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AN EVALUATION OF THE ACTUAL ENERGY AND INDOOR ENVIRONMENTAL QUALITY PERFORMANCE OF ON-CAMPUS BUILDINGS DESIGNED IN ACCORDANCE WITH LEED V4 RATING CRITERIA FOR NEW CONSTRUCTION

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GLOSSARY

ASHRAE:	American Society of Heating Refrigeration and Air-conditioning Engineers
CAV:	Constant Air Volume
CCT:	Correlated Color Temperature
CFM:	Cubic Feet per Minute
CMU:	Concrete Masonry Unit
CRI:	Color Rendering Index
DCV:	Demand Control Ventilation
DOAS:	Dedicated Outdoor Air System
DKT:	Deka Therm
EUI:	Energy Use Intensity
fc:	Foot candle
fl:	Foot lambert
GWB:	Gypsum Wall Board
HVAC:	Heating, Ventilation, and Air-conditioning
IAQ:	Indoor Air Quality
IESNA:	Illumination Engineers Society of North America
IEQ:	Indoor Environmental Quality
IMC:	International Mechanical Code
kWh:	Kilo Watt Hour
LED:	Light Emitting Diode
LEED:	Leadership in Energy and Environmental Design
O&M:	Operation and Maintenance
PMP:	Performance Measurement Protocols
PMV:	Predicted Mean Vote
STC:	Sound Transmittance Class
VAV:	Variable Air Volume
VOC:	Volatile Organic Compound

ABSTRACT

Objective

The research presented in this report develops a suite of guidelines for architects and engineers to ensure adequate Indoor Environmental Quality (IEQ) along with providing measures for reducing energy consumption in the operation of Green buildings. The guidelines prompt designers to account for occupant comfort via means of ensuring adequate IEQ when considering implementation of energy efficiency strategies in Green buildings. This study also establishes a hands-on experience for students of architecture and engineering in evaluating the physical performance of building systems. By establishing this experience, the study underlines the importance as well as the correlation between energy efficiency and IEQ in Green buildings.

Approach

A study was conducted to evaluate the IEQ performance of buildings in the Montana State University campus in Bozeman Montana that are compliant with the LEED Rating System. The study evaluated building performance using established metrics, measurement protocols and calibrated instruments. Current conditions of IEQ were assessed by occupant surveys. The results of the evaluations were then compiled and assessed using standard procedures and protocols. Finally, recommendations were made to reduce energy performance and improve IEQ of these buildings. Based on the case-study assessments, general guidelines and recommendations were compiled in a final report for architects and engineers to design and operate Green buildings.

In order to perform the evaluation, conditions were created for the students of architecture and engineering programs on campus to work together and assess the performance of buildings in terms of energy consumption and IEQ. An interdisciplinary class was conducted that facilitated the evaluation and documentation of the physical performance of buildings. In this class the students gained hands-on experience: to use measuring and monitoring devices; to monitor building performance; and to assess data collected from the selected case-studies on the Montana State University campus.

Results

This report provides guidelines and recommendations for implementing design strategies and building operations for proposed savings and includes a comprehensive explanation of the methodology utilized by the team to reach its conclusions, and the data utilized to conduct this analysis.

Key Words

Energy efficiency, indoor environmental quality, post occupancy evaluation

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INTRODUCTION:

The Challenge Definition

According to U.S. Energy Information Administration, energy consumption from buildings in the U.S. in 2015 accounted for 40% of the total energy consumption, which amounted to 39 quadrillion Btu (U.S. EIA 2016). This indicates that buildings have substantial impacts on the environment. These facts have prompted the drive towards high performance buildings and the resultant creation of green building standards, certifications, and rating systems such as Leadership in Energy and Environmental Design (LEED) aimed at mitigating the impact of buildings on the natural environment through sustainable design. (NIBS 2016).

High performance buildings address reduction in energy consumption by implementing energy efficiency measures and ensuring optimal operation of building systems, at the same time assuring acceptable IEQ. The LEED rating system provides categories for both energy and IEQ for a building to demonstrate compliance. The Energy and Atmosphere (E&A) category was created to address energy use reduction, energy efficient design strategies and incorporation of renewable energy resources. The Indoor Environmental Quality (IEQ) category was created to provide comfort, well-being, and productivity of occupants. The LEED IEQ Category addresses design and construction guidelines especially: indoor air quality (IAQ), thermal quality, and lighting quality. However, many of the requirements to ensure optimal IEQ often counteract the requirements for energy efficiency.

While many studies in the subject of sustainable design, construction, and operation high performance buildings have been focusing on validating the conservation and cost savings of energy, water, and natural materials, the evaluation of resultant IEQ in these buildings is often ignored and very little information is available as to how these buildings perform in terms of IEQ after the building has been occupied. (Lee and Kim 2008). In addition, there are very few studies focusing on occupants' evaluation on whether these criteria contribute to their satisfaction and performance in the LEED-certified buildings. (Lee and Guerin 2010).

The above discussion demonstrates that there is a need for a combined evaluation of the energy and IEQ performance of Green buildings in order to ensure efficient operation of buildings and occupant comfort.

Indoor Environmental Quality

Indoor Environmental Quality (IEQ) encompasses the conditions inside a building, & their effects on occupants or residents. There are four distinct characteristics that IEQ looks at; acoustics, lighting/daylighting, indoor air quality, and thermal comfort. Strategies for addressing IEQ include those that protect human health, improve quality of life, & reduce stress & potential injuries. Better indoor environmental quality can enhance the lives of building occupants, increase the resale value of the building, & reduce liability for building owners.

Acoustics:

Acoustics is defined by the ability to contain noise pollution and sounds within designated areas. Reverberation time, noise, acoustical anomalies, and loudness all affect the acoustics of a building. Poor acoustical quality can cause physical and emotional discomfort. A space with good acoustics allows for confidential conversations among collaborating workers without affecting those engaged in individual, focused work. It also ensures the space is not too loud, does not echo too much, & does not emit excess noise pollution from both indoor & outdoor sources. To be optimally effective & affordable, integrated acoustic design requires that acoustics be considered at the beginning of the design process – not “fixed” afterward. Sustainable design often requires attention to materials used in furnishings & construction. Materials that achieve sustainability goals may not be the best choice for acoustic comfort. Goals to decrease energy use by enhancing daylight penetration can also inadvertently create acoustic problems associated with lower workstation panels which offer fewer opportunities for sound absorption.

Lighting/Daylighting:

Lighting is defined as the degree to which the luminous environment supports the visual acuity, social interaction & communication, mood, health and safety, and aesthetic judgement requirements of the occupants of a particular space. Lighting is created through two categories, daylight and electric light. There are several factors that can affect the quality of light that is required, desired, or needed in a space for an occupant to perform a visual task. Some of these factors include occupant age, task size, light level, and glare.

Lighting can be evaluated through three components: illuminance, luminance, and glare. There are specific measurement devices that can physically measure the amount of light falling on a surface or even the amount of light output from fixtures within a space. Both of these tools are conducted after construction. Daylight simulations can be conducted prior to construction during design phases using daylight modeling software to test and simulate light levels and find high amounts of glare or underlit spaces.

Indoor Air Quality:

Indoor Air Quality (IAQ) refers to the air quality within & around buildings & structures, especially as it relates to the health & comfort of building occupants. Understanding & controlling common pollutants indoors can help reduce risk of indoor health concerns. Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later. Indoor air contaminants can originate within buildings or may be drawn from outdoors. IAQ of a building is a result of interaction between Site, Climate, Building System, Construction Techniques, Contaminant Sources, & Building Occupants. Each of those aspects must be examined and any source of contaminant should be addressed prior to commencement of construction.

Thermal Comfort:

Thermal comfort is the human perception of satisfaction with the thermal environment Thermal comfort is maintained when the heat generated by the human metabolism is allowed to disseminate at a rate that maintains thermal equilibrium in the body. Any heat gain or loss beyond this generates substantial discomfort. Thermal comfort is influenced by environmental, personal & work-related factors. Thermal comfort is different for each individual, therefore the ability to control the thermal environment is key to addressing thermal comfort on an individual basis.

Energy

Energy tends to be the primary focus of many green high-performance buildings. Most of the resources spent during design and development stages are focused towards the optimization of the building’s energy usage. Energy generation also uses up many resources during the design and development phases of the building process. The performance of energy often comes at the sacrifice of the indoor environmental quality. They are directly linked between each other, but simultaneous optimization of both is not intuitively developed. In order to best design the performance of both, they need to be considered holistically in the interactions between them.

Energy, IEQ and LEED

Energy assessment in LEED is straightforward. In addition to the prerequisite commissioning process and minimum energy performance requirement that require demonstrating an improvement over ASHRAE Standard 90.1, credits can be obtained for enhanced commissioning, further optimization of building energy performance, implementation of demand response strategies, and implementation of renewable energy technologies.

On the other hand, the methods of assessment of IEQ in LEED have been questioned by various studies. Lee and Kim in their assessment of IEQ in LEED certified buildings in the U.S. comment that mechanical engineering aspects of IEQ dominate the requirements of the LEED IEQ even though the issue of the quality of indoor environment is beyond the mechanical engineering aspects (Lee and Kim 2008). The authors comment that encompassing mechanical aspects, the meaning of IEQ addresses a broad range of issues related to occupant comfort, health, and safety, which includes functional space layout, thermal comfort, indoor air quality (IAQ) lighting, acoustics, ergonomics, aesthetics, etc. In another study on post occupancy evaluation of Green buildings, Marlin observes that in the LEED IEQ area, normative requirements are referenced to other environmental standards such as those of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in a prescriptive manner (Marlin, 2003). However, the author observes that these requirements have not been validated in terms provision of better occupant's satisfaction and productivity than conventional buildings.

The above discussion demonstrates that there are shortcomings of current LEED criteria for IEQ. The study is conducted by interdisciplinary group of students consisting or architects and engineers who lend their expertise to identify and resolve issues resulting from poor IEQ identified in Green buildings in addition to maintaining reduced energy consumption levels.

Occupant Assessment of IEQ

Occupant assessment may be defined as a systematic evaluation of the effectiveness of design components in built environment based on occupants' responses to their environment (Preiser et. al 1988). Several studies have concluded that occupant assessment on the built environment is necessary to ensure the effectiveness of the indoor environment of LEED-certified buildings (Lee and Kim 2008; Gonchar, 2008; Mendler et al. 2006; Heerwagen and Zagreus, 2005; Mendleret al., 2005; Marlin, 2003). This assessment is important mainly due to the lack of available information on how buildings that are designed and constructed with sustainable building standards and guidelines including LEED actually perform regarding occupant's satisfaction and performance. In addition, occupant assessment can be used as an effective tool to identify and evaluate weaknesses and strengths of the current sustainable design practice and enhancing future design practice (Marlin, 2003).

The above discussion emphasizes the need to validate occupant comfort addition to measuring energy consumption and levels of IEQ in Green buildings. This study will use occupant assessment strategies to evaluate the resultant occupant comfort in Green buildings.

GOALS AND OBJECTIVES:

Overview:

The goals of this research are to assess and evaluate the performance of LEED certified buildings in terms of energy and IEQ with the intent of providing recommendations to both architects and engineers to ensure appropriate building performance.

The objectives of this research are as follows:

1. To conduct an evaluation of IEQ and energy performance of two LEED certified buildings using established protocols for observation, measurement and post occupancy evaluation.
2. To develop a set of guidelines for architects and engineers to ensure adequate IEQ along with providing measures for reducing energy consumption in the design, construction and operation of Green buildings.

METHODOLOGY:

Overview:

In order to conduct the analysis, two buildings with similar functions were selected on the MSU campus. These two buildings were selected because of their performance in meeting the criteria for LEED certification. More specifically, each building was reviewed in terms of their compliance with criteria specified for IEQ and Energy as described in the LEED Version 3 certification process. Criteria for LEED V4 certification was also used to establish an updated benchmark for LEED certification.

A preliminary walkthrough was conducted through the buildings and ground conditions for energy consumption and IEQ were observed. The IEQ analysis was taken up by the architecture students and the energy analysis was then taken up by the engineering students. The students formulated individual hypotheses based on their observations from the initial walkthrough and information.

The formulated hypotheses were evaluated using methods and metrics established in the ASHRAE Performance Measurement Protocols and ASHRAE Commercial Building Audits. Energy data was made available from the Montana State University Facilities.

Methods and metrics established in the ASHRAE Performance Measurement Protocols that were used in the analysis included: documenting observations from the walk-through checklists, analysis of collected data, measurement of various parameters associated with IEQ and post occupancy surveys of the occupants. Metrics established in the ASHRAE Commercial Building Audits that were used in this analysis included the use of Energy Use Index.

The results from the observations, data and surveys were compiled and evaluated using various statistical and graphical methods of analysis. Final recommendations were developed based on the conclusions. Various resources from ASHRAE and EPA were consulted to inform these recommendations. An overview of the methodology adopted for this study is presented in Figure 1.

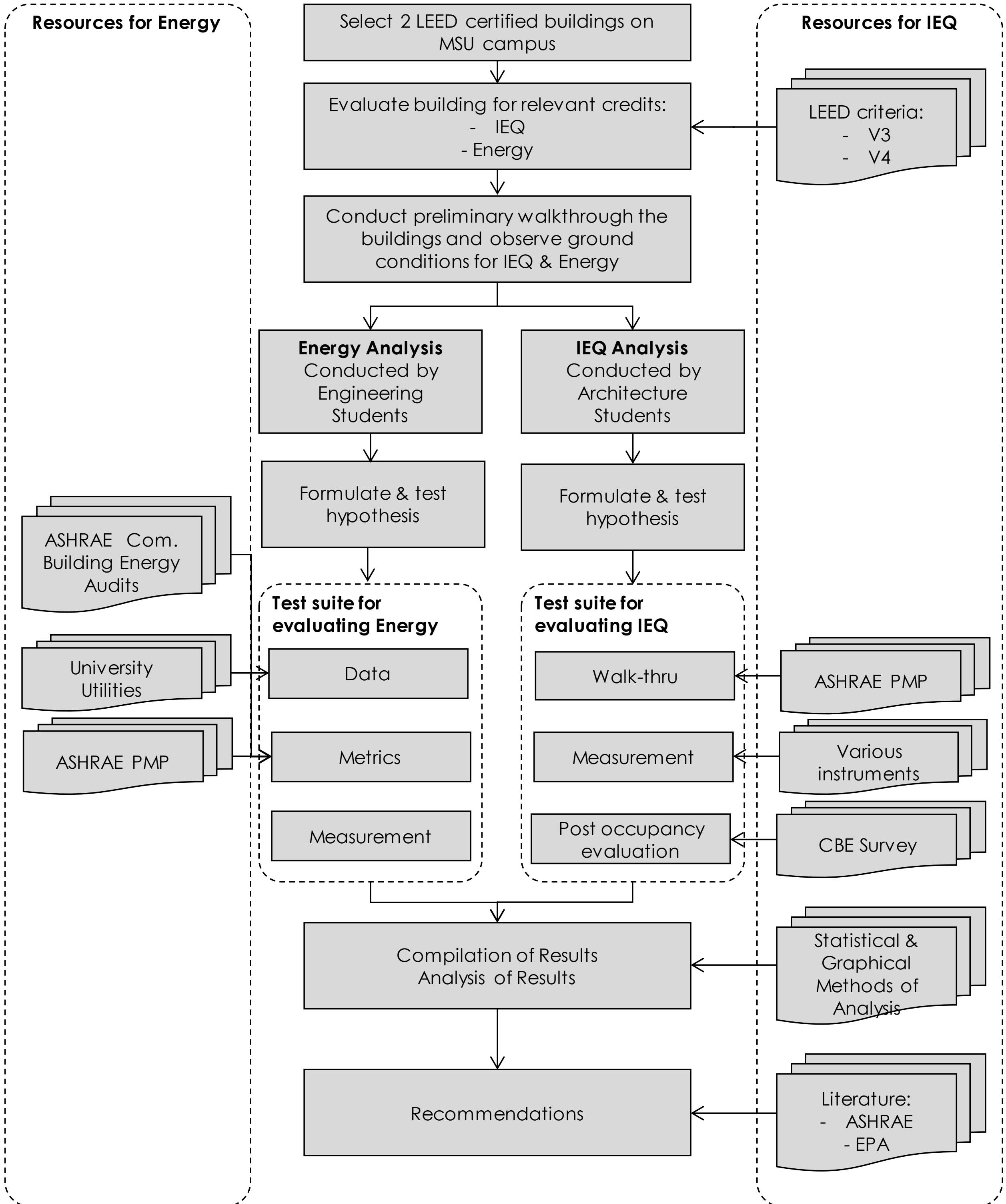


Figure 1: Overview of the methodology adopted by this study

CASE-STUDY BUILDINGS:

Overview:

For this analysis, the research team proposes to select LEED-certified buildings on Montana State University campus to conduct the evaluations. It is important that two buildings of similar purpose be eligible for comparison. This will ensure proper analysis and create a wholistic approach to the evaluation for Energy and IEQ. There are currently five LEED certified buildings on the Montana State University Campus. Four are gold and one is silver. Out of the four gold buildings, two are residence halls and two are classroom halls.

Selection:

Gallatin Hall is a 30,000 SF, four story LEED 2009 Gold certified building with 70 beds. This dorm has a semi-seasonal occupancy with full occupancy from months September to May and occasional occupancy from months May to September. It has a total occupant load of 163 with the first floor being 50 and the additional floors being from 30 and 45. In 2017, Gallatin Hall had an EUI of 49.222 kBtu/yr/sf.

When considering heating, ventilation and air-conditioning (HVAC) systems, Gallatin Hall utilizes one full forced air system with ductwork in every resident room as well common spaces for the supply of air. Outside air is provide at 10 – 15 CFM per person. The system is also configured to remove exhaust air from each toilet and bathroom in the building. Exhaust air removal is configured at 65 – 100 CFM per room. The system operates continuously when the building is occupied. The exhaust system is also configured to remove air from the corridors when the temperature is above 78ºF, and outside air temperature is at least 4ºF higher than the average floor temperature. Residents can open/close windows as desired to control whether they want to pull in cool air from outside. For supplemental heating, Gallatin Hall utilizes radiant heaters in the resident rooms. Mechanical cooling is provided for 3rd and 4th floor areas on east side of building with large windows. Cooling was provided after project was completed due to very high temperatures in these areas. See system diagram below (Figure 2) for reference.

Yellowstone Hall is a 121,000 SF, four story LEED 2009 Gold certified building with 400 beds. This dorm also has a semi-seasonal occupancy with full occupancy from months September to May and occasional occupancy from months May to September. It has a total occupant load of 575 with the first floor being 120 and the additional floors being 150. In 2017, Yellowstone Hall had an EUI of 45.532/yr/sf.

When considering HVAC systems, Yellowstone Hall utilizes three smaller forced air systems per floor with supply air being provided only to the bathrooms and central common spaces. Outside air is provide at 10 – 15 CFM per person. The system is also configured to remove exhaust air from each toilet and bathroom in the building. Exhaust air removal is configured based on bathroom size. The system operates continuously when the building is occupied. The amount of natural ventilation within resident's rooms depends on windows on other side of building being open, and an open path to that area. Residents can open/close windows as desired to control whether they want to pull in cool air from outside. For heating within the resident's rooms, Yellowstone Hall utilizes radiant heaters. Mechanical cooling is provided for 1st floor lobby and other common areas. Cooling in common spaces was provided due to expected high cooling load requirements from windows and large number of occupants. See system diagram below (Figure 2) for reference. Drawings and detailed information are presented in Appendix A. Architectural renderings of the two buildings are provided in Figure 3.

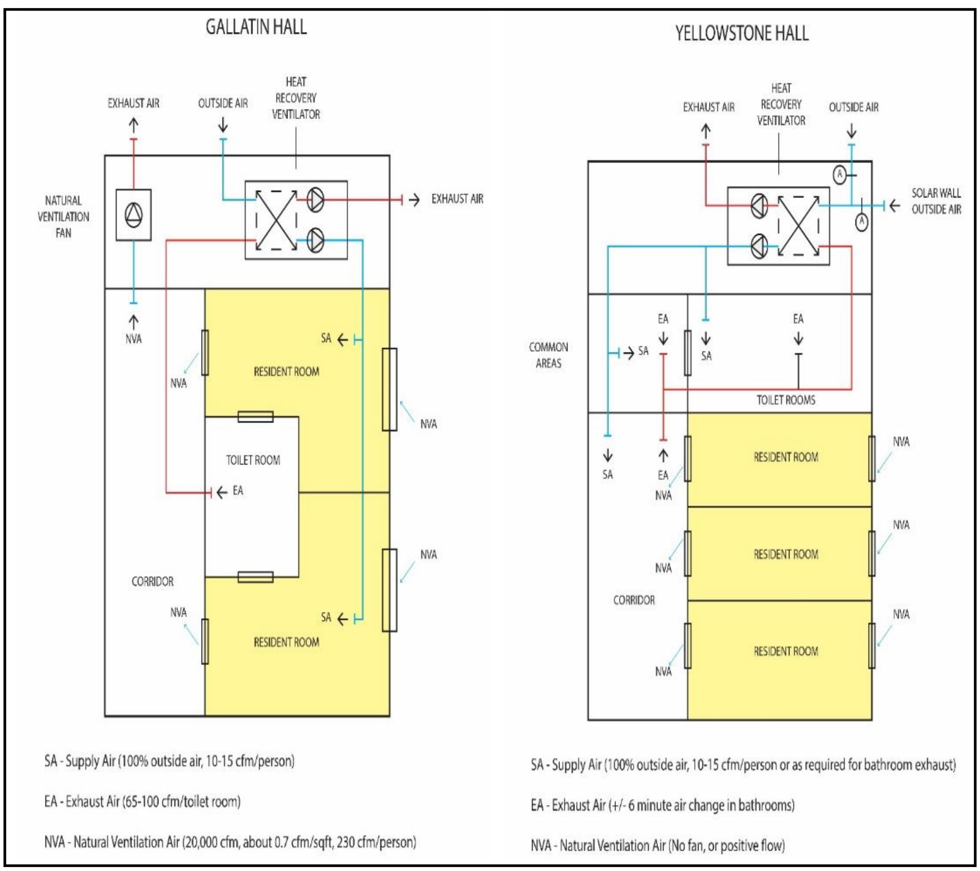


Figure 2: HVAC Diagrams for Gallatin and Yellowstone Halls

a. Gallatin Hall

b. Yellowstone Hall

Figure 3: Renderings of the Gallatin Hall (a.) and Yellowstone Hall (b.)

LEED CRITERIA ANALYSIS OF CASE STUDIES:

LEED Overview:

LEED, or Leadership in Energy and Environmental Design, is the most widely used green building rating system in the world. Available for virtually all building, community and home project types, LEED provides a framework to create healthy, highly efficient and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement (USGBC 2019).

Projects pursuing LEED certification earn points across several categories: Location & Transportation, Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, Indoor Environmental Quality, Innovation and more. Based on the number of points achieved, a project then earns one of four LEED rating levels: Certified, Silver, Gold or Platinum. (USGBC 2019).

LEED V4 is the most current version of the certification that was unveiled in 2013 is by far the most stringent version of the LEED green building rating system. Some of the changes in LEED v4 are included in Table 1 & 2.

The focus of this report is the LEED criterial for IEQ and energy. The LEED IEQ Category addresses design and construction guidelines especially indoor air quality (IAQ), thermal quality, and lighting quality. However, many of the requirements to ensure optimal IEQ often counteract the requirements for energy efficiency. The Energy and Atmosphere (E&A) category was created to address energy use reduction, energy efficient design strategies and incorporation of renewable energy resources. The Indoor Environmental Quality (IEQ) category was created to provide comfort, well-being, and productivity of occupants. (USGBC 2019).

A detailed discussion on compliance with LEED criteria for IEQ and Energy by the two case-study buildings are presented in the subsections below. While the case studies were LEED V3 certified, a discussion on how these buildings compared to LEED V4 criteria is presented to better understand how to address the issues related with IEQ.

Table 1: Changes in LEED V4 for Energy Credits

Prerequisite	Fundamental Commissioning and Verification	• Credit title renamed from "Fundamental Commissioning of Building Energy Systems". • Modified intent to ensure project meets the owner's projects requirements related to energy, water, indoor environmental quality and durability. • Added requirement for preparing an Operations and Maintenance Plan. • Added requirement to engage a Commissioning Authority by the end of the design development phase. • Clarified language for who can be the commissioning authority. • Included requirements for a design review of the enclosure.
Prerequisite	Minimum Energy Performance	• Updated referenced standard to ASHRAE 90.1-2010. • Added requirements for data centers. • Added retail-specific process load requirements • Updated Advanced Energy Design Guides prescriptive option to 50% AEDG for Office, Retail, Schools, and Healthcare. • Updated Core Performance Guide prescriptive option to meeting core requirements plus six additional strategies.
Prerequisite	Building-Level Energy Metering	• New prerequisite. • Requires each project to be capable of measuring whole building energy use.
Prerequisite	Fundamental Refrigerant Management	• No substantive changes.

Table 1: Continued

Credit	Enhanced Commissioning	• Added options for monitoring based commissioning and envelope commissioning. • Added requirements to prepare the building operators for the intended operation of building systems • Clarified language for who can be the commissioning authority.
Credit	Optimize Energy Performance	• Updated referenced standard to ASHRAE 90.1-2010. • Added requirements for data centers. • Added retail-specific process load requirements • Updated Advanced Energy Design Guides prescriptive option to 50% AEDG for Office, Retail, Schools, and Healthcare. • Updated Core Performance Guide prescriptive option to meeting core requirements plus six additional strategies.
Credit	Advanced Energy Metering	• New credit. • Requires all energy end-uses that represent 10% or more of the total energy consumption of the building to be metered. • Meters must be connected to the building automation system and log data at appropriate intervals. • Core and Shell projects required to address future tenant spaces.
Credit	Demand Response	• New credit. • Encourages projects to design and install systems necessary to participate in a demand response program. • Also available to projects located in areas without demand response programs. • Added requirement to include demand response processes in the commissioning scope.
Credit	Renewable Energy Production	• Credit title renamed from "On-Site Renewable Energy". • Added provision for community-scale renewable energy systems. • Points adjusted significantly.
Credit	Enhanced Refrigerant Management	• Added retail-specific requirements.
Credit	Measurement and Verification	• Credit removed. • Installation of measurement and verification infrastructure addressed in Building-Level Energy Metering prerequisite and Advanced Metering credit.
Credit	Green Power and Carbon Offsets	• Credit title renamed from "Green Power". • Credit based on total building energy usage. • Carbon offsets allowed for scope 1 or 2 emissions • Required contract length extended from 2 years to 5 years. • Eligible resources must have come online after January 1, 2005.

Table 2: Changes in LEED V4 for IEQ Credits

Prerequisite	Minimum Indoor Air Quality Performance	• Added requirements for outside air delivery monitoring • Added requirements for residential projects addressing combustion appliances, CO monitors, and radon.
Prerequisite	Environmental Tobacco Smoke Control	• Removed allowance for designated smoking areas inside the building for al projects but residential. • Reduced the maximum allowable leakage rate for compartmentalized residential units. • Prohibited smoking on the entire site for Schools projects.
Prerequisite	Minimum Acoustic Performance (Schools)	• Harmonized ANSI & ASHARE standards. • Added exterior noise control exceptions for projects located on quiet sites. • Added exceptions for projects with limited renovation scopes or strict historic preservation requirements.
Credit	Outdoor Air Delivery Monitoring	• Credit requirements moved to “Minimum Indoor Air Quality Performance” and “Enhanced Indoor Air Quality Strategies” credits.
Credit	Increased Ventilation	• Credit requirements moved to “Enhanced Indoor Air Quality Strategies” credit.
Credit	Enhanced Indoor Air Quality Strategies	• Credit is a combination of “Outdoor Air Delivery Monitoring”, “Increased Ventilation”, and “Indoor Chemical and Pollutant Source Control” credits. • Added additional options for mathematical modeling, additional sensors, and mixed mode systems.
Credit	Low-Emitting Materials	• Credit is a combination of the “Low-Emitting Materials” credits. • Requirements based on VOC emissions rather than VOC content. • Systems approach to emissions within a space. • Added requirement for TVOC disclosure. • Modified requirements for formaldehyde.
Credit	Construction Indoor Air Quality Management Plan	• Credit title renamed from “Construction Indoor Air Quality Management Plan—During Construction”. • No substantive changes.
Credit	Indoor Air Quality Assessment	• Credit title renamed from “Construction Indoor Air Quality Management Plan—Before Occupancy”. • Added a maximum temperature limit for flush outs. • Expanded the list of contaminants for which to test under Option 2. • Clarified that furniture must be installed.
Credit	Indoor Chemical and Pollutant Source Control	• Credit requirements moved to “Enhanced Indoor Air Quality Strategies” credit.
Credit	Controllability of Systems—Lighting	• Credit requirements moved to “Interior Lighting” credit.

