

MASTER IN INDUSTRIAL TECHNOLOGY ENGINEERING

SENIOR DESIGN PROJECT

Energy Master Plan: IIT Campus

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Madrid

Declaration

I declare, under my responsibility, that the project submitted with the title

"Energy Master Plan for Illinois Institute of Technology Campus"

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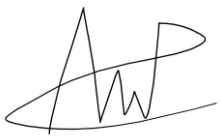

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ENERGY MASTER PLAN: IIT CAMPUS

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Collaborating Entity: ICAI – Universidad Pontificia Comillas and IIT – Illinois Institute of Technology

ABSTRACT

The research project aims to develop a comprehensive Energy Master Plan for the Illinois Institute of Technology (IIT) campus. This initiative is driven by the urgent need to mitigate climate change and reduce carbon emissions by enhancing energy efficiency in buildings. The project involves a detailed assessment of the current energy generation and consumption patterns on the IIT campus, with a focus on optimizing both energy production and consumption to achieve sustainability goals.

Keywords: Energy Master Plan, Illinois Institute of Technology (IIT), energy efficiency, greenhouse gas emissions, financial viability, building simulation, sustainability, campus-wide analysis.

Methodology

These are the steps followed to achieve the Energy Master Plan of IIT campus:

1. Historical Analysis
2. Building-Specific Simulation
3. Campus-Wide Simulation
4. Interconnected Building Network
5. Renewable Integration
6. Comprehensive Energy Master Plan



Fig. 1 Energy Master Plan Strategy Steps

Single OpenStudio Analysis

The study used OpenStudio to model IIT's Alumni Hall, focusing on:

- **Spatial Layout:** Modeled 3018.98 m^2 of space, including labs, offices, and classrooms for optimal HVAC efficiency.
- **Window-to-Wall Ratio (WWR):** Optimized for natural light and energy efficiency, especially on North and South facades.
- **Thermal Zones:** Divided into 24 zones to improve temperature control.
- **Construction:** Roof insulation met ASHRAE 90.1 requirements, but walls and windows needed upgrades.
- **Lighting & Plug Loads:** Analyzed for code compliance; most areas met standards, though some needed optimization.

The model compared to real consumption showed:

- **Accuracy:** The model overestimated electricity use in summer and underestimated steam use in winter. Metrics indicated high variability and poor accuracy.
- **End-Use:** Total energy use was 4,137,904 kBTU with an EUI of 127.36 kBTU/ft^2. Major consumers were interior equipment, lighting, and cooling, indicating areas for efficiency improvements.
- **Sensitivity:** Cooling and heating were highly sensitive to changes, significantly affecting energy use, while other factors had minimal impact.

Overall, the analysis highlighted the need to optimize heating and cooling systems to enhance energy efficiency.

End Uses	Electricity [GJ]	Natural Gas [GJ]	District Heating [GJ]
Heating	0.00	138.27	1763.14
Cooling	501.33	0.00	0.00
Interior Lighting	661.03	0.00	0.00
Interior Equipment	1234.51	0.00	0.00
Fans	52.43	0.00	0.00
Pumps	15.00	0.00	0.00
Total End Uses	**2464.31**	**138.27**	**1763.14**
Total Load (GJ)	**4365.72**		
Total Load (kBTU)	**4,137,904.16**		

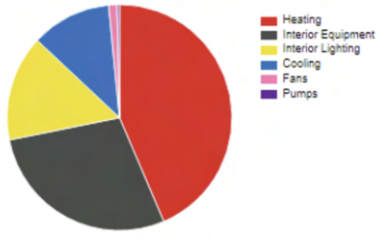

Fig. 2 Total Loads Consumption

Single RETScreen Analysis

This section analyzes energy savings, financial viability, and GHG emissions reductions for Alumni Hall at IIT using RETScreen software. It compares the current energy use with performance improvements from proposed design changes.

Current Performance: Alumni Hall has an energy use intensity (EUI) of 16.99 kWh/ft² and an emissions intensity of 0.004 tCO2/ft². The 2025 targets are a 50% reduction in EUI to 8.49 kWh/ft² and a 90% reduction in emissions intensity to 0.0004 tCO2/ft².

Proposed Enhancements:

- **Heating System**: Upgrade from a 284.76 kW system with 75% efficiency to a 304 kW system with 90% efficiency.
- **Cooling System**: Retain existing system with COP 4.0.
- **Building Envelope**: Increase insulation R-value from 13.89 to 20, reducing heating and cooling energy by 30.6%.
- **Ventilation**: Shift to occupancy-based scheduling, saving 55.4% in heating and 67.8% in cooling energy.
- **Lighting**: Replace lamps with LEDs, cutting electricity consumption by 37.8%.
- **Electrical Equipment**: Upgrade to efficient equipment, achieving 54.2% energy savings.
- **Hot Water System**: Reduce usage, saving 49.9% in energy.
- **Pumps**: Upgrade to a premium efficiency motor with variable speed, saving 64.9% in energy consumption.
- **Solar Water Heater**: Meet 66.3% of hot water demand, saving 3,289 kWh annually.
- **Solar Air Heater**: Save 130,675 kWh annually, reducing consumption by 17.5%.
- **Photovoltaic System**: Install a 148 kW system generating 246,331 kWh annually, cutting electricity costs and emissions.

Additional savings are achieved through improvements in heating systems, ventilation, electrical equipment, pumps, and the solar water heater.

The total initial investment is $454,110, with annual fuel cost savings of $27,049. However, after studying the financial viability, it is viable to:

- **Include:** Lighting upgrades, electrical equipment upgrades, ventilation, and photovoltaic systems.

- **Exclude:** Heating systems, domestic hot water systems, and solar air heaters due to financial impracticality.
- **Consider with Caution:** Building envelope improvements, heating/cooling pumps, and solar water heaters based on their long-term benefits and sustainability goals.

Excluding financially unviable measures improves overall project metrics, resulting in a revised pre-tax internal rate of return (IRR) of 11.8%, a net present value (NPV) of $29,689, and positive annual lifecycle savings.

The proposed energy-saving measures lead to a substantial reduction in GHG emissions:

- **Base Case Emissions:** 118 tonnes of CO2 annually.
- **Proposed Case Emissions:** 5.2 tonnes of CO2 annually, achieving a 95.6% reduction.

Overall, the implemented measures significantly enhance energy efficiency and reduce GHG emissions, aligning with IIT's sustainability goals and contributing to broader climate change mitigation efforts.

Show: All / Energy saved	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs $	Fuel cost savings $	Incremental O&M savings $	Simple payback yr
Heating							
Heating System				0	-3.849	0	None
Domestic hot water				125.380	-40,5	0	None
Cooling							
Cooling System				0	0	0	
Building envelope							
Building envelope	0	2.018		16.000	14,2	0	1.123,7
Ventilation							
Ventilation	0	27.149		0	192	0	Immediate
Lights							
Lights			53.027	600	5.303	100	0,1
Electrical equipment							
Electrical equipment			20.053	4.400	2.005	0	2,2
Hot water							
Hot water	4.938			600	-162	0	None
Pumps							
Heating/Cooling			5.243	5.000	524	0	9,5
Heating							
Solar water heater	3.289		0	6.930	365	0	19,0
Solar air heater	22.828		0	14.000	-2.017	0	None
Power							
Photovoltaic			246.331	281.200	24.633	-3.700	13,4
Total	**31.055**	**29.167**	**324.655**	**454.110**	**26.968**	**-3.600**	**19,4**

Fig. 3 Energy Saved by Proposed Case

Campus-Wide Analysis

The energy analysis covers 42 IIT buildings categorized as residential, religious, educational, industrial, and transport. Key findings include:

- **Fuel Consumption**: Significant reductions were observed, particularly in high-energy-use facilities like the Heating Plant.
- **GHG Emissions**: Costs for reducing emissions vary, with some facilities facing high costs due to ambitious reduction targets.
- **Energy Use Intensity (EUI)**: Proposed reductions in EUI across all building types indicate substantial potential energy savings, with educational buildings seeing targeted improvements.
- **Financial Viability**: Initial costs vary widely; for example, the IIT Tower's costs exceed $10 million, while most facilities are between $1 million and $4 million, highlighting the need for strategic financial planning.

Optimizing building interconnections focuses on:

- **Steam Distribution**: Proposals include reducing sharp turns and upgrading insulation to improve efficiency.
- **Roof Areas**: With 799,900 square feet of roof space, options like solar panels and green roofs could significantly reduce energy costs and enhance sustainability.
- **Electrical and Telecom Systems**: Recommendations include efficient routing, redundancy, and smart monitoring to improve reliability and performance.

This summary highlights the key findings and recommendations for enhancing energy efficiency and sustainability across the IIT campus.

Conclusion

In this project, the challenge of optimizing energy management across the IIT campus was addressed. Through detailed individual analyses and a structured methodology, key areas for improvement were identified. The proposed solutions enhance the Energy Master Plan by increasing energy efficiency, reducing greenhouse gas emissions, and ensuring financial feasibility. These measures address both immediate energy needs and align with long-term sustainability goals, effectively meeting the project's objectives and setting a clear path for future advancements.

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ENERGY MASTER PLAN: IIT CAMPUS

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RESUMEN DEL PROYECTO

El proyecto de investigación tiene como objetivo desarrollar un Plan Maestro de Energía integral para el campus del Instituto de Tecnología de Illinois (IIT). Esta iniciativa está impulsada por la urgente necesidad de mitigar el cambio climático y reducir las emisiones de carbono mejorando la eficiencia energética de los edificios. El proyecto consiste en una evaluación detallada de los patrones actuales de generación y consumo de energía en el campus del IIT, centrándose en la optimización tanto de la producción como del consumo de energía para alcanzar los objetivos de sostenibilidad.

Palabras Clave: Plan Maestro de Energía, Instituto Tecnológico de Illinois (IIT), eficiencia energética, emisiones de gases de efecto invernadero, viabilidad financiera, sostenibilidad, análisis de todo el campus.

Metodología

Los pasos seguidos para la realización del Plan Director Energético del campus del IIT incluyen:

1. Análisis histórico
2. Simulación específica del edificio
3. Simulación en todo el campus
4. Red de edificios interconectados
5. Integración de energías renovables
6. Plan Maestro Energético Integral



Fig. 4 Pasos estratégicos del Plan Maestro de Energía

Análisis de OpenStudio

El estudio utilizó OpenStudio para modelar el Alumni Hall del IIT, centrándose en:

- **Disposición espacial:** Modelado de 3018,98 m² de espacio, incluyendo laboratorios, oficinas y aulas para una eficiencia óptima de climatización.
- **Relación entre ventanas y paredes:** Optimización de la luz natural y la eficiencia energética, especialmente en las fachadas norte y sur.
- **Zonas térmicas:** Divididas en 24 zonas para mejorar el control de la temperatura.
- **Construcción:** El aislamiento del tejado cumplía con las normas ASHRAE 90.1, pero las paredes y ventanas necesitaban mejoras.
- **Iluminación y cargas de enchufes:** Se analizó el cumplimiento de la normativa; la mayoría de las zonas cumplían las normas, aunque algunas necesitaban optimización.

El modelo comparado con el consumo real mostró:

- **Precisión:** El modelo sobrestimó el consumo eléctrico en verano e infravaloró el consumo de vapor en invierno. Las métricas indicaron una alta variabilidad y una precisión deficiente.
- **Uso Final:** El consumo total de energía fue de 4.137.904 kBTU con un EUI de 127,36 kBTU/ft². Los principales consumidores fueron los equipos interiores, la iluminación y la refrigeración, lo que indica áreas para mejorar la eficiencia.
- **Sensibilidad:** La refrigeración y la calefacción fueron muy sensibles a los cambios, afectando significativamente al consumo de energía, mientras que otros factores tuvieron un impacto mínimo.

