University of Illinois Urbana-Champaign

TEAM INSP.I.R.
PROJECT RETRHIGH

University of Illinois Urbana-Champaign

U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON

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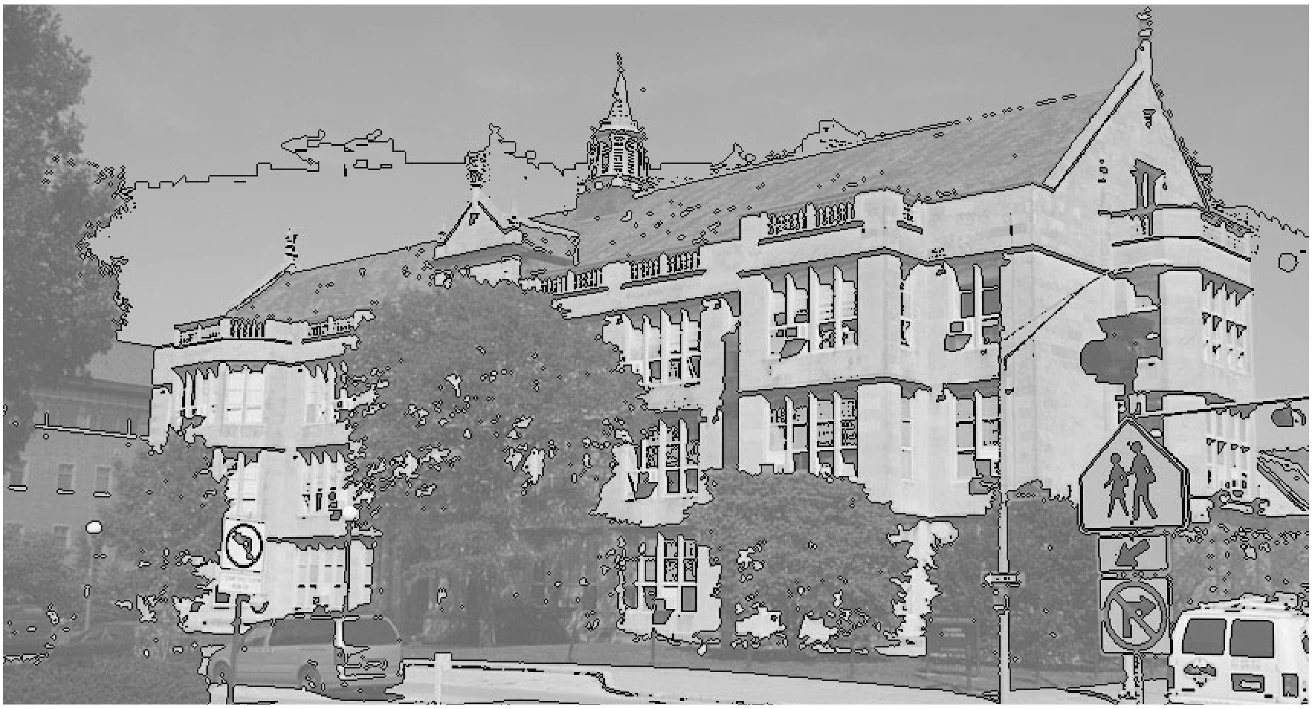
UNIVERSITY OF ILLINOIS ELEMENTARY SCHOOL



PROJECT SUMMARY

With origins as early as 1876, University Laboratory High School (Uni) remains a unique element on the Illini campus. However, in its current form, it is not meeting the potential program proposed by the original architect.[1] This, combined with extremely subpar sustainability metrics[2], inspired Illinois Retrofit (INSP.I.R.), in conjunction with Facilities and Services, to reimagine a complete Uni. Our retry of the original design, RetrHigh, will help to educate and excite the next generation on the topics of sustainability and building science while furthering the University's commitment to the Illinois Climate Action Plan (iCAP)[3].
INSP.I.R. aims to develop the originally proposed east wing with modernized sustainable design while reinforcing the dual purpose of the building: education and education research. The new addition will provide faculty and students with proper gymnasium, theatre, auditorium, cafeteria, and additional offices/classrooms.

PROJECT DATA
Location: Urbana, IL
Lot Size: 97,260.78 ft2
Building Size: 54,941.8 ft2
EUI Target: ≤ 57 kBTU/ft2yr
Estimated Utility Cost: $1,670/month

TECHNICAL SPECIFICATIONS
Existing/New R-Values
Wall Insulation: 13/18
Foundation Insulation: 10/15
Roof Insulation: 35/43
Existing/New U-Factors
Windows: 0.95/0.30
HVAC – Conditioning Energy Recovery Ventilator (CERV)
Onsite PV: 250 kW

1 "Preface - University Laboratory High School - University of ...." https://uni.illinois.edu/about-uni/preface.shtml. Accessed 17 Nov. 2019.

2 "THE IMPACT OF PLACE: - UOCPRES - University of Illinois ...." 28 Aug. 2018, https://www.uocpres.uillinois.edu/UserFiles/Servers/Server_7758/file/UIUC/mastrpln/uiucmp-tech-rpt-20180828.pdf. Accessed 17 Nov. 2019.

3 "Illinois Climate Action Plan - institute for sustainability, energy ...." https://sustainability.illinois.edu/wp-content/uploads/2016/12/2015iCAPweb.pdf. Accessed 19 Nov. 2019.

TEAM INFORMATION

Team ISNP.I.R.'s parent organization, Illinois Solar Decathlon, has a rich history of participation in both the Design and Build Challenge competitions, with roots in Race to Zero. Our team's strength lies in our educational diversity and mix of upper and lower level students, with members from various engineering disciplines, architecture, and technical systems. Together, our team aims to work alongside Facilities and Services to develop and implement University sustainability goals while developing our professional skills.

Role	Name	Level	Department
Project Manager	Cole Froelich	Graduate	NPRE
Architecture	Prajakta Gharpure (Lead)	Graduate	ARCH
	Adalberto Dejesus	Graduate	ARCH
	Kriti Chaudhry	Graduate	ARCH
	Jesse Chukwuka-Dibie	Sophomore	ARCH
	Oka Bavuudorj	Junior	ARCH
HVAC	Peter Davis (Lead)	Sophomore	ME
	Matthew Lawrence	Sophomore	ME
	Syed Touseef Ahmed	Graduate	CEE
	Nana Akenten-Busia	Junior	TSM
	Devansh Kothari	Freshman	ME
PV&E	Kyle Kovitz (Lead)	Graduate	NPRE
	Kristian Martinez	Graduate	NPRE
	Elisa Krause	Sophomore	ECE
Water	Lara Iriarte (Lead)	Junior	CE
	Rong Jin	Senior	ABE
	Kabir Fakoya	Sophomore	ABE
Energy Analysis	Khee Lim Low	Graduate	ME
	Alkesh Sumant	Sophomore	ECE
Construction Management	Angshuman Baruah	Graduate	CEE
	Kweku Osei	Sophomore	CE
Home Automation	Jack Lanser	Junior	ECE

ACADEMIC PROFILE

Our home, the University of Illinois at Urbana-Champaign, is also home to some of the most prestigious architecture and engineering departments in the United States. The newly minted Grainger College of Engineering is known for innovations such as the PLATO computer system, a predecessor to many modern internet collaboration technologies, as well as entrepreneurs like PayPal co-founders Luke Nosek and Max Levchin. The Illinois School of Architecture is famous for producing the first male and female architecture graduates in the United States, Nathan Ricker and Mary Louisa Page. Our diverse course catalog continues to expand offerings outside of core courses for bright students interested in sustainable design.

A particularly unique course, ABE 498, allows students participating in the design challenge to present their work for credit while encouraging further University collaboration.

Couse	Name	Couse	Name
ABE 436	Renewable Energy Systems	ECE 333	Green Electric Energy
ABE 476	Indoor Air Quality Engineering	ECE 476	Power Systems Analysis
ABE 498	Engineering Design for a Net-Zero Solar Smart-Home	ENG 571	Theory of Energy & Sustainability Engineering
ACE 210	Environmental Economics	ENSU 310	Renewable & Alternative Energy
ARCH 321	Environment, Architecture, and Global Health	ME 400	Energy Conversion Systems
ARCH 519	Conservation of Building Materials	ME 432	Fundamentals of Photovoltaics
CEE 424	Sustainable Construction Methods	TSM 372	Environmental & HVAC Control
CEE 446	Air Quality Engineering	UP 136	Urban Sustainability

ACADEMIC PARTNERS

Illinois Solar Decathlon continues to build stronger relationships with relevant faculty each competition cycle, creating a resource well for future teams and empowering University collaboration.
Professors and staff assist students by reviewing design decisions and implementations. Seminars are organized throughout the semester to pinpoint important topics and encourage discussion. Specific recognition is given to Prof. Wang who hosts our course, ABE 498.

Name	Department
Prof. Xinlei Wang	ABE
Prof. Yun Kyu Yi	ARCH
Prof. Scott Murray	ARCH
Prof. Ashlynn S. Stillwell	CEE
Prof. Warren Larvey	NRES

INDUSTRY PARTNERS

Team RetrHigh began working with UIUC Facilities and Services from the initialization of the challenge to identify campus buildings most in need of a sustainable redesign. Their department has provided a wealth of resources to understand campus construction management and sustainability goals. Particular praise is given to Morgan White, Associate Director for Sustainability, who acts as a student liaison in student lead projects.
Build Equinox, the company behind the CERV system, has provided additional resources and technical advice to our HVAC team for their design implementation. Co-founded by retired University professor Ty Newell, Equinox is an innovator in the HVAC industry. By manufacturing with recyclable materials and 100% renewable energy sources, Equinox sets a gold standard for modern sustainable industry.

PROJECT HIGHLIGHTS & GOALS

RetrHigh's redesign focuses on a few global goals which help to restrict and direct design choices. Preservation of the original building's facades and interior detail is considered in each retrofitting procedure and in the connection to the east wing. This retains the rich history and unique nature of the west wing but creates many challenges in applying modern techniques.
As RetrHigh is a school, including an educational element seemed natural. Many Uni students enroll at UIUC after graduation; priming these young minds with sustainable design fundamentals expressed through the building they learn in will lead to continued course development and research. Additionally, productivity improvements through air quality control and environmental comfort enhance the ability of the building to provide its core purpose.

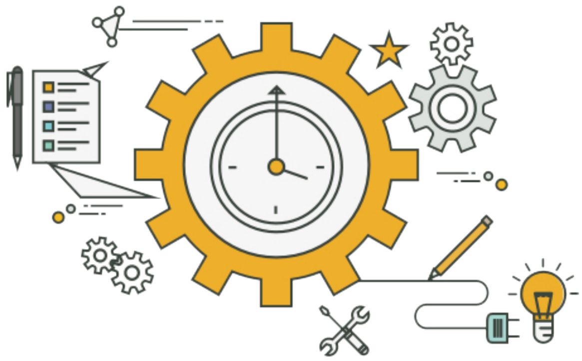


Fig 1. Project involved collaboration between several students from different fields, innovation and idea generation

These goals and their achievement through design are explored below, organized by the Solar Decathlon competitions with the most direct relevance.

1 Fig 1. https://www.proprofs.com/c/wp-content/uploads/2016/09/The-Importance-of-Goal-Setting-.jpg

MARKET POTENTIAL

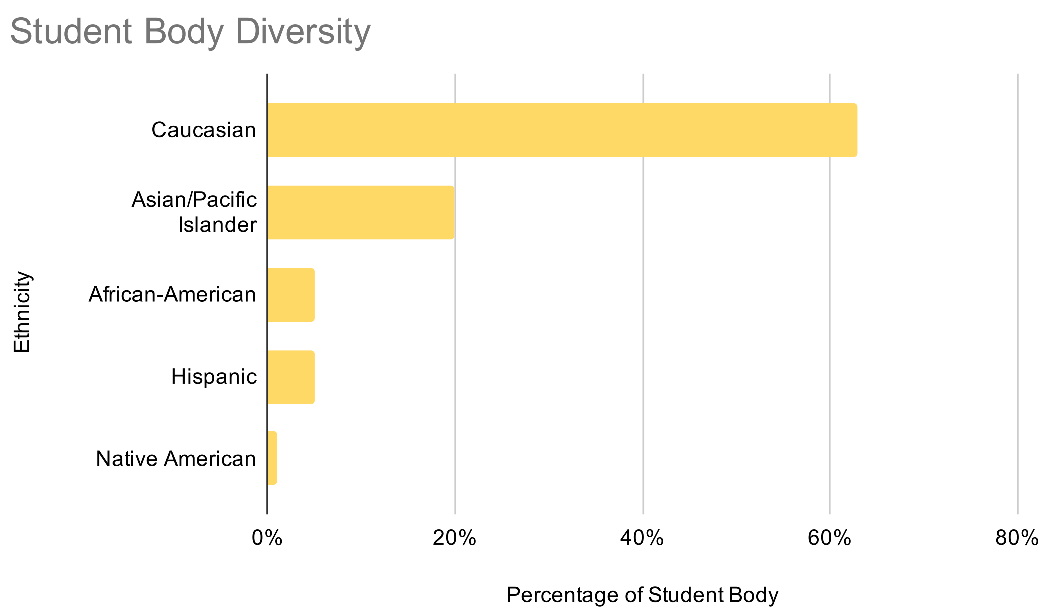
Project RetrHigh is highly marketable to both the primary financer (UIUC) and the intended occupants. Various efforts have been put forth by University staff to rebuild the high school and fully realize its original intended form. These have not been implemented due to limited space and higher priority given to student housing construction. Our solution, which utilizes the already allocated lot space, allows for retrofitting during the summer and new construction throughout the school year with minimal disturbance to classroom activities. A large pool of grant capital decreases University financial burden in a market which already has high incentives for investment.

The least resistance would come from parents, even with some construction funds likely sourced from their donations. With primary focuses in education opportunities and student health, RetrHigh will gain community support rapidly, further enticing the University to invest.

Research into lowering construction costs further by employing pre-formed structural walls, minimizing material waste, and intelligent construction scheduling are being explored to make the project more attractive in terms of turnaround time for both investors and contractors.

MARKET AUDIENCE

RetrHigh aims to improve the comfort and learning environment for an average student body of 300, alongside roughly 50 staff members. The student body is relatively diverse, and 1 in 3 students have a University faculty parent. Uni boasts impressive alumni including Theodore Gray, co-creator of Mathematica, and three Nobel laureates: Philip W. Anderson (physics), Hamilton O. Smith (medicine), and James Tobin (economics).

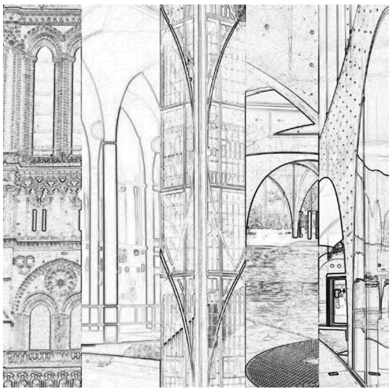


Uni has been on the forefront of curriculum development and innovation, even after separating for the College of Education as a proper laboratory high school. Students and their parents have come to expect an exemplary education which the current structure struggles to provide. Classroom upgrades are gradually being implemented, but limited space and poor environmental quality continues to hinder progress.

By completing the original vision of a two wing high School, team RetrHigh will provide students and staff with updated educational spaces, crucial missing amenities, and ample space to develop the young minds of the future.

DESIGN STRATEGY

INSP.I.R. aims to merge modern and gothic architectural styles through a gradual transition in the facade from west to east using elements like cladding, framing, and sustainable materials. Integrative landscape and use of classical proportions form the basis of the architectural design approach. The benefits of the existing University utilities (steam and chilled water) are being considered alongside modern solutions. A variety of PV technologies, placements, and installations are being examined to maximize exposure while avoiding alienation.



