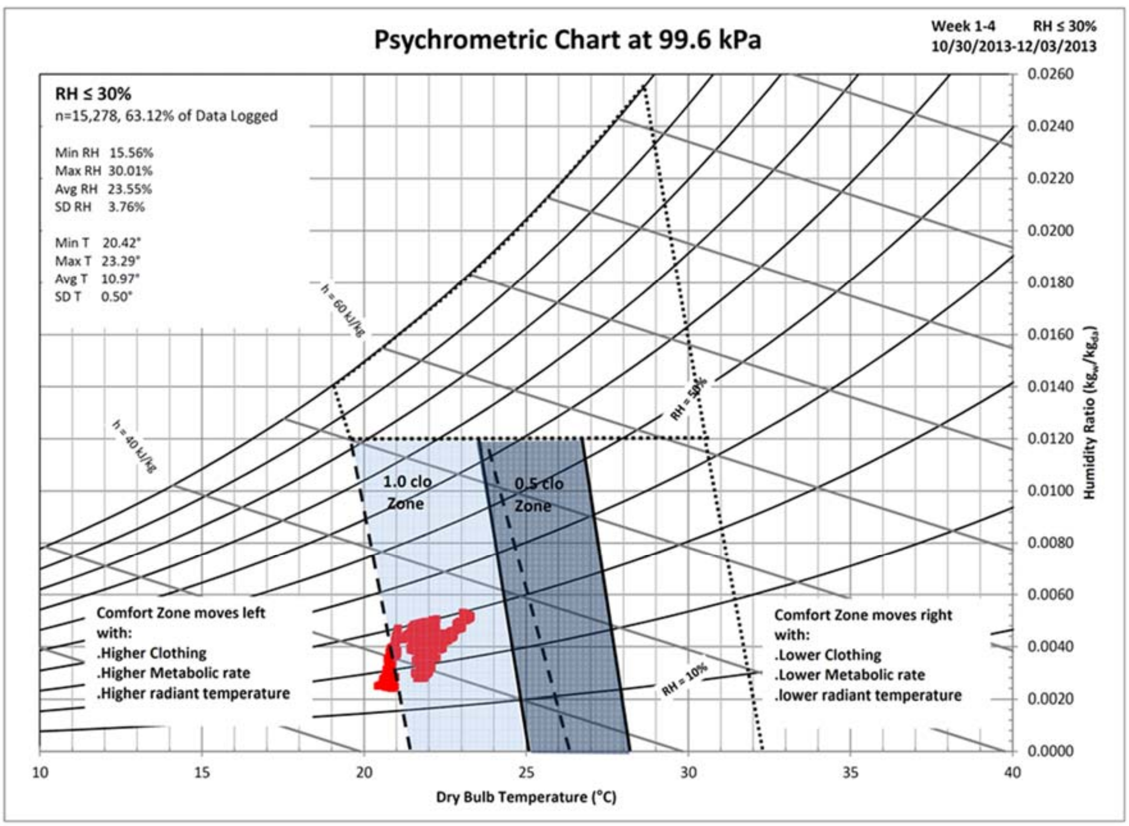


Figure 48-Low Indoor Humidity (Relative Humidity RH ≤ 30%)

Given students spend a majority of their time working on their computers, low RH may negatively influence these activities (Wyon et al. 2006). The negative impacts may be due to the following: blink frequency and reduction of overall visual acuity resulting in tiredness and eye irritations. Increase in blink frequency due to eye irritations can eventually result in musculoskeletal tiredness and overloading of the eye (Piccoli et al. 2003, Sunwoo et al. 2006) even though PTF stability may be retained.

There are indications that low RH alters the PTF and exacerbates the desiccation process. In another study a 10% increase in RH resulted in an average decrease of 36% in eye evaporation rate (McCulley et al. 2006, Tsubota 1998). When using computers and electronics, eye irritations and desiccation is further amplified; associated with risk factors such as reduced blink frequency (Wolkoff et al. 2003, 2005). Based on the work of Sterling et al. (1985) problematic indoor air humidity ranges to be avoided, are outlined in Table 81.

Table 81-Biological and chemical agents and indoor relative humidity thresholds

Biological/Chemical Agent	Preferred Relative Humidity	Agents	Adverse Health Effects
Several Bacterial Species	RH<40%	Escherichia, coli, Aerobacter, Aerogenes, Mycoplasma Gallisepticum	
Several Bacterial Species	RH>40%	Serratia marcescens, E.Coli	
Several Bacterial Species	RH>75% and RH<25%	Mycoplasma Laidlawi	
Viruses	RH<50%	Cowpox, Venezuelan equine encephalitis, influenza virus, para influenza virus, myxoviruses (including measles)	
Viruses	RH>50%	Polio virus, herpes virus remain viable longer	
Viruses	70%<RH>80%	Adeno virus	
Fungi	RH Varies	Penicillium (RH=92%), Cladosporium (RH=81.2%), Rhodotorula (RH=75.9%), Aspergillus (RH=31.3%).	
Ozone	RH<30%	Catalyst for chemical interactions resulting in irritants and toxic substances (Indoor Smog).	Ozone irritates the eyes, nose, throat, and respiratory tract.

Table 82 outlines the ideal relative humidity ranges to ensure a healthy living environment in buildings (Sterling et al. 1985). These ranges reduce the risk of biological and chemical interactions and overall health risks. The biological contaminants include bacteria, viruses, and fungi. Pathogens causing respiratory problems include respiratory infections, allergic rhinitis (inflation of the mucous membrane in the nose), asthma and hypersensitivity pneumonitis (inflammation of alveoli within the lung related to inhaled organic dusts). Chemical interactions include ozone production and localized smog.

Table 82-Ideal indoor relative humidity (RH) ranges to reduce health threats (Sterling et al., 1985)

Biological/Chemical Agent	Optimal Indoor Relative Humidity to Minimize Health Threats
Bacterial Populations Minimized	30%-60%
Viral Populations Minimized	50%-70%
Fungus Populations Minimized	Below 80%

Based on the findings of Sterling et al., the interaction between RH and biological contaminants are either naturally or mechanically introduced into the building, through ventilation, heating and cooling systems and they primarily effect occupants via respiratory infections and allergies. Based on previous epidemiological studies, incidences of acute respiratory illness is lower among occupants of buildings with mid-range (30% to 60%) humidity levels as compared to occupants of buildings with low humidity levels (below 30%) (Sterling et al. 1985).

Based on the work of Gelperin (1973), Green (1975, 1979, and 1982), Ritzel (1966), Sale (1972) and Serati and Wutrich (1969) a statistically significant reduction in respiratory infections was found among occupants of humidified buildings. The researchers hypothesized that due to the settling rate of aerosols at higher humidity levels and/or a decrease in the survival of bacterial and viral biological agents, respiratory infections are minimized. They found a decreasing trend in respiratory infections as humidity increased from 0% to 50%.

Low relative humidity below 30% increases health problems of asthmatics and individuals with allergies (Strauss et al. 1978). Low relative humidity may also have adverse health effects on the elderly and newborns (Strauss et al. 1978), however in this study student occupants are all within the 18-20 age group. However their health conditions (allergies and asthma) are unknown, as it is beyond the scope of this study.

Researchers discussed above also point out ‘indoor smog’ enhanced by ozone could be responsible for a large proportion of symptoms commonly associated with the tight building syndrome. Very high ozone levels in combination with poorly ventilated kitchen areas (combustion appliances) could result in occurrences of indoor smog in residential applications. The researchers recommend a range of 40% to 60% as the optimal levels of indoor relative humidity.

To further explore reasons for the potential vast variation between outdoor RH and Indoor RH in this study, research on the topic of indoor materials is included. In a recent study it was found indoor materials adsorb and desorb moisture, and current methods of predicting indoor relative humidity do not account for these factors (Virtanen et al. 2000). In another study using permeable and non-permeable materials it was found that on average permeable environments had higher indoor temperatures by 1°C-2°C, due to phase change energy released during adsorption; while the RH was as much as 25% higher in the non-permeable materials case (Virtanen et al. 2000). Researchers indicate moisture produced in a space, is not directly transferred to the ventilation air as assumed in current design methods. Passive moisture transfer between indoor air and hygroscopic structures has the potential to moderate differences of indoor RH and therefore improve comfort and perceived air quality (Virtanen et al. 2000, Simonson et al. 2002).

In assessing the amount of moisture lost between indoor and outdoor conditions, the facilities department was contacted to inquire about their humidification processes. They indicated they do not humidify the fresh air intake and their Building Energy Management System (BEMS) does not track indoor humidity levels. In graphing the outdoor and indoor conditions, a sample of 567 points were examined. This sample was based on low indoor RH conditions, and the granularity of the outdoor humidity and temperatures provided by National Oceanic and Atmospheric Association (NOAA) for the logging study period. Figure 49 depicts the vast difference between the outdoor and indoor RH conditions.

Given the air within the residence hall is not humidified, it can be seen that a large portion of the RH is lost when the air is introduced. On average the indoor RH was 23.61% while the outdoor RH was 55.47%, a value almost 2.5 times higher than found indoors.

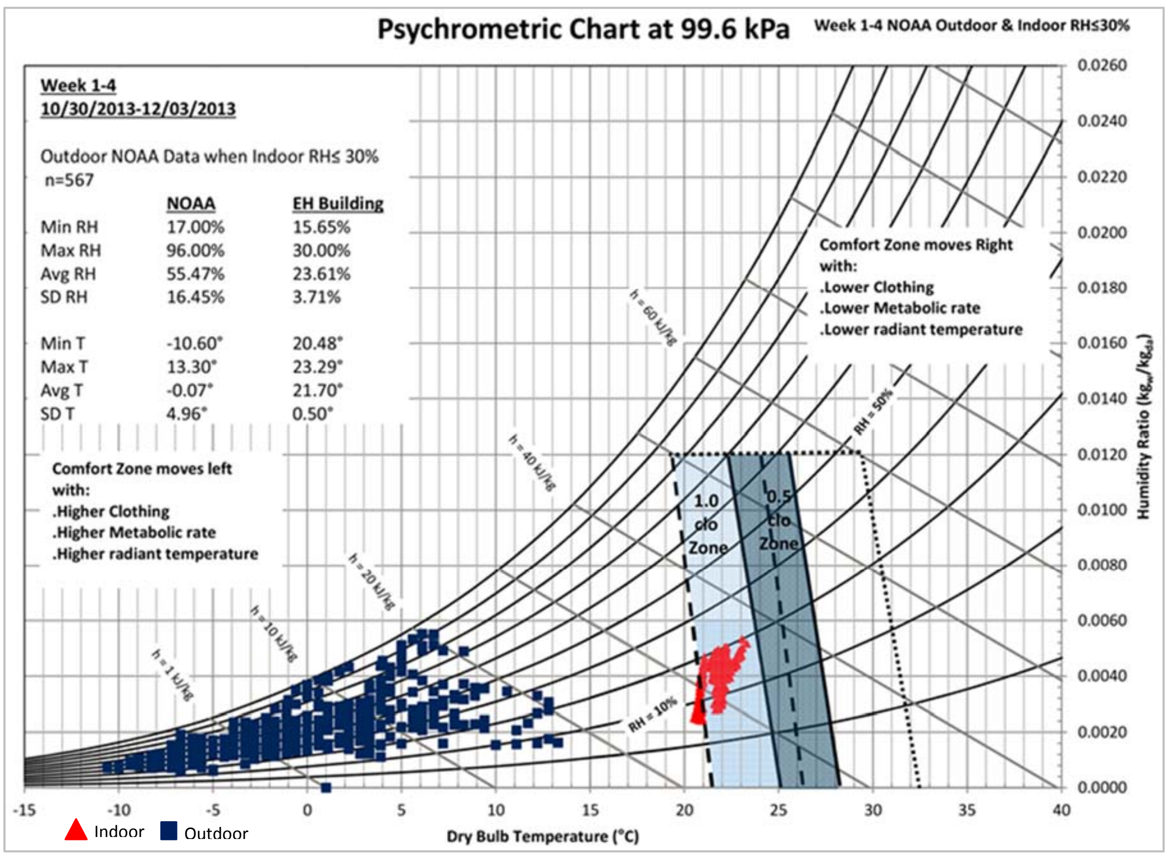


Figure 49-Week 1 to 4 Indoor and Outdoor Data for Relative Humidity (RH) ≤30% Indoor Condition

In running a bivariate correlation analysis on the sole impact of outdoor RH on indoor RH an r-value of 0.287 was realized indicating a weak relationship with statistical significance at the 95% level. This implies outdoor relative humidity alone does not have a significant impact on the indoor RH levels at an R-square of 0.08. Therefore only 8% of outdoor RH can explain indoor RH conditions. Even in cases when outdoor RH was 96% the indoor RH was below 30%.

Given the fresh air intake is not humidified, it is evident a significant portion of RH is lost and not reintroduced into the indoor air distribution system. Further study of indoor materials is required, to understand where the RH is being diminished and why. However, it is recommended the air distribution system introduce humidified air to ensure a healthy environment.

The logged data was also split on a weekly basis delineating living room and bedroom logged conditions, it was found that on average the bedroom conditions were warmer than the living room. Appendix A-Thermal Logging Study Logged Data (Bedroom and Living Room) depict the differentials between living room and bedroom thermal conditions in weeks 1 to 4. As can be seen the bedrooms were on average warmer by 0.6°C, and experienced higher RH by an average of 0.2% as compared to the living rooms.

Even though these are small differentials it must be noted students provided negative feedback on their thermal conditions, indicating in their comments it was cold and dry; even though their rooms were warmer, and almost the same RH as the living rooms. On average students spend 63% of their time in the residence hall and 74% in their bedrooms, with no methods/strategies to individually control their bedroom temperature or relative humidity.

If thermal zone separation and adaptive strategies are provided on a per bedroom basis, their satisfaction with indoor thermal comfort parameters may increase. Students mainly commented their lack of control over temperature, singular thermostat per suite and small windows are a hindrance to their satisfaction with thermal conditions. This supports arguments by researchers on the provision of adaptive strategies and increased occupant control (Steemers and Yun 2009, Stevenson and Leaman 2010, Gram-Hanssen 2010).

4.3.3 Thermal Logging Study Conclusions

This study logged a LEED-Gold certified New Construction residence hall EH, located in Worcester, MA. Fourteen suites' indoor dry-bulb temperature and relative humidity were examined for compliance with ASHRAE standard 55-2013 "Thermal Environment Conditions for Human Occupancy". 53 students' conditions were logged, 23.25% of total EH population, over a four week period (October 30th 2013 till December 3rd 2013). Surveys were also distributed to thermal logging study participants, on a weekly basis during the data download days. Selected suites were located both on the North and South side of the building to capture the full post occupancy experience of students.

Student feedback was collected for triangulation with logged data, for acceptability of indoor conditions. Topics of metabolic rate (MET unit), clothing insulation factor, drafts, air ventilation, indoor temperature, and indoor humidity were covered within the survey. Questions related to adaptive strategies were not provided, these questions have been added for future POE studies. The overall responses rate over the four week period was 36.32%, surpassing requirements of ASHRAE 55-2013.

The survey identified various areas (clothing factor, indoor air humidity needs, temperature and controls need, and localized smog conditions) which can inform the design process and ensure user thermal comfort in future designs.

Based on survey results students spend 63% of their time in the residence hall and 74% in their bedrooms. Students voiced dissatisfaction with suite thermal zone designs. Preference were voiced for individualized bedroom thermal zones and controls. Thermostat controls were also deemed extremely restrictive, given the tight range of temperature variation provided to them (20°C to 22°C).

Student survey also uncovered the typical student clothing insulation factor at on average 0.73 with an SD of 0.23. The average is equivalent to wearing: long sleeve underwear top and bottoms, sweatpants, a T-shirt and calf length socks (ASHRAE Standard 55-2013-*Garment Insulation Table 5.2.2.2B*). The student clothing insulation factor increased over the duration of the study period by an average of 6% reflective of the decrease in outside temperature from October to December. However the SD increased by an average of 159%, indicating large variations between occupant clothing preferences. The results indicate that the higher spectrum of their clothing insulation factor (0.96) still falls shy of ASHRAE standard 55-2013, 1-clothing zone; while the lower range (0.5) falls within its 0.5-clothing zone.

Students indicated perceived indoor air temperature at an average of 'slightly cool' and in the range of 'cool' to 'neutral'. However the indoor satisfaction at 'neutral' on average and in the range of 'slightly dissatisfied' to 'slightly satisfied'. Examining student perception of indoor air humidity the results indicated an average of 'dry' and in the range of 'dry' to 'neutral'. The indoor air humidity satisfaction ranked at 'neutral' and in the range of 'slightly dissatisfied' to 'satisfied'. The logged data supported students' feedback indicating indoor temperature conditions were indeed cooler than acceptable given their clothing factor and uncovered their exposure to unhealthy humidity levels.

To gain insight into factors impacting student satisfaction and perception of indoor air temperature it was found that: (1) the higher students' clothing insulation factor the less likely they were to be satisfied with indoor temperature, (2) the more satisfied they were with their indoor air humidity, the more likely they were to be satisfied with their indoor air temperature conditions, (3) an increase in their clothing insulation factor, did not translate into the perception of warmer indoor temperature conditions (some students commented sometimes they need to wear a blanket), (4) Students who perceived their indoor conditions as drier, were more likely to perceive indoor temperature conditions as warmer, (5) students who felt a draft in their space, were more likely to perceive their indoor air temperature as colder (students commented that due to poor ventilation they had to open windows and turn on fans. Given the study timeframe this finding may be the result of their adaptive strategies), (6) students who were more satisfied with their indoor temperature, were more likely to feel warmer.

Assessing factors impacting student satisfaction and perception of indoor air humidity it was found that: (1) as conditions became more humid, students were more likely to be satisfied with their indoor air humidity, (2) as their satisfaction with indoor temperature increased they were more likely to be satisfied with their indoor air humidity, (3) Students who said their air was stuffy were more likely to be satisfied with their indoor air humidity conditions versus those who did not, (4) the more satisfied they were with indoor air humidity the more humid they perceived their conditions, (5) the higher their clothing factor the more humid they perceived their environment, (6) students on the lower floors perceived the indoor air humidity to be drier, (6) the warmer they perceived their indoor air temperature, the more humid they perceived their indoor air humidity conditions. In graphing the logged data on AHSRAE Psychrometric charts, the indoor conditions fell in unacceptable ranges. Majority of the logged data (n=15,278) representative of 63.12% of the time, fell under the 30% acceptable humidity conditions and within the 1.0 clothing insulation zone and beyond. Results of a bivariate correlation analysis showed outdoor humidity alone did not have an effect on indoor relative humidity. Indicating that during the air intake process a substantial amount of humidity is lost and not re-introduced into the air distribution system.

Given the findings and comments it supports the students' complaints about: very dry indoor humidity conditions, cold temperatures, poor ventilation and localized smog. In particular several students complained of nose bleeds, dry skin and eye irritations. Some students even mentioned the HE institution should buy them humidifiers due to their daily exposure to unhealthy environment within the residence hall. Further dissecting the clothing insulation factor given its importance in the regression results, the suites were filtered into North and South suites. The clothing factor in the North suites was higher at an average of 0.77 versus the South suites at 0.73. It must be noted the difference between their activity levels was minimal, South suites were less active (avg.

1.01) than North suites (avg. 1.10) therefore the expectation would have been that the North suites clothing insulation factor would be less. Students' perception of their indoor temperature was warmer in the South suites, and on average more satisfied than those in the North suites. The perception of indoor temperature was cooler in the North suites and students were less satisfied with their indoor temperature conditions, even though their recorded indoor temperatures were higher than the South suites. In terms of indoor humidity both North and South suites showed no differential except in their SDs. These results indicate that locational factors must also be accounted for in the design process and thermal zoning by designers.

Scientific research indicates exposure to low relative humidity levels can result in adverse health effects including pre-corneal tear film (PTF) damage, irritations of the upper airways, reduction of visual acuity, and musculoskeletal tiredness and overloading of the eyes (Paschides et al. 1998, Piccoli et al. 2003, Kjaegaard et al. 2004, Wolkoff et al. 2005, Wyon et al. 2006, Sunwoo et al. 2006). Other adverse health impacts are related to biological and chemical interactions and contamination resulting in respiratory infections, allergic rhinitis, hypersensitivity pneumonitis, asthma and ozone production/indoor smog (Sterling et al. 1985). Although the collection of medical information was beyond the scope of this study due to the Health Insurance Portability and Accountability Act (HIPAA) of 1996 ("Privacy Rule"), this information may still be collected via HE institutions if it is not "individually identifiable". Tracking the number of complaints and office visits due to various related illnesses by occupants of EH will provide further insight into the health effects related to extended exposure to low relative humidity conditions. Also given ASHRAE standard 55-2013 does not identify acceptable lower humidity thresholds only upper boundaries, further research would benefit the establishment of an acceptable lower limit to ensure healthy environments for occupants.

The findings of this study support the work of researchers in that air temperature and humidity are closely interlinked and indicative of healthy indoor environments (Deuble and de Dear, 2012). Students' satisfaction with thermal comfort was highly influenced by these variables including their clothing factor. Even though researchers indicate occupants are less sensitive to humidity as compared to temperature; this study found perception and satisfaction with indoor humidity impacts perception and satisfaction with indoor air temperature.

Given the scientific research on health hazards of low humidity environments, it is evidenced humidity regulation, introduction, measurement and tracking should not be overlooked. These findings also emphasize the need for investigative POEs and it depicts their added value. The feedback from this study is critical in informing future designs and identified the current need for course correction measures in EH.

4.4 Student Survey (POE Indicator 7, 8, 10 and 12)

4.4.1 Overview and Methodology

Student surveys were distributed via email through the collaboration of individual HE institution's residential life offices. The surveys were all incentivized with a $50 sweepstakes facilitated through SurveyMonkey Sweepstakes tool. In the case of PS two $50 prizes were distributed. Weekly reminders were distributed to students via residential life personnel, to encourage participation in the survey. The surveys were designed to be taken online via the SurveyMonkey platform. Weekly email correspondence to students provided them with information related to: response rates to date, target response rates, purpose for taking the survey, and sender contact information in case of questions.

The survey collection periods are indicated in Table 83 per residence hall. The survey collection dates differed due to academic institution and residential life schedules. In some cases residential life personnel also requested a delay in the distribution of this survey, due to their own internal student surveys.

The response rate per HE institution differed with an average response rate of 34% for all institutions. The overall response rate was shy of ASHRAE 55-2013 requirements by 1%. Based on ASHRAE 55-2013 section 7.3.1. "Surveys of Occupant Responses to Environment" if more than 45 occupants have been selected a minimum of 35% response rate must be achieved. In an alternate study carried out by GreenerU hired by Brown University to carry out a Dorm Energy Efficiency Project (DEEP) a 25% response rate was achieved, indicating meeting the 35% ASHRAE response rate is a challenge even for industry professionals.

Table 83-Student survey details

Res. Hall	LEED Rating	Age Yrs.	Total # of Occupants	Respondents 'N'	Response Rate	Res. Hall Gender Split (% of female)	Survey Collection Dates
EH	LEED Gold	5	232	82	35%	F=31%	10/21/2013 – 01/16/2014
CSC	LEED Gold	3	450	162	36%	F=53%	10/21/2013 – 11/20/2013
PS	LEED Silver	3	622	201	32%	F=44%	11/24/2013 – 01/06/2014
WT	Non LEED	11	475	148	31%	F=18%	10/21/2013 – 01/16/2014

Table 83 also outlines the residence hall LEED certification level, total number of occupants, response rate, percent female population, and overall residence hall age. The student survey was subdivided into several sections, and questions were developed based on the importance given in the LEED certification process and scientific literature included within this report.

Questions were posed related to thermal comfort, student energy and water consumption and institutional sustainability awareness efforts. Each question posed in the survey allowed for direct student feedback through ample space to provide comments. Comments were divided into two pools: negative, and non-negative to highlight the topics of importance to student occupants.

Questions related to thermal comfort were assessed through the use of terminology and sample survey seven point thermal sensation scale provided within the ASHRAE 55-2004 and ASHRAE 55-2013 standard as found in section 7.3.1.2 “Point in Time Surveys”. It must be noted at the time the survey was designed ASHRAE 55-2004 was used as a template; however it was edited to include additional questions, now included in the ASHRAE 55-2013 sample survey template.

The survey administered covered questions related to metabolic rate, clothing insulation, drafts/air ventilation, temperature, and humidity. Clothing insulation factor (Clo.) and metabolic unit (MET unit) descriptions were developed using ASHRAE 55-2013. The clothing insulation factor and MET unit were also compared to findings from the thermal logging study within this report. Furthermore the clothing insulation factor and MET unit of all school averages were compared to identify student clothing factors and typical MET Unit for this specific demographic and building typology.

Questions related to adaptive strategies were not provided to students, however they should be included in future surveys. Hence, questions from ASHRAE Standard 55 have been added for future use. Table 84 outlines the various vote collection methods per major survey section question.

Table 84-Survey response vote collection methodology per major section

Student Survey Questions	Vote Collection Method
Months in residential hall	Scale from 1 to 4 1=1-3 months, 2=4-6 months, 3=7-12 months, and 4=more than 12 months
Perceived Indoor Temperature	7 Point-Likert Scale: 1= cold, 4=neutral, and 7=hot conditions
Satisfaction Indoor Temperature & Indoor Relative Humidity	7 Point-Likert Scale: 1=very dissatisfied, 4=neutral, and 7=very satisfied
Perceived Indoor Relative Humidity	7 Point-Likert Scale: 1=too dry, 4=neutral, and 7=too moist/humid
Satisfaction with Indoor Noise Levels	7 Point-Likert Scale: 1=completely dissatisfied, 4=neutral, and 7= completely satisfied
Satisfaction with Level of Control over changing indoor temperature	Yes/No with provisions for additional comments
Ease of thermostat control use	Yes/No with provisions for additional comments
% Indicating Conservation Awareness programs on campus/residence hall	Yes/No with provisions for additional comments
% Indicating Participation in Awareness programs on campus/residence hall	Yes/No, No awareness programs offered and provisions for additional comments
% Indicating a change in their energy and water consumption behavior from awareness programs	Yes/No with provisions for additional comments
Frequency of thinking about energy and water consumption	6 Point Likert Scale: 1= never, and 6=always

Statistical Package for Social Sciences (SPSS) version 19 was used to analyze the survey responses collected. Multi-variable linear regression was carried out for the various survey questions using single-tailed significance testing, both in stepwise and non-stepwise methods to identify independent variables with the largest impact on dependent variables. Collinearity was examined through the examination of variance inflation factors and scatterplots (graphing regression standardized predicted values and regression standardized residual values). This examination ensured no one variable's impact has been misrepresented in the findings. The strength of each independent variable was observed in relation to its beta coefficient, t-distribution and significance test. The beta coefficient represents the estimate of average number of SD changes in the criterion that will result in a change in one SD of the dependent variable. The lower the beta coefficient of an independent variable the weaker is the variable's role in the regression model. Values from the t-distribution and significance test provide for the constant and regression coefficients. They further indicate the strength if dependent-independent variable relationships.

When carrying out the multi-variable linear regression using SPSS the responses with missing values were not considered. The cases analyzed were based on responses with no missing values for any variable, therefore the sample size analyzed for the regressions are notated below in Table 85. The lower sample size was used in some cases, therefore the findings notate the sample size in every analysis. The instances where variables were unanswered by respondents occurred for the following: clothing insulation factor, metabolic unit, shower duration, number of toilet flushes, and frequency of cognizance about energy and water consumption.

Table 85-Multi-variable linear regression sample size cases analyzed

Residential Hall	Total # of Occupants	Survey Respondents 'N'	SPSS Cases Analyzed 'N'
EH	232	82	67
CSC	450	162	141
PS	622	201	170
WT	475	148	123
Totals	**1,779**	**593**	**501**

4.4.2 Results and Discussion

4.4.2.1 LEED Residence Hall Student Survey Results

4.4.2.1.1 Residence Hall EH

The total number of EH respondents analyzed over the collection period (10/21/2013-01/16/2014), consisted of 82 responses. This generated a 35% response rate meeting the target ASHRAE Standard-55, 35% response rate requirement. The total residential hall gender split consists of 31% female and 69% male.

The survey respondents were 34% female and 66% male. On average the respondents have lived between one to four months in the residential hall (avg. 2.04, *SD* 1.04), and spend on average 60% of their time in the building with an SD of 20%. 91% of respondents indicated spending majority of their time in their respective bedrooms. 82% of respondents indicated most of their time near a window. Of the total number of respondents 18% indicated the air in their area was stale and 22% indicated a draft.

EH has one thermostat per suite located in the living room. The thermostat controls the temperature for all rooms (bedrooms and common space). 30% indicated satisfaction with their level of control over changing their temperature in the area they spend most of their time and 59% of the respondents indicated the controls are easy to use.

On average the respondents clothing factor was 0.59 with an SD of 0.35 placing student clothing factor within the 0.24-0.94 range. On the lower end 0.24 is equivalent to wearing a T-shirt and thin trousers, and on the higher of 0.94 is equivalent to wearing long sleeve underwear top and bottoms, long sleeve flannel shirt, thick trousers and thick knee socks (ASHRAE Standard 55-2013-*Garment Insulation Table 5.2.2.2B*). Students' metabolic unit averaged at 1.03 with a *SD* of 0.20, which equates to '*seated quiet'* (ASHRAE Standard 55-2013-*Metabolic rates for typical tasks Table 5.2.1.2*). Upon visual inspection during the thermal logging study discussed within this report, students were typically in their rooms performing miscellaneous work on their computers. This visual finding is supported by the MET unit results.

Respondent votes on perception and satisfaction with indoor air temperature averaged at the neutral point respectively, with an SD range falling between 'cool' to 'slightly warm' and 'dissatisfied' to 'satisfied' respectively. Respondent votes on perception and satisfaction with indoor air humidity averaged at the neutral point respectively, with an SD range falling between 'moderately dry' to 'moist/humid' and 'somewhat dissatisfied' to 'completely satisfied' respectively.

Student responses resulted in an average satisfaction with noise levels falling within the 'somewhat satisfied' category with an SD range between 'somewhat dissatisfied' and 'completely satisfied'. Respondent votes on perception and satisfaction with indoor temperature and indoor air humidity in the area they spend most of their time and noise levels are indicated below in Table 86 outlining the Likert range their votes fall within. Table 86 also outlines the results of the two sample populations with and without the missing values. The sample size with the missing values is listed as SPSS n.

Table 86-EH results of indoor temperature, air humidity and noise levels (Total n=82, SPSS n=67)

Student Survey Question	EH Respondent Votes n=82	EH Respondent Votes SPSS n=67*
Perceived Indoor Temperature in the area you spend most of your time	Avg. 3.59 SD 1.44	Avg. 3.60 SD 1.47
Indoor Temperature Satisfaction in the area you spend most of your time	Avg. 3.99 SD 1.54	Avg. 4.01 SD 1.55
Perceived Indoor Air Humidity in the area you spend most of your time	Avg. 3.46 SD 1.11	Avg. 3.49 SD 1.10
Indoor Air Humidity Satisfaction in the area you spend most of your time	Avg. 4.45 SD 1.51	Avg. 4.45 SD 1.51
Satisfaction with noise levels between indoor and outdoor environment.	Avg. 4.82 SD 1.61	Avg. 4.85 SD 1.61

*Sample size with missing values used for multi-variable regression analysis.