En general, el análisis puso de manifiesto la necesidad de optimizar los sistemas de calefacción y refrigeración para mejorar la eficiencia energética.

End Uses	Electricity [GJ]	Natural Gas [GJ]	District Heating [GJ]
Heating	0.00	138.27	1763.14
Cooling	501.33	0.00	0.00
Interior Lighting	661.03	0.00	0.00
Interior Equipment	1234.51	0.00	0.00
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Pumps	15.00	0.00	0.00
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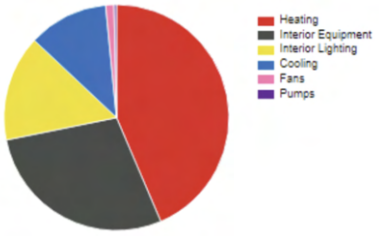

Fig. 5 Consumo Total de Cargas

Análisis de una Única Pantalla RETScreen

Esta sección analiza el ahorro energético, la viabilidad financiera y la reducción de emisiones de GEI del Alumni Hall del IIT utilizando el software RETScreen. Se compara el uso actual de la energía con las mejoras de rendimiento de los cambios de diseño propuestos.

Rendimiento Actual: El Alumni Hall tiene una intensidad de uso de energía (EUI) de 16,99 kWh/pie² y una intensidad de emisiones de 0,004 tCO2/pie². Los objetivos para 2025 son una reducción del 50% de la EUI a 8,49 kWh/pie² y una reducción del 90% de la intensidad de las emisiones a 0,0004 tCO2/pie².

Mejoras Propuestas:

- **Sistema de Calefacción:** Actualización de un sistema de 284,76 kW con una eficiencia del 75% a un sistema de 304 kW con una eficiencia del 90%.
- **Sistema de Refrigeración:** Mantener el sistema existente con COP 4.0.
- **Envolvente del Edificio:** Aumentar el valor R del aislamiento de 13,89 a 20, reduciendo la energía de calefacción y refrigeración en un 30,6%.
- **Ventilación:** Cambiar a una programación basada en la ocupación, ahorrando un 55,4% en calefacción y un 67,8% en refrigeración.
- **Iluminación:** Sustituir las lámparas por LED, reduciendo el consumo eléctrico un 37,8%.
- **Equipos Eléctricos:** Actualización a equipos eficientes, con un ahorro energético del 54,2%.
- **Sistema de Agua Caliente:** Reducir el uso, ahorrando un 49,9% de energía.
- **Bombas:** Actualizar a un motor de alta eficiencia con velocidad variable, ahorrando un 64,9% en el consumo de energía.
- **Calentador de Agua Solar:** Cubre el 66,3% de la demanda de agua caliente, ahorrando 3.289 kWh anuales.
- **Calentador de Aire Solar:** Ahorra 130.675 kWh anuales, reduciendo el consumo en un 17,5%.
- **Sistema Fotovoltaico:** Instalar un sistema de 148 kW que genere 246.331 kWh anuales, reduciendo los costes de electricidad y las emisiones.

Se consiguen ahorros adicionales mediante mejoras en los sistemas de calefacción, ventilación, equipos eléctricos, bombas y el calentador solar de agua.

La inversión inicial total es de $454.110, con un ahorro anual en costes de combustible de $27.049. Tras estudiar la viabilidad financiera, es viable:

- **Incluir:** Actualizaciones de iluminación, equipos eléctricos, ventilación y sistemas fotovoltaicos.
- **Excluir:** Sistemas de calefacción, sistemas de agua caliente sanitaria y calentadores de aire solares por inviabilidad económica.
- **Considerar con Precaución:** Las mejoras de la envolvente del edificio, las bombas de calefacción/refrigeración y los calentadores de agua solares en función de sus beneficios a largo plazo y sus objetivos de sostenibilidad.

La exclusión de las medidas inviables desde el punto de vista financiero mejora las métricas generales del proyecto, dando como resultado una tasa interna de rentabilidad (TIR) revisada antes de impuestos del 11,8%, un valor actual neto (VAN) de $29.689 y un ahorro anual positivo durante el ciclo de vida.

Las medidas de ahorro energético propuestas conllevan una reducción sustancial de las emisiones de GEI:

- **Emisiones del Caso Base:** 118 toneladas de CO2 anualmente.
- **Emisiones del Caso Propuesto:** 5,2 toneladas de CO2 anualmente, logrando una reducción del 95,6%.

En general, las medidas implementadas mejoran significativamente la eficiencia energética y reducen las emisiones de GEI, alineándose con los objetivos de sostenibilidad del IIT y contribuyendo a los esfuerzos más amplios de mitigación del cambio climático.

Show: All / Energy saved	Heating kWh	Cooling kWh	Electricity kWh	Incremental initial costs $	Fuel cost savings $	Incremental O&M savings $	Simple payback yr
Heating							
Heating System				0	-3.849	0	None
Domestic hot water				125.380	-40,5	0	None
Cooling							
Cooling System				0	0	0	
Building envelope							
Building envelope	0	2.018		16.000	14,2	0	1.123,7
Ventilation							
Ventilation	0	27.149		0	192	0	Immediate
Lights							
Lights			53.027	600	5.303	100	0,1
Electrical equipment							
Electrical equipment			20.053	4.400	2.005	0	2,2
Hot water							
Hot water	4.938			600	-162	0	None
Pumps							
Heating/Cooling			5.243	5.000	524	0	9,5
Heating							
Solar water heater	3.289		0	6.930	365	0	19,0
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Power							
Photovoltaic			246.331	281.200	24.633	-3.700	13,4
Total	**31.055**	**29.167**	**324.655**	**454.110**	**26.968**	**-3.600**	**19,4**

Fig. 6 Energía Ahorrada por el Caso Propuesto

Análisis a Nivel de Campus

El análisis energético cubre 42 edificios del IIT categorizados como residenciales, religiosos, educativos, industriales y de transporte. Los hallazgos clave incluyen:

- **Consumo de Combustible**: Se observaron reducciones significativas, particularmente en instalaciones de alto consumo energético como la Planta de Calefacción.
- **Emisiones de GEI**: Los costos para reducir las emisiones varían, con algunas instalaciones enfrentando costos elevados debido a objetivos de reducción ambiciosos.
- **Intensidad de Uso de Energía** : Las reducciones propuestas en el EUI en todos los tipos de edificios indican un considerable potencial de ahorro energético, con mejoras específicas en los edificios educativos.
- **Viabilidad Financiera**: Los costos iniciales varían ampliamente; por ejemplo, los costos para la Torre IIT superan los $10 millones, mientras que la mayoría de las instalaciones están entre $1 millón y $4 millones, lo que subraya la necesidad de una planificación financiera estratégica.

La optimización de la interconexión de los edificios se centra en:

- **Distribución de Vapor**: Las propuestas incluyen reducir las curvas cerradas y mejorar el aislamiento para aumentar la eficiencia.

- **Áreas de Techo**: Con 799.900 pies cuadrados de espacio en techos, opciones como paneles solares y techos verdes podrían reducir significativamente los costos energéticos y mejorar la sostenibilidad.

- **Sistemas Eléctricos y de Telecomunicaciones**: Se recomiendan un enrutamiento eficiente, redundancia y monitoreo inteligente para mejorar la fiabilidad y el rendimiento.

Este resumen destaca los hallazgos y recomendaciones clave para mejorar la eficiencia energética y la sostenibilidad en todo el campus del IIT.

Conclusión

En este proyecto, se abordó el desafío de optimizar la gestión energética en todo el campus del IIT. A través de análisis detallados individuales y una metodología estructurada, se identificaron las áreas clave de mejora. Las soluciones propuestas mejoran el Plan Maestro de Energía al aumentar la eficiencia energética, reducir las emisiones de gases de efecto invernadero y garantizar la viabilidad financiera. Estas medidas abordan tanto las necesidades energéticas inmediatas como los objetivos de sostenibilidad a largo plazo, cumpliendo eficazmente con los objetivos del proyecto y estableciendo un camino claro para futuros avances.

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List of Symbols

Symbol	Definition
BESS	Battery Energy Storage System
CAEE	Civil, Architectural, and Environmental Engineering
CFM	Cubic Feet per Minute
CHP	Combined Heat and Power
COP	Coefficient of Performance
CTA	Chicago Transit Authority
CVRSME	Coefficient of Variation of the Root Mean Square Error
DC	Direct Current
DOE	Department of Energy
EUI	Energy Use Intensity
GHG	Greenhouse Gas
HRDS	High-Reliability Distribution System
HRSG	Heat Recovery Steam Generators
HVAC	Heating, Ventilation, and Air Conditioning
IIT	Illinois Institute of Technology
LED	Light Emitting Diode
NMBE	Normalized Mean Bias Error
NOC	Network Operations Center
NPV	Net Present Value
O&M	Operations and Maintenance
PMU	Phase Measurement Unit
PV	Photovoltaic
ROI	Return on Investment
SHGC	Solar Heat Gain Coefficient
T&D	Transmission and Distribution
WWR	Window-to-Wall Ratio

Chapter 1

Introduction

Energy efficiency in buildings is a critical aspect of the global effort to mitigate climate change and reduce carbon emissions. As buildings are significant consumers of energy, enhancing their energy performance is essential for achieving sustainability goals. The development of comprehensive energy master plans has emerged as a key strategy in this endeavor, aiming to optimize energy usage and integrate sustainable practices. This chapter provides an overview of the antecedents, motivation, methodology, and project destination for creating an Energy Master Plan for the Illinois Institute of Technology (IIT) campus. The subsequent sections delve into the background and rationale for the study, outline the research objectives and phases, describe the methods employed, and present the scope of the project within the IIT campus.

1.1 Antecedents

In response to the urgent need for mitigating climate change and reducing carbon emissions, significant attention has been directed towards enhancing energy efficiency in buildings. Buildings are known to contribute significantly to carbon emissions because of how much energy they use. As a result, creating thorough energy master plans for buildings has become a key tactic in accomplishing sustainability objectives.

Several strategies have been put forth and put into practice to increase building energy efficiency. These include replacing old boilers with newer, more efficient units, updating heating and cooling systems, and implementing energy-saving lighting systems. Although these isolated acts help reduce energy use, there is an increasing awareness of the need for comprehensive strategies that can optimize efficiency gains and produce long-term results.

The creation of building energy master plans has goals beyond energy reduction. It includes the broader goals such as maximizing energy output and consumption while

providing affordable, sustainable, safe, and reliable energy to a campus or cluster of buildings.

Installing microgrids on campuses is an innovative strategy that is gaining popularity. Microgrids provide a distributed power distribution system that can improve energy efficiency, increase resiliency, and facilitate the integration of renewable energy sources. Campuses and building complexes can reduce their carbon footprint, decrease their reliance on non-renewable energy sources, and effectively control their energy consumption by implementing microgrids.

In summary, creating energy master plans for buildings is a calculated step toward achieving comprehensive energy efficiency goals. Campuses and building complexes can create resilient, sustainable, and environmentally responsible energy systems by utilizing both active and passive energy management strategies.

1.2 Motivation

The main objective of this research project is to create a thorough Energy Master Plan to evaluate the energy generation and consumption of the Illinois Institute of Technology (IIT) campus. This means examining the various buildings on campus, analyzing the current microgrid, and the active and passive components of energy management. In order for this research project to successfully achieve its goals, a strategic plan with several critical phases will be followed as shown in Figure 1.1:

1. Assessment of Conditions and Needs: The first step entails a comprehensive evaluation of the energy circumstances and requirements that exist at the Illinois Institute of Technology (IIT) campus. Data on patterns of energy usage, the capacity of the infrastructure, and current energy management techniques will all be gathered for this study.