Gradual facade transition from Gothic Revival to modern architectural styles

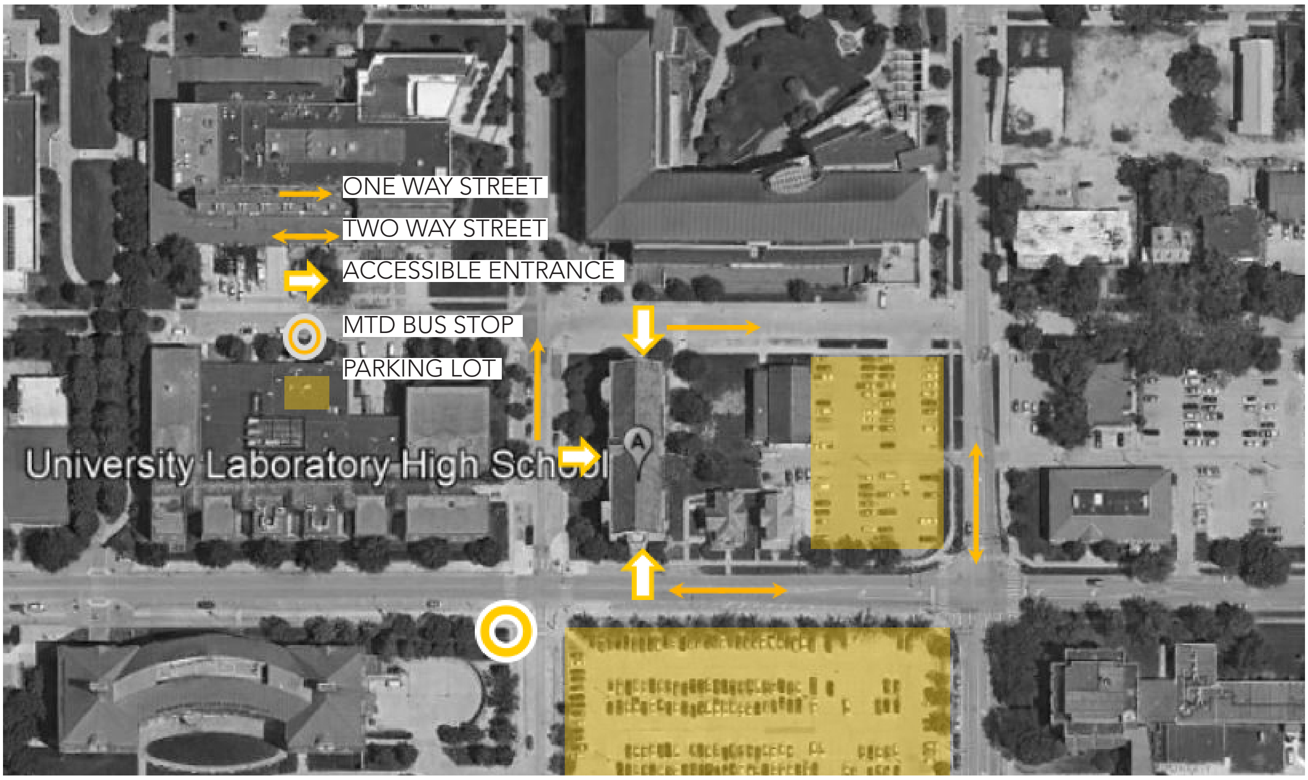
DESIGN CONSTRAINTS

LOCATION AND NEIGHBORHOOD

The RetrHigh site is located on a rectangular lot just east of the southern edge of the University engineering quad. Students often take a quick ten minute walk south to Green Street to access a variety of restaurants, as well as having ample access to University libraries scattered around campus.

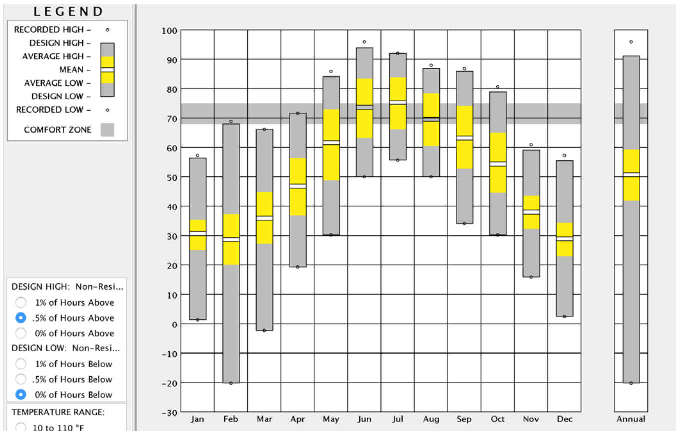
TRANSPORTATION

Uni does not have access to district bussing services, so a majority of students are currently dropped off at dedicated unloading lanes on Stoughton. Students can also take advantage of Urbana-Champaign's Mass Transit District's convenient bus stops nearby or utilize the University's bike friendly roads. Parking for staff and upper level students is available in the east adjacent parking lot, with additional streetside and University parking nearby. We plan to improve the safety and convenience of drop off lanes by routing them through the aforementioned parking lot.

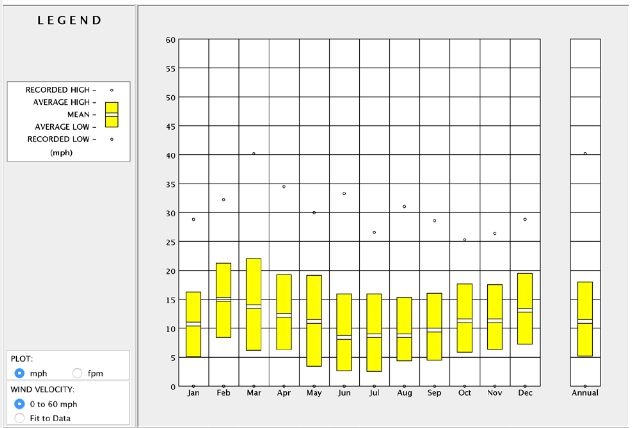


CLIMATE

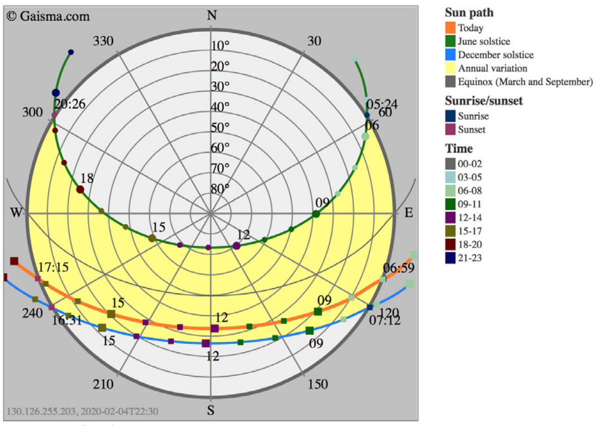
The city of Champaign has a humid continental climate. The summers are hot with temperature exceeding 90 °F on some days whereas the winters are cold and moderately snowy the temperature falling below 0 °F about six days annually. The average annual percipitation is 39.68 inch and the average snowfall is 22.8 inch. The average wind velocity is about 12 mph.



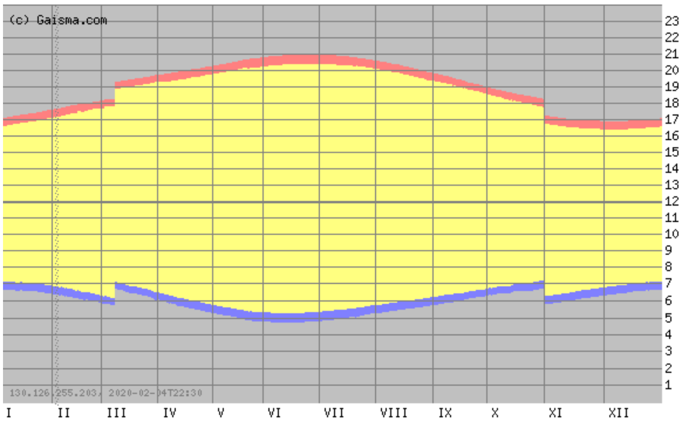
Temperature range[1]



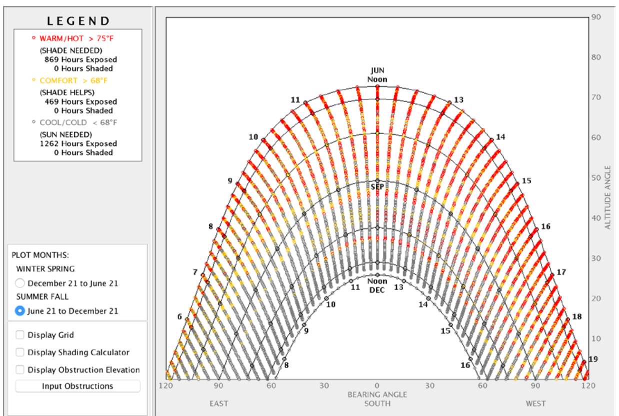
Wind Velocity



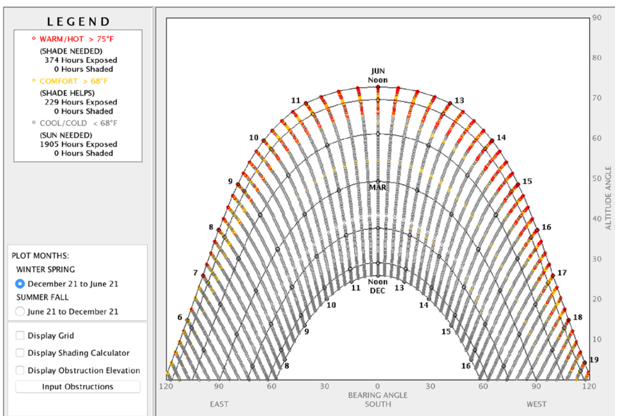
Sun path diagram



Daylight Hours

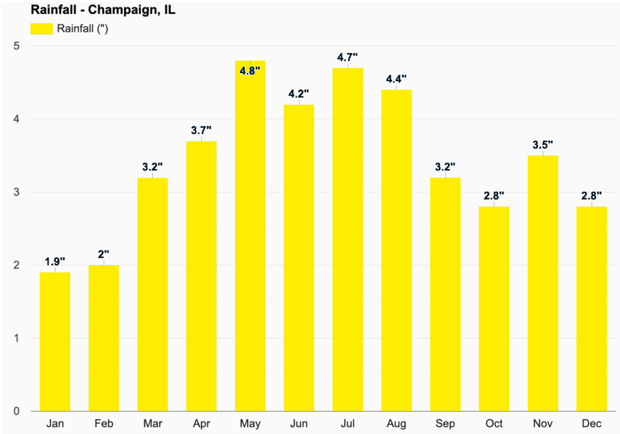


Sun shading: Jun - Dec

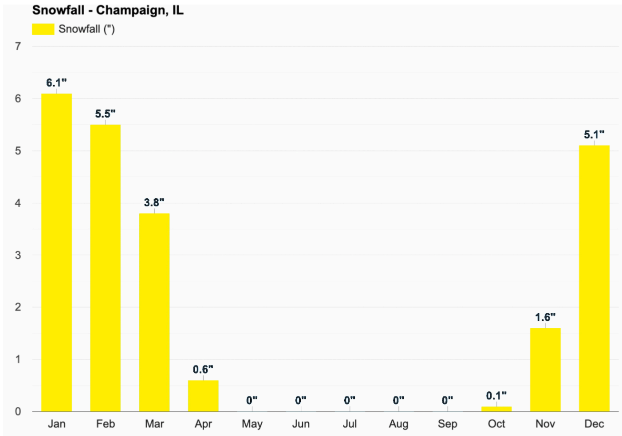


Sun shading: Dec-Jun

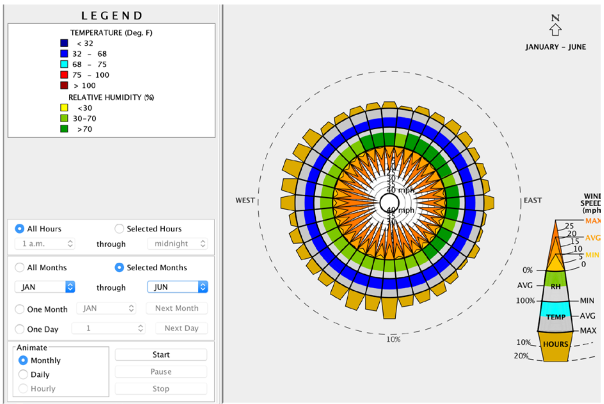
1 Data from Climate consultant



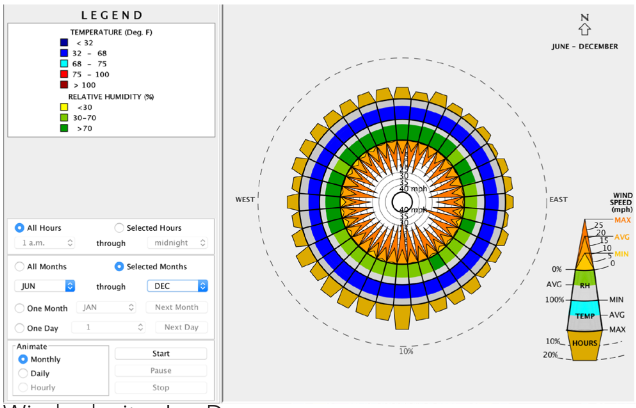
Average Rainfall [1]



Average Snowfall



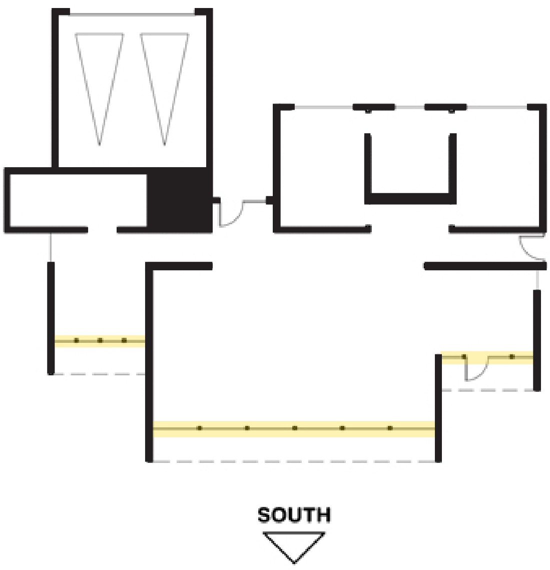
Wind velocity: Jan - Jun



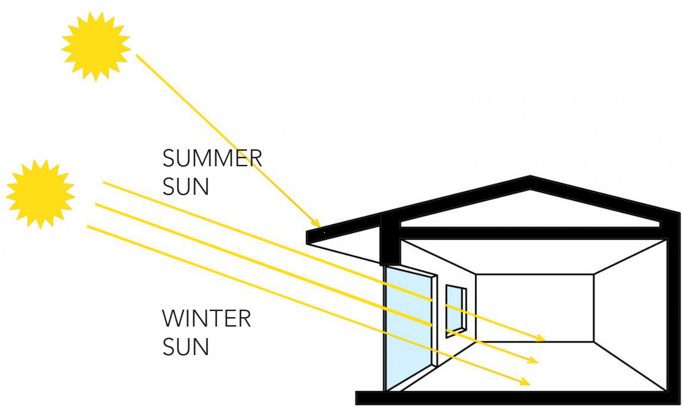
Wind velocity: Jun-Dec

DESIGN STRATEGIES

Solar Heat Gain: Solar glazing (facing the equator) is sized to admit enough sunlight on an average sunny winter day to heat a space over the full 24-hour period. Design overhangs to fully shade in summer

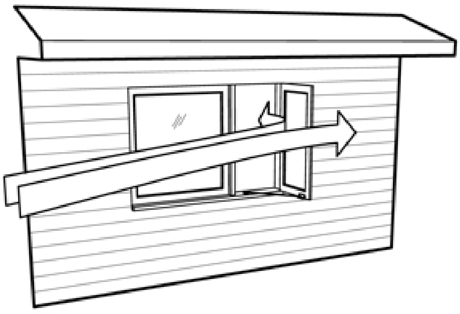


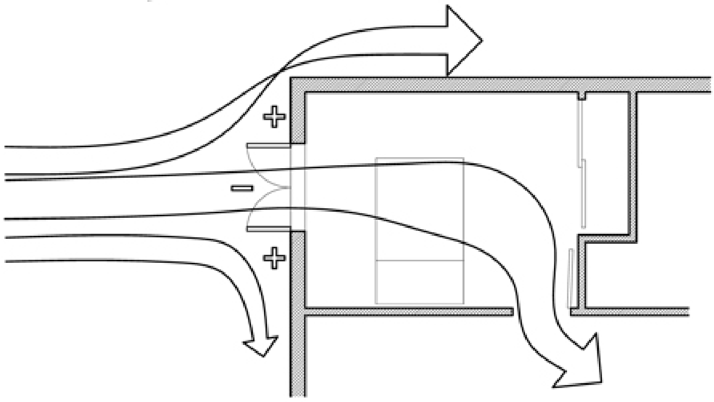
South facing glazing



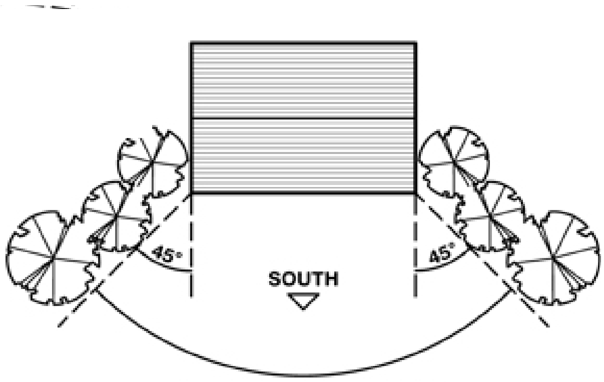
Solar shading

1 Data from Climate Consultant





Tree Placement: Trees (neither conifer nor deciduous) should not be planted in front of passive solar windows, but rather beyond 45 degrees from each corner