4.4.2.1.1.1 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Temperature

In regressing perception of indoor air temperature on all other variables within the survey, the variables with the strongest relationships were tied to: MET unit, and satisfaction with the indoor air temperature.

This indicates students who were more satisfied with their indoor air temperature perceived indoor air temperature as warmer. Students with higher activity levels (MET unit) perceived their indoor air temperature as warmer. Table 87 outlines the standardized beta coefficient and significance of the model with the most power to predict perception of indoor air temperature in the area students spend most of their time.

Table 87-EH Relationship between perception of indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=67)

Dependent Variable	Perception of indoor air temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.895
Indoor Temperature Satisfaction	0.337	0.005
MET Unit	0.333	0.005
Model	**r=0.428, R square=0.183**	

All other variables had weaker and insignificant relationships to perception of indoor temperature, with the strongest relationship showing a negative correlations with gender. Females perceived indoor air temperature as cooler on average than males. Table 88 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 88-EH Relationship between perception of indoor air temperature (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=67)

Dependent Variable	Perception of indoor air temperature in the area you spend most of your time

Independent Variables with Weak Relationships	Standardized Beta Coefficients	Significance
Gender	-0.203	0.073
Months in Residential Hall	0.035	0.763
Average time spent in Residential Hall	-0.002	0.986
On Floor where they spent most of the time	-0.074	0.542
Whether they spent most of their time in their bedrooms	-0.105	0.377
Whether they spent most of their time near a window	-0.091	0.437
Perception of indoor air humidity	0.073	0.550
Satisfaction with indoor air humidity	-0.151	0.193
If the air was stale (stuffy, not fresh)	0.042	0.723
If there was a draft in their space	-0.100	0.383
If they were satisfied with the level of control over changing the temperature	0.024	0.852
If temperature controls are easy to use	-0.129	0.282
Clothing Insulation Factor	-0.100	0.449
Level of satisfaction with noise levels	-0.162	0.162

In regressing satisfaction with indoor air temperature on all other variables within the survey, the variable with the strongest relationship was tied to: satisfaction with the level of control over changing their indoor air temperature.

Students were more likely to be satisfied with their indoor temperature, if they were satisfied with the level of control they had over changing their indoor temperature. Table 89 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air temperature in the area students spend most of their time.

Table 89-EH Relationship between satisfaction with indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=67)

Dependent Variable	Satisfaction with indoor air temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Satisfaction with level of control over changing their indoor temperature	0.468	0.000
Model	**r=0.468, R square=0.219**	

All other variables had weaker and insignificant relationships to satisfaction with indoor air temperature, with the strongest relationship within the weaker subset relating to if they spent most of their time in their bedrooms. This indicates on average students who spend their time in their bedrooms, were more likely to be satisfied with their indoor air temperature than those who did not. Table 90 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 90-EH Relationship between satisfaction with indoor air temperature (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=67)

Dependent Variable	Satisfaction of Indoor Air Temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.000	0.998
Months in Residential Hall	-0.053	0.635
Average time spent in Residential Hall	-0.153	0.164
On Floor where they spent most of the time	0.057	0.607
Whether they spent most of their time in their bedrooms	0.208	0.058
Whether they spent most of their time near a window	0.061	0.585
Perception of indoor air humidity	-0.149	0.175
Satisfaction with indoor air humidity	0.160	0.145
If the air was stale (stuffy, not fresh)	-0.046	0.680
If there was a draft in their space	0.065	0.562
If temperature controls are easy to use	0.122	0.324
Clothing Insulation Factor	-0.107	0.360
MET Rate	-0.149	0.177
Level of satisfaction with noise levels	0.135	0.222
Perceived Indoor Temperature	0.210	0.058

4.4.2.1.1.2 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Humidity

In regressing the perceived indoor air humidity on all other variables with in the survey, the strongest relationships were tied to: indoor air humidity satisfaction, MET unit, if they spend their time in their bedrooms, and if the thermostat controls are easy to use.

This indicates students who were satisfied with their indoor air humidity, were more likely to perceive their indoor air humidity to be humid. The higher their activity level (MET unit), the more humid they perceived indoor air humidity. Students who spent most of their time in their bedrooms, were more likely to perceive indoor air humidity to be drier than those who did not. Students who thought thermostat controls were easy to use, perceived indoor air humidity to be drier. Table 91 outlines the standardized beta coefficient and significance of the model with the most power to predict perception of indoor air humidity in the area students spend most of their time.

Table 91-EH Relationship between perception of indoor air humidity (dependent variable) and independent Variables using multiple linear regression analysis model (n=67)

Dependent Variable	Perception of indoor air humidity in the area you spend most of your time

Independent Variables with Strong Relationships	Standardized Beta Coefficients	Significance
(Constant)		0.096
Indoor air humidity satisfaction	0.617	0.000
MET Unit	0.306	0.001
If spend most of their time in bedroom	-0.308	0.001
If thermostat controls are easy to use	-0.206	0.025
Model	**r=0.727, R square=0.529**	

Per Table 92 all other variables had weak and insignificant relationships to their perception of indoor air humidity.

Table 92-EH Relationship between perception of indoor air humidity (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=67)

Dependent Variable	Perception of indoor air humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.049	0.594
Months in Residential Hall	-0.081	0.359
Average time spent in Residential Hall	-0.022	0.815
On Floor where they spent most of the time	0.099	0.297
Whether they spent most of their time near a window	0.041	0.666
If the air was stale (stuffy, not fresh)	0.093	0.320
If there was a draft in their space	-0.084	0.391
Satisfaction with level of control over changing their indoor temperature	0.013	0.895
Clothing Insulation Factor	-0.039	0.706
Level of satisfaction with noise levels	-0.049	0.591
Perceived Indoor Temperature in the area they spend most of their time	0.067	0.468
Satisfaction with indoor air temperature in the area they spend most of their time	-0.136	0.156

In regressing satisfaction with indoor air humidity on all other variables within the survey, the variables with the strongest relationships were tied to: perception of indoor air humidity, indoor temperature satisfaction, perception of indoor temperature, floor they spent most of their time on, whether the air was stale in their area and if they spent most of their time in their bedrooms.

This indicates students who perceived indoor air humidity as humid, were more likely to be satisfied with their indoor air humidity conditions. Students who were more satisfied with their indoor air temperature, were more likely to be satisfied with their indoor air humidity. Students who perceived their indoor temperature as cooler, were less likely to be satisfied with their indoor air humidity.

Students who were on the lower floors, were less likely to be satisfied with their indoor air humidity. Students who experienced stale air, were less likely to be satisfied with their indoor air humidity conditions. Students who spent most of their time in their bedrooms, were more likely to be satisfied with their indoor air humidity on average than those who did not. Table 93 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air humidity in the area students spend most of their time.

Table 93-EH Relationship between satisfaction with indoor air humidity (dependent variable) and independent variables using multiple linear regression analysis (n=67)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.341
Perceived indoor air humidity	0.701	0.000
Indoor temperature satisfaction	0.352	0.000
Perceived indoor air temperature	-0.238	0.012
Floor they spend most of their time	-0.258	0.004
If the air is stale in the area they spend most of their time	-0.206	0.021
If they spend most of their time in their bedrooms	0.185	0.048
Model	**r=0.751, R square=0.564**	

All other variables had weaker and insignificant relationships to satisfaction with indoor air humidity. Table 94 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 94-EH Relationship between satisfaction with indoor air humidity (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=67)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.142	0.110
Months in Residential Hall	0.020	0.822
Average time spent in Residential Hall	0.043	0.649
Whether they spent most of their time near a window	0.028	0.780
If there was a draft in their space	0.080	0.380
Satisfaction with level of control over changing their indoor air temperature	-0.014	0.889
If temperature controls are easy to use	0.116	0.222
Clothing Insulation Factor	-0.002	0.983
MET Unit	-0.065	0.542
Level of satisfaction with noise levels	0.115	0.201

4.4.2.1.1.3 Education Indicator Feedback

Examining educational efforts by HE institutions, the survey asked students several questions related to their cognizance of energy and water consumption. The questions posed were related to the provision of educational programs highlighting conservation awareness programs on campus or within the residential halls, given that they inhabit LEED certified buildings.

Only 34% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls with only 11% indicating participation in any such programs. From the behavioral perspective only 1% believed it had any type of impact on changing their energy and water consumption behavior. On average they only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'very rarely' to 'very frequently'. Table 95 below outlines the student survey results as pertaining to student education on consumption conservation.

Table 95-EH Education indicator findings (n=67)

Survey Question	**EH Respondent Votes n=67**
% Indicating presence of conservation awareness programs on campus/res. hall	34%
% Indicating participation in conservation awareness programs on campus/res. hall	11%
% Indicating a change in their energy and water consumption behavior from programs	1%
Frequency of thinking about water consumption	Avg. 3.79 SD 1.20
Frequency of thinking about energy consumption	Avg. 3.94 SD 1.22

4.4.2.1.1.4 Overall Feedback Analysis

Of the total comments provided by EH residents, 55% commented on the level of control over changing their indoor temperature. Followed by the ease of use of thermostat controls and satisfaction with indoor ventilation at 23% each respectively. Table 96 and Figure 50 outline the various survey questions, and total percent of students who commented on particular questions posed.

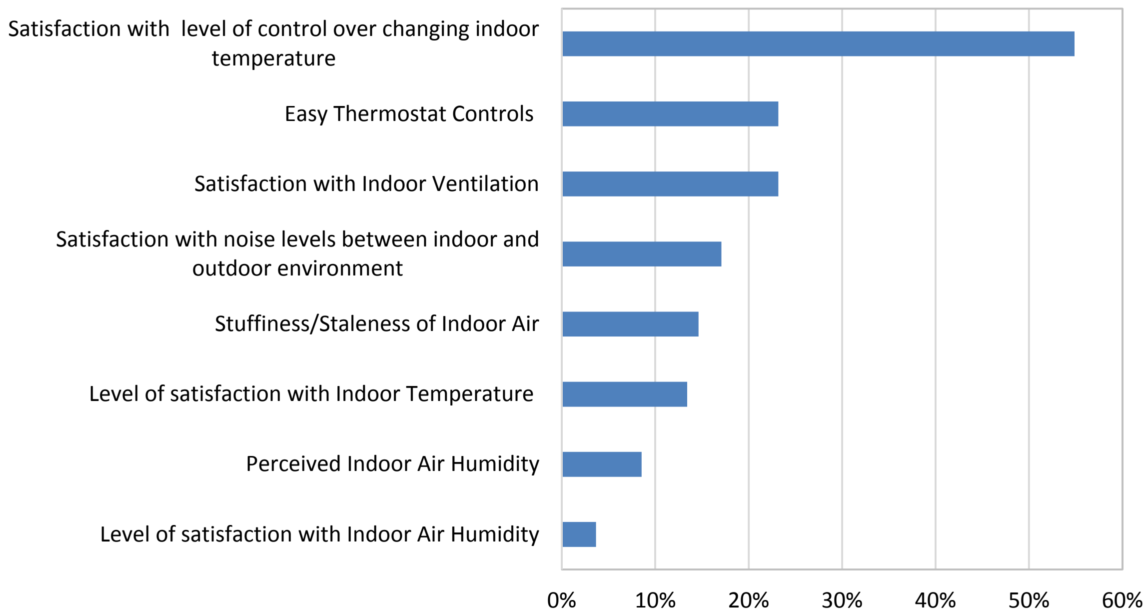


Figure 50-EH Percent of Total Comments Provided

Table 96-EH percent of total comments received per survey question (n=82)

Survey Question Description	EH-% Comments*
Satisfaction with level of control over changing indoor temperature	55%
Easy thermostat controls	23%
Satisfaction with indoor ventilation	23%
Satisfaction with noise levels between indoor and outdoor environment.	17%
Stuffiness/Staleness of indoor air	15%
Level of satisfaction with indoor temperature	13%
Perceived indoor air humidity	9%
Level of satisfaction with indoor air humidity	4%

*Total number of specific comments per occupant divided by the total number of respondents.

As can be seen the parameter of highest importance to student occupants is their level of control over changing their indoor temperature. A total of 419 comments were received from EH residents, with 135 of them directly related to thermal comfort, and controls parameters. Given that over 32% of comments were directly related to these parameters, it highlights their importance to student occupants. Of the 32% total percentage over 98% were negative comments as related to their satisfaction with their level of control over changing indoor temperature. Negative comments were mainly related to their lack of ability to adjust the temperature controls beyond the threshold provided to them (20°C to 22°C) by the facilities department and that the thermostat simply did not alter their indoor temperature. Table 97 below indicates the percent of total negative comments received per survey question posed.

Table 97-EH percent negative comments per survey question (n=82)

Survey Question Description	EH-% Negative Comments
Satisfaction with level of control over changing indoor temperature	98% out of 55%
Easy thermostat controls	100% out of 23%
Satisfaction with indoor ventilation	68% out of 23%
Satisfaction with noise levels between indoor and outdoor environment.	79% out of 17%
Stuffiness/Staleness of indoor air	92% out of 15%
Level of satisfaction with indoor temperature	91% out of 13%
Perceived indoor air humidity	100% out of 9%
Level of satisfaction with indoor air humidity	100% out of 4%

4.4.2.1.1.5 Multi-variable Linear Regression of Variables Related to Feedback

Given the results, satisfaction with level of control over changing indoor temperature was regressed on all other variables within the survey. The variables with the strongest relationships were tied to: indoor temperature satisfaction, and if temperature controls are easy to use.

This indicates students who were satisfied with their indoor temperature, were more likely to be satisfied with their level of control over changing their indoor temperature (thermostat controls). Students who found temperature controls easy to use, were more likely to be satisfied with the level of control over changing their indoor temperature than those who did not. Table 98 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with level of control over changing their indoor temperature.

Table 98-EH Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and independent variables using multiple linear regression analysis (n=67)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.019
Indoor temperature satisfaction	0.361	0.001
If temperature controls are easy to use	0.344	0.002
Model	**r=0.571, R square=0.326**	

All other variables had weaker and insignificant relationships to satisfaction with level of control over changing indoor temperature. Table 99 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 99-EH Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=67)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Perceived indoor air temperature	0.078	0.477
Perceived indoor air humidity	0.052	0.621
Indoor air humidity satisfaction	-0.060	0.570
Gender	0.088	0.413
Months in Residential Hall	0.017	0.868
Average time spent in Residential Hall	0.069	0.511
Floor they spend most of their time	-0.016	0.880
If they spend most of their time in their bedrooms	-0.084	0.434
If they spend most of their time near a window	-0.122	0.236
If the air is stale in the area they spend most of their time	0.109	0.291
If there was a draft in their space	-0.030	0.788
Clothing Insulation Factor	-0.150	0.168
MET Unit	0.035	0.740
Level of satisfaction with noise levels	0.024	0.822

4.4.2.1.2 Residence Hall CSC

The total number of CSC respondents analyzed over the collection period (10/21/2013-11/20/2013), consisted of 162 responses. This generated a 36% response rate exceeding the target ASHRAE Standard-55 35% response rate requirement by 1%. The total residential hall gender split consists of 35% female and 65% male.

The survey respondents were 67% female and 33% male. On average the respondents have lived between one to three months in the residential hall (avg. 1.32, *SD* 0.82) and spend on average 52% of their time in the building with an SD of 18%.

77% of respondents indicated spending majority of their time in their respective bedrooms. 78% indicating spending their time near a window. Of the total number of respondents 36% indicated the air in their area was stale and 23% indicated a draft.

CSC has one thermostat per suite located in the living room. The thermostat controls the temperature for all the rooms. 43% indicated satisfaction with their level of control over changing their temperature in the area they spend most of their time and 83% of the respondents indicated the controls are easy to use.

On average the respondents clothing factor was 0.44 with an SD of 0.30 placing the clothing factor of students within the 0.14-0.74 range. On the lower end 0.14 is equivalent to wearing a T-shirt and short shorts, and on the higher range 0.74 is equivalent to wearing long sleeve underwear top and bottoms, sweatpants, a T-shirt and calf length socks (ASHRAE Standard 55-2013-*Garment Insulation Table 5.2.2.2B*). The students' metabolic unit averaged at 1.01 with an SD of 0.15, which equates to '*seated quiet'* (ASHRAE Standard 55-2013-*Metabolic rates for typical tasks Table 5.2.1.2*).

Respondent votes on perception of indoor air temperature averaged at 'slightly cool', with an SD range falling between 'cool' to 'warm'. Votes on satisfaction with indoor air temperature averaged at 'slightly dissatisfied', with an SD range falling between 'dissatisfied' to 'satisfied'. Votes on perception of indoor air humidity averaged at 'dry', with an SD range falling between 'dry' to 'moist/humid'. Votes on satisfaction with indoor air humidity averaged at the neutral point with an SD ranging between 'dissatisfied' to 'satisfied'. Votes on satisfaction with noise levels averaged at 'somewhat dissatisfied', with an SD ranging between 'dissatisfied' to 'mostly satisfied'. Table 100 outlines the results of the two sample populations with and without the missing values. The sample size with the missing values is listed as SPSS n.

Table 100-CSC results of indoor temperature, air humidity and noise levels (n=162, Regression n=141)

Survey Question	**CSC Respondent Votes n=162**	**CSC Respondent Votes SPSS n=141***
Perceived Indoor Temperature in the area you spend most of your time	Avg. 3.91 SD 1.65	Avg. 3.91 SD 1.69
Indoor Temperature Satisfaction in the area you spend most of your time	Avg. 3.97 SD 1.71	Avg. 3.92 SD 1.71
Perceived Indoor Air Humidity in the area you spend most of your time	Avg. 3.93 SD 0.85	Avg. 3.94 SD 0.84
Indoor Air Humidity Satisfaction in the area you spend most of your time	Avg. 4.54 SD 1.27	Avg. 4.57 SD 1.26
Satisfaction with noise levels between indoor and outdoor environment.	Avg. 3.93 SD 1.84	Avg. 3.93 SD 1.84

*Sample size with missing values used for multi-variable regression analysis.

4.4.2.1.2.1 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Temperature

In regressing perception of indoor air temperature on all other variables within the survey, the variables with the strongest relationship were tied to: indoor air temperature satisfaction, presence of a draft, clothing insulation factor and gender.

This indicates students who were more satisfied with their indoor air temperature, were more likely to perceive their indoor air temperature as cooler. Students who felt a draft in their area, were more likely to perceive their indoor air temperature as cooler versus students whom did not. Students with higher clothing factors perceived their indoor air temperature as cooler. Females perceived indoor air temperature as cooler on average than males. Table 101 outlines the standardized beta coefficient and significance of the model with the most power to predict perception of indoor temperature for CSC dataset.

Table 101-CSC Relationship between perception of indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=141)

Dependent Variable	Perception of Indoor Air Temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Indoor Temperature Satisfaction	-0.330	0.000
If there is a draft in the area you spend most of your time	-0.247	0.002
Clothing Insulation Factor	-0.208	0.007
Gender	-0.157	0.042
Model	**r=0.492, R square=0.242**	

All other variables had weak and insignificant relationships to perception of indoor temperature. Table 102 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 102- CSC Relationship between perception of indoor air temperature dependent variable and other independent variables excluded from multiple linear regression analysis model (n=141)

Dependent Variable	Perception of Indoor Air Temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Months in Residential Hall	-0.034	0.647
Average time spent in Residential Hall	-0.032	0.670
On Floor where they spent most of the time	0.073	0.334
Whether they spent most of their time in their bedrooms	0.045	0.562
Whether they spent most of their time near a window	0.083	0.284
Perception of indoor air humidity	-0.063	0.407
Satisfaction with indoor air humidity	-0.029	0.718
If the air was stale (stuffy, not fresh)	0.095	0.220
If they were satisfied with the level of control over changing the temperature	-0.048	0.591
If temperature controls are easy to use	0.055	0.476
MET Rate	0.049	0.513
Level of satisfaction with noise levels	0.029	0.714

In regressing satisfaction with indoor air temperature on all other variables within the survey, the variables with the strongest relationships were tied to: satisfaction with the level of control over changing their temperature, satisfaction with indoor air humidity, if they spend more time in their bedrooms, satisfaction with noise levels and perception of indoor air temperature.

Students who were more satisfied with their indoor air humidity and level of control over changing their temperature, were more likely to be satisfied with their indoor air temperature. On average students who spend most of their time in their bedrooms, were less satisfied with their indoor air temperature conditions. Students who were satisfied with noise conditions, were more likely to be satisfied with their indoor temperature conditions. Students who perceived their indoor air temperature to be cooler, were more likely to be satisfied with their indoor air temperature conditions. Table 103 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air temperature in the area students spend most of their time.

Table 103-CSC Relationship between satisfaction with indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=141)

Dependent Variable	Satisfaction with Indoor Air Temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Satisfaction with level of control over changing their indoor temperature	0.434	0.000
Satisfaction with indoor air humidity	0.213	0.003
If spend most of their time in the bedroom	-0.158	0.021
Level of satisfaction with noise levels	0.180	0.008
Perception of indoor air temperature	-0.166	0.017
Model	**r=0.641, R square=0.411**	

All other variables had weaker and insignificant relationships to satisfaction with indoor air temperature. Table 104 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 104-CSC Relationship between satisfaction with indoor air temperature dependent variable and other independent variables excluded from multiple linear regression analysis model (n=141)

Dependent Variable	Perception of Indoor Air Temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.079	0.250
Months in Residential Hall	0.003	0.962
Average time spent in Residential Hall	0.015	0.892
On Floor where they spent most of the time	0.061	0.366
Whether they spent most of their time near a window	0.064	0.347
Perception of indoor air humidity	-0.027	0.698
If the air was stale (stuffy, not fresh)	0.042	0.573
If there was a draft in their space	-0.120	0.085
If temperature controls are easy to use	0.036	0.604
Clothing Insulation Factor	-0.046	0.515
MET Rate	-0.009	0.899

4.4.2.1.2.2 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Humidity

In regressing the perceived indoor air humidity on all other variables with in the survey, the strongest relationships were tied to: indoor air humidity satisfaction, and satisfaction with noise levels.

Students who were satisfied with their indoor air humidity, were more likely to perceive indoor air humidity to be humid. Students who were satisfied with their indoor noise conditions, perceived indoor air humidity as dry, versus students who were not satisfied with indoor noise conditions. Table 105 outlines the beta coefficient and significance of independent variables on the perception of indoor air humidity.

Table 105-CSC Relationship between perception of indoor air humidity (dependent variable) and independent Variables using multiple linear regression analysis model (n=141)

Dependent Variable	Perception of indoor air humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Indoor air humidity satisfaction	0.233	0.005
Level of satisfaction with noise levels	-0.177	0.033
Model	**r=0.276, R square=0.076**	

As can be seen in Table 106 all other variables had weak and insignificant relationships to perception of indoor air humidity.

Table 106-CSC Relationship between perception of indoor air humidity (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=141)

Dependent Variable	Perception of indoor air humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.024	0.778
Months in Residential Hall	0.069	0.400
Average time spent in Residential Hall	-0.027	0.745
On Floor where they spent most of the time	0.098	0.235
Whether they spent most of their time in their bedroom	-0.132	0.114
Whether they spent most of their time near a window	-0.075	0.364
If the air was stale (stuffy, not fresh)	-0.057	0.520
If there was a draft in their space	-0.088	0.288
Satisfaction with level of control over changing their indoor temperature	-0.009	0.913
If thermostat is easy to use	-0.014	0.863
Clothing Insulation Factor	0.026	0.761
MET unit	0.036	0.670
Perceived Indoor Temperature in the area they spend most of their time	-0.039	0.640
Satisfaction with indoor air temperature in the area they spend most of their time	-0.002	0.980

In regressing satisfaction with indoor air humidity on all other variables asked within the survey, the variables with the strongest relationships were tied to: whether the air was stale in their area, indoor temperature satisfaction, if they spent most of their time in their bedrooms, perception of indoor air humidity and MET unit.

Students who experienced stale air, were less likely to be satisfied with their indoor air humidity conditions. Students who were more satisfied with their indoor air temperature, were more likely to be satisfied with their indoor air humidity. Students who spent most of their time in their bedrooms, were more likely to be satisfied with their indoor air humidity on average than those who did not. Students who perceived indoor air humidity as humid, were more likely to be satisfied with their indoor air humidity conditions. Students with higher activity levels perceived indoor air humidity as humid. Table 107 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air humidity in the area students spend most of their time.

Table 107-CSC Relationship between satisfaction with indoor air humidity (dependent variable) and independent variables using multiple linear regression analysis (n=141)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.175
If the air was stale (stuffy, not fresh)	-0.337	0.000
Indoor temperature satisfaction	0.274	0.000
If they spend most of their time in their bedrooms	0.256	0.001
Perceived indoor air humidity	0.173	0.018
MET Unit	0.170	0.019
Model	**r=0.560, R square=0.314**	

All other variables had weaker and insignificant relationships to satisfaction with indoor air humidity. Table 108 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 108-CSC Relationship between satisfaction with indoor air humidity dependent variable and other independent variables excluded from multiple linear regression analysis model (n=141)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.043	0.549
Months in Residential Hall	-0.029	0.689
Average time spent in Residential Hall	0.132	0.071
Floor they spend most of their time	-0.008	0.913
Whether they spent most of their time near a window	-0.034	0.644
If there was a draft in their space	0.047	0.515
Satisfaction with level of control over changing their indoor air temperature	-0.060	0.486
If temperature controls are easy to use	0.021	0.775
Clothing Insulation Factor	0.071	0.331
Level of satisfaction with noise levels	0.068	0.367
Perceived indoor air temperature	-0.040	0.596

4.4.2.1.2.3 Education Indicator Feedback

Examining educational efforts by HE institutions, the survey asked students several questions related to their cognizance of energy and water consumption. The questions posed were related to the provision of educational programs highlighting conservation awareness programs on campus or within the residential halls, given that they inhabit LEED certified buildings.

Only 25% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls with only 12% indicating participation in any such programs. From the behavioral perspective 0% believed it had any type of impact on changing their energy and consumption behavior. On average they only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'very rarely' to 'very frequently'. Table 109 below outlines the student survey results as pertaining to student education on consumption conservation.

Table 109-CSC Education indicator findings (n=141)

Survey Question	**CSC Respondent Votes n=141**
% Indicating presence of conservation awareness programs on campus/res. hall	25%
% Indicating participation in conservation awareness programs on campus/res. hall	12%
% Indicating a change in their energy and water consumption behavior from programs	0%
Frequency of thinking about water consumption	Avg. 4.05 SD 1.12
Frequency of thinking about energy consumption	Avg. 4.06 SD 1.15

4.4.2.1.2.4 Overall Feedback Analysis

Of the total comments provided by the CSC residents, 47% commented on the level of control over changing their indoor temperature. Followed by level of satisfaction with indoor temperature, satisfaction with indoor ventilation and satisfaction levels between their indoor and outdoor environment at 39%, 32%, and 25% respectively. Table 110 and Figure 51 outline the various survey questions and total percent of students whom commented on particular questions posed.

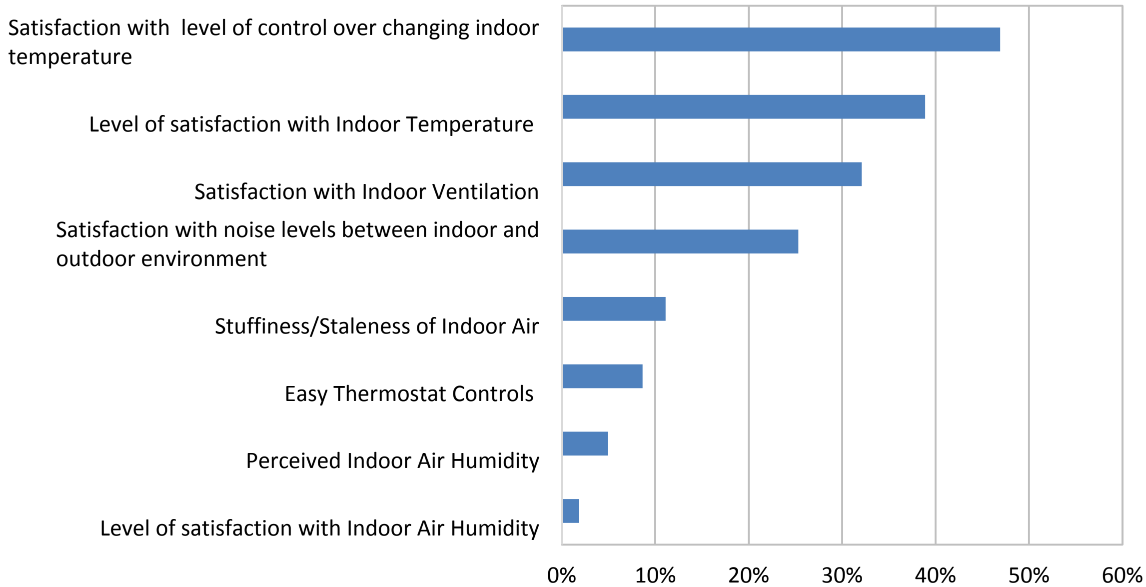


Figure 51-CSC Percent of Total Comments Provided

Table 110-CSC percent of Total comments received per survey question (n=162)

Survey Question Description	CSC-% Comments*
Satisfaction with level of control over changing indoor temperature	47%
Level of satisfaction with indoor temperature	39%
Satisfaction with indoor ventilation	32%
Satisfaction with noise levels between indoor and outdoor environment.	25%
Stuffiness/Staleness of indoor air	11%
Easy thermostat controls	9%
Perceived indoor air humidity	5%
Level of satisfaction with indoor air humidity	2%

*Total number of specific comments per occupant divided by the total number of respondents.

As can be seen the parameter of highest importance to student occupants is their level of control over changing their indoor temperature. A total of 623 comments were received from CSC residents, with 283 of them directly related to thermal comfort. Given that over 45% of comments were directly related to these parameters, it highlights their importance to student occupants. Of the 45% total percentage over 96% were negative comments as related to their satisfaction with their level of control over changing indoor temperature. Table 111 below indicates the percent of total negative comments received per survey question posed.

Table 111-CSC percent negative Comments per Survey Questions Posed (n=162)

Survey Question Description	CSC-% Negative Comments
Satisfaction with level of control over changing indoor temperature	96% out of 47%
Easy thermostat controls	100% out of 9%
Satisfaction with indoor ventilation	65% out of 32%
Satisfaction with noise levels between indoor and outdoor environment.	98% out of 25%
Stuffiness/Staleness of indoor air	100% out of 11%
Level of satisfaction with indoor temperature	99% out of 39%
Perceived indoor air humidity	63% out of 5%
Level of satisfaction with indoor air humidity	67% out of 2%

4.4.2.1.2.5 Multi-variable Linear Regression of Variables Related to Feedback

Given the results, satisfaction with level of control over changing indoor temperature was regressed on all other variables within the survey. The variables with the strongest relationships were tied to: indoor temperature satisfaction, if temperature controls are easy to use and clothing insulation factor.