2. Goal Setting: To guide the creation of the Energy Master Plan, specific, quantifiable goals will be established in response to the assessment results. These include minimizing environmental impact, optimizing energy production and consumption within the campus or building cluster, reducing energy consumption, increasing renewable energy integration, and improving resiliency.

3. Options for Improvement: This phase explores various alternatives and tactics to increase energy efficiency and sustainability. This includes assessing the feasibility and effectiveness of integrating renewable energy technologies, implementing energy-efficient building designs and systems, fine-tuning microgrid operations, and incorporating smart energy management solutions to maximize energy output and consumption.

4. Comprehensive Plan: Based on the identified goals and selected improvement options, a comprehensive energy master plan is developed. This strategy, which

will include both short-term and long-term efforts, will provide specific recommendations and solutions tailored to the unique needs and characteristics of the IIT campus. It will also include investment plans that define the return on investment (ROI) and quantify the amount of money needed to implement the proposed solutions.

5. Implementation: After the energy master plan is developed, the next phase would be to implement the proposed tactics and initiatives. Implementing energy management protocols, installing renewable energy generation systems, upgrading microgrid infrastructure, and retrofitting buildings with energy-efficient technologies are some examples of actions that can be taken to optimize energy generation and consumption while maintaining cost effectiveness.

6. Measurement and Verification: Rigorous measurement and verification methods would be used to evaluate the performance and effectiveness of the solutions adopted, both during and after the implementation process. This includes monitoring operational efficiency, environmental impact, renewable energy production, energy consumption, and refinement of the energy master plan. It also regularly evaluates the return on investment of the measures implemented.

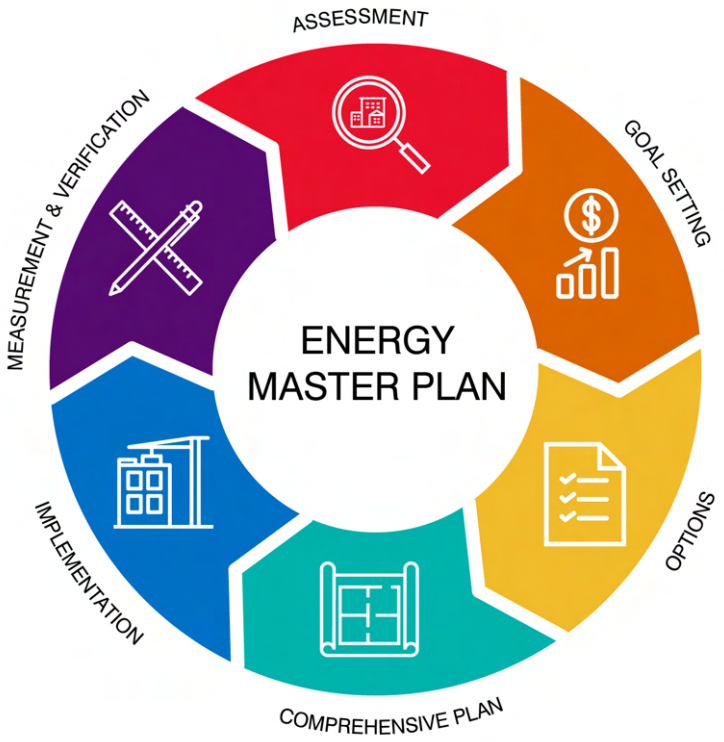

Fig. 1.1 Energy Master Plan Strategy Steps

Reprinted from "Energy Master Plan and Climate Action Plan," by University of Colorado Anschutz Medical Campus, n.d., CU Anschutz Medical Campus.

However, it's important to note that due to the scope and nature of this research, the final two steps of Implementation (5) and Measurement and Verification (6) will not be feasible. While these steps are necessary for the full implementation and evaluation of an energy master plan, their implementation will not occur within the confines of this research project. Instead, the focus will be on developing a robust plan that lays the groundwork for future implementation efforts.

By following this strategic plan, the research project hopes to maximize both energy production and consumption while providing practical suggestions and assisting the IIT campus in transitioning to a more resilient, efficient, and sustainable energy infrastructure.

1.3 Methodology

The methodology for developing the comprehensive Energy Master Plan for the Illinois Institute of Technology (IIT) campus is structured into several key phases, as illustrated

in Figure 1.2. The process begins with the analysis of historical energy data to establish a baseline for current energy usage. This is followed by a detailed case study of the existing power plant, including site visits and reviews of operational data to identify areas for improvement.

Subsequently, site visits to various campus buildings are conducted to assess the physical condition of energy systems and infrastructure. This hands-on assessment provides essential insights that complement the collected data. The optimization of the distribution system is then undertaken, focusing on enhancing the efficiency of energy delivery across the campus through analysis and proposed upgrades.

Energy modeling is a crucial part of the methodology, using advanced software to simulate various energy-saving measures and their impacts. These simulations guide the development of effective strategies to reduce energy consumption and increase efficiency. Continuous data collection and analysis throughout the project ensure that progress is tracked and measures are validated.

Building-specific and campus-wide simulations evaluate the potential impacts of proposed energy efficiency measures. These simulations help understand the interactions and overall effects on campus energy performance. The results and findings from these analyses are synthesized to develop actionable recommendations.

Finally, a set of recommendations is formulated based on the comprehensive analysis, aimed at optimizing energy production and consumption on the IIT campus. The final proposal includes detailed implementation plans and investment analyses to guide future actions, ensuring sustainability, efficiency, and resilience.

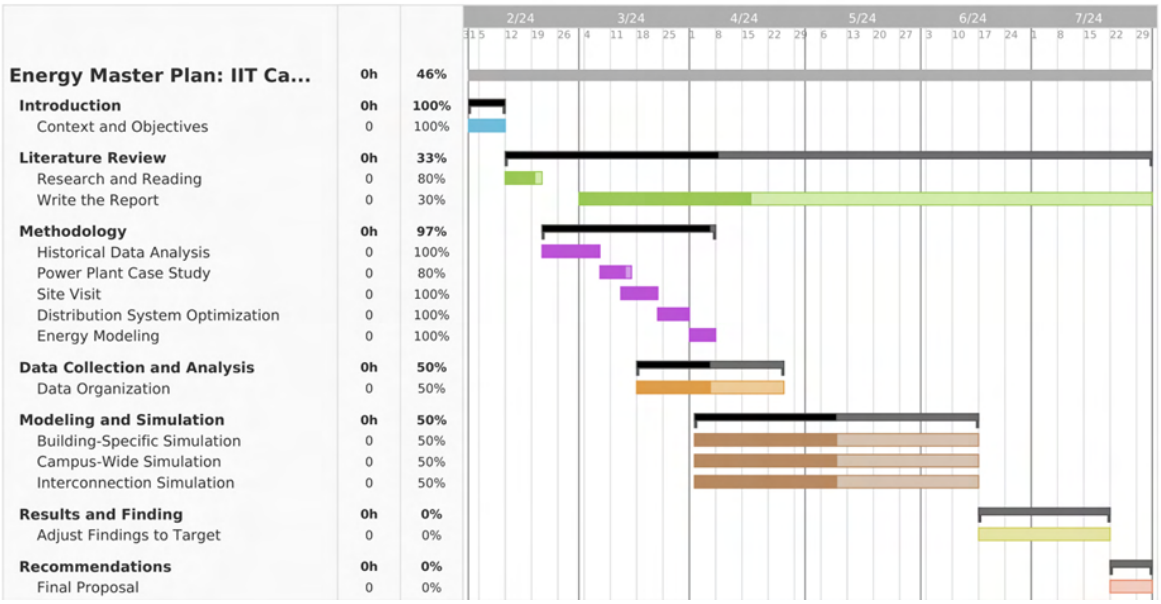

Fig. 1.2 Timeline and phases of the Energy Master Plan methodology

1.4 Project Destination

The project's main focus is on the systems and facilities at the Illinois Institute of Technology Main Campus, which is located at 10 West 35th Street, Chicago, IL 60616, for short. It is important to mention that, as illustrated in the attached Figure 1.3, the Illinois Institute of Technology consists of four campuses in total.

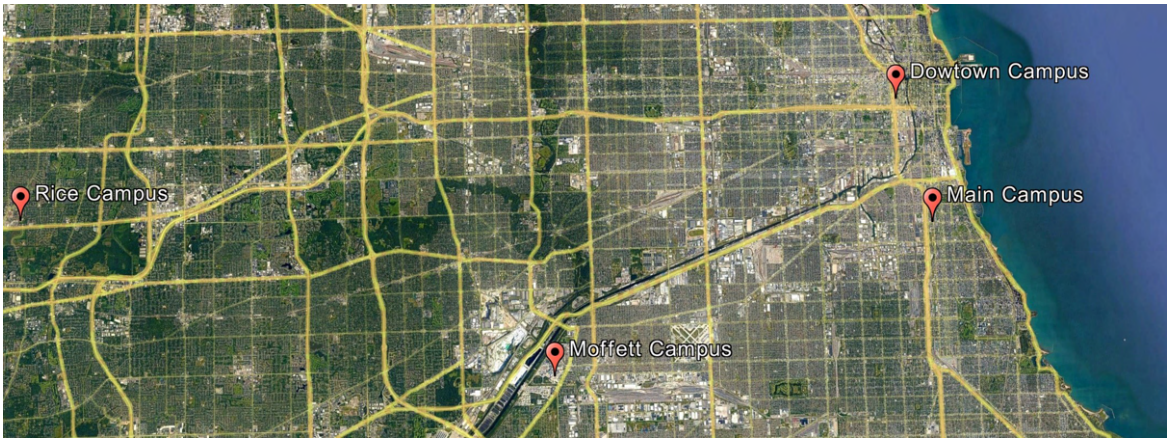

Fig. 1.3 Illinois Institute of Technology Campus Locations

The Illinois Institute of Technology's Main Campus is a hive of administrative, academic, athletic, and residential activity. Covering an area of about 5 million square feet, it is large enough to house a wide range of amenities that are necessary for campus life. Among its notable features are 9 academic buildings, providing spaces for teaching, research, and learning endeavors. The campus also has 2 facilities service buildings to maintain the seamless operation of the school infrastructure, as well as an athletics complex that accommodates sports and recreational events. The vibrancy of student life extends beyond campus boundaries, as evidenced by the presence of 7 fraternities and sororities within the university community. In addition, there are 8 student services facilities that meet a range of student needs, 13 resident halls that provide housing for students, and 2 rental properties. In all, there are 41 buildings on the Main Campus, each contributing to the vibrant campus community and supporting the diverse needs of students, faculty, and staff.

Chapter 2

Assessment of Energy Management at IIT

In the late 1980s, the Illinois Institute of Technology (IIT) launched a significant project to install an 8 MW gas-fired cogeneration plant. This facility featured two 4 MW turbines, Heat Recovery Steam Generators (HRSGs), and existing steam boilers to satisfy the campus's heating and electricity needs. Alongside this, a 1200-ton absorption chilled water loop was introduced, making use of surplus steam from the electricity generation process.

The campus's electrical system, initially designed in the 1950s with feeders, loops, and manual control technology, supported the implementation of cogeneration in the late 1980s. Other major energy users in the Chicago area, with similarly planned campus layouts, also reaped the benefits of cogeneration for heating and electricity. This early iteration of the IIT microgrid was a conventional Campus Microgrid, not yet an advanced Smart Microgrid.

Around 2007, IIT began developing its Smart Microgrid system by integrating modern electric control technology into the existing manual microgrid. Converting a manually controlled Campus Microgrid into a Smart Microgrid provided numerous operational benefits, cost reductions, regional connectivity between distant microgrids, and a glimpse into a future electric grid less dependent on large regional power plants. The development of the Smart Grid system enabled localized resiliency, allowing the IIT Smart Microgrid to function in island mode, achieving a goal nearly four decades in the making.