Table 2: Continued

Credit	Thermal Comfort	• Credit title renamed from "Thermal Comfort—Design". ASHRAE 55-2010. • Credit removed from Core and Shell.
Credit	Interior Lighting	• New Credit. • Incorporates controls requirements from "Controllability of Systems—Lighting" credit. • Added an option that addresses lighting quality.
Credit	Daylight	• Credit title renamed from "Daylight and Views—Daylight". • Removed prescriptive option. • Added option for spatial daylight autonomy. • Changed units from footcandles to lux. • Added a timing requirement to measurement option.
Credit	Quality Views	• Credit title renamed from "Daylight and Views—Views". • Added requirement for quality view, defined by the LEED 2009 exemplary performance criteria. • Added provisions for interior atria.
Credit	Acoustic Performance	• New credit except in Schools and Healthcare. • Added requirements for room noise levels, speech privacy and sound isolation, reverberation time, and paging, masking, and sound reinforcement systems. • Harmonized ANSI and ASHRAE standards.
Credit	Mold Prevention (Schools)	• Credit requirements moved to "Thermal Comfort" credit.

LEED Criteria for Case-study Buildings:

Both Case-study Buildings were evaluated with LEED v3 criteria.

Gallatin Hall was awarded Gold Certification in December of 2015, with 61 out of the 109 possible points. Sustainable features of the hall included:

- Solar panels used in building hot water generation
- 94% of construction waste recycled
- Water efficiency systems reduced consumption by 34%
- Energy performance optimization system

From the 61 points that were obtained, 21 of the 26 points came from ‘Sustainable Sites’, 3 out of 10 points came from ‘Water Efficiency’, 17 out of 35 points came from ‘Energy and Atmosphere’, 4 out of 14 points came from ‘Materials and Resources’, 11 out of 15 points came from ‘Indoor Environmental Quality’ and 5 out of 9 points came from ‘Innovation in Design’ and ‘Regional Priority Credits’.

On closer examination of credits for ‘Indoor Environmental Quality’ it was observed that compliance with improved ventilation and thermal comfort were not obtained. In addition, when considering credits for ‘Energy and Atmosphere’, the building met all the prerequisites and met 13 out of 19 possible credits for the category ‘Optimize Energy Performance’.

Yellowstone Hall was awarded Gold Certification in August of 2016, with 62 out of the 110 possible points. Points on the LEED rating system for numerous performance factors and design features of the Hall, including the following:

- Diverting 96 percent of construction waste from the landfill.
- Using recycled materials for nearly 12 percent of the total building materials.
- Reducing potable water use by 42 percent in the building.
- Providing covered bicycle storage facilities to encourage alternative transportation use.
- Projected energy cost savings of more than 30 percent.
- Using regional materials (those manufactured and extracted within 500 miles of the project site) for more than 23 percent of the total building materials.

From the 62 points that were obtained, 17 of the 26 points came from ‘Sustainable Sites’, 4 out of 10 points came from ‘Water Efficiency’, 17 out of 35 points came from ‘Energy and Atmosphere’, 5 out of 14 points came from ‘Materials and Resources’, 9 out of 15 points came from ‘Indoor Environmental Quality’ and 10 out of 10 points came from ‘Innovation in Design’ and ‘Regional Priority Credits’.

On closer examination of credits for ‘Indoor Environmental Quality’ it was observed that compliance with outdoor air delivery monitoring, improved ventilation, lighting controls and thermal comfort were not attempted. In addition, when considering credits for ‘Energy and Atmosphere’, the building met 10 out of 19 possible credits for the category ‘Optimize Energy Performance’, which implies the performance of the building was 30% more efficient than the corresponding base-case modelled using specifications from ASHRAE Standard 90.1-2007. Other credits obtained under this category included credits for green power, measurement and verification, and enhanced commissioning.

Credits obtained for energy and IEQ for the Gallatin Hall are presented in Table 1 and for Yellowstone Hall are presented in Table 2.

Table 3: LEED V3 and V4 Checklist for Energy and IEQ Credits for Gallatin Hall

GALLATIN HALL				
	LEED V3	GRADED ANALYSIS	LEED V4	POSSIBLE ANALYSIS
INDOOR ENVIRONMENTAL QUALITY	Minimum IAQ Performance	Y	Minimum Indoor Air Quality Performance	Y
	Environmental Tobacco Smoke Control	Y	Environmental Tobacco Smoke Control	Y
	Outdoor Air Delivery Monitoring	1/1	Enhanced Indoor Air Quality Strategies	1/2
	Increased Ventilation	0/1	Indoor Air Quality Assessment	2/2
	Construction IAQ Management Plan During Construction	1/1	Low-Emitting Materials	3/3
	Construction IAQ Management Plan Before Occupancy	0/1	Construction Indoor Air Quality Management Plan	1/1
	Low Emitting Materials – Adhesives and Sealants	1/1	Acoustic Performance	0/1
	Low Emitting Materials – Paints and Coatings	1/1	Thermal Comfort	1/1
	Low Emitting Materials – Flooring Systems	1/1	Interior Lighting	2/2
	Low Emitting Materials – Composite Wood and Agrifiber Products	1/1	Daylight	3/3
	Indoor Chemical Pollutant Source Control	1/1	Quality Views	1/1
	Controllability of Systems Lighting	1/1		
	Controllability of Systems – Thermal Control	1/1		
	Thermal Comfort – Design	0/1		
	Thermal Comfort – Verification	0/1		
	Daylight and Views – Daylight	1/1		
	Daylight and Views - Views	1/1		
ENERGY	Fundamental Commissioning of the Building Energy System	Y	Fundamental Commissioning and Verification	Y
	Minimum Energy Performance	Y	Minimum Energy Performance	Y
	Fundamental Refrigerant Management	Y	Building-Level Energy Metering	Y
	Optimize Energy Performance	13/19	Fundamental Refrigerant Management	Y
	On-Site Renewable Energy	2/7	Enhanced Commissioning	2/6
	Enhanced Commissioning	2/2	Optimize Energy Performance	13/18
	Enhanced Refrigeration Management	0/2	Advanced Energy Metering	1/1
	Measurement and Verification	0/3	Demand Response	1/2
	Green Power	0/2	Renewable Energy Production	1/3
			Enhanced Refrigerant Management	0/1
			Green Power and Carbon Offset	0/2

Table 4: LEED V3 and V4 Checklist for Energy and IEQ Credits for Yellowstone Hall

YELLOWSTONE HALL				
	LEED V3	GRADED ANALYSIS	LEED V4	POSSIBLE ANALYSIS
INDOOR ENVIRONMENTAL QUALITY	Minimum IAQ Performance	Y	Minimum Indoor Air Quality Performance	Y
	Environmental Tobacco Smoke Control	Y	Environmental Tobacco Smoke Control	Y
	Outdoor Air Delivery Monitoring	0/1	Enhanced Indoor Air Quality Strategies	0/2
	Increased Ventilation	0/1	Indoor Air Quality Assessment	1/2
	Construction IAQ Management Plan During Construction	1/1	Low-Emitting Materials	3/3
	Construction IAQ Management Plan Before Occupancy	0/1	Construction Indoor Air Quality Management Plan	1/1
	Low Emitting Materials – Adhesives and Sealants	1/1	Acoustic Performance	0/1
	Low Emitting Materials – Paints and Coatings	1/1	Thermal Comfort	0/1
	Low Emitting Materials – Flooring Systems	1/1	Interior Lighting	2/2
	Low Emitting Materials – Composite Wood and Agrifiber Products	1/1	Daylight	3/3
	Indoor Chemical Pollutant Source Control	1/1	Quality Views	1/1
	Controllability of Systems Lighting	0/1		
	Controllability of Systems – Thermal Control	1/1		
	Thermal Comfort – Design	0/1		
	Thermal Comfort – Verification	0/1		
	Daylight and Views – Daylight	1/1		
	Daylight and Views - Views	1/1		
ENERGY	Fundamental Commissioning of the Building Energy System	Y	Fundamental Commissioning and Verification	Y
	Minimum Energy Performance	Y	Minimum Energy Performance	Y
	Fundamental Refrigerant Management	Y	Building-Level Energy Metering	Y
	Optimize Energy Performance	10/19	Fundamental Refrigerant Management	Y
	On-Site Renewable Energy	0/7	Enhanced Commissioning	2/6
	Enhanced Commissioning	2/2	Optimize Energy Performance	10/18
	Enhanced Refrigeration Management	0/2	Advanced Energy Metering	1/1
	Measurement and Verification	3/3	Demand Response	1/2
	Green Power	2/2	Renewable Energy Production	0/3
			Enhanced Refrigerant Management	0/1
			Green Power and Carbon Offset	2/2

LEED Criteria for IEQ - Acoustics:

There are no requirements for acoustical performance in LEED v3 in regards to dormitories or residential buildings. LEED v3 only addresses schools and healthcare rating systems. Requirements for effective acoustical design are introduced LEED v4 for all new construction buildings. LEED v4 requires spaces to comply with specifications for HVAC background noise, reverberation time, and sound reinforcing and masking.

For HVAC background noise, LEED v4 requires meeting the specifications of maximum background noise levels as outlined in 2011 ASHRAE Handbook, HVAC Applications, Chapter 48, Table 1; AHRI Standard 885-2008, Table 15; or a local equivalent. For sound transmission, the designer would need to meet the composite sound transmission class (STC) ratings (Table 3). For reverberation time requirements, specifications for different room types have to be complied with (Table 4). Requirements are also provided for sound reinforcement and masking systems wherever these systems are deemed necessary. Two options are provided for compliance:

1. Option 1: Speech privacy, sound isolation and background noise. Meeting the requirements for speech privacy, sound isolation and background noise are required for this option.
2. Option 2: Acoustical finishes and site exterior noise. Meeting the requirements for acoustical finishes and site exterior noises are required for this option.

The key issue with the evaluation of the acoustic performances of Gallatin Hall and Yellowstone Hall is that during the time these buildings were built, LEED v3 didn't have any design requirements to properly design the interior spaces and take the necessary steps to sounds proof the interior spaces. Due to this reason, architect of these two buildings either ignored this component (acoustic performances) or weren't knowledgeable enough in the subject to accurately soundproof the interior spaces. However, this research will evaluate these buildings by following the LEED v4 requirements to better understand the steps architects taken to soundproof the interior spaces. Also, this evaluation will help to understand the steps necessarily needed to improve the sounds quality of the interior spaces.

LEED v4 provide a list of requirements/provisions in order to properly sound proof the interior spaces. In order to reduce or eliminate the HVAC background noise, architects need to "Achieve maximum background noise level from HVAC applications, chapter 48 Table 1" (USGBC). This helps the architects to achieve acoustical comfort and to minimize the unwanted noise generated from the HVAC systems. Architects need to make sure that their design strategies are efficient by measuring the background noise with the use of a sound level meter that "confirms to ANSI S1.4 for type 1 or type 2 sound measurement instrumentation." (USGBC). Architects/designers needs to achieve the minimum sound level by following the sound transmission class (STC) rating. Also, LEED v4 provided architects/designer with several construction practices to sound proof the interiors and that includes single or double wall. According to STC rating systems, selecting a proper material/finishes helps to minimize the impact of the noise generated by the HVAC systems and exterior sources.

Table 5: Maximum composite sound transmission class rating for adjacent spaces (Source: USGBC 2013)

Adjacency combinations		STC_c
Residence (within a multifamily residence), hotel or motel room	Residence, hotel or motel room	55
Residence, hotel or motel room	Common hallway, stairway	50
Residence, hotel or motel room	Retail	60
Retail	Retail	50
Standard office	Standard office	45
Executive office	Executive office	50
Conference room	Conference room	50
Office, conference room	Hallway, stairway	50
Mechanical equipment room	Occupied area	60

Table 6: Reverberation time requirements (Source: USGBC 2013)

Room type	Application	T60 (sec), at 500 Hz, 1000 Hz, and 2000 Hz
Apartment and condominium	—	< 0.6
Hotel/motel	Individual room or suite	< 0.6
	Meeting or banquet room	< 0.8
Office building	Executive or private office	< 0.6
	Conference room	< 0.6
	Teleconference room	< 0.6
	Open-plan office without sound masking	< 0.8
	Open-plan office with sound masking	0.8
Courtroom	Unamplified speech	< 0.7
	Amplified speech	< 1.0
Performing arts space	Drama theaters, concert and recital halls	Varies by application
Laboratories	Testing or research with minimal speech communication	< 1.0
	Extensive phone use and speech communication	< 0.6
Church, mosque, synagogue	General assembly with critical music program	Varies by application
Library		< 1.0
Indoor stadium, gymnasium	Gymnasium and natatorium	< 2.0
	Large-capacity space with speech amplification	< 1.5
Classroom	—	< 0.6

LEED Criteria for IEQ - Lighting and Daylighting:

Based on LEED v3 both buildings were awarded one credit for controllability of systems – lighting, and two credits for daylight and views.

In LEED v3, the credit for controllability of systems – lighting required the buildings to provide high level of lighting system control by individual occupants or groups of occupants. To attain this credit, it was required to provide individual lighting controls for at least 90% of the building occupants to enable adjustments for individual tasks and preferences. It was also required to provide lighting system controls for all shared multi-occupant spaces to meet the different requirements of the spaces.

In LEED v4, in addition to lighting control, points could be obtained for lighting quality. Points could be obtained for ensuring use of lighting sources with CRIs of 80 or higher, use of long-lasting light sources, direct-only light fixtures, ensuring adequate reflectance for surfaces and furniture in the building, meeting adequate illuminance ratios.

In LEED v3, the credit for daylight and views-daylight, required a connection between indoor spaces and outdoors through the introduction of daylight and views. There are several options in which the design of the building could demonstrate this connection. Options include: simulation, prescriptive, measurement or a combination of the three options. Both the buildings used the simulation option to obtain credit. Through a computer simulation model, the applicable spaces within the buildings achieved daylight illuminance levels between 10 fc and 500 fc. In addition, provision of glare control devices was required to avoid issues with glare. The credit for daylight and views required at least 90% of applicable spaces within the buildings to achieve a direct line of sight to the exterior via vision glazing.

In LEED v4, the credit for daylight was modified to include metrics for spatial daylight autonomy and annual sunlight exposure as one of the options. In addition, the range of illuminance levels is tighter with illuminance levels between 30 fc and 300 fc. The credit for views now incorporates additional requirements to qualify.

In order to qualify for LEED v3 credits, dorm room spaces in both Halls have manual control shading devices that are operable to block excessive daylight. The aperture size also impacted the amount of daylight that each space received and as seen below they were large enough in relation to the square footage to receive passing credit for daylight and views. Lounge/ Study Area spaces in both Gallatin Hall and Yellowstone Hall were included in qualifying area for this IEQ credit. After accessing the space in Gallatin Hall there were high amounts of glare due to large glazing and reflective surfaces. Whereas

Yellowstone Hall addressed these spaces better with smaller operable openings and carpeted floor materials. In Gallatin Hall the excessive amounts of daylight may have made the building pass however it made the space intolerable and uncomfortable to be in. If this same space were to be analyzed again under LEED v4 this space would most likely not pass due to the high levels of daylight within the space.

LEED Criteria for IEQ - Indoor Air Quality:

LEED v3 included ten LEED Criteria sections involving Indoor Air Quality (IAQ) totaling 8 credit points. The first two sections are mandatory prerequisite for LEED certifications. Minimum Indoor Air Quality Performance and Environmental Tobacco Smoke (ETS) Control are both health/safety regulations that LEED requires a building to meet. Even without LEED most building codes have some sort of regulations on this. The following eight sections are not required for LEED, but are potential credit points. Outdoor Air Delivery Monitoring, Increased Ventilation, Construction IAQ Management (both during construction and before occupancy), and the choice of Low-Emitting Materials still relate to health, but are less critical to the safety of a building's occupants.

When it comes to credit criteria, because they are less critical for life safety, some credits are not considered. The Gallatin Hall attempted and received the Outdoor Air Delivery Monitoring credit, but did not attempt the Increased Ventilation credit. If a mechanically ventilated system is utilized an outdoor airflow measurement device can be installed in order to measure the supply airflow. This is what the Gallatin Hall did to gain the Outdoor Air Delivery Monitoring credit.

The Yellowstone Hall did not attempt either the Outdoor Air Delivery Monitoring credit or the Increased Ventilation credit. Yellowstone Hall is a much larger building servicing over 6 times the students. The outdoor airflow measurement device for this system would be much greater and more expensive. The reason neither buildings attempted the Increase Ventilation credit could be because of the cost of mechanical equipment required to increase the ventilation by 30% in all occupied spaces, it could also be that they saw better potential in other criteria credits elsewhere.

Both Gallatin Hall and Yellowstone Hall attempted and received all credits for Low Emitting Materials, this was done during the designing phase while choosing materials. They also both achieved the Construction IAQ Management credit for during construction; however, they did not submit testing between completion and occupation, therefore they did not receive the Construction IAQ Management credit for before occupancy.

Additionally, prerequisite criteria is required to be considered for LEED. Both Gallatin Hall and Yellowstone Hall were reviewed for Minimum Indoor Air Quality Performance. The main difference is that the Gallatin Hall was reviewed at a design level and given potential revisions for construction review. During this process, the Gallatin Hall was required to make a few changes in order to qualify for LEED upon completion, these changes were made, and the certification was granted. The Yellowstone Hall, in comparison, was approved for the preliminary design, but not reevaluated.

LEED v4 simplified the credit sections for IAQ. The two prerequisites are still the same, however there is only four credit sections after that. Although they have combined the credit sections, there is still 8 credits available for IAQ.

LEED Criteria for IEQ - Thermal Comfort:

The goal of the three IEQ credits for thermal comfort in the LEED is to allow for localized controllability of the systems (IEQc6.2), ensure that the thermal comfort is compliant with ASHRAE Standard 55-2010 for LEED v4 or ASHRAE Standard 55-2004 for LEED v3 (IEQc7.1), including the HVAC system and verification of thermal comfort compliance through surveys of the building six to eighteen months after occupancy (IEQc7.2). Thermal comfort design (IEQc7.1) can be evaluated through Predicted Means Vote (PMV) and Predicted Percentage Dissatisfied (PPD). The controllability of thermal comfort (IEQc6.2) should meet the requirements of 50% of individual occupant spaces (such as dorm rooms) and 100% of multi-occupant spaces have thermostats (LEED v4).

The following results were achieved by Gallatin Hall and Yellowstone Hall, based on the LEED v3 requirements. It should be noted that LEED v4 requirements now use ASHRAE Standard 55-2010 instead of ASHRAE Standard 55-2004. In addition to the changes in the codes, LEEDv4 has simplified the criteria sections into one cohesive 1 credit section, while LEEDv3 had three separate Thermal credit sections.

Gallatin Hall has updated many of the multi-occupant space to have thermal controls and therefore is compliant with the IEQc6.2 credit. Yellowstone Hall demonstrates compliance with IEQc6.2 by implementing thermostats in all individual dorm rooms as well as common spaces. Neither of the case-studies attempted to implement the IEQc7.1 or IEQc7.2 credit.

LEED Criteria for Energy:

LEED v3 included three LEED prerequisites and six LEED Criteria sections involving Energy. These credit sections total 35 credit points. Fundamental Commissioning of the Building Energy System, Minimum Energy Performance and Fundamental Refrigerant Management are all standards LEED requires a building to meet. The additional six sections; Optimized Energy Performance, On-Site Renewable Energy, Enhanced Commissioning, Enhanced Refrigeration Management, Measurement and Verification and Green Power are not required by LEED, but are potential credit points.

Both Gallatin Hall and Yellowstone Hall received completions on their prerequisites, full credit for Enhanced Commissioning and partial credits for Optimized Energy Performance. Gallatin Hall also received partial credit for On-Site Renewable Energy, while Yellowstone Hall received full credits in both Measurement and Verification as well as Green Power.

The primary intent of the Optimize Energy Performance credit criteria is to achieve increasing levels of energy performance beyond the prerequisite standard to reduce environmental and economic harms associated with excessive energy use. This requires an establishment of an energy performance target no later than the schematic design phase. The target must be established as kBtu per square foot-year (kW per square meter-year) of source energy use. Designers are required to analyze efficiency measures during the design process and account for the results in design decision making. Use energy simulation of efficiency opportunities, past energy simulation analyses for similar buildings or published data (e.g. Advanced Energy Design Guides) from analyses for similar buildings. Analyze efficiency measures, focusing on load reduction and HVAC-related strategies (passive measures are acceptable) appropriate for the facility. Project potential energy savings and holistic project cost implications related to all affected systems. Project teams pursuing the Integrative Process credit must complete the basic energy analysis for that credit before conducting the energy simulation.

LEED v4 has renamed a few credit sections and also added one for Demand Response. It also created an additional prerequisite for Building Energy Metering. Although they have added a new credit section, there is now only 33 credits available for energy instead of 35.

IEQ PERFORMANCE MEASUREMENT PROTOCOLS (PMP):

Introduction:

ASHRAE Performance Measurement Protocols were referenced to evaluate the performance of the two case study buildings. ASHRAE Performance Measurement Protocols are a standardized set of protocols that can be used to evaluate the performance of buildings in terms of IEQ and energy. The PMPs are used to perform consistent measurements of building components such as energy, water, and indoor environmental quality. The protocols for each IEQ component consist of a two-part process; an occupant survey and field observations. ASHRAE Performance Measurement Protocols proposes set of protocols to evaluate the performances of commercial building, ensure healthy living condition for the occupants.

Objective:

Acoustics:

The objective is to evaluate the acoustical performances of the Gallatin Hall and Yellowstone Hall. In order to better understand how occupants of these buildings are impacted by the noise generated by the HVAC systems and to measure the acoustical performances. It was necessary to measure and record the background noise level in hallway, lounge, conference rooms and dorms. This helps to understand quality of the design strategies that was implement by the architects. An overview of the use of PMP for evaluating acoustical conditions in the two buildings is provided in Figure 4.

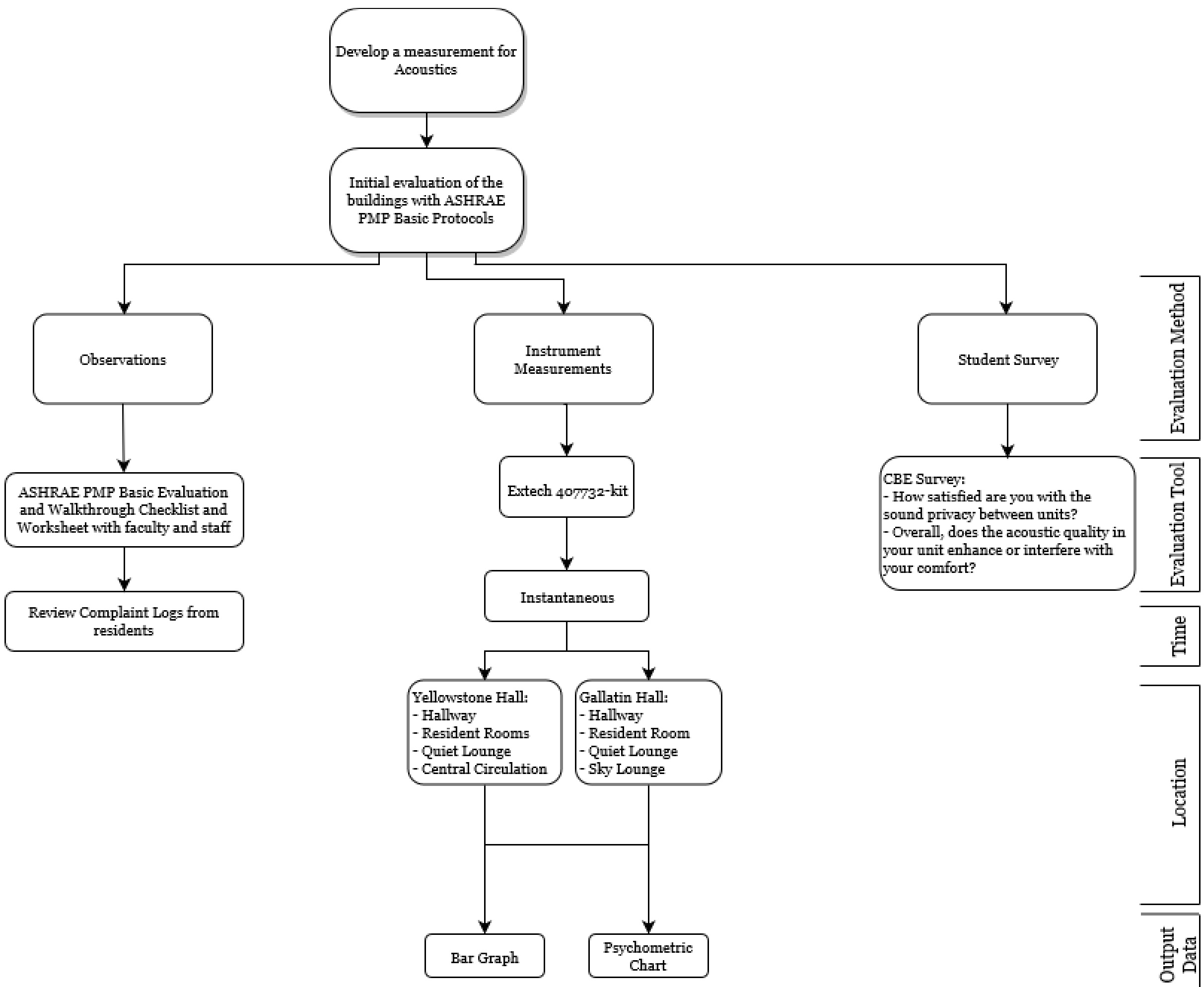


Figure 4: Flowchart indicating the use of ASHRAE PMP for evaluating acoustical conditions

Lighting/Daylight:

The main objective was to determine if adequate lighting levels were met and appropriate lighting quality was ensured through both electric lighting and daylighting. The study utilized the performance measurement protocols for evaluating electric lighting and daylighting that were developed by ASHRAE to conduct the assessment. A checklist is used to evaluate the potential weakness in the lighting system by addressing issues such as visual acuity, lighting control, daylighting, and illuminance levels.

As part of the protocols, three methods were used to conduct the assessment: a walkthrough, measurements and survey. A walkthrough included evaluating issues of quality and quantity of light, glare, controls, lamps and ballasts as well as maintenance. Measurements of illuminance and luminance were conducted with light meters and luminance meters respectively. Occupant survey was used to gauge occupant satisfaction with the performance of lighting systems and to find out recurring problem areas. Using the methods described above, several metrics were implemented to evaluate the light-related parameters, which include: occupant satisfaction, illuminance levels, luminance ratios, and evaluating the potential for glare. The potential for glare in the spaces was evaluated through observations made from walkthroughs, results from instrument measurements, and post occupancy surveys.