This indicates students who were satisfied with their indoor temperature, were more likely to be satisfied with their level of control over changing their indoor temperature (thermostat controls). Students who found temperature controls easy to use, were more likely to be satisfied with the level of control over changing their indoor temperature.

Students with higher clothing insulation factors, were more satisfied with their level of control over changing their indoor temperature. Table 112 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with level of control over changing their indoor temperature.

Table 112-CSC Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and independent variables using multiple linear regression analysis (n=141)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Indoor temperature satisfaction	0.474	0.000
If temperature controls are easy to use	0.189	0.009
Clothing insulation factor	0.178	0.014
Model	**r=0.571, R square=0.326**	

All other variables had weaker and insignificant relationships to satisfaction with level of control over changing indoor temperature. Table 113 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 113-CSC Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=141)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.067	0.348
Months in Residential Hall	-0.037	0.607
Average time spent in Residential Hall	0.061	0.385
Floor they spend most of their time	-0.098	0.165
If they spend most of their time in their bedrooms	0.042	0.564
If they spend most of their time near a window	0.077	0.277
Perceived indoor air temperature	-0.048	0.527
Perceived indoor air humidity	-0.003	0.967
Indoor air humidity satisfaction	-0.020	0.793
If the air is stale in the area they spend most of their time	-0.093	0.206
If there was a draft in their space	-0.053	0.458
MET Unit	0.013	0.858
Level of satisfaction with noise levels	-0.064	0.376

4.4.2.1.3 Residence Hall PS

The total number of PS respondents analyzed over the collection period (11/24/2013-01/06/2014), consisted of 201 responses. This generated a 32% response rate, shy of the ASHRAE Standard-55 target response rate of 35% by 3%. The total residential hall gender split consists of 44% female and 56% male.

The survey respondents were 63% female and 37% male. On average the respondents have lived between one to three months in the residential hall (avg. 1.80, SD 1.21), and spend on average 60% of their time in the building with an SD of 17%.

86% of respondents indicated spending majority of their time in their respective bedrooms. 83% indicating spending time near a window. Of the total number of respondents 39% indicated the air in their area was stale and 24% indicated a draft.

PS has one thermostat per suite located in the living room. The thermostat controls the temperature for all the suite rooms. 51% indicated satisfaction with their level of control over changing their temperature in the area they spend most of their time and 34% of the respondents indicated the controls are easy to use.

On average the respondents clothing factor was 0.47 with an SD of 0.25 placing student clothing factor within the 0.22-0.72 range. On the lower end 0.22 is equivalent to wearing a T-shirt and thin trousers and on the higher of 0.72 is equivalent to wearing long sleeve underwear top and bottoms, sweatpants and a T-shirt (ASHRAE Standard 55-2013-*Garment Insulation Table 5.2.2.2B*). The students' metabolic unit averaged at 1.10 with an SD of 0.26, which equates to '*seated quiet'* (ASHRAE Standard 55-2013-*Metabolic rates for typical tasks Table 5.2.1.2*).

Respondent votes on perception of indoor air temperature averaged at 'slightly cool', with an SD range falling between 'cool' to 'slightly warm'. Votes on satisfaction with indoor air temperature averaged at the neutral point with an SD range falling between 'dissatisfied' to 'satisfied'. Votes on perception and satisfaction with indoor air humidity averaged at the neutral point respectively, with an SD range falling between 'dry' to 'moist/humid' and 'slightly dissatisfied' to 'slightly satisfied' respectively.

Student responses resulted in an average satisfaction with noise levels falling within the 'neither satisfied nor dissatisfied' category with an SD range between 'mostly dissatisfied' and 'mostly satisfied'. Respondent votes on perception and satisfaction with indoor temperature and indoor air humidity in the area they spend most of their time and noise levels are indicated below in Table 114 outlining the Likert range their votes fall within. Table 114 also outlines the results of the two sample populations with and without the missing values. The sample size with the missing values is listed as SPSS n.

Table 114-PS respondents Likert range indication with indoor temperature, air humidity and noise levels (n=201, SPSS n=170)

Student Survey Question	**PS Respondent Votes n=201**	**PS Respondent Votes SPSS n=170***
Perceived Indoor Temperature in the area you spend most of your time	Avg.3.22 SD 1.19	Avg.3.28 SD 1.22
Indoor Temperature Satisfaction in the area you spend most of your time	Avg. 4.58 SD 1.60	Avg. 4.64 SD 1.63
Perceived Indoor Air Humidity in the area you spend most of your time	Avg. 3.99 SD 0.53	Avg. 4.00 SD 0.47
Indoor Air Humidity Satisfaction in the area you spend most of your time	Avg. 4.71 SD 1.22	Avg. 4.78 SD 1.20
Satisfaction with noise levels between indoor and outdoor environment.	Avg. 4.24 SD 1.66	Avg. 4.24 SD 1.66

*Sample size with missing values used for multi-variable regression analysis.

4.4.2.1.3.1 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Temperature

In regressing perception of indoor air temperature on all other variables within the survey, the variables with the strongest relationships were tied to: clothing insulation factor and if there was a draft in the area they spent most of their time.

This indicates students with higher clothing factors perceived indoor air temperature as cooler. Students who felt a draft were more likely to perceive indoor air temperature as cooler, than those who did not feel a draft. Table 115 outlines the standardized beta coefficient and significance of the model with the most power to predict perception of indoor temperature in the area students spend most of their time.

Table 115-PS Relationship between perception of indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=170)

Dependent Variable	Perception of indoor air temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Clothing insulation factor	-0.228	0.003
If there was a draft in their space	-0.163	0.030
Model	**r=0.285, R square=0.081**	

All other variables had weaker and insignificant relationships, with the strongest relationship tied to satisfaction with the level of control over changing their temperature in the area they spend most of their time. Students who were satisfied with their level of control over changing indoor temperature, were more likely to perceive indoor temperature as warmer. Table 116 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 116- PS Relationship between perception of indoor air temperature dependent variable and other independent variables excluded from multiple linear regression analysis model (n=170)

Dependent Variable	Perception of indoor air temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.031	0.677
Months in Residential Hall	-0.091	0.223
Average time spent in Residential Hall	-0.070	0.353
Whether they spent most of their time in their bedrooms	-0.056	0.457
Whether they spent most of their time near a window	0.008	0.917
On Floor where they spent most of the time	-0.050	0.499
Satisfaction with indoor temperature	0.087	0.250
Perception of indoor air humidity	-0.012	0.870
Satisfaction with indoor air humidity	-0.028	0.709
If the air was stale (stuffy, not fresh)	0.105	0.160
If they were satisfied with the level of control over changing the temperature	0.130	0.081
If temperature controls are easy to use	0.104	0.165
MET Unit	-0.004	0.955
Level of satisfaction with noise levels	0.021	0.774

In regressing satisfaction with indoor air temperature on all other variables within the survey, the variable with the strongest relationships were tied to: satisfaction with the level of control over changing their indoor air temperature, satisfaction with indoor air humidity, and satisfaction with the noise levels between their indoor and outdoor environment.

This indicates students satisfied with the level of control they have over changing their indoor air temperature, were more likely to be satisfied with their indoor air temperature. Students who were satisfied with their indoor air humidity, were more likely to be satisfied with their temperature. Students who were satisfied with the noise conditions, were more likely to be satisfied with their indoor air temperature. Table 117 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air temperature in the area students spend most of their time.

Table 117-PS Relationship between satisfaction with indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=170)

Dependent Variable	Satisfaction with indoor air temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Satisfaction with level of control over changing their indoor temperature	0.398	0.000
Satisfaction with indoor air humidity	0.211	0.002
Level of satisfaction with noise levels	0.196	0.004
Model	**r=0.568, R square=0.323**	

All other variables had weaker and insignificant relationships to satisfaction with indoor air temperature, with the strongest relationships within the weaker subset relating to: months students were in the residence hall, and clothing insulation factor.

This indicates students who have lived in the residence hall less months, were more likely to be dissatisfied with their indoor temperature as compared to those residing longer. Students with higher clothing factors, were more likely to be dissatisfied with the indoor air temperature. Table 118 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 118-PS Relationship between satisfaction with indoor air temperature dependent variable and other independent variables excluded from multiple linear regression analysis model (n=170)

Dependent Variable	Satisfaction with Indoor Air Temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.017	0.799
Months in Residential Hall	-0.118	0.069
Average time spent in Residential Hall	-0.039	0.546
Whether they spent most of their time in their bedrooms	0.091	0.157
Whether they spent most of their time near a window	-0.019	0.775
On Floor where they spent most of the time	-0.034	0.594
Perception of indoor air humidity	-0.032	0.622
If the air was stale (stuffy, not fresh)	-0.112	0.095
If there was a draft in their space	0.046	0.473
If temperature controls are easy to use	0.032	0.664
Clothing Insulation Factor	-0.120	0.060
MET Unit	-0.016	0.801
Perceived Indoor Temperature	0.056	0.388

4.4.2.1.3.2 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Humidity

In regressing the perceived indoor air humidity on all other variables with in the survey, strong correlations were not found with any one variable using either the stepwise or non-stepwise enter method. Table 119 outlines the standardized beta coefficients and significances of the variables in the regression analysis.

Table 119-PS Relationship between perception of indoor air humidity (dependent variable) and independent variables using multiple linear regression analysis (n=170)

Independent Variables	Standardized Beta Coefficients	Significance
(Constant)		0.000
Gender	-0.101	0.223
Months in Residential Hall	-0.046	0.574
Average time spent in Residential Hall	0.101	0.214
Which floor they spend most of their time	-0.118	0.138
Whether they spent most of their time in their bedrooms	-0.062	0.454
Whether they spent most of their time near a window	-0.017	0.846
Perceived indoor air temperature	-0.041	0.623
Level of satisfaction with noise levels	-0.042	0.671
Level of satisfaction with indoor air humidity	-0.133	0.125
If the air is stale in the area they spend most of their time	0.100	0.254
If there was a draft in their space	-0.087	0.293
Satisfaction with level of control over changing their indoor air temperature	0.062	0.544
If temperature controls are easy to use	0.050	0.597
Clothing Insulation Factor	-0.081	0.348
MET Unit	-0.059	0.493
Level of satisfaction with noise levels	-0.064	0.463
Model	**r=0.282, R square=0.079**	

In regressing satisfaction with indoor air humidity on all other variable within the survey, the variables with the strongest relationships were tied to: indoor temperature satisfaction, and satisfaction with noise levels between their indoor and outdoor environment.

This indicates students who were satisfied with their indoor temperature, were more likely to be satisfied with their indoor air humidity. Students who were satisfied with noise levels between indoor and the outdoor environment, were more likely to be satisfied with their indoor air humidity than those who were not. Table 120 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air humidity in the area students spend most of their time.

Table 120-PS Relationship between satisfaction with indoor air humidity (dependent variable) and independent variables using multiple linear regression analysis (n=170)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Indoor temperature satisfaction	0.294	0.000
Level of satisfaction with noise levels	0.151	0.048
Model	**r=0.370, R square=0.137**	

All other variables had weaker and insignificant relationships with the strongest relationship tied to: whether they spend most of their time near a window. This indicates students who spent most of their time near a window, were more likely to be satisfied with their indoor air humidity than those who did not. Table 121 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 121-PS Relationship between satisfaction with indoor air humidity dependent variable and other independent variables excluded from multiple linear regression analysis model (n=170)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.123	0.094
Months in Residential Hall	0.008	0.915
Average time spent in Residential Hall	-0.113	0.120
Whether they spent most of their time in their bedrooms	-0.033	0.647
Whether they spent most of their time near a window	0.121	0.092
Which floor they spend most of their time	-0.007	0.926
If the air is stale in the area they spend most of their time	-0.061	0.418
If there was a draft in their space	-0.015	0.839
Satisfaction with level of control over changing their indoor air temperature	0.054	0.509
If temperature controls are easy to use	0.024	0.744
Clothing Insulation Factor	0.016	0.826
MET Unit	-0.026	0.722
Perceived indoor air temperature	-0.058	0.426
Perceived indoor air humidity	-0.113	0.118

4.4.2.1.3.3 Education Indicator Feedback

Examining educational efforts by HE institutions, the survey asked students several questions related to their cognizance of energy and water consumption. The questions posed were related to the provision of educational programs highlighting conservation awareness programs on campus or within the residential halls, given that they inhabit LEED certified buildings.

Only 42% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls with only 28% indicating participation in any such programs. From the behavioral perspective only 13% believed it had any type of impact on changing their energy and consumption behavior. On average they only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'rarely' to 'very frequently'. Table 122 below outlines the student survey results as pertaining to student education on consumption conservation.

Table 122-PS Education indicator findings (n=170)

Survey Question	PS Respondent Votes
% Indicating presence of conservation awareness programs on campus/res. hall	42%
% Indicating participation in conservation awareness programs on campus/res. hall	28%
% Indicating a change in their energy and water consumption behavior from programs	13%
Frequency of thinking about water consumption	Avg. 4.07 SD 1.09
Frequency of thinking about energy consumption	Avg. 4.11 SD 1.09

4.4.2.1.3.4 Overall Feedback Analysis

Of the total comments provided by PS residents, 48% commented on the level of control they have over changing their indoor temperature. Followed by the ease of use of thermostat controls and satisfaction with indoor ventilation at 46%, and 33% respectively. Table 123 and Figure 52 outline the various survey questions and the total percent of students whom commented on particular questions posed.

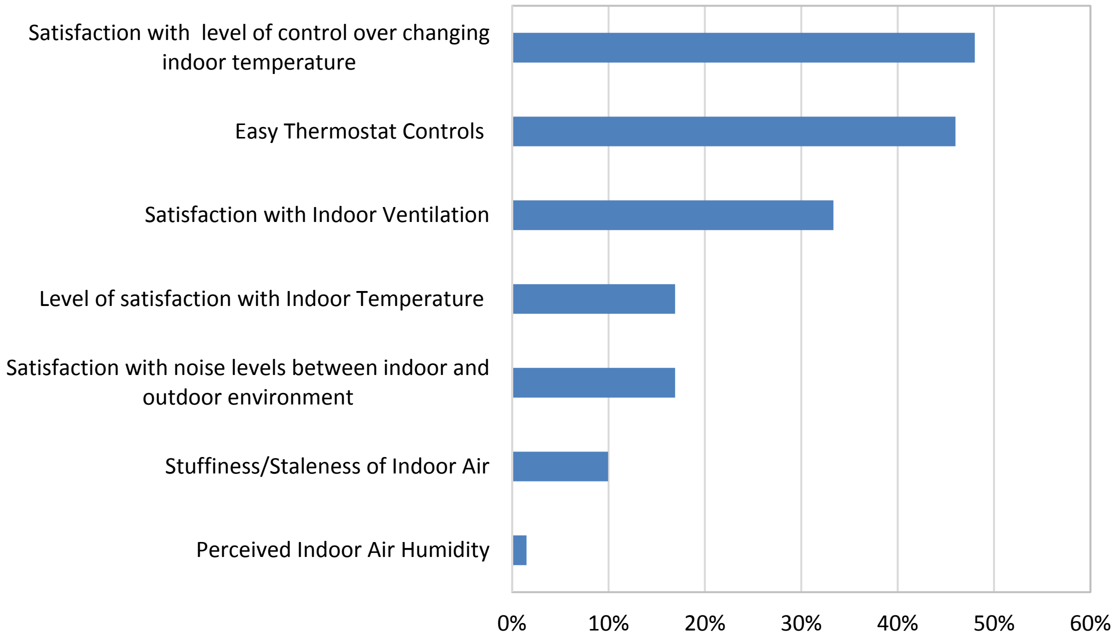


Figure 52-PS Percent of Total Comments Provided

Table 123-PS percent of total comments received per survey question (n=201)

Survey Question Description	PS-% Comments*
Satisfaction with level of control over changing indoor temperature	48%
Easy thermostat controls	46%
Satisfaction with indoor ventilation	33%
Level of satisfaction with indoor temperature	17%
Satisfaction with noise levels between indoor and outdoor environment.	17%
Stuffiness/Staleness of indoor air	10%
Perceived indoor air humidity	1%
Level of satisfaction with indoor air humidity	0%**

*Total number of specific comments per occupant divided by the total number of respondents.
**No Comments Provided.

As can be seen the parameter of highest importance to student occupants is their level of control over changing their indoor temperature. A total of 648 comments were received from PS residents, with 363 of them directly related to thermal comfort, and controls parameters. Given that over 56% of comments were directly related to these parameters, it highlights their importance to student occupants. Of the 56% total percentage over 100% were negative comments as related to their satisfaction with their level of control over changing indoor temperature. Table 124 below indicates the percent of total negative comments received per survey question posed.

Table 124-PS percent negative comments per survey question (n=201)

Survey Question Description	PS-% Negative Comments
Satisfaction with level of control over changing indoor temperature	100% out of 48%
Easy thermostat controls	91% out of 46%
Satisfaction with indoor ventilation	54% out of 33%
Satisfaction with noise levels between indoor and outdoor environment.	88% out of 17%
Stuffiness/Staleness of indoor air	90% out of 10%
Level of satisfaction with indoor temperature	85% out of 17%
Perceived indoor air humidity	100% out of 1%
Level of satisfaction with indoor air humidity	0%*

*No Comments Provided.

4.4.2.1.3.5 Multi-variable Linear Regression of Variables Related to Feedback

Given the results, satisfaction with level of control over changing indoor temperature was regressed on all other variables within the survey. The variables with the strongest relationships were tied to: indoor temperature satisfaction and if temperature controls were easy to use.

This indicates students who were satisfied with their indoor temperature, were more likely to be satisfied with their level of control over changing their indoor temperature (thermostat controls). Students who found temperature controls easy to use, were more likely to be satisfied with the level of control over changing their indoor temperature than those who did not. Table 125 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with level of control over changing their indoor temperature.

Table 125-PS Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and independent variables using multiple linear regression analysis (n=170)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.215
Indoor temperature satisfaction	0.366	0.000
If temperature controls are easy to use	0.414	0.000
Model	**r=0.621, R square=0.385**	

All other variables had weaker and insignificant relationships to satisfaction with level of control over changing indoor temperature. Table 126 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 126-PS Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=170)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.030	0.624
Months in Residential Hall	0.026	0.678
Average time spent in Residential Hall	0.008	0.896
Floor they spend most of their time	0.010	0.867
If they spend most of their time in their bedrooms	-0.050	0.415
If they spend most of their time near a window	0.057	0.350
Perceived indoor air temperature	0.049	0.424
Perceived indoor air humidity	0.018	0.774
Indoor air humidity satisfaction	0.041	0.523
If the air is stale in the area they spend most of their time	-0.026	0.690
If there was a draft in their space	-0.022	0.719
Clothing Insulation Factor	0.052	0.398
MET Unit	0.085	0.165
Level of satisfaction with noise levels	0.029	0.647

4.4.2.2 Non-LEED Residence Hall Student Survey Results

4.4.2.2.1 Residence Hall WT

The total number of WT respondents analyzed over the collection period (10/21/2013-01/06/2014), consisted of 148 responses. This generated a 31% response rate, shy of the target ASHRAE Standard-55 35% response rate requirement by 4%. The total residential hall gender split consists of 18% female and 82% male.

The survey respondents were 23% female and 77% male. On average the respondents have lived between one to three months in the residential hall (avg. 1.76, SD 1.11), and spend an average 54% of their time in the building with an SD of 18%.

76% of respondents indicated spending majority of their time in their bedrooms. 63% indicating spending their time near a window. Of the total number of respondents 30% indicated the air in their area was stale and 34% indicated a draft.

WT has one thermostat per suite located in the living room. The thermostat controls the temperature for all the rooms. 34% indicated satisfaction with their level of control over changing their temperature in the area they spend most of their time and 64% of the respondents indicated the controls are easy to use.

On average the respondents clothing factor was 0.46 with an SD of 0.26 placing student clothing factor within the 0.20-0.72 range. On the lower end 0.20 is equivalent to wearing a T-shirt, walking shorts, and briefs/panties and on the higher of 0.72 is equivalent to wearing long sleeve underwear top and bottoms, sweatpants and a T-shirt (ASHRAE Standard 55-2013-*Garment Insulation Table 5.2.2.2B*). The students' metabolic unit averaged at 1.08 with an SD of 0.27, which equates to '*seated quiet'* (ASHRAE Standard 55-2013-*Metabolic rates for typical tasks Table 5.2.1.2*).

Respondent votes on perception of indoor air temperature averaged at 'slightly cool', with an SD range falling between 'cold' to 'Neutral'. Votes on satisfaction with indoor air temperature averaged at the neutral point with the SD range falling between 'dissatisfied' to 'satisfied'. Votes on perception of indoor air humidity averaged at 'dry', with an SD range falling between 'dry' to 'moist/humid'. Satisfaction with indoor air humidity averaged at the neutral point with an SD ranging between 'slightly dissatisfied' to 'slightly satisfied'.

Student responses resulted in an average satisfaction with noise levels falling within the 'neither satisfied nor dissatisfied' category with an SD range between 'somewhat dissatisfied' and 'mostly satisfied'. Respondent votes on perception and satisfaction with indoor temperature and indoor air humidity in the area they spend most of their time and noise levels are indicated below in Table 127 outlining the Likert range their votes fall within. Table 127 also outlines the results of the two sample populations with and without the missing values. The sample size with the missing values is listed as SPSS n.

Table 127-WT respondents Likert range indication with indoor temperature, air humidity and noise levels (n=148, SPSS n=123)

Student Survey Question	WT Respondent Votes n=148	WT Respondent Votes SPSS n=123*
Perceived Indoor Temperature in the area you spend most of your time	Avg. 3.26 SD 1.63	Avg. 3.21 SD 1.62
Indoor Temperature Satisfaction in the area you spend most of your time	Avg. 4.05 SD 1.53	Avg. 4.11 SD 1.50
Perceived Indoor Air Humidity in the area you spend most of your time	Avg. 3.81 SD 0.76	Avg. 3.76 SD 0.75
Indoor Air Humidity Satisfaction in the area you spend most of your time	Avg. 4.37 SD 1.23	Avg. 4.38 SD 1.24
Satisfaction with noise levels between indoor and outdoor environment.	Avg. 4.65 SD 1.56	Avg. 4.68 SD 1.53

*Sample size with missing values used for multi-variable regression analysis.

4.4.2.2.1.1 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Temperature

In regressing perception of indoor air temperature on all other variables within the survey, the variable with the strongest relationship was tied to: whether there was a draft in the area they spend most of their time.

This indicates students who felt a draft in their space, were more likely to perceive indoor air temperature as cooler than those who did not. Table 128 outlines the standardized beta coefficient and significance of the model with the most power to predict perception of indoor temperature in the area students spend most of their time.

Table 128-WT Relationship between perception of indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=123)

Dependent Variable	Perception of indoor air temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
If there was a draft in their space	-0.231	0.010
Model	**r=0.231, R square=0.053**	

All other variables had weaker and insignificant relationships. Table 129 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 129- WT Relationship between perception of indoor air temperature dependent variable and other independent variables excluded from multiple linear regression analysis model (n=123)

Dependent Variable	Perception of indoor air temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.046	0.605
Months in Residential Hall	-0.001	0.989
Average time spent in Residential Hall	0.052	0.558
On Floor where they spent most of the time	-0.141	0.115
Whether they spent most of their time in their bedrooms	0.026	0.777
Whether they spent most of their time near a window	-0.017	0.848
Satisfaction with indoor temperature	-0.112	0.206
Perception of indoor air humidity	0.120	0.179
Satisfaction with indoor air humidity	0.102	0.251
If the air was stale (stuffy, not fresh)	0.054	0.544
If they were satisfied with the level of control over changing the temperature	-0.031	0.725
If temperature controls are easy to use	-0.143	0.107
Clothing insulation factor	-0.102	0.252
MET Unit	-0.052	0.562
Level of satisfaction with noise levels	0.002	0.978

In regressing satisfaction with indoor air temperature on all other variables within the survey, the variable with the strongest relationships were tied to: satisfaction with the level of control over changing their indoor air temperature and satisfaction with indoor air humidity.

This indicates students who were satisfied with their level of control over changing their indoor air temperature, were more likely to be satisfied with their indoor air temperature. Students who were satisfied with their indoor air humidity, were more likely to be satisfied with their indoor air temperature. Table 130 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air temperature in the area students spend most of their time.

Table 130-WT Relationship between satisfaction with indoor air temperature (dependent variable) and independent variables using multiple linear regression analysis (n=123)

Dependent Variable	Satisfaction with indoor air temperature in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Satisfaction with level of control over changing their indoor temperature	0.486	0.000
Satisfaction with indoor air humidity	0.275	0.000
Model	**r=0.576, R square=0.332**	

All other variables had weaker and insignificant relationships to satisfaction with indoor air temperature, with the strongest relationships within the weaker subset relating to perception of indoor air humidity and satisfaction with noise levels.

This indicates students who perceived indoor air humidity as humid, were less likely to be satisfied with their indoor air temperature. Students who were satisfied with the noise conditions, were more likely to be satisfied with their indoor air temperature than those who were not. Table 131 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 131- WT Relationship between satisfaction with indoor air temperature dependent variable and other independent variables excluded from multiple linear regression analysis model (n=123)

Dependent Variable	Satisfaction with Indoor Air Temperature in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.023	0.767
Months in Residential Hall	0.056	0.473
Average time spent in Residential Hall	0.031	0.690
On Floor where they spent most of the time	0.041	0.589
Whether they spent most of their time in their bedrooms	0.081	0.283
Whether they spent most of their time near a window	0.022	0.768
Perception of indoor air humidity	-0.147	0.069
If the air was stale (stuffy, not fresh)	0.007	0.933
If there was a draft in their space	-0.033	0.665
If temperature controls are easy to use	0.004	0.956
Clothing Insulation Factor	-0.013	0.860
MET Unit	-0.020	0.794
Level of satisfaction with noise levels	0.152	0.056
Perceived Indoor Temperature	-0.118	0.114

4.4.2.2.1.2 Multi-variable Linear Regression of Perception and Satisfaction-Indoor Air Humidity

In regressing perceived indoor air humidity on all other variables within the survey, the strongest relationships were tied to: satisfaction with indoor air humidity and temperature.

This indicates students who were satisfied with their indoor air humidity, were more likely to perceive indoor air humidity as humid. Students who were satisfied with their indoor air temperature, were less likely to perceive indoor air humidity as humid. Table 132 outlines the beta coefficients and significances of independent variables on the perception of indoor air humidity.

Table 132-WT Relationship between perception of indoor air humidity (dependent variable) and independent Variables using multiple linear regression analysis model (n=123)

Dependent Variable	Perception of indoor air humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.000
Indoor air humidity satisfaction	0.430	0.000
Satisfaction with indoor temperature	-0.192	0.030
Model	**r=0.413, R square=0.171**	

As outlined in Table 133 all other variables had weak and insignificant relationships to perception of indoor air humidity.

Table 133- WT Relationship between perception of indoor air humidity (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=123)

Dependent Variable	Perception of indoor air humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.048	0.570
Months in Residential Hall	-0.027	0.749
Average time spent in Residential Hall	0.073	0.395
On Floor where they spent most of the time	0.061	0.466
Whether they spent most of their time in their bedrooms	-0.087	0.303
Whether they spent most of their time near a window	-0.038	0.648
If the air was stale (stuffy, not fresh)	0.099	0.280
If there was a draft in their space	0.055	0.512
Satisfaction with level of control over changing their indoor temperature	-0.008	0.937
If thermostat is easy to use	-0.040	0.640
Clothing Insulation Factor	0.008	0.927
MET unit	0.025	0.765

Level of satisfaction with noise levels	-0.021	0.816
Perceived Indoor Temperature in the area they spend most of their time	0.042	0.621

In regressing satisfaction with indoor air humidity on all other variables within the survey, the variables with the strongest relationships were tied to: if the air in their space was stale/stuffy, indoor temperature satisfaction, perceived indoor air humidity, level of satisfaction with noise levels, and average time spent in the residential hall.

This indicates students who experienced stale air, were less likely to be satisfied with indoor air humidity conditions than those who did not. Students satisfied with their indoor temperature, were more likely to be satisfied with indoor air humidity conditions. Students who perceived indoor air humidity as humid, were more likely to be satisfied with their indoor air humidity. Students who were satisfied with the noise levels between the indoor and outdoor environment, were more likely to be satisfied with their indoor air humidity. Students who spent more time in the residence hall, were less satisfied with indoor air humidity. Table 134 outlines the standardized beta coefficient and significance of the model with the most power to predict satisfaction with indoor air humidity in the area students spend most of their time.

Table 134-WT Relationship between satisfaction of indoor air humidity (dependent variable) and independent variables using multiple linear regression analysis (n=123)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.020
If the air was stale (stuffy, not fresh)	-0.288	0.000
Indoor temperature satisfaction	0.235	0.002
Perceived indoor air humidity	0.347	0.000
Level of satisfaction with noise levels	0.186	0.014
Average time spent in Residential Hall	-0.154	0.033
Model	**r=0.647, R square=0.418**	

All other variables had weaker and insignificant relationships to satisfaction with indoor air humidity with the strongest relationship tied to gender. This indicates females are less satisfied with indoor air humidity than males. Table 135 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 135-WT Relationship between satisfaction with indoor air humidity dependent variable and other independent variables excluded from multiple linear regression analysis model (n=123)

Dependent Variable	Satisfaction with indoor air humidity in the area you spend most of your time	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	-0.134	0.059
Months in Residential Hall	-0.041	0.571
On Floor where they spent most of the time	-0.047	0.515
Whether they spent most of their time in their bedrooms	0.023	0.753
Whether they spent most of their time near a window	0.019	0.794
If there was a draft in their space	0.059	0.408
Satisfaction with level of control over changing their indoor air temperature	-0.082	0.327
If temperature controls are easy to use	0.014	0.853
Clothing Insulation Factor	0.089	0.210
MET Unit	-0.023	0.754
Perceived indoor air temperature	0.099	0.167

4.4.2.2.1.3 Education Indicator Feedback

Examining educational efforts by HE institutions, the survey asked students several questions related to their cognizance of energy and water consumption. The questions posed were related to the provision of educational programs highlighting conservation awareness programs on campus or within the residential halls, it must be notes that WT is a non-LEED building.

40% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls, 20% indicated participation in such programs. From the behavioral perspective only 5% believed it had any type of impact on changing their energy and consumption behavior. On average they only thought about their energy and water consumption behavior ‘rarely’ with an SD ranging from ‘rarely’ to ‘occasionally’. Table 136 below outlines the student survey results as pertaining to student education on consumption conservation.

Table 136-WT Education indicator findings (n=123)

Student Survey Question	WT Respondent Votes n=123
% Indicating presence of conservation awareness programs on campus/res. hall	40%
% Indicating participation in conservation awareness programs on campus/res. hall	20%
% Indicating a change in their energy and water consumption behavior from programs	5%
Frequency of thinking about water consumption	Avg. 3.88 SD 1.18
Frequency of thinking about energy consumption	Avg. 3.98 SD 1.13

4.4.2.2.1.4 Overall Feedback Analysis

Of the total comments provided by WT residents of, 55% commented on the level of control they have over changing their indoor temperature. Followed by satisfaction with indoor ventilation, ease of use of thermostat controls and satisfaction with indoor temperature at 34%, 23% and 22% respectively. Table 137 and Figure 53 outline the various survey questions and total percent of students whom commented on particular questions posed.