The initial design of the Campus Microgrid, with its feeders and loops, and the early recognition of microgrid planning successes, lays the groundwork for developing more smart microgrids. Some new projects are "blank slate" initiatives, which can incorporate the latest technology, including ground source geothermal systems.

There are several reasons why large energy consumers might opt to install their own Smart Microgrids. These include financial gains from energy storage, timing of market rate pricing, and the provision of electricity, chilled water, data, and thermal energy. Moreover, microgrids enhance resiliency, connectivity with other microgrids, and the potential to sell energy back to the larger electric grid. The future of microgrids is promising, with growing opportunities for innovation and efficiency.

2.1 Early Campus Microgrid

The Illinois Institute of Technology (IIT) is situated approximately 2.5 miles south of downtown Chicago, bordered by 35th Street to the south, Michigan Avenue to the east, 29th/30th Street to the north, and the Metra Rock Island line to the west. By 2006, IIT's electricity supply came from the local utility, ComEd, through two substations located on the campus's west end: the South Substation at 3400 South Federal Street and the North Substation at 3200 South Federal Street. These substations, depicted in Figure 2.1, were connected via three feeders from ComEd—two dedicated feeders for each substation and one shared feeder. The feeders had a nominal capacity of 20 MW for the campus, but ComEd limited the campus to drawing no more than 14 MW. If the campus demand exceeded this, a new substation would be required.

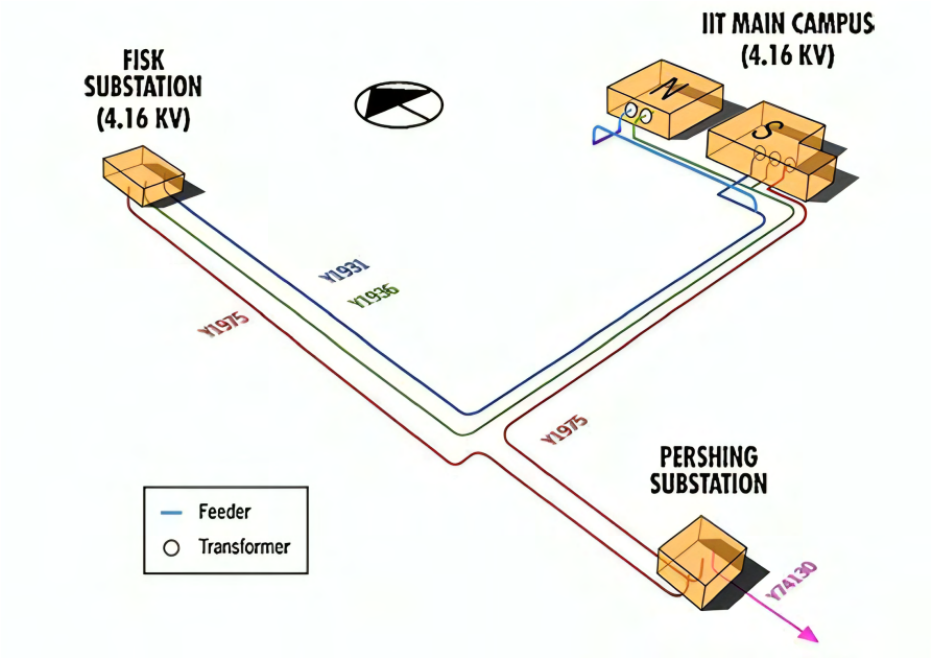

Fig. 2.1 Connection between the IIT Main Campus and the Substations

Reprinted from "Spatial-temporal power distribution network planning considering the impact of distributed generation," by Y. Wang, Y. He, X. Duan, and J. Wen, 2012, IEEE Transactions on Power Systems, 28(2), pp. 1560-1568

The substations were integral to distributing electricity across almost all campus buildings. The design and technology of these substations dated back to the 1940s and 1950s, based on the Mies Van Der Rohe campus plan, which placed nearly all electrical distribution systems underground or within buildings. This approach protected the infrastructure from storm damage and other threats. A cross-tie feeder between the substations allowed for backup operations if one feeder failed, ensuring continuous operation.

In 2003, the aging equipment and increasing unreliability of the electrical grid led IIT to start a renovation process. This involved modernizing the North Substation with new equipment and controls, while ComEd upgraded its equipment at the same substation. Despite these improvements, IIT experienced frequent and sporadic outages over the decade preceding the implementation of the microgrid. These outages affected various services, necessitating costly and disruptive responses.

The underground placement of electrical infrastructure required detailed and expensive surveys to identify and prioritize repairs for the most troubled feeder segments. Sporadic outages led to power losses in buildings, disrupting laboratory work and space conditioning, resulting in lost experimental data and necessitating equipment repair or replacement. Feeder damage on the residential side of the campus caused outages that forced the temporary relocation of residents to nearby hotels, incurring significant costs.

These issues underscored the need for a more resilient and reliable electrical system, ultimately paving the way for the development of the IIT Smart Microgrid.

2.2 Development of the Smart Microgrid

A microgrid is a self-contained energy system that serves a specific area, such as a college campus, hospital, business center, or neighborhood. Typically powered by distributed energy sources like solar panels, wind turbines, and generators, microgrids can also include energy storage solutions such as batteries and electric vehicle charging stations. One of the key features of microgrids is their "islandable" capability, which allows them to disconnect from the central grid and operate independently, ensuring continuous power even during large-scale outages.

At the Illinois Institute of Technology (IIT), the Perfect Power microgrid exemplifies these principles, providing a reliable and intelligent power system. This microgrid incorporates a high-reliability distribution system, smart metering, and renewable energy sources to enhance overall efficiency, demand response, and resiliency. As one of the first functioning microgrids in the nation, it includes solar panels, wind turbines, LED street lights, and charging stations for electric vehicles. In emergencies, such as severe weather events or cyber-attacks, the system can disconnect from the larger power grid, making the campus self-sufficient. The IIT microgrid aims to achieve several critical objectives:

* Prove the effectiveness of Perfect Power at IIT.

* Cut the campus's grid electricity consumption by 50%.
* Achieve a permanent 20% reduction in peak demand from 2007 levels.
* Delay the need for new substation investments through demand reduction.
* Highlight the economic benefits of Perfect Power.
* Provide a design that can be replicated by other microgrids.

Furthermore, Figure 2.2 illustrates the hierarchical structure of the IIT microgrid system, centered around the master controller and its interactions with various control systems.

1. **Master Controller**: At the top, it oversees the entire microgrid operation, ensuring optimal performance, reliability, and efficiency.
2. **Generation Control System**: Manages electricity generation from gas turbines, solar PV panels, and wind turbines. The master controller directs these sources to meet campus energy demands.
3. **Storage Control System**: Handles energy storage, including battery storage and electric vehicle charging stations. It stores excess energy and releases it during high demand.
4. **Building Control System**: Uses Zigbee technology within buildings to manage energy consumption at a granular level. The master controller adjusts usage based on real-time data for optimal efficiency.
5. **Distribution System Control**: Oversees the distribution of electricity across the campus, ensuring efficient and reliable power delivery to all buildings. The master controller monitors and controls this system to prevent outages and maintain stability.

Arrows indicate the flow of information and commands between the master controller and the subsystems, enabling efficient, sustainable, and reliable microgrid operation.

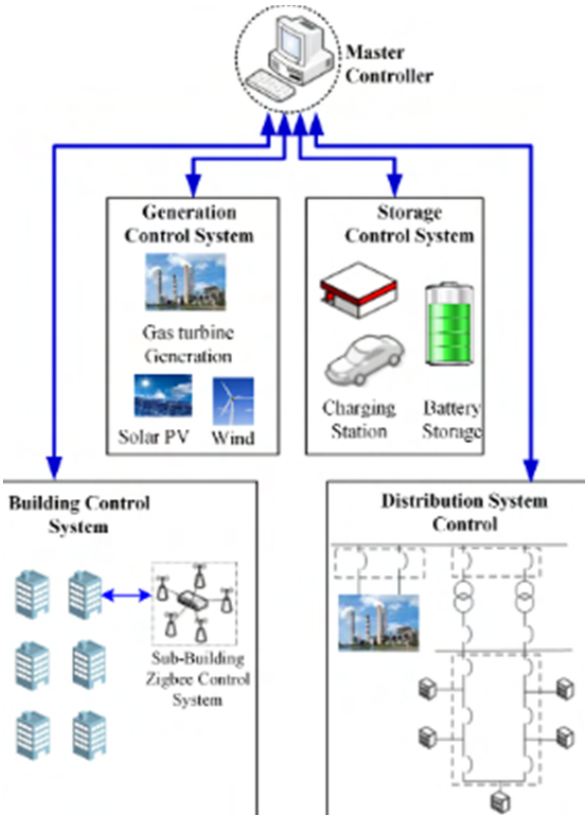

Fig. 2.2 Hierarchical Structure of IIT Microgrid System

The microgrid focuses on three areas: reliability, efficiency, and sustainability.

2.2.1 Reliability

The microgrid enhances campus reliability through several key strategies:

* **High-Reliability Distribution System (HRDS):** This system replaces the traditional radial feeder structure with a loop feeder system using smart switches. These switches can automatically isolate ground faults in feeder segments while maintaining service to all buildings on the loop.

* **Loop Configuration:** The IIT campus is divided into seven loops, each connected to one of the two substations equipped with HRDS switches. This configuration, as shown in Figure 2.3, significantly reduces the risk of campus-wide outages from multiple simultaneous failures. The smart switches within each loop allow the system to quickly isolate faults and restore normal operation within a fraction of a second, greatly minimizing downtime and associated costs.

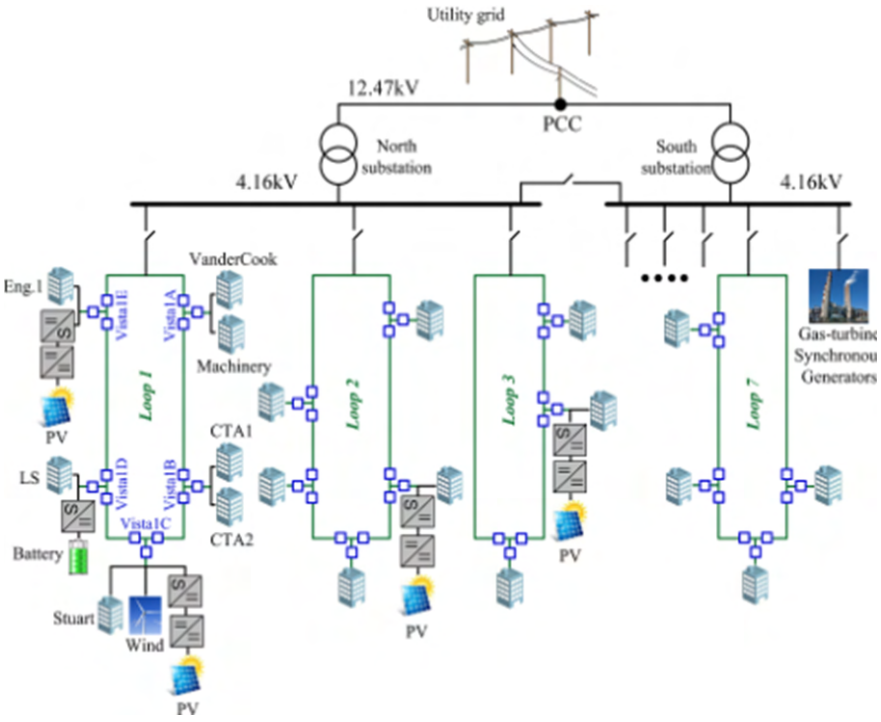

Fig. 2.3 IIT Microgrid Division in Loops

Since the project's inception, IIT has experienced no feeder outages at the North Substation. In the event of losing utility feed, on-site generation maintains the loads. The master controller, depicted in the second image, is essential for monitoring the distribution system and making decisions to meet critical loads.