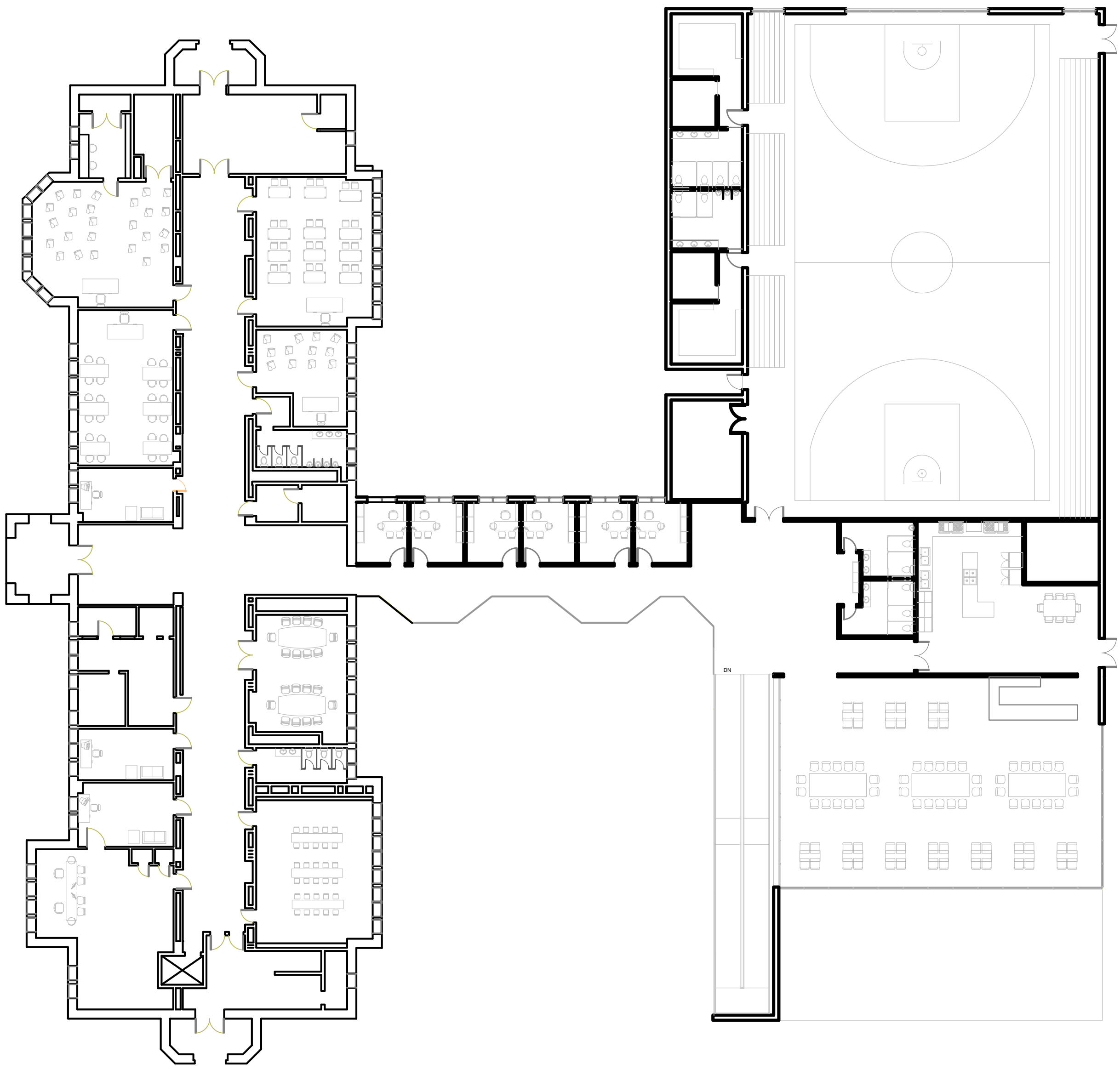
Thermal mass: Masonry floors, walls and/or ceilings – absorb and store daytime solar heat in winter for release at night. A large portion of the sunlight (heat gain) admitted into a space during the daytime must be stored inside the same space for release during the nighttime hours.[1]

1 Data from Climate Consultant

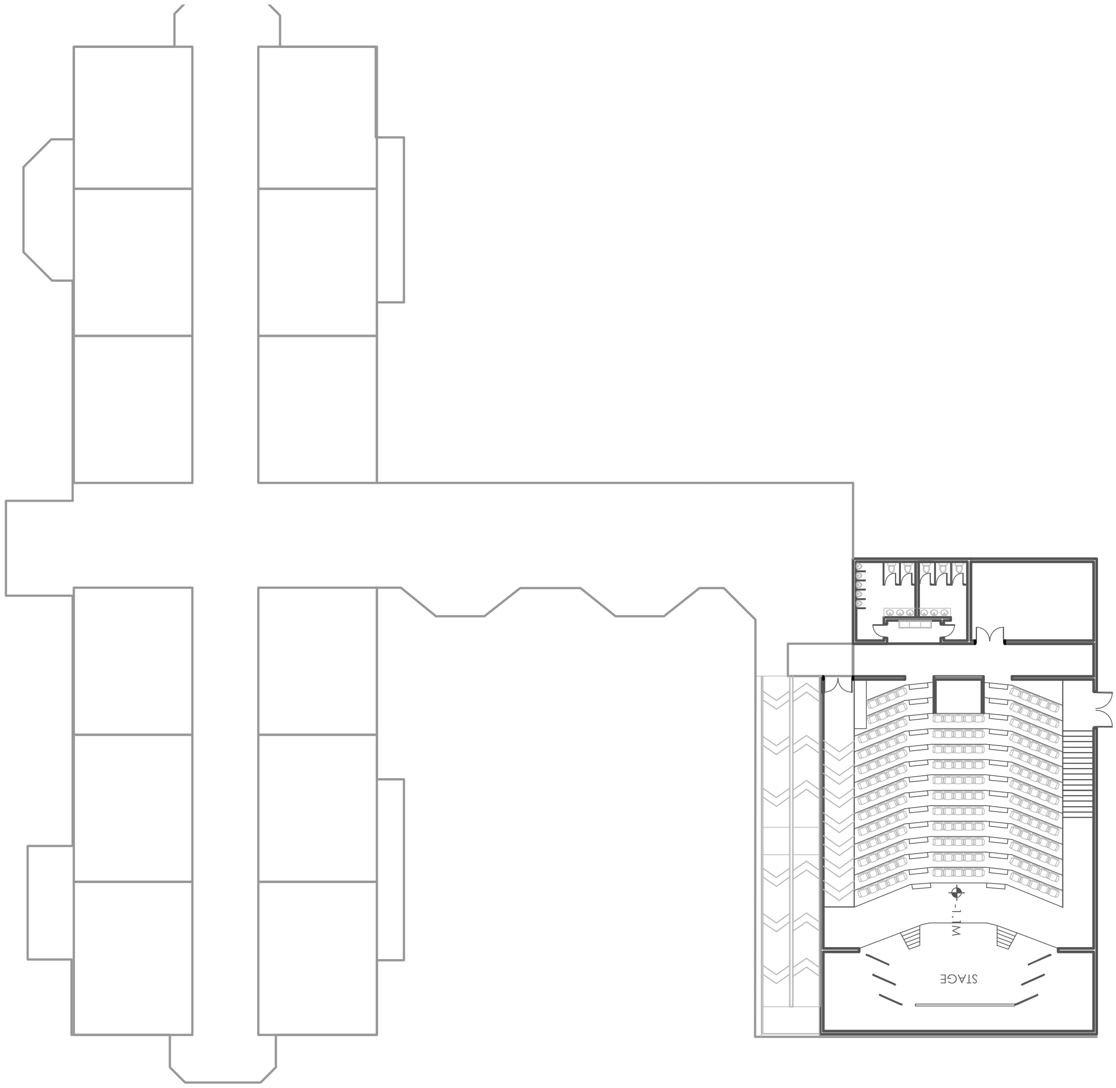
ARCHITECTURE

The existing structure poses many interesting, but difficult challenges for architectural design. Our team has a strong desire to preserve the history and beauty while incorporating modern design elements in the new east wing. This lends towards hidden retrofitting of the existing west wing by upgrading window panes, framing, and sealing, flattening the roof, and covering exposed utility runs in classrooms.

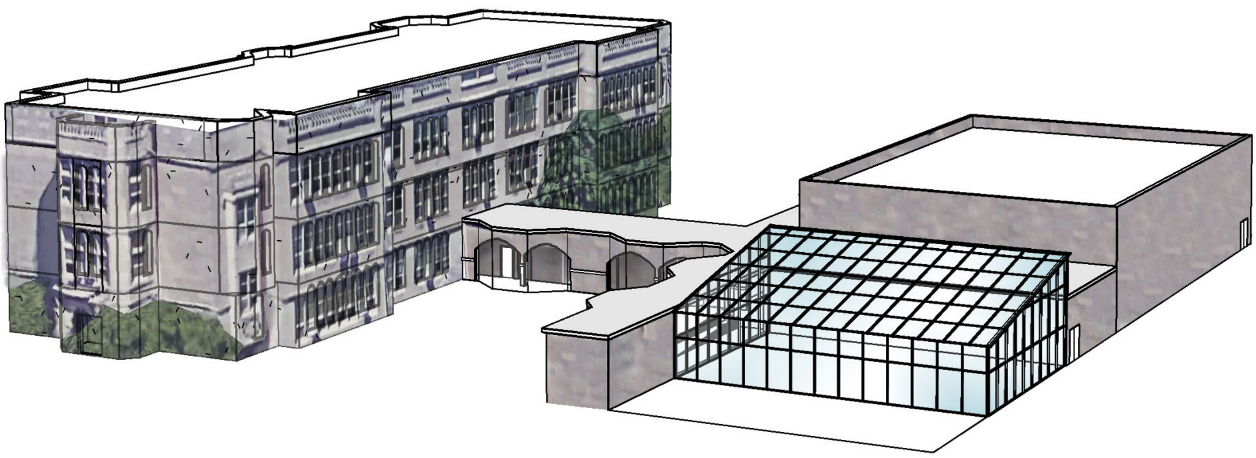
Much more freedom is available in the design of the east wing. By providing more effective spaces for offices, a cafeteria, classrooms, and a gymnasium, the counterparts in the existing structure can be converted to more comfortable classrooms and offices. The gym employs transparent aerogel insulation, providing privacy while creating an active facade of the activities within. Southward, the solarium cafeteria maximizes heat capture from sunlight while providing views of the active University and scenic courtyard.



Ground Floor Plan

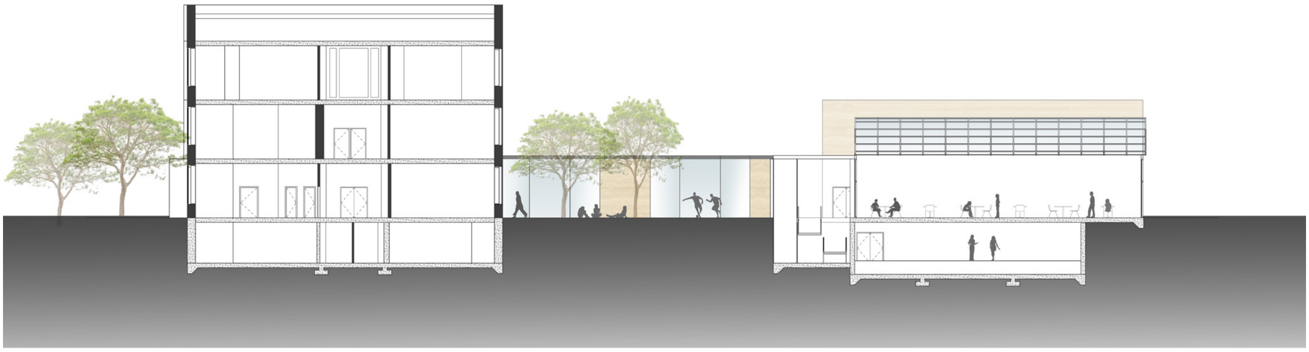


Basement plan



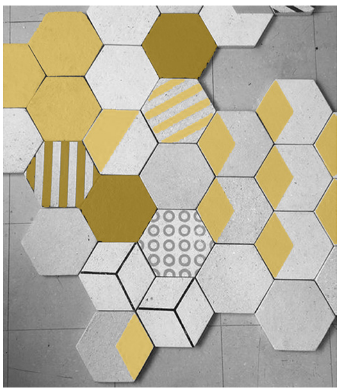
South Elevation

The solarium is zoned on the south facade for maximum heat gain. The design of the corridor connecting the existing building and the new addition offers spaces for interaction. The Wall and flooring in the corridor is interactive and informative.



South Section

Extra attention has been paid to the transition between the two distinct spaces. Using glass and sustainable cladding with stone-like texture, a gradual progression from the old to the new provides both connection and distinction between the wings. The hallway flooring contains Pavegen tiles which respond to occupant footsteps, allowing for integration with energy monitoring to convey sustainability goals and progress through user interaction. Recycled papertile wall panels allow students and staff to express creativity similar to the colorful handprints which cover the walls of the existing Uni.



1. Pavegen - Interactive, innotvative
Footsteps into enegry.
2. Papertile - Recycle, personalize, patterns, design

RELEVANT CODES AND STANDARDS

The University provides a very comprehensive building code which will act as our primary source of reference. If these codes are lacking in detail or another is found to be more strict, other references will be used; however, we have not found this to be necessary.

WALLING SYSTEMS

COMPOSITE SOLAR WALL - South Facade

This type of wall includes glazing, non-ventilated air layer, massive wall, ventilated air layer, installing panel, upper vent, lower vent and anti-reverse thermo circulation system.Its functions are as follows:

1. Massive walls absorbs part of the solar energy and heats up by greenhouse effect.
2. Part of this energy is exchanged with the air through convection depending on the thickness of the walls.
3. Just a small part of this energy is release into the building.[1]

All the aforementioned stages of the composite solar wall are to avoid overheating and reverse heat circulation. In general, the composite solar wall has some advantageous such as: good heat resistance, no infiltration of cool air, reducing of stored supply in the massive wall and the supply is controllable at all times. Having said that, the main downside of this wall is that a preventative system is essential to be used in order to avoid heat circulation in the ventilated air layer. This problem occurs when massive wall is cooler than the air in the ventilated layer. To prevent this, plastic film is inserted in the vent, which functions as a thermal diode.

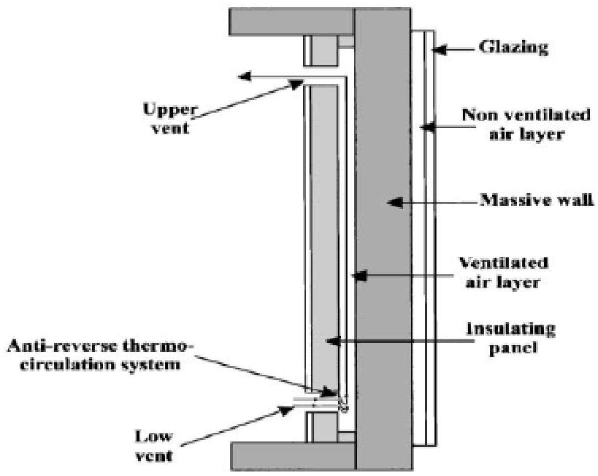
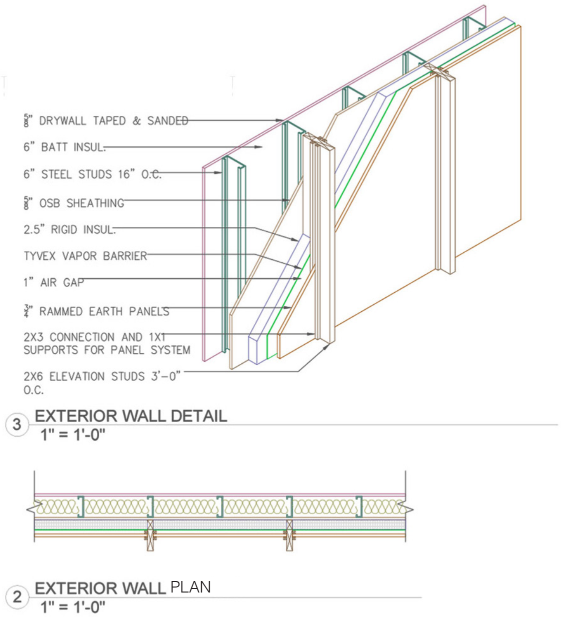
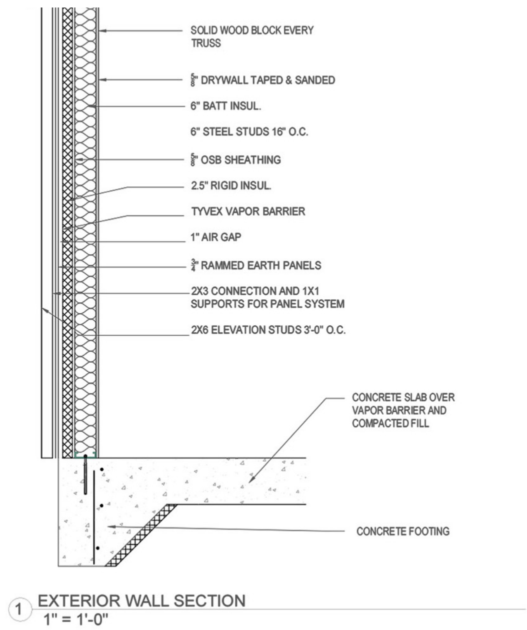


Fig: Solar Composite Wall

DETAIL OF THE MASSIVE WALL





1 Haleh Sadeghi , Saeed Reza Mohandes , The Hong Kong University of Science and Technology https://www.researchgate.net/publication/271195907
2 Saban Andi, Kriti CHaudhary, Prajakta Gharpure, Healing Outpost, Master's Project, University of Illinois Urbana Champaign, 2019.