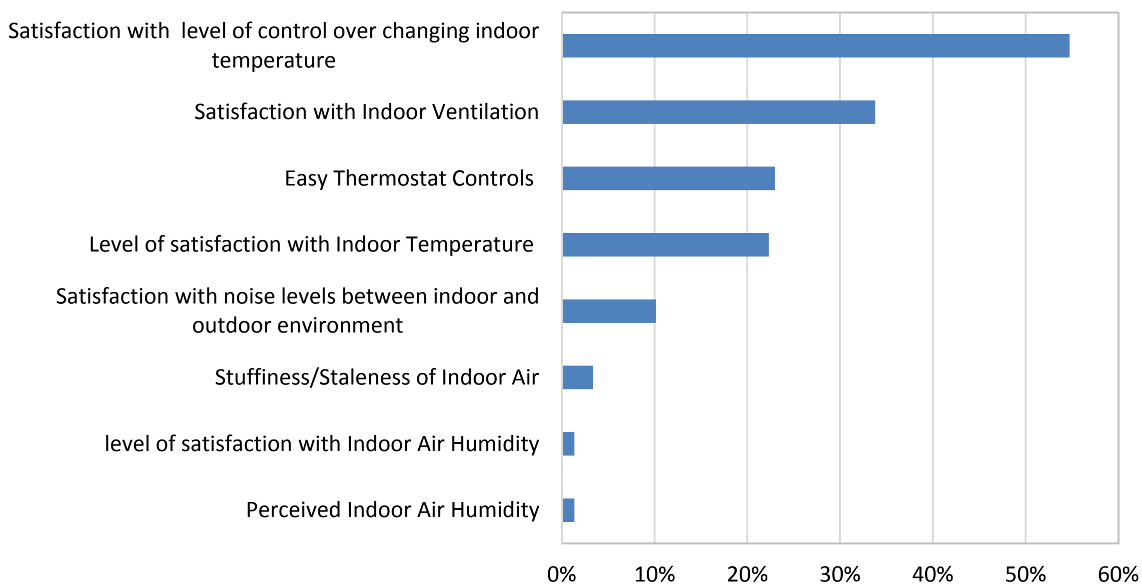


Figure 53-WT Percent of Total Comments Provided

Table 137-WT percent of total comments received per survey question (n=148)

Survey Question Description	WT-% Comments*
Satisfaction with level of control over changing indoor temperature	55%
Satisfaction with indoor ventilation	34%
Easy thermostat controls	23%
Level of satisfaction with indoor temperature	22%
Satisfaction with noise levels between indoor and outdoor environment.	10%
Stuffiness/Staleness of indoor air	3%
Perceived indoor air humidity	1%
Level of satisfaction with indoor air humidity	1%

*Total number of specific comments per occupant divided by the total number of respondents.

As can be seen the parameter of highest importance to student occupants is their level of control over changing their indoor temperature. A total of 523 comments were received for residence hall WT, with 227 of them directly related to thermal comfort, and controls parameters. Given that over 43% of comments were directly related to these parameters, it highlights their importance to student occupants. Of the 43% total percentage over 98% were negative comments as related to their satisfaction with their level of control over changing indoor temperature. Negative comments were mainly related to their lack of ability to adjust the temperature controls as they believed it was being controlled by the facilities department. They also commented thermostat controls simply did not work or change the indoor temperature. Table 138 below indicates the percent of total negative comments received per survey question posed.

Table 138-WT percent negative Comments per Survey Questions Posed (n=148)

Survey Question Description	WT-% Negative Comments
Satisfaction with level of control over changing indoor temperature	98% out of 55%
Easy thermostat controls	100% out of 23%
Satisfaction with indoor ventilation	68% out of 34%
Satisfaction with noise levels between indoor and outdoor environment.	80% out of 10%
Stuffiness/Staleness of indoor air	60% out of 3%
Level of satisfaction with indoor temperature	98% out of 22%
Perceived indoor air humidity	100% out of 1%
Level of satisfaction with indoor air humidity	100% out of 1%

4.4.2.2.1.5 Multi-variable Linear Regression of Variables Related to Feedback

Given the results, satisfaction with level of control over changing indoor temperature was regressed on all other variables within the survey. The variables with the strongest relationships were tied to: indoor temperature satisfaction and if temperature controls are easy to use.

This indicates students who were satisfied with their indoor temperature, were more likely to be satisfied with their level of control over changing their indoor temperature (thermostat controls). Students who found temperature controls easy to use, were more likely to be satisfied with the level of control over changing their indoor temperature than those who did not. Table 139 outlines the standardized beta coefficients and significances of the model with the most power to predict satisfaction with level of control over changing their indoor temperature.

Table 139-WT Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and independent variables using multiple linear regression analysis (n=123)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Strong Relationships	**Standardized Beta Coefficients**	**Significance**
(Constant)		0.001
Indoor temperature satisfaction	0.473	0.000
If temperature controls are easy to use	0.192	0.015
Model	**r=0.541, R square=0.292**	

All other variables had weaker and insignificant relationships to satisfaction with level of control over changing indoor temperature, with the strongest relationships within the weaker subset relating to months in the residential hall, and satisfaction with indoor and outdoor noise levels.

This indicates students who have lived in WT for shorter a duration, were more likely to be dissatisfied with their level of control over changing their indoor air temperature, than those who have lived there longer. Students satisfied with the noise levels between the indoor and outdoor environment, were less likely to be satisfied with the level of control they have over changing their indoor air temperature versus those who did not. Table 140 outlines the various beta coefficients and significances within the weaker subset of variables excluded from the stepwise regression analysis.

Table 140-WT Relationship between satisfaction with level of control over changing indoor temperature (dependent variable) and other independent variables excluded from multiple linear regression analysis model (n=123)

Dependent Variable	Satisfaction with level of control over changing indoor temperature	
Independent Variables with Weak Relationships	**Standardized Beta Coefficients**	**Significance**
Gender	0.016	0.835
Months in Residential Hall	-0.140	0.069
Average time spent in Residential Hall	0.027	0.725
Floor they spend most of their time	-0.118	0.132
If they spend most of their time in their bedrooms	0.012	0.875
If they spend most of their time near a window	0.021	0.787
Perceived indoor air temperature	0.059	0.451
Perceived indoor air humidity	-0.042	0.590
Indoor air humidity satisfaction	-0.112	0.167
If the air is stale in the area they spend most of their time	-0.022	0.791
If there was a draft in their space	-0.036	0.644
Clothing Insulation Factor	-0.081	0.292
MET Unit	0.099	0.204
Level of satisfaction with noise levels	-0.154	0.053

4.4.2.3 LEED and Non-LEED Residence Hall Summary of Results

4.4.2.3.1 Overall Results

Given the residence halls differ in terms of their location, LEED rating, and heating ventilation and air conditioning systems, data from all surveys was not universally compiled to run regression analyses. A comparison of individual regression results between institutions was carried out, to gauge similar and dissimilar experiences in terms of commentary and Likert satisfaction feedback. This section discusses the results of LEED and non-LEED residence hall WT.

Compiling all residence halls the average gender split was 50% female, providing an even split of student experience based on gender with a total sample size of 593 and SPSS sample size of 501 students.

The average months students lived in the halls was 1-3 months, with an SD range falling between 1-3 months and 4-6 months. Given the nature of this building typology, it is not surprising students are not long-term residents. This duration also supports the non-permanent mentality of occupants in this building typology.

Overall the average time students spent in the residence hall was 56% with an SD of 18%; of which 82% is spent in their bedrooms. This is a very high percentage, fortifying their arguments for individualized thermal zone controls. Currently all LEED residence halls have a singular thermostat in the living room. It must be noted student comments also related to their internal suitemate differences in thermal condition requirements.

Currently HE residential life offices select suitemates based on a lottery system; adding thermal parameters in the decision making process, will add value by increasing the probability of student thermal satisfaction. Therefore residential life personnel should include thermal parameters as one of their variables in assigning suitemates. This will aide in clustering students with similar thermal requirements in same suites; to ensure thermal conflicts do not arise.

77% of students indicated spending time near a window. Upon inspection their bedroom configurations all include windows, however students complained they are small and should allow for more ventilation. In discussing their comments with designers of the residence halls, it was noted that window size is code driven. However if indeed larger windows cannot be provided, additional ventilation should be considered since students complained of localized smog and stuffy air. Overall 33% of students indicated the air in their space was stuffy and stale. In the case of EH students tamper with the smoke detectors due to localized smog, representing a fire hazard and exposing students to unhealthy indoor environments. It must also be noted such issues expose HE institutions to legal risks and ramifications.

4.4.2.3.2 Overall Indoor Air Humidity Results (Occupant Satisfaction with Temperature and Humidity-POE Indicator 7)

4.4.2.3.2.1 Satisfaction with Indoor Air Humidity

Examining student satisfaction with indoor air humidity in EH, CSC, PS and WT strong correlations and statistical significances were tied to: 'perception of indoor air humidity', 'indoor temperature satisfaction', and 'if the air was stale in their area'. This indicates: (1) students who perceived indoor air humidity as humid, were more likely to be satisfied with their indoor air humidity (2) students satisfied with their indoor temperature were more likely to be satisfied with indoor air humidity condition, and (3) students who experienced stale air were less likely to be satisfied with their indoor air humidity conditions.

In EH and CSC whether they spent most of their time in their bedrooms was also a predictor of their satisfaction with indoor air humidity. Students who spent most of their time in their bedrooms, were more likely to be satisfied with their indoor air humidity on average than those who did not.

In PS and WT it was found that students who were satisfied with noise levels between the indoor and outdoor environment, were more likely to be satisfied with their indoor air humidity.

Additional regression results not shared amongst the residence halls but individually realized include: (1) students who spend most of their time near a window were more likely to be satisfied with their indoor air humidity than those who did not (PS), (2) students who spent more time in the residence hall were less satisfied with indoor air humidity (EH), (3) females were less satisfied with their indoor air humidity than males (EH), (4) students on lower floors were less likely to be satisfied with their indoor air humidity conditions (EH), (5) students with higher activity levels were more likely to perceive indoor air humidity as humid (CSC).

4.4.2.3.2.2 Perception of Indoor Air Humidity

Examining student perception of indoor air humidity strong positive correlations and statistical significances were found tied to: 'satisfaction with indoor air humidity'. In EH, CSC, and WT students who were satisfied with their indoor air humidity were more likely to perceive indoor air humidity as humid. In PS no one variable could be identified as a predictor of indoor air humidity satisfaction.

Additional regression results not shared amongst the residence halls but individually realized include: (1) higher their activity level (MET unit) the more humid they perceived indoor air humidity (EH), (2) students who spent most of their time in their bedrooms were more likely to perceive indoor air humidity to be drier than those who did not (EH), (3) students who thought thermostat controls were easy to use, perceived indoor air humidity to be drier (EH), (4) students who were satisfied with their indoor noise levels perceived indoor air humidity as dry, versus students who were not satisfied with their indoor noise conditions (CSC), (5) students who were satisfied with their indoor air temperature, were less likely to perceive indoor air humidity as humid (WT).

4.4.2.3.3 Overall Indoor Air Temperature Results(Occupant Satisfaction with Temperature and Humidity-POE Indicator 7)

4.4.2.3.3.1 Satisfaction with Indoor Air Temperature

Examining student satisfaction with indoor air temperature, strong positive correlations and statistical significances were found tied to: 'satisfaction with the level of control over changing indoor temperature'. In EH, CSC, PS and WT the shared results indicated students were more likely to be satisfied with their indoor temperature, if they were satisfied with the level of control they had over changing it.

In CSC, PS and WT 'satisfaction with indoor air humidity' was also a predictor of 'satisfaction with indoor air temperature'. The results indicated students who were satisfied with their indoor air humidity, were more likely to be satisfied with their temperature.

Shared results in CSC, PS, and WT indicated students who were satisfied with noise conditions between their indoor and outdoor environment, were more likely to be satisfied with their indoor air temperature than those who were not. Although the impact of noise on temperature satisfaction has not been researched extensively a potential study may highlight the impact of other sensations on satisfaction with thermal conditions.

Other results, not shared by all, but realized in CSC include: (1) students who spend most of their time in their bedrooms were less satisfied with their indoor air temperature conditions, and (2) students who perceived indoor air temperature to be cooler were more likely to be satisfied with their indoor air temperature conditions. CSC occupants indicated in their comments the hall is overheated, and they have limited ventilation given the small window size. Hence the correlation results support their statements on temperature and ventilation challenges.

Other results, not shared by all, but realized in PS include: (1) students who have lived in the residence hall less months were more likely to be dissatisfied with their indoor temperature as compared to those residing longer, (2) students with higher clothing factors were more likely to be dissatisfied with the indoor air temperature. The first result may be due to the transitional process and adjustment period associated with new living conditions. The clothing insulation factor mimics the findings from the thermal logging study of EH where students indicated, the higher their clothing insulation factor the less likely they were to be satisfied with indoor temperature ('Thermal Logging Study' section 3.3.2.2 of this report).

In WT it was also found that students who were satisfied with their indoor air humidity, were more likely to be satisfied with their indoor air temperature.

4.4.2.3.3.2 Perception of Indoor Air Temperature

Examining student perception of indoor air temperature in EH and CSC females perceived indoor air temperature as cooler on average than males. In EH students who were more satisfied with their indoor air temperature, perceived indoor air temperature as warmer, while in CSC students who were more satisfied with their indoor air temperature, perceived indoor air temperature as cooler. This result highlights student comments on the thermal conditions of both buildings. Students in EH complained of cool/cold indoor thermal conditions, whilst students in CSC complained the building is overheated and have limited ventilation. In CSC and PS students with higher clothing factors perceived indoor air temperature as cooler/colder.

In CSC, PS and WT students who felt a draft in their space were more likely to perceive indoor air temperature as cooler than those who did not. PS dataset also resulted in a strong correlation to 'satisfaction with the level of control over changing indoor temperature', students who were satisfied with their level of control over changing indoor temperature were more likely to perceive indoor temperature as warmer.

4.4.2.3.4 Building Controls Ease of Use Indicator Results (POE Indicator 8)

Overall 42% indicated satisfaction with 'satisfaction with the level of control over changing indoor temperature' with 51% of respondents commenting on this parameter. 98% of student comments were negative on their level of control over changing their indoor temperature. The overwhelming majority indicated they should be given 'more control'. Students voiced frustration over complicated controls and inability to actually change the temperature. One specific student's comment indicated it was akin to 'Parental Controls' and should be removed. 58% of students in indicated temperature controls were easy to use, however many comments indicated it was easy because they didn't work and nothing changed.

Based on the previous section student feedback it is evident temperature controls are key in ensuring student satisfaction. Given the importance of 'level of control over changing indoor temperature' and overpowering student feedback on this parameter, it was regressed within the various datasets.

In regressing 'satisfaction with level of control over changing indoor temperature' variable, the regression results of all residence halls showed high correlations and significances to shared independent variables. The overwhelming results were tied to: indoor temperature satisfaction and if temperature controls were easy to use. These variables shared positive statistically significant relationships within EH, CSC, PS, and WT dataset.

This indicates students who were satisfied with their indoor temperature were more likely to be satisfied with their level of control over changing their indoor temperature (thermostat controls) and those who found temperature controls easy to use were more likely to be satisfied with the level of control over changing their indoor temperature than those who did not. Given the findings it is evident a gap exists between what designers, and facilities management personnel are delivering and student expectations. Other results which were not shared by each residence hall but were relevant were the clothing insulation factor in CSC, and months in residence hall and satisfaction with noise levels in WT.

In CSC students with higher clothing insulation factors were more likely to be satisfied with their level of control over changing their indoor temperature. This may be the result of the adaptive strategy of wearing more clothing to adapt to their indoor environment.

In WT students living there for a shorter duration were more likely to be dissatisfied with their level of control over changing their indoor air temperature, than those who have lived there longer, which may be the result of adapting to new living conditions. Also students satisfied with the noise levels between the indoor and outdoor environment, were less likely to be satisfied with the level of control they have over changing their indoor air temperature versus those who did not. This finding does not support or refute the level of satisfaction with level of control over changing indoor temperature, due to the sample size it may have simply shown a correlation by chance.

4.4.2.3.5 Clothing Insulation Factor and Metabolic Unit Identification

Given the importance and feedback on thermal parameters the survey also resulted in the identification of actual clothing insulation factor and metabolic unit (MET unit) for this specific demographic and building typology. Even though residence halls were located in different climate zones, both parameters did not show high variability. Figure 54 outlines the LEED and all inclusive averages and individual residence hall occupants' clothing insulation factor and metabolic unit.

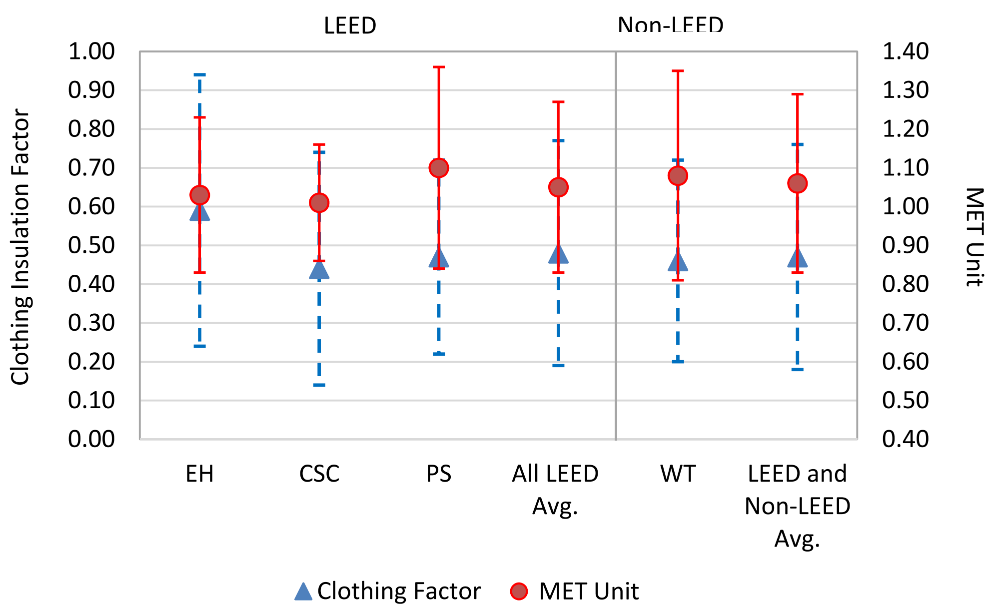


Figure 54-Student Survey Results LEED and Non-LEED Clothing Insulation Factor and Typical Activity Level (MET unit) Residence Hall EH, CSC, PS and WT

The average clothing insulation factor of LEED residents fell at an average of 0.48 with an SD of 0.29. Including WT the average and SD is slightly lower at an average of 0.47 and SD of 0.29. On the lower end 0.18 is equivalent to wearing a T-shirt, walking shorts, and briefs/panties and on the higher of 0.76 is equivalent to wearing long sleeve underwear top and bottoms, sweatpants, T-shirt and knee socks (ASHRAE Standard 55-2013-*Garment Insulation Table 5.2.2.2B*). The average metabolic unit for LEED halls was at an average of 1.05 and SD of 0.22, including WT it increases to an average 1.06 with an SD of 0.23. This MET unit equates to '*seated quiet'* (ASHRAE Standard 55-2013-*Metabolic rates for typical tasks Table 5.2.1.2*). As can be seen in Figure 54 the clothing insulation factor and MET unit are consistent within this demographic group and for this building typology. It is evident locational factors did not impact this parameter across geographies.

4.4.2.3.6 Education Indicator Results (POE Indicator 10)

Examining educational efforts by HE institutions, only 36% of respondents indicated a presence of conservation awareness programs on campus or within their residence halls with only 19% indicating participation in any such programs. From the behavioral perspective only 6% believed it had any type of impact on changing their energy and water consumption behavior. It must be noted frequency of thinking about water and energy consumption was higher in residents occupying LEED residence halls. Table 141 outlines the various averages of their frequency of thinking about water and energy consumption.

Table 141-Cognizance of water and energy consumption all residence halls (EH, CSC, PS and WT)

Survey Question	EH	CSC	PS	All LEED Res. Halls	WT	LEED & Non-LEED Res. Halls
Frequency of thinking about water consumption	Avg. 3.79 SD 1.20	Avg. 4.05 SD 1.12	Avg. 4.07 SD 1.09	**Avg. 4.01 SD 1.13**	Avg. 3.88 SD 1.18	**Avg. 3.98 SD 1.14**
Frequency of thinking about energy consumption	Avg. 3.94 SD 1.22	Avg. 4.06 SD 1.15	Avg. 4.11 SD 1.09	**Avg. 4.06 SD 1.14**	Avg. 3.98 SD 1.13	**Avg. 4.04 SD 1.13**

It is evident the difference between LEED and non-LEED occupants in terms of their cognizance of energy and water consumption is minimal. On average they only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'very rarely' to 'very frequently'. Given the vast difference in SDs, and proximity of average results between LEED and non-LEED residence halls; it is clear an educational gap exists in all HE institutions. Findings from the 'Water Study Section' within this report highlight the education gap. Please refer to section 3.1.5.4 of this report, for regression results summary of the education indicator related to water consumption awareness. For additional findings related to the education indicator Section 2.2 Table 6 provides an outline of its inclusion within this report.

4.4.2.3.7 Noise Indicator Identification and Results (POE Indicator 12)

The assessment of students' satisfaction with noise levels between their indoor and outdoor environment in the area they spend most of their time were relatively consistent. The average fell at 4.33 with an SD of 1.71, indicating an average of 'neither satisfied nor dissatisfied' within the range of 'mostly dissatisfied' and 'mostly satisfied'. It must be noted frequency of student comments on this parameter was higher amongst LEED halls than in the non-LEED hall. On average 10% of WT respondents voiced comments on this parameter while 20% commented from LEED residents. EH, CSC, PS and WT are all located in city centers.

In examining student comments about noise satisfaction many students indicated due to their location (near train lines, kindergarten facilities, and city center) it would be inevitable outside noise would infiltrate. However they voiced negative comments related to indoor noise infiltration between floors and within suites between bedrooms. On average 18% of respondents commented on this parameter, of which 86% was negative feedback. Amongst some of their notable comments it was highlighted sound easily travels from the toilet, therefore increasing sound proofing would be welcomed. Other comments related to noise were directed towards indoor applications versus the indoor and outdoor application posed to them in the survey. Given student responses an additional indicator examining indoor sound insulation, has been added to the proposed POE framework (Indicator 12-Indoor Sound Insulation).

4.4.3 Student Survey Conclusions

The student survey study was aimed at soliciting feedback from student occupants on demographics, satisfaction with indoor air humidity and temperature (POE Indicator 7), ease of use of environmental controls (POE Indicator 8) and occupant consumption conservation awareness programs facilitated by HE institutions (POE Indicator 10). An additional question was also posed related to noise conditions between indoor and outdoor environments; however in students' comments, it was evident indoor between bedroom, bathroom and floor noise was more relevant. Therefore this framework added POE Indicator 12-Indoor Sound Insulation, based on student survey results.

The results indicated satisfaction with indoor air humidity is tied to: 'perception of indoor air humidity', 'indoor temperature satisfaction', and 'if the air was stale in their area'. It was found that students were more satisfied if the indoor air is humid, and if they were happy with their indoor temperature. Stale air represented a problem as students were more likely to be dissatisfied under this condition. These findings support the work of researchers on indoor thermal comfort parameters and the need for ventilation and air movement. These findings support the work of researchers indicating that increased air movement increases occupant satisfaction. Students' perception of indoor air humidity was closely tied to their satisfaction with indoor air humidity, this indicates the complex interplay and dependence of the various thermal parameters in providing user comfort. Students also indicated higher satisfaction when conditions were humid versus dry. Given this finding and the adverse health impacts of low relative humidity, discussed in the 'Thermal Logging' section of this report, it is imperative these conditions are not overlooked.

Satisfaction with indoor air temperature was tied to: 'satisfaction with the level of control over changing indoor temperature'. In all residence halls this shared result indicates students prefer 'control' over 'parental control' by HE institutions. Researchers also highlight the importance in providing occupants more power over their indoor environments to make adjustments and adapt (Steemers and Yun 2009, Stevenson and Leaman 2010, Gram-Hanssen 2010). Satisfaction with indoor air humidity also played a role in temperature satisfaction echoing the need to ensure all thermal parameters are factored in collectively versus singularly (i.e. only temperature regulation). These findings indicate that students should be provided the ability to control both indoor temperature and humidity as both parameters impact thermal satisfaction. This also supports the work of researchers indicating the inclusion of various thermal parameters to ensure comfort (Deuble and de Dear 2012).

Results also highlighted singular strong correlations, which require further study. For example in CSC, PS, and WT students who were satisfied with noise conditions between their indoor and outdoor environment, were more likely to be satisfied with their indoor air temperature than those who were not. This indicates further study is required to address the impact of various sensations on collective occupant comfort.

One finding between residence halls showed opposing results. In EH students who were more satisfied with their indoor air temperature, perceived indoor air temperature as warmer, while in CSC students who were more satisfied with their indoor air temperature, perceived indoor air temperature as cooler. The reason behind this would have been a mystery lest the student survey. Based on student feedback it was found that CSC was overheated leading to students being more satisfied with temperature if they perceived it as cooler and the opposite for EH. This finding highlights the added value this POE framework brings to the performance evaluation of residence halls by identifying the gaps between what is being delivered (designers and FM departments) and what is being experienced (occupants).

Further examining the feedback provided by occupants the overwhelming area of concern was 'satisfaction with the level of control over changing indoor temperature'. 58% indicated dissatisfaction with their ability to control their indoor environment in terms of temperature and 98% of their comments were negative on this parameter. This highlights the gap that currently exists between designer and FM processes and understandings of what they are providing occupants. The regression results showed students satisfied with their indoor temperature, were more likely to be satisfied with their level of control over changing their indoor temperature (thermostat controls) and those who found temperature controls easy to use were more likely to be satisfied with the level of control over changing their indoor temperature than those who did not.

Clearly a vast gap exists signifying designers and FM personnel need to account for this in their designs and operations of the residence halls.

For example in EH students commented thermostats are easy to use simply because they don't work. EH thermostats are regulated by the FM department and students voiced frustration over their lack of control and variability in temperature provisions. In the case of PS and CSC students commented on the complex thermostats which have been installed that are simply unworkable.

This study also identified the clothing insulation factor and typical activity level (MET unit) of this demographic and building typology. It must be noted geographical and indoor conditions did not result in a clothing insulation differential between residence halls. However the SDs indicated student clothing preferences vary. Regression results indicated that on average they were more satisfied with their indoor thermal conditions, when they wore less clothing. Their overall MET unit was stable as well, indicating that their average activity in the residence halls is sedentary (1.06 MET unit).

Examining the education indicator results (POE Indicator 10) it was seen across HE institutions much is left to be desired in terms of awareness programs, behavioral changes and cognizance of energy and water consumption. These findings highlight the need to implement research carried out by Sterling et al. (2013) on creating 'living lab' environments in HE institutions. No difference was found between LEED and non-LEED occupants in terms of their cognizance of energy and water consumption. On average they only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'very rarely' to 'very frequently'. Given the vast difference in SDs, and proximity of average results between LEED and non-LEED residence halls; it is clear an educational gap exists in all HE institutions.

This POE framework also identified the need for the inclusion of POE Indicator 12-Indoor Noise Insulation. Previous research indicated that majority of students showed concern between indoor and outdoor noise conditions (McGrath and Horton 2011). However this study found the opposite. Students were forgiving of noise experienced from the outside environment as they indicated it was not the fault of the building but that they were living in cities. However provided negative comments related to indoor noise infiltration between floors, within suites and between bedrooms. 86% of their comments on this parameter was negative. Amongst some of their notable concerns was sound travel from the bathrooms and between bedrooms within suites.

The data collected and analyzed in this study did not uncover any substantial differences in any one parameter between LEED and the non-LEED residence halls. This shows certification alone is not sufficient to promote sustainability or occupant comfort in any one parameter. An all-inclusive approach needs to be undertaken to triangulate information, adjust, and benchmark; to understand how occupants are interacting with the building, and what their actual expectations and frustrations are. The proposed POE framework also showed the added value occupant comments have, in understanding

Likert satisfaction data collected. Without student comments regression results may be perplexing (i.e. temperature satisfaction results of CSC and EH), leading to faulty conclusions about indoor thermal conditions.

The proposed POE framework resulted in the discovery of various important issues to student occupants, designers, and HE institutions. Notably student occupants' satisfaction with indoor thermal conditions can increase with easy unregulated workable controls. Designers and FM departments will benefit from this insight to inform their current and future designs and operations, altering the 'status quo' thermal assumptions. HE institutions can be awakened to the increased need for the promotion of sustainability in practice by creating 'living labs', given the poor student awareness and cognizance of energy and water consumption results.

4.5 Facilities Management Feedback (POE Indicator 5, 7, 8, 9, 10 and 11)

4.5.1. Survey Methodology

The FM survey was administered in person for EH and CSC, and via telephone for PS and WT. Questions were posed related to the daily operations of residence halls EH, CSC, PS and WT. The survey respondents were all FM directors of the HE various institutions. This survey was carried out to provide insight into POE Indicators 5, 9 and 11, highlighted in scientific literature for their sustainability possibilities and potential resource reduction capabilities. Table 142 provides an outline of the various open-ended questions posed as related to POE Indicator 5, 7, 8, 9, 10, and 11.

Table 142-FM Survey questions for POE Indicators 5, 7, 8, 9, 10, and 11

FM Questions	POE Indicator
Has the building been commissioned and how frequently?	5
Do you monitor the indoor temperature and humidity	7
Do you receive any complaints related to: temperature, humidity, ventilation, drafts, respiratory problems or allergens & temperature controls	7
Are the temperature controls complicated or simple?	8
How frequently are HVAC filters changed? What preventative maintenance programs are carried out to ensure thermal satisfaction?	9
Have you implemented POEs related to: thermal comfort and consumption behavior?	7 & 10
Have you implemented any consumption conservation awareness programs or informational tools within the residence hall or on campus?	10
To what extent are the BACS/BEMS systems installed optimized/manipulated?	11
What information does the BEMS provide? Is it being tracked and benchmarked?	11
Are there any 'intelligent' systems installed? Have they resulted in energy and water consumption savings?	11

4.5.2 FM Survey Results and Discussion

Given various POE indicators are intertwined, the FM survey results have been discussed collectively herein.

4.5.2.1 POE Indicator 5 and 11

POE Indicator 5 provides insight into the commissioning process and any HVAC problems, translated into the operational phase of the residence hall. Commissioning information can provide insight into actual energy consumption values experienced and potential issues with indoor air quality (temperature and humidity). POE Indicator 11 addresses the customization of BACS, BEMS and AI in tracking, measuring and reducing energy consumption. Manipulation of HVAC start-stop times along with space utilization programming, to minimize energy consumption and model occupant behavior. This indicator can highlight whether these systems are being manipulated or customized. Often times when these systems are not customized they may result in wasteful consumption.