2.2.2 Sustainability

Reducing energy consumption and demand naturally lowers emissions. The IIT microgrid supports sustainability through:

* **Renewable Energy Integration:** The system incorporates renewable energy sources such as solar panels and wind turbines. These sources reduce reliance on fossil fuels and decrease greenhouse gas emissions.

* **Energy Storage Solutions:** The microgrid includes advanced energy storage systems that capture and store excess energy generated by renewable sources. This stored energy can be used during periods of high demand or when renewable generation is low, enhancing overall sustainability.

2.2.3 Efficiency

A better understanding of campus electricity needs, combined with improved control, leads to more efficient energy use. The master controller uses real-time data from the grid to manage load priorities and prevent excessive demand. The system includes 12-phase measurement units (PMUs) that deliver real-time usage information, enabling the master controller to make informed decisions. Smart feeders and Siemens building controllers enhance the campus's ability to manage higher electricity use during peak times by shifting low-priority loads, adjusting comfort standards, or communicating with occupants to change behaviors.

The implementation of wireless control and monitoring system at the device level demonstrates rapid load management. These technologies allow IIT to better manage energy use and improve overall efficiency, reducing operational costs and enhancing the reliability of the energy supply.

2.2.4 Conclusion

The Perfect Power microgrid at IIT represents a significant advancement in creating a reliable, sustainable, and efficient energy system. By leveraging advanced technology and renewable resources, IIT has created a model for future community electricity distribution, achieving substantial reductions in CO2 emissions and improving energy efficiency.

2.3 Co-generation Plant

The Illinois Institute of Technology (IIT) has a rich history of leveraging innovative energy solutions to meet its campus needs. A notable example is the co-generation plant established in 1990. This system included two 4 megawatt natural gas turbines and two heat recovery boilers with duct burners, designed to generate both electricity and heat. The co-generation plant aimed to enhance energy efficiency by utilizing waste heat for campus heating, chilling, and other process uses, which is a key advantage of Combined Heat and Power (CHP) systems. At its peak, the plant could produce approximately 6 megawatts of electricity during the summer months, with waste heat generation estimated at 30,000 pounds per hour. Figure shows the co-generation plant at IIT.



Fig. 2.4 IIT Co-generation Plant

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

Co-generation, or Combined Heat and Power (CHP), is a process that generates electricity and useful heat simultaneously from the same energy source. At IIT, natural gas turbines produce electricity. The heat generated in this process, which would otherwise be wasted, is captured by heat recovery boilers to produce steam. This steam is then used for campus heating, hot water, and driving absorption chillers for cooling. This simultaneous production of electricity and heat makes the system highly efficient compared to separate heat and power systems.

Despite its efficiency and environmental benefits, the co-generation plant at IIT was eventually shut down in favor of purchasing electricity from the grid under a special rate structure known as Rider 27. Rider 27 is a rate structure offered by the local utility, ComEd, which provides a significantly reduced electricity rate for on-peak energy in exchange for the ability to request the customer to generate a specified minimum amount of power during peak demand periods. This decision was driven by a comprehensive analysis of various operating scenarios, which revealed that Rider 27 offered significant cost savings compared to full co-generation operation.

In the mid-1990s, a co-generation analysis conducted by International Power Technology highlighted the economic challenges associated with maintaining and operating the co-generation system. The Rider 27 rate, offered by the local utility ComEd, provided a highly competitive electricity rate of $0.037 per kilowatt-hour (kWh) for on-peak energy. This rate was significantly lower than the cost of generating electricity with the cogeneration plant, which was approximately $0.051 per kWh. Additionally, the Rider 27 agreement included a monthly allotment of 1,689,304 kWh of on-peak energy at the favorable rate, with a requirement to generate 80% of displaced capability when requested by ComEd.

The Table 2.1 provides a detailed comparison between the cogeneration plant and grid power options based on several key factors: cost comparison, efficiency, environmental impact, and operational flexibility. It highlights the strengths and weaknesses of each option, demonstrating why IIT opted for the grid power under Rider 27 despite the cogeneration plant's higher efficiency and lower environmental impact.

Table 2.1 Comparison of Co-generation Plant and Grid Power

Factors to Consider	**Cogeneration Plant**	**Grid Power**
Cost Comparison	-Total Revenue: $4,474,355 -Total Fuel Cost: $2,279,287 -Gross Revenue: $2,195,068 -Cost per kWh: $0.051	-Rate: $0.037 per kWh for on-peak energy
Efficiency	Higher efficiency due to simultaneous production of electricity and heat (Overall efficiency: 95.57%).	Lower efficiency due to transmission losses and lack of heat utilization.
Environmental Impact	Lower emissions per unit of energy produced due to higher efficiency and utilization of waste heat.	Generally higher emissions due to less efficient power plants and transmission losses.
Operational Flexibility	Provides on-site power generation and heat, enhancing reliability and reducing dependence on the grid.	Dependent on grid stability and availability.

The final decision to shut down the co-generation plant and utilize grid electricity under Rider 27 was primarily driven by cost considerations. The Rider 27 rate of $0.037 per kWh offered substantial savings compared to the co-generation plant's cost of $0.051 per kWh. Despite the higher efficiency and lower environmental impact of the co-generation plant, the financial benefits of Rider 27 were significant, as summarized in Table 2.2

Table 2.2 Summary of Co-generation Plant vs Grid Power

Factors to Consider	**Cogeneration Plant**	**Grid Power**
Cost Comparison		✓
Efficiency	✓	
Environmental Impact	✓	
Operational Flexibility	✓	

However, the co-generation plant remains a valuable asset for IIT, providing flexibility and reliability in energy management. The ability to generate power on-site and use waste heat for campus heating and cooling enhances overall energy efficiency. Strategic planning should focus on maintaining this flexibility and preparing for future changes in rate structures and energy demands. Ultimately, the combination of immediate cost savings from Rider 27 and the long-term benefits of co-generation positions IIT to effectively manage its energy needs while advancing sustainability goals.

2.4 Existing Renewable Facilities

The Illinois Institute of Technology (IIT) has developed and integrated various renewable energy facilities on its campus as part of its commitment to sustainability and energy innovation. These facilities include wind turbines, solar panels, energy storage systems, and electric vehicle charging stations. This section provides an overview of these existing renewable energy installations and their roles within the IIT microgrid.

2.4.1 Wind Units

In this section, the wind generation facilities at the Illinois Institute of Technology (IIT) are discussed.

Figure 2.5 focus on the 10 kW wind turbine installed on IIT's main campus at Stuart Field. This turbine, part of the IIT Wind Energy Consortium, serves as a test unit for research and optimization. The real-time data displayed from this turbine, including output power and various operational metrics, is crucial for analyzing its performance and identifying areas for improvement. This continuous monitoring supports the development of advanced algorithms aimed at enhancing the turbine's efficiency and reliability.



Fig. 2.5 10 kW wind turbine at IIT's Stuart Field with real-time output data

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

Furthermore, Figure 2.6 highlights the 1.5 MW GE wind turbine located on a wind farm in Marseilles, Illinois. This turbine is part of the IIT Wind Energy Consortium and is operated and maintained by Invenergy. It features advanced technology designed to increase energy output and reduce wear on components, thereby improving its lifespan and overall performance. The research conducted on this turbine provides valuable insights into optimizing large-scale wind energy systems, contributing to IIT's efforts to enhance wind energy technology and reduce costs.



Fig. 2.6 1.5 MW GE wind turbine in Marseilles part of the IIT Wind Energy Consortium

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

Also, Figure 2.7 showcases the Aris Wind Units, small-scale turbines installed on the IIT campus. These units are part of a broader initiative to integrate renewable energy sources into the campus infrastructure, aligning with IIT's sustainability goals. These turbines contribute to the campus's renewable energy mix and serve as a practical demonstration of small-scale wind energy applications.



Fig. 2.7 Aris wind units installed on the IIT campus

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

These wind energy projects at IIT underscore the commitment to advancing wind energy technology and integrating renewable energy sources into campus operations. Through

continuous research, real-time data analysis, and the implementation of both large-scale and small-scale wind turbines, the aim is to enhance the efficiency, reliability, and sustainability of wind energy systems.

2.4.2 Solar Energy

The total capacity of solar-PV installed across the IIT campus amounts to 350 kW. Each energy generation project is connected directly to a building distribution system, allowing the energy performance of these assets to be integrated into the building monitoring systems that communicate with the campus Network Operations Center. This comprehensive approach ensures efficient management and utilization of solar energy across the campus.

A notable addition to IIT's renewable energy initiatives is the installation of photovoltaic solar panels on the roof of S. R. Crown Hall. The newly installed 75 kilowatt-hour (kWh) solar panels allow Crown Hall to function as a nanogrid, capable of operating independently of the university's microgrid for short durations in the event of a blackout. This retrofit brings together historical architecture and modern sustainability practices, demonstrating a blend of old and new.

The project is emphasized by Mohammad Shahidehpour, director of the Robert W. Galvin Center for Electricity Innovation at IIT, who highlights its significance. While energy efficiency was not a primary consideration during Crown Hall's original design, it has now become a crucial aspect of architectural practice. The integration of solar panels at Crown Hall serves as an exemplary case study in sustainable renovation, showcasing the potential for integrating modern energy solutions into historic structures. Figure 2.8 shows this installation.



Fig. 2.8 Solar panels installed on the roof of S. R. Crown Hall at IIT

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

These solar energy projects at IIT underline the university's commitment to integrating renewable energy sources into its campus operations. By combining advanced technology with architectural heritage, IIT aims to enhance energy efficiency and sustainability while maintaining the integrity of its historic buildings.

2.4.3 Energy Storage

Energy storage systems, particularly batteries, play a crucial role in enhancing the efficiency and reliability of the Illinois Institute of Technology (IIT) microgrid. These systems store excess energy generated by renewable sources, such as solar panels and wind turbines, and release it during periods of high demand or when renewable generation is low. This section discusses the various energy storage solutions implemented at IIT.

A notable addition to IIT's energy storage capabilities is the Tesla 500 kWh lithium-ion battery installed at S. R. Crown Hall. This battery provides up to eight hours of independent operation during power outages, making Crown Hall a self-sufficient nanogrid within the campus microgrid. This installation not only ensures the building's operational resilience but also integrates seamlessly with the building's solar panel system.

In addition to the Tesla battery at Crown Hall, IIT has deployed a 180 kW solar photovoltaic (PV) system with Aquion Energy Aqueous Hybrid Ion (AHI) batteries at Keating Hall. These AHI batteries, with a storage capacity of 160 kWh, are part of a hybrid nanogrid that powers both AC and DC systems within the building. This setup enhances the building's sustainability and reliability by storing solar energy for use during peak demand periods and potential outages.

Moreover, the Stuart Data Center features a 300 kW Tesla Battery Energy Storage System (BESS) with a 500 kWh storage capacity. This system, which works in conjunction with two solar PV systems (87 kW) and a 10 kW wind turbine, provides backup power, peak shaving, and reduced demand on the electric utility. The BESS at Stuart not only ensures uninterrupted power supply but also contributes to significant cost savings and improved energy efficiency (Figure 2.9).



Fig. 2.9 Tesla battery system installed at IIT

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Additionally, an EnSync 500 kWh battery system was added to IIT's energy storage portfolio. This installation supports the campus's renewable energy initiatives by providing substantial storage capacity, thereby enhancing the overall efficiency and reliability of the microgrid. Figure 2.10 shows this battery system.



Fig. 2.10 EnSync 500 kWh Battry at IIT

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

These energy storage projects at IIT highlight the university's commitment to advancing renewable energy technology and integrating sustainable solutions into campus operations. By leveraging advanced energy storage systems, IIT aims to maximize the benefits of renewable energy while maintaining energy security and cost efficiency.