It was important to also create a comparison of similar spaces in both Gallatin Hall and Yellowstone Hall, this would create a baseline comparison for types of glazing, types of artificial lighting, and types of shading devices that were either the same in both buildings or if different how one type compared to the other. The spaces that were selected for the analysis from both buildings include: the sky lounge, corridors, the lobby, and the dorm room. An overview of the use of PMP for evaluating acoustical conditions in the two buildings is provided in Figure 5 below.

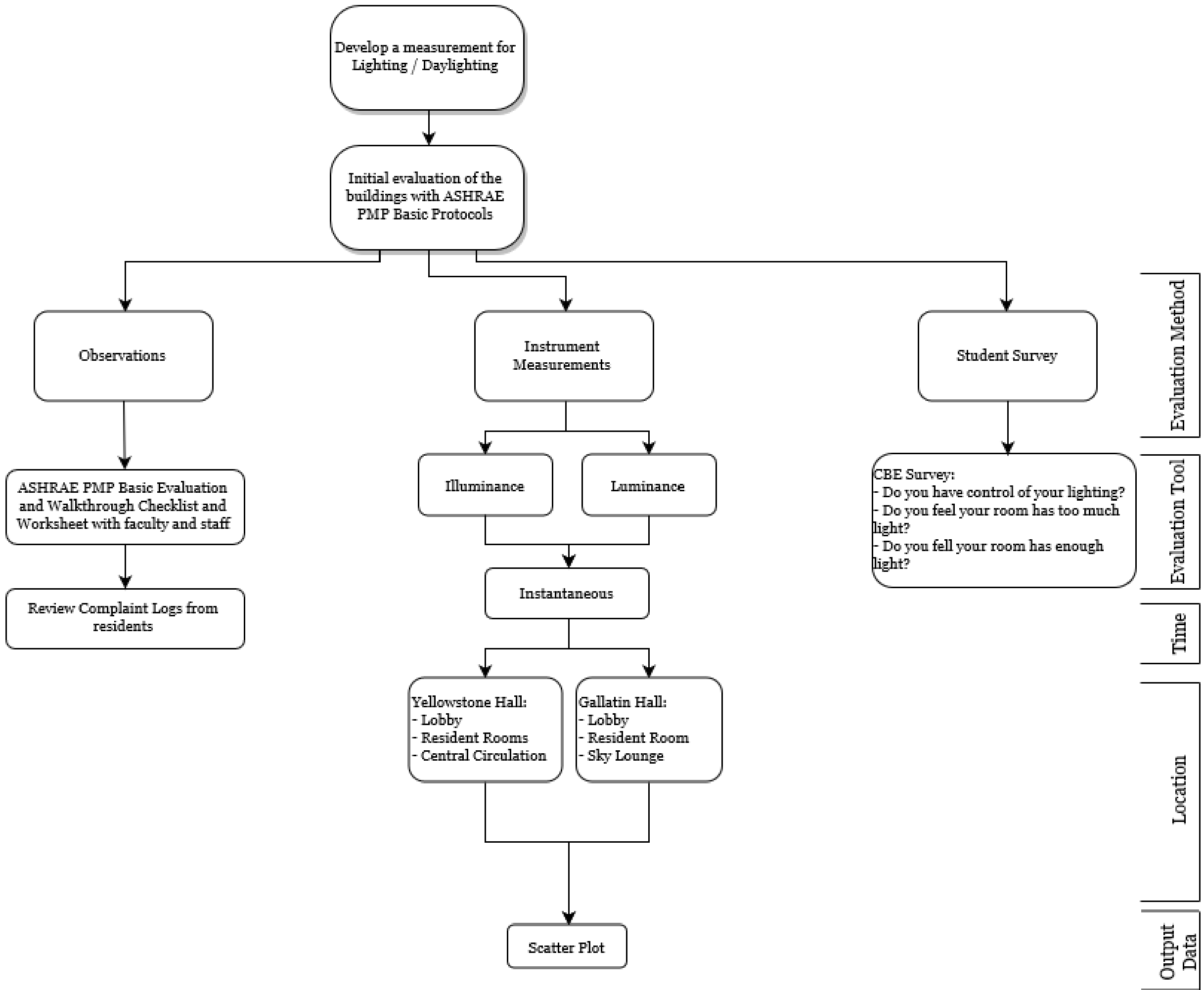


Figure 5: Flowchart indicating the use of ASHRAE PMP for evaluating daylight conditions

Indoor Air Quality:

One objective of test protocols for indoor air quality is to evaluate the compliance with the minimum standard of care required for the building. Another objective is to identify any problems for indoor air quality as well as the source of each problem. The final objective is to evaluate the differences between living quarters with a forced air system and living quarters without a forced air system. An overview of the use of PMP for evaluating IAQ conditions in the two buildings is provided in Figure 6 below.

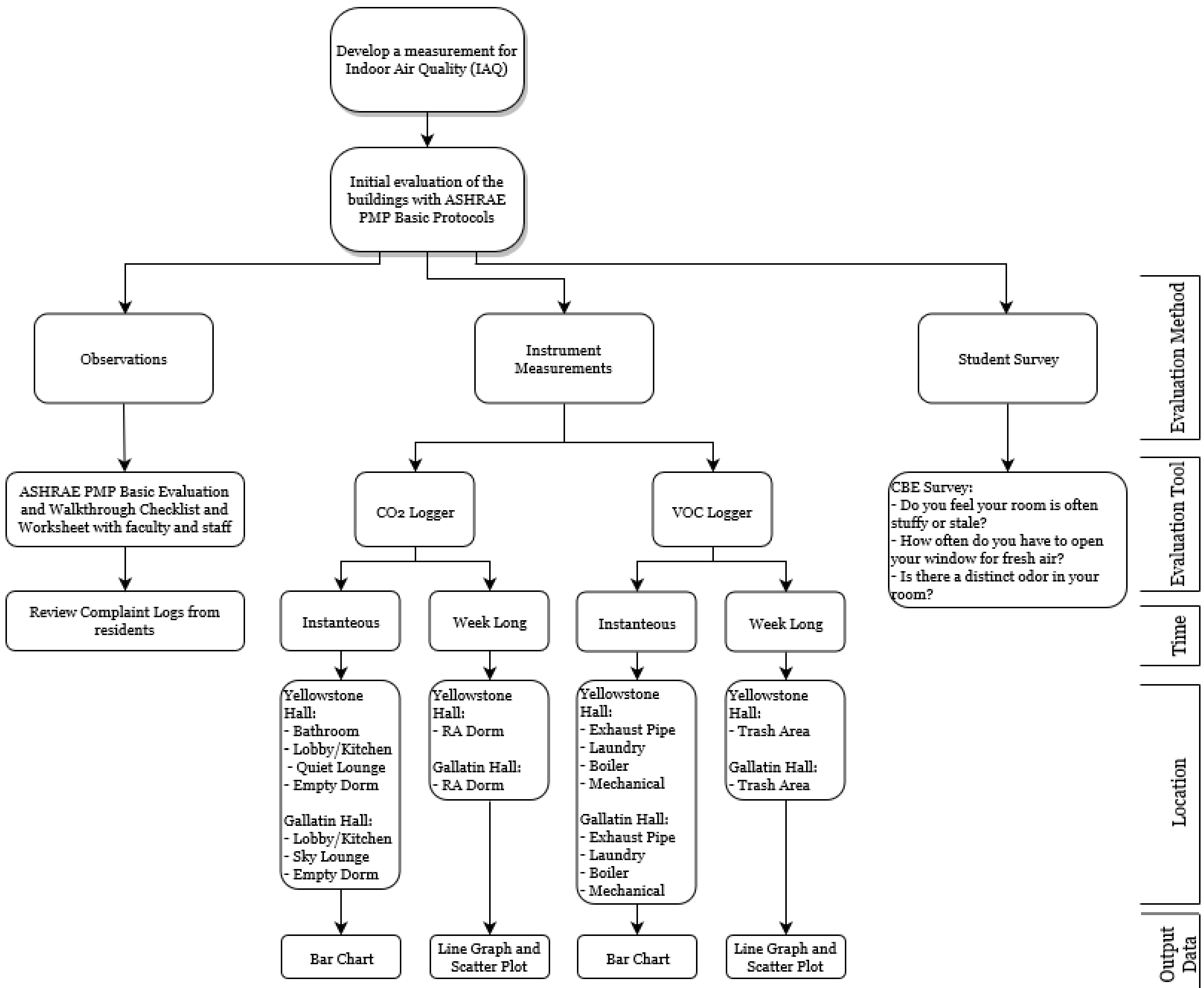


Figure 6: Flowchart indicating the use of ASHRAE PMP for evaluating IAQ conditions

Thermal Comfort:

The first objective is to determine if the building is meeting the minimum standard for thermal comfort required in the ASRAE Basic Level PMP. In any case where it does not meet these requirements, the problem is to be identified as well as the source of the problem. Additionally, the building is to be evaluated based on its compliance with the LEED criteria regarding thermal comfort. An overview of the use of PMP for evaluating thermal comfort conditions in the two buildings is provided in Figure 7 below.

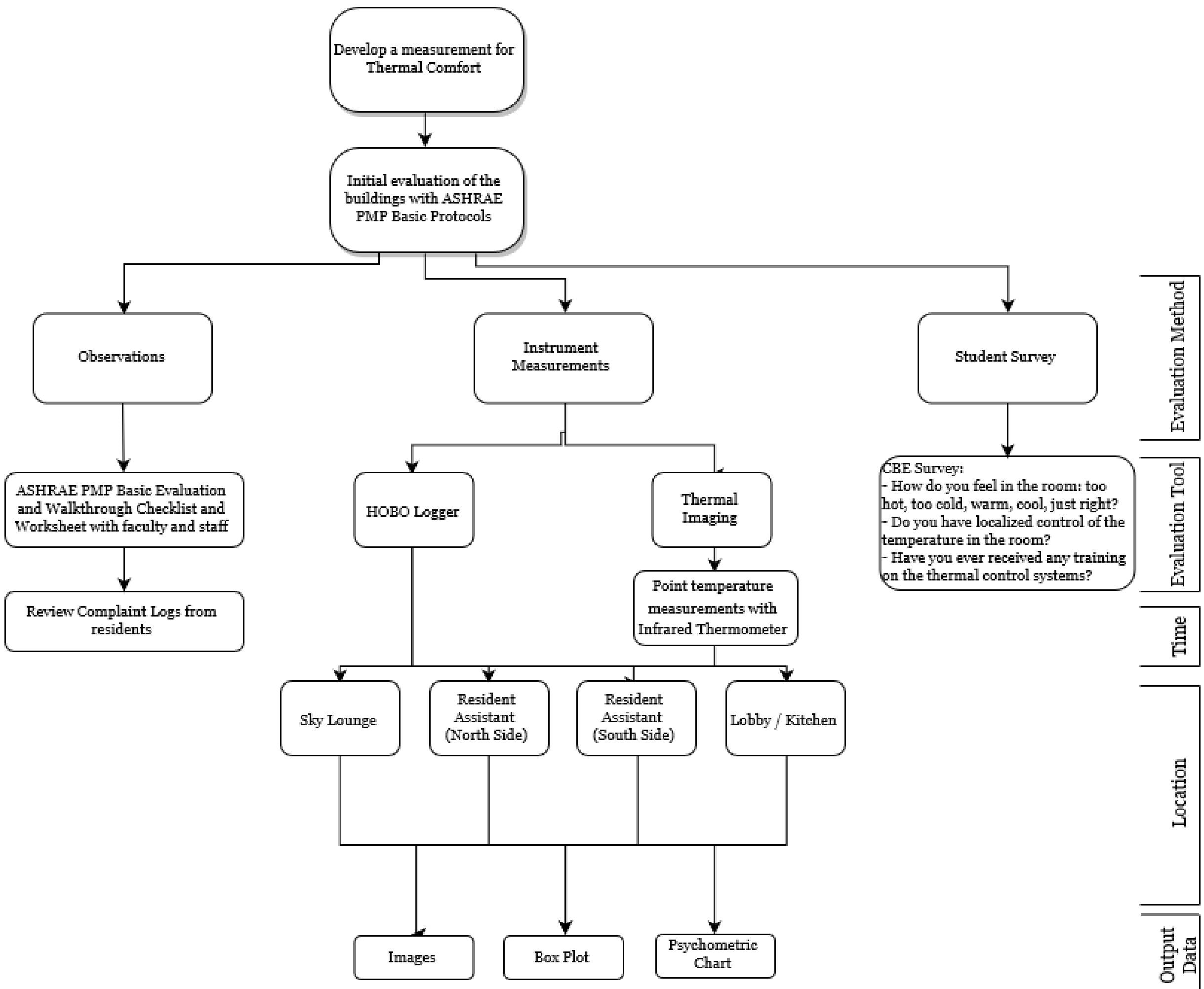


Figure 7: Flowchart indicating the use of ASHRAE PMP for evaluating thermal comfort conditions

Methods and Metrics:

For both the Gallatin Hall and Yellowstone Hall numerous methods and metrics were used which included: observation walk-throughs, instrument measurements and post occupancy survey will be used to prove or disprove the posed hypotheses.

Observation Walk-through

The first method of PMP is the observation walk through. This is where the analyst walks through the building and completes the check list provided by the ASHRAE in order to understand how the building performs. Each ASHRAE Basic Evaluation Walkthrough Checklist and Worksheet will be completed with a facility staff member for both of the resident halls. The checklists include issues that may be encountered during the walkthrough. A sample walkthrough checklist for IEQ Acoustics from the ASHRAE PMP document is provided in Figure 8 below. The walkthrough checklists and their results are documented in Appendix B-E for each IEQ. A description of the walkthroughs is provided in the section below.

BASIC EVALUATION LEVEL
Walk-Through Checklist and Recommended Corrective Actions

IEQ Acoustics

Category	Issue	Photo ID	Space ID	Recommended Corrective Actions
Background Noise	Is the mechanical equipment (heating, cooling and ventilation) noise unacceptable?	yes		Verify that the HVAC system and controls are operating as designed and that the equipment is properly maintained. If so, proceed to Diagnostic Measurement and/or Advanced Analysis levels.
	Is the noise from the office equipment unacceptable (telephones, copiers,)?	no		Replace noisy office equipment with quieter models. Consider moving noisy equipment to more isolated areas.
	Is the noise from the lighting unacceptable?	no		Establish a program for reporting noisy light fixtures and quickly replace ballasts.
	Can you hear plumbing noise?	no		Proceed to Diagnostic Measurement and/or Advanced Analysis levels.
	Does the background noise vary significantly with the time of day or season?	yes		Proceed to Diagnostic Measurementand/or Advanced Analysis levels.
Noise Intrusion	Are you startled or disturbed by the intrusion of noise from other rooms?	yes		Proceed to Diagnostic Measurement and/or Advanced Analysis levels.
	Can you hear noise from adjacent rooms through the wall, ceiling or ductwork?	no		For rooms with ceiling tile systems, select tiles with high sound transmission loss, extend interposing wall to ceiling deck and seal
	Are you disturbed by footfall noise from the floor above?	no		Add carpet to the floor above. If this corrective action is not adequate, then proceed to the Diagnostic Measurement and/or Advanced Analysis levels.
	Can you hear noise from the outside through the wall, windows or ventilation openings?	no		Proceed to Diagnostic Measurement and/or AA levels.
Acoustic Privacy	Does sound privacy in your workplace interfere with employees getting their job done?	no		Proceed to Diagnostic Measurement and/or Advanced Analysis levels.
	Can you overhear other people talking on the phone from one workspace to another?	no		Establish a training program on telephone etiquette or introduce new telephone equipment with headset and quiet signaling features. If these "personal" corrective actions are not adequate, then proceed to the Diagnostic Measurement level.
	Can you overhear private conversations from neighboring areas or offices?	yes		Designate acoustically isolated spaces for private conversations. If these "personal" corrective actions are not adequate, then proceed to
Speech Communication	Is it difficult to understand or hear speech in meeting rooms or lecture halls?	no		Proceed to Diagnostic Measurement and/or Advanced Analysis levels.
	To communicate in the space do you have to raise your voice?	no		Proceed to Diagnostic Measurementand/or Advanced Analysis levels.
	Does the background noise interfere with speech communication?	no		Proceed to Diagnostic Measurement and/or Advanced Analysis levels.
	Is speech difficult to understand because of echoing of voices and other sounds?	no		Add sound absorptive furnishings and/or sound absorptive materials to the room surfaces, for example: an acoustical ceiling system,
	Does the sound persist when you clap your hands?	no		See above corrective actions.

Figure 8: Sample walkthrough checklist for acoustics from ASHRAE PMP

<u>Walk-through for IEQ Acoustic:</u>

Through observation, acoustics can be evaluated by observing sounds from operating equipment and systems, as well as background noises from adjacent spaces. A site assessment of the noises within the building helps to in determine if the acoustic quality is acceptable. This site assessment can include an initial walk through of mechanical and public spaces, an interview with the building management faculty and custodial staff and observation of complaint logs. It's important to review and evaluate interior spaces individually since each interior spaces/program are impacted differently by the unwanted noise and the source of unwanted noise is different at each space.
Also, it's important to review/evaluate the background noise level at two different times: once during the month of September and once during the month of October to better understand how buildings are impacted by the issue of the noise at different time of year.

Walk-through for IEQ Lighting / Daylight:

Determining the building occupant's satisfaction and identifying issues with electric lighting and daylighting systems can be made from a walkthrough. In addition, the walkthrough can also be used to determine all the problem areas to possibly correct. A basic checklist provided in the ASHRAE PMP serves as a guideline to help determine some of these issues. Issues such as those pertaining to quality and quantity of light, glare, controls, lamps and ballasts, as well as issues with maintenance are addressed in the walkthrough checklist.

Issues with quality / quantity of lighting are addressed by assessing issues such as placement of lamps, age of occupants, size of visual tasks, and visual contrast. Issues with glare can be highlighted during a walkthrough by observing whether room surfaces near daylight openings are shiny or dark, if direct sunlight is reaching workstations, whether windows are covered during the day, and if reflections are observed on computer screens. Lighting controls can be evaluated by observing lights on in areas with ample daylight, or after hours in a space that is unused. Lighting controls include occupancy sensors in rooms and lights that come on when passing by the building entrance. Finally, maintenance of lighting system is evaluated.

Walk-through for IEQ Indoor Air Quality:

Through observation, IAQ can be evaluated by damage to equipment and materials, staining or discoloration of surfaces, and odors in spaces. A site assessment of the conditions of the building and its HVAC system can aid in determining how it affects the indoor air quality. This site assessment can include an initial walk through of mechanical and public spaces, an interview with the building management faculty and custodial staff. The initial walk through can provide insight on cleanliness and maintenance of the mechanical systems, including cleanliness of drainage pipes and coils, conditions of ducts and outside air intake filters, and proper minimum reporting value level. If any issues are observed, the impact of indoor air quality should be evaluated and the appropriate faculty should be advised. While interviewing the faculty and staff, questions regarding cleaning and maintenance schedules and protocols should be addressed.

Walk-through for IEQ Thermal Comfort:

The walkthrough is an in-person site assessment of the public spaces of the building and the first impressions of the spaces in terms of thermal comfort. This walkthrough is conducted with the faculty and staff of the building, who can answer questions regarding specifics within the ASRAE Basic Level Evaluation. The walkthrough for thermal comfort observes the accessibility of system controls and thermostats. It also evaluates how the use of fenestration impacts thermal comfort of the interior spaces, as well as any issues with the HVAC system. Common issues with the HVAC include inoperable vents or diffusers, faulty thermostats and the need for personal supplemental heating or cooling. Complaint logs and service logs can also be utilized to supplement the walkthrough observations by describing any day to day insights of residents.

Instrument Measurement:

The second method of PMP is to utilize instruments to measure compliance with ASHRAE Standards. Analysts will measure for compliance in acoustics, daylighting, indoor air quality and thermal comfort.

<u>IEQ Acoustics:</u>

Indices: Through measurements, acoustics can be evaluated by volumes of sounds in a space that can cause disturbances and discomfort.

Metrics: Sounds are measured in dB or decibel. Most living situations measure between 40 and 70 dB. According to ASHRAE Design Guidelines for HVAC Related Background Sound in Rooms, Residence living areas should not exceed 35 dBA or 60 dBC.

Instruments: The Extech 407732 Type 2 sound meter with 94dB sound calibrator (Figure 9) is a high accuracy sound measuring tools which helps to measure the sound in the interior and the exterior spaces. This tool can measure from 35 to 130 dB and has an accuracy of 1.5 dB. One of the benefits of this tool is that it comes with its own 94 dB sound calibrator. The calibrator can be used to calibrate the Extech on the spot to increase the accuracy of the result. One of the challenges or limitations of this tool is that the spaces that are being observed must be unoccupied otherwise the result will be inaccurate and individual must redo the measurement in order to achieve the accurate results.

Figure 9: Extech 4077322 Type 2 Sound meter with sound calibrator

Measurement Durations: Measurements should be taken at two different times: once during the month of September and once during the month of October to better understand how buildings are impacted by the issue of the noise at different time of year. Also, it's important to conduct measurement once at 9 AM and once at 3 PM to understand how the occupant's activity affect the acoustical performances of the building.

Measurement Locations: Spaces in the Gallatin Hall to be measured includes; hallways, rooms/dorm, quiet lounge, and sky lounge. In order to produce more accurate results, it is important to review and evaluate second and fourth floor. Spaces in the Yellowstone Hall to be measured includes; hallways, rooms/dorm, quiet lounge, and lounge/central circulation. In order to produce more accurate results, it is important to review and evaluate second and fourth floor.

Output Evaluation: A bar chart will be used to represent the data/results of the measurement. This type of graph allows for easy understanding of the data. The data can be represented in term of time and dBA. Also, the Data/result from the Gallatin Hall and Yellowstone Hall can be compared in order to understand how these building are performing.

<u>IEQ Lighting / Daylighting:</u>

Indices: Through measurements, lighting and daylighting can be evaluated by light levels. Illuminance are measured in foot candles or FC, while luminance levels are measured in terms of foot Lamberts (fL).

Metrics: IESNA has set industry standards for illuminance levels and is being used to compare the light levels found in Gallatin Hall and Yellowstone Hall. IESNA recommended ranges include: 10 – 30 FC for lounge/breakroom spaces, 20 – 30 FC for bedrooms/dormitories and lobby spaces, and 30 – 75 FC for kitchen/food prep areas. In addition, luminance values and luminance ratios will be calculated. LEED v4 protocols were used to evaluate glare. According to the protocols any value for illuminance levels above 300 fc is considered as glare.

The IES survey methodology is utilized for conducting measurements for taking illuminance measurements for lighting systems.

For calculating illuminance, spot measurements were taken and mathematically manipulated to derive average illuminance values. Guidelines to conduct field measurements are provided in the ASHRAE PMP. In addition, the ASHRAE PMP provides forms that can be used to record photometric measurements. Methods to manipulate measurement data are provided in the IESNA Handbook. Detailed illuminance data is collected by taking measurements on a grid. The height of these points would be determined on where the primary task is performed.

For calculating luminance ratios, common positions of students were identified in the dorm rooms and study lounges of the two buildings and luminance of different surfaces were measured. Protocols were adopted from the ASHRAE PMP to conduct the measurement. Luminance measurements were made with a luminance meter:

- On all luminaires within the normal field of view
- On the ceiling near any luminaire
- On the ceiling between two luminaires
- On the opposite wall above, even with and below eye level, in line with a luminaire
- On the opposite wall above, even with. and below eye level, in between two luminaires
- On the floor
- On any windows, shades, and blinds within the normal field of view
- At the task
- At the area immediately surrounding the task
- At the peripheral surroundings of the task
- At the highest luminaire in the field of view

IES recommended luminance ratios are presented in Figure 10 below. To limit the effects of adaptation and disability glare, luminance ratios generally should not exceed the following:

- Over the task itself – 1.4:1
- Between the task and an adjacent visual display terminal screen – 3:1
- Between the task and the immediate surroundings – 3:1
- Between the task and remote surfaces – 10:1

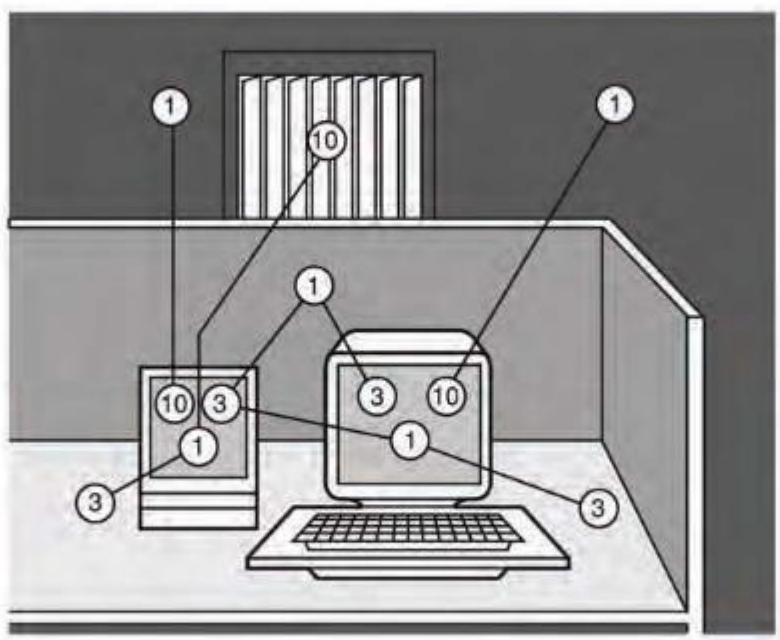


Figure 10: Recommended Luminance Ratios for a Typical Office Space

Different forms are used to document measurements for illuminance and luminance levels in space. These forms have been adopted from the ASHRAE Performance Measurement Protocols for Commercial Buildings and are compiled in Appendix C of this report.

Instruments: Illuminance meters were used to take spot measurements which were reported in foot-candles in the sky lounge of Gallatin Hall, the Knuckle of Yellowstone Hall, lobby spaces, and dorm rooms in both buildings. These measurements were used to assess the light output of the fixtures and natural daylight. The Extech SDL400 Light meter device (Figure 11) will spot measure daylight illuminance levels in the spaces in foot candles. LI-250A +LI-200R-BNC-2 light meter, this device will show instant light levels

A luminance meter (Figure 12) was used take luminance readings and derive luminance ratios for different surfaces in lobby spaces, and dorm rooms in both buildings. Konica Minolta LS-100 was utilized for this purpose.

Figure 11: Konica Minolta LS-100 Luminance Meter used in the measurement of lighting levels

Figure 12: Extech SDL400 Light meter device (right) used in the measurement of lighting levels

Measurement Durations: All measurements are instantaneous and were taken at times of day where both daylight and electric light influenced the measurements.

Measurement Locations: Measurements were taken with a light meter in the spaces including: Sky Lounge (Gallatin Hall), Lobby Space (Gallatin Hall and Yellowstone Hall), Dorm Room (Gallatin Hall and Yellowstone Hall), and the knuckle (Yellowstone Hall).

Output Evaluation: Both illuminance and luminance measurements taken at the different spaces in the two case-study buildings were compared to the levels established by the IESNA standards. The potential for glare was evaluated by comparing the illuminance measurements to the limit established by the LEED v3 criteria, which is 300 fc.

<u>Indoor Air Quality:</u>

Indices: Through measurements, IAQ can be evaluated by gasses in a space that can cause odor and discomfort. CO2 is a gas that is exhaled from all mammals. Volatile organic compounds (VOC) can also be measured in the spaces to evaluate adequate

IAQ. VOCs are things like, benzene, ethylene glycol, formaldehyde, methylene chloride, tetrachloroethylene, toluene, xylene, and 1,3-butadiene. All of these things can be found in most typical living situation.