In order to have effective insulation the massive wall is composed of metal studs with rammed earth panels on the exterior. Rammed earth has R Value of approximately 2.48 depending on the thickness. The thickness can vary from 100mm to 400mm thick. Rigid Insulation, OSB sheathing followed by Batt insulation is used for higher energy performance.

The entire combination with Glazing, air gap, rammed earth - metal studs wall, air gap and insulation layer with plastic film air vents creates a rock-solid system for reducing heat loss and maximizes insulation.

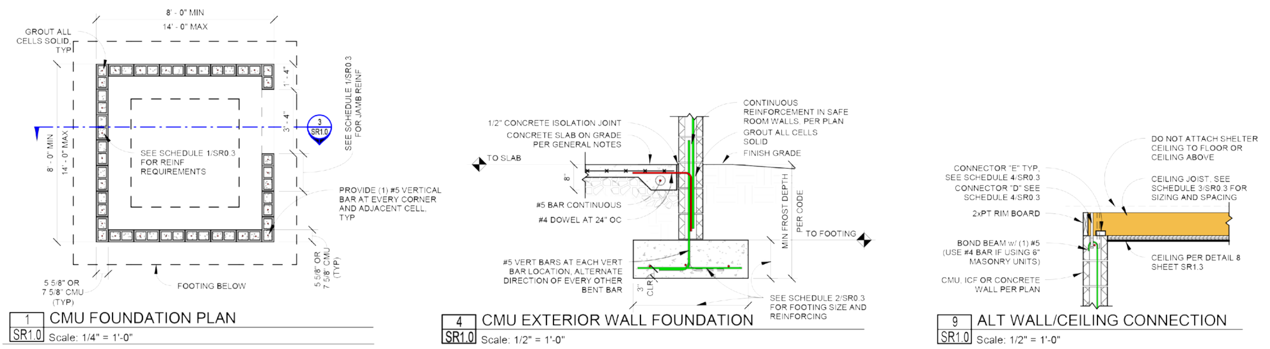
On rest of the facades, rammed earth -metal studs wall is used. Composite Solar wall is expensive and hence restricted to the facade receiving maximum incident sunlight.

RESILIENCE

With any building, but especially in the design of school, safety of residents must be carefully considered. Illinois is prone to tornado weather events, requiring secure and resilient spaces where occupants can wait out the storm. The partial underground theatre space proposed in the east wing will provide ample space for a full student body and staff with thick concrete walls, free of glass and other shatter prone materials. The ramp entrance provides easy access for disabled or injured persons.

Battery systems are being considered to provide an alternative method to store excess energy produced by the solar arrays for disaster scenarios. This system will be sized to run critical loads for the extent of predicted catastrophes or grid blackout.

Additional considerations in security systems, visibility, and traffic control are expressed through elements of architecture and engineering. In light of contemporary events, their need cannot be ignored; however, efforts will be made to blend these solutions into the architectural flow or hide them from sight.



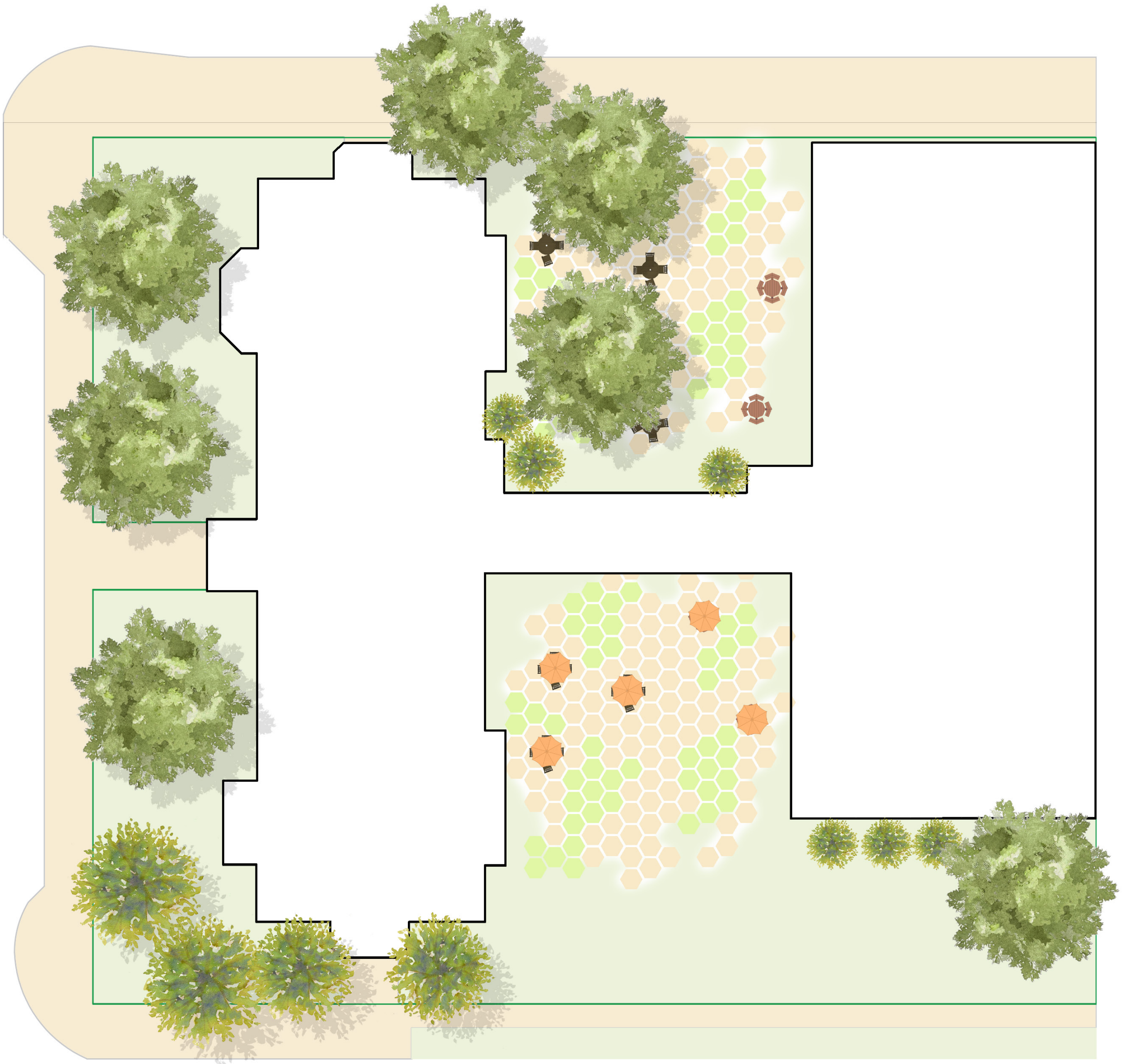
FEMA - Wall structure - For tornado resilience

SOLAR PANEL INSTALLATION

The beautiful gothic architecture of the existing structure poses challenging problems in terms of solar panel installations. By leveling the roof of Uni, panels can be more effectively hidden. Installations over the parking lot and scattered throughout the courtyard provide additional capacity while emphasizing the transition towards the more modern east wing.

Parking lot covered with solar panels

LANDSCAPE DESIGN



The landscape will function as an extension of the cafeteria and student lounge space. It will feature shrubs and native deciduous trees which will provide shading for comfort and screening for privacy of users. As water evaporates into the atmosphere off of plants and trees through the evapotranspiration process, the surrounding atmosphere is cooled. The courtyard surface will have a playful design that combines pavers with vegetation which will act as a center for learning and recovery. The pavers in the design are permeable which will help reduce stormwater runoff which holds a risk of carrying pollutants on the street into the nearest body of water and allows stormwater to infiltrate into the soil to replenish the groundwater.

Fig: Shows honey-comb landscape pattern iteration

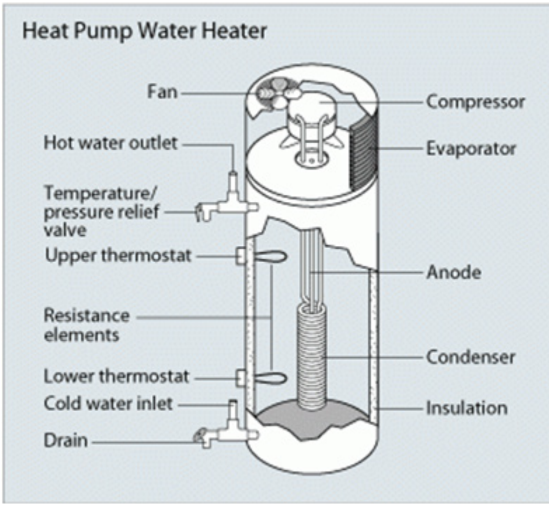
Landscaping for shade - https://www.energy.gov/energysaver/landscaping-energy-efficient-homes/landscaping-shade
Outdoor Design Source - https://www.outdoordesign.com.au/news-info/honeycomb-piazza/4566.htm
Organic Lock-
https://www.organic-lock.com/benefits-permeable-surfaces/

WATER EFFICIENCY AND CONSERVATION STRATEGIES

The approach involves strategies that implement energy efficient heating and cooling measures in terms of water, support non-potable water collection for outdoor use, and minimize daily consumption of water per person through the installation of water conserving technology. The benefits of water conscious design include educating the next generation on the importance of water conservation as well as long term financial benefits.

I. SUSTAINABLE HEATING AND COOLING

Heating and cooling of water makes up a large sum of a building's energy expenses. For this reason, it is especially important to implement sustainable technology in place of existing heating tanks. In recent years, heat pumps have become especially popular to complete the task of water heating and cooling. Heat pumps operate by using electricity, as opposed to gas, to move heat from one place to another. It pulls in heat from the surrounding air and transfers it to a tank containing water. It is possible to retrofit a heat pump with an existing water heater that can serve as an alternate source when air temperatures are below the required minimum of 40F.



Main functions and components of a conventional heat pump.

The heat pump will require a minimum of a thousand cubic feet of space in order to properly operate. Due to this specific space requirement, the best placement for the heat pump was determined to be in the existing University High building. The heat pump will connect through and underground piping system that will connect it to bathrooms and other facilities that require water in the new building. It is also possible to retrofit existing water heaters with heat pumps. This would allow the existing piping to remain intact while enabling a more sustainable heating and cooling alternative.

A heat pump can be retrofitted to replace the traditional gas heating system that University High School currently employs. In order to supply hot water to the 300 faculty members and students, a larger heat pump will need to be utilized. Commercial building heat pumps can be purchased at a high initial cost, with long term financial benefits from decreasing gas and electricity costs. It is necessary to employ a commercial building heat pump in order to meet the hot water needs of the school's population, despite higher initial costs.

Since a large heat pump can be retrofitted in the existing building, an underground piping system will transport water from the heat pump to the bathrooms in the newly constructed building. Because there is no cafeteria and no need for using water to cook, a single large, commercial heat pump is sufficient to cover the necessity for bathroom water. Tankless water heaters are also an option for the new bathrooms in the newly constructed building. This would function by placing a tankless water heater in each bathroom that could heat water for hand washing. However, the financial constraints must be recognized. Since a heat pump has a high initial cost, it is worth analyzing whether it would be cheaper to install underground piping that connects to the bathrooms in the new building rather than installing individual tankless water heaters.

II. NON-POTABLE WATER REUSE

According to the Water Research Foundation, outdoor use of potable water makes up the largest percentage of all potable water use at sixty-four percent. Taking this into account, there are numerous ways to reduce potable water use outdoors for lawn care and upkeep. A potential solution to using potable water for non-drinking purposes involves the installation of a rainwater barrel. Reducing the amount of potable water dedicated to outdoor use decreases the overall water footprint that a property has on a large scale. Rainwater barrels are easy to install, and cheap to acquire. Based on central Illinois weather patterns, a mid to large sized rain barrel will be placed adjacent to the newly constructed building with a gutter that connects the barrel to the roof. The gutter will collect rain during sporatic storms and supply maintenance staff with gallons of non-potable water that can be used outside. Illinois law prohibits bringing any non-potable water indoors, meaning that this rainwater can only be used for outdoor purposes. However, given the large footprint that outdoor water use has on water consumption as a whole, supplying gallons of non-potable water as a substitute for outdoor use has a sizable impact on overall water consumption. The team intends to purchase a rainwater barrel from an existing manufacturer. This decision will be based on research regarding consumer feedback for the barrel as well as aesthetics, durability, and price.

It is ideal to find a barrel that can be easily connected to a hose to minimize effort when transporting water. It would be difficult to transport the barrel to the site where non potable water is necessary. However, attaching a hose will allow for easy transport of the water around the premises.

III. WATER CONSERVATION AND MANAGEMENT

Aside from reducing the amount of potable water used for outdoor care, as well as reducing the amount of energy expenditure in heating and cooling, the team hopes to minimize everyday water consumption for each student and faculty member. Considering that the school does not have a cafeteria, water use for cooking will be considered negligible. This means that the majority of water consumption involves using the bathroom, washing hands, and filling water bottles.

There are numerous ways to address water conservation with traditional faucets and toilets. A cheap, efficient method to decrease the amount of water used would include the purchase of low flow aerators that can be retrofitted onto existing faucets and installed on newly constructed ones. These low flow aerators reduce the flow of water from a faucet without reducing the pressure, saving both water and energy. They can be attached to existing faucets and purchased at a low price

Example of a potential rainwater harvesting system.

Aside from reducing faucet flow, low flow toilets have been employed by residential and commercial buildings for years. These toilets can be both retrofitted in the existing building should money allow it, and placed in the bathrooms in the newly constructed building. Both low flow aerators and water conserving toilets can be cheaply installed, and will have long term cost benefits by reducing water costs.

ENERGY PERFORMANCE

The crux of team INSP.I.R.'s energy solution lies in data. By monitoring energy use of systems and spaces, continuous improvement towards optimization can be achieved, with studies predicting up to 49% consumption reduction.[1] Assisted by intelligent choices in system elements like heat pump water heaters and combined heating and cooling through the CERV, we hope to push these numbers even further.

Additional data is available though the University's Electronic Billing System (EBS), which records all utility expenditures and allows for easy comparison towards iCAP goals. Additional modeling of the project both with and without our design implementation will provide a system by system breakdown of problem areas prime for innovation.

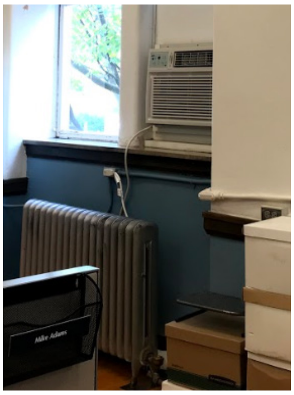
COMFORT AND ENVIRONMENTAL QUALITY

RetrHigh takes an innovative approach to air quality in targeting productivity gains from lowering CO2 and volatile organic compound levels.[2] This is particularly important in a classroom environment where both staff and students will benefit. This is accomplished most directly by the CERV HVAC solution which has integrated filters and monitoring for both.

Architecturally, natural light is maximized by window placement and exposed facades oriented to avoid shading from nearby structures. This increases comfort and lowers the heating load on the HVAC system. Additionally, the IoT monitoring solutions gives staff and students the ability to see the quality of their environment and makes changes to meet needs.