Responses from FM departments indicate typically during the first year of operation many adjustments are made to the heating, ventilation and air conditioning (HVAC) and

BACS systems; to ensure they are accurately calibrated, and communicating with one another. FM personnel are often hesitant to independently interfere with the BACS systems, due to the warranties issued on the equipment. Therefore they typically have to follow up with the designers and manufacturers to ensure systems perform as promised.

All the residence halls were commissioned, however the FM departments indicated increasing commissioning frequency is a challenge given their limited resources in terms of personnel and operating budgets.

In particular the FM department of PS indicated it was as complicated as a 'rocket ship' when all we are trying to operate is a building. They indicated operating their equipment on manual override conditions due to BACS/BEMS complications. PS' FM department also indicated these systems should be critically analyzed for actual return on investment, as they do not perform as advertised. They also voiced frustration with BACS/BEMS systems stating they are far too complicated, a waste of money and too excessive for operating a simple building. They recommended designers incorporate simple equipment with less complicated fancy technology features, to ensure ease in the operational phase.

The sentiments of PS' FM department was shared amongst other FM departments. However it must be noted in EH the BACS/BEMS systems were manipulated and experimentation with start-stop times and temperature set points carried out, resulting in over 10% in savings.

All FM departments indicated interest in measurement and tracking (an optional LEED credit), however are inhibited due to tight operating budgets and limited personnel. They all indicated that given their current metering structures it is often difficult to isolate buildings to create accurate benchmarks and comparisons. FM departments also voiced interest in sub-metering their buildings however they note it is the first design feature that gets value engineered out of their projects. This mimics the responses from the Design Firm Survey section of this report. Given these findings it is evident that HE decision makers need to be involved in the conversation, so that the benefits of sub-metering is not lost to them.

FM departments also indicated Artificial Intelligence (AI) systems were not installed in any of the residence halls, therefore no specific feedback on this parameter was collected. It must be noted in some cases they indicated given the complexity of these AI systems, they actually prefer not incorporating them.

4.5.2.2 POE Indicator 7 and 8

Indicator 7 and 8 are related to the indoor temperature and humidity, and thermal control conditions that student occupant experience. It is discussed in this section to triangulate student experiences versus FM perceptions of conditions.

In terms of student occupant complaints they indicated that they occasionally receive complaints, however only during the transitional periods between seasons. A comment of note regarding CSC, is that they indicated receiving no complaints. However, the student responses indicate the building was overheated and when they complained the FM department took no action.

Examining indoor temperature and humidity tracking and regulation all FM departments' BEMS systems tracked indoor air temperature, and outdoor humidity but not indoor humidity conditions. They further indicated typically they do not track indoor humidity levels. In all cases the air introduced into the building was not humidified or controlled for this parameter.

In terms of provision of easy controls in the residence halls, FM departments indicated that the controls were easy to use. However in CSC students indicated controls were far too complicated, and collectively (EH, CSC, PS and WT) all students indicated wanting more control over their ability to change their indoor air temperature. In the case of EH the high regulation on the thermostat even resulted in cool indoor winter conditions as outlined in the 'Thermal Logging Study' section herein.

Majority of FM departments also indicated they had not carried out POEs in any of the residence halls and it is in the jurisdiction of residential life personnel.

4.5.2.3 POE Indicator 9

Indicator 9 (Preventative Maintenance) ensures residence hall envelope and HVAC systems are performing as intended. For example if window sensors have been incorporated to shut off HVAC systems when windows are open, this indicator can ensure such design features are actually delivering on their intended outcomes.

FM departments indicated routine (every 6 months) HVAC filter replacement, typically during the seasonal switches between heating/cooling. During which time they check the HVAC equipment to ensure problems are minimized. However it must be noted that due to their limited resources they are more reactive than proactive.

4.5.2.4 POE Indicator 10

Indicator 10 requires the active involvement of residential life personnel and HE institution as a whole, to inform occupants of sustainable behaviors. Given its educational requirements it should also require the involvement of FM insights. However none of the FM departments had undertaken the task of educating occupants.

In the case of EH project documentation on sustainability is present in the residence hall. It outlines the various LEED credits pursued and how they were secured (i.e. water saving features, energy reduction etc…). However actual awareness campaigns and behavioral tracking was not undertaken by the HE institution.

In some cases this indicator was deemed as ‘beyond their scope of services’; however given FM personnel are the most knowledgeable, they should be at the forefront educating occupants.

4.6 Design Firm Surveys

4.6.1 Design Firm Survey Overview and Methodology

Designer surveys were distributed via email through the collaboration of two top design firms in the Boston area. Per their request their identity has been withheld. They are referred to as Firm 1 and Firm 2, for the purposes of this study. Both design firms specialize in HE student residence halls and clients include numerous top ranking HE institutions nationwide and internationally.

The surveys were distributed via email using the online platform SurveyMonkey. A total of 23 questions were posed with ample space for additional comments for every question asked. The survey was a combination of open-ended, yes/no, and 5 and 7 point Likert scale questions. Table 143 outlines the various questions and corresponding response collection methods.

Table 143-Design firm survey details

Designer Survey Question	Response Collection Method
Level of importance of various project parameters: Facility construction cost, facility life cycle cost, Facility design and planning overall schedule, and Facility construction overall schedule.	7 Point Likert Scale 1=unimportant, 4=Neutral, and 7=very important
Level of importance of various design parameters: Indoor water, electricity, and gas consumption, Easy controls (thermostats), Occupant control over environment control, Easy maintenance of building skin, and Easy maintenance of building automation control systems.	7 Point Likert Scale 1=unimportant, 4=Neutral, and 7=very important
If energy and water sub-metering is recommended	Yes/No
If tracking and measurement of energy and water is recommended	Yes/No
Importance to HE owners to LEED certify their buildings	7 point Likert scale 1=unimportant, 4=Neutral, and 7=very important
If design firms carry out POEs	Yes/No
If implementation of energy and water conservation awareness programs are recommended to HE owners	Yes/No
Rating of the level of influence various stakeholders have in the design process	5 point Likert scale, with 5 indicating most influence
Rating of the level of interest various stakeholders have in pushing the sustainability agenda in their residence hall designs	5 point Likert scale, with 5 indicating most interest

A total of 34 HE student residence hall designers responded to the survey. The pool of respondents included engineers, architects, interior designers, planners and urban designers. Table 144 outlines the total number of various design professionals who responded to the survey per firm.

Table 144-Design firm survey respondents (Design Firm 1 and 2)

Design Professional	Firm 1 N	Firm 2 N	Total	% of Total
Engineers	0	12	12	35%
Architects	10	5	15	44%
Interior Designers	2	2	4	12%
Planners	1	1	2	6%
Urban Designer	0	1	1	3%
Total	**13**	**21**	**34**	**100%**

4.6.2 Results and Discussion

4.6.2.1 Design Firm 1 Survey Results

31% of designers indicated their clients were involved with the Association for the Advancement of Sustainability in Higher Education (AASHE), however 69% indicated they were unsure. 8% indicated their HE clients were signatories to the declaration of United Nations Higher Education Sustainability Initiative (UNHESI) Rio+20, while 15% indicated 'never heard of it' and 77% were 'unsure'.

Designers were asked whether their HE clients initiate the request to incorporate sustainability features or if designers push the conversation. Their responses were mixed, indicating in some cases they do whilst in others the clients initiate it. Designers also indicated, depending on the sophistication of the client, sustainability may or may not be on their agenda.

In terms of energy analysis 54% indicated carrying out energy modeling using various tools, at different stages of the design process from the concept to final design stage.

When asked if they recommend sub-metering of energy (electricity and gas) only 31% indicated 'yes'; while 8%, 8%, 23%, 8%, indicated 'no', 'beyond their scope of services', 'clients request it', and 'don't get client buy-in' respectively. 31% of designers recommended water sub-metering while 15%, 8%, 8%, 16% indicated 'no', 'beyond their scope of services', 'clients request it' and 'clients decline it' respectively. 62% of designers recommend measurement and tracking of energy consumption while 8% indicated 'clients decline it' and 8% indicated it is typically the first component to be value engineered (VE) out of the design.

54% of designers recommend measurement and tracking of water consumption while 8% indicated 'no', 'clients decline it', 'clients request it', and 'beyond typical metering requirements' respectively.

Examining importance of LEED certification to their HE clients, they indicated certification is becoming less attractive due to the upfront costs and that it is "economically prohibitive". Designers also indicated, HE owners are increasingly becoming more cognizant of operating costs and are trying to minimize it as much as possible.

When designers were asked if they carry out POEs 46% indicated 'yes', however no examples of their efforts were provided in the survey. In their comments they indicated: client resistance in data provision is prohibitive, lack of payment for POE analysis is a deterrent, and it should be carried out to comprehend life cycle costs.

When asked about whether they recommend implementation of awareness programs to HE clients to educate occupants on conserving water and energy, 31% said 'yes', while 23% said 'no'.

Examining their idea of a sustainable HE residence hall facility their response indicated a facility limiting resource consumption, efficient, and healthy providing high comfort and performance. Designer comments included: (1) from design, through construction and occupation the design seeks to limit the use of energy, reduce waste and change and improve behavior when it comes to protecting the environment, and (2) design residential housing as a "living Lab" to change and influence better behavior. Improve the predictive modeling capacity in firms and improve the design delivery process.

In terms of the importance HE owners give to LEED certifying their residence halls, designers indicated on average it is 'moderately important' (Avg. 5.29, SD 1.80). To gain insight into the design process respondents were asked to rate the level of influence and interest each stakeholder has in pushing the sustainability initiative in HE student residence hall projects. The results indicate a gap between the level of influence and interest stakeholders have in pushing sustainability forward and into reality.

As can be seen in Figure 55 designers believe owners and owner representatives hold the most influence over the design process yet the least amount of interest in incorporating sustainability features. This gap highlights the need to educate owners, ensuring participation and support in the sustainability initiative. To make sustainability a reality, HE owner advocacy is critical.

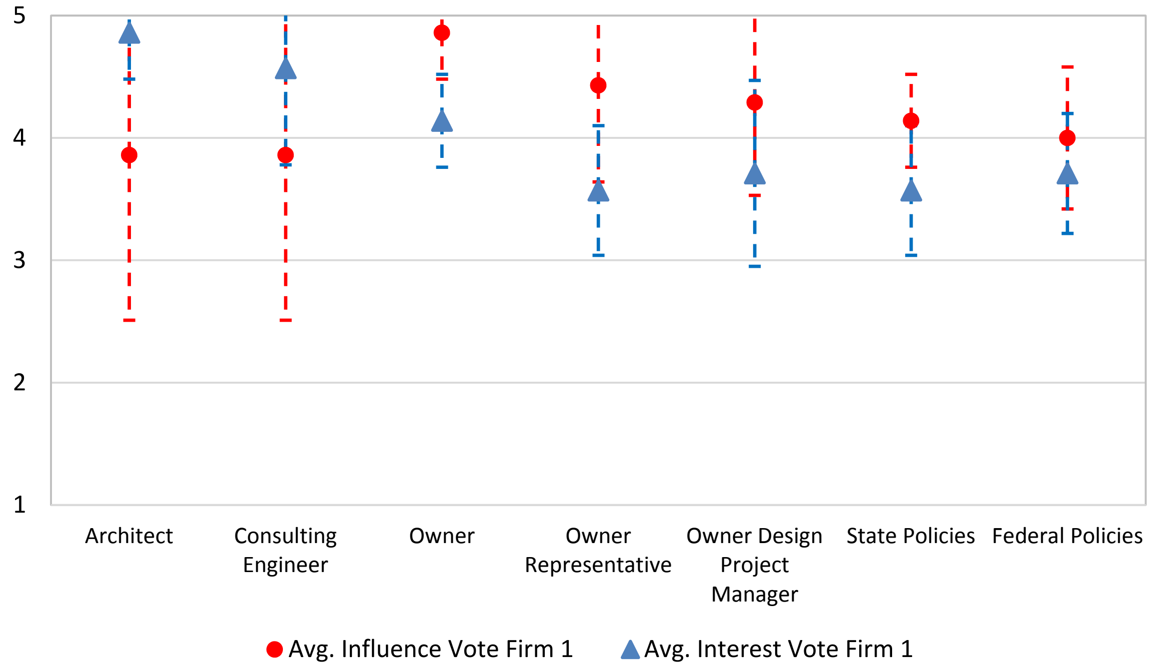


Figure 55-Stakeholder level of influence (scale 1-5) in the design process and interest (scale 1-5) in pushing the sustainability agenda in residence hall design (scale 1-5) (Firm 1 votes)

Designer comments indicates owners need attractive fiscal arrangements to make investments in sustainability a reality. In order to promote investment in employing sustainable strategies, a holistic life cycle cost approach should be undertaken versus the limiting first-cost analysis. However this analysis is not possible if POEs are not undertaken, because actual benefits of sustainability must be measured, documented, reported and benchmarked. Table 145 outlines designer's ratings of various project controls parameters, which highlights the gap between first costs and life cycle cost importance on projects.

Table 145-Level of importance of various project controls parameters (Design Firm 1)

Question	Result Firm 1 (Avg., SD)*
Level of importance of facility construction cost	Avg. 6.46, SD 0.88
Level of importance of facility life cycle cost	Avg. 5.69, SD 1.03
Level of importance of facility design and planning overall schedule	Avg. 5.54, SD 0.97
Level of importance of facility construction overall schedule	Avg. 5.46, SD 0.97

*Avg. =average, SD=standard deviation

When designers were asked to rate various controls parameters related to facility construction cost, life cycle cost, design and overall schedule and construction schedule. The top rated variable was the facility construction cost at an average of 6.46 indicating 'important', followed by facility life cycle cost at an average of 5.69 'moderately important'. Given Figure 55 and the rating results of the various components outlined in Table 145 it is apparent a shift in thinking is required. New financial mechanisms suggested by the Sustainable Endowments Institute (SEI) in collaboration with AASHE may be the answer for HEs, to ensure sustainability becomes a reality. SEI and AASHE recently released a joint report highlighting fiscal solutions HE institutions can employ to specifically address this issue (Indvik et al. 2013).

Assessing various design features' importance to designers, it can be seen based on Table 146 all parameters received high ranks. However based on student feedback in the 'Student Survey' section of this report it is evident there is a gap. The parameter with the most importance to students was 'easy indoor environmental controls (thermostats)' and 'level of control over changing their indoor thermal conditions'. As can be seen in Table 148 both these parameters were ranked very high by designers, yet in reality they have not met student occupant expectations. However it is noteworthy to mention facilities departments, also hold the key to occupant satisfaction due to operational adjustments typically made.

Table 146-Level of importance of various design features to designers (Design Firm 1)

Question: Importance given to the following parameter in decision making process when designing student residence halls	**Result Firm 1 (Avg., SD)***
indoor water consumption	Avg. 6.13, SD 0.64
indoor electricity consumption	Avg. 6.38, SD 0.92
indoor gas consumption	Avg. 5.38, SD 1.06
Easy indoor environmental controls	Avg. 6.13, SD 0.83
End user control over their environment	Avg. 6.63, SD 0.52
Ease of building skin maintenance	Avg. 5.38, SD 1.19
Easy maintenance of building automation control systems	Avg. 5.50, SD 1.07

*Avg. =average, SD=standard deviation

4.6.2.2 Design Firm 2 Survey Results

24% of designers indicated their clients were involved with AASHE, 62% indicated 'unsure' and 14% 'never heard of it'. 5% indicated their HE clients were signatories to UNHESI Rio+20. However 29% indicated 'never heard of it' and 67% 'unsure'.

Designers were asked whether their HE clients initiate the request to incorporate sustainability features or if designers push the conversation. They indicated that clients typically share their sustainability goals even if they do not wish to LEED certify their buildings. Also that as part of many campus planning programs developed by HE institutions sustainability goals are identified.

In terms of energy analysis 76% indicated carrying out energy modeling using various tools, at different stages of the design process (concept to final design stage). They also indicated that it is their company policy to carry out energy analysis three times during the design phase. Typically from schematic design on to design development, however dependent on the project this process may occur in higher or lower frequencies.

When asked if they recommend sub-metering of energy (electricity and gas), 71% indicated 'yes' while 14%, 5%, 10%, indicated, 'beyond their scope of services', 'clients request it', and 'client decline it' respectively. 52% of designers recommended water sub-metering while 14%, 24%, 10%, indicated 'no', 'beyond their scope of services', and 'clients decline it' respectively. Designers' comments also included that they do not believe in metering all the way down to branch-circuit level as it is not cost-effective yet down to the panel board. They also indicated that facility optimization can only occur if consumption is quantified to inform post occupancy operational strategies. They also indicated that it is a debate with clients due to the first costs associated with sub-metering. A comment which was also echoed by Design Firm 1 was that typically sub-metering is the first casualty of the VE process.

86% of designers recommend measurement and tracking of energy consumption while 5% indicated 'no' and 5% indicated 'clients decline it', with only 5% indicating 'clients request it'. 76% of designers recommend measurement and tracking of water consumption while 24% indicated they don't. When designers were asked if they carry out POEs 76% indicated 'yes', while '14%' indicated 'no'.

When asked about whether they recommend implementation of awareness programs to HE clients to educate occupants on conserving water and energy, 76% said 'yes' while 5% said 'no'. Designer comments include: (1) people tend to conserve energy when they are made aware that they are capable of conserving it, (2) multiple methods have be attempted through website, graphic panels, workshops, competitions and printed materials, (3) I think we are at the forefront for making clients aware of methods to practice sustainability, (4) occupant, and facility operator, behavior and training a major hurdle in achieving sustainability, and (5) This is usually driven by the institutions own policies on communication of sustainability initiatives, and/or curriculum integration (living-lab research projects for students).

Examining their idea of a sustainable HE residence hall facility their responses included: (1) a healthy, high-performance low/no energy facility that supports the education and living of students, (2) one which effectively integrates all aspects of good Indoor Environmental Quality and efficiency, (3) A facility that is able to meet the needs (functional, energy, etc.) of the users for an ongoing period of time, and can be easily modified to provide additional services needed in the future, (4) A sustainable student housing facility is one that is designed and constructed using best-practice technologies that are flexible and expandable enough that the facility can last through its entire life cycle operating at optimum efficiency and with minimum impact when changes must be made (i.e., renovations, expansions, upgrades, etc.). It is also important the facility is set up to provide data and feedback, to inform operational decisions throughout the life of the building, (5) One with an energy payback in the foreseeable future for the institution and noticeable living standard improvements for the student, (6) The definition is evolving from an initially narrow energy/water/material use to a much more inclusive definition to include user satisfaction/performance; institutional performance say of Res Life in their development of the whole student; ability to adapt to use pattern changes/reconstruction/deconstruction. Perhaps the term would evolve to regenerative rather than sustainable, (7) a sustainable student housing facility is designed with reduced energy and water use over the typical building. Additionally, the occupants are aware and engaged in behaviors that further reduce energy and water consumption, (8) A facility that uses the least amount of energy as possible, while also giving back to the environment, the society, and the end users as a whole, (9) A facility that the students enjoy living in, is durable and safe, and uses the minimal amount of energy and water, (10) Net-zero is a good goal, and (11) a facility where the occupants and operators are aware of their energy impact and actively work to minimize it on an ongoing basis.

When designers were asked to provide additional comments in regards to parameters that were deemed important to them in terms of sustainability they commented as follows: (1) Quality of living/life - if the building is not thermally comfortable, functional, and students don't love the building, then it is not sustainable and the building will change, (2) Student Housing Facilities are unique buildings, mostly due to their uneven usage over the course of a school year. We must design in the ability to roll back the building systems during long periods of vacancy. Also, during the most rigorous parts of the school year, these become 24-hour facilities. While at peak usage it is important to maintain efficiency wherever possible, (3) Occupant behavior is very important especially in residence halls. Energy use can be dramatically reduced by simple strategies such as keeping the thermostat a couple degrees lower or higher, as well as unplugging cords when not in use, taking shorter showers, or turning off lights. Building automation systems are able to play a role in these things more and more, but it will always be important for the occupant to have a desire to act responsibly, and (4) the missing link in achieving sustainability is not occurring during design but in post-occupancy evaluation, and assessment of building operations.

Designer comments regarding POEs, and measurement and tracking included: (1) most clients track energy and water use from a cost and performance perspective, but generally don't have the capacity to measure the performance against energy or water models, (2) value engineering casualty and client typically doesn't have the resources to use the tools we give them or are reluctant to engage us in long term post-occupancy evaluation, (3) often clients are open to tracking and will do it in-house for their own reasons, and (sometimes) be willing to share information with us, and (4) post-occupancy feedback is critical in confirming the impact of decisions made during the design phase, for optimizing the efficiency of the facility as it starts to be used, and for identifying energy usage trends that can potentially steer operational strategies moving forward.

Additional comments by designers include: (1) we need to do much more in terms of POEs! There is a lot of information we can get, to really understand if the designs works, (2) Yes, we always request that the Owner shares this information with us. We have actually done this for many HE projects we have designed. This process is extremely valuable both to us and to the Owner, (3) simple reason is we want to know how our buildings perform, we also realize many variables are out of design doesn't control: building management, schedules and occupant behavior, (4) we are trying to do this more and more, however It can be difficult to get client participation in some situations, (5) we want to see if our energy modeling and water consumption estimates are accurate, (6) we would love to but clients typically decline services, most often the value is weighed more for the LEED Measurement and Verification point than the actual data, and (7) we have begun doing this on several projects, clients are sometimes reluctant to share info, if they didn't know we were going to ask for it though.

HE advocacy for POEs is critical to ensure they reap the benefits of their substantial investments. In terms of the importance HE owners give to LEED certifying their residence halls, designers indicated on average it is ‘moderately important’ (Avg. 5.12, SD 1.32). To gain insight into the design process respondents were asked to rate the level of influence and interest each stakeholder has in pushing the sustainability initiative in student residence hall projects. The results indicate a gap between the level of influence and interest stakeholders have in pushing sustainability forward and into reality. This gap mimics the findings in Design Firm 1 indicating a need for further HE advocacy is needed.

Figure 56 highlights designers believe owners and owner representatives hold the most influence over the design process, yet the least amount of interest in incorporating sustainability features.

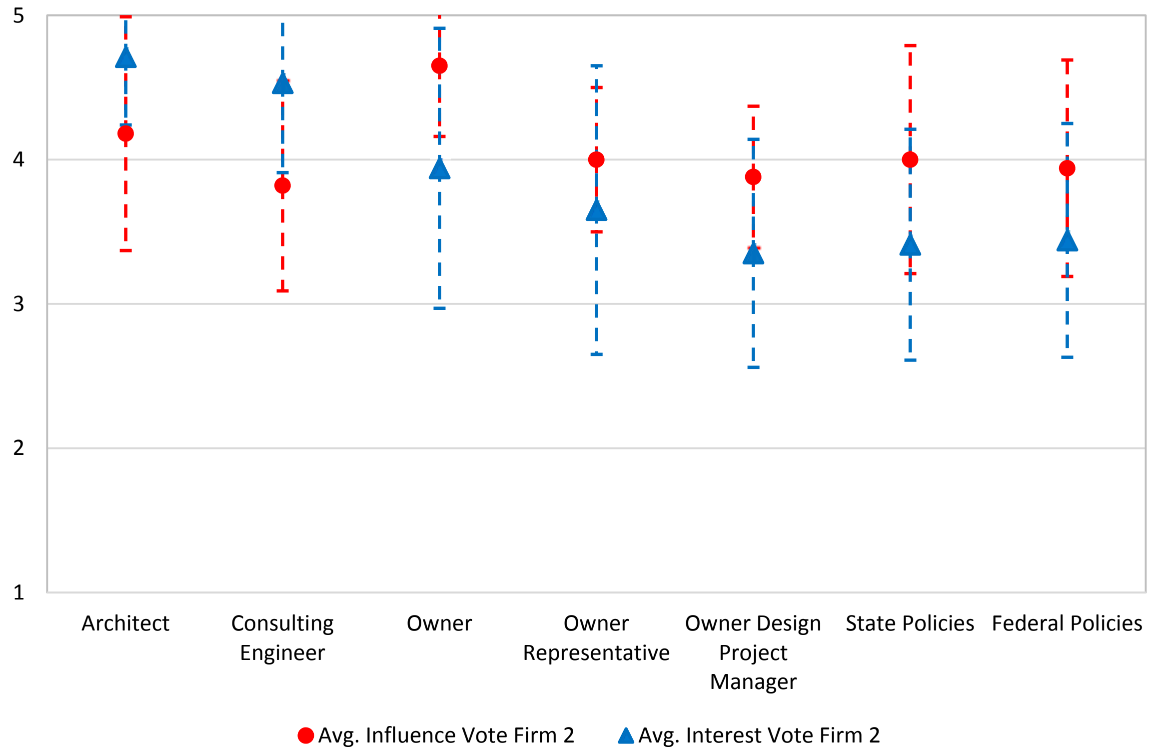


Figure 56-Stakeholder level of influence (scale 1-5) in the design process and interest (scale 1-5) in pushing the sustainability agenda in residence hall design (scale 1-5) (Design Firm 2 votes)

Table 147 outlines designer's ratings of various project controls parameters exposing the large gap between first cost and life cycle cost importance on projects.

Table 147-Level of importance of various project controls parameters (Design Firm 2)

Question	Result Firm 2 (Avg., SD)*
Level of importance of facility construction cost	Avg. 6.19, SD 0.75
Level of importance of facility construction overall schedule	Avg. 5.85, SD 0.88
Level of importance of facility design and planning overall schedule	Avg. 5.80, SD 0.62
Level of importance of facility life cycle cost	Avg. 5.76, SD 0.77

*Avg. =average, SD=standard deviation

When designers were asked to rate various components related to facility construction cost, life cycle cost, design and overall schedule and construction schedule. The top rated variable was the facility construction cost at an average of 6.19 indicating 'important', followed by facility construction overall schedule, design and planning overall schedule and lastly life cycle cost at an average of 5.76 indicating 'moderately important'. Design Firm 1 also mimics findings in Figure 56 and Table 147, indicating a shift in thinking is required to ensure sustainability in practice.

All design features were ranked highly by designers, outlined in Table 148. However based on student feedback in the 'Student Survey' section of this report it is evident there is a gap. Parameters with the most importance to students were 'easy indoor environmental controls (thermostats)' and 'level of control over changing their indoor thermal conditions'. As can be seen in Table 148, both these parameters were ranked very high by designers, yet in reality did not meet student expectations. It must be noted however satisfaction with thermostat controls may greatly increase, if they are not regulated by HE's facilities departments. Facilities departments, also hold the key to occupant satisfaction and contribute to occupant satisfaction and comfort.

Based on Table 148 indoor water consumption was scored at 'important', however little POE is being done on consumption behavior and actual consumption. Without POE data water consumption models may never truly be accurate, as benchmarking data does not exists for specialized typologies.

Table 148-Level of importance of various design features to designers (Design Firm 2)

Question: Importance given to the following parameter in decision making process when designing student residence halls	**Result Firm 2 (Avg., SD)***
indoor electricity consumption	Avg. 6.16, SD 0.96
Easy maintenance of building automation control systems	Avg.6.00, SD 0.88
indoor gas consumption	Avg. 5.53, SD 1.07
Ease of building skin maintenance	Avg. 5.53, SD 0.96
Easy indoor environmental controls	Avg. 5.47, SD 1.07
End user control over their environment	Avg. 5.58, SD 1.22
indoor water consumption	Avg. 5.58, SD 1.22

*Avg. =average, SD=standard deviation

4.6.3 Design Firm Survey Conclusions

Based on responses from both firms, it is evident awareness of POE added value exists. However HE owner advocacy is lacking for POEs, resulting in a hindrance to its implementation. Both firms indicated their HE clients were involved with AASHE and signatories to UNHESI. Even though the percentage were low their awareness of their existence, and commitment to sustainable practices is encouraging.

Based on their responses on whether their HE clients initiate the request to incorporate sustainability features or if designers push the conversation. It is clear a varied level of sophistication exists amongst HE owners and FM departments. Hence designers should take the lead in pushing the sustainability envelope by further educating clients on the topic. Given LEED's new minimum water and energy consumption reporting requirement, it should be an easier conversation to have.

Measurement and verification is still a challenge given owners do not want to pay for sub-metering's additional upfront costs and typically value engineer them out of designs. However increased POEs can highlight the benefits of sub-metering by providing owners with economic incentives to incorporate them. Furthermore additional resources such as the joint SEI and AASHE (Indvik et al., 2013) guidance on fiscal solutions, can be used as a resource to help HE's financially plan for sustainability features.

It is clear designers face resistance from owners in collecting actual data to compare modelled performance. Therefore contractual language requiring POE data, could aide in making the leap from request to require. Alternately HE owners should also include contractual language tied to promised performance. In this arrangement both parties will be required to actually follow through with performance promises.

In terms of importance HE owners give to LEED certifying their residence halls, designers indicated on average it is 'moderately important' (Avg. 5.20, SD 1.56). They also commented HE owners sometimes want LEED features, but without LEED certification due to added first costs. Designers were also asked to rate the level of influence and interest each stakeholder has in pushing the sustainability initiative. They indicated owners and owner representatives hold the most influence over the design process, yet the least amount of interest in incorporating sustainability features. Such results support the need to further ensure HE owners are onboard with sustainable initiatives through fiscally attractive solutions.

When designers were asked to rate the level of importance of various project controls parameters, it was evident facility construction cost was more important than facility life cycle cost (LCC). In both firms LCC was deemed 'moderately important', while it should have been 'very important'. This finding is in direct conflict with the theoretical idea of sustainability; and highlights that in practicality financial solutions must be developed to ensure sustainability in practice.

In terms of building performance when designers were asked to indicate the level of importance they give various design features, 'easy indoor environmental controls (thermostats)' and 'level of control over changing their indoor thermal conditions' were highly rated. In triangulating student feedback with designers, it is clear there is a gap. However designers are not the sole source of this performance gap, FM departments are to be included as well. Figure 57 outlines the various design features and project controls parameters rated on based on importance by both Design Firms.