Metrics: Both CO2 and VOC are measured in ppm. Typical outdoor CO2 levels are 300-350ppm in Montana. ASHRAE 62.1 says that CO2 concentrations of about 700 ppm above the exterior levels are the acceptable boundaries. When improper ventilation occurs, CO2 is increased which can cause odor and discomfort as well as health issues if high levels of CO2 are sustained for a long period of time. Like CO2, VOCs can cause odor and discomfort and can lead to health issues if the gas persists.

Instruments: Instruments like sensors and monitors can be used to conduct these measurements. We used the Indoor Air Quality Meter for instantaneous CO2 measurements and a HOBO CO2 logger (Figure 13) for logged CO2 measurements. Instantaneous CO2 levels, while easy to measure are hard to read. Unless a steady and constant CO2 measurement has been equalized, readings will not reflect the efficiency of a building ventilation system accurately. The logged measurements are more accurate because they are constantly equalizing. We used a VOC Sensor to take instantaneous measurements. This sensor is particularly difficult to use because it is not very sensitive. Unless the sensor is within 6 inches of the emitting object, the sensor has a hard time picking it up.

Figure 13: MX1102 HOBO Indoor Air Quality Logger

Measurement Durations: Measurements can be taken both instantaneously or as a prolonged log of data. Instantaneous data is used for quick checks of code compliance, while logged data can be used for analysis of spaces for comparison. Instantaneous measurements help with the first two objectives of the assignment while the logged measurements are used to prove the initial hypothesis.

Measurement Locations: Spaces in the Gallatin Hall to be measured instantaneously include; the sky lounge, an empty dorm, the lobby/kitchen space, the laundry room, the boiler room, the mechanical room and the overall exhaust pipe discharge. Spaces in the Yellowstone Hall to be measured for instantaneous CO2 and VOC logs include, a quite lounge, a bathroom, an empty dorm, the lobby/kitchen space, the laundry room, the boiler room, the mechanical room and the overall exhaust pipe discharge. Both halls will be monitored for a week in an RA dorm room for CO2 and the trash area for VOC.

Output Evaluation: Measurement data can be explained in a multitude of graphs. Outputs to express code compliances are better explained in bar charts, while outputs to express correlations can be explained with line graphs and scatter plots. Bar charts can give an initial understanding of compliance of logged materials and to future understand the anomalies, the data can be compared to time or temperature in line graphs and scatter plots to create inferences.

<u>Thermal Comfort:</u>

Indices: Through measurements, thermal comfort can be evaluated by the dry bulb temperatures and relative humidity in a space that can cause discomfort. Dry bulb temperature is temperature that is usually thought of as air temperature. Humidity is the moisture within the air. Thermal comfort is also evaluated by assessing surface temperatures of interior spaces, which indicate the potential of thermal bridging.

Metrics: The dry bub temperature was recorded in degrees Fahrenheit and the relative humidity is the percentage of moisture in the air relative to the amount of moisture the air can hold. Surface temperatures can be recorded using thermal imaging photographs. In addition, the images can be used to identify the location of thermal bridging within building envelope assemblies.

Instruments: The instruments used were nine HOBO UX100-003 loggers and a FLIR T530 24 Thermal Imaging Camera (Figure 14).

Measurement Durations: The HOBO logger recorded the temperature and relative humidity every 30 minutes for seven days. Thermal imaging and point measurements of temperature will be conducted in each of the spaces at 8:00 AM and 3:00 PM in each of the designated location. This is intended to capture a complete picture of the thermal properties of the space in relation to temperature changes throughout the day (solar gains and cooling) as well as the effect of occupancy use on the temperature.

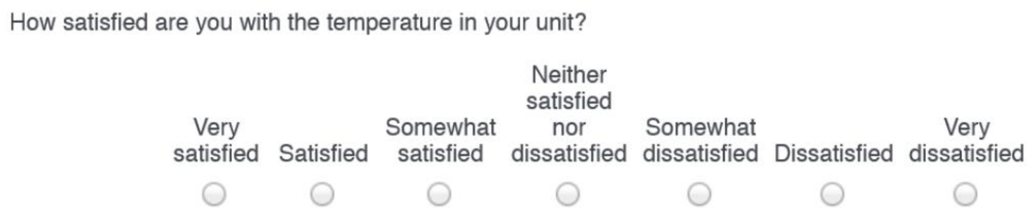
Figure 14: A FLIR T530 24 Thermal Imaging Camera

Measurement Locations: Several key locations in each building have been selected to evaluate in terms of thermal comfort. In Gallatin Hall these spaces include the Sky Lounge, the first floor Main Lobby and Kitchen, a north side RA room, and a south side RA room. In Yellowstone Hall these spaces include the Quiet Lounge on the fourth floor, the first floor Recreation Lounge, the study lounge on the fourth floor, the laundry room on the first floor, a north side RA room, and a south side RA room. These rooms have been selected due to their orientation in the building, their percentage of glazing, and their occupancy use. Evaluation will focus on localized control of temperature (walkthrough), utilization of passive strategies (walkthrough), temperature and relative humidity measurements of the space (HOBO logger), profile of surface temperatures in the space and thermal bridging within envelope assemblies (thermal imaging camera), and specific point temperatures in the space (infrared and contact thermometer). Thermal bridging can be observed from both the interior and exterior of a building, however for best results external imaging should be done at night or on a cloudy day to decrease infrared interference. Potential locations of thermal bridging include: around internal windows, where external walls meet the floor, highlighting external stud walls and corner connections. In addition, by examining these images, it is possible to identify locations of air leakage and infiltration.

Output Evaluation: The data will be analyzed in a series of graphs, specifically psychrometric charts and box plots to understand the correlation between the data in the different locations. These graphs will be used to evaluate anomalies as well as relate temperature to thermal comfort and building orientation. Thermal imaging cameras allow for observation of the radiant heat energy they receive. These instruments produce infrared images, called thermograms. Thermograms show darker colors to indicate cool temperatures, while lighter colors indicate warmer temperatures. These images are evaluated to observe hot spots and identify locations of thermal bridging.

Post Occupancy Survey:

The third method is to conduct the survey from the occupants of each buildings. Using the CBE occupant survey in association with UC – Berkley, a post occupancy survey will be distributed to residence in order to evaluate the building performance and to identify IEQ problem in buildings (CBE 2008). Figure 15 presents an excerpt from the post occupancy survey that was conducted for the two buildings. The entire survey is presented in Appendix A.


How satisfied are you with the temperature in your unit?

Very satisfied	Satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Dissatisfied	Very dissatisfied
○	○	○	○	○	○	○

Figure 15: Sample questions from the CBE occupant survey

<u>Acoustic:</u>

The survey given to occupants measures the overall satisfaction of the occupants in different interior spaces. The questions included in the survey address topics such as sound privacy between units, overhearing your neighbors, and acoustic quality in the building. The survey contains three main questions, which are:

- How satisfied are you with the sound privacy between units?
- Overall, does the acoustic quality in your unit enhance or interfere with your comfort?
- Please describe any other issues related to acoustics that are important to you.

The survey will be conducted during the month of November. This survey will evaluate the occupant's satisfaction in regard of acoustic conditions and create a better understanding of overall acoustic properties within the building. Occupants' feedback at each unit will help to understand the issues of unwanted noise and the source of noise. This will inform what design strategies must be applied to reduce unwanted noise in the space.

Lighting/Daylighting:

Once the walkthrough has been completed and measurements have been taken, the occupant survey can be compiled using questions that require the occupant to answer satisfaction with the levels and quality of lighting. Three main categories: glare, controls, and quantity/quality were used to evaluate the spaces and occupant comfort. The survey questions also implicate areas where improvements can be made.

Indoor Air Quality:

Through survey, IAQ can be evaluated by satisfaction or dissatisfaction of the occupants. Complaint logs can also be reviewed for any notable dissatisfaction of the occupants. The survey should ask basic questions about reliance on fresh air, stuffiness, percentage of time the windows are open, reason for opening windows, excessive odors. Surveys can also give a basic occupant demographic and occupancy types, which can be crucial information to determine how stringent indoor air quality standards are to be evaluated. Once surveys have been distributed and data has been collected, the buildings can be evaluated against benchmark data of similar building types. Complaint logs can also be reviewed to see if anything pertaining to IAQ comes up.

Thermal Comfort:

The student survey allows for a post-occupancy evaluation of thermal comfort. The survey addresses basic questions about the temperature of rooms, how comfortable students feel in these rooms, and controllability of their environment to maintain satisfactory thermal comfort. This can supplement the building’s complaint logs to understand specific concerns regarding thermal comfort. Additionally, the surveys provide a basic understanding of the demographics of the buildings.

ENERGY ASSESSMENT PROTOCOLS:

Introduction:

Procedures for Commercial Building Energy Audits (ASHRAE 2011) were referenced to evaluate the performance of the two case study buildings. The primary goals of these procedures are to: define levels of effort for energy audits; provide a reference guide for building owners, managers, government entities, and other consumers illustrating best practices for conducting energy assessment and associated deliverables, and serve as an introductory guide to best practices for energy auditors. Four levels of audits and analysis are associated with these procedures, which are identified as: Preliminary Energy-use Analysis, Level 1 walkthrough survey, Level 2 – Energy Survey and Analysis, and Level 3 – Detailed Analysis of Capital Intensive Modifications. This study utilizes the Preliminary Energy-use Analysis, and Level 1 walkthrough survey to conduct analysis.

Objective

The objective of this study was to identify any issues involving energy performances of the Gallatin Hall and Yellowstone Hall. An overview of the use of procedures for evaluating energy conditions in the two buildings is provided in Figure 16 below.

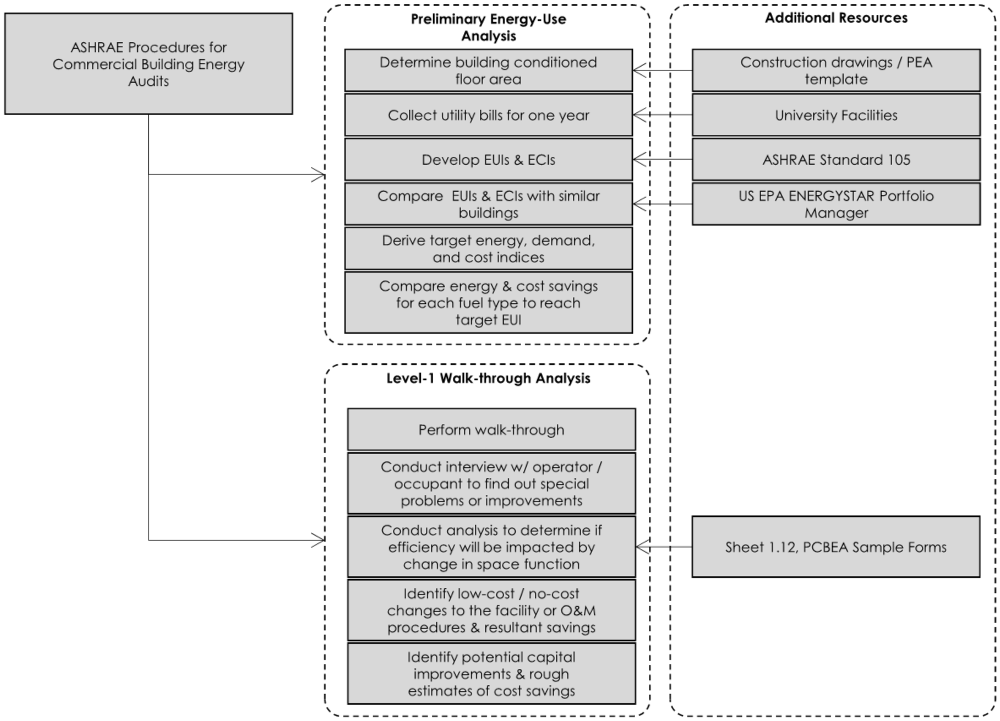


Figure 16: Sample questions from the CBE occupant survey

Methods and metrics:

Preliminary Energy-use Analysis (PEA)

The PEA precedes an audit of the building. During the PEA the analyst analyzes the historic utility use, peak demand and cost; develops the Energy Cost Index (ECI) of the building (dollars per floor area per year); and develops the Energy Utilization Index (EUI) of the building (kBtu / ft^2 per year). The analyst then compares the building EUI to similar buildings' EUIs to assess the potential for improved energy performance and to determine whether further engineering study and analysis are likely to produce significant energy savings. Monthly energy use and peak demand or, if available, interval billing data are reviewed to identify efficiency and behavioral modification opportunities.

The process of conducting the PEA is listed below:

1. Determine the buildings gross conditioned floor area and record this information. Classify the primary use of the building. Ensure that the standard definition of gross floor area is used. Gross floor area is defined as

> *“the sum of the floor areas of all the spaces within the building with no deductions for floor penetrations other than the atria. It is measured from the exterior faces of the exterior walls or from the centerline of walls separating buildings, but it excludes covered walkways, open-roofed-ver areas, porches and similar spaces, pipe trenches, exterior terraces or steps, roof overhangs, parking garages, surface parking, and similar features.”*

2. Assemble copies of the utility bills and summarize them for at least a one year period, preferably for a two- or three- year period. Review the monthly bills for opportunities to lower costs by taking advantage of different utility rate classes, taking into account peak electric demand patterns. Review the monthly patterns for irregularities.
3. Complete the energy performance summary to develop the EUI and ECI for each fuel and demand type and their combined total using methods outlined in ASHRAE Standard 105 (ASHRAE 2007).
4. Compare EUI and ECI with those of buildings that have similar characteristics. A common benchmark comparison for peer buildings is the ENERGYSTAR Portfolio Manager of the US Environmental Protection Agency (US EPA 2018). Montana State University, the owner of these buildings has similar buildings for this comparison. Comparison should also be made with publically available energy of similar buildings. In all cases, care should be taken to ensure that comparison is made with current data, using consistent definitions of building usage and floor area.
5. Derive target energy, demand, and cost indices for a building with the same characteristics as the building being analyzed. This was done by choosing from a database of similar buildings those buildings with the lowest energy index.
6. Compare the energy and cost savings for each fuel type if the building were to reach the target EUI, Using these values, determine whether further engineering analysis is recommended.

Level 1 – Walk-through Survey

The buildings energy cost and efficiency are first assessed by analyzing energy bills, compiled in the PEA, and conducting a brief on-site survey of the building. A Level-1 energy survey will identify low-cost / no-cost measures for improving energy efficiency and provide a list of potential capital improvements that merit further consideration. Because calculations at this level are minimal, savings and costs are approximate. A Level 1 analysis is applicable when there is a need to establish the general energy savings potential of a building.

Level 1 – Walk-through Analysis includes all the work performed for the PEA and certain other steps, which are listed below:

1. Perform a brief walk-through survey of the facility to become familiar with its construction, equipment, operation, and maintenance.
2. Meet with the owner / operator and occupants to learn of special problems or planned improvements.
3. Perform a space function analysis, guided by information in the PEA sample forms. Determine whether efficiency may be affected by functions that differ from the original functional intent of the building.
4. Identify low-cost / no-cost changes to the facility or to O&M procedures and estimate the approximate savings that will result from these changes.
5. Identify potential capital improvements for further study and provide an initial rough estimate of potential costs and savings.

DOCUMENTING RESULTS FOR IEQ:

Preliminary Observations and Formulation of Hypotheses:

A preliminary observation was conducted through the two case-study buildings and certain observations were made. The observations are presented in Table 5. These observations informed the formulation of hypotheses for each IEQ component, which are presented in the subsections below.

Table 7: Observations Documented from Preliminary Walk-through

COMPONENTS OF IEQ	OBSERVATIONS	
	Gallatin Hall	**Yellowstone Hall**
Acoustics		Noise generated by air-conditioning system can be heard in interior spaces. However, it is not disturbing.
Lighting / Daylighting	Sky lounge in both halls have glare issues because of the large glazing in those areas. Types of shading devices used in both halls are different. Exterior shading devices do not appropriately shade the windows.	
Thermal Comfort	Lounges are hot and uncomfortable especially when it is cool outside. Corridors were comfortable during site visit but there could be a potential problem as there is no ventilation. Prevailing winds are from west to east, so Gallatin Hall has advantage of providing cross ventilation.	
		Conditions on the north facing dorm room were uncomfortable even when the space was not occupied. Lounges were warmer than those at the Gallatin Hall.
Indoor Air Quality		Odor and stuffiness in individual rooms. Odor from garbage disposal areas in the hall.

Hypothesis for Acoustics:

The cause of acoustical discomfort can be hypothesized to originate from three specific parts of a building. These parts include – mechanical or HVAC systems, specialty equipment, such as laundry rooms, and interior materials and finishes.

Hypothesis for Lighting/Daylighting:

Multiple hypotheses can be drawn and tested for Lighting (Electric and Lighting) within the spaces. Most hypotheses relate to private offices. The hypotheses are documented below:

- The use of operable windows will increase the length of natural daylight in a space and reduce the need/use of blinds or shades.
- Orientation of office furniture to face windows also reduces glare on computer screens and allows for longer period of natural daylight within the space.
- Decreasing the size of glazing will decrease the potential of glare, but also the amount of daylight available.
- Lighting (Electric + Daylighting) levels and quality are appropriate in all spaces for both buildings.

For the purpose of this analysis the hypothesis “Lighting (Electric + Daylighting) levels and quality are appropriate in all spaces for both buildings” was considered.

Hypothesis for Indoor Air Quality:

Selection of environmental control systems impact the IAQ of a space. The selection of a forced air system in addition to radiant panel systems in the dorm rooms of Gallatin Hall ensures adequate IAQ in these spaces.

Hypothesis for Thermal Comfort:

In addition to common assumptions about thermal comfort being impacted by the amount of glazing and orientation, space volume, and connectivity to other spaces are as important to consider.

Walk-through Results:

Acoustics:

Appendix B – Table B2 shows the Walkthrough Checklist for Gallatin Hall. During the Walkthrough conducted in Gallatin Hall, the first observation was the airborne noise pollution of the HVAC systems. The noise generated by the HVAC systems is distributed evenly around the building and can be distracting. However, the noise pollution generated by the HVAC systems was observed as more intense in the summer months than the winter months. Other sources of unwanted noise such as music, movies, or conversations within the rooms themselves were not observed.

Appendix B – Table B1 shows the Walkthrough Checklist for Yellowstone Hall. During the Walkthrough conducted in Yellowstone Hall, the building appeared to be quiet. However, near the supply air duct, airborne noise pollution was observed. In addition to the airborne noise pollution from the mechanical system, the main sources of acoustical disturbances were background noises such as music, movies, and conversations within the rooms themselves.

Lighting/Daylighting:

Appendix C – Table C1 shows the Walkthrough Checklist utilized to determine how a space is performing based on initial observations. Questions that were answered with a yes were ultimately determined to be the sources of negative connotation found within the spaces.

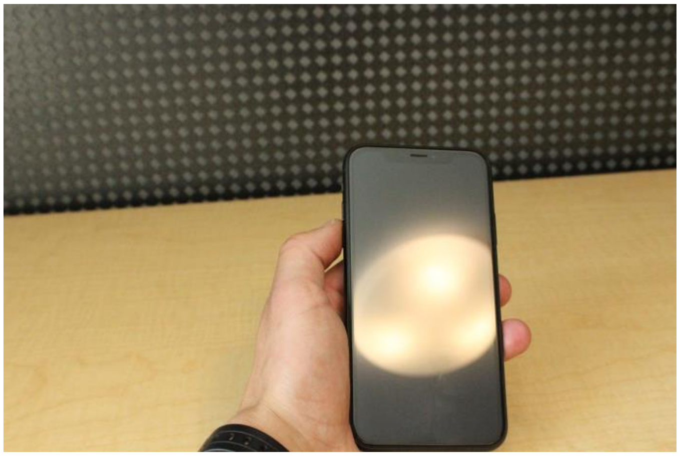
A walkthrough was conducted in both the buildings and certain observations were made using the checklist provided. It was found that the lighting systems for most part were left unaltered. Both common spaces and dorm rooms were well lit with daylight. However, it was observed that for dorm rooms the occupants brought in supplemental light fixtures from home. This allowed the occupants to change their individual electric light levels at their desks. Overall, the lighting systems (electric & daylighting) provided sufficient light levels in the different spaces of the two buildings.

When evaluating for glare, especially in the lobby area and study lounges of the two buildings reflections of luminaires, and windows were noticed on computer screens, room surfaces near the daylight openings were particularly shiny, and direct sunlight was reaching study areas (Figure C1). In addition, various surfaces in these spaces were bright and reflective thus contributing to the potential of glare (Figure C2). It was also observed that while blinds were installed on all windows, they were open for most part of the day. The blinds were only lowered to keep out direct sunlight from entering into the space (Figure C3).

When considering controls, in the lobby areas of both buildings, most of the lights were controlled by timers with manual overrides (Figure C4). The study lounges in both buildings were equipped with occupancy sensors. However, the occupancy sensors for some of the lounges in Yellowstone Hall were not functioning. The lighting system in the dorm rooms of both buildings was controlled by manual switches.

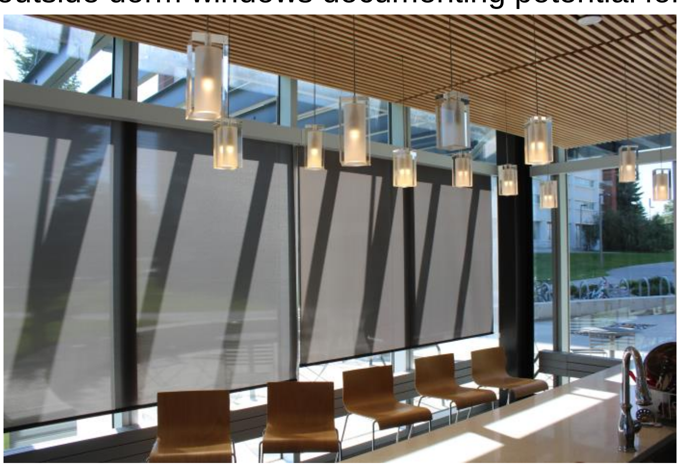
When looking at lamps and ballasts, it was observed that some of the lamps were burnt out in the kitchen, and sky lounge areas of the Gallatin Hall (Figure C5). In the sky lounge and lobby areas of both buildings, the fixtures seem to have a different color appearance from other fixtures. No issues were found with either flickering or noise with the fixtures.

When considering maintenance, the fixtures were in good condition. In both the buildings the tall ceilings of the sky lounge made it particularly difficult to relamp and clean the fixtures located on the ceiling (Figure 17 and Figure 18).



Documenting luminaire reflections on shiny screens

View outside dorm windows documenting potential for glare



Shading devices implemented in the main lobby

Figure 17: Snapshots of walkthrough observations for Gallatin Hall

Various lighting controls within the building

Maintenance condition of lighting system

Shading devices implemented in the main lobby

Figure 18: Snapshots of walkthrough observations for Yellowstone Hall

Indoor Air Quality:

Appendix D – Table D1 shows the Walkthrough Checklist for IAQ. The only observation that was made that could add to poor IAQ was the maintenance and cleanliness of the equipment floor in the boiler room of Gallatin Hall. All other spaces observed were clean and functioning as they should. Equipment logs for air exchange rate, boiler temperatures and operation schedule of AHUs posted on walls of mechanical rooms were also reviewed which ensured that the mechanical equipment is implementing the correct air exchanges required for spaces with mechanical ventilation.

Thermal Comfort:

Appendix E – Table E1 shows a Walkthrough Checklist that reviews the typical building characteristics and design features such as types of glazing and shading implemented. Windows and shading impact the thermal comfort of occupants because of the transmittance of solar radiation through glass.

Appendix E – Table E2 shows a Walkthrough Checklist that reviews the system controls and the access to daylight from spaces. For both buildings the system controls and daylight are accessible in all units.

Appendix E – Table E3 shows a Walkthrough Checklist that reviews the common issues found in buildings. In common areas in Gallatin Hall, the internal shades were observed as always drawn, and maintenance staff reported the cause to excessive heat. In Yellowstone Hall, however the internal blinds were observed as only closed during the night.

Measurement Results:

Measurement Results for Acoustics:

<u>Instantaneous:</u>

dB(A) Spot Measurements: dB(A) Spot measurements were taken in both Gallatin Hall and Yellowstone Hall. Figure 19 provides the locations of spot measurements. The measurements were taken in hallways, rooms/dorm, quiet lounge, and sky lounge/central circulation. The measurements were taken twice, once at 10 AM and once at 3 PM.

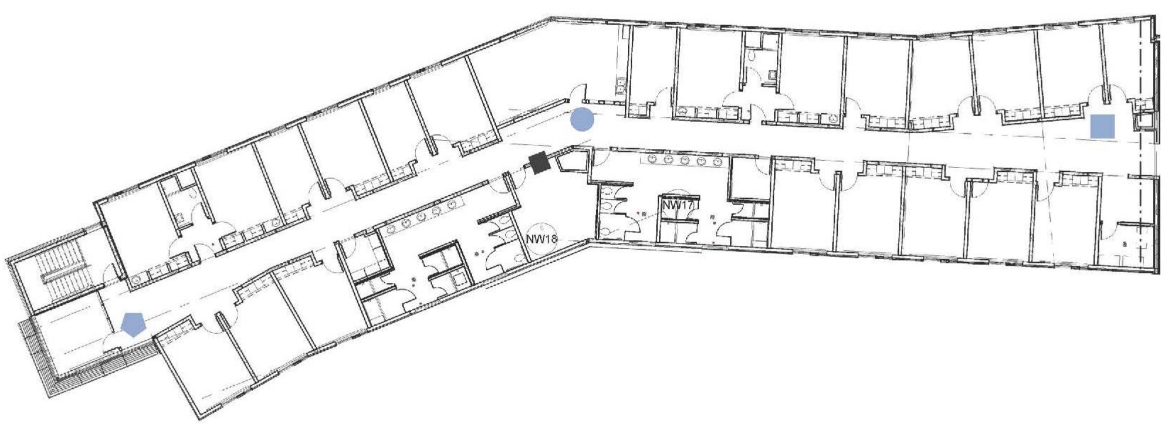
Hallways: The measurements taken in the hallways were measured in three different locations, these locations are represented in Appendix B – Figures B1 and B2. These locations were determined with regards to the HVAC locations and impacts. Appendix B – Figures B3 and B4 show that Gallatin Hall is typically within the Ideal Level and only exceeds it directly adjacent to the HVAC diffusers. Yellowstone Hall on the other hand is at the top end of the Ideal Level and exceeds it in most locations. Excerpts of the analysis are provided in Figure 20.

Quiet lounge and Study lounge: The spot that measurements were taken is represented by the square in Appendix B – Figures B5 and B6. Appendix B – Figure B7 shows that the background noise for Yellowstone Hall is above the max level recommended for LEED in three out of the four measurements. For Gallatin Hall it is nearing and almost exceeding the max level recommended for LEED in the two measurements taken. The 3 PM measurement in the Yellowstone Halls Quiet Lounge was affected by the University Band practicing in the field behind the building.

Gallatin Hall Sky lounge and Yellowstone Hall Central Circulation: Appendix B – Figure B10 shows that the background noise is higher than LEED recommended max level for all measurements for the Yellowstone Hall. The background noise is higher than the LEED recommended ideal level for both measurements, however they are below the max level.