Existing System

University Laboratory High School currently relies on natural ventilation through fans and windows, with no active central ventilation system. However, the building does contain a complete duct system, but this has not been utilized in decades.
Heating is supplied through steam radiators throughout the building. The steam is provided by Abbott Power Plant, and is cogenerated with campus electricity. Cooling is achieved in most rooms through window coolers. A select few rooms were renovated to include mini-split coolers, powered by a chiller unit.



KEY RETROFIT IMPROVEMENTS

Achieve a flowrate of 35 cfm / student in classrooms

Active monitoring and elimination of VOCs and CO2

Allow Local Control of temperature in classrooms

1 "Report Delves Into the Impacts of Commercial ... - Energy.gov." 20 Sep. 2017, https://www.energy.gov/eere/buildings/articles/report-delves-impacts-commercial-building-controls-energy-savings. Accessed 17 Feb. 2020.
2 "Report Delves Into the Impacts of Commercial ... - Energy.gov." 20 Sep. 2017, https://www.energy.gov/eere/buildings/articles/report-delves-impacts-commercial-building-controls-energy-savings. Accessed 17 Feb. 2020.

BENEFITS OF ENHANCED AIR QUALITY

Cognitive ability and performance

High School students experience elevated mental demands on a daily basis. A 2016 study examined the effects of flow rate, VOCs, and CO2 on performance on cognitive tests.[1] Over a 6 day period, a group of participants were exposed to three different conditions: 'conventional' with high VOCs and 20 cfm, 'Green' with low VOCs and 20 cfm, and 'Green+' with low VOCs and 40 cfm. On average, cognitive scores were 61% higher for the Green IEQ conditions, and 101% higher for the Green+ IEQ conditions.

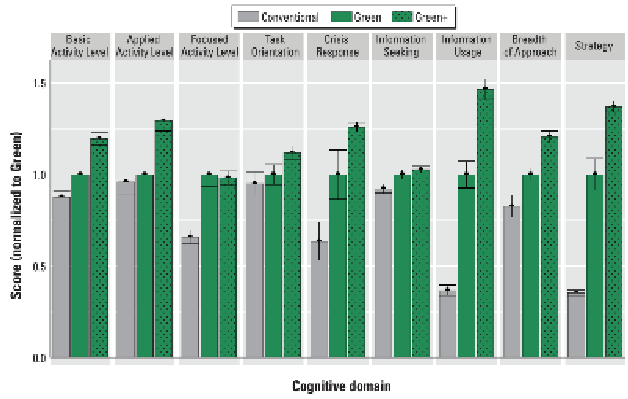


Figure 1. Average cognitive function scores and standard error bars by domain for the Conventional, Green, and two Green+ conditions, normalized to the Green condition by dividing all scores by the average score during the Green condition.

REDUCE ILLNESS AND PREVENT ABSENCE

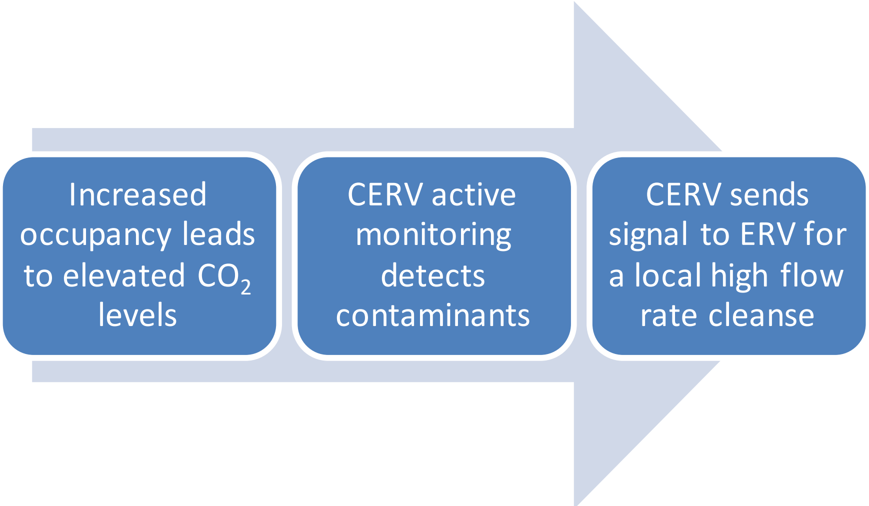
School attendance is one of the most important factors in student success, but can often be affected by factors like health and spread of diseases. A well-designed and persuasive study in office buildings by Milton et al. (2000)[2] found that ventilation rates substantially above current recommended levels were consistently associated with decreases of about one-third in short-term sick leave. Compared to a flow rate of 50 cfm, a flow rate of 25 cfm was found to have a relative risk of 1.5 for airborne illness.

APPROACH

The crux of our system design is the Circulating Energy Recovery Ventilator (CERV), developed by Equinox systems in Urbana Illinois. This system provides cutting-edge active monitoring of CO2 and VOCs, and can remotely monitor and control other ventilation and heating units. Our design pairs the CERV with two Renewaire ERVs, capable of supplying a ventilation rate of 11,000 cfm for the entire building. As 300 students are enrolled, this will allow for a constant flowrate of 35 cfm/student in classrooms, far exceeding ASHRAE codes. To maximize the benefit of this system, we intend to incorporate sensors for CO2 and VOC in each classroom; when high levels of these contaminants are present, the CERV will activate a short term period of high flow rate circulation of up to 60 cfm per student to purify the room. At other times, a flowrate of 35cfm per student per room will be maintained. In this way, students will not be exposed to harmful contaminants, and will be able to perform to their maximum ability. Our design makes use of the existing vents in University High School, and we plan to incorporate new ductwork into the new construction of gymnasium and underground theatre.
To maximize student comfort and energy performance, ductless mini split heat pumps will be installed in each classroom, allowing complete local control of comfort. Furthermore, this ensures that energy is only used in classrooms where it is needed, unlike the current steam heating system. Condenser boxes have ample space on the roof.

1 Spengler et al. "Associations of Cognitive Function Scores with Carbon Dioxide, Ventilation, and Volatile Organic Compound Exposures." 2016.

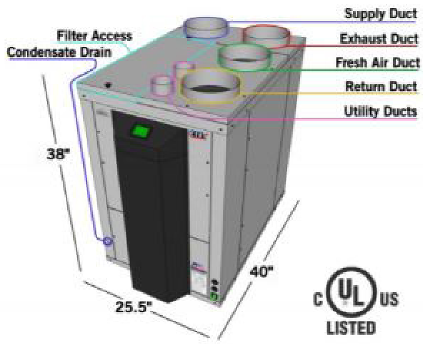
2 Milton et al. "Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints." 2000.



KEY COMPONENTS:

Circulating Energy Recovery Ventilator (CERV)

The CERV enables smart monitoring and control of air quality to maximize student comfort and performance. Paired with sensors integrated into each classroom, the CERV monitors CO2 and Volatile Organic Compounds including hydrocarbons and organic acids. The CERV can operate in a multitude of operating modes, and optimizes ventilation based on the needs of individual classrooms. Three CERV systems will be incorporated: two in the main building and one in the gymnasium. In the main building, one CERV will be used exclusively for chemistry labs and art spaces on the third floor, which will have much higher risk of airborne contaminants. [1]



SPECIFICATIONS

Electrical

Voltage Supply	120V (60hz)
Minimum Circuit Size	12 A
Connection	Standard NEMA 5-15P Plug, 6ft cord

System

Airflow Rate	100-300 CFM
Air Filter Size	10"x20"x1"
Duct Size	8" Main 3" Utility
Condensate Drain	3/4" PVC
System Weight	6EC:139lbs 8EC:142lbs

Sensors

Temperature	- 40 to 185F +/- 0.36F
Relative Humidity	0 to 100% +/- 2%
CO_2	400 to 5000ppm +/- 25ppm +/-3%
VOC	450 to 2000ppm CO2 Equivalent

VOCs Detected

Alcohols, Aldehydes, Aliphatic Hydrocarbons, Amines, Aromatic Hydrocarbons, CO, CH4, LPG, Ketones, Organic Acids

Warranty

5 Years

PERFORMANCE

Heating: 47F Outside, 68F Inside

Heating Capacity (Btu/h)	4731 (Recirc)* 6531 (Vent)**
Heating Efficiency (COP) (excludes fan power - see below)	3.6 (Recirc) 4.8 (Vent)
Heating Elec Power (W) (excludes fan power - see below)	379 (Recirc) 399 (Vent)

Heating: 32F Outside, 68F Inside

Heating Capacity (Btu/h)	3702 (Recirc) 6789 (Vent)
Heating Efficiency (COP) (excludes fan power - see below)	3.3 (Recirc) 5.4 (Vent)
Heating Elec Power (W) (excludes fan power - see below)	331 (Recirc) 366 (Vent)

Heating: 17F Outside, 68F Inside

Heating Capacity (Btu/h)	2674 (Recirc) 7046 (Vent)
Heating Efficiency (COP) (excludes fan power - see below)	2.8 (Recirc) 6.2 (Vent)
Heating Elec Power (W) (excludes fan power - see below)	283 (Recirc) 332 (Vent)

Cooling: 95F(DB)/75F(WB) Outside, 80F(DB)/67F(WB) Inside

Total Cooling Capacity (Btu/h) Sensible + Latent	2230 (Recirc) 5314 (Vent)
Sensible Cooling (Btu/h)	1318 (Recirc) 3891 (Vent)
Latent Cooling (Btu/h)	912 (Recirc) 1423 (Vent)
Dehumidifcation (Liters/Day)	9.6 (Recirc) 14.9 (Vent)
Cooling Efficiency (COP) (excludes fan power - see below)	3.2 (Recirc) 7.6 (Vent)
Cooling Elec Power (W) (excludes fan power - see below)	202 (Recirc) 204 (Vent)

Fans

Total Fan Power (W) ECM Fans (heating & cooling)	38.6(50% Speed) 98.1(70% Speed)

* Recirculation mode heating and cooling capacity is relative to indoor conditions

** Ventilation mode heating and cooling capacity is relative to outdoor air conditions

1 https://www.buildequinox.com/downloads/

RenewAire Energy Recovery Ventilator

This energy recovery ventilator provides the ventilation power needed to purify rooms of all contaminants, paired with MERV 13 filters. Through the ERV core, humidity will also be naturally regulated, increasing comfort and preventing the growth of mold. A HE-6XIN will be incorporated inside the basement of the school building, and an HE-4XINV will be installed in a mechanical room adjacent the new gymnasium and theatre. [1]

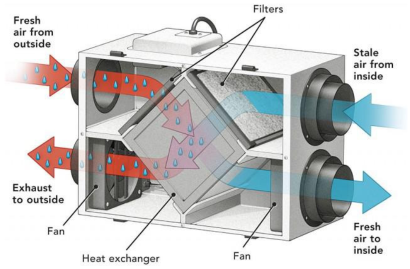


Fig 2: ERV system

Specifications for Existing building

HE 4XINV

Application Type: Indoor

Ventilation Type: Static plate, heat and humidity transfer

Typical Airflow Range: 1,000-4,400 CFM

AHRI 1060 Certified Core: Four L125-G5

OA Filter(s): Total Qty. 4, MERV 8: 20" x 20" x 2"

RA Filter(s): Total Qty. 4, MERV 8: 20" x 20" x 2"

Unit Dimensions & Weight: 50 3/4" L x 81 1/2" W x 62" H, 753-1,196 lbs. (varies by option)

Specifications for New building

HE 6XIN

Application Type: Indoor

Ventilation Type: Static plate, heat and humidity transfer

Typical Airflow Range: 1,500-6,500 CFM

AHRI 1060 Certified Core: Six L125-G5

OA Filter(s): Total Qty. 6, MERV 8: 20" x 20" x 2"

RA Filter(s): Total Qty. 6, MERV 8: 20" x 20" x 2"

Unit Dimensions & Weight: 88" L x 113 1/2" W x 81 3/4" H, 2,235-3,099 lbs. (varies by option)

Mitsubishi Ductless Mini Split Heat Pump

With an air handler in each classroom, this ductless system allows for complete local control of temperature on a room by room basis. Furthermore, since each room will receive heating from its own rooftop condenser, heating loads can be variably modified, and energy will not be wasted on unoccupied rooms. [2]

Rated Conditions (Capacity / Input)		
Cooling[1]	Btu/h / W	17,200 / 1,640
Heating at 47° F[2]	Btu/h / W	18,000 / 1,590

Capacity Range		Minimum	Maximum
Cooling[1]	Btu/h	5,800	18,000
Heating at 47° F[2]	Btu/h	5,400	20,900
Heating at 17° F[3]	Btu/h	-	15,000
Heating at 5° F[4]	Btu/h	-	12,700

[1] Cooling | Indoor: 80° F(27° C)DB / 67° F(19° C)WB; Outdoor: 95° F(35° C)DB / 75° F(24° C)WB*
[2] Heating at 47°F | Indoor: 70° F (21° C)DB / 60° F (16° C)WB; Outdoor: 47° F (8° C)DB / 43° F (6° C)WB*
[3] Heating at 17° F | Indoor: 70° F(21° C)DB / 60° F(16° C)WB; Outdoor: 17° F(-8° C)DB / 15° F(-9° C)WB*
[4] Heating at 5° F | Indoor: 70° F (21° C)DB / 60° F(16° C)WB; Outdoor: 5° F(-15° C) DB / 5° F(-15° C)WB
* Rating Conditions per AHRI Standard:

Operating Conditons (Indoor Intake Air Temp.) (Max./ Min.)	
Cooling	90° F (32° C) DB / 67° F (19° C) DB
Heating	80° F (27° C) DB / 70° F (21° C) DB

Operating Conditons (Outdoor Intake Air Temp.) (Max./ Min.)	
Cooling[5]	115 F (46° C) DB / 14° F (-10° C) DB
Heating	75° F (24° C) DB / 5° F (-15° C) DB**

[5] Applications should be restricted to comfort cooling only; equipment cooling applications are not recommended for low ambient temperature conditions.
** System cuts out at -9° F (-27° C) to avoid thermistor error and automatically restarts at -4° F (-20° C).

AHRI Efficiency Ratings	
SEER / HSPF	18.0 / 8.5
COP at 47° F / 17° F	3.32 / 2.59

Indoor Unit		
Blower Motor (ECM)	F.L.A.	0.67
Blower Motor Output	W	30
SHF / Moisture Removal		0.86 / 2.1 pt./h
Field Drainpipe Size O.D.	In.(mm)	5/8 (15)

Outdoor Unit		
Compressor		DC INVERTER-driven Twin Rotary
Fan Motor (ECM)	F.L.A.	0.5

Airflow Rate (Lo - Med - Hi - Super Hi)			
Indoor (Cooling)	DRY	CFM	328-431-530-625
	WET		295-388-477-562
Indoor (Heating)	DRY		307-431-530-625
Outdoor			1,243 / 1,229

1 https://www.renewaire.com/erv/he4xinv/
2 https://www.acwholesalers.com/manuals/MSZHM18NA-MUZHM18NA-sb.pdf

Component:	Quantity:	Cost per unit:	Total Unit Cost:	Comments:
Air Handler: MSZ-HM18NA-U1	75	$587.25	$44,043.75	18 SEER
Condeser: MUZ-HM18NA-U1	75	$1,200.00	$90,000.00	18,000 BTU / 18 SEER
PVC Braided Drain Tubing	75	$50.00	$3,750.00	for mini split
Connecting Cable	75	$41.25	$3,093.75	for mini split
Line Set with Flare Fittings	75	$104.00	$7,800.00	for mini split
Anti Allergy Enzyme Filter	75	$43.20	$3,240.00	for mini split
CERV	3	$5,000.00	$15,000.00	cost estimated
RenewAire HE-4INXV	1	$6,000.00	$6,000.00	cost estimated
RenewAire HE-6INX	1	$7,000.00	$7,000.00	cost estimated
TOTAL	-	-	$179,927.50	
Misc Info:				
Heating Capacity: (BTU)	1350000	(a little more due to CERV and ERV)		
Cooling Capacity: (BTU)	1290000			

OPERATIONS

Currently, Uni's basement contains a large, unused, central ventilation unit. By removing this device, the space can accommodate many of the larger engineering systems for HVAC, water, and electrical. With an exterior access door, maintenance personnel can easily perform routine tasks from one central location without disturbing daily functions of the school. Additional space is provided on the roof of both wings as well as maintenance closets located near entrances in the east wing.

Combined with the University's EBS system, an Internet of Things (IoT) monitoring solution gives the administration data on all energy use cases to locate problem areas and make adjustments. Additionally, this data can be used to educate students on analytics and sustainable technology.

INNOVATIONS

Many (if not all) of RetrHigh's design elements are innovative either in technology or application, as discussed above. A select few are highlighted here.

Architecturally, the combination of gothic and modern design is both uncommon and difficult to properly achieve. Our focus on air quality for student success should be a pivotal element in future educational institution designs. The integration of system monitoring and student education on sustainability aims to produce a future generation of architects and engineers who will be innovators themselves.