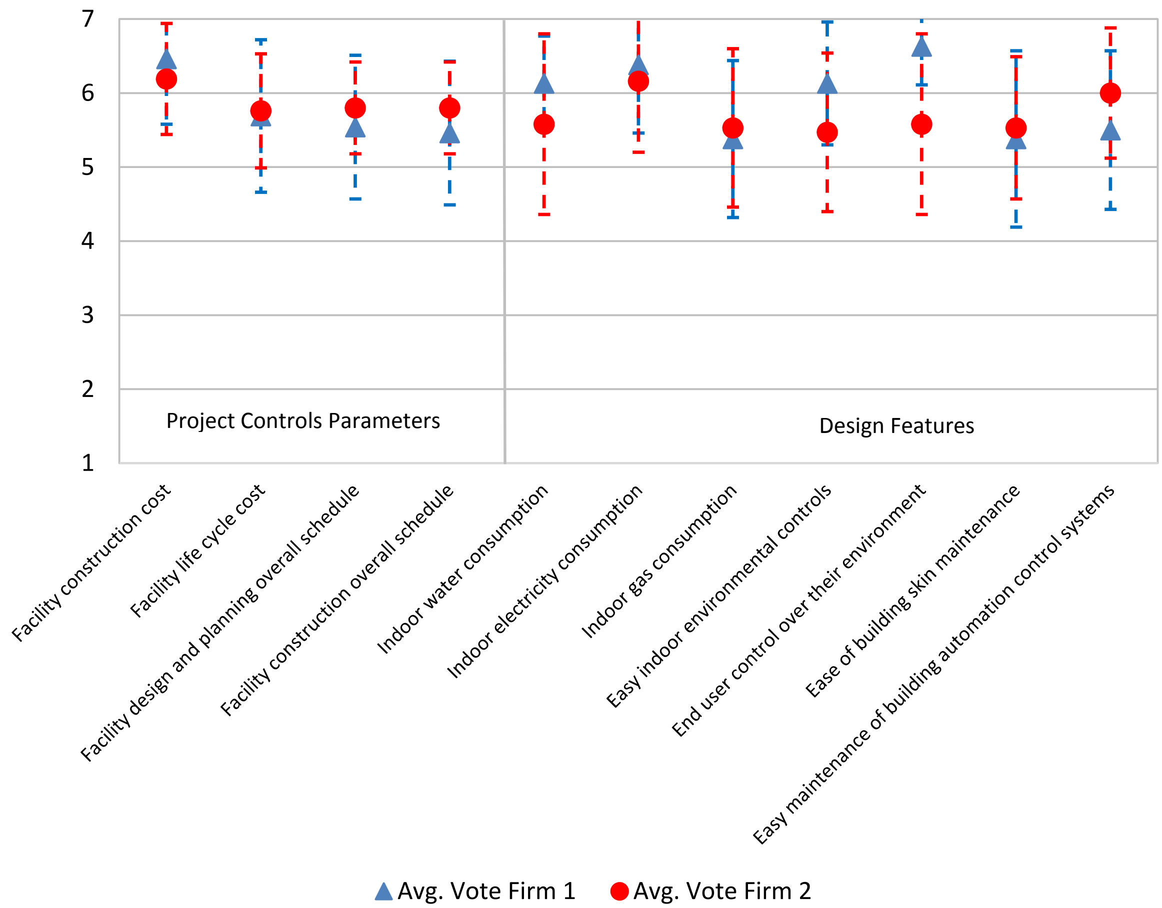


Figure 57-Designer Votes on Importance (1-7 scale) of Various Parameters in the Design Process (Design Firm 1 and 2)

Per Figure 57 it is clear that even between reputable design firms there is a differential in the ranking of importance of various design and project controls parameters. There should be a unification between designers in their goals to further push forth the sustainability agenda.

Given these findings stakeholders need to unite and include industrial and behavioral psychologist to shift the sustainability conversation into reality. HE FM departments, designers and behavioral psychologist should carry out POEs. Since the design parameters and operational processes impact occupant experiences. FM respondents indicated POEs should be carried out by residential life, however designers and FM departments play the critical role in ensuring occupant comfort. Many designer comments also indicated the unknown variable of occupant behavior which impacts building performance. Researchers have also highlighted the criticality of occupant behavior in ensuring sustainability in practice (Stevenson and Leaman 2010, Berardi 2013, GhaffarianHoseini et al. 2013); this indicates inclusion of behavioral psychologist in the POE process will add value by providing occupants options and alternative behaviors to shift sustainability into practice.

Finally adoption of the proposed POE framework would serve stakeholders well in informing the design and operations processes. As building specifications are shifting from prescriptive to performance based, feedback from POEs will become critical in informing this process. POEs can ensure design firms can actually deliver on performance promises and collectively improve the design, operations and education process.

5. Summary of Findings

5.1 Introduction

This section provides a summary of the technical conclusions for the selected post occupancy evaluation (POE) indicator framework for certified sustainable higher education (HE) residence halls. It is arranged as follows: (section 5.2) basis for POE indicator selection and selected indicators, (section 5.3) POE indicator method of data collection, (section 5.4-5.9) individual results per POE indicator and student feedback findings as related to the POE indicators, (section 5.8) facilities management (FM) and (section 5.10) designer feedback associated with the POE indicators, (section 5.11) recommendations in the design and operations phase of the residence hall, recommendations for higher education (HE) residential life and HE FM departments, and for the LEED rating system and reporting agencies, and (5.12) conclusions.

5.2 Basis for POE Indicator Selection

The POE indicators were selected based on published scientific research, results of occupant feedback and sustainability rating systems. The 12 POE indicators selected for HE implementation in residence halls include: Indicator 1-water, Indicator 2-electricity, Indicator 3-gas consumption, Indicator 4-on-site renewable energy generation and use, Indicator 5-building systems commissioning, Indicator 6-monitoring of indoor air temperature and humidity, Indicator 7-occupant satisfaction with controllability of systems-temperature and humidity, Indicator 8-building controls ease of use, Indicator 9-routine preventative maintenance for HVAC systems and building enclosure, Indicator 10-education efforts by HE owners to promote sustainable occupant behaviors (Education Indicator), Indicator 11-optimization of Building Automation Control Systems (BACS), Building Energy Management Systems (BEMS) and Artificial Intelligence (AI) systems and Indicator 12-the indoor sound insulation indicator, was added to the framework based on student comments (n=593). The collection of data for indicator 11 is reliant on whether the building design incorporates such advanced systems.

5.3 POE Indicator Method of Data Collection

The data for the selected indicators were collected using quantitative and qualitative POE techniques. Indicator specific data collection methodologies may be found in Table 5 and 6 of Section 3.2 *'Selected POE Indicators and Data Collection Methods (POE Indicators 1-12)'*. The POE indicator framework included feedback and actual consumption data from: student occupants, facilities management personnel, residential life, actual water and energy consumption data and thermal logging.

The use of hard (actual consumption data and design targets) and soft data (surveys and questionnaires) constructed a comprehensive building performance picture, shedding light on actual LEED HE residence hall performance in practice. This allowed the measurement of whether LEED delivered on its sustainability promises and target energy reduction values. Given this specialized demographic (college student residence hall occupants) and typology (HE residence halls) is not well represented by energy and water reporting agencies, isolation of accurate comparative metrics is a challenge. The findings of this research uncovered vast differences between available benchmarks between US and EU reporting agencies. This indicates a better solution to the benchmarking dilemma is to develop tailored metrics versus universal benchmarks. Given the shortcomings of available data on HE residence halls, this research identified water and energy consumption metrics specific to HE residence halls, which can aide in the design and operations processes.

5.4 Indicator 1-Water Consumption Summary of Findings

The actual water consumption data was collected from nine residence halls (LEED and non-LEED). The results of water consumption between residence halls, showed technology alone does not guarantee water savings. Larger reductions in water consumption need improved user attitudes and changes in occupant behaviors (Stevenson and Leaman 2010, Berardi 2013, GhaffarianHoseini et al. 2013). Based on the results of this research, non-LEED residence halls had higher consuming flow fixtures values than those installed in LEED halls, however they still outperformed LEED residence halls in terms of total liters per person per day (LPD) consumption.

The data identified a total indoor water consumption range of 85 to 175 LPD for HE residence halls. Overall average residence hall consumption was lower than values found in US-DOE (375 LPD), EPA (265 LPD), EC (168 LPD), AWWA US (212 LPD) and EC (143 LPD) engineer's metric. On average non-LEED residence halls consumed 4% more than LEED ones, however the LEED buildings resulted in high SDs. On a yearly and monthly basis, non-LEED residence halls depicted steadier consumption values with an overall 3% increase for the entire time data was collected. On the other hand LEED residence halls showed an increase of 5% over the years and, on average, higher variations in consumption patterns. The average water consumption of LEED residence halls were 60% higher when compared to their LEED design 'green' cases. The high actual consumption values indicates, that the modeled consumption values fell short. The yearly decrease in savings rendered LEED residence halls less sustainable than their non-LEED counterparts.

The student occupants' feedback indicated that on average they run the water in the shower for over 12 minutes with an SD of 5 minutes. This value is 50% higher than the shower duration assumption values of both LEED and AWWA, typically used by designers in the design phase. The findings indicate large variations in actual practice versus modeled assumptions. Poor student survey results about consumption awareness programs, student participation and behaviors indicate that HE institutions must increase awareness and do more in educating students. Student survey results indicated high SDs on cognizance about water consumption and high ignorance percentages on the presence of conservation awareness programs on their campuses. The student feedback indicated: gender inequity in water consumption (Vinz 2009, Elliott 2013) and that increasing awareness programs will result in reduced water consumption in line with the findings of other researchers (Brown and Cole 2009, Stevenson and Leaman 2010, Streimikiene and Volochovic 2011, Zalejska-Jonsson 2012, Sterling et al. 2013).

5.5 Indicators 2, 3, and 4-Energy Consumption Summary of Findings

The actual energy consumption data was collected from three LEED and one non-LEED certified residence halls. The data collected for these indicators identified: (1) indoor energy consumption of HE residence halls, (2) compared LEED to non-LEED residence hall consumption patterns, (3) compared the LEED modeled case projections with actual energy consumption, and (4) compared the actual energy consumption to US and EU benchmark metrics.

The data indicated an indoor energy consumption range of 24 to 62 kBtu/Sq.m/Month. Overall actual residence hall consumption resulted in mixed savings as compared to values found in US-DOE BEPD residential (NE=20.63 kBtu/Sq.m/Month, W=87.01 kBtu/Sq.m/Month), US-DOE BEPD commercial (NE=39.47 kBtu/Sq.m/Month, W=106.74 kBtu/Sq.m/Month), CBECS (89.70 kBtu/Sq.m/Month), and EU-EC (11,598.40 kBtu/Sq.m/Person).

The non-LEED residence hall consumed 47% more than average LEED residence hall consumption (42.49 kBtu/Sq.m/Month), with the highest SD value of 20.06 kBtu/Sq.m/Month. This indicates LEED residence halls were not consistent in their savings, and compared poorly to their LEED proposed design cases; however overall they were more sustainable and resulted in less variation than the non-LEED residence hall WT.

On a yearly and monthly basis, the non-LEED residence hall had an overall 3% increase in energy consumption, and resulted in a higher SD. On the other hand, LEED residence halls showed a decrease of 14.43% over the years, and on average lower SDs in consumption patterns. LEED halls consumed on average 21.05% less when compared to their LEED design 'green' cases (PDC). Given the combined yearly decreases in energy consumption, LEED residence halls were more sustainable than the non-LEED residence hall WT. Assessing the residence halls on the east coast separately from the one on the west coast, an increase in consumption of 3.20% was seen in the LEED dataset. These mixed results highlight LEED labeling does not fully capture actual user behavior, and results in unsustainable overall energy reduction expectations.

It was also found that LEED documentation combines electricity and gas modeled consumption values as a basis for the cost savings metric. This process minimizes transparency of actual energy savings and should be reverted to its original components. Breaking the value into its original parts and in terms of consumption rather than cost, allows for transparency in energy consumption. Increased transparency facilitates accurate measurement and tracking potentials, while the compounded metric dilutes actual savings and energy consumption reduction values. It is noteworthy to highlight that if LEED was based on actual performance versus anticipated modeled energy cost savings, residence hall CSC would lose points but EH while PS would be entitled to more points.

5.6 Indicator 6 (Thermal Logging), and Indicators 7 and 8 (Student Survey Feedback) Summary of Findings

The data for Indicators 6, 7 and 8, were collected using quantitative and qualitative methods. For these indicators one LEED Gold residence hall was logged and a student survey distributed during the weekly data-logger data download process. Additional student feedback was also collected from four (3 LEED, 1 non-LEED) residence halls, which were not logged.

The student survey and logging related to the thermal logging study, identified residence hall specific information such as: student clothing insulation factors, typical activity levels, indoor temperature and relative humidity conditions, localized smog conditions, and exposure to unhealthy indoor air relative humidity levels.

Assessment of the building data showed poor building performance and unsustainable conditions. Findings indicate students' satisfaction with thermal comfort is highly correlated with indoor air temperature and humidity satisfaction. The results also indicate analysis of multi-variable regressions must be contextualized to ensure accurate deductions are made on the occupants' experience and indoor building conditions. The results of the POE analysis should not be generalized and applied to every residence hall. Therefore it is recommended, when implementing the proposed POE framework students' feedback is compared with actual physical measurements.

A summary of the notable findings on students' satisfaction and perception of indoor air temperature in the logged LEED residence hall include: (1) the higher students' clothing insulation factor the less likely they were to be satisfied with indoor temperature, indicating they prefer wearing less clothing, (2) the more satisfied they were with their indoor air humidity, the more likely they were to be satisfied with their indoor air temperature conditions, in line with the findings of Deuble and de Dear (2012), (3) an increase in their clothing insulation factor, did not translate into the perception of warmer indoor temperature conditions (some students commented sometimes they need to wear a blanket), indicating cold indoor conditions existed, (4) students who felt a draft in their space, were more likely to perceive their indoor air temperature as colder (students commented due to poor ventilation they had to open windows and turn on fans. Given the study timeframe, this is the result of cold outside air), and (5) students who were more satisfied with their indoor temperature, were more likely to feel warmer.

A summary of the notable factors impacting students' satisfaction and perception of indoor air humidity in the logged LEED residence hall include: (1) as conditions became more humid, students were more likely to be satisfied with their indoor air humidity, this agrees with their negative comments about dry indoor conditions, (2) as their satisfaction with indoor temperature increased, they were more likely to be satisfied with their indoor air humidity, (3) students who indicated that the air was stuffy, were more likely to be satisfied with their indoor air humidity conditions versus those who did not, (4) the more satisfied they were with indoor air humidity, the more humid they perceived their indoor conditions, (5) the higher their clothing factor the more humid they perceived their environment, (6) students on lower floors perceived the indoor air humidity to be drier, and (7) the warmer they perceived their indoor air temperature, the more humid they perceived their indoor air humidity conditions.

Given student responses, the logged data was graphed on AHSRAE Psychrometric charts showing indoor conditions were unacceptable. The majority of logged data (n=15,278), representative of 63.12% of the time, fell under the 30% acceptable humidity conditions and within the 1.0 clothing insulation zone. The students clothing insulation factor was substantially lower than the 1.0 clothing insulation zone. Results of a bivariate correlation analysis showed outdoor humidity, did not have an effect on indoor relative humidity. These results indicate that during the air intake process a significant amount of humidity is lost and not re-introduced into the air distribution system. This creates uncomfortable indoor thermal conditions.

Assessing and comparing logged data with student feedback, students complained indoor conditions were dry, cold, and offered poor ventilation (localized smog). In particular several students complained of nose bleeds, dry skin and eye irritations. Some students even commented that the HE institution should buy them humidifiers, due to their daily exposure to an unhealthy indoor environment within the residence hall. Their frustrations are in line with the statements of Berker et al. (2011) on the presence of problems even in sustainable buildings. Based on research and findings discussed in the 'Thermal Logging Study' section, it is evident that action must be taken to remedy this unhealthy exposure. The FM department should implement a course correction measure, and designers should learn from these findings to ensure mistakes are not repeated. The FM department of the logged residence hall was contacted, and provided the findings. They indicated their lack of awareness of the importance of relative humidity and are currently implementing course correction measures.

Upon visual inspection during the thermal logging study, it was found that students manipulated indoor systems with workarounds. An example of a workaround includes the avoidance of setting off fire alarms due to localized smog in their living rooms. Such conditions represent both a health and fire hazard. These findings further highlight the added value of carrying out this POE framework in certified sustainable HE residence halls. Given the context of the thermal logging study, it must be noted that the results of each residence hall differed based on differing indoor thermal conditions. Noting the differences in indoor thermal conditions between residence halls, it is critical that students' comments are analyzed on an individual basis. Hence a 'one solution for all' residence halls does not exist, given the specificity of the localized indoor building conditions.

Evaluating the findings from the online student survey section of the POE analysis, it was found that satisfaction with indoor air humidity was tied to: 'perception of indoor air humidity', 'indoor temperature satisfaction', and 'if the air was stale in their area'.

Students were more satisfied if indoor air is humid, and if they were happy with their indoor temperature. Stale air represented a problem, as students were more likely to be dissatisfied under this condition. The data results indicate the need for ventilation and air movement, and highlight their importance in the measurement of thermal comfort. Students' perception of indoor air humidity was closely tied to their satisfaction with indoor air humidity, showing that a complex interplay between thermal parameters exists in providing occupant thermal comfort. Students also indicated higher satisfaction when conditions were humid versus when they were dry.

Examining satisfaction with indoor air temperature it was found that it is tied to the 'satisfaction with the level of control over changing indoor temperature'. In all residence halls this shared result indicated students prefer 'control' over 'parental control' by HE institutions. Researchers also highlight the importance in providing occupants more control over their indoor environments to make adjustments and adapt (Steemers and Yun 2009, Stevenson and Leaman 2010, Gram-Hanssen 2010). Satisfaction with indoor air humidity also played a key role in temperature satisfaction fortifying the need to ensure all thermal parameters are factored in collectively versus singularly (i.e. only temperature regulation). These findings point out that students should be provided the ability to control both indoor temperature and humidity, given both parameters impact their thermal satisfaction.

A finding that solidifies the need for contextualization of POE results was seen in regression results for EH and CSC. In EH students who were more satisfied with their indoor air temperature, perceived indoor air temperature as warmer, while in CSC students who were more satisfied with their indoor air temperature, perceived indoor air temperature as cooler. The reason behind this would have been a mystery lest student feedback. Based on the student feedback CSC was overheated, therefore students were more satisfied with temperature if they perceived it as cooler, while the opposite indoor thermal conditions and student feedback was seen in EH. This finding highlights the added value this POE framework brings to the performance evaluation of residence halls. The POE identified the gap between what is being delivered (designers and FM departments) and what is being experienced (occupants). Also contextualizing findings must not be overlooked to ensure accurate deductions are made.

The student feedback indicated that the overwhelming area of concern was 'satisfaction with the level of control over changing indoor temperature'. Majority of students (58%) indicated dissatisfaction with their ability to control their indoor temperature and 98% of their comments were negative on this parameter. This highlights the current gap between designers and FM processes, and their collective understanding of what they are providing to occupants. The regression results showed: (1) students who were satisfied with their indoor temperature, were more likely to be satisfied with their level of control over changing their indoor temperature (thermostat controls), and (2) students who found temperature controls easy to use were more likely to be satisfied with the level of control over changing their indoor temperature than those who did not.

Clearly a vast gap exists in the operational phase of the building. This signifies that designers and FM personnel need to account for easier and more adaptive controls in their designs and operations of the residence halls. A simple course correction measure would be to provide occupants more control echoing the suggestions of researchers (Brown and Cole 2009, Stevenson and Leaman 2010, Guerra-Santin and Itard 2010).

Survey results also identified the clothing insulation factor and the typical activity level (MET unit) of this student occupants in residence halls. It must be noted geographical and indoor conditions did not result in a clothing insulation differential between residence halls. However the SDs indicated student clothing preferences vary considerably. Regression results showed that on average they were more satisfied with their indoor thermal conditions, when they wore less clothing. Their overall MET unit was stable, which indicated sedentary activity (1.06 MET unit).

5.7 Indicator 10-Education Awareness Feedback Summary of Findings

Evaluating the education indicator results across HE institutions it was seen that much work is to be done, in terms of: awareness programs, and behavioral changes and cognizance of energy and water consumption. These findings highlight the need to implement awareness strategies to shift behavior. Based on the work of researchers Streimikiene and Volochovic (2011) and Sterling et al. (2013), educational efforts such as 'living lab' environments and awareness programs can motivate conservational behavior.

The data showed no difference between LEED and non-LEED occupants, in terms of their cognizance of energy and water consumption. These findings refute the work of Zalejska-Jonsson (2012) on increased consumption awareness in sustainable buildings. However it must be noted their results were based on the residential mindset versus the non-residential mindset in this application given students do not pay utility bills. On average the surveyed student occupants only thought about their energy and water consumption behavior 'occasionally' with an SD ranging from 'very rarely' to 'very frequently'. Given the vast difference in SDs, and proximity of average results between LEED and non-LEED residence halls; it is clear that an educational gap exists in all HE institutions.

5.8 Indicators 5, 7, 8, 9, 10 and 11-FM Feedback Summary of Findings

This POE framework solicited the feedback of FM departments, given their importance in the building performance picture in the operations phase. Indicators requiring their feedback include: 5, 7, 8, 9, 10 and 11. Responses from FM departments indicated that typically during the first year of operations, many adjustments are made to: heating, ventilation and air conditioning (HVAC) and BACS systems. These adjustments ensure that they are accurately calibrated, and communicating with each another. However on complex systems, FM personnel are hesitant to independently interfere due to the warranty related liability issues. Therefore they typically need to follow up with designers and manufacturers to ensure systems perform as promised. This process is often time consuming and frustrating for FM departments, as in the interim systems run inefficiently and waste energy.

In the case of the dataset analyzed all residence halls were commissioned, however FM departments indicated increasing the commissioning frequency is a challenge due to limited personnel and building operations budgets. In particular FM departments voiced concern about overtly complicated systems, and stressed the need for simple equipment and systems. In one notable case the FM director indicated it was as complicated as a 'rocket ship', and that simplicity should be the target. These statements are in line with researchers recommendations to focus on simplicity instead of complexity (Stevenson and Leaman 2010). FM personnel indicated BACS, BEMS and AI systems, should be critically analyzed for actual return on investment, as they do not perform as advertised. FM departments also indicated Artificial Intelligence (AI) systems were not installed in any of the residence halls, therefore no specific feedback on this parameter was collected. It must be noted in some cases, FM personnel preferred a lack of AI systems incorporation given the complexity in the operations and maintenance phases.

All FM departments indicated interest in measurement and tracking (an optional LEED credit), however are said they are inhibited due to tight operating budgets and limited personnel. They all pointed out given their current metering structures it is often difficult to isolate buildings to create accurate benchmarks and comparisons. FM departments also indicated interest in sub-metering their buildings, however they note it is the first design feature value engineered out of their projects. This mimics the responses from the 'Design Firm Survey' section of the research results. Given these findings it is clear HE decision makers need to be involved in the conversation and educated on the benefits.

Examining student occupants' complaints to FM departments, FM directors indicated occasional complaints but only during the seasonal transitions. A comment of note in the case of CSC, the FM department indicated receiving no complaints. However, the student responses indicate the building was overheated and when they complained the FM department took no action. This highlights the need for student occupants' feedback and comparison of feedback information received from all parties to uncover the honest state of indoor conditions.

Examining the tracking of indoor temperature and humidity and their regulation, all FM departments' BEMS systems tracked indoor air temperature, and outdoor humidity but not indoor humidity conditions. FM directors further indicated typically they do not track indoor humidity levels. In all cases the air introduced into the building was not humidified or controlled for this parameter.

In terms of provision of easy controls in the residence halls, FM departments indicated that the controls were easy to use. However in CSC students indicated controls were far too complicated, and collectively (EH, CSC, PS and WT) all students indicated wanting more control over their ability to change their indoor air temperature. The majority of FM departments also indicated they had not carried out POEs in any of the residence halls. They believed that POE implementation should be carried out by the residential life personnel. However it is evident POEs are a collective data collection effort, in which FM departments play a key role.

In all cases FM departments indicated that they had not undertaken any educational efforts. In some cases it was even noted that educating occupants is 'beyond their scope of services'; however given FM personnel are the most knowledgeable, they should be at the forefront educating occupants, residential life and the campus at large.

5.9 Indicator 12-Noise Satisfaction Summary of Findings

In analyzing the student feedback from the student surveys, Indicator 12-Indoor Noise Insulation was identified. Previous research indicated that majority of students showed concern between indoor and outdoor noise conditions (McGrath and Horton 2011). However the results of this research showed the opposite student noise concern was of importance to students.

Based on students' comments, they were forgiving of noise experienced from the outside environment, but less so with interior noise between rooms and floors. They indicated it was not the fault of designers it was noisy outside, since their residence halls are located in cities. However provided negative comments related to indoor noise infiltration between floors, within suites and between bedrooms. An average of 86% of their comments on this parameter was negative. Amongst some of their notable concerns was sound travel from the bathrooms and between bedrooms within their suites.

5.10 Summary of Designer Feedback

This POE framework also solicited feedback from designers, two top firms were solicited specializing in HE student residence hall designs. Based on their responses it was evident that awareness of the added value of POEs exists. However POE advocacy is lacking by HE owners, this results in a hindrance to its implementation. Both firms indicated their HE clients were involved with AASHE and were signatories to UNHESI. Even though the percentages on AASHE and UNHESI were low their awareness of their existence, and commitment to sustainable practices is encouraging. Their responses on whether HE clients initiate the request to incorporate sustainability or if designers push the conversation, showed that a varied level of sophistication exists amongst HE owners and FM departments. Hence designers should take the lead in pushing the sustainability envelope by further educating clients on the topic.

Designers indicated measurement and verification is still a challenge given owners do not want to pay for sub-metering's additional upfront costs, and typically value engineer them out of designs. However increased POEs can highlight the benefits of sub-metering by providing owners with economic incentives to incorporate them. It was also found that designers face resistance from owners to collect actual consumption data to compare modelled performance. Therefore contractual language requiring POE data, could aide in making the leap from simply requesting the information to ensuring its provision. HE owners should also include contractual language to hold designers liable for building performance. This would tie 'promised' performance goals to 'actual' performance in operations. In this arrangement both parties will be required to actually follow through with performance promises.

In terms of the importance HE owners give to LEED certifying their residence halls, designers indicated on average it is 'moderately important' (Avg. 5.20, SD 1.56). They also commented that HE owners sometimes want LEED features, but without LEED certification due to the added first costs. Designers were also asked to rate the level of influence and interest each stakeholder has in pushing the sustainability initiative. They indicated owners and owner representatives hold the most influence over the design process, yet the least amount of interest in incorporating sustainability features. Such results highlight the need to further ensure HE owners are onboard with sustainable initiatives through fiscally attractive solutions. However the fiscal solutions and saving potentials requires the collection of actual performance data, which can be obtained through POEs.

When designers were asked to rate the level of importance of various project controls parameters, they indicated that facility construction cost was more important than facility life cycle cost (LCC). In both firms LCC was deemed 'moderately important', while it should have been 'very important'. This finding is in direct conflict with the theoretical idea of sustainability; and highlights that in practicality financial solutions must be developed to ensure sustainability measures are adopted.

When designers were asked to indicate the level of importance they give various design features, 'easy indoor environmental controls (thermostats)' and 'level of control over changing their indoor thermal conditions' were the highest rated. Based on the students' feedback on this parameter and their dissatisfaction with their level of control, it is clear a vast gap exists. However designers are not the sole source of this performance gap, FM departments are to be included as well. Communication efforts between FM departments and designers are needed to ensure that building performance expectations are clear and met in operations.

Designers' level of importance ranking of project controls and design parameters, suggests misaligned overall design goals. Given this finding it is clear a unification between designers in their goals to further push forth the sustainability agenda is required. Given that sustainability is highly reliant on behavior and that it is interdisciplinary in nature, the inclusion of additional professionals should be examined.

5.11 Recommendations for Specific Stakeholders, Reporting Agencies, LEED Rating System and During Project Phases

The findings of this study did not uncover any substantial differences in any one parameter between LEED and non-LEED residence halls. Other researchers also did not find considerable differences in their comparisons of LEED and non-LEED buildings (Abbaszadeh et al. 2006, Brager and Baker 2009). Given in many cases non-LEED residence halls performed better than LEED ones, it provides evidence that certification alone is not sufficient to promote sustainability or occupant comfort. The proposed POE framework highlighted the added value occupant feedback has in interpreting quantitative data collected. Without students' feedback regression results may be perplexing (i.e. temperature satisfaction results of CSC and EH), leading to faulty conclusions about indoor thermal conditions. The findings also highlight that LEED does not capture the human element of our built environment, as it does not factor in any type of occupant feedback. Since this feedback is not collected, the design and operations processes are never informed for improvement measures.

The proposed POE framework resulted in the discovery of various important issues which impact student occupants, designers, and HE institutions. Notably student occupant behavior is the driving variable towards sustainability in practice. To attain sustainability in practice occupants are the most valuable and unknown variable. Occupant behavior and habits have the power to promote or demote sustainability in practice. HE institutions must be awakened to the increased need for the promotion of sustainability in practice by creating 'living labs' and educating occupants. It is clear that occupants are ignorant on the topic given the poor student awareness and cognizance of energy and water consumption results. Student occupants' behavior indicated irrational behavior, which results from habits as was seen in the clothing insulation factor. All occupants regardless of the residence hall location, wore similar clothing insulation in the winter. However they could have easily increased their clothing insulation factor with season appropriate clothing. This points to the need for behavioral change awareness, and that occupants need to adapt to their environment and not vice versa.

To impact behavior it is evident stakeholders must unite and include industrial and behavioral psychologists to shift the sustainability conversation into reality through behavioral change. HE FM departments, designers, and behavioral psychologist should carry out POEs to paint a true building performance picture, and provide alternative options to change unsustainable behavior. FM respondents indicated POEs should be carried out by residential life, however designers and FM departments play the critical role in shaping the operational phase of the building and ensuring occupant comfort. Therefore, FM involvement is critical in educating and informing the design and operations phases. Inclusion of interdisciplinary teams in the design and operations phases to achieve sustainability in practice is also suggested by leading researchers (Stevenson and Leaman 2010, Berardi 2013, GhaffarianHoseini et al. 2013).

Based on the POE results of each indicator discussed above it is clear much needs to be done to realize sustainability in practice. The proposed POE framework provided an honest investigation of the current state of affairs in HE student residence halls. It identified actual water and energy consumption metrics for residence halls. The US and EU comparative metrics and variances between residence halls consumption values indicate that tailored benchmarking is more valuable and accurate than universal benchmarks found in reporting agency datasets. It is a more useful analysis if 'best case performance' benchmark values are developed for each residence hall and compared to their actual performance. This type of analysis provides a more accurate picture of the residence hall performance.

As prescriptive building specifications shift to performance based, feedback from POEs will become critical in informing the process and meeting performance goals. It is clear that the proposed POE framework was successful in identifying if LEED delivered on its promises, and identified areas requiring course correction measures. The proposed POE framework is simple and easy to implement yet comprehensive due to the incorporation of occupant feedback.

The findings highlight the need for various parameters to be amended in the design and operations phases for residence halls. These changes will ensure a path to sustainability in practice. Changes need to occur within the different phases and between different stakeholders to attain sustainability in practice. Stakeholder unity is needed to shift the 'status quo' by creating a clear and simple roadmap to sustainability in practice. The next sub-sections provide stakeholder and phase specific recommendations. They are organized as follows: (5.11.1) recommendations in the design and operations phases, (5.11.2) recommendations for HE residential life and facilities management personnel, and (5.11.3) recommendations for the LEED rating system and reporting agencies.

5.11.1 Recommendations in the Design and Operations Phases

Designers and owners must recognize student occupants are transient users of residence halls, even though the life expectancy of the buildings may surpass 50 years. Given the feedback from FM departments on the use of complex systems, it is evident they are unnecessary and actually pose additional operational problems. Since life cycle cost analyses are not carried out on the use of such complex expensive systems, the benefits are unclear and not realized. FM departments rarely re-program the systems due to warranty liability issues and expensive commissioning costs. This results in an inability to fully capture automation benefits in their day to day operational activities. Therefore designs should follow the mantra of simplicity versus complexity. The design of simple HVAC systems, larger operable window areas for ventilation, and larger freedom in thermal controls will provide occupants more control. The added occupant control will allow occupants to adapt their indoor thermal environment naturally versus mechanically. Hence simple measures will also reduce first costs, life cycle costs of operating residence halls and provide greater user satisfaction.