Residents Room: Appendix B – Figure B13 shows that the background noises are higher in Gallatin Hall than Yellowstone Hall with the windows open and closed. The main source of this background noise in Gallatin Hall is the HVAC systems. Appendix B – Figure B13 shows that the background noise is higher than LEED recommended ideal level for all measurements for the Yellowstone Hall. There was a small increase in measurements with the windows open versus the windows closed, however it was negligible in terms in overall noise levels.

a. Gallatin Hall



b. Yellowstone Hall

Figure 19: Snapshots of floorplans for Gallatin Hall and Yellowstone Hall indicating the spots where measurements were taken

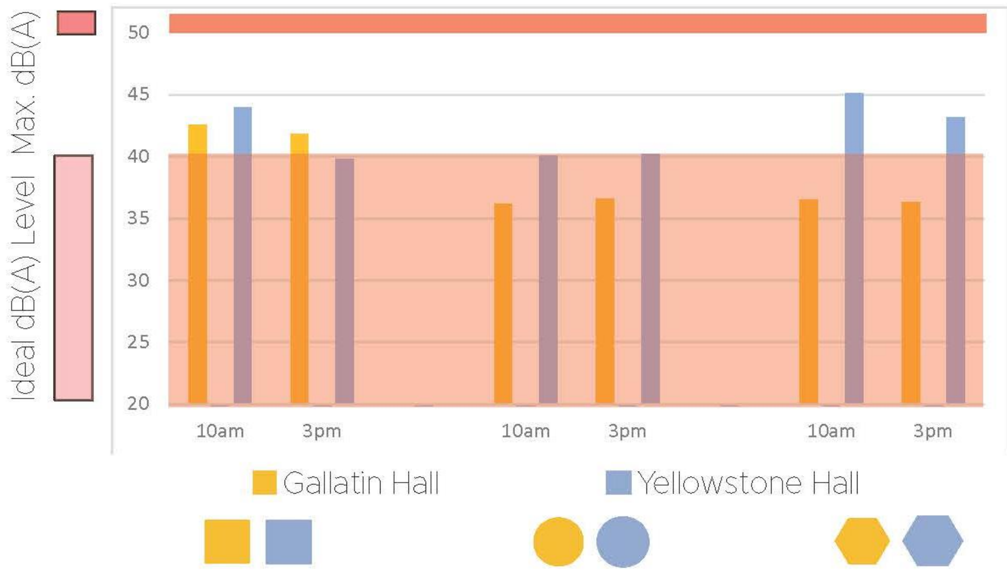


Figure 20: Snapshots of measurements for sound levels for 2nd floor hallway measurements for Gallatin Hall and Yellowstone Hall

<u>Logged Measurements:</u>

No logged measurements were conducted for the acoustics assessment.

Measurement Results for Lighting / Daylighting:

<u>Instantaneous:</u>

Illuminance Spot Measurements:

Illuminance measurements in foot-candles (fc) were taken at different spaces in the two buildings (Figure 21 and Figure 22). The spaces considered included: lobbies, study lounges, dorm rooms, and corridors. These spaces have been identified in Figures 21 and 22. Average horizontal illuminance values were established using protocols developed in the IESNA Lighting Handbook (DiLaura et al., 2011). The values were then compared to the recommended illuminance values for different spaces presented in the IESNA Lighting Handbook. The recommended and measured values are provided in Table 6 below.

The measurements indicate that almost all the values are above the recommended minimum values set by the IESNA, with the exception of illumination levels on the desk in dorm rooms with the task lights turned off, which is reported to be 11.6 fc while the recommended illuminance levels are 40 fc. Although provisions for task lighting is made at the desks, other factors such as glare from the luminaire or color appearance of the light from the luminaire impel the occupants to get supplemental lighting from home. This trend has been observed in the initial walkthrough of the building. This observation should prompt further investigation into the design of task lighting systems.

Table 8: Measurements Documented from Preliminary Walk-through

SPACE	IESNA RECOMMENDATIONS (footcandles)	AVERAGE ILLUMINANCE MEASUREMENTS (footcandles)	
		Gallatin Hall	Yellowstone Hall
Lobbies - Multipurpose	30	150.7	49.8
Corridors	5	14.7	23.3
Study lounges	30		211.1
Dorm rooms - General - Desk	 4 40	 32.4 (w/ blinds up) 51.8 (desk at window) 10.2 (desk near door)	 21.1 (w/ blinds up) 7.5 (w/ blinds down) 29.6 (desk near door w/ light on) 11.6 (desk near door w/ lights off)

Luminance Spot Measurements:

Luminance measurements in foot-lamberts (fL) were taken at the different spaces in the two buildings. It was assumed that the occupant was seated at a desk in the space. The luminance measurements were taken at different points in the room with a luminance meter. After conducting the measurements, luminance ratios were calculated and the space was evaluated for the potential of glare. The IESNA recommended luminance ratios (DiLaura et al., 2011) along with the calculated values for the selected spaces in the two buildings are presented in Table 7.

As seen in Table 7, the window openings at dorm rooms with blinds up in both buildings was a potential source of glare. Although no direct sunlight entered through the windows at the time of measurement, the scene outside the windows in both rooms was bright as a result of sunlight being reflected from surfaces surrounding the window thus making the window appear brighter than the other features in the room causing it to be a potential source of glare. A solution to this issue could be to make the window less bright in comparison to other surfaces in the room (FSEC 2014). This can be done by covering the window with a plastic covering (FSEC 2014). Another solution is to make the room surfaces brighter to match the brightness of the window (FSEC 2014). This can be done by increasing the amount of electric lighting in the room, or by painting the walls with higher reflectance paint, and selecting higher reflectance surfaces for floors and furniture (FSEC 2014).

Table 9: Measurements Documented from Preliminary Walk-through

RATIOS	LUMINANCE RATIO RECOMMENDATIONS	LUMINANCE RATIO MEASUREMENTS			
Gallatin Hall		**Lobby Area**		**Dorm room w/ Blinds Up**	
Over the task	1:3	3.1		2.3	
Task to surrounding	1:3	1.1		2.0	
Task to remote light surface	1:10	5.5		50.6	
Yellowstone Hall		**Lobby Area**	**Study Lounge**	**Dorm room w/ Blinds Up**	**Dorm room w/ Blinds Dn**
Over the task	1:3	0.2	3.4	0.7	1.0
Task to surrounding	1:3	0.8	3.8	1.3	3.0
Task to remote light surface	1:10	13.3	100.1	202.3	1.4

<u>Logged Measurements:</u>

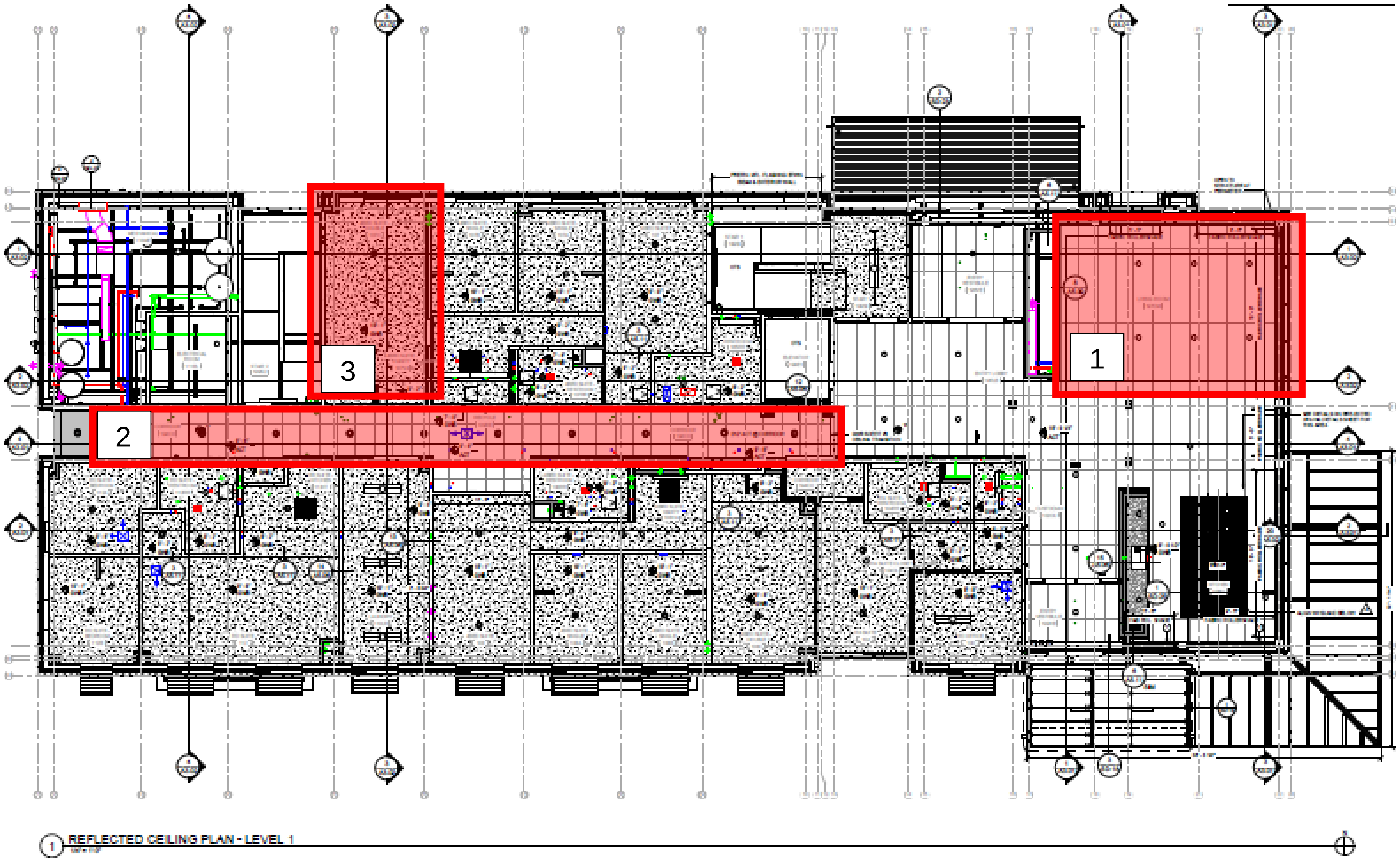
No logged measurements were conducted for the acoustics assessment.

Proving the Hypothesis:

For most part the average illuminance levels were within acceptable range of the values set by the IESNA standards. While on one hand from the spot measurement results the potential of glare could not be determined on the other hand through initial walkthrough, luminance ratios and survey results it appears that there is glare within the spaces being observed. This discrepancy in results prompt a more detailed measurement for illuminance levels using full grid illuminance measurements as outlined in the intermediate level of ASHRAE PMP for lighting / daylighting or by performing daylighting lighting simulations.

Significant glare was observed in the lounge areas where there were large expanses of glazing. This concludes that there is too much glazing in the sky lounge compared to other observed spaces within the two case-study buildings. When considering the mitigation of glare, while the interior shading devices do help mitigate these uncomfortable light levels; however, they still allow solar radiation to pass through the glazing which results in higher temperatures and requires more HVAC needs in the buildings. When considering the use of exterior shading in the mitigation of glare, it was also observed that the exterior shading devices on Yellowstone Hall did not demonstrate a clear difference in light levels and have minimal performance impacts on the light levels that enter the spaces measured indicating that the exterior shading was not carefully designed to keep out unwanted direct sunlight.

If Montana State were to utilize this information for future building designs, high standards may need to be implemented. LEED v4 does start to close this gap by reducing the range of light levels within a space from a maximum of 500fc to 287fc however MSU may want to further improve designs through better exterior shading designs to reduce the overall HVAC building loads.



1) Lobby area, 2) Corridor, 3) Dorm room

Figure 21: Spaces selected for calculation of average illuminance values & luminance ratios in the Gallatin Hall

1) Lobby area, 2) Corridor, 3) Study lounge, 4) Dorm room

Figure 22: Spaces selected for calculation of average illuminance values & luminance ratios in the Yellowstone Hall

Measurement Results for Indoor Air Quality:

Instantaneous Measurements:

CO_2 Spot Measurements: Spot measurements were taken in both the Gallatin Hall and Yellowstone Hall. For each measurement, the instrument was left away from human breath on a flat surface for a minimum of 30 seconds. In Appendix D - Figure D1, when comparing CO2 levels between Gallatin Hall and Yellowstone Hall, you can see that CO_2 levels in Yellowstone Hall read significantly higher than Gallatin Hall. In addition, the lowest CO_2 reading for Yellowstone Hall is in the communal bathroom where there is a forced air system implemented.

VOC Spot Measurements: Spot measurements were taken in both the Gallatin Hall and Yellowstone Hall. For each measurement, the instrument was left on a flat surface for a minimum of 30 seconds. In Appendix D – Figure D2, you can see that the VOC reader did not detect any gases in any of the spaces. The boiler rooms in both halls had an odor from the glycol, but the reader did not detect anything. It was determined that the VOC Sensor was not sensitive enough to register gases, such as glycol, prominent in the spaces.

Logged Measurements:

Overall CO_2 Measurements (Bar Chart): Logged measurements were taken in both the Gallatin Hall and Yellowstone Hall during different weeks. For each measurement, the instrument logged the CO_2 level in a Resident Assistant Room every 15 minutes for a minimum of 4 days. Typical exterior CO2 levels range from 300 ppm and 400 ppm (ASHRAE 2013). For the Gallatin Hall, Appendix D – Figure D3, the majority of CO_2 measurements were in the 500ppm to 600ppm range and nothing higher than 850ppm or lower than 350ppm. For Yellowstone Hall, Appendix D - Figure D4, the majority of CO_2 measurements were in the 350ppm to 450 ppm range and nothing lower than 350ppm, but there are CO_2 levels as high as 1400 ppm. Based on ASHRAE 62.1, if the 400ppm is the exterior base level, then 1100ppm would be the limit of acceptable CO_2 levels. Anything above 1100 ppm is an increase in health risks and out of the 96 hours logged for Yellowstone Hall, 3 hours were above acceptable levels (ASHRAE 2013).

CO_2 Compared to Temperature (Line Charts): Each building was broken down into 24 hour periods to review how the data correlated with the outside temperature. Appendix D - Figure D5 shows the 96 hours logged for the Gallatin Hall and Appendix D - Figure D6 shows the 96 hours logged for the Yellowstone Hall. Each 24-hour segment starts at 3:00 PM and concludes at 2:45 PM the following day.

CO_2 Compared to Temperature (Scatter Plot): When considering the correlations between outside air (OA) temperature and CO2 levels in Gallatin Hall, as OA temperature increases, the CO2 levels decrease to a certain point after which spikes in CO2 levels are observed (Appendix D Figure D7). This is because occupants keep their windows closed during periods of very cold and very hot OA temperatures, but open during moderate OA temperatures. In addition, the air circulation provided by the forced air system to the spaces maintained the CO2 levels within an acceptable range. A different trend in CO2 levels was observed for Yellowstone Hall (Appendix D – Figure D8). The absence of forced air system delivering ventilation air to spaces caused spikes in CO2 levels at all instances of OA temperatures, which implies occurrences when residents entered the room with a closed window and spent some time in an unventilated environment before opening the windows. It should be noted that by collecting data in two separate weeks, the temperatures are drastically different, which leads us to interpret the data with some skepticism. The hypotheses would ideally be tested in cold weather in both buildings where opening a window is less likely to be an option. Excerpts of the analysis are provided in Figure 23 and Figure 24.

VOC: Logged measurements were not taken for the week-long analysis due to the previous finding that our sensors were not sensitive enough to formulate any results.

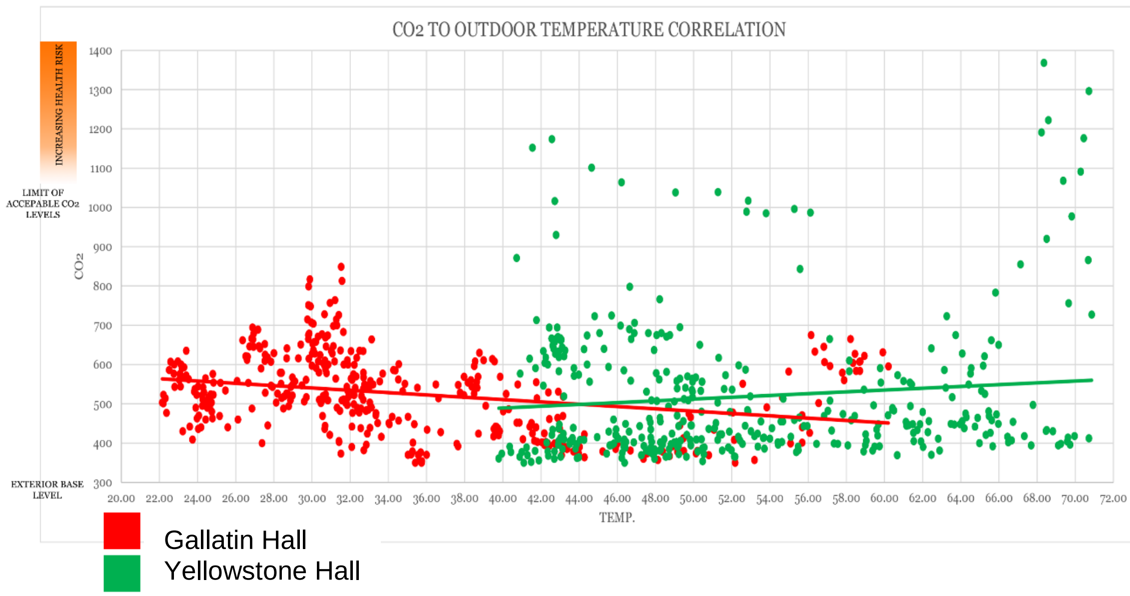


Figure 23: Scatterplot evaluation of CO2 levels at Gallatin Hall & Yellowstone Hall dorm rooms

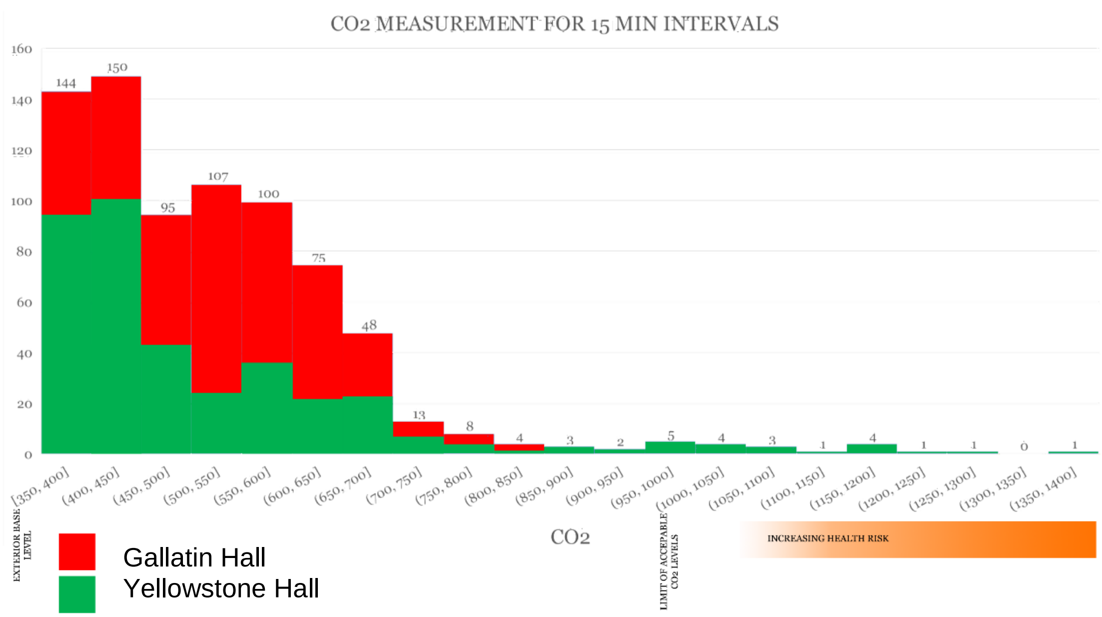


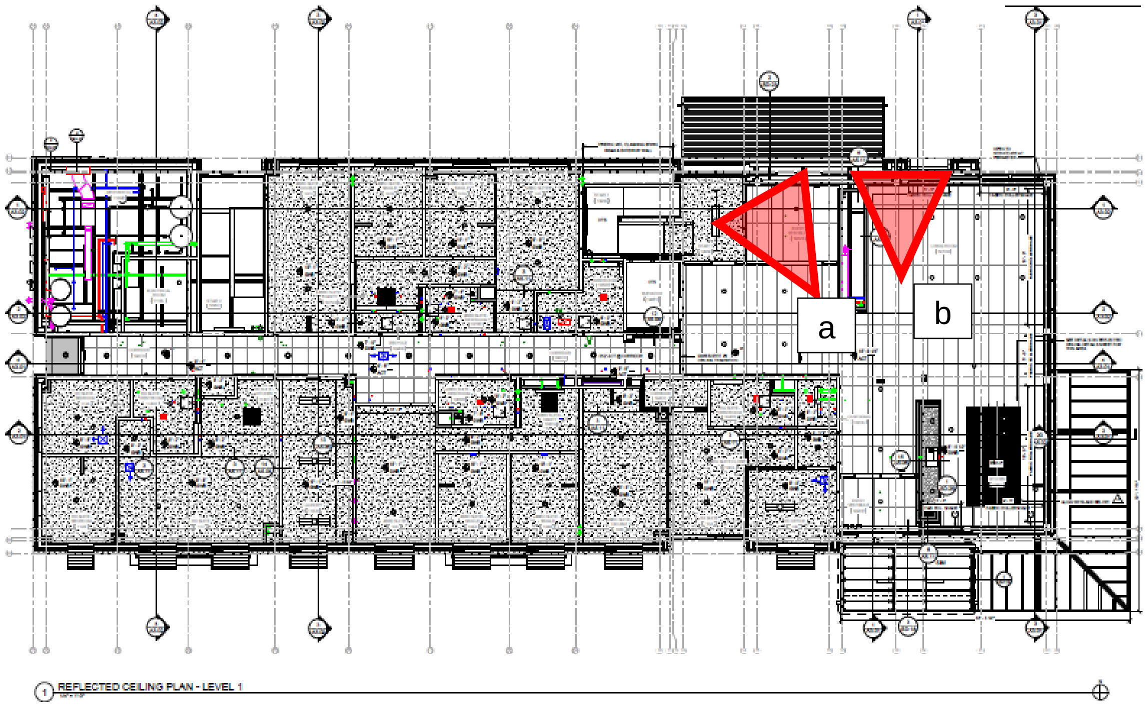
Figure 24: Histogram evaluation of CO2 levels at Gallatin Hall & Yellowstone Hall dorm rooms

Measurement Results for Thermal Comfort:

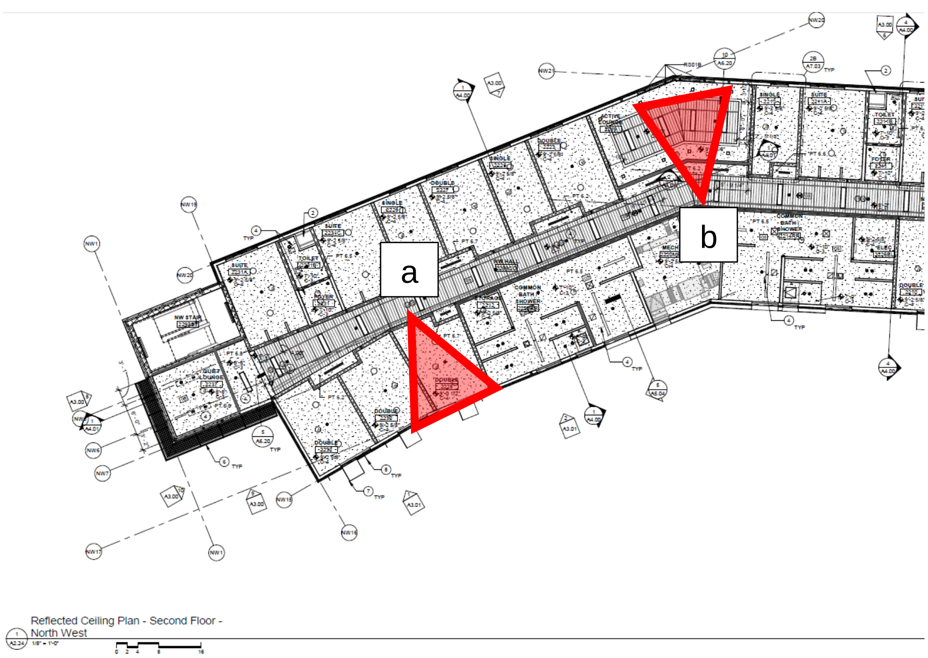
Instantaneous Measurements:

A series of thermal images were captured in each of the locations (Appendix E – Figure E4 and Figure E5). Location of images are provided in Figure 25. When looking at images of Gallatin Hall, columns in the sky lounge and lobby emit absorbed solar radiation at 3:00 PM. The stud components of the wall assembly on the north wall were colder than the insulation components (Figure 26a). For north facing windows in the dorm rooms no difference in surface temperatures was observed for 9:00 AM and 3:00 PM (Figure 26b)

In Yellowstone Hall, for west facing study lounges, the glass surfaces and frames are colder than ceilings and walls at 9:00 AM and warm up at 3:00 PM. Large glazing surfaces if inadequately insulated have surface temperatures that are closer to outside conditions, which can be drastically different than temperatures of other surfaces in the space. This results in surface temperature asymmetry between two opposite surfaces causing thermal discomfort. In the north facing dorm rooms, the studs' components of the wall assembly were colder than the insulation components. However, on the south facing study lounge no difference was observed between the stud and insulation components of the wall assembly at 2:00 PM when the wall heated with solar radiation. The column supporting the overhanging floor of the Hall shows the significant temperature difference between the connection point and the rest of the column.