Altogether, a complete Uni in the form of RetrHigh will represent the future of modern educational institutions, fulfilling the structure's original purpose and acting as a model for others nationwide.

1 https://www.acwholesalers.com/Mitsubishi-MSZ-HM18NA-U1/p81566.html, https://www.acwholesalers.com/Mitsubishi-MUZ-HM18NA-U1/p81562.html, https://www.acwholesalers.com/Mini-Split-Accessories-DRAINTUBING-50/p51002.html, https://www.buildequinox.com/, https://www.renewaire.com/erv/he4xinv/, https://www.sylvane.com/dri-eaz-f413-revolution-lgr-dehumidifier.html

PHOTOVOLTAIC SYSTEM DESIGN

According to data in University's FY2018 Energy Consumption Report, the high school consumes about 328,826 kWh of electricity per year.[1] Even though the new section would require additional energy, increased energy efficiency will likely offset this, thus making the overall consumption about the same. Ideally if the sun was shining all day we would meet this entire demand; however, Urbana, IL only has about 5 peak sun hours per day so the additional 19 hours must be purchased through utilities; however, Illinois offers net metering. Net metering allows excess energy to be fed back to the grid for credits that can be used to offset the times when the system is not able producing. Thus the system is a grid-tied system sized to meet the electricity needs over the course of the year.

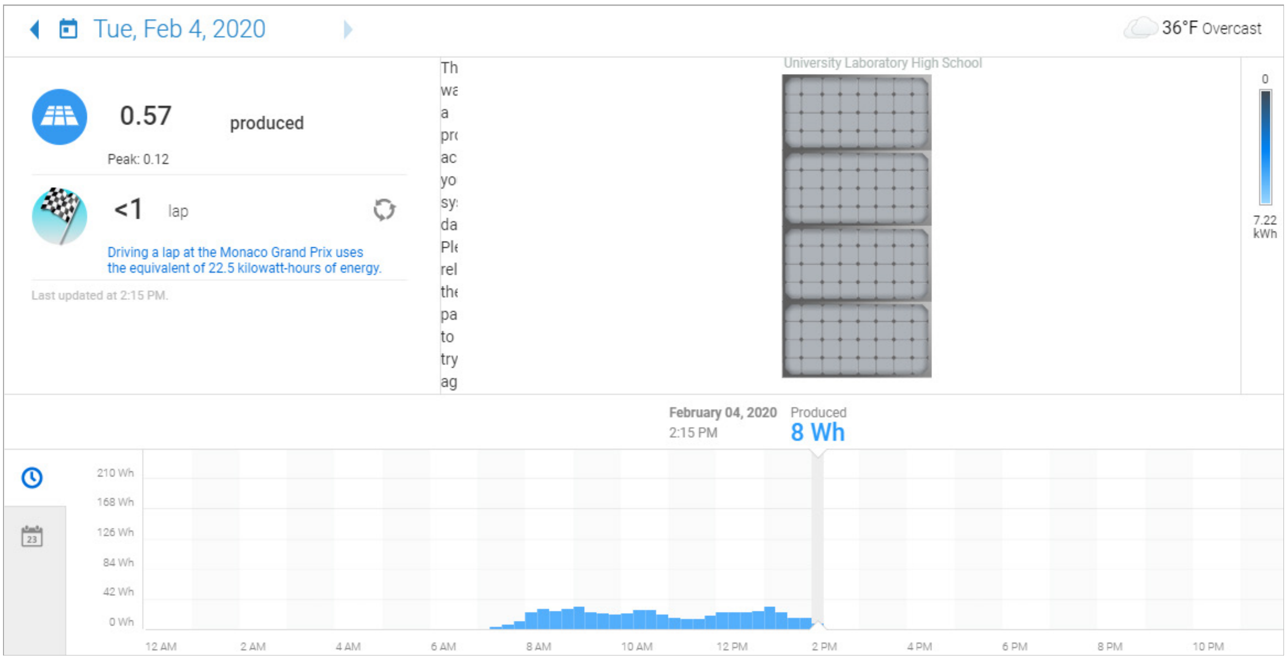
CURRENT SYSTEM

University High currently has a 1kW solar photovoltaic system made up of four 255 watt ReneSola JC255M-24/Bb modules each with 15.70% efficiency. These panels are mounted on the flat part of the gym roof as shown in the figure to the right. The system was funded through means of the Illinois Clean Energy Fund (ICECF) K-12 Solar Schools Program. These panels do not contribute a significant amount to the energy usage of the building, providing "less than 1% per month of the energy Uni uses as a whole". [3]

Sharlene Denos

Solar Panel Installation on Gym Roof[2] 2

However, they are an important educational tool to teach students about different aspects of renewable energy, including through their website which reports the energy production of the panels:



1 Facilities & Services, "FY 2018 Energy Consumption Report - Top 175 Buildings," University of Illinois, Champaign-Urbana, 2018.

2 E. Gibson, "Solar panels installed on Uni Gym," The Gargoyle, 4 September 2015.

3 L. Dankowicz, "Uni Goes (Went) Solar!," The Gargoyle, 12 May 2017.

PLACEMENT CONSIDERATIONS

The five main placement options for a solar array are roof mounted panels on the existing school building, roof mounted on the new addition, mounted above the parking lot, ground mounted in the remaining landscape area on the property or some form of Building Integrated Photovoltaics (BIPV). The existing roof is facing east and west which is not optimal for a solar array in the Northern Hemisphere. Additionally, it would be difficult to mask the panels against the gothic architecture. In order to achieve a more optimal orientation and reduce shading, the roof will be knocked down and made flat. Ground mounted panels would likely be more susceptible to shading and BIPV is not widely available in the market yet; therefore, these were not explored further.

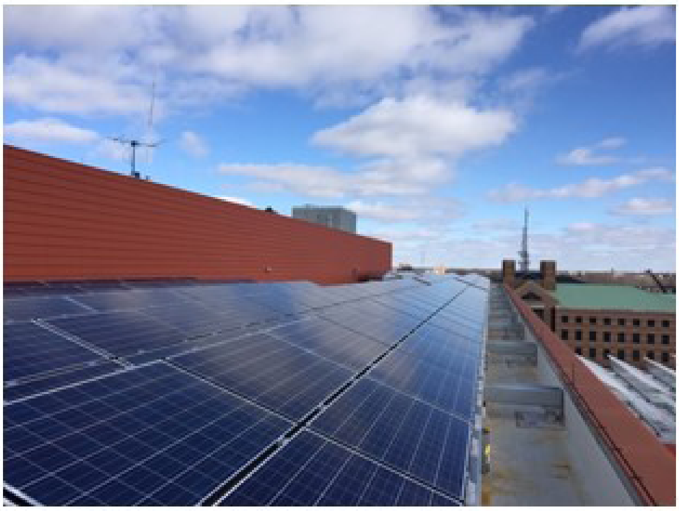
TYPE OF SOLAR PANELS

In order to meet the electricity demand of the building, a combination of technologies will be used. These technologies include traditional polycrystalline silicon panels mounted on the roof of the current building and the new addition, and bifacial solar modules mounted over the parking lot.

POLYCRYSTALLINE SILICON

Traditional polycrystalline silicon panels are by far the most cost effective way to generate energy by PV as the technology is well established and they don't need to be as pure as monocrystalline silicon panels. Talesun, Canadian Solar, Eoplly, Suniva, and Jinko are the top 5 cheapest from wholesalers and retailers on the Internet according to Energy Informative.[1]

In addition, an investigation was done into some of the panels already implemented around campus. The University of Illinois Urbana Champaign Solar Farm 1.0 has two types panels, 310W and 315W, both made by JA Solar. The Electrical and Computer Engineering Building uses a variety of SunPower panels ranging from 240-425W some of which are shown in the figure to the right. There was also a Solar Project Feasibility Study done on Krannert Center for the Performing Arts that proposed the use of Mage Solar 250W panels; however, those panels are made with monocrystalline silicon.[2]



A few of the solar panels mounted on the campus's Electrical and Computer Engineering building[3]

[1]Energy Informative, "Top 10 Cheapest (Best Value) Solar Panels," [Online]. Available: https://energyinformative.org/cheapest-best-value-solar-panels/.

[2]Hanson, "Krannert Center for the Performing Arts Solar Project Feasibility Study," Urbana-Champaign, 2014.

[3]Institute for Sustainability, Energy, and Environment, "Image Gallery for ECE Rooftop Solar PVs," [Online]. Available: https://icap.sustainability.illinois.edu/project/178/gallery.

In order to reduce the carbon footprint of the project, the manufacturing location of the panels were taken into consideration. This narrowed down the potential companies to Canadian Solar, Suniva, and JinkoSolar which offer polycrystalline panels that are manufactured in North America. The products considered are shown in table below.

Company/Model	Efficiency	Area/Size
Canadian Solar HiKu Super High Power Poly PERC Module (395~415W)	17.88%-18.79%	2108x1048x40mm (83.0x41.3x1.57in)
Jinko Solar Eagle 72 (340W)	17.52%	-
Suniva MV Series MVX 72 cell modules (310~320W)	16.0%-16.5%	1956x992x40mm (77.0x39.05x1.6in)

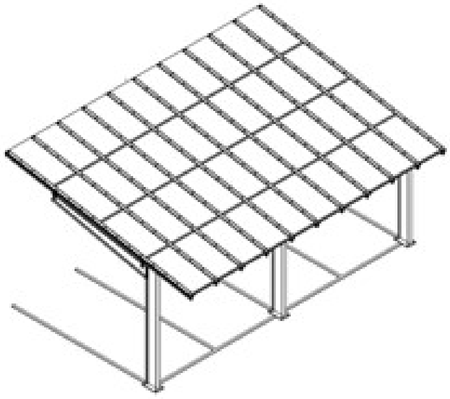
Ultimately Canadian Solar's HiKu Super High Power Poly PERC Module was selected due to its higher efficiency and power rating of up to 18.79% and 415W respectively. SunModo SunTurf Roof Mount system was selected based on its ability to elevate the system over HVAC equipment which helps to effectively utilize the limited roof area available. Additionally, it allows for a tilt angle between 10-50 degrees which is ideal for our configuration.[1]

SunModo SunTurf Roof Mount configuration[2]

BIFACIAL MODULES

The bifacial modules offer increased efficiency with collection on both sides. The parking lot is a prime location for these types of modules because the back side efficiency depends on the surface underneath the panels, which in the case of the parking lot, will be cars and asphalt, both of which are fairly reflective.

For the mounting of the parking lot solar modules, the SunRail CPR Bifacial Carport was chosen.[3] This mounting was decided upon specifically because it is optimized for bifacial; there is no structure under the panels that might cause shading. This mounting system also works well with the current layout of the school parking lot.



Carport panel configuration[3]

[1]SunModo, "SunTurf Flat Roof System One Sheet," [Online]. Available: https://sunmodo.com/wp-content/uploads/SunTurf-Flat-Roof-System-One-Sheet.pdf.
[2]SunModo, "SunTurf Multi-Purpose System - Roof Mount," [Online]. Available: https://sunmodo.com/sunturf-roof-mount/.
[3]OpSun Systems Inc., "CPR Carport," [Online]. Available: https://opsun.com/wp-content/uploads/2017/08/CPR-Carport-20170720.pdf.

Similar to the traditional panels, several companies were explored for the bifacial modules including, Canadian Solar, LG Solar, SunPreme, and Prism Solar. Again manufacturing location was taken into account and the list was narrowed down to Canadian Solar, SunPreme, and Prism Solar.

Company/Model	Efficiency	Area/Size
Canadian Solar BiHiKu Super High Power Bifacial Poly PERC Module (410 W)	18.35%, up to 23.85%	2132x1048x30 mm (83.9x41.3x1.2 in)
SunPreme Maxima GxB 390 SM Bifacial Smart Module (390W)	19.8%, up to 23.8%	1985x990x6 mm (6.50x3.25x0.02 ft)
Prism Solar BN72 Bifacial Modules (370W)	18.8%, up to 21.2%	1991x989x7 mm (78.39x38.94x0.275in)

Although Canadian Solar was initially considered because Canadian Solar modules were already going to be used on the roof of the existing school building and the new gym, the size of the Canadian Solar modules are incompatible with the mounting chosen for the parking lot. Therefore, the SunPreme Maxima module was chosen due to its more standard size. The SunPreme Maxima GxB 390 SM Bifacial Smart Module has an efficiency of 19.8% under standard testing conditions that can reach up to 23.8% from the additional collection on the backside depending on the albedo of the surface below. This would help contribute immensely to the energy consumption of the buildings and any excess can be stored for emergency or sold to the grid.

Example of installation in Sunnyvale, CA[1]

TILT AND SPACING

The solar panels will have a fixed tilt all year round. The benefits of a tracking system or adjusting the tilts during the year were outweighed by the greater cost of maintaining these systems. The tilt angle was determined by multiplying the latitude by 0.76 and adding 3.1° to find the optimal angle for annual energy production.[2] Once the angle was decided, the shading caused by each panel was calculated to determine how far apart the rows of panels should be spaced. The height difference between the base of the panel, the top, and the solar elevation angle were initially used to calculate the row spacing. The azimuth correction angle was found from a sun path chart for the high school's specific location, and the row spacing was minimized using the correction.[3] The optimum tilt angle of the roof mounted panels is 33 deg with a spacing of 9 feet while the parking structures each have a tilt of 13 deg with 45 feet spacing between each unit.

[1]SunPreme, "Carport," [Online]. Available: http://sunpreme.com/carport/.
[2]D. J. Torres and J. Crichigno, "Influence of Reflectivity and Cloud Cover on the Optimal Tilt Angle of Solar Panels," Resources, vol. 4, no. 4, pp. 736-750, 2015.
[3]University of Oregon Solar Radiation Monitoring Laboratory, "Sun path chart program," [Online]. Available: http://solardat.uoregon.edu/SunChartProgram.php.

Through comparing the surface area of the current school's roof and the surface needed per solar module, it was determined 140 panels will fit on the roof. Using the same method, the new addition roof can hold 100 panels and a maximum of 320 panels can be placed over the parking lot. The solar modules on the current building's roof and new addition's roof will be placed individually, but the modules over the parking lot will be grouped into 10x4 units. All together, only accounting for shading from the panels themselves, the total capacity of all the possible systems is about 220kW.

INVERTER SELECTION

Research was conducted into four main types of inverter: string, micro, smart, and hybrid. Chint Power Systems (CPS), and Yaskawa Solectria Solar are the top string inverter manufacturers. While CPS, Pika, and Sol-Ark are the top hybrid inverter manufacturers according to Solar Power World.[1] In order to reduce the carbon footprint, the manufacturing location of the inverters was a top priority in the selection process. Another consideration was a safety check to make sure that the inverter is not overloaded. String inverters were determined to be the best solution because they are more efficient and cost effective.

Company/Model	Efficiency	Maximum PV Power Input
Yaskawa Solectria XGI 1000 - 65/65	98.2% / 98.0 %	97.6 kW
CPS SCA50KTL-DO/US-480	98.8%	75 kW
CPS SC20KTL-DO/US-480	97.5%	27 kW

These inverters have comparable efficiencies but they have different maximum rated PV input because they account for different size systems. The prime deciding factor will be through the overloading calculations in order to confirm that the solar array will not generate more electricity than the inverter can handle. Overall, two inverters were chosen. for the current building roof, gym roof, and the solar parking structure. For the current building roof and new gym roof, the Yaskawa Solectria XGI 1000 - 65/65 inverter was selected because it met all of the requirements for max current, voltage, and power in both normal operating conditions and extreme weather. Similar calculations were done for the solar parking structures. Each one will use the CPS SC20KTL-DO/US-480 inverter.

OVERLOAD CALCULATIONS

Inverter Specifications	Current Building Roof	New Gym Roof	Parking lot
Model	Yaskawa Solectria XGI 1000 - 65/65	Yaskawa Solectria XGI 1000 - 65/65	CPS SC20KTL-DO/US-480
Operating Voltage Range (VDC)	350-950	350-950	260-580
Max. Rated Power (W)	97,600	97,600	27,000
Max. DC input current (A)	180	180	91

[1] Solar Power World, "Global Inverter Manufacturing Locations," [Online]. Available: https://www.solarpowerworldonline.com/global-inverter-manufacturing-locations/.

PV Module Specs	Standard Panels	Bifacial Panels
Model	Canadian Solar CS3W-395	Sunpreme Maxima GxB 390
Efficiency	17.88%	20.1-24.1%
Isc (A)	10.82	9.38
Voc (V)	47	53
Vmpp (V)	38.5	43.9
Peak Power (W)	395	390-468
Power Temp Coef.	−0.37%	−0.28%
Voltage Temp Coef.	−0.29%	−0.23%
Current Temp Coef.	0.05%	0.03%

The calculations depend on the arrange of the panels in series and in parallel. Checks are made using the short circuit current (Isc), open circuit voltage (Voc), maximum power point voltage (Vmpp) and peak power. A safety factor (SF) of 1.25 is used for the current calculations. Often several different configurations must be tried before an optimal layout is found. The arrangement for the current building roof system is given below and similar calculations were done for the other two systems.