2.4.4 Charging Stations

The Illinois Institute of Technology (IIT) has made strides in sustainable transportation with its smart electric vehicle (EV) charging station, opened on March 19, 2012. The setup includes nine EV chargers: one DC Quick Charger, which charges a vehicle in about 15 minutes, and six Level 2 stations, which take five to six hours. Additionally, there are two chargers for the I-GO car-sharing program.

Adjacent to a 25kW solar canopy, the charging station utilizes solar energy to power the vehicles, preventing overloads on the campus grid. The electric vehicle charging station is connected to the IIT Microgrid, which coordinates EV charging with on-campus battery usage and building load management (Figure 2.11). This integration minimizes the impact of daytime EV charging on the campus load, ensuring efficient energy use and stability. The new charging stations were donated by Eaton Corporation for demonstration on the IIT Microgrid, with additional funding from the U.S. Department of Energy.



Fig. 2.11 EV charging station at IIT with solar canopy

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

By implementing these advanced charging stations, IIT demonstrates its leadership in sustainable energy practices and its commitment to reducing the campus's carbon footprint. The charging stations serve as a practical example of how renewable energy can be harnessed to support clean transportation, aligning with IIT's broader vision of innovative and environmentally responsible energy solutions.

Chapter 3

Individual Analysis on OpenStudio

In this chapter, an individual analysis is conducted using OpenStudio to understand the energy needs and current performance of institutional buildings at the Illinois Institute of Technology (IIT) campus. Alumni Hall serves as the representative model for this analysis, given that a significant portion of the campus buildings are of this type. OpenStudio is utilized to create detailed energy simulations, providing insights into the building's energy consumption patterns and identifying opportunities for improvement. This initial analysis lays the groundwork for developing comprehensive strategies to enhance energy efficiency and sustainability across all institutional buildings on the IIT campus.

3.1 Spatial Division and 3D Model

In this section, the division of spaces within Alumni Hall and the corresponding 3D model are presented. The building's layout is designed to optimize the efficiency of the HVAC system while ensuring comfort for occupants. Alumni Hall has two floors, each with distinct functional areas such as laboratories, offices, classrooms, and corridors.

The total building area of Alumni Hall is 3018.98 m^2, all of which is conditioned space. There is no unconditioned building area, as shown in Table 1.

Table 3.1 Building Area

Area	**[m²]**
Total Building Area	3018.98
Net Conditioned Building Area	3018.98
Unconditioned Building Area	0.00

Alumni Hall is divided into two stories. Story 1 includes various functional spaces such as the CAEE training lab, classrooms, laboratories, and office spaces. The design ensures that each functional area is appropriately configured to maintain consistent temperature control and energy efficiency. Story 2 houses additional labs, offices, and tech labs. Similar to the first story, each space is categorized to optimize HVAC performance.

The 3D model of Alumni Hall (Figure 3.1) visualizes the spatial configuration of the building, including the detailed layout of windows, walls, and roof structures. This model helps in understanding the physical arrangement and interaction of different spaces within the overall building structure.

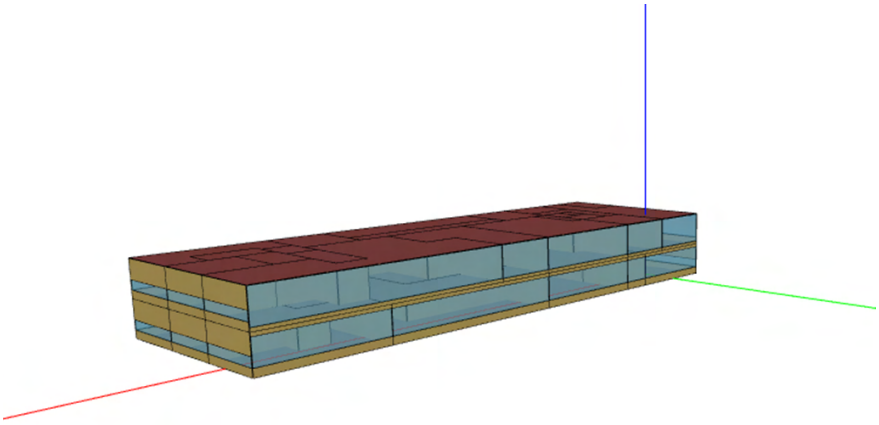


Fig. 3.1 3D Model of Alumni Hall

The assignment of different space types to the rooms of Alumni Hall was made considering their actual use and the technical indications of the plans. The table below shares the total number of space types and their percentages for the building model. Also, Figure 3.2 provides a clear view of the space type breakdown.

Table 3.2 Space Type Classification of Alumni Hall Spaces

Space Type	**Nº Of Spaces**	**Percentage**
Lounge	1	0.92%
Office	7	19.36%
Conference	1	1.12%
Classroom	2	6.36%
Corridor	10	9.36%
Restroom	2	0.96%
Utility	1	0.14%
Stairs	1	3.84%
Lobby	3	4.00%
Laboratory	7	47.70%
Storage	1	0.22%

The spatial breakdown of Alumni Hall reveals a diverse distribution of functional areas, with the majority dedicated to laboratories, which occupy approximately 47.7% of the total floor area. Offices account for 19.36%, indicating a significant allocation for administrative purposes. Corridors comprise 9.36%, reflecting the building's emphasis on circulation space. Classrooms take up 6.36%, underscoring the hall's educational function. The lobby areas, crucial for ingress and egress, cover 4.00%, while stairs, essential for vertical circulation, occupy 3.84%. Conference rooms, lounges, restrooms, storage, and utility spaces collectively form the remaining areas, each contributing to the building's overall functionality and support infrastructure. This distribution highlights the hall's primary focus on research and administrative activities, complemented by necessary support and circulation spaces to facilitate smooth operations within the building.

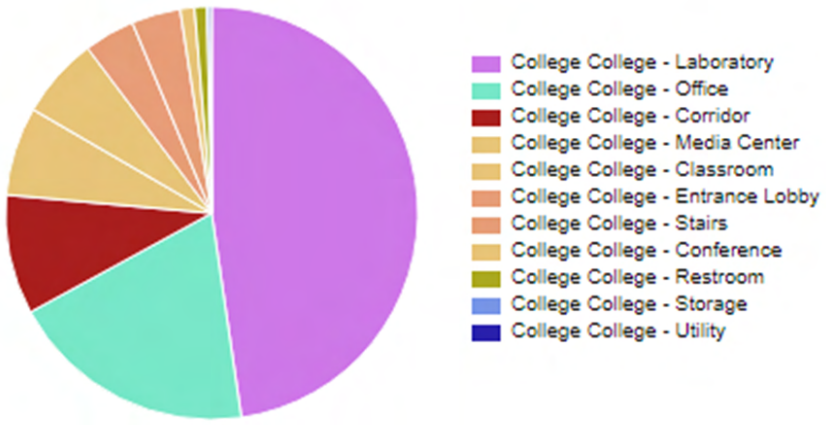


Fig. 3.2 Space Type Breakdown

Despite these variations, there is some uniformity in the allocation of utilitarian spaces, corridors, and stairways in the three buildings, indicating a common focus on circulation and functionality. Overall, although the percentages vary, the buildings share the need to balance administrative, educational, and research functions, each with a distinctive approach that reflects its objectives.

In conclusion, the space type classification for Alumni Hall reveals a deliberate allocation of space to support both administrative and research functions. The significant proportion of space dedicated to laboratories underscores the building's focus on research, while the distribution of other space types ensures a balanced and functional environment for all users.

3.2 Window-to-Wall Ratio (WWR)

To calculate the window-to-wall ratio (WWR) for Alumni Hall, Google Earth Pro was used to measure the building. The WWR is determined as a percentage by dividing the total window area by the total wall area and then multiplying by 100. The formula used for this calculation is:

$$\text{WWR} = \frac{\text{Total windows area}}{\text{Total wall area}} \times 100$$

This calculation is essential for understanding the distribution of windows relative to the overall wall surface area, which impacts both natural lighting and energy efficiency.

Table 7 presents the WWR values for the different facades and stories of Alumni Hall. The measurements indicate that the WWR varies significantly between the North, South,

East, and West facades. Specifically, the West and East facades have a WWR of 26% for both stories, while the North facade has a WWR of 68% for Story 1 and 90% for Story 2. The South facade has a WWR of 65% for Story 1 and 77% for Story 2.

Table 3.3 WWR of Alumni Hall

WWR Alumni Hall	**Story 1**	**Story 2**
West	52%	52%
East	26%	26%
North	68%	90%
South	65%	77%

The higher WWR on the North and South facades allows more natural light to penetrate the building's interior, reducing the need for artificial lighting during daytime. This enhances occupant comfort and productivity while contributing to energy savings. The North facade, with its substantial WWR, benefits from indirect sunlight exposure, which minimizes heat gain in the summer and maximizes heat retention in the winter, aiding in thermal comfort and energy efficiency. Conversely, the South facade, which also has a high WWR, is subject to significant solar heat gain, particularly in the summer months. While this can increase cooling loads, it can be effectively managed with appropriate shading devices and high-performance glazing solutions.

On the other hand, the lower WWR on the West and East facades helps to mitigate the effects of low-angle sunlight in the morning and evening, reducing heat gain and glare issues. This strategic variation in WWR across different facades and stories of Alumni Hall optimizes the building's energy performance and enhances occupant comfort. By carefully balancing the window-to-wall ratios, the design achieves an effective integration of natural lighting and thermal management, contributing to the overall sustainability goals of Alumni Hall.

In conclusion, the calculated WWR values for Alumni Hall highlight a thoughtful design approach that leverages natural lighting while addressing thermal performance and energy efficiency. The strategic use of varying WWR across the building's facades and stories ensures a balance that enhances both energy performance and occupant comfort, aligning with the building's sustainability objectives.

3.3 Thermal Zones

When determining thermal zones for Alumni Hall, several critical factors were considered to optimize HVAC performance, including building orientation, room function, internal heat loads, room size, and proximity among rooms. These considerations resulted in a total of 24 thermal zones, tailored to meet specific environmental requirements.

Orientation: Building orientation affects sunlight exposure and heat accumulation. Areas facing south receive more sunlight, which can increase heat gain, necessitating separate thermal zones.

Room Function: Rooms with distinct functions, such as offices, laboratories, and restrooms, have varying thermal comfort requirements. Laboratories with significant heat generation need dedicated thermal zones for stable temperature control.

Internal Heat Loads: Spaces with substantial internal heat generation, like media rooms or laboratories, are assigned separate thermal zones to manage the additional heat load effectively.

Room Size: Larger spaces often require their own thermal zones to ensure consistent temperature regulation across the entire area.

Proximity and Continuity: Proximity among rooms and their functional similarities influence the grouping into shared thermal zones. Corridors and stairways of the first and second floors belong to the same thermal zone due to their continuity.

Figure 3.3 illustrate the thermal zones for both the first and second floors of Alumni Hall.