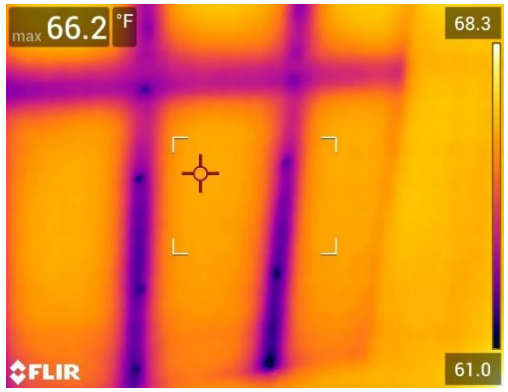


a. *Gallatin Hall*

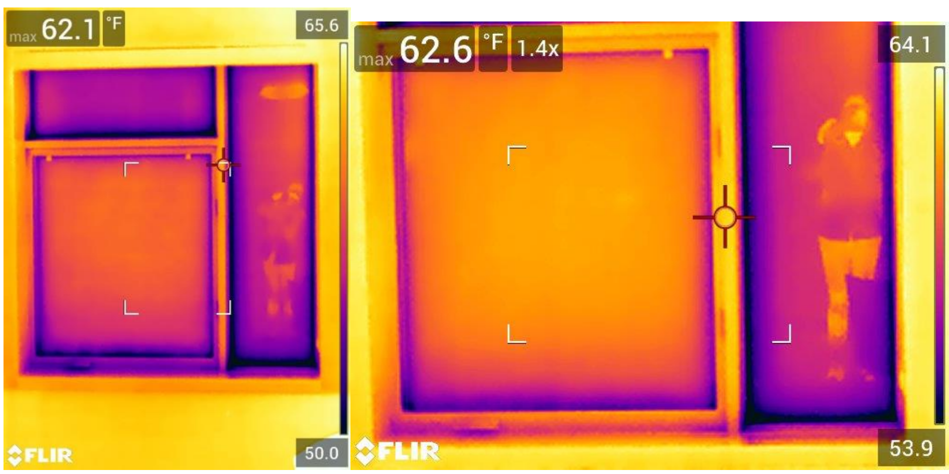


b. Yellowstone Hall

Figure 25: Snapshots of floorplans for Gallatin Hall indicating the spots where thermal images were taken

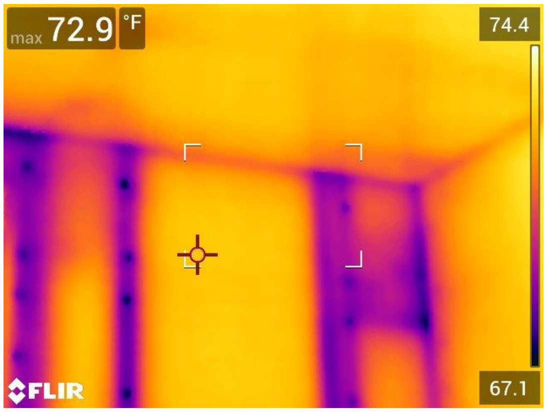


a. Stud wall construction in the stairwell on the north-side of the building

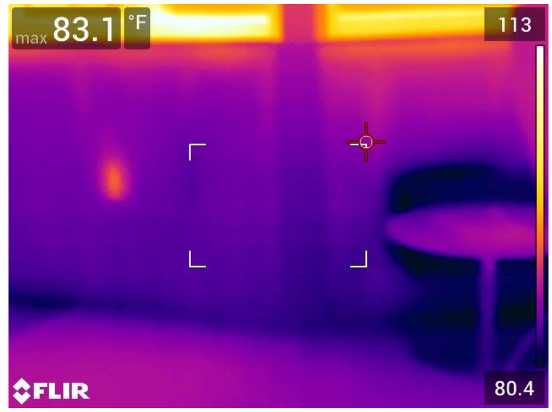


b. Window in an unoccupied dorm room on the north-side of the building

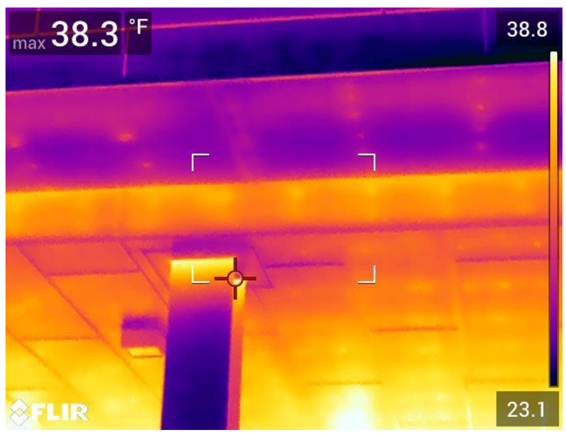
Figure 26: Thermal images from Gallatin Hall



a. Stud wall construction in the dorm room on the north-side of the building



b. Stud wall construction in the study lounge on the south-side of the building



c. Column supporting the overhanging floor

Figure 27: Thermal images from Yellowstone Hall

Logged Measurements:

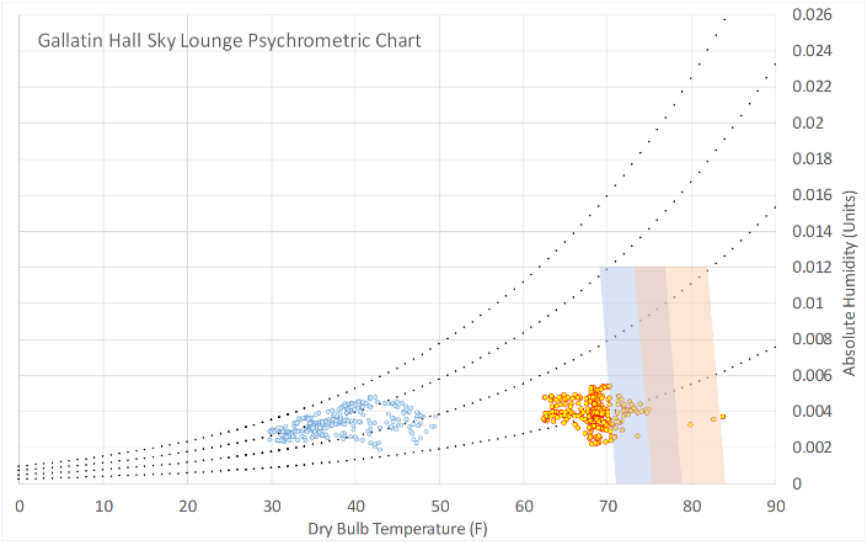
HOBO Loggers Temperatures and Relative Humidity (Psychrometric Charts):
Psychrometric charts are a graphical representation of the temperature and humidity characteristics of air. These properties can include the dry bulb temperature, relative humidity, air density, enthalpy, and wet bulb temperature. In this case, both the dry bulb temperature and the relative humidity were logged over the duration of seven days in four locations in Gallatin Hall and five locations in Yellowstone Hall.

These measurements were taken every 30 minutes. These were then plotted alongside the outdoor temperature and relative humidity during the same time frame and intervals on a series of psychrometric charts, one for each location of the HOBO logger (refer to Appendix E – Figure E1 and Figure E2). The outdoor temperature and relative humidity are plotted in blue and the indoor temperature and relative humidity from the HOBO logger are plotted in red. The light blue and light red zones on each of the charts indicate the thermal comfort range. The blue zone is the 1.0 clo zone and the red zone is the 0.5 clo zone, referring to the clothing insulating value for a person. A naked person would correspond to 0.0 clo and a normal person in a business suit at 70 degrees Fahrenheit at less than 50% relative humidity would correspond to 1.0 clo. If thermal comfort was being met 100% of the time, all of the data from the HOBO loggers in each location would fall within these blue and red zones.

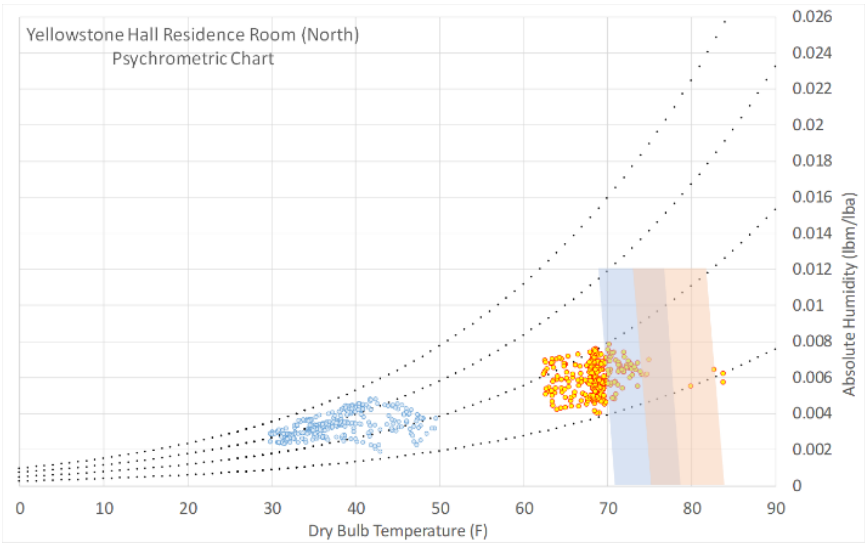
In every single location that was analyzed, the temperature was lower than the thermal comfort zones, indicating that the rooms were often colder than the recommended thermal comfort. Additionally, in all locations, there were outlying data points that exceeded the thermal comfort zones to the right, indicating that the rooms occasionally experienced temperatures warmer than the recommended thermal comfort. While these charts do not provide significant insights into the effect of orientation on thermal comfort, they do provide a clear snapshot that the thermal comfort according to ASRAE Basic Level PMP and LEED standards are not being met.

The relative humidity in the individual residential rooms is also greater than the lounge and common spaces. This is likely due to a greater concentration of people in a smaller space and limited contact with outdoor air. For example, a residential room only has a small, operable window and a door that exits to the hallway. But in the Recreation Lounge in Yellowstone Hall, not only does it have a two-story curtain wall system to the south, but there are two exits to the outdoors that connect with the Recreation Lounge. This exposure to continual outdoor air would decrease the overall relative humidity in this space.

It should be noted this data was recorded October 5th through October 12th, 2018. During this time, the outdoor temperature was between 30 degrees Fahrenheit and 50 degrees Fahrenheit, significantly lower than the recommended 70 degrees Fahrenheit for indoor temperature. Therefore, it is assumed that heat is being lost through wall sections with minimal insulation, such as glazing. This would account for the indoor temperatures falling below the thermal comfort zones in each room that was analyzed. For a complete understanding of thermal comfort in Gallatin Hall and Yellowstone Hall, this data should be collected again during a period of time when the outdoor temperature is greater than the recommended indoor temperature of 70 degrees Fahrenheit. Excerpts of the analysis are presented in Figure 28.



a. Sky lounge, Gallatin Hall



b. Dorm Room (North), Yellowstone Hall

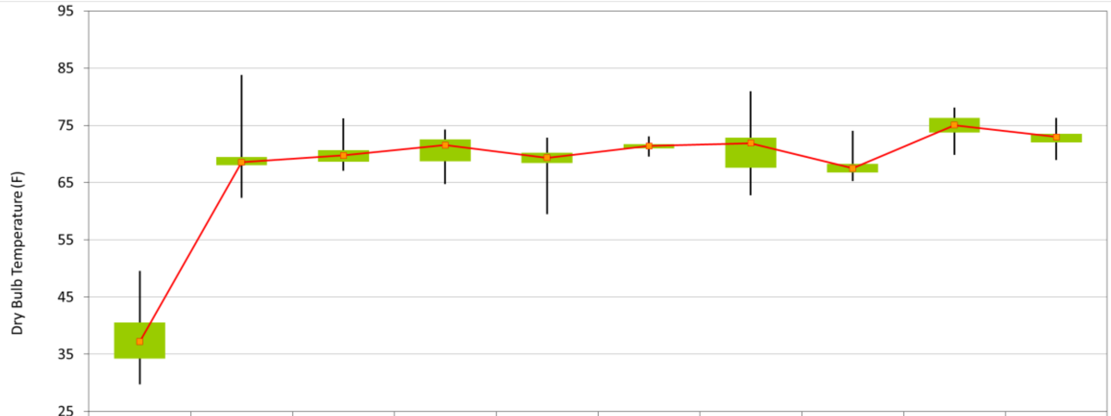
Figure 28: Snapshots of indoor temperature and humidity conditions at Gallatin and Yellowstone Halls

HOBO Loggers Temperatures (Box Plot): The temperature and relative humidity were logged over the duration of seven days in four locations in Gallatin Hall and five locations in Yellowstone Hall. These measurements were taken every 30 minutes. Once this data was logged, the temperatures for each location were plotted in a box plot (Figure 29). A box plot depicts a distribution of series of data based on the minimum, the first quartile (25%), the median, the third quartile (75%) and the maximum. By analyzing this distribution, outliers in the data can be seen, as well as trends in how tightly grouped the series of data is or is not. While the median temperature across the nine location was between 65 – 75 °F, the swings in temperature (minimums and maximums) and the quartiles presented a very different picture.

The biggest temperature swings as observed from the minimum and maximum temperature readings are in the sky lounge of Gallatin Hall and the Quiet Lounge of the Yellowstone Hall. In the Sky Lounge, the second quartile is tightly grouped, yet there is the greatest difference between the minimum and maximum (~20 degrees Fahrenheit). While this room is oriented to the east side of Gallatin Hall, it has a large amount of glazing (>50%), implying that the amount of glazing, not orientation, has more influence on solar gains and thermal comfort. Furthermore, the Sky Lounge has a smaller more compact volume than the Lobby and Kitchen. In addition, while the lobby and the kitchen spaces are open to the entrance lobby and corridors, the sky lounge is closed off from the adjacent corridor with a door. The Lobby and Kitchen space had only a ~9 degree spread between the minimum and maximum temperatures and >50% glazing, indicating that the volume and connectivity of space has as much bearing on thermal comfort as the orthogonal orientation within the building. Similarly, the Quiet Lounge in Yellowstone Hall not only has a large swing in temperatures (minimum and maximum) but also has a loosely grouped second quartile. In this case, the Quiet Lounge is south facing on the third floor with nearly 50% glazing, a small volume, and is cut off from the corridor with a door, implying that the large deviation in temperatures is due to solar gains from orientation, space volume and connectivity to other spaces.

The south facing Resident Room (dorm room) in Gallatin Hall also shows an unlikely dip in minimum temperature. This dip can be attributed to the placement of the logger near a window and the window being opened on several occasions. The southern room in Yellowstone Hall does not seem subject to the large temperature swings, most likely due to its location within the interior courtyard of the building. This would shade it during most of the day when the southern exposure is usually in the sun. The north facing Resident Room (dorm room) in Yellowstone Hall has a higher median temperature and a narrower band of 25% tile, 75%tile, minimum and maximum temperatures because it is an unoccupied room.

The study lounge within the Yellowstone Hall has a tight range of temperatures because it is served by a forced air system and there are no operable windows. In addition, the space has a big volume and is connected to the stairwell and the corridors.



Location	Outside	GH Sky Lounge	GH Lobby/Kit	GH Res Room, North	GH Res Room, South	YH Study Lounge	YH Quiet Lounge	YH Recreation Lounge	YH Res Room, North	YH Res Room, South
25%	34.2518	68.02	68.619	68.749	68.448	70.981	67.591	66.735	73.783	72.014
Min	29.7626	62.368	67.077	64.765	59.448	69.564	62.753	65.237	69.865	68.92
Max	49.532	83.791	76.255	74.302	72.833	73.049	80.989	74.086	78.13	76.298
75%	40.5248	69.435	70.637	72.531	70.25	71.712	72.876	68.234	76.298	73.524
Median	37.2416	68.535	69.735	71.541	69.348	71.411	71.884	67.505	75.038	72.963
	Outside	GH Sky Lounge	GH Lobby/Kit	GH Res Room, North	GH Res Room, South	YH Study Lounge	YH Quiet Lounge	YH Recreation Lounge	YH Res Room, North	YH Res Room, South

Figure 29: Box plot of temperature of the nine selected locations in Gallatin Hall (GH) and Yellowstone Hall (YH)

Student Survey Result

Acoustics:

The results from the student survey (Appendix B – Figures B16 through B21) created a better understanding of the satisfaction of acoustical quality in both Gallatin Hall and Yellowstone Hall. 50% of the residents of Gallatin Hall also say they are satisfied with the sound privacy between units. Only 30% of the participants think that acoustical quality in the rooms interferes with their comfort while over 50% of the occupants believes that acoustical quality in the room enhances their comfort (Appendix B – Figure B20). Even with all the background noise observed in the walkthrough, over 50% of the occupants in Yellowstone Hall are satisfied with the sound privacy between units and only 30% of the participants thinks that acoustical quality in the rooms interferes with their comfort while over 40% of the occupants believes that acoustical quality in the room enhances their comfort (Appendix B – Figure B17).

The survey also gave an insight into the source of unwanted noise in the rooms. In both Gallatin Hall and Yellowstone Hall, common complaints are that talking and music playing in the adjacent units, talking in the adjacent public areas and the hallway, noise generated by HVAC systems, and outdoor traffic noise (Appendix B – Figures B18 and B21).

Lighting / Daylighting:

The student survey was intended to understand if the students felt they had control of light within the resident's rooms, if there was enough light and if the light they had was of good quality.

When asked about the type of controls that were available for lighting in dorm rooms, (Appendix C – Figure C11 and C12) results show that the majority of residents have three options for controlling light; light switches, task lighting, and window blinds.

When asked about how satisfied were the participants with the amount of light in the room, (Appendix C – Figure C13 and C15) results show that most of the occupants were either satisfied or very satisfied. However, Yellowstone Hall has a higher percentage of satisfaction with the amount of light in their room.

When about how satisfied were the occupants with the visual comfort of lighting (Appendix C – Figure C14 and C16), both the Gallatin Hall and Yellowstone Hall results show that roughly 70% of residents are either satisfied or very satisfied with the comfort of the light in their rooms.

Occupants were also asked about whether lighting quality enhances or interferes with their comfort. Nearly 75% of residents in Gallatin Hall think that the quality of light enhances their comfort at least slightly while only 66% residents in Yellowstone Hall feel the same way (Appendix C – Figures C17 and C18). Participants were also asked about the different factors that contributed to their dissatisfaction. A few participants from the Gallatin Hall indicated that the electric lighting was of undesired color. Other issues noted by the survey included: spaces either being too light or too dark, not enough daylight in dorm rooms, too much electric light, flickering of light, no task light and reflections on shiny surfaces such as glass, TV and computer screens. Most of the responses from Yellowstone Hall were that the lighting conditions were too bright followed by too much daylight and electric light, and electric light being of an undesired color.

From the survey results it appears that the dorm rooms seem to have obtained an appropriate lighting quantity and quality within the space. Yellowstone Hall also appeared to have a higher satisfaction associated with its occupants in the dorm room spaces. These results could be used in relation to the spot measurements to determine what levels of lighting occupants find satisfactory. There does appear to be some room for improvement within the space and the primary source of improvement seems to stem from the lighting quality. This could be improved with more fixtures being provided in the rooms or better adjustability such as dimming switches or other lighting fixtures. Lighting quality could also be improved by using lamps with CRIs over 90.

Indoor Air Quality:

The student survey was to provide insight on how the occupants utilize the space and how they feel about ventilation in their dorms, which include use of operable windows. The results of the survey added to an understanding on how residents with forced air systems view their IAQ compared to how residents without forced air systems view their IAQ.

When evaluating space utilization, the survey shows that 80% of Gallatin Hall residents and 64% of Yellowstone Hall residents spend 8-15 hours in their residence hall (Appendix D – Figure D11 and D12). The higher rates of time in Gallatin Hall over Yellowstone Hall could endorse the notion of comfort within the Gallatin Hall building. The survey also shows that about 50% of residents in both buildings said they spend the majority of their time in their dorm rooms. This endorses the fact that ensuring acceptable IAQ levels is crucial in these spaces.

The majority of both buildings report to be satisfied with their IAQ in their living spaces, however there is a larger percentage that is dissatisfied (Considering categories of ‘Somewhat Dissatisfied’, ‘Dissatisfied’, and ‘Very Dissatisfied’) in Yellowstone Hall (21%) than Gallatin Hall (16%) (Appendix D – Figures D15 and D16). Also, out of the people that were dissatisfied with the IAQ, more people in Gallatin Hall felt it was detrimental to their comfort and productivity (Appendix D – Figures D17 and D18). Both buildings declared stuffiness and odor as the major problems with the air quality. Odor can be caused by many different things. The leading causes reported by Gallatin Hall Residents is tobacco smoke, furniture/carpet and food odors. The leading causes reported by Yellowstone Hall Residents is other people, food odors and other substances.

When asked to “Please describe any other issues related to the ease of using operable windows that are important to you.” While the main concern for both residences was that the windows do not open nearly enough to help regulate the air flow, numerous residents of Yellowstone Hall stated that they fear opening their windows due to threats of harming the heaters and causing costly damages, one even stated that they “do it anyways because the rooms get so hot and stuffy” (Appendix D – Tables D2 and D3).

Thermal Comfort:

The student survey provides some significant insights into the post-occupancy user’s experience in the buildings in terms of thermal comfort. The residents were asked a series of questions regarding their thermal comfort, with the two most consequential questions being “overall, does your thermal comfort in your unit enhance or interfere with your comfort?” (Q23) and “which of the following do you personally adjust or control in your unit? (check all that apply)” (Q21). These results are represented in pie charts in Appendix E – Figures E6 through E9.

In Gallatin Hall, the overall thermal comfort is seen to enhance the overall comfort of residents (60%), with 20% stating it neither enhanced or interfered their thermal comfort, and 20% saying it interfered with their thermal comfort (Appendix E – Figure E6)**.** Most residents in Gallatin Hall adjusted their thermal comfort by using the blinds on their windows or opening their operable windows (Appendix E – Figure E7)**.**

In Yellowstone Hall, the overall thermal comfort is seen to enhance the overall comfort of residents (56%), with 15% stating it neither enhanced or interfered their thermal comfort, and 29% saying it interfered with their thermal comfort (Appendix E – Figure E8). Like in Gallatin Hall, most residents in Yellowstone Hall adjusted their thermal comfort by using the blinds on their windows or opening their operable windows (Appendix E – Figure E9). The student surveys for both Gallatin Hall and Yellowstone Hall would suggest that most (>50%) students are content with their thermal comfort, although the temperatures in their rooms fell below the thermal comfort zones and the recommended 70 degrees Fahrenheit for indoor temperature.

Evaluation of Results:

Acoustics:

After completing the ASHRAE Basic Evaluation General Forms and conducting measurement, acoustical discomfort was found in both Gallatin Hall and Yellowstone Hall. The cause of acoustical discomfort was originally attributed to noise generation from mechanical systems. However, after evaluating the results from observations, instantaneous measurements, and student survey, it was concluded that acoustical discomfort is primarily caused by sound transmission between spaces.

In both Gallatin Hall and Yellowstone Hall the impact of HVAC systems seem to be negligible in terms of acoustical discomfort, as most discomfort comes from occupant background noise. The level of noise from the mechanical systems is greater in Gallatin Hall than in Yellowstone Hall. This main explanation for this difference is the use of different systems between buildings. The forced air system in Yellowstone Hall serves only the hallways and lobby spaces and hence is much smaller than the system for Gallatin Hall, therefore it causes less acoustical discomfort.

Daylighting and Lighting:

For most part the average illuminance levels were within acceptable range of the values set by the IESNA standards. While on one hand from the spot measurement results the potential of glare could not be determined on the other hand through initial walkthrough, luminance ratios and survey results it appears that there is glare within the spaces being observed. This discrepancy in results prompt a more detailed measurement for illuminance levels using full grid illuminance measurements as outlined in the intermediate level of ASHRAE PMP for lighting / daylighting or by performing daylighting / lighting simulations.

Significant glare was observed in the lounge areas where there were large expanses of glazing. This concludes that there is too much glazing in the sky lounge compared to other observed spaces within the two case-study buildings. When considering the mitigation of glare, while the interior shading devices do help mitigate these uncomfortable light levels; however, they still allow solar radiation to pass through the glazing which results in higher temperatures and requires more HVAC needs in the buildings. When considering the use of exterior shading in the mitigation of glare, it was also observed that the exterior shading devices on Yellowstone Hall did not demonstrate a clear difference in light levels and have minimal performance impacts on the light levels that enter the spaces measured indicating that the exterior shading was not carefully designed to keep out unwanted direct sunlight.

If Montana State were to utilize this information for future building designs, high standards may need to be implemented. LEED v4 does start to close this gap by reducing the range of light levels within a space from a maximum of 500fc to 287fc however MSU may want to further improve designs through better exterior shading designs to reduce the overall HVAC building loads.

Indoor Air Quality:

In conclusion, while both buildings are typically within the acceptable range as specified in ASHRAE Standard 62.1, there are some issues throughout the buildings as the reported in the evaluation of results from the walkthrough, measurements and student survey. Gallatin Hall has a foul odor observed in the walk through and survey results. Yellowstone Hall has a few readings of high CO2 levels and reported stuffiness. A conclusion to the hypothesis is that the forced air system implemented in the dorm rooms of Gallatin Hall keeps the CO2 levels low. On the other hand, the radiator panels installed in the dorm rooms of Yellowstone Hall don’t regulate the supply air into the rooms, which contribute to spikes in CO2 levels observed within the rooms. A conclusion based on the survey results indicate the majority of students in both halls are satisfied with the IAQ, however less students are dissatisfied in Gallatin Hall than in Yellowstone Hall.

Thermal Comfort:

Both buildings were not found to be within the acceptable thermal comfort zones according to the data obtained through the HOBO loggers. While this conclusion is ubiquitous across the nine rooms that were analyzed, the swing in temperatures were greater in rooms with more than 50% glazing. Furthermore, orthogonal orientation had little bearing on the thermal comfort of a given room, yet the volume and connection to other spaces had a statistically significant influence on the temperature swing in the room. However, when this data was compared to the results of the student survey, it was found that most (>50%) of residents were satisfied with the thermal comfort of their individual rooms.

DOCUMENTING RESULTS FOR ENERGY:

Preliminary Walk-through and Formulation of Hypotheses:

Three hypotheses can be drawn and tested for Energy Consumption. The hypotheses are documented below:

- Buildings with a single block module have a lower energy usage than building with multiple wings.
- The use of radiant heating in place of forced air system in Yellowstone Hall allow for less energy consumption.
- Staff and occupants within the building play a large role in energy consumption due to lack of education about tactics in play.

Results for Preliminary Energy-use Analysis:

Documenting Building Characteristics:

Using the definitions provided for the gross floor area in the methodology section of this report, information regarding building characteristics for the two halls has been compiled.

For Gallatin Hall:

- Gross floor area of about 30,000 ft^2
- Four stories tall
- Block module massing
- Utilizes forced air in all spaces
- Occupant load of 163

For Yellowstone Hall:

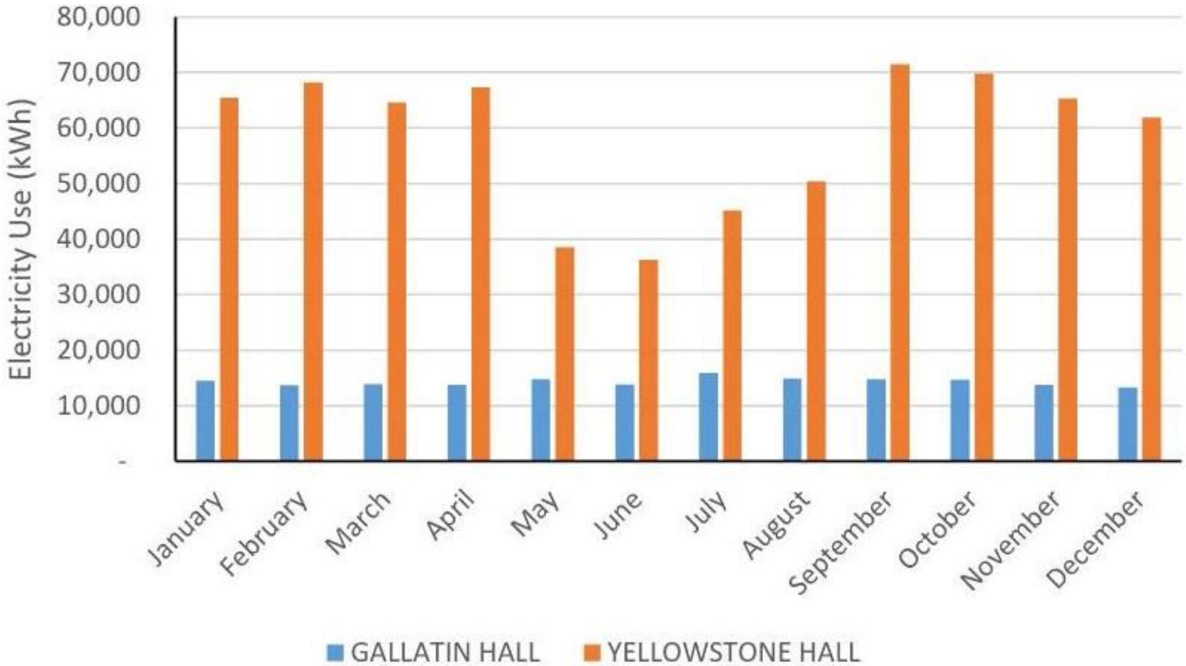
- Gross floor area of about 121,000 ft^2
- Four stories tall
- Three wing massing
- Selective about which spaces are mechanically ventilated
- Occupant load of 57

Information from facilities:

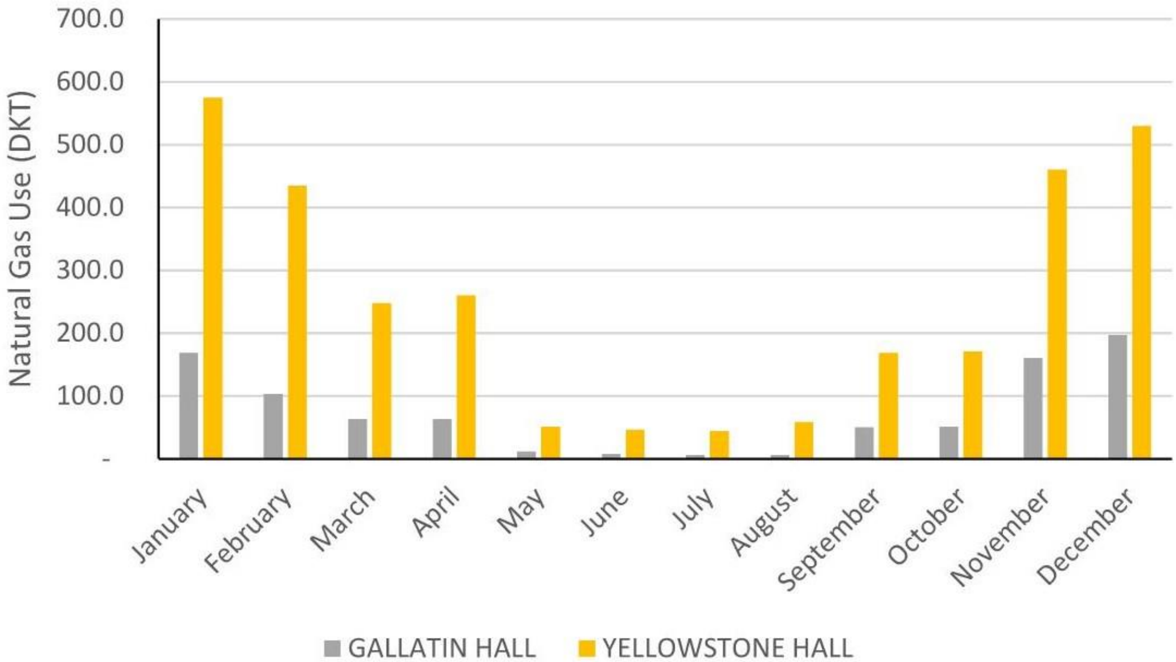
Monthly electricity and natural gas usage for the two buildings was provided by the university facilities. This monthly break down of energy usage in terms of kWh, kW, and DKT for the two buildings is presented in Figure 30 and Table 8.