HE owners should remove the split incentives from the energy consumption equation by sub-metering and individual billing of occupants for utility consumption. Currently owners charge occupants a flat fee for inhabiting the residence halls, hence creating split incentives for lowered energy and water consumption. Owners want occupants to use less resources (energy and water), as such highly regulate indoor conditions. This leads to student dissatisfaction and dangerous workarounds, as found in the case with localized smog. By sub-metering FM departments can remove their strict regulations on indoor thermal controls, and allow students the freedom to make consumption decisions freely. Albeit some students may consume more, however when held financially accountable for their consumption, behaviors will be more apt to change.

Consumption behavior is not always tied to logic, but by habits and social norms. Occupant consumption behaviors do not follow logical patterns of behavior, they are highly reliant on upbringing, socioeconomics, and habits formed prior to their entry to the HE institution. During the design phase HE owners should include educational components such as signage within the suites to promote sustainable behaviors through increased awareness and education. Incentivizing sustainable behaviors will also aide in the reduction of consumption through the provision of 'green bucks' when consumption is below a certain threshold, or competitions between suites within the same residence hall. Such activities build a sense of community and positively impact behavior by bringing sustainability to the forefront of students' consciousness. The combination of sub-metering, individual utility billing and positive incentives can result in a shift in occupant behavior towards sustainability. The inclusion of behavioral psychologists will add value by incorporating strategies, which can impact consumption behavior positively and resonate with student occupants for the remainder of their lives as they enter the 'real world'. Given that HE institutions are in a position to shift mindsets and educate their community, educating students about sustainable consumption behaviors can easily be implemented in their processes.

5.11.2 Recommendations for HE Residential Life and Facilities Management Departments

The HE residential life departments should change the method suitemates are selected. Currently it is based on a lottery system, an arbitrary method not accounting for students' indoor thermal preferences. Many students voiced discontent within their suites as to their individual thermal preferences. Such issues can be easily addressed if residential life personnel select suitemates based on thermal preferences, rather than random assignment. This method provides the potential to minimize consumption and disharmony between suitemates.

HE residential life and FM departments must also educate student occupants on the use of the building, by increasing their communication efforts on efficient use of the building and energy conservation. As was found in this research technological efficiency alone did not result in reduced consumption behavior. Given that building performance is tied to resource consumption behavior, it is critical this parameter is not be overlooked in the operations phase. In the case of the clothing insulation factor all students wore the same levels of clothing (summer clothing), even though they were in varied geographical areas and experienced varying cold thermal conditions. This shows a behavioral gap between expected behavior and actual behavior by end-users. Students in the Northeast cold environments should have had higher clothing insulation factors, yet they were the same as students in California experiencing very mild winters. This indicates educational efforts are needed to shift unsustainable illogical behavior. Recommendations previously discussed on HE educational efforts should be implemented to remedy this situation and shift unsustainable habits.

5.11.3 Recommendations for the LEED Rating System and Reporting Agencies

Given the various comparisons discussed within this research, it is evident that the LEED rating system falls short in actual building performance. The LEED calculations and modeling requirements generate tailored benchmarks on building consumption targets, this can be used to compare actual performance. Yet the follow through at the post occupancy stage should be a required step in the process.

The variation between and within EU and US benchmarking values showed a low level of specificity, accuracy and applicability in the case of residence halls. Therefore reporting agency values (EU and US) should not be used for comparative purposes, since they do not accurately measure building performance in this application. Instead tailored metrics should be developed, analyzed and compared, which are residence hall specific and reflect true resource consumption and efficiency.

The data analysis results showed that LEED residence halls fall dramatically short creating unhealthy indoor environments, possibly opening HE institutions to legal liability issues. LEED design assumptions and guidelines should include: (1) higher allowances for shower duration in the design phase, (2) requirement for indoor air humidification in operations, (3) tracking of indoor air conditions, temperature and relative humidity, (4) solicitation of occupant feedback through POEs, and (4) sharing of performance data with the design community. Amending LEED certification to require the above mentioned parameters, would inform the design community and set measurable goals for data collection and analysis.

5.12 Conclusions

This section provided a summary of the technical findings from the implementation of the POE indicator framework for certified sustainable higher education (HE) residence halls. The results of the findings highlight one overwhelming finding, that occupants drive sustainability in practice. Given the power occupants have to shift theoretical sustainability into reality, focus must be placed on educating and greening the occupant. Greening the occupant should be a critical factor in the plight of sustainability in practice. The next section of this report discusses this ideology in detail.

6. Conclusions

Historically civilizations have been successful in promoting life through appropriation of resources and exploiting nature. Evidence shows many such successful civilizations have collapsed due to their own success, due to the imbalances they have created in nature. Such fallen civilizations created unsustainable environments by depleting their local habitats and consuming at unsustainable rates. We are currently dangerously toying with the same destiny, if we continue our unsustainable resource consumption and record carbon emissions. Our global ecological footprint has reached the highest historic levels and is on a steady rise.

Humankind's pursuit for constant economic growth and globalization, has resulted in a ramping up in resource consumption and an increase in pollution by record numbers. Based on a NOAA recent report we have broken every record as related to carbon emissions and global pollution. Given a global energy conservation policy does not exist, our civilization as a whole has taken an individualistic stance on this issue. This has resulted in haphazard policies and a lack of collective effort on changing our unsustainable consumption course. It is clear anthropogenic activity is causing environmental degradation and depleting our natural resources. Even though some countries have united to implement energy policies securing their energy futures such as EU member states, many such as the US are lagging in their conservational efforts. To ensure our civilization is a sustainable one we need to radically change our behavior and outlook. The primary marketing of sustainability has been through technology efficiency, however the focus should be placed on consumption reduction. Industry is driven by our energy and resource demands, therefore we can influence sustainability by changing our 'status quo' consumption behaviors and resource demands. Shifting supply and demand is the classic economic solution to changing course. However the reduction of resource demand can only be accomplished by changes in: habits, accountability for usage/consumption, self-awareness of consumption patterns and rational decision making.

Given sustainable certification is one of the ways we target addressing sustainable changes in our built environment; the proposed POE framework was developed to examine this situation in practice. The proposed POE examined whether LEED certified HE residence halls deliver on their sustainability promises and if occupants were practicing sustainable consumption behaviors. In particular HE institutions should depict exemplary sustainability educational efforts, therefore it was critical to analyze whether student occupants were educated on these topics. The LEED rating system provides guidance on implementing sustainable strategies, promising sustainable performance through improved technology efficiencies. However, LEED does not require actual verification of promised outcomes in practice, or factor in occupant feedback and conservation measures. Hence, designer assumptions are never examined in practice and occupant interactions and expectations never recorded or analyzed.

The findings of this research show that LEED and HE institutions' are falling short in sustainable practices, whether their facilities are LEED certified or not. A vast knowledge gap exists in HE educational efforts which results in ‘status quo’ consumption behaviors and lack of consumption awareness. Based on the results of the POE framework proposed herein, it is evident the variable requiring the most attention and course correction is occupant behavior. Without sustainable occupant behavior, sustainability efficiency technologies will fail to deliver on their promises every time. The results of quantitative and qualitative data collection methods showed, in order to paint a true performance picture both data collection methods must be implemented; and occupant feedback should be mandatory.

In the US society an individualistic societal pattern is seen, which focuses on satisfying the individual’s needs and wants versus societal gain. It is clear it directly clashes with the primary objective of sustainability: to ensure access to resources for future generations. In the case of sustainability a collectivist outlook is necessary as sustainable behavior may minimize individual opportunities, but maximize the outlook for future generations. Guaranteeing the availability of resources for future generations is a collectivist outlook. To shift individualistic behaviors experienced in US HE residence halls, it is imperative occupants are educated and vested in the effort to shift to collectivist outlooks.

Sustainable collectivist behavior by individualistic societies is not rare, this is seen in the consumption comparisons to EU member states. Even though EU member states are individualistic societies, in the case of environmental sustainability their mentality is a collectivist one. However in the US the individualistic capitalistic mentality is blanketed across all areas, including consumption of resources. This was also evident in the student comments from this research, which included comments such as: “I consume because I can and I pay for it”. The mentality of students should be consuming what is needed, instead of what they feel entitled to. This shows US HE institutions need to address sustainability by creating mindsets promoting the collective good versus individual gains. To attain true sustainability in practice occupants need to realize their behavioral consumption patterns, will indeed have an impact on the availability of resources now and in the future.

HE institutions need to increase their focus on educating residence hall occupants on consuming what is necessary and avoiding wasteful behavior. This grass root level education needs to commence at the start of the freshman year, so that the sustainable culture is imprinted onto students early on. After all students of HE institutions are part of a larger collective community at the HE institution. This can also promote pride of place and belonging to the HE sustainability mantra. HE institutions should capitalize on this sense of pride of place by shifting unsustainable habits to sustainable ones, highlighting to students the sustainable culture of the institution. Positive reinforcement and behavioral change efforts can re-program wasteful consumption behaviors, which they can carry into their ‘real-world’ adult lives. Given students are the largest demographic entering the residential market post college, it is critical they are impacted and educated early on. The culture of the institution should be one of behavioral sustainability through ‘greening the occupant’ and reduction of wasteful consumption for the collective good for generations to come.

The findings of this research are in agreement with arguments by behavioral economists; in that, human beings do not always make decisions based on facts and logic but based on habits and normative behavior. As was seen in the case of the student clothing insulation factor, almost all students in all facilities were wearing light summer clothing in the winter. This indicates collective behavior was not based on logic, if it were then students would be wearing more clothing given the season. However as was seen in the dataset students wore light clothing, in fact they were more satisfied with indoor conditions if they were able to wear less clothing. This is illogical given the outdoor winter conditions. Minor components such as their clothing factor can have a large impact on overall energy consumption used for heating their spaces. The regression results of the data and student comments indicated, student behavior was not based on logic rather their habits and preferences. This highlights in order for our society to cause change, all parameters including normative and habitual behaviors must be identified, analyzed and course corrected.

A design factor is that HE residence halls are transient spaces and as such should be simple in design and operation. However, they should be a place for students to learn about behavioral accountability and their eventual transition into the ‘real world’. The simplest solution to occupant behavioral shift is sub-metering and closing the current gap on split incentives between HE owners and occupants. If student occupants are responsible for their own utilities a dramatic shift in consumption will be seen. This course correction method will allow occupants the higher level of control they seek, and shape more responsible individuals who will take ownership of their actions. They will be held accountable for their habits and behaviors through fiscal ramifications. HE educational efforts should provide occupants behavioral alternatives to reduce resource consumption. Educating students and increasing cognizance about reduced water and energy consumption, will shift habitual consumption to rational consumption. These habit forming cues will eventually translate into the ‘real world’ once student occupants graduate, and enter society as working adults.

It is the responsibility of HE institutions to increase awareness and educational efforts to change habits. It is evident attaining sustainability is not in the technologies implemented alone but also in occupant behaviors. The variable with the largest possible impact is the greening of the occupant and not just the building. HEs should employ multiple strategies to course correct this parameter. It is possible to change behaviors through positive reinforcement such as incentives to save and feedback on real time consumption values. Some examples include: (1) sub-metering each suite to increase awareness on water and energy consumption and billing students directly, (2) the provision of green bucks for reduced consumption which they may use on campus to purchase goods or services, (3) signage in their rooms to turn off lights and unplug electronics when not in use, and (4) increased competitions on sustainability topics.

It is clear an increase in efficiency strategies alone do not translate into lowered consumption, given the systematic rise in US energy consumption over the past 30 years. The battle for sustainable practices will not be won over night, it requires a re-programming of habits and an increase in educational efforts on conservation of available resources. The solution to sustainability in practice is based on the efficient use of resources and greening the occupant. We must shy away from complex technological strategies and increase our educational efforts to minimize consumption. HE institutions have a societal responsibility to educate students in ethical, rational decision making and sustainable behaviors should not be excluded from this expectation. If we do not take action and promote sustainable behaviors, our expectations of our built environment will collapse like past civilizations.

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Appendix A-Thermal Logging Study Logged Data (Bedroom and Living Room)

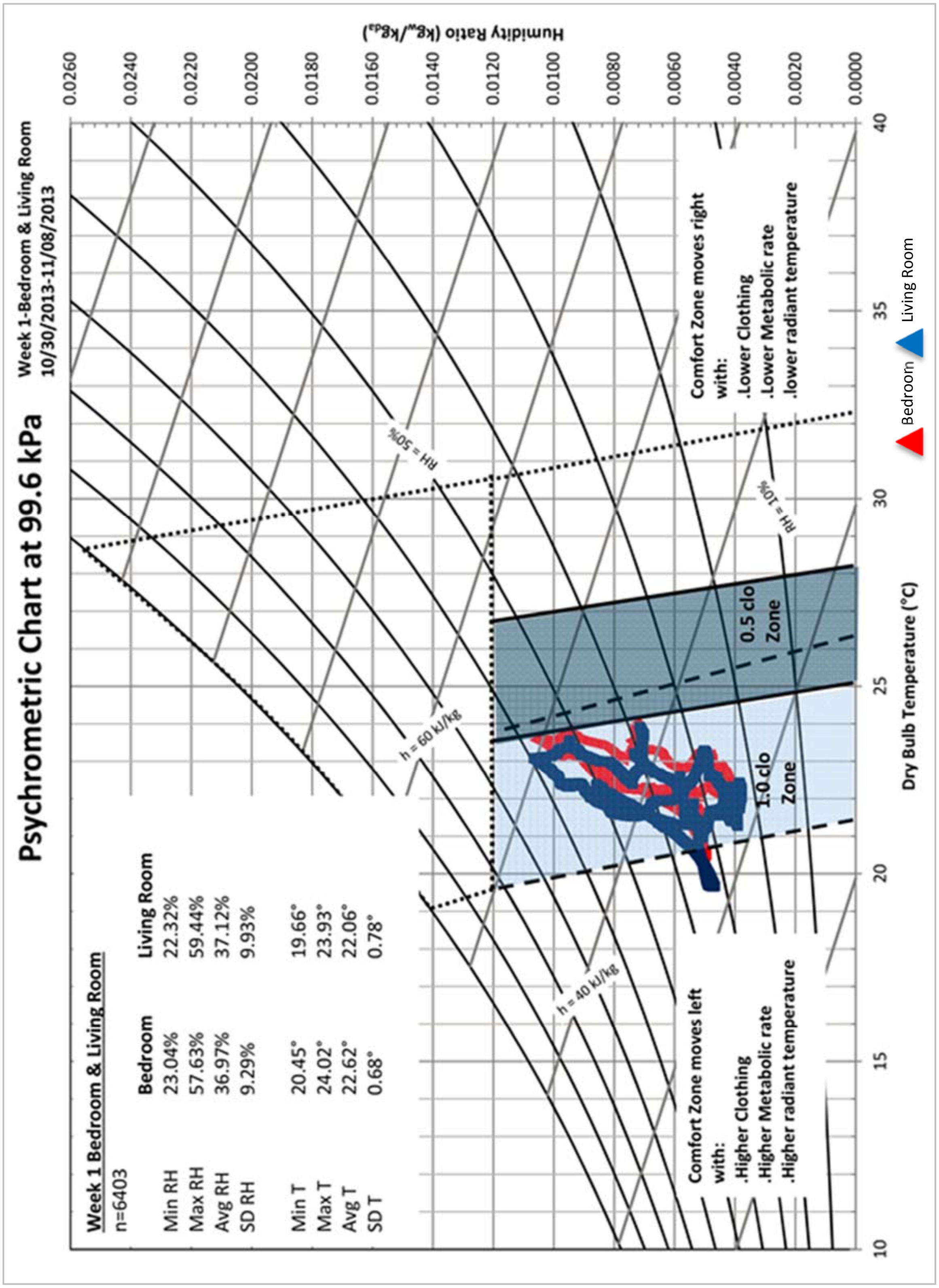

Figure 58-Week 1 Bedroom and Living Room Logged Data

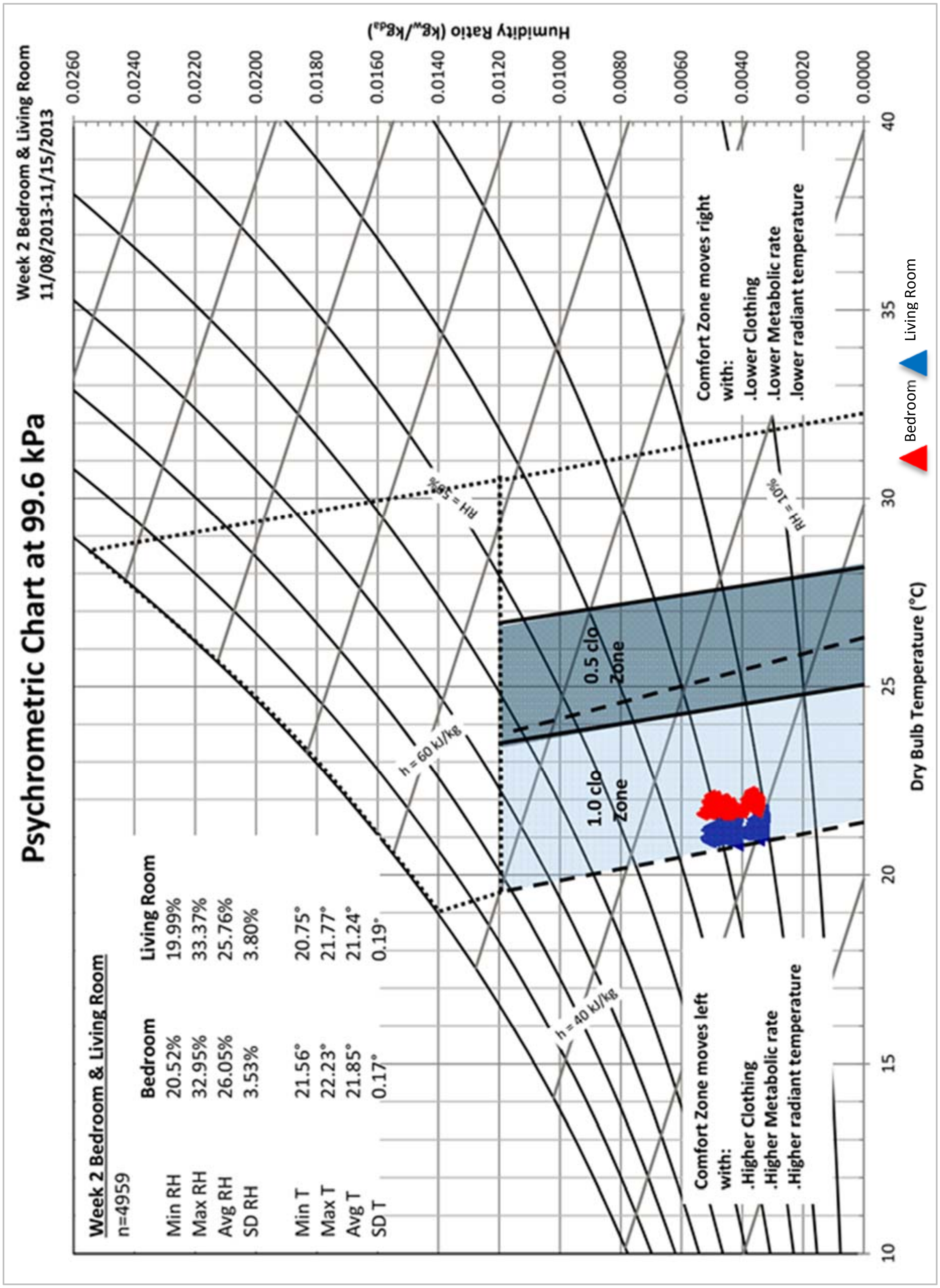

Figure 59-Week 2 Bedroom and Living Room Logged Data

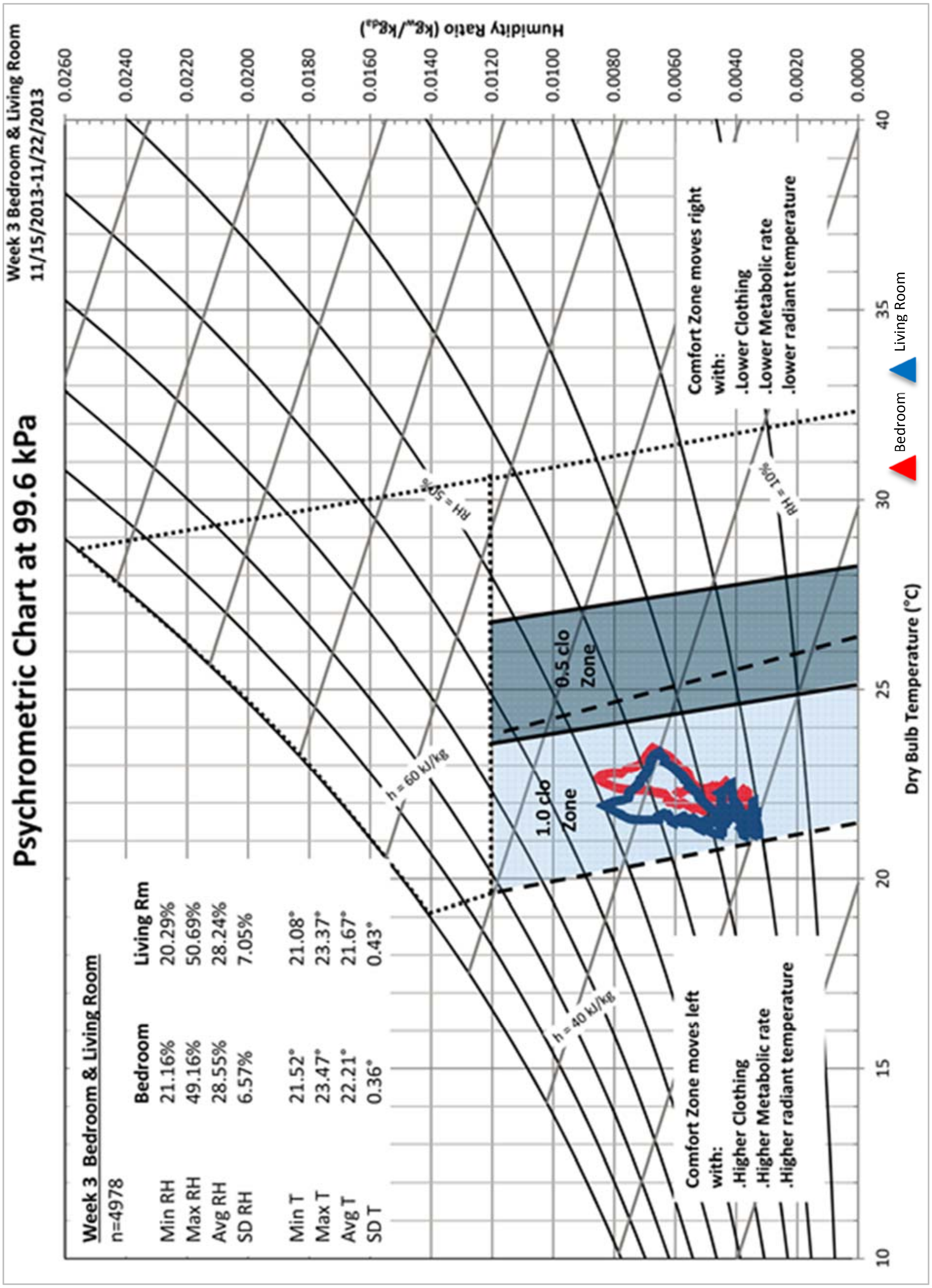

Figure 60-Week 3 Bedroom and Living Room Logged Data

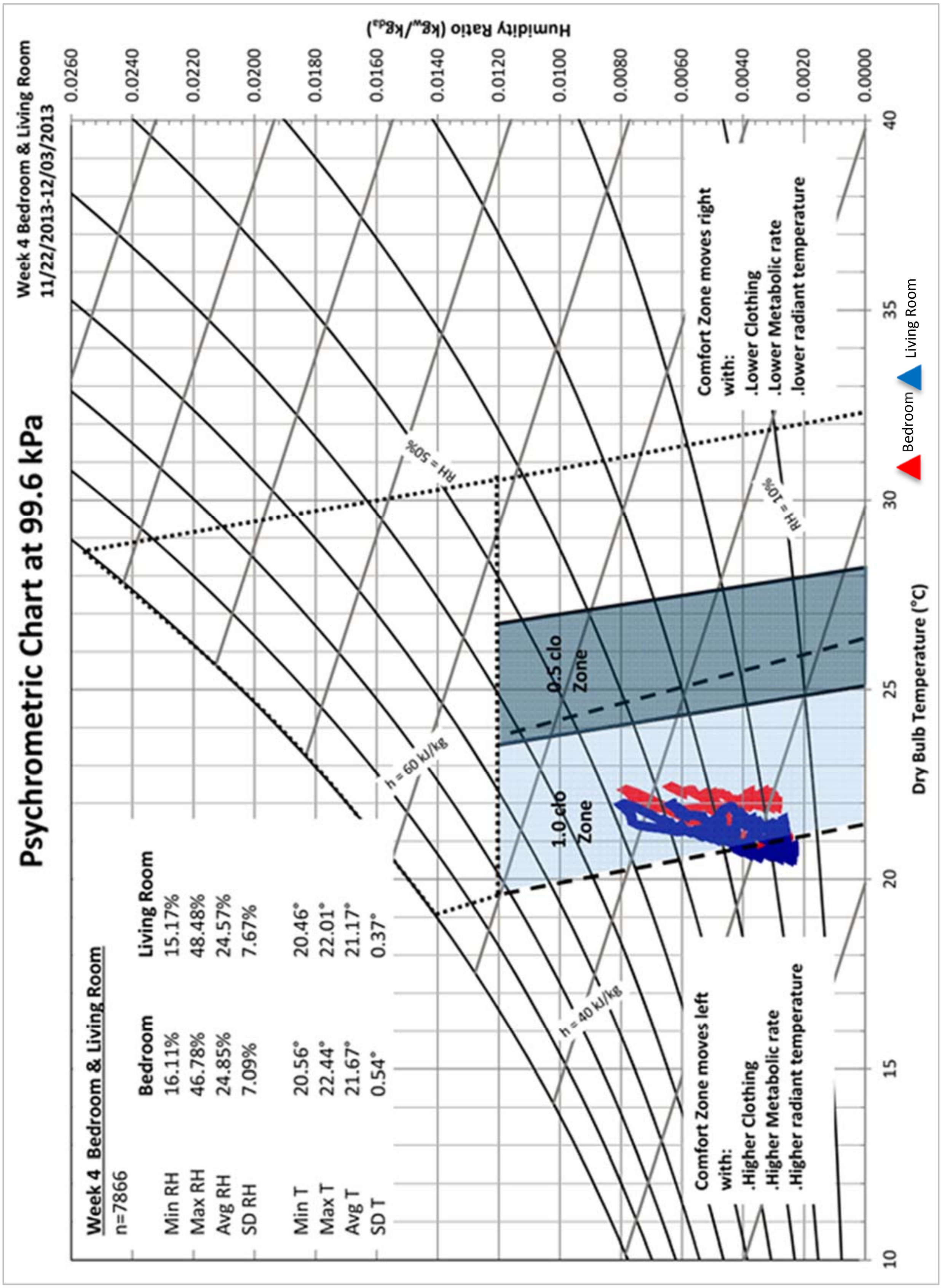

Figure 61-Week 4 Bedroom and Living Room Logged Data

Appendix B-Thermal Logging Study Time Range Analysis of Low Relative Humidity (RH≤30%)