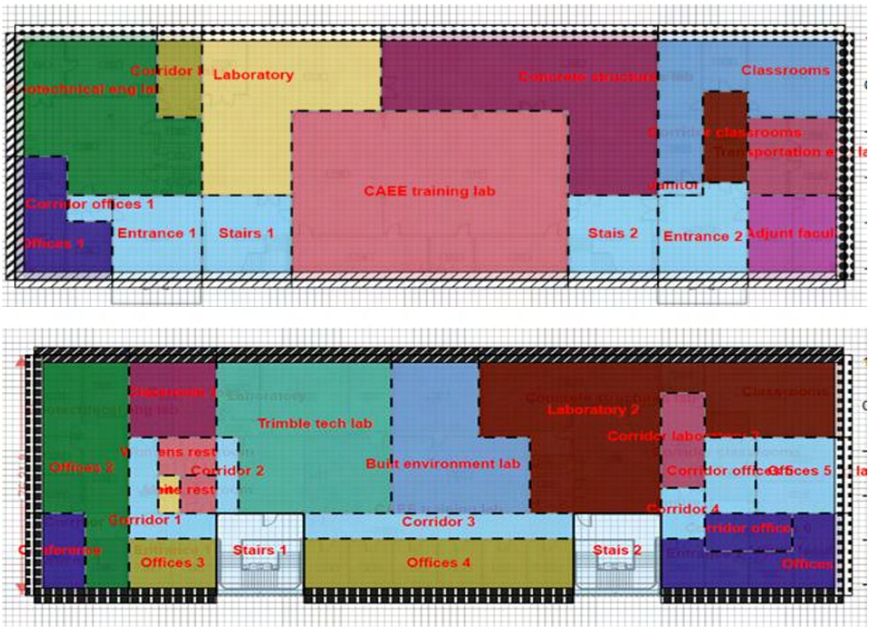


Fig. 3.3 Stories 1 and 2 for floors of Alumni Hall

Each thermal zone is controlled by a dedicated thermostat, ensuring precise and efficient temperature regulation.

First Floor:

* **Thermal Zone 1:** Central corridor and office areas, controlled by a single thermostat.
* **Thermal Zones 10-12:** Laboratory, entrance, and stair areas, each with individual HVAC controls.
* **Thermal Zones 13-15:** Additional office and laboratory spaces, each with dedicated thermostats.
* **Thermal Zones 16c-18:** CAEE training lab and classrooms, with specific HVAC setups for comfort and efficiency.

Second Floor:

* **Thermal Zones 19-21:** Trimble tech lab, built environment lab, and corridor areas, each with dedicated HVAC systems.
* **Thermal Zones 22-24:** Larger office areas and laboratory spaces, each with individual thermostats.

This thermal zoning strategy ensures that areas with similar environmental needs are grouped together, enhancing both comfort and energy efficiency. By segmenting the building into distinct zones, the HVAC system operates more effectively, reducing energy consumption while maintaining a comfortable environment for all occupants.

Furthermore, Figure 3.4 presents a detailed analysis of the thermal performance for different zones in Alumni Hall. It displays various parameters, including unmet heating hours (Unmet Htg hr), unmet heating hours during occupied times (Unmet Htg - Occ hr), the distribution of temperatures across different ranges (from <56°F to >=88°F), unmet cooling hours (Unmet Clg hr), unmet cooling hours during occupied times (Unmet Clg - Occ hr), and the mean temperature (Mean Temp (°F)) for each thermal zone.

Zone	Unmet Htg (hr)	Unmet Htg - Occ (hr)	< 56 (F)	56-61 (F)	61-66 (F)	66-68 (F)	68-70 (F)	70-72 (F)	72-74 (F)	74-76 (F)	76-78 (F)	78-83 (F)	83-88 (F)	>= 88 (F)	Unmet Clg (hr)	Unmet Clg - Occ (hr)	Mean Temp (F)
THERMAL ZONE 1	0	0	0	2351	1126	1153	285	2144	437	1144	100	20	0	0	0	0	66.8 (F)
THERMAL ZONE 10	59	0	0	395	1792	1619	899	2404	966	685	0	0	0	0	0	0	68.0 (F)
THERMAL ZONE 11	9	4	0	1496	1171	1377	700	1523	878	1605	10	0	0	0	0	0	67.8 (F)
THERMAL ZONE 12 PTAC B	154	42	0	2345	996	1041	466	1954	556	1306	88	8	0	0	0	0	67.0 (F)
THERMAL ZONE 13	36	0	0	647	1779	1545	661	2216	683	821	8	0	0	0	0	0	67.6 (F)
THERMAL ZONE 14	0	0	0	2874	1157	611	201	2335	343	915	89	30	5	0	0	0	66.2 (F)
THERMAL ZONE 15	0	0	0	2583	1165	924	243	1941	336	1363	125	69	11	0	0	0	66.8 (F)
THERMAL ZONE 16 C	65	0	0	1927	1250	1316	432	2235	550	1002	44	4	0	0	0	0	67.0 (F)
THERMAL ZONE 17 C	62	0	0	2065	1315	1359	322	2482	594	608	15	0	0	0	0	0	66.5 (F)
THERMAL ZONE 18	2	0	0	2576	1127	966	290	1777	491	1488	39	6	0	0	0	0	66.7 (F)
THERMAL ZONE 19	33	13	0	2152	1073	1165	453	1684	518	1687	42	6	0	0	0	0	67.3 (F)
THERMAL ZONE 2 PTAC B	198	85	0	2438	1016	1059	503	2092	475	1068	79	10	0	0	0	0	66.7 (F)
THERMAL ZONE 20	20	5	0	1559	1149	1434	617	1006	702	2256	36	1	0	0	0	0	68.1 (F)
THERMAL ZONE 21	3	1	0	2123	998	1187	466	1542	575	1785	74	10	0	0	0	0	67.5 (F)
THERMAL ZONE 22	47	0	0	1913	1068	1300	513	1983	573	1348	56	8	0	0	0	0	67.3 (F)
THERMAL ZONE 23	38	0	0	2248	1079	1106	412	1929	522	1381	75	8	0	0	1	1	67.1 (F)
THERMAL ZONE 24 PTAC B	7	0	0	2666	1067	896	258	1995	357	1311	134	70	6	0	0	0	66.7 (F)
THERMAL ZONE 3	9	4	0	1606	1119	1382	690	1525	819	1608	11	0	0	0	0	0	67.8 (F)
THERMAL ZONE 4	25	0	0	2014	1083	1312	551	2694	575	322	9	0	0	0	0	0	66.6 (F)
THERMAL ZONE 5	11	3	0	1208	1180	1429	814	1220	891	2008	10	0	0	0	0	0	68.4 (F)
THERMAL ZONE 6	6	1	0	580	1423	1679	919	651	763	2545	0	0	0	0	0	0	69.0 (F)
THERMAL ZONE 7	11	4	0	1336	1116	1365	791	1255	895	1989	13	0	0	0	0	0	68.3 (F)
THERMAL ZONE 8 PTAC B	981	152	0	3264	1086	566	489	1975	349	890	89	39	11	0	0	0	65.8 (F)
THERMAL ZONE 9	2	1	0	2149	1062	1126	551	1711	645	1502	14	0	0	0	0	0	67.2 (F)

Fig. 3.4 Thermal Performance Analysis of Alumni Hall Zones

Key observations:

* **Unmet Heating Hours**: Some zones, such as Thermal Zone 12 PTAC B and Thermal Zone 5, show significant unmet heating hours (154 and 198 hours, respectively), indicating periods when the heating system could not meet the demand.

* **Temperature Distribution**: The majority of the zones have a substantial number of hours in the temperature range of 66-74°F, which suggests that the building's HVAC system maintains these zones within this comfortable range for a significant portion of time. However, some zones also experience considerable hours in the cooler range (56-66°F), which might indicate areas that are under-heated.

* **Unmet Heating during Occupied Hours**: Zones like Thermal Zone 12 PTAC B and Thermal Zone 9 have higher unmet heating hours during occupied periods, which can significantly impact occupant comfort.

* **Unmet Cooling Hours**: There are no unmet cooling hours reported across the zones, suggesting that the cooling system is adequately meeting the demand.

* **Mean Temperature**: The mean temperatures for the zones are fairly consistent, mostly hovering around 68-69°F, which is within a typical comfort range.

Overall, while the cooling system appears to perform well, the heating system has notable deficiencies in several zones, particularly during occupied hours. Addressing

these heating shortfalls could improve overall thermal comfort in Alumni Hall. The data indicates areas for potential improvements in the HVAC system to ensure more consistent and comfortable temperatures throughout the building.

3.4 Constructions

To add the correct construction set, it is important to know when the building was designed and constructed. After researching the University's website, it was found that Alumni Memorial Hall was designed by Mies van der Rohe and built in 1945. Therefore, the DOE Pre-1980 library should be used for the construction set. According to ASHRAE, Chicago is classified as climate zone 5A.

The ASHRAE 90.1 code sets minimum requirements for the energy efficiency of buildings. These requirements vary depending on the climate zone and the type of building. The code represents a minimum standard, and it is possible to exceed these requirements to achieve higher energy efficiency. The construction details for Alumni Hall, as seen in the figures, reflect this code and provide specific information on the types of materials and their thermal properties.

The exterior surfaces of Alumni Hall include roofs, walls, and fenestrations, each with specific construction details to ensure energy efficiency. Table 3.4 shows the base surface constructions.

Table 3.4 Base Surface Constructions

Construction	**R-Value [ft² · h · °F/Btu]**
Typical Lead Roof R-13.89	13.11
Typical Insulated Steel Framed Exterior Wall R-6.41	5.56

For the exterior wall construction, the code requires an R-value of 20, so it does not meet the code requirements. For the roof, ASHRAE 90.1 requires an R-value of 38. The model shows that Alumni Hall has a well-insulated roof, but the exterior walls are under-insulated. Table 3.5 shows the subsurface constructions.

Table 3.5 Subsurface Constructions

Construction	**U-factor [Btu/ft² · h · °F]**	**SHGC**
U 0.62 SHGC 0.41 Simple Glazing Window	0.62	0.41

The U-factor of a window is a measure of its thermal resistance. The lower the U-factor, the better the insulation and the less heat transfer through the window. The ASHRAE 90.1 code requirement for U-factor in Chicago is 0.47. Therefore, the subsurface construction in the model does not meet the code requirement.

The opaque interior constructions of Alumni Hall, which include interior walls and floors, are designed to ensure thermal efficiency within the building's conditioned spaces.

In conclusion, Alumni Hall's construction details, including the types of materials and their thermal properties, have been carefully selected to enhance the building's energy efficiency. While some elements meet the ASHRAE 90.1 code requirements, others, such as the exterior wall insulation and window U-factors, need improvement to fully comply with the code standards for climate zone 5A.

3.5 Lighting

Alumni Hall's lighting power density and plug load density were analyzed in detail to ensure compliance with ASHRAE 90.1 code requirements and to optimize energy efficiency. The following tables provide detailed lighting power density and plug load density information for various spaces in the building.

The ASHRAE 90.1 code requirements for lighting power density are:

* Offices: 1.8 W/ft²
* Conference rooms: 1.8 W/ft²
* Corridors: 0.8 W/ft²
* Stairs: 0.6 W/ft²
* Classrooms: 2.0 W/ft²
* Utility spaces: 1.5 W/ft²
* Restrooms: 0.8 W/ft²

Table 3.6 below shows the plug load density for various spaces within Alumni Hall.

The total load for the plug load density of all spaces in Alumni Hall is calculated as 46973.60 W.

In conclusion, the lighting and plug load densities for Alumni Hall were carefully analyzed to ensure compliance with the ASHRAE 90.1 code requirements and to optimize energy efficiency. While most spaces meet the code requirements, a few areas show slight deviations that could be addressed to enhance overall energy performance.