The energy and utility profile of the Montana state residence halls is very diverse and incorporates many different sources. This provides a unique challenge to when analyzing and monitoring utility use in the campus residence halls. With various kinds of heat sources, whether it be electric, natural gas or steam generated form natural gas, there is a different cost per unit energy associated with each utility. Table 9 outlines the cost of electricity and natural gas.

Because each utility varies in cost it is very effective to look at how much money is being spent on each utility not just the total amount of a specific utility used. From this approach, it can help determine where to focus efforts to reduce cost the most effective way by reducing consumption. The following charts provide insight into Gallatin Hall and Yellowstone Hall.



a) Electricity usage for 2017



b) Natural gas usage for 2017

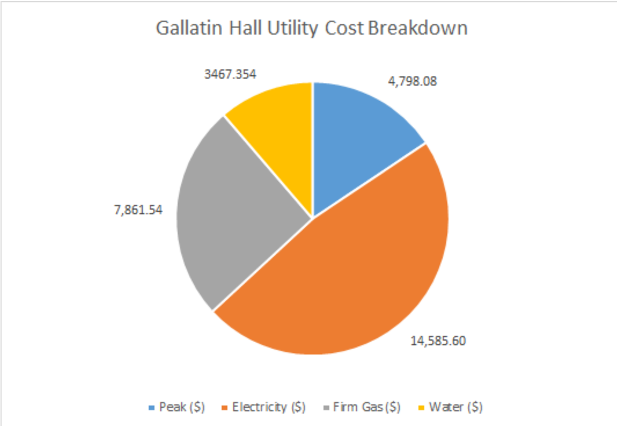
Figure 30: Comparing the Electricity and Natural gas Usage for Gallatin and Yellowstone Halls

Table 10: Monthly Breakdown of Energy Usage for Gallatin Hall and Yellowstone Hall

Month	Gallatin Hall			Yellowstone Hall		
	Gas (DKT)	Elec (KWH)	Peak Elec. (kW)	Gas (DKT)	Elec (KWH)	Peak Elec. (kW)
1/2017	168.7	14,471	37.00	595.7	65,430	157
2/2017	103.5	13,666	39.00	450.8	68,212	155
3/2017	63.5	13,906	37.00	256.5	64,573	151
4/2017	63.5	13,726	35.00	269.5	67,357	141
5/2017	11.9	14,767	40.00	53.0	38,548	124
6/2017	8.2	13,817	39.00	46.9	36,241	95
7/2017	6.1	15,908	40.00	44.1	45,225	106
8/2017	6.0	14,892	36.00	58.8	50,322	163
9/2017	50.3	14,754	40.00	169.0	71,517	165
10/2017	51.5	14,669	36.00	170.9	69,809	143
11/2017	160.9	13,739	37.00	460.5	65,274	148
12/2017	196.9	13,297	36.00	530.1	61,905	158
Annual Total	891	171,612		3105.8	704,413	

Table 11: Utility Cost Matrix for Fiscal Year 2017

Utility	Cost /unit
Electric	$0.08 /kWh
Electric (Peak Demand)	$10.08 KW
Natural Gas	$8.51 DKT



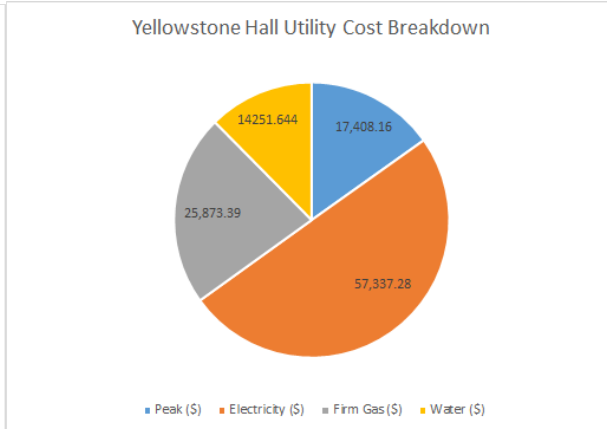


Figure 31: Utility Cost Breakdown for Gallatin Hall (left) and Yellowstone Hall (right)

Calculating EUIs and ECIs for Gallatin Hall and Yellowstone Hall:

The study calculates the EUIs for each fuel and resultant ECIs for both buildings using methods outlined in ASHRAE Standard 105 (ASHRAE 2007a).

For Gallatin Hall:

Annual energy consumption for the year 2017:

Gas in kBtu/yr:	891,000
Electricity in kBtu/yr:	585,564.59
Total in kBtu/yr:	1,476,654.59

EUIs for the year 2017:

Gas EUI in kBtu/yr/sf:	29.7
Electricity EUI in kBtu/yr/sf:	19.5
Total EUI in kBtu/yr/sf:	49.2

ECI for the year 2017:

Total ECI in $/kBtu/sf/yr:	0.7

For Yellowstone Hall:

Annual energy consumption for the year 2017:

Gas in kBtu/yr:	3,105,800
Electricity in kBtu/yr:	2,403,557.5
Total in kBtu/yr:	5,509,357.5

Gas EUI in kBtu/yr/sf: 25.668
Electricity EUI in kBtu/yr/sf: 19.864
Total EUI in kBtu/yr/sf: 45.532
ECI for the year 2017:
Total ECI in $/kBtu/sf/yr: 0.68

Comparing EUIs to values from CBECs, target values, and other buildings on campus:

According to CBES 2012, an average dormitory has an EUI of 57.9 kBtu/yr/sf (EIA 2016). Both of our case study buildings have a lower EUI than the CBECS average. According to Energy Star, our buildings fall right around the 10th percentile for least consumptive and are well below the medium EUI of 27 kBtu/yr/sf (EPA 2018).
The Energy Usage Index (EUI) of each residence hall was calculated using available utility history data. The EUI is a useful metric in which it describes a buildings energy performance. By normalizing the energy usage by total square footage of the buildings, an informative comparison can be made to other similar buildings.

Figure 31 highlights the different magnitudes of energy use in the two Residence halls. A number of other dormitory halls on the MSU campus were considered for the comparison of EUIs. Hapner, Langford, South Hedges, North Hedges and Roskie Halls were considered for this study. The corresponding EUIs are presented in Figure 32.

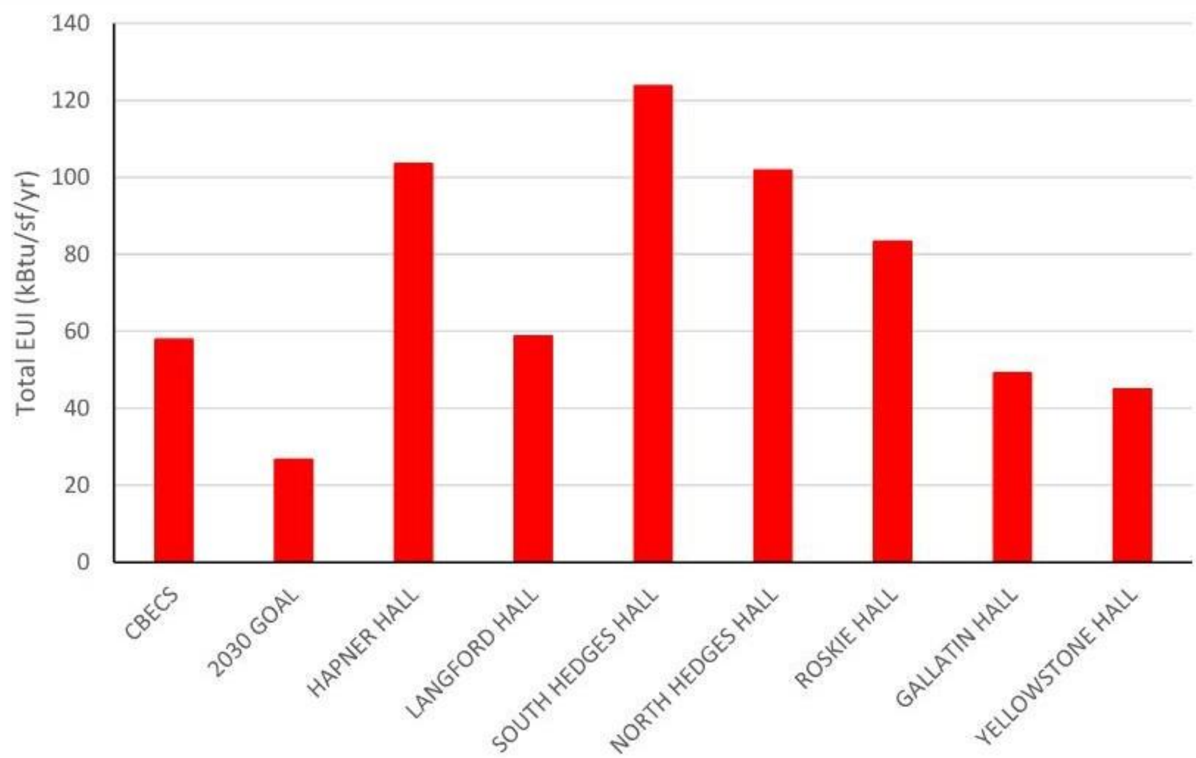


Figure 32: Comparison of EUIs for different dorm buildings on MSU campus with CBECS data and 2030 goals.

Comparing energy savings to reach target EUIs

In order to reach the 2030 Goal of 26.7 kBtu/sf/yr, Gallatin Hall's EUI needs be to lower by 22.52 kBtu/sf/yr and Yellowstone Hall's EUI needs be to lower by 18.36 kBtu/sf/yr.

Results for Level 1 – Walkthrough Analysis:

For this part, the building operators were contacted and interviewed. Interviews included questions related to operation and maintenance of systems, as well as HVAC replacements, with the intention of finding out if maintenance problems and or practices affect the efficiency.

According to the interview with the O&M staff responsible, the two buildings are relatively new hence there are a very few O&M problems that need to be tackled on a daily basis. The few problems that were pointed out include;

- Heating up of the dorm rooms and lobby spaces
- Timers of lighting systems in bathrooms are inconvenient to operate
- Window sill showing condensation
- Malfunctioning of occupant sensors in certain public areas

The first three issues identified are related to the design of the building envelope and HVAC system and can be addressed with suitable retrofits. For example, heating up of the dorm rooms can be mitigated by opening of windows or pulling shades over windows. The heating up of lobby spaces can also be addressed by pulling shades over windows. In addition, dedicated packaged roof tops had to be installed to provide cooling to the sky lounge located on the third floor of Gallatin Hall. Timers on public bathrooms proved to be inconvenient and could be replaced with motion sensors in the space. Condensation on window sills occur due to moist air condensing on cold surfaces and can be mitigated by dehumidifying this air.

Performance Observations Results:

EUI Results:

The EUI of the selected residence halls generally follows the trend of when they were built. Gallatin Hall and Yellowstone Hall being the newest in the comparison had the lowest EUIs while N. and S. Hedges being the oldest buildings have the highest EUIs. This is to be expected, as newer residence halls are built they feature improved construction and improved building systems. The EUIs of the two halls were better than the CBECs values reported for such building types.

It was also observed that the EUI’s from Gallatin Hall consumes more energy than Yellowstone Hall. These results disprove the initial hypothesis that buildings with a single block module have a lower energy usage than building with multiple wings and proved the hypothesis that the use of radiant heating in place of forced air system in Yellowstone Hall allow for less energy consumption. There was not enough data to address the third hypothesis.

RECOMMENDATIONS:

Energy:

Buildings consume 41% of the United States Energy and 40% of the CO_2 emissions (U.S. EIA 2016). The EIA shows the 2011 breakdown of these end-uses as follows: residential buildings 22%; commercial buildings 19%; industrial manufacturing 31%; and transportation 28%. According to Building Green, building energy consumption is actually much greater when you consider that a portion of industrial manufacturing and transportation are both affiliated with the building process as well (Building Green 2019). Studies have shown that dormitories are the most consumptive buildings on college campuses, sometimes making up as much as 75% of all campus energy (Real, 2011). In addition to savings realized, energy reduction in these high consuming buildings can be crucial for the future of CO_2 emission reductions.

Typical Energy Issues:

Decisions made at all three stage of building: design, construction and operation are equally important when considering energy performance of buildings. Decisions in the design phase including inappropriate choice of materials and environmental control systems, as well as a disconnect between design intent and subsequent usage of systems and technologies have a detrimental impact on energy performance. In the construction phase, the use of poor construction techniques resulting in thermal bridging and air infiltration through the building envelope further hinder energy efficiency. Finally, operations and maintenance have a big impact on the energy performance of the building (Amiri, Ottelin, and Sorvari, 2019).

Basic Resolutions:

The following sub-sections introduce several energy efficiency strategies. The sub-sections also discuss synergies between the selected energy conservations measures and IEQ. The synergies are reported for the impact on IEQ and the precautions design teams have to take to ensure appropriate IEQ in buildings.

The energy efficiency strategies are organized under three categories: building envelope, lighting, and mechanical systems. Appropriate selection and operation of systems are considered by the measures. Measures for both retrofits and new construction are discussed. Figure 33 presents the structure of evaluating energy efficiency measure and the potential impact of these measures on IEQ.

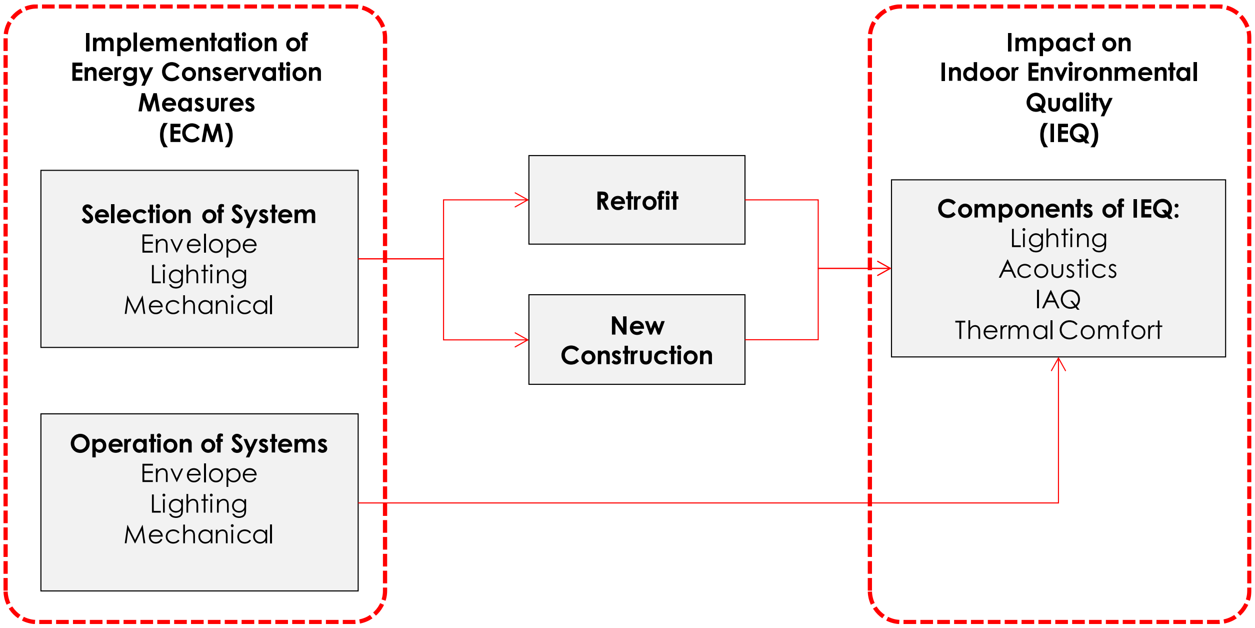


Figure 33: Potential impact of energy conservation measures on IEQ

Selection of energy efficient strategies for envelope:

The energy efficiency strategies selected for the envelope primarily focus on the improvement in thermal insulation, reduction in infiltration, mitigation of thermal bridging, and provisions for natural ventilation. The execution of robust construction methods is paramount to maximize the impact of the measure on energy efficiency and IEQ. The measures identified include:

- Increase thermal insulation
- Thermally efficient windows
- Operable windows
- Measures for reduced air leakage

Increased thermal insulation in building envelope:

By increasing thermal insulation there is a potential increase in thermal comfort because of reduced radiant heat transfer between occupants and building envelope. However, there is also a potential decrease in IAQ if fibers or binders get into the space or if insulation releases VOCs at a high rate. Increasing layers of thermal insulation also contribute to establishing higher sound transmission classes (STCs) in envelope construction (Babineau, 2017), which ensure appropriate acoustics within the space. To ensure appropriate IAQ, design teams have to consider use of insulation products with low emission rates of VOCs, especially odors. This practice of appropriate selection of materials is reinforced by green rating systems such as LEED.

Thermally efficient windows:

The selection and appropriate installation of thermal efficient windows contributes to improvements in thermal comfort from reductions in drafts, radiant heat exchange between occupants and the window, and potential for condensation. The higher surface temperatures associated with these windows, reduce the potential of condensation and growth of micro-organisms which contribute to an improved IAQ. The use of thermally efficient windows enable designers to incorporate larger glazing areas, which contributes to improved daylighting conditions at the same time reducing the potential pollutant emissions from indoor materials caused by increased exposure to direct sunlight. Thermally efficient windows are also associated with higher sound transmission classes (STCs) (Lee, 2008), which ensure appropriate acoustics within the space. However, design teams need to ensure the appropriate selection of efficient windows and shading devices for effective management of solar heat gains within the building.

Operable windows

The use of operable windows provides a potential for natural ventilation. Operable windows also provide better opportunities for occupants to regulate their environment to improve thermal comfort and IAQ. Thermal comfort may increase with increased ventilation rates and reduced temperatures provided when window is open. In addition, increased ventilation rates through operable windows contributes to the mitigation of solar heat gains. The potential of operable windows can be maximized if coupled with the implementation of strategies that enhance natural ventilation in the building, which include: appropriately sizing and placement of windows, appropriate design and area of floor plate, and volumes. However, operable are associated with potential increase in outdoor pollutants and decreased isolation from outdoor sounds. Design teams need to consider placement and size of operable windows to optimize benefits from natural ventilation. While most operable windows are manually operated, automated operation can be considered for certain building types and occupancies to ensure optimized use.

Reduced air leakage:

Implementation of strategies for reduced air leakage in new and existing buildings can have a substantial energy impact especially in cold climates (Hackel et al, 2015).

Factors such as building type, climate and the selection of HVAC systems impact the potential energy savings for infiltration reduction.

Implementing measures for reduced air leakage contribute to increased thermal comfort due to reduced entry of unconditioned air. In addition, reducing air leakage may isolate indoor spaces from outdoor sounds, and infiltration of outdoor pollutants. However, improperly place vapor barriers can lead to condensation and formation of mold and mildew.

For new construction design of building envelope assemblies should include air tight materials such as continuous insulation (i.e. medium or high density rigid or sprayed insulation), and air barriers (i.e. membranes). Design teams have to ensure that vapor barriers are located near the warm side of the building envelope. The correct installation of these assembles is also critical. Reduced infiltration of outside air also increase concentrations of indoor generated pollutants, however magnitude of increase is insignificant especially when outside air ventilation is being provided mechanically. For retrofits, leaks must first be found with use of techniques such as smoke tests and infrared thermography (Hackel et al. 2015). Once found air leaks should be sealed using materials such as one-component polyurethane foam sealant, two-component polyurethane foam insulating air seal kits, weather stripping, caulk, and air seal/fire stop systems and mastic (Hackel et al. 2015).

Selection of energy efficient strategies for lighting and equipment:

The energy efficiency strategies selected for the lighting and equipment primarily focus on the improvement in efficiency, and implementation of controls. The measures identified include:

- Energy efficient lamps and fixtures
- Lighting controls
- Shading controls

Energy efficient lamps and fixtures:

When installing energy efficient lamps and fixtures, design teams should ensure appropriate lighting quality and levels. The implementation of such lighting systems is also associated with improved thermal comfort because of the reduced dissipation of heat from such systems. LED lighting systems are currently being installed in new construction. However, when retrofitting lighting systems certain considerations need to be made, which include the decisions to change either the lamp or the entire lighting system (Stouch Lighting N.D.). Most LED lamps are made to be compatible with standard fixtures. On the other hand, the hardware for dimming LED lights is generally not compatible when retrofitting fluorescent lighting systems and require additional installations (Shine Retrofits 2018). LED light fixtures can be expensive if you need to replace the existing lighting infrastructure (Shine Retrofits 2018).

Lighting controls:

The use of various lighting controls for dimming, daylighting, and occupancy have the potential to reduce energy consumption. Strategies for lighting controls include the implementation of occupant controlled task lighting, manual switches, scene controls, photo sensors, and occupancy and vacancy sensors. The use of such systems contribute to improved lighting quality and use of appropriate lighting levels. Integrating the use of windows, skylights and light tubes for provision of required lighting levels reduce the dependence on artificial lighting, which can be done with the appropriate use of daylighting controls.

However, improperly operating control systems can result in excessive energy use, inappropriate light levels and degraded lighting quality. Design teams have to consider commissioning of control systems prior to occupancy. Design teams should also consider educating both occupants and maintenance staff on operation of such systems. In addition, design teams need to consider both occupant profiles and maintenance schedules of buildings before selecting appropriate user friendly control systems. Designers should ensure proper design of natural lighting systems to prevent lighting problems such as glare, incorrect or uneven lighting levels. Design teams should pay attention to the placement and optimal characteristics of various building elements to ensure improved lighting quality.

Shading strategies and controls:

In addition to lighting, shading strategies and controls are crucial to ensuring appropriate lighting levels and occupant comfort. Shading strategies include: interior, exterior and window films. These strategies can be categorized as either fixed or operable. Each strategy can be either manually or automatically controlled. Some triggers for automatic controls include: temperature, light levels, and solar radiation. Timers may also be used. Manual controls may be initiated with switches.

Shading strategies and controls aim to: optimize lighting quality and levels; prevent glare; and improve thermal comfort by reducing direct solar gains. Certain strategies such as light shelves contribute to the even distribution of light throughout the space. Shading can reduce the potential pollutant emissions from indoor materials caused by increased exposure to direct sunlight.

However, improperly designed and operated lighting shades and controls can degrade lighting quality and contribute to the potential of glare. Design teams have to select sensors based on robustness and appropriate use. Certain shading strategies that are inappropriately managed can trap solar radiation causing thermal discomfort. Regular and adequate maintenance is required to ensure proper management of shading strategies. Design teams should also consider educating both occupants and maintenance staff on operation of such systems.

Selection of energy efficient strategies for HVAC systems:

Installation and operation of appropriate HVAC systems is crucial to mitigate excessive energy consumption while still ensuring appropriate IEQ is met in the building. The following discussion on energy efficiency strategies for HVAC systems is divided into two sections, the first section describing the components of HVAC systems and the second section describing the operation of HVAC systems. The following information has been compiled from the International Performance Measurement Protocols (IPMVP 2002).

Components of HVAC Systems:

Improved energy efficiency of HVAC components such as motors, pumps, fans, and chillers does not have any adverse influence on IEQ if the components have sufficient capacity. Commissioning of HVAC systems needs to be conducted to ensure proper performance under full- and part-load conditions.

Dedicated Outdoor Air System (DOAS):

Potential Impact on IEQ: Dedicated outdoor air systems condition 100% of outdoor air reducing loads on the primary HVAC equipment and in turn improving the IAQ within spaces. The reduction in HVAC equipment loads can result in significant savings in energy consumption. In addition, the implementation of DOAS system also provides superior humidity control thus contributing to improved thermal comfort of occupants.

IEQ Precautions: When implementing and operating DOAS system care should be taken to size the system in order to ensure adequate supply of fresh air to designated zones for adequate IAQ. In addition, the design and operation of the system should ensure appropriate dehumidification of outdoor air in humid climates to prevent formation of mold and for appropriate thermal comfort. Finally, filtering of outdoor air is recommended in locations with high levels of air pollution to ensure adequate IAQ.

Heat Recovery:

Potential Impact on IEQ: Heat recovery systems extract heat from exhaust ventilation air or other sources of waste heat and transmits it into the supply air for the building. This systems often acts as a preheat system before air is passed through an air handling unit. By preheating the air, the heating components of the air handling units do not have to work nearly as hard which reduces energy consumption. Heat recovery systems also allow for an increase in rate of outside air supply, which in turn usually improves the IEQ within a space.

IEQ Precautions: If improperly maintained and monitored, some heat recovery systems may transfer moisture or pollutants from the exhaust air to the supply air stream.

Use of Outside Air Economizer for a Free Cooling:

Potential Impact on IEQ: IAQ typically improves with the increase in average ventilation rates. However, during periods of elevated outdoor pollutant concentrations, the use of economizers may increase indoor concentrations of pollutants. Also, in humid climates, economizers may increase indoor humidity which could result in moisture related issues with IAQ.

IEQ Precautions: Locating outdoor intakes as far as practical from pollutant sources such as vehicle exhausts, kitchen exhausts, HVAC exhausts, and trash storage. The use of activated charcoal filters is recommended to clean highly polluted outdoor air. In addition, economizer controls and associated minimum outdoor air flow rates should be regularly calibrated.

Use of Variable Air Volume (VAV) Ventilation System in Place of Constant Air Volume (CAV) Ventilation System:

Potential Impact on IEQ: The use of a VAV ventilation system may risk the insufficient supply of outside air supply when indoor cooling and heating loads are low. For HVAC systems with fixed outside air fraction there is a risk of excessive cooling and thermal discomfort when cooling loads are low and the supply air temperature is not increased.

IEQ Precautions: Precautions would include: maintaining outside air intake into air handlers at or above minimum requirements for all supply airflow rates; avoiding VAV control units that close fully when space temperatures are satisfied; increasing supply air temperatures when cooling loads are low; and the use of supply registers, minimum supply flow rates and temperatures that do not cause supply air dumping and discomfort.