Array Set					
Series	14	Parallel	10	Total	140

Check Condition for Operation			
Normal Weather			
Check Power			
Type	Value	Unit	Inverter Requirement
Max Power	55300	W	97600
Check Current			
Type	Value	Unit	Inverter Requirement
Max Isc Current	135.25	A	180
Check Voltage			
Type	Value	Unit	Inverter Requirement
DC Voltage Minimum (Vmpp)	539	V	350-950
DC Voltage Maximum (Voc)	658	V	

Extreme weather conditions were taken the State Climatologist Office for Illinois where the record high and low temperatures for Champaign-Urbana are 109°F (42.78 °C) and -25 °F (-31.67 °C). Additionally, the standard testing condition temperature for both solar panels is 25 °C.[1]

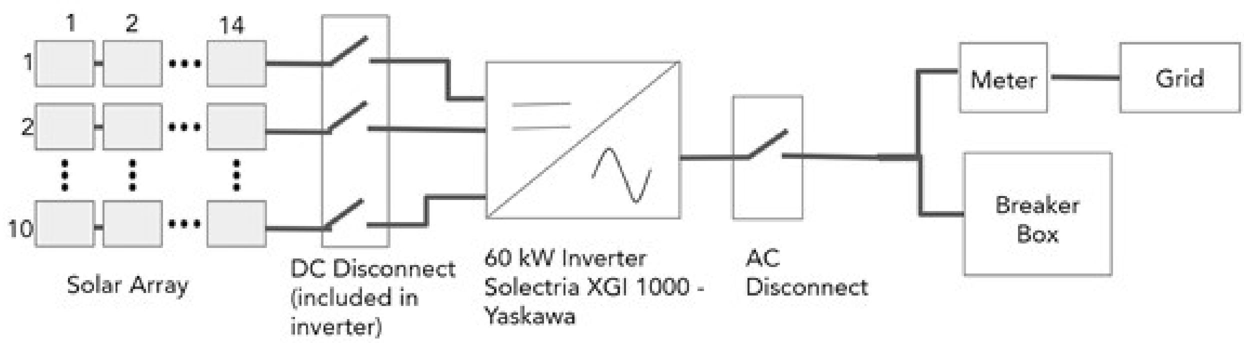
[1] State Climatologist Office for Illinois, "Averages and Records for Champaign-Urbana, Illinois," [Online]. Available: https://www.isws.illinois.edu/statecli/cuweather/cu-averages.htm.

Extreme Weather			
Check Power			
Type	Value	Unit	Inverter Requirement
Max Power	66894.57	W	97600
Check Current			
Type	Value	Unit	Inverter Requirement
Isc due to weather	10.92	A	180
Max Isc Current	136.45	A	
Check Voltage			
Type	Value	Unit	Inverter Requirement
Vmpp due to weather	44.83	V	350-950
Voc due to weather	54.72	V	
DC Voltage Minimum (Vmpp)	627.58	V	
DC Voltage Maximum (Voc)	766.13	V	

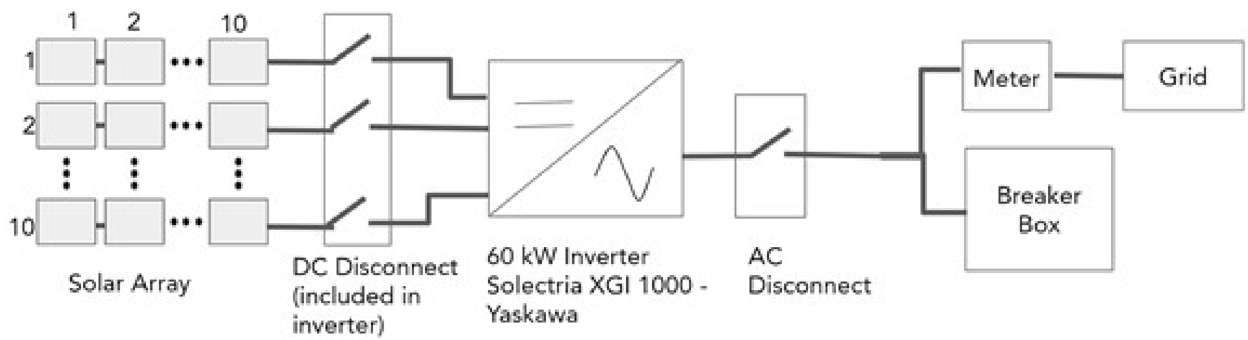
SINGLE LINE DIAGRAMS

Single line diagrams were created to further illustrate the layout of the panels and the interconnection of each system.

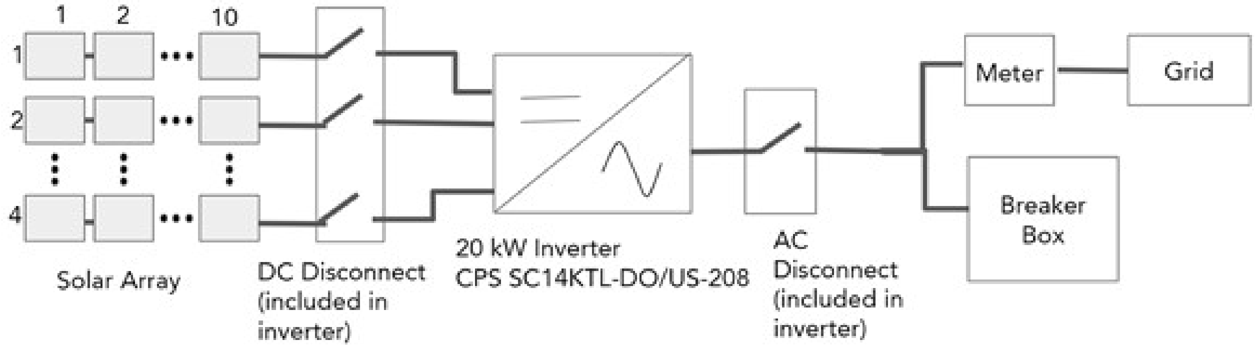
Current Building Rooftop Single Line Diagram



Gym Rooftop Single Line Diagram



One Unit of Panels Parking Lot Single Line Diagram
(8 total units)



ENERGY GENERATION

The energy generated by each system was determined by multiplying the daily insolation by 365 days per year as well as the efficiency and total area of the panels. For the roof systems the insolation was 4.93 kWh/m²/day. The parking lot system had a lower insolation value 4.65 kWh/m²/day due to the lower tilt angle. Both values were obtained using NREL's PVWatts calculator.

System	Energy Output (kWh)
Current Building Roof	99,510.11
New Gym Roof	71,078.65
Parking Lot	188,335.82
Total	358,924.59

This is enough energy to meet the yearly needs of the building with some additional energy that allows for a margin of error (higher demand or lower production).

ECONOMIC FEASIBILITY

A quick economic analysis was used to determine the financial viability of the project. At an installation cost of $1.83/W, the capital cost of the system is $401,868.[1] The levelized cost of energy (LCOE) was found to be 7.1 cents per kWh using NREL'S online LCOE calculator which is less than the current utility rate of 7.94 cents per kWh. The total annual savings due to production is $28,498.61 and results in a payback period of 14.10 years. The lifetime of the panels is 25 years therefore the system is economically feasible due to this short payback time.

Total Energy Generated		Total System Capacity		Total Modules	
358,924.59	kWh/yr	219.6	kW	560	Units
Capacity Factor (CF)		Unit Price		Total Price	
18.66%		1.83	$/W	401,868	$
LCOE of the system		Electricity Rate UIUC		Savings in term of rate	
7.1	cents/kWh	7.94	cents/kWh	0.84	cents/kWh
Savings per year		Simple Payback Period			
28,498.61	$	14.10	years		

[1] R. Fu, D. Feldman and R. Margolis, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018," National Renewable Energy Laboratory, Golden, 2018.

ENERGY ANALYSIS

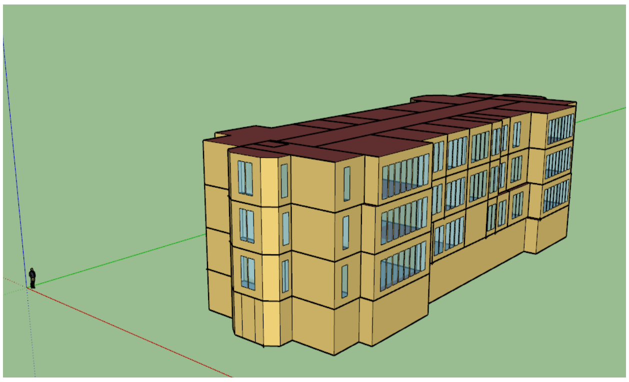
GOALS

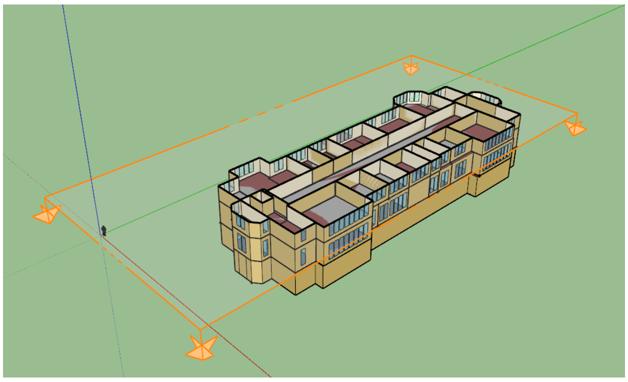
The main goal for Energy Analysis was to use software such as OpenStudio and SketchUp to obtain an energy model as close to University Highschool as possible. From the data obtained from the simulation, possible improvement could be suggested to building to potential reduce Energy Use Intensity and finally, cost. In addition to that, the energy model of planned extension was simulated to observe energy major energy consumption sources and make improvements accordingly.

METHODOLOGY

Building Model

A full-scale model off University Highschool was first imported from Revit to SketchUp as an outline of each floor. Each floor would have full details on the number and area of rooms as well as the amount of windows that should be included in each room.

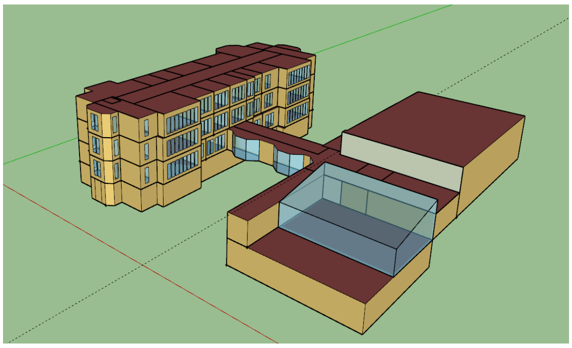


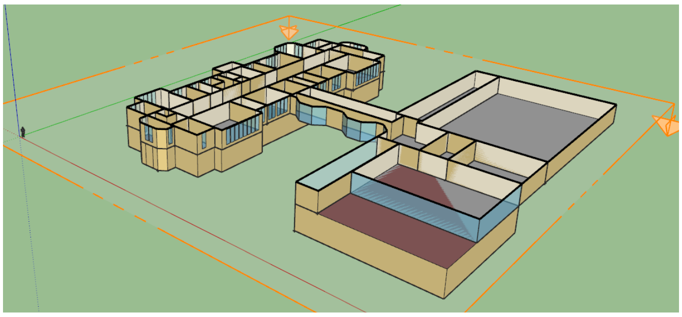


Perimeters
For accuracy, the simulation will be based on the weather and design days of Illinois, the data was provided from Bondville, IL. For simplicity, each room is modelled as a typical high school classroom. Which means that the human activity, lighting consumptions, and equipment usages are kept constant for each room. For thermal and heating load, the same simplification was used as well, with each room following the same heating and cooling schedule. The construction used in the simulation would be typical material used in OpenStudio for secondary school. To observe the thermal load impact of each room, every room were designated with their respective thermal zones instead of single thermal zone for multiple rooms.

Extension Building Model

Extension Building model
A full-scale model of the extension was first imported from Revit to SketchUp as an outline of each floor. Each floor would have full details on the number and area of rooms as well as the amount of windows that should be included in each room. The extension were then merged with the original building in order to investigated overall energy consumption of the whole structure





Perimeters
Since the extension would have room defined with their space type such as gym, kitchen and cafeteria. Each room would be modelled after the load schedule of their respective space type. To simplify, all space type have the same heating and cooling schedule as well. The construction used in the simulation would also be used in conjunction with specification mentioned (by Architecture) with some of the south facing wall being passive solar wall. To observe the thermal load of each room, every room were designated with their respective thermal zones instead of single thermal zone for multiple rooms.

OPEN STUDIO AND ENERGYPLUS OUTPUT

With the perimeter and modelled setup with no error, OpenStudio will output annual data of total site energy in kBtu and total site EUI of kBtu/ft^2. OpenStudio also provided annual overview of energy end use, energy type use, as well as monthly overview of energy consumptions. Other data such as envelop summary and zone condition could also useful throughout the project to improve the building.

Case Study

For the purpose of the report, five cases will be simulated and compared to investigate the results of improvement made to the building.

Case 1: Original Building with no improvement with thermal load provided by district energy.

Case2: Improved building with HVAC provided by district energy.

Case 3: Improved original with HVAC provided by low mini-split systems

Case 4: Improved building with extension with HVAC provided by district

Case 5: Improved building with extension with HVAC provided by mini split systems

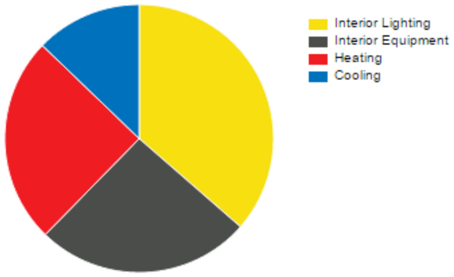
RESULTS

Case 1

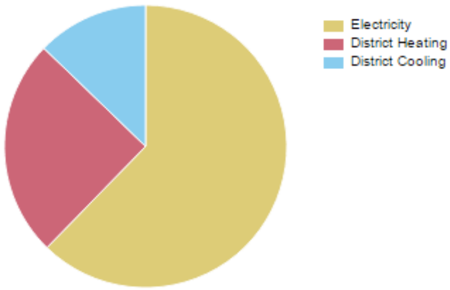
From Building Energy summary the total annual site energy from the simulation was 2,469 Mbtu, with total site EUI to be 51.26 kBtu/ft^2. According to Energy Star Portfolio Manager1, the average K-12 school EUI was about 48.5 kBtu/ft^2.

From the building end use summary, and the pie charts, most of the energy used were for interior lighting and equipment. Although this project would not be changing the lighting and interior equipment. It is still recommended for University High School to replace them with higher efficiency equipment.

The state of Illinois is a temperate climate and from the local data, heating were required for 9 months in a year. Therefore insulation was an important aspect for University Highschool. As previously discussed, University Highschool currently uses single pane window with heating and cooling delivered by district energy through ducts in the building which are highly inefficient. The basement of the building also account for about of quarter of thermal loads, adding insulation to the basement could be a cost-efficient way to reduce thermal loads.



Building End Use pie chart for Case 1



Building Energy End use pie chart for Case 1

Data	Value
Case	1
Total Site Energy	2,468,997 kBtu
Total Building Area	48,167 ft^2
Total Site EUI	51.26 kBtu/ft^2

Building Energy Summary for Case 1

End Use	Consumption (kBtu)
Heating	615,219
Cooling	315,727
Interior Lighting	899,441
Interior Equipment	638,620

Building End Use summary for Case 1

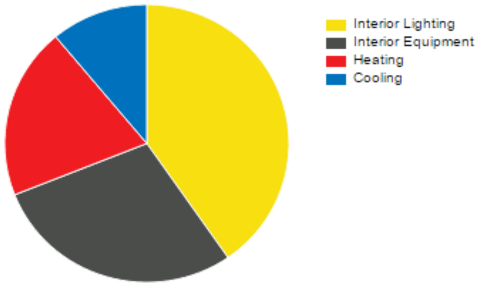
Reference: https://portfoliomanager.energystar.gov/pdf/reference/US%20National%20Median%20Table.pdf

Case 2

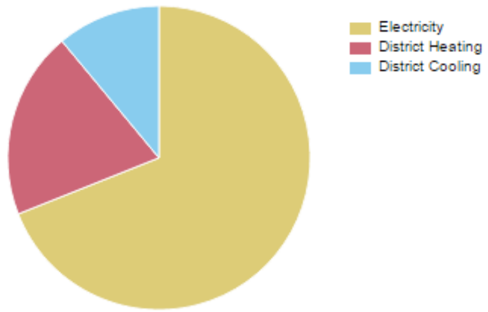
In case 2, the improvements made to the building was to replace all single glazed windows with a Low E double glazed window as well as adding 4 inches of fiberglass batts in the basement with increased the basement R value to 16 from the original.