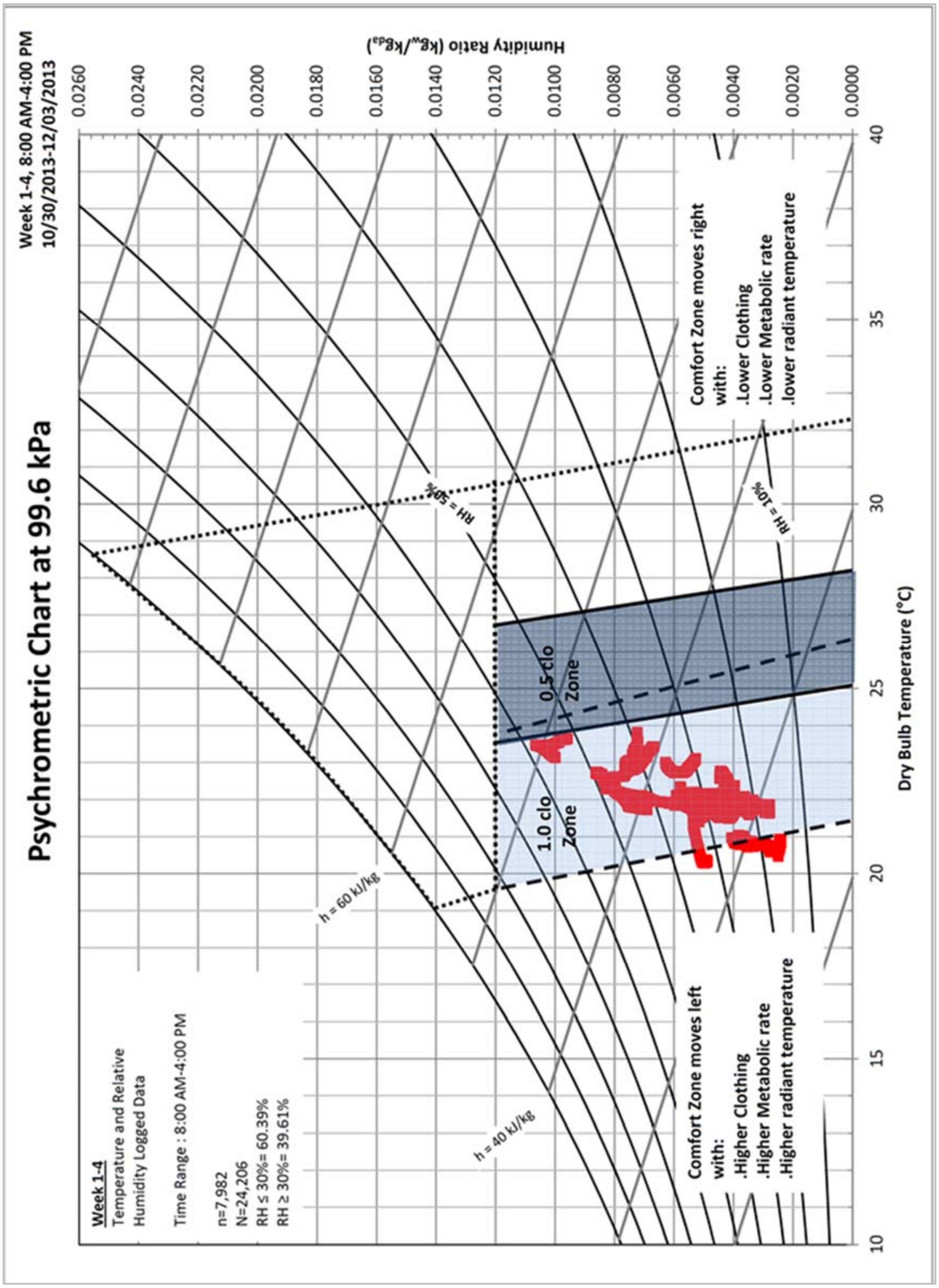

Figure 62-Week 1-4 Logged Data 8 AM-4 PM

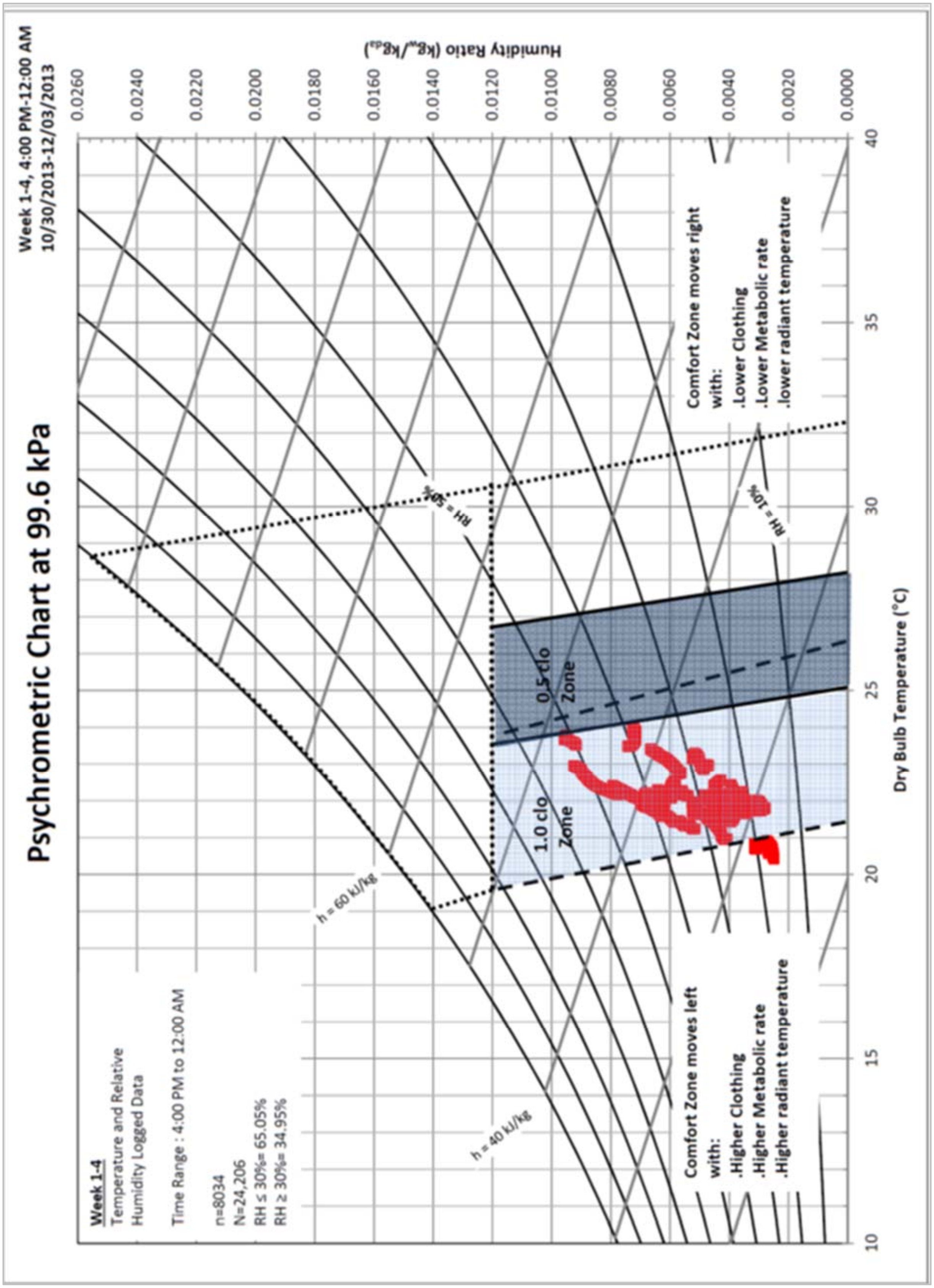

Figure 63-Week 1-4 Logged Data 4 PM-12 AM

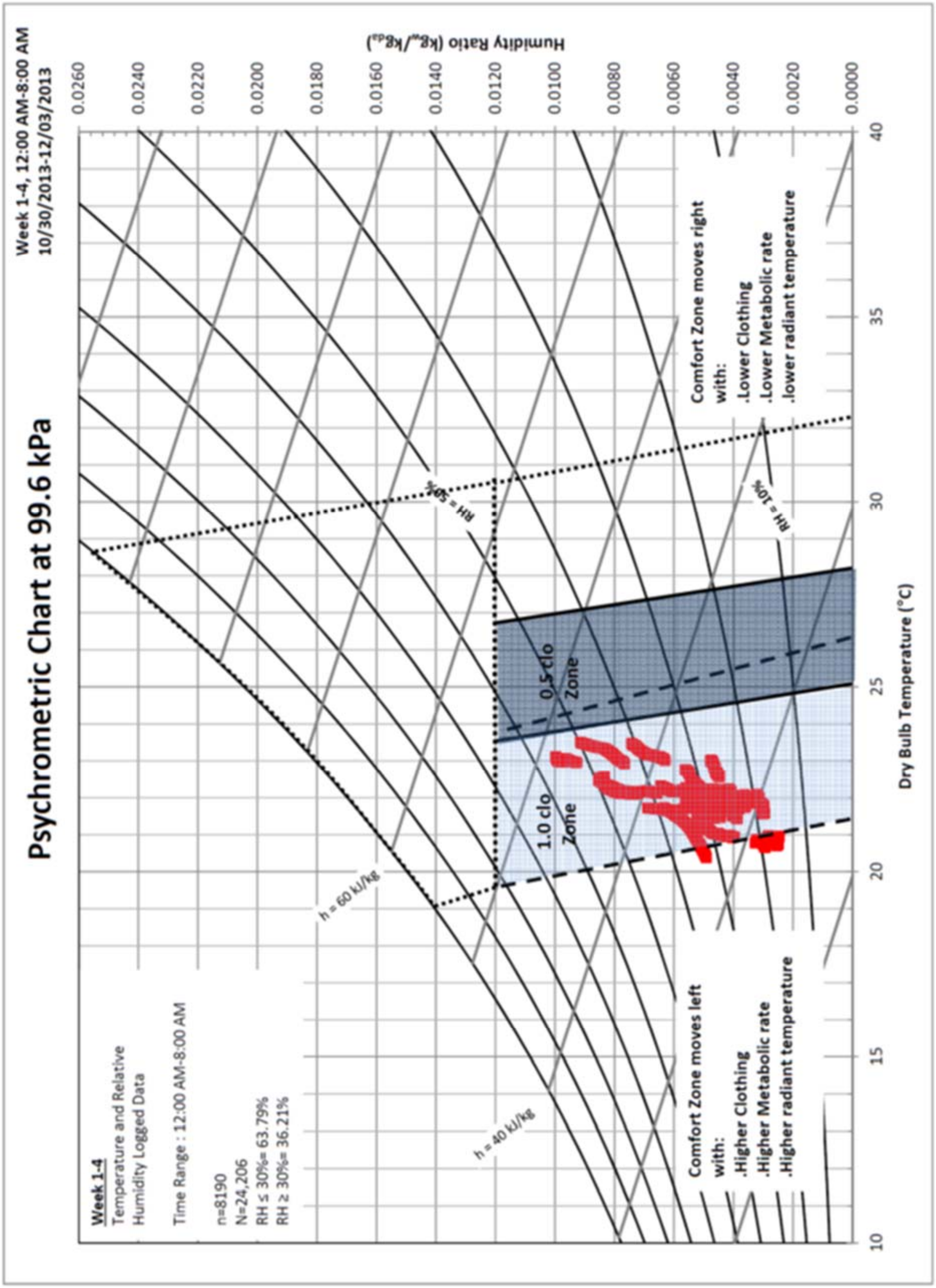

Figure 64-Week 1-4 Logged Data 12 AM-8 AM

Appendix C-Thermal Logging Study Weekly Logged Temperature and Relative Humidity Data (All weeks and Weeks 1, 2, 3 and 4)

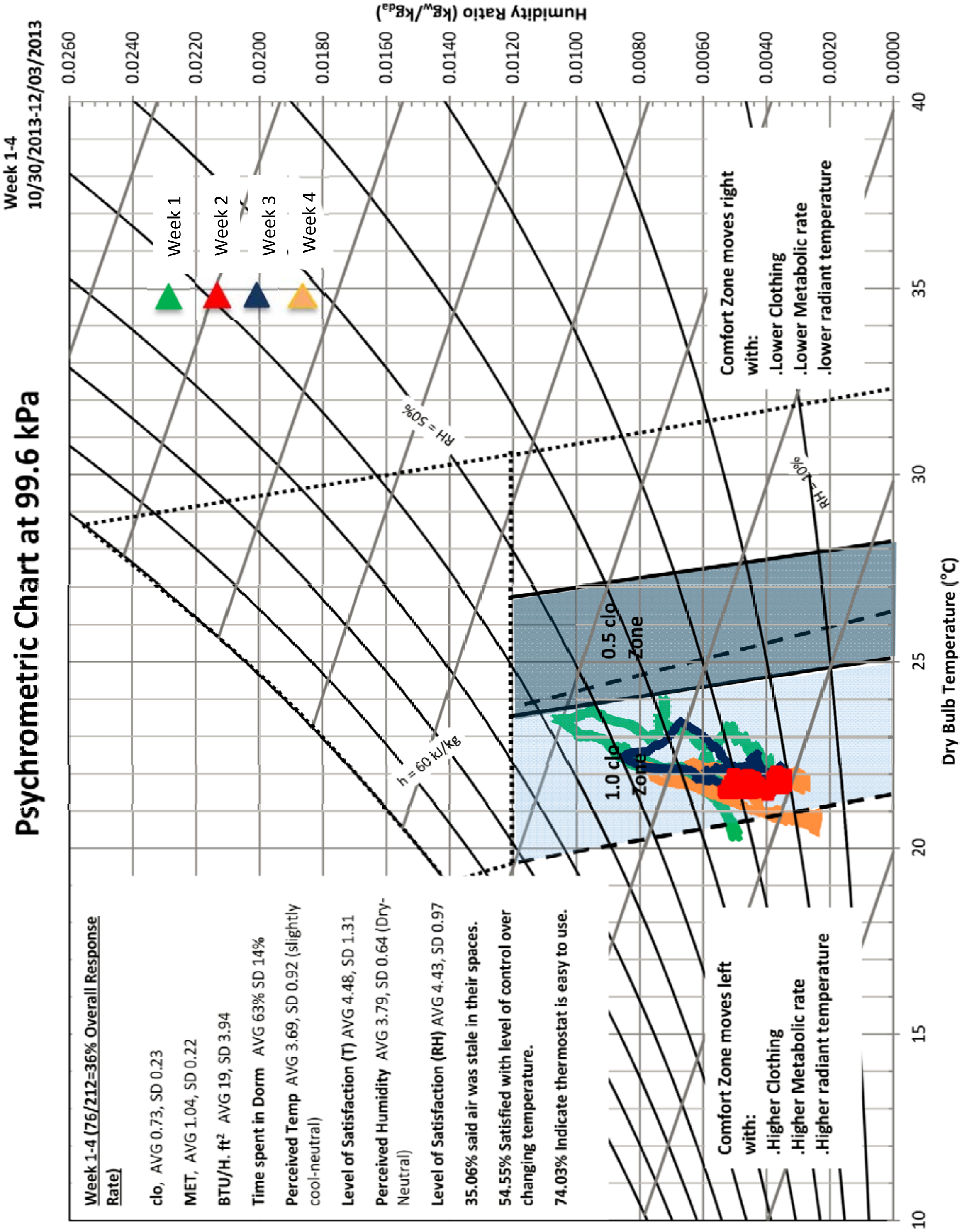

Figure 65-All Weeks Logged Data

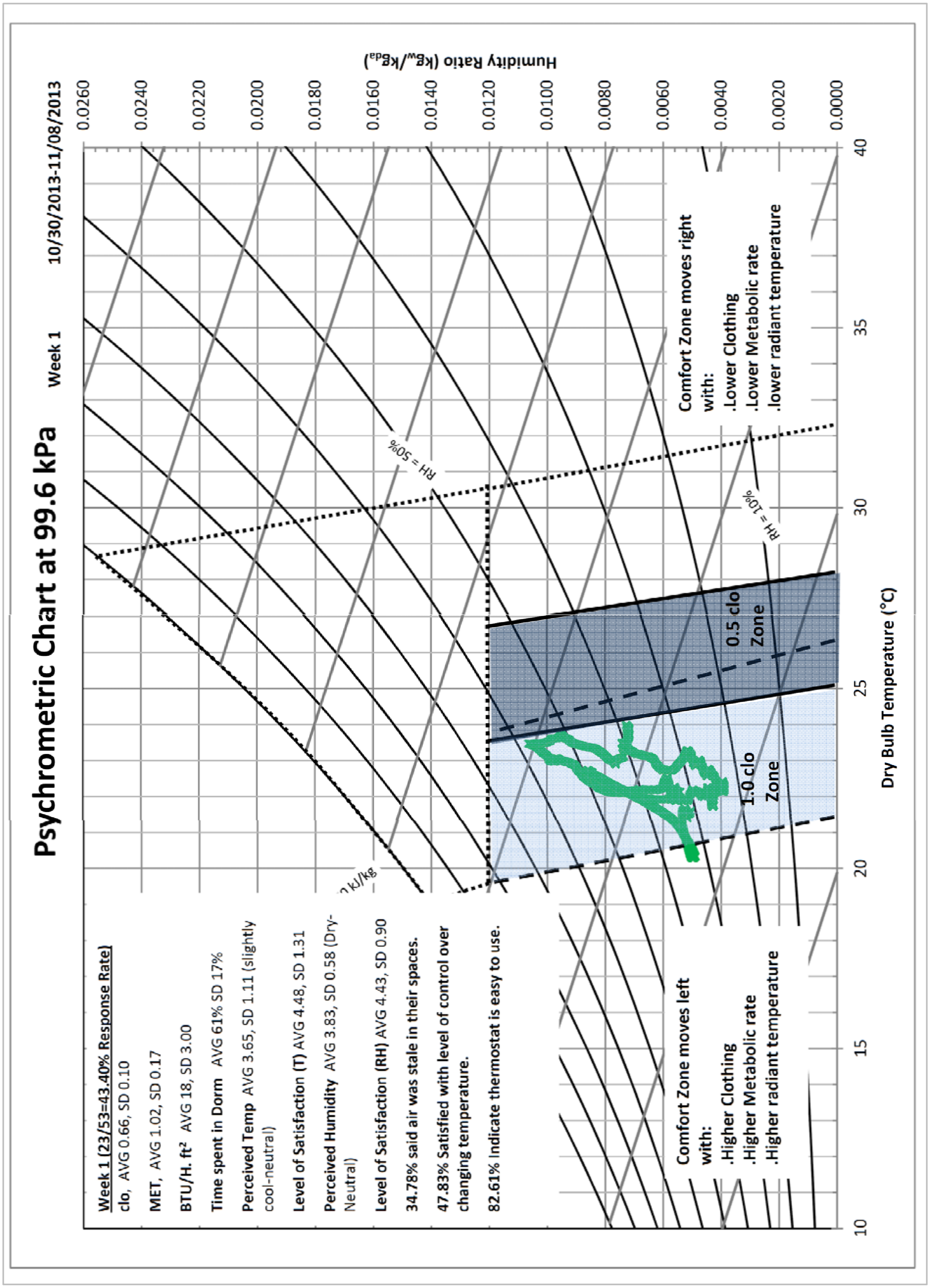

Figure 66-Week 1 Logged Data

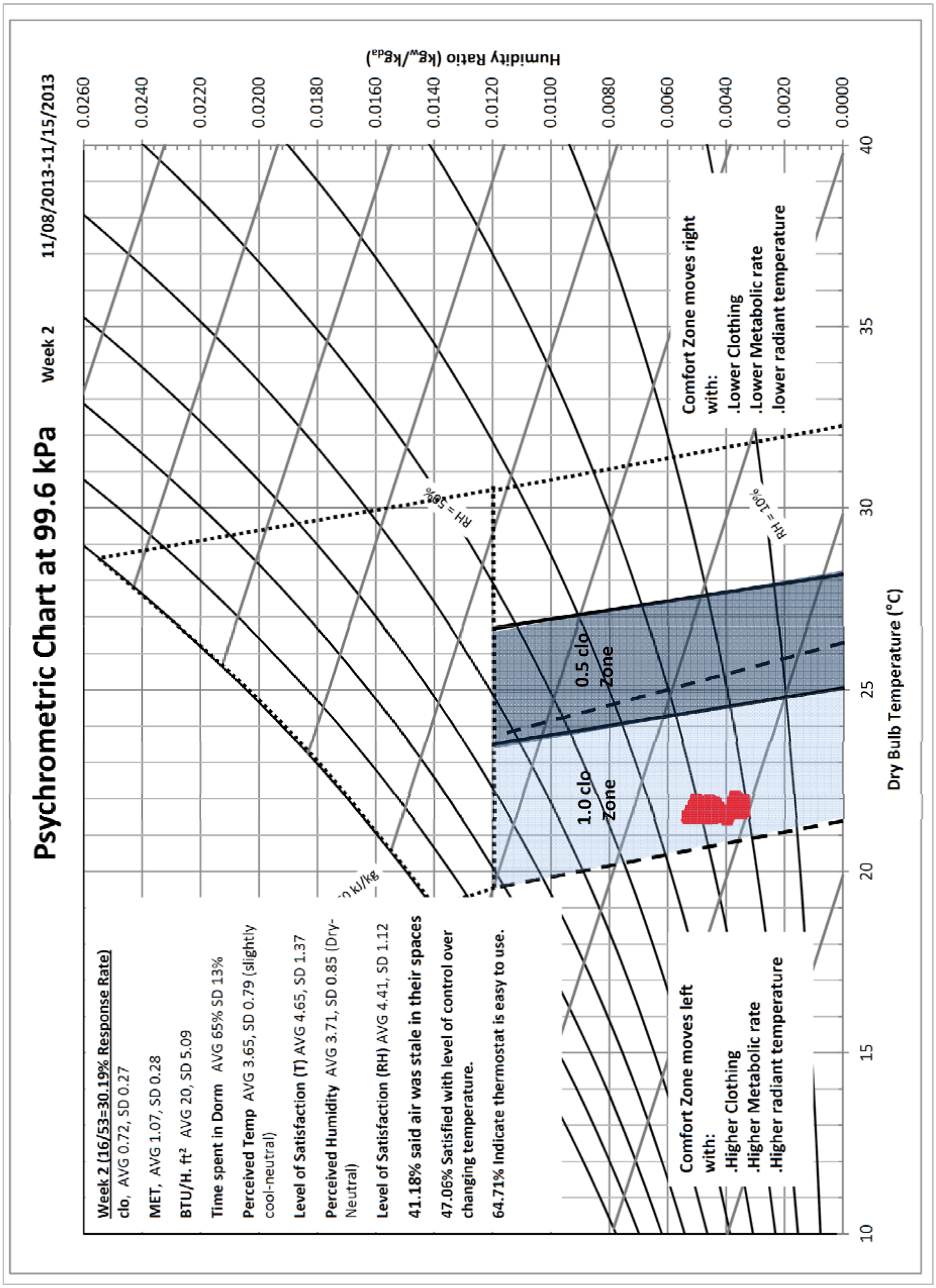

Figure 67-Week 2 Logged Data

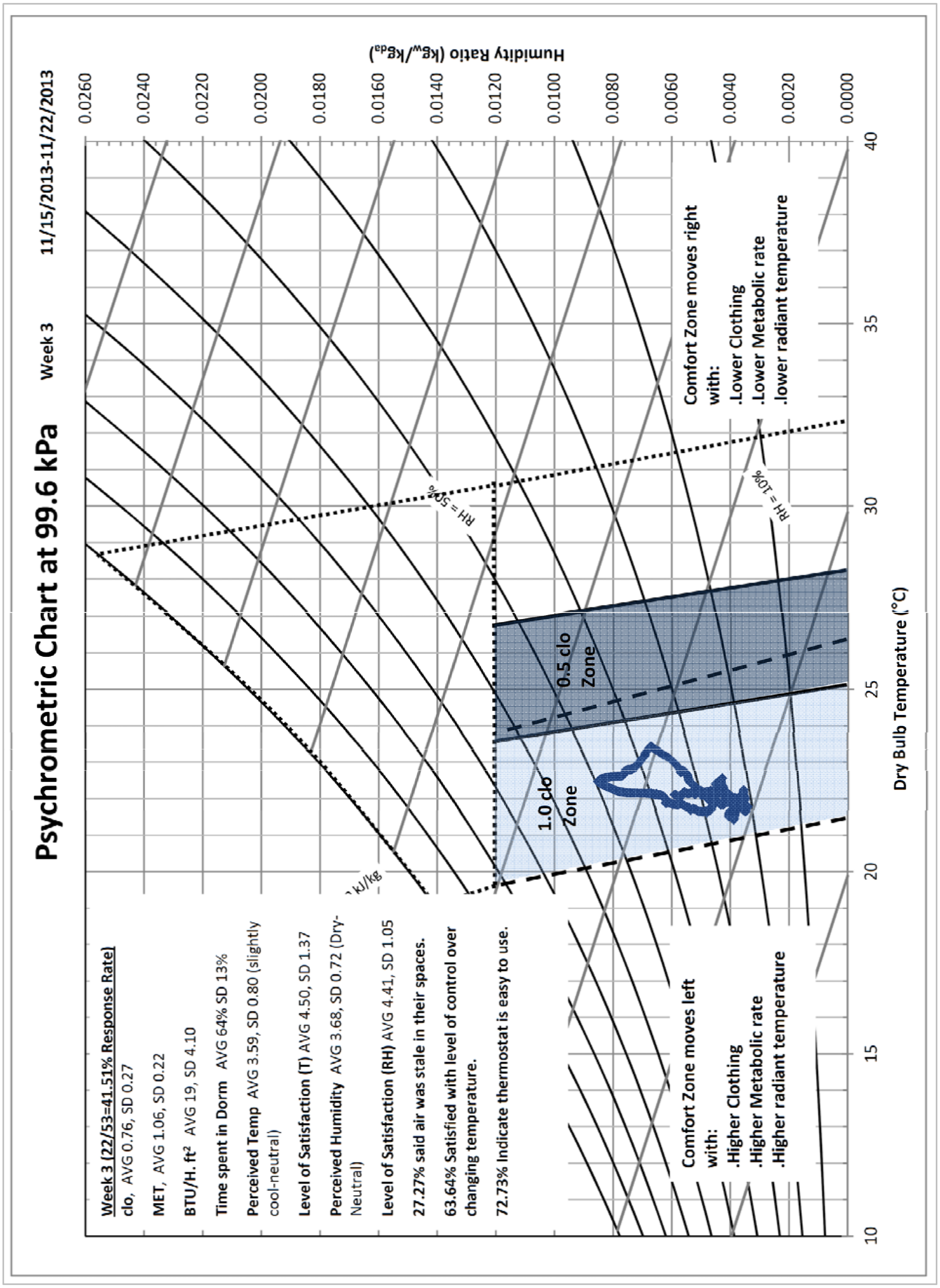

Figure 68-Week 3 Logged Data

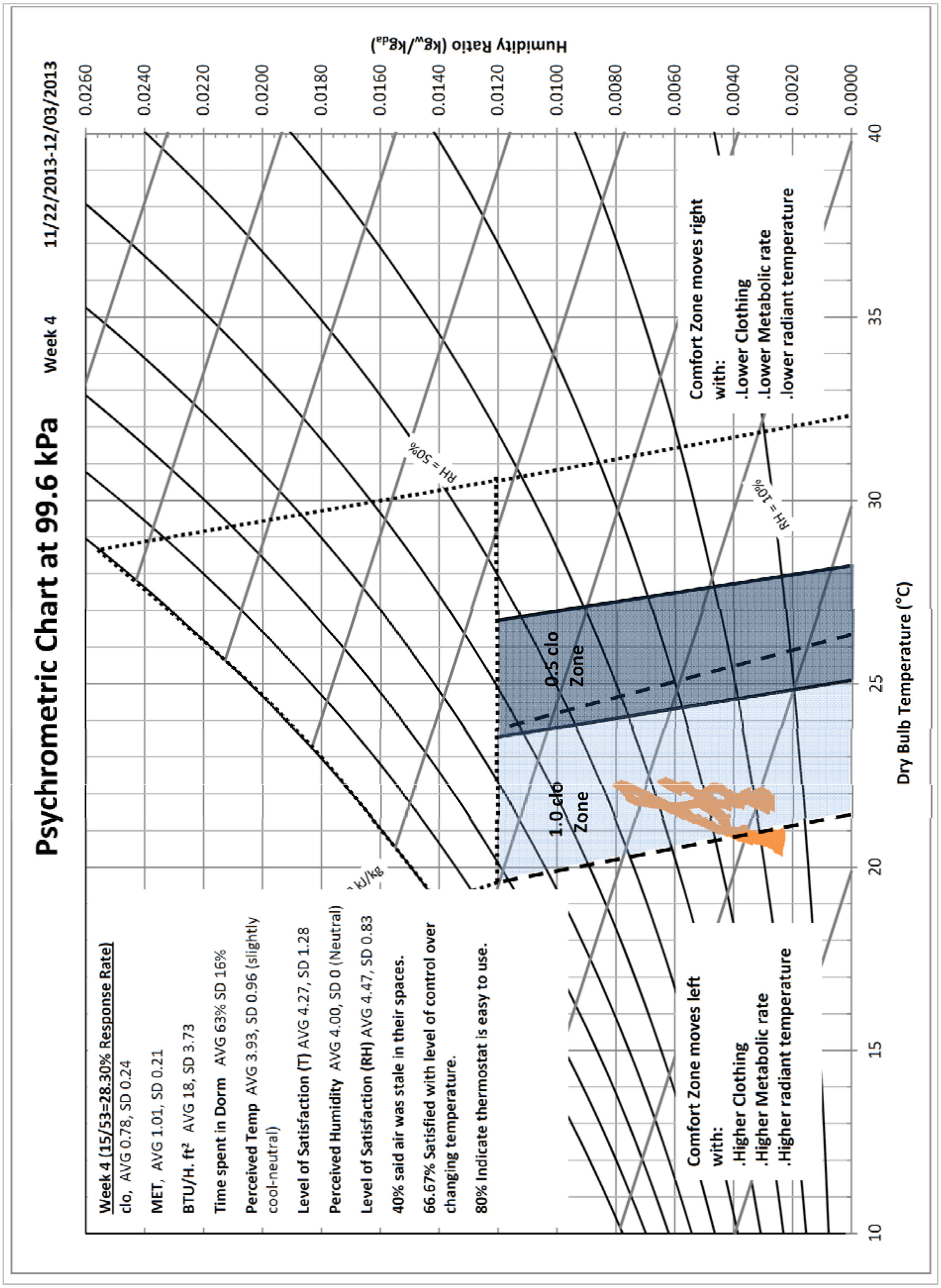

Figure 69-Week 4 Logged Data

Appendix D-Thermal Logging Study Student Comments

Type of Comment	Week 1 Comments 11/08/2013	Week 2 Comments 11/15/2013	Week 3 Comments 11/22/2013	Week 4 Comments 12/03/2013
Positive Humidity & Ventilation	(1) Acceptable			
Negative Humidity & Ventilation	(1) It's too dry, (2) I keep a fan on most of the time for air circulation, since only the bedroom windows open I need a fan at all times or it gets really stuffy, (3) triggered windows regulate heat etc…, slight ventilation, no open windows (4) None of the windows in this apartment open.	(1) it's not great wish the windows opened more (2) WAY TOO DRY IN THE WINTER, THERE should be humidity control (3) I keep a fan on most of the time for air circulation, sine only the bedroom windows open I need a fan at all times or it gets really stuffy. (4) No ventilation here	(1) NEED WINDOWS TO BE ABLE TO OPEN (2) WAY TOO DRY IN THE WINTER, THERE should be humidity control (3) I keep a fan on most of the time for air circulation, sine only the bedroom windows open I need a fan at all times or it gets really stuffy. (4) No ventilation here (5) SEEMS LIKE TEMP DOESN'T CHANGE	(1) NEED WINDOWS TO BE ABLE TO OPEN (2) LITTLE STUFFY AT TIMES (3) I keep a fan on most of the time for air circulation, sine only the bedroom windows open I need a fan at all times or it gets really stuffy. (4) occupancy sensor is a pain, window sensors not working either too cold or too hot
Neutral Humidity & Ventilation		(1) I leave my window open	(1) I leave my window open (2) I have felt colder, we also don't open the windows	
Positive Thermostat Comments	(1) I cannot tell so far, it has never been too hot or cold but that may change in the winter			

Negative Thermostat Comments	(1) thermostat restrictive, ignores user preferences, Range is far too small on thermostat, (2) basically useless, (3) Do not like the limitations on the thermostat, No control over thermostat, it's too cold, (4) Easiest way to change temp is to open window (5) Thermostat never adjusts to correct temperature, (6) Temperature setting is too low. Air conditioning goes on at unnecessary times. Thermostat is very restrictive, (7) basically no thermostat exists, buttons do not seem to change anything, (8) the thermostats do not allow much temperature control, the thermostat is not a clear interface,	(1) No, I think as a paying resident I should be able to control my own thermostat personally I don't like this as I don't feel that they work (2) the things don't seem to work (3) NOT COOL ENOUGH IN THE SUMMER, THE DEVICE has set mind we can't change it. (4) the range on the thermostat could be larger (5) basically no thermostat exists, buttons do not seem to change anything (6) Individual room control would be nicer (7) I don't know how to use it I think it only has ranges of 69-72 why does this make sense?	(1) No, I think as a paying resident I should be able to control my own thermostat personally I don't like this as I don't feel that they work (2) Windows don't open thermostat is awkward and I can't tell if it works (3) Seems unresponsive at low temperatures (4) Temperature setting is too low. Air conditioning goes on at unnecessary times. Thermostat is very restrictive (5) the range on the thermostat could be larger (6) IF I don't purchase a humidifier my nose will bleed. HE should buy me one. (7) basically no thermostat exists, buttons do not seem to change anything (8) I don't use them (9) Seems like the temperature doesn't change	(1) No, I think as a paying resident I should be able to control my own thermostat personally I don't like this as I don't feel that they work (2) Windows don't open thermostat is awkward and I can't tell if it works (3)

	(9) only allows 4 degree variation			
Neutral Thermostat Comments	(1) Do not have any comments	(1) Do not have any comments	(1) I cannot tell so far, it has never been too hot or cold but that may change in the winter (2) Do not have any comments	(1) I cannot tell so far, it has never been too hot or cold but that may change

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