Use of computerized digital heating ventilation and air conditioning (HVAC) control systems:

Potential Impact on IEQ: Computerized digital HVAC control systems are systems that regulate the inputs and outputs of HVAC systems. By regulating the systems, energy consumption is much more consistent and IEQ may be improved. In addition, digital controls facilitate the use of demand controlled ventilation based pollution sensors.

IEQ Precautions: To ensure energy reduction and maintenance of appropriate IEQ, proper commissioning of the system as well as adequate training of building operators is required.

Use of hydronic radiant heating and cooling with consequent fan energy savings:

Potential Impact on IEQ: The use of hydronic systems impacts mean radiant temperatures, which may positively impact thermal comfort. However, hydronic systems may increase the risk of water leaks or water condensation leading to formation of mold. In addition, a system dedicated to bringing outdoor air is required.

IEQ Precautions: Design, operating and maintenance practices of hydronic heating and cooling systems should assure acceptable thermal comfort and supply of adequate outside air as well low risk of water leakage and condensation. Periodic cleaning of radiant panels or radiators may be necessary.

Increasing interior or exterior thermal insulation of piping and duct systems:

Potential Impact on IEQ: Increasing the insulation on piping and duct systems will have a negligible influence on IEQ. However, there is a potential for improved thermal comfort if the insulation enables HVAC system to satisfy peak thermal loads. Increased insulation along with vapor barriers can reduce moisture condensation and potential for mold formation. There is a potential increase in irritation symptoms if fibers or particles from insulation enter occupied space or if insulation releases VOCs at a high rate. Interior insulation in ducts can reduce fan noise (ASHRAE 2015). However, this insulation can be susceptible to mold formation (Morey and Williams 1991).

IEQ Precautions: To ensure adequate IAQ, fibrous insulation has to be isolated from the indoor air. Fiber and particle release during installation of insulation needs to be minimized and a cleanup of space needs to be performed prior to occupancy. In addition, the use of insulation products with low emission rates of VOCs have to be used. The surface of insulation installed on the interior of ducts should prevent the release of fibers or particles and not degrade. Interior duct insulation should not be located in places where it can become damaged or wet.

Operation of HVAC Systems:
Optimized operation of HVAC systems does not have any adverse influence on IEQ if the components have sufficient capacity. HVAC systems have to be commissioned to ensure proper operation under full- and part-load conditions in heating and cooling modes.

Reducing Operating Time of HVAC Components:

Potential Impact on IEQ: There is a risk of degraded indoor thermal environment and / or increased indoor air pollutant concentrations if components are not operated during periods of occupancy. Also, when HVAC systems are not operating, indoor pressure differences and the associated transport of pollutants between zones or between outdoors and indoors are not controlled.

IEQ Precautions: Operating periods must be sufficient to ensure acceptable thermal comfort and ventilation during occupancy. Ventilation with outside air should precede occupancy to reduce concentrations of air pollutants emitted from building materials and furnishings during unoccupied / low ventilation periods. Minimize indoor pollutant sources to reduce the pollution burden on the ventilation system. Equipment shutdown to limit peak energy demands should be infrequent and of limited duration. Use energy efficient HVAC systems or thermal energy storage to limit peak energy demands without sacrificing thermal comfort. Sequencing the startup of HVAC equipment may also reduce peak demands often without adverse influence on IEQ.

Operation Nighttime Purge Fans:

Potential Impact on IEQ: Purge Fans can be included in designs. Purge Fans draw a high velocity of exhaust air out of the building during the night to provide a night flushing effect. However, nighttime ventilation with humid air may result in condensation on HVAC equipment or building components increasing the risk of mold formation.

IEQ Precautions: Design and operate nighttime ventilation systems to prevent moisture problems. Often controls prevent nighttime cooling when outdoor dew-point temperature is excessive.

Reduction of air pressure drops and air leakage in duct systems:

Potential Impact on IEQ: Reducing air pressure drops and air leakage in systems may allow for improved air supply and thermal control. Implementing this strategy may reduce noise generation in duct systems.

IEQ Precautions: It may be necessary to conduct air system balancing after retrofitting. It is also necessary to ensure quality of duct assembly to reduce noise.

Reduction in average or minimum rate of outside air supply (especially closure of outside air dampers):

Potential Impact on IEQ: Primary effect in reducing the average or minimum rate of outside air is that concentrations of indoor-generated air pollutants will increase potentially leading to complaints and adverse health effects even though indoor concentrations of pollutants from outdoor air may be reduced (especially pollutants like ozone and particles that react with or deposit on indoor surfaces). In air conditioned buildings, indoor humidity may also be reduced.

IEQ Precautions: It is suggested to maintain rates of outside air supply specified in applicable codes and standards. It is not recommended to fully close outside air dampers during occupancy. Also, it is necessary to minimize indoor pollutant sources to decrease pollution burden on ventilation systems. Finally, the use of improved particle and gaseous air cleaning is recommended.

Increase supply air temperature when cooling space (may decrease chiller energy but increase fan energy):

Potential Impact on IEQ: Higher supply air temperatures in VAV ventilation systems will increase supply air flow rates. In many VAV systems, outside air flow rates will also increase leading to reduced concentrations of indoor generated pollution. However, increasing chiller water temperatures often reduces the moisture removal by the HVAC system resulting in higher indoor humidity.

IEQ Precautions: Maintain chilled water temperature sufficiently low for control of indoor humidity.

Increasing thermostat set points during periods of space cooling and decreasing thermostat set points during space heating to save energy or limit peak energy demand:

Potential Impact on IEQ: By rising the set points during cooling demands and lowering the set points during heating demands, the outside temperature and inside temperature become closer together and the cooling or heading load is not as demanding. In addition, if the building temperature is allowed to gradually rise throughout the day instead of demanding a large temperature change very quickly, the HVAC equipment can run more smoothly and is not required to run extremely hot for a short period of time to meet those demands which reduces energy consumption. However, air temperatures near or outside of the boundaries of locally applicable thermal comfort zones are likely to increase complaints of thermal discomfort, especially in air conditioned building that are not provided with occupant control. Also occupant perceived acceptability of air quality decreases as the temperature increases (Fang et al. 1997). Increased air temperature is associated with increased prevalence of acute building related health symptoms (Mendell 1993).

IEQ Precautions: It is recommended to maintain the temperatures within the bounds of applicable comfort standards. In addition, the provision of occupant controllable fans and space heaters may contribute to improved thermal comfort. Thermally efficient windows and walls may help to maintain thermal comfort. Resetting of space temperatures to limit peak energy demands should be infrequent and of limited duration. The use of energy efficient HVAC systems or thermal energy storage to limit peak energy demands without sacrificing thermal comfort.

CO_2 based demand controlled ventilation (DCV):

Potential Impact on IEQ: IEQ may improve of degrade depending on the reference condition and on the outside air control strategy used for DCV. Improved IEQ is most likely in spaces with high occupancy where occupant generated pollutants dominate. DCV systems that provide outside air only after the CO_2 concentrations exceed a setpoint may lead to substantially increased indoor concentrations of pollutants from building components and furnishings during the first few hours of occupancy.

IEQ Precautions: It is recommended to avoid CO_2 based DCV when the building has strong pollutant emissions from sources other than occupants. Also, it is necessary to ventilate prior to occupancy to reduce concentrations of pollutants from non-occupant sources. CO_2 measurement locations must provide data representative of concentrations in occupied spaces. Consider advanced DCV control strategies that supply outside air in proportion to the indoor CO_2 generation rate, which is a better surrogate for occupancy than CO_2 concentration (Federspiel 1996). In addition, the CO_2 sensors need to be calibrated.

Use of natural ventilation with operable windows as a substitute for air-conditioning:

Potential Impact on IEQ: In some climates occupants in naturally ventilated buildings have a tolerance to a wider range of thermal conditions. However, thermal comfort may decrease because of elevated indoor temperatures and humidity. In addition, open windows admit sound from the outdoors, which can contribute to the degradation of the acoustical environment inside the building.

IEQ Precautions: Elements of building design which include: size, layout, openings to the outside, and shading need to ensure adequate natural ventilation and thermal conditions throughout the building. Cross ventilation is typically desired. The installation of fans that are occupant controls contribute to the enhancement of thermal comfort. Operable windows should not be located near sources of pollution or loud noises.

Preventing maintenance of HVAC systems:

Potential Impact on IEQ: Preventive maintenance assures proper HVAC operation. The correct implementation of preventive maintenance plan in the facility contributes to energy savings and improved IEQ. Preventive maintenance measures such as calibration of sensors, periodic replacement of air filters, maintenance of airflow and pressure control systems, balancing of airflows to provide proper air distribution, and cleaning of coils and other components to reduce resistance to airflow and pollutant sources in HVAC systems.

IEQ Precautions: It needs to be ensured that preventive maintenance practices do not disturb or release asbestos fibers.

Issues in Residence Halls:

The first issue to note is the impact of large amounts of glazing in the two halls. Both halls were designed with public spaces that express extensive floor to ceiling glazing systems (i.e., Yellowstone Hall utilizes air-conditioning in the entrance lobby and Gallatin Hall utilizes air-conditioning in the sky lounge). The sky lounge was retrofitted post construction to include an air conditioning unit to combat the cooling loads associated with solar gains. The lobby of Yellowstone Hall was designed with the use of air conditioning to address to potential solar gains of the south facing curtain wall. In addition to the design decisions, optimal operation of the internal solar gain mitigation systems was not observed for these spaces. Gallatin Hall did not have a known schedule for optimized times to open and close the internal shades to mitigate the solar heat gain. Yellowstone Hall had a daylight tracking shading device in the main lobby; however, it was inoperable due to difficulty of operation. Because of the design decisions made in regards to the glazing in the halls, coupled with the operation and maintenance of shading devices, the two buildings use more energy than necessary to combat the solar gains.

The second issue to note is that the Heat Recovery systems in both buildings do not have a bypass. In other words, there is no way to turn off the heat exchange from exhaust air to the fresh air, therefore, when cooler fresh air is desired to help cool the spaces, it is automatically heated from the heat exchanger anyways.

The lack of a forced air ventilation system in the dorm rooms of Yellowstone Hall also causes residents to open their windows, even when temperatures are less than ideal. The open windows cause the radiant heaters, directly below the sill, to work harder to heat the outside air than it would have had to if the air was first through the heat exchanger in the DOAS System.

Another issue in Yellowstone Hall is that there are multiple offices sharing one thermostat and heating zone. Sharing heating zones can cause thermal discomfort among staff and requires additional personal space heaters to correct the thermal comfort.

Recommended Retrofits:

The least expensive and most feasible retrofits to both Gallatin Hall and Yellowstone Hall, is providing staff/occupant training and information about building equipment, operations and maintenance. Information about shading and equipment schedules and operation can greatly reduce the energy consumption of the building and ensure equipment is utilized and optimized to their fullest potential. In addition, occupants should be aware of building systems and components throughout the building that are susceptible to damage.

HVAC Component retrofits are often not viable after construction due to limits of access to equipment as well as cost. HVAC components should be selected and sized appropriately during the design phases of the building project. Including maintenance personnel in design phases of the project is also crucial to providing appropriate space for equipment.

IEQ Strategies:
Acoustics:

Acoustical discomfort can be caused by building occupants and building components. Excessive noise pollution caused by occupants is often predictable in certain occupancies but overlooked in others. Building acoustics can affect comfort levels for occupants. Discomfort can be caused by overhearing conversations or another occupant’s noise, but it can also be caused by the fear of being overheard as well. Occupant privacy can be affected by poor acoustical qualities between spaces. Discomfort can also be caused by building components such as mechanical systems. Mechanical systems have a lot of moving parts and can cause structure borne noise pollution as well as air borne pollution.

Typical Acoustic Issues:

Occupant caused noise pollution is often an effect of poor choice of materials within and between spaces. These materials choices could have been lowest cost, or simply oversight in the design, either way these choices in most cases cause uncomfortable occupants on either end.

Structure borne noise pollution is an effect of poor isolation techniques. Isolation techniques ensure that mechanical equipment does not create a humming noise throughout the entire building. Rattling and a low drone can be heard in most small structures due to the lack of isolation techniques.

Airborne noise pollution from forced air mechanical equipment is primarily created by ducts. Ducts are often perfect carriers for sound waves and noise due to poor choices for duct design include insulation, duct sizing and layout.

Basic Resolutions:

Occupant pollutants can typically be resolved with thicker walls, insulation between walls and softer materials within spaces. Thicker walls allow for sound to travel into the space and bounce around enough to dissipate. Insulation within the wall cavities also allow for sound to be trapped and not transmitted. A double stud wall could be a better option since the designer provided a gap between the studs and the GWB to prevent the sounds from transferring through the rooms. Utilizing GWB which has a STC rating of 32-37 depending on the thickness of the GWB helps to reduce the noise. Softer materials within the spaces also absorb sound better and therefore reduce the amount of sound reaching the barrier walls. Materials can be upgraded in a retrofit; however, it is far less expensive to address these issues in the design stage of the building.

Architects need to apply different type of sound proofing details for different type of mechanical systems. Isolation techniques are source mitigation techniques. Things like gasketed slabs and rubber mats under equipment are all forms for reducing structure borne pollution at the source. Insulating the equipment and ensuring minimal contact with all other objects is another isolation technique. Isolation techniques have to be implemented in the initial design to certify that all equipment meets codes and clearances.

Airborne pollutants can be mitigated by proper duct insulation, sizing and layout, which have to be addressed in the design phase. Strategies also include minimizing contact points with other structural elements (i.e. systems to suspend ductwork from the ceiling), which has to be addressed in the construction phase. Ductwork can also form structure borne pollution if the contact points with the structure are too extensive. Addressing these retrofits in the post-occupancy phase can be costly.

Issues in Residence Halls:

After reviewing the Gallatin Hall drawings (wall and roof/ceiling types), it was observed that architects failed to properly soundproof the interior wall type. Architects used the acoustical insulation to reduce the unwanted noise generated by the HVAC systems. Unfortunately, the main issue with this type of detailing is that metal stud helps to transfer the sound between rooms since there is no gap between the gypsum wall board (GWB) and the metal stud. The strategies that architects used to sound proof the interior spaces seemed to be unsuccessful since the noise generated by the HVAC system can be heard in the hallways, conference rooms and the bedrooms. The noise generated by the HVAC systems are distributed equally around the building and obviously this noise can be distracting.

After reviewing the Yellowstone Hall drawings (wall and roof/ceiling types), it was observed that the architects took advantage of CMU blocks that have a higher STC rating than other materials which helps to reduce the unwanted noise from the HVAC systems. Also, architects take advantage of adding resilient channels to prevent the stud from transferring noise between rooms. STC rating of the interior wall types is similar in both buildings.

In both buildings, the noise levels increased closer to supply vents. From the observation it can be inferred that this noise is airborne and not structure borne. Both buildings are subjected to different levels of airborne noise. Gallatin Hall, contains higher levels of airborne pollution within the dorm rooms due to the forced air heating system implemented in all the dorm rooms. On the other hand, Yellowstone Hall only utilizes forced air in the common spaces and the humming dissipates within the dorm rooms.

Another source of the unwanted noise within both residence halls is caused by occupants. Noise from activities such as music playing, conversations and movies playing lingered in the hallway. However, while this noise was the most recognizable, it was sporadic and often trailed off fairly quickly.

Recommended Retrofits:

After review of the source of the unwanted noise, it's necessary to apply different design strategies to reduce the noise generated by the HVAC systems and occupants.

Material choices and additive panels are the easiest retrofit to implement for occupant induced sound pollution. Decorative sound absorbing panels should be added to the corridors and lounge areas of both buildings to reduce reverberation time and improve acoustical comfort. Many companies create acoustical panels that can double as art work to provide a more pleasing aesthetic (Appendix B – Figure B22 through B27). Another more expensive retrofit is to replace all the resident's doors with high-performance acoustic doors with have an STC rating for 43 to 64, which is closer to a wall than a door.

The next easiest retrofit is to install duct insulation and sound silencers at all supply vents. Sound silencers such as ISOVER glass wool can be placed within the supply vent to absorb any unwanted noise before the air is pushed through (ISOVER). Duct insulation, exterior or interior is also effective on reducing the airborne noises generated by the movement of air. There are a variety of duct liner designs that can help to reduce the noise. Most common are glass fiberboard liner, glass fiber blanket, honeycomb glass fiber silencer, and sinusoid glass fiber silencer (Appendix B – Figure B29).

Lighting/Daylighting:

Lighting is created through two categories: daylight and electric interior light. Design teams have to address both quantity and quality of lighting in spaces. The use and type of space determine the required light levels and qualities. The factors that affect the light levels include occupant age, task size, and glare. Daylight provides the most acceptable quality of light for many spaces.

Typical Lighting Issues:

In addition to ensuring adequate lighting levels, typical lighting issues that need to be addressed include: appearance of space, color, glare, distribution, integration with daylighting, and system control and flexibility. When considering appearance of space, issues such as composition of the lighting design, coordination with furniture arrangements, and style have to be considered to reinforce design intentions. Color encompasses color appearance, contrast and modeling of faces. For example: Harsh white florescent lighting can cause occupants to see colors and skin tones as grey and muted while harsh yellow lights can over saturate colors. Direct and reflected glare can result from both electric light sources and daylight. Glare affects visual comfort of the occupant and the ability to see. Space usage determines requirements for the distribution of light. Various issues that need to be reviewed for appropriate distribution of light include: uniformity, shadows, peripheral detection, light pollution, luminance of room surfaces. Appropriate integration with daylighting needs to be considered. For example, natural ambient light can often boost morale in a workplace, while direct sunlight can cause glare and thermal discomfort. In addition, contrast between bright windows and dark walls can cause visual discomfort. System control and flexibility have to be addressed when designing multi-purpose spaces.

Basic Resolutions:

IESNA Standards provide guidelines for adequate lighting levels in different spaces. These guidelines provide illuminance levels that incorporate occupant age, task size, and glare into the specifications. When addressing appearance of space, design teams should create a carefully designed visual composition which includes coordinating with furniture arrangements, and fixtures styles. Design teams also need to ensure adequate color appearance by implementing metrics such as Correlated Color Temperature (CCT) and Color Rendering Index (CRI), when selecting lighting systems. Direct glare can be mitigated by appropriate luminaire design. Reflected glare can be controlled by the use of appropriate surfaces. When addressing proper distribution in spaces, design teams should address issues such as luminaire spacing, pattern of light on the work plane, luminaire selection, and layering of lighting. Issues with inappropriate daylighting can be resolved in the design phase of the building by proper placement, sizing and shading of windows. Design teams should provide access to operating different lighting systems within a space to ensure multiple use. Systems such as task lighting, wall washing, accent lights, can be used in conjunction with overhead lighting to create layering of light which contribute to the visual attractiveness.

Issues in Residence Halls:

Incidents of glare were observed in the sky lounge areas and lobbies of both buildings. Glare was a result of openings in these spaces being designed with inappropriate placement, sizing and shading. The resultant large expanse of glazing (i.e. curtain wall systems) in these spaces was almost excessive due to minimal shading devices that were implemented. Glare control devices such as interior shades allowed occupants to control direct sunlight, but these still allowed solar radiation into the space, increasing the temperature of the space and contributing to thermal discomfort. These interior shades were also only implemented at occupant eye level, which in some spaces resulted in only half of curtain wall being unshaded. The problem associated with this is that these reduce views for occupants and are still allowing for solar radiation to penetrate a space.

Other issues documented were the color and use of electric lights in the dorm rooms. According to the occupant survey, electric lighting used in dorm rooms was found to be too white. In addition, widespread use of electric lighting in dorm rooms was observed to provide adequate lighting levels.

Recommended Retrofits:

In order to reduce glare, design teams need to consider alternative glazing types, use of matt finishes, and appropriate shading strategies. Replacement of existing glazing panels with options such as fritted, opaque glass, and thermochromic glazing reduces the amount of light within a space. Operable windows can be incorporated in retrofits to control the temperature of a space.

Indoor Air Quality:

When IAQ is bad, building owners and managers spend considerable amount of resources to resolving occupant complaints, dealing with extended periods of building closure, major repair costs and expensive legal action. When IAQ is good, buildings are more desirable places to work, to learn, to conduct business, and to rent. IAQ affects occupant health, comfort and productivity. Serious health impacts resulting from poor IAQ can range from spreading the common cold to asthma to even lung cancer from exposure to radon.

Typical IAQ Issues:

There are several reasons for poor IAQ within built environments, which include tight building construction schedules, prioritization of IAQ in the design and construction of buildings, selection, sizing and placement of HVAC system. Some general recommendations to improve IAQ include: inclusion of IAQ along with all other IEQ measures when deciding priorities in the design and construction process; correct selection and sizing of HVAC equipment in the building to ensure adequate supply of outdoor air and regulating humidity levels; design and placement of outdoor air intakes, avoiding placement of near potential contaminants (ASHRAE 2009).

Basic Resolutions:

In order to resolve issues concerning schedules and priorities an integrated design process should be used. All areas of the design team can work together to ensure IAQ is continually reviewed and equipment revised.

Ductwork can consume a lot of space. A number of space saving solutions are available which include the use of plenum space for return air ducts, use of ducts with bigger aspect ratios, and selecting a different system such as radiant heating. However, these strategies have negative implications on IEQ and energy. For example: plenums are associated with excessive infiltration and dust collection; ducts with bigger aspect ratios contribute to acoustical discomfort and higher energy consumption; while radiant slabs do not have a way to regulate deliver of outdoor air and humidity in spaces.

Sizing the correct forced air system can change the IAQ drastically. Filtration is calculated through outdoor airflow rates which are determined by the International Mechanical Code (IMC) for occupancy type. These rates are the bare minimum and are based on ventilation requirements specified by ASHRAE Standard 62.1. Sizing a forced air system to deliver adequate supply air rates is not only about the size of the handling units and fans, but also the ducts running through the spaces. If the floor to floor height is pre-determined, changes later to provide enough space for ducting will be costly.

Placement of Outdoor Air Intakes is crucial to providing adequate IAQ. Placing intakes near potential contaminants can cause poor IAQ. The south façade is ideal for the installation of transpired solar collectors. The southern part of the site is also a great place for parking lots and loading docks (a source of pollutants) to reduce snow build up in the cold months. Parking lots / loading docks and outdoor air intakes are not favorable to be within the same vicinity. One recommendation is to place the parking toward the north-west façade if possible and the intakes on the south façade, keeping the intakes as far from the contaminants as possible. Operable windows may be used to provide ventilation on days when temperatures and humidity are within the thermal comfort range. But when temperature and humidity are outside the standard thermal comfort range, the intake of untreated outdoor air may potentially cause damage to interior surfaces and systems.

Issues in Residence Halls:

During the research, the main issue with IAQ in Gallatin Hall that was observed was within the boiler room. The high concentration of Glycol used for heating, put off a foul odor. While this measurement was undetectable by the instruments, this odor was nauseating. The odor did not appear to transfer to any living spaces because the boiler room had a mechanical ventilation exhausting the room's air, however when the door was open for more than a few minutes the odor traveled to the hall. Maintenance of this space also appeared to be lacking, there was spillage and accumulated grime around the drains.

For Yellowstone Hall, the logged measurements of a sample dorm room showed that on average CO2 levels exceeded the acceptable limit for one hour per day. While the corridors and bathrooms were mechanically ventilated, the dorm rooms relied on operable windows for ventilation. This situation is unfavorable in a cold climate such as Montana because the intake of untreated outdoor air may potentially cause damage to interior surfaces and systems.

Recommended Retrofits:

Before recommending a retrofit for Gallatin Hall, the maintenance and sanitation of the boiler room should be the first priority. Once the room is cleaned up and maintained, evaluation should be reviewed again. If the room is still foul, one retrofit to put in place for this room is to add ductwork into it to provide adequate ventilation of the space. For Yellowstone Hall, introducing duct work into each dorm room is not feasible in terms of cost considerations, spatial limitations and appropriate acoustical treatment. A feasible retrofit may include adding louvers to the doors to allow for passive ventilation to happen more easily if the door is closed. However, adding louvers to the doors may have an adverse effect on acoustics and privacy that needs to be considered.

Thermal Comfort:

Thermal comfort is an important IEQ in buildings. Research has found that buildings in which occupants report unacceptable thermal comfort, result in negative effect on occupants in terms of health and productivity. This is particularly important in dormitory buildings, where students are residing and spending substantial amounts of time inside.

Thus, designing buildings with thermal comfort in mind, by using passive and active strategies is crucial.

Typical Thermal Comfort Issues:

Adequate thermal comfort requirements differ for different space use and is dependent on individual occupant preferences. There are six primary factors that must be addressed when defining conditions for thermal comfort, which include: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity (ASHRAE 2017). A huge aspect of addressing the issue of thermal comfort is addressing localized non uniformities in thermal sensation. These issues include: asymmetric thermal radiation, draft, vertical air temperature difference, warm or cold floors. Common causes for asymmetrical thermal radiation include cold windows, improperly sized heating panels, and cold or warm equipment. Drafts are caused by infiltration, inappropriate air speeds from supply air ducts in spaces. Vertical air temperature differences are associated with certain HVAC systems such as underfloor air conditioning systems and displacement ventilation systems. Warm and cold floors can be a result of supply air plenums being run under floor, radiant heating panels or floor construction such as overhanging floors or floors over crawl spaces. Secondary aspects of affecting thermal comfort include: age, adaption, gender, seasonal and circadian rhythms.

Basic Resolutions:

Asymmetric thermal radiation can be resolved by, insulating windows, reducing solar gains through windows, reducing air infiltration, and if possible providing even distribution of heating and cooling panels for radiant systems. When mitigating draft, resolutions include reducing air infiltration and providing appropriate air speeds for supply air in spaces. In order to reduce vertical air temperature differences in space, design teams should aim to provide even distribution of heating and cooling panels for radiant systems. Solutions for reducing negative impact of warm or cold floors on thermal comfort, design teams should consider providing appropriate material finishes, improving insulation under floors, and reducing infiltration from underfloor plenums.

Issues in the Residence Halls:

According to the measurement data obtained from HOBO loggers, both Gallatin Hall and Yellowstone Hall were not found to be within the acceptable thermal comfort zones. However, when this data was compared to the results of the student survey, it was found that most (>50%) of residents were satisfied with the thermal comfort of their individual rooms. This confirms the dependence of thermal comfort on aspects such as age, adaption, seasonal and circadian rhythms. Also, the ability to manipulate space conditions by occupants to ensure comfortable conditions played a key role in satisfaction with thermal conditions. The use of strategies such as operation of fans, blinds and clothing contributed to the ability of the occupants to manipulate space conditions.

Regardless of installation of dedicated cooling systems in the sky lounge of Gallatin Hall and lobby areas of the Yellowstone Hall, measurements documented greater swings in temperatures for these rooms than what was recorded in the dorm rooms. This increased swing in temperatures was due to the presence of large glazing panels in these rooms, which in turn contributed to the creation of uncomfortable thermal conditions.

Recommended Retrofits:

With the basic resolutions in mind, addressing the major issue of temperature swings caused by solar radiation being trapped in rooms with >50% glazing is critical. In order to improve thermal comfort the reduction of solar radiation gains through windows needs to be considered. Design teams need to consider alternative glazing types, operable windows, and appropriate shading strategies.

Replacement of existing glazing panels with glazing options such as fritted, opaque glass, and dynamic glazing (i.e. thermochromic glazing that uses solar radiation to tint the surface of windows) (Efficient Windows Collaborative, 2019) reduces the amount of unwanted solar heat gains within a space. In addition, operable windows can be incorporated in retrofits to control the temperature of a space. Automated operable windows may be installed to ensure that the space does not get overheated. Retrofitting with exterior shading is also a possibility but involves extensive construction costs. Retrofitting with additional, thicker interior blinds, is a more economical option but is not very effective because of the solar radiation that is trapped between the glazing and the interior blinds.

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