From Building Energy summary the total annual site energy from the simulation was 2,230 MBtu, with total site EUI to be 46.29 kBtu/ft^2. This is a decrease of additional 235 MBtu and 4.97 kBtu/ft^2 compared to case 2.

From the building end use summary, and the pie charts, the heating load were decreased by 29% and cooling load decreased by 22% with respect to case one.



Building End Use pie chart for Case 2



Building Energy End use pie chart for Case 2

Data	Value
Case	2
Total Site Energy	2,229,806 kBtu
Total Building Area	48,167 ft^2
Total Site EUI	46.29 kBtu/ft^2

Building Energy Summary for Case 2

End Use	Consumption (kBtu)
Heating	445,000
Cooling	246,755
Interior Lighting	899,441
Interior Equipment	638,620

Building End Use summary for Case 2

Case 3

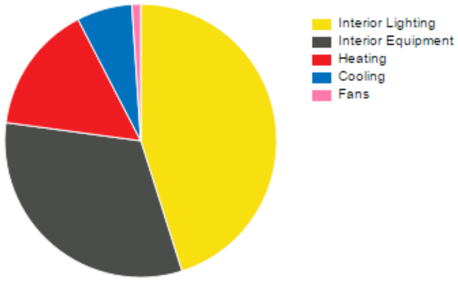
In case 3, the improvements made to the building was the same as case 2 with addition to replacing all heating and cooling solutions with mini split systems.

From Building Energy summary, although there is an additional energy consumption to run the fan for the mini-split system. The total annual site energy from the simulation was 1,994 MBtu, with total site EUI to be 41.40 kBtu/ft^2. This is a decrease of 235 MBtu and 4.89 kBtu/ft^2 compared to case 2. That brings down to total reduction of 474MBtu and 9.86 kBtu/ft^2 compared to original building(case 1).

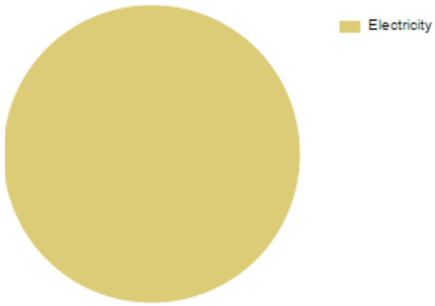
From the building end use summary, and the pie charts, the heating load were decreased by 32% and cooling load decreased by 47% with respect to case 2.

With comparison to case 1, the heating load was decreased by total heating load of 51% and cooling load of 58%.

Notice that in Building Energy End use pie chart that the electricity is the only source of energy. Since all heating and cooling are performed by mini-split systems instead of district energy, only electricity were used fans and compressor in the system for relieving thermal loads.



Building End Use pie chart for Case 3



Building Energy End use pie chart for Case 3

Data	Value
Case	3
Total Site Energy	1,994,217 kBtu
Total Building Area	48,167 ft^2
Total Site EUI	41.40 kBtu/ft^2

Building Energy Summary for Case 3

End Use	Consumption (kBtu)
Heating	304,003
Cooling	131,320
Interior Lighting	899,441
Interior Equipment	638,620
Fans	20,833

Building End Use summary for Case 3

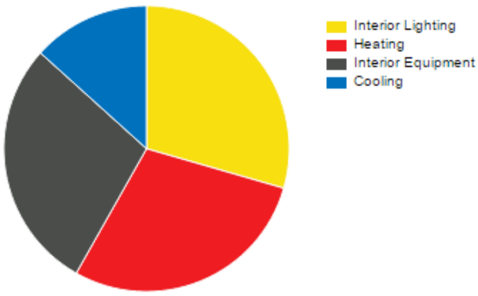
Case 4

In case 4, all upgrades from case 2 were applied with additional extension added to the original building. The extension construction wall materials are also different from the original building. With the extension, The total building area increased from
48,000 ft^2 to 68,754 ft^2
In this case, all heating and cooling are solely provided by district energy.

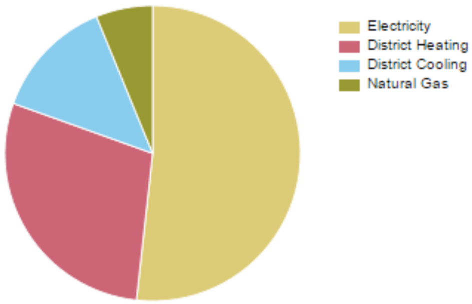
From Building Energy summary, The total annual site energy from the simulation was 4,018 MBtu, with total site EUI to be 58.45 kBtu/ft^2. This is a increased of 1,789 MBtu and 12.16 kBtu/ft^2 compared to case 2. That brings up to total increase of 474MBtu and 9.86 kBtu/ft^2 compared to original building(case 1).

Naturally, the total site energy increased as the building area increases. However there was an increase in Total Site EUI, it was suspected that due to the rooms such as gym auditorium and solarium having much larger open space compared to the rooms in original building. In addition that windows to wall ratio increased as well with the extension which contributes increased thermal load. However, the students in the building would be able to enjoy modern looking cafeteria with huge space for recreational activities compared to cramped space of original building

From building end use summary and pie chart. Heating load became one of the major energy use as opposed to previous cases.



Building End Use pie chart for Case 4



Building Energy End use pie chart for Case 4

Data	Value
Case	4
Total Site Energy	4,018,347 kBtu
Total Building Area	68,754 ft^2
Total Site EUI	58.45 kBtu/ft^2

Building Energy Summary for Case 4

End Use	Consumption (kBtu)
Heating	1,154,583
Cooling	535,327
Interior Lighting	1,183,748
Interior Equipment	1,144,688

Building End Use summary for Case 4

Case 5

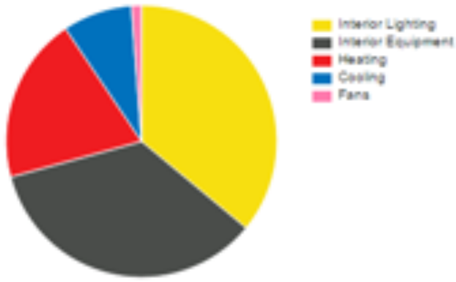
In case 5, the setup was similar to case 4 but with all the heating and cooling provided by mini-split system.

From Building Energy summary, The total annual site energy from the simulation was 3,289 MBtu, with total site EUI to be 47.85 kBtu/ft^2. This is a decrease of 729 MBtu and 10.6 kBtu/ft^2 compared to case 4. That brings down to total decrease of 3.41 kBtu/ft^2 compared to original building(case 1).

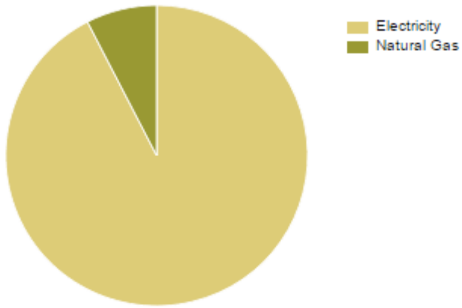
The impact of when using low temperature mini-split system to handle thermal loads were huge especially for building extensions.

From building end use summary and pie chart. Heating load became one of the major energy use as opposed to previous cases, the energy used for heating and cooling were reduced by 44% and 49% respectively compared to case 4 as well.

Notice that for case 4 and case 5, there were natural gas in building energy end use pie charts. This is because one of the space types were kitchen in the extension which uses natural gas solely for cooking.



Building End Use pie chart for Case 5



Building Energy End use pie chart for Case 5

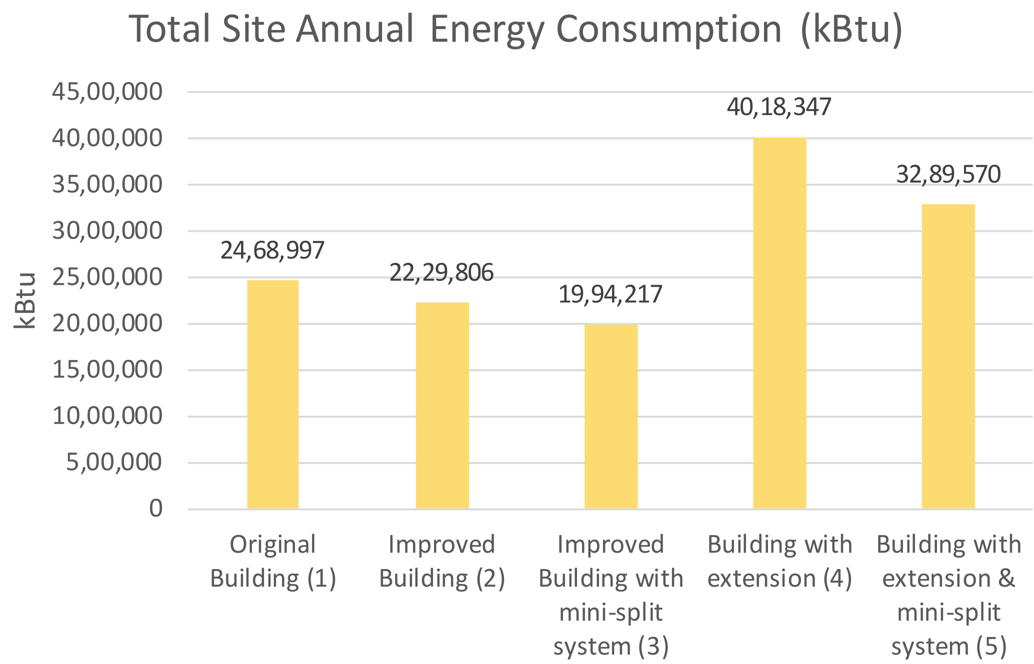
Data	Value
Building Name	5
Total Site Energy	3,289,570 kBtu
Total Building Area	68,754 ft^2
Total Site EUI	47.85 kBtu/ft^2

Building Energy Summary for Case 5

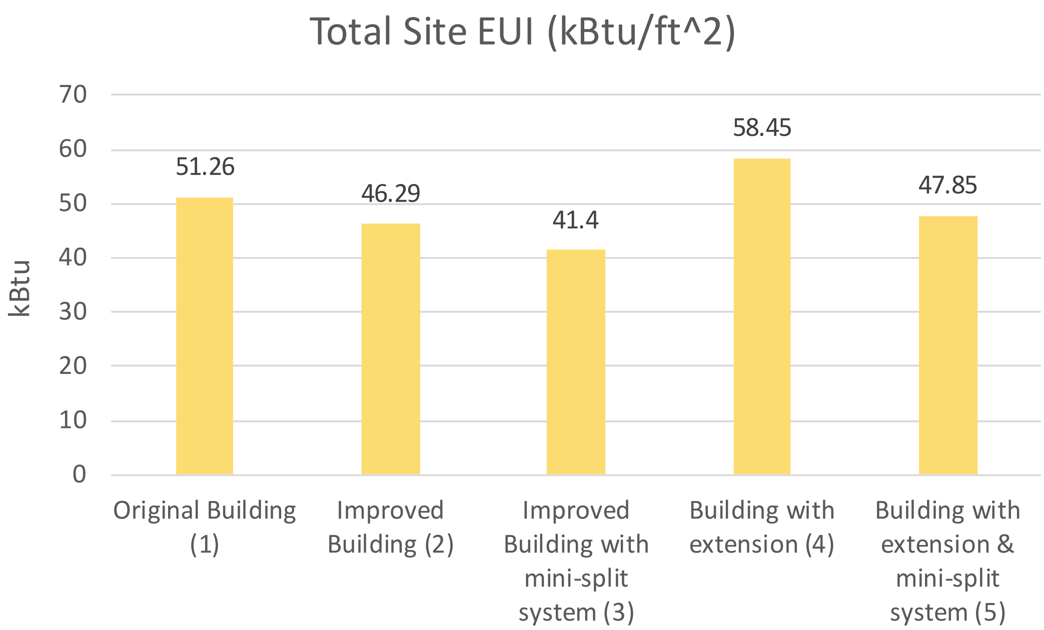
End Use	Consumption (kBtu)
Heating	649,549
Cooling	272,507
Interior Lighting	1,183,748
Interior Equipment	1,144,688
Fans	39,078

Building End Use summary for Case 5

All Cases



Total site annual energy consumption for each case in bar charts



Total site EUI for each case in bar chart

ANALYSIS

The original building was poorly insulated and did not utilize efficient HVAC system. Not much improvement has been made since it's construction to alleviate the high EUI of the building. With the insulation improvement as well as the integration of better HVAC technology to the original building the EUI was reduced significantly to below K-12 standard of 48.5 kBtu/ft^2 (see case 2). This allows the school to have an option to add an extension to the original building. With the extension, not only the student's quality of life will be improved with facilities like gym and auditorium, the EUI of the building with extension(see case 5) lower than the original building.

HOME AUTOMATION

With the rise of IoT technology in the past decade, automation in many areas of society has become much more accessible. One area that has seen great benefit is energy use in residential and commercial buildings. Through monitorization of building temperature, occupancy, and outside seasonal changes, smart energy controls can lead to massive increase in energy efficiency. Our goal in this design is to make the existing university high school more efficient by providing automation in the systems within the school and to outfit the new addition with automation from the start. Along with reducing energy costs, this can serve as an opportunity to teach students about energy conservation and to make them more conscious about their energy use.

SENSOR PACKAGE

According to the Office of Energy Efficiency & Renewable Energy, when a building deploys properly implemented automation controls, it can cut building energy use by approximately 29%.[1] The study goes even further in saying that secondary schools could experience up to a 49% decrease in energy use. The greatest reductions in energy were achieved by adjusting setpoints for heating and cooling with respect to the day and night cycle and limiting the heating and cooling to when the building is occupied. This makes sense because as noted in the study "Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings", heating and cooling a building takes large amounts of energy and usually accounts for up to 40% of a building's energy use.[2] In order to monitor these conditions, we are aiming to deploy a small sensor package in each room that can take readings on the heating, cooling, occupancy, and CO2 levels which would be fed into a central server located in the school's central office. From this server, data driven decisions could be made and used to modulate the existing conditions in the building to limit excessive heating, cooling, and lighting energy use.

EDUCATIONAL OPPORTUNITY

With sensors being deployed in most of the rooms within the school, large amounts of environmental data will be gathered. This provides us with an opportunity to leverage the data as an educational tool to assist students in learning about engineering systems and sustainable energy design. In the new addition, we plan on having several displays where students and visitors would be able to see how the IoT building automation improves energy efficiency by comparing it to historical data from the school. Students will also be able to see how the different areas of the school use different amounts of energy and they can be conscious of their own energy use and how they can save money by being more sustainable.

[1] Office of Energy Efficiency & Renewable Energy, "Report Delves Into the Impacts of Commercial Building Controls on Energy Savings," 20 September 2017. [Online]. Available: https://www.energy.gov/eere/buildings/articles/report-delves-impacts-commercial-building-controls-energy-savings.

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Two displays will be added to monitor the output of the solar panels. One will be located on the first floor of the old building right as you walk in. The other will be placed in the new cafeteria. The screens will display the output from the meter connecting to the grid as well as the total energy generation of the panels going into the building. This can be done with a web page similar to the current system in place. Since the current system is located on the old gym roof, these four panels will need to be relocated and switching them to adjustable frames allows for a unique hands on learning opportunity. Placing them in the courtyard would allow for classes to use them for demonstration and show how changing the panel tilt positioning affects the energy output in real time on the monitors.

FINANCIAL FEASIBILITY & AFFORDABILITY

Currently, construction and improvement projects to Uni are funded through a budget consisting of Illinois State Board of Education (60%), donations to an endowment fund (25%), and a portion of the UIUC budget. This budget would not alone be close to enough for RetrHigh as Uni still needs to pay annual wages, operating costs, and incidentals. Using land area and size of the proposed structure, initial construction cost estimates sit at $5.5 million.

The RetrHigh project benefits in access to a wide pool of funding sources due to being both a public school and a part of the larger University. Analysis of applicant criteria shows that RetriHigh would be eligible for many grants provided by government agencies including: the Illinois School Construction Program, the Illinois Clean Energy Community Foundation, and the Net Zero Energy Building Program.

Illinois Clean Energy
community foundation

NETZERO
ENERGY BUILDING CERTIFICATION℠

Approval of the project and University funding will be under the supervision of the University Office of Capital Programs and Real Estate Services, with additional approval requiring signatures from various executive members.

We estimate our chances of project approval to be high due to University iCAP goals, increasing financial incentives for sustainable buildings, and a desire to retain the deep history and success of Uni. Additional funding for retrofitting procedures on the existing structure could take advantage of a separate Facilities and Services budget which does not require approval from University executive members.

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