Table 3.6 Plug Load Density

Space Name	**Load [W/m²]**	**Total Load [W]**
Corridor classrooms	8.6111	268.80
Corridor offices 1	8.6111	76.80
Corridor labs	8.6111	249.60
Corridor 2	8.6111	135.36
Corridor offices 6	8.6111	230.40
Corridor 3	8.6111	473.60
Corridor laboratory 2	8.6111	268.80
Corridor offices 5	8.6111	268.80
Corridor 1	8.6111	307.20
Corridor 4	8.6111	153.60
Entrance 2	10.7639	672.00
Entrance 1	10.7639	624.00
Stairs 2	6.4583	374.40
Stairs 1	6.4583	374.40
CAEE training lab	15.0695	5387.20
Concrete structures lab	15.0695	3360.00
Transportation eng lab	15.0695	873.60
Geotechnical eng lab	15.0695	2828.80
Laboratory	15.0695	2486.40
Built environment lab	15.0695	2150.40
Laboratory 2	15.0695	4614.40
Offices 1	19.3750	1346.40
Offices 2	19.3750	1648.00
Offices 3	19.3750	776.00
Offices 4	19.3750	2397.60
Offices 5	19.3750	1036.80
Offices 6	19.3750	1648.00
Janitor 1	16.1459	72.00
Janitor 2	10.7639	72.00
Mens restroom	8.6111	96.00
Womens restroom	8.6111	153.60
Classroom 1	21.5278	2888.00
Classroom 2	21.5278	1244.80
Trimble tech lab	20.4514	4286.40
Conference	19.3750	655.20

3.6 Results

3.6.1 Model Accuracy

The provided data for the buildings includes the historical consumption records for electricity and steam. Since Alumni Hall lacks data on chilled water consumption, only the heating and electricity consumption data will be compared in this section.

Given the lack of data on various end-use energy consumption from the building data, only the total results for electricity and steam consumption can be compared.

It is worth noting that the provided electricity data is in kilowatt-hours (kWh), and the steam data is in pounds (lbs). The results have been converted to kilo British thermal units (kBtu) for the purpose of comparisons with the data obtained from OpenStudio models.

The following graphs illustrate the comparison of electricity and steam consumption for Alumni Hall.

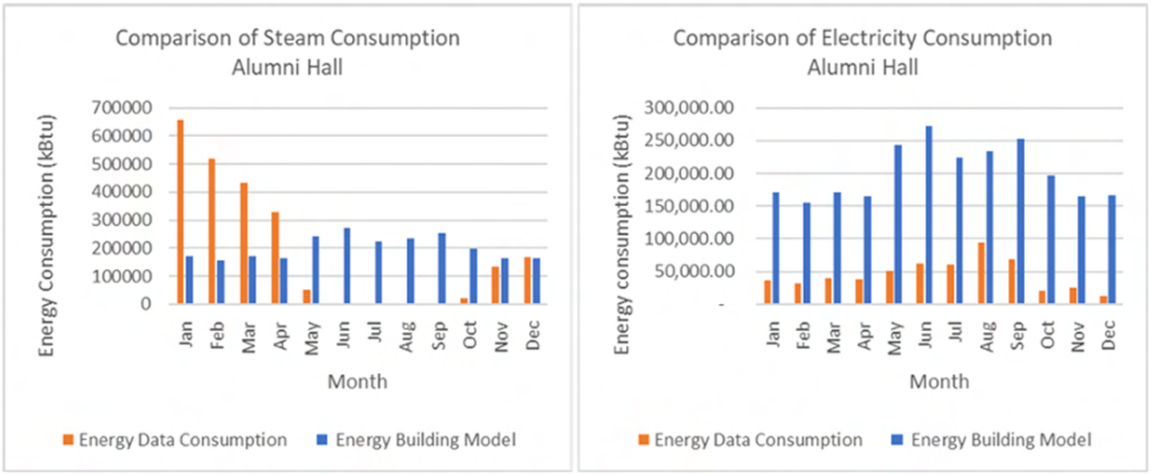


Fig. 3.5 Comparison of electricity and steam consumption for Alumni Hall.

As can be seen, all electricity graphs follow the same trend, with the results of the simulations being higher than the actual consumption of the building. The difference between the simulation and actual consumption is more pronounced in the summer months when electricity consumption is typically higher.

Likewise, for steam consumption, the simulation predicts lower consumption than actual data. This discrepancy is more pronounced in the winter months when steam consumption is typically higher.

To evaluate the accuracy of the energy model, the Coefficient of Variation of the Root Mean Square Error (CVRSME) and the Normalized Mean Bias Error (NMBE) are used.

These metrics provide insights into the performance of the model by comparing the predicted values from the model against actual measured data.

CVRSME measures the model's accuracy by quantifying the variation between the predicted and actual data. A lower CVRSME value indicates a model that closely matches the actual data, whereas a higher value indicates greater deviation and variability in the predictions.

NMBE assesses the bias in the model's predictions. It indicates whether the model tends to overestimate or underestimate the actual values. A positive NMBE indicates a general overestimation, while a negative NMBE indicates an underestimation.

These metrics are essential for validating the energy model, ensuring it can reliably simulate the building's energy consumption patterns.

The following has been calculated: CVRSME and NMBE for steam and electricity consumption data separately.

Table 3.7 CVRSME and NMBE for Steam

Building	**CVRSME**	**NMBE**
Alumni Hall	153.10	103.09

Table 3.8 CVRSME and NMBE for Electricity

Building	**CVRSME**	**NMBE**
Alumni Hall	368.52	-379.04

The model for Alumni Hall shows a considerably high CVRSME, indicating significant variability in predictions. The strongly negative NMBE indicates a substantial underestimation in electricity consumption. These results suggest that the energy model does not match well with the actual model. For steam consumption, the relatively high CVRSME indicates variability in predictions, and the positive NMBE suggests an overall overestimation in steam consumption.

These analyses highlight areas where the energy model of Alumni Hall does not accurately reflect actual consumption patterns. Future adjustments to the model could improve its accuracy and the building's overall energy efficiency.

3.6.2 End Use Consumption

The total energy consumption of Alumni Hall was analyzed to evaluate the building's energy efficiency and identify areas for improvement. Table 3.9 presents the detailed breakdown of energy consumption by end use.

Table 3.9 Total Loads

End Uses	Electricity [GJ]	Natural Gas [GJ]	District Heating [GJ]
Heating	0.00	138.27	1763.14
Cooling	501.33	0.00	0.00
Interior Lighting	661.03	0.00	0.00
Interior Equipment	1234.51	0.00	0.00
Fans	52.43	0.00	0.00
Pumps	15.00	0.00	0.00
Total End Uses	**2464.31**	**138.27**	**1763.14**
Total Load (GJ)	**4365.72**		
Total Load (kBTU)	**4,137,904.16**		

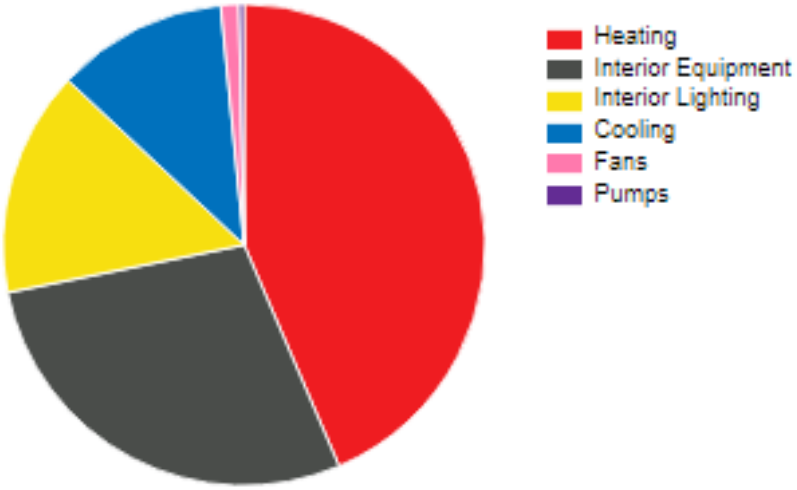


Fig. 3.6 End Use Consumption (%)

Based on these results, the building in question has a total energy consumption of 2464.31 GJ in electricity, 138.27 GJ in natural gas, and 1763.14 GJ in district heating, with a total load of 4365.72 GJ (4137904.158 kBTU). This detailed breakdown helps in understanding the distribution of energy usage across different functions within the building, providing a benchmark for evaluating the building's energy efficiency in comparison to standards or other similar buildings. Figure 3.6 shows the End use percentage consumption.

Table 3.10 Building Summary

Data	Value
Total Site Energy [kBTU]	4,137,904.16
Total Building Area [ft²]	32,489
Total Site EUI [kBTU/ft²]	127.36

Based on these results, the building has a total energy consumption of 4,137,904.158 kBTU in an area of 32,489 ft², which translates into an EUI of 127.36 kBTU/ft². This EUI value provides an important benchmark for evaluating the building's energy efficiency in comparison to standards or other similar buildings.

The pie chart in Figure 3.7 illustrates the breakdown of energy usage intensity (EUI) by different end uses within Alumni Hall. It can be observed that the largest share of energy consumption from electricity is attributed to interior equipment, followed by interior lighting, cooling, fans, and pumps. This visual representation helps in understanding which areas contribute most significantly to the building's overall energy consumption.

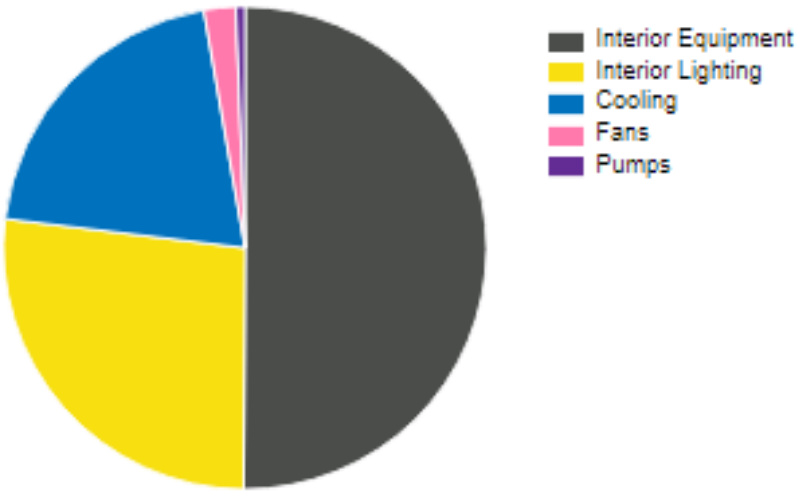


Fig. 3.7 EUI for Equipments that use Electricty

The provided graph in Figure 3.8 offers a detailed monthly breakdown of electricity consumption by various components in a building, illustrating distinct patterns throughout the year. The data categories include heating, cooling, interior lighting, exterior lighting, interior equipment, fans, and pumps.

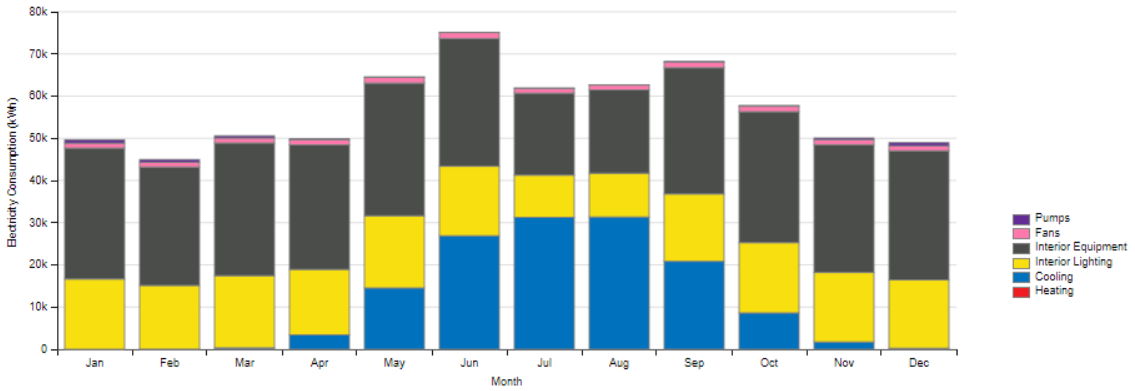


Fig. 3.8 Electricity Consumption in Monthly Overview (kWh)

Cooling patterns are inversely related to heating, with significant energy consumption from May through September, peaking particularly in June and July. This uptick corresponds with the heightened demand for air conditioning during the summer months.

Interior lighting and equipment display consistent energy usage across all months, indicating their continual operation and essential role within the building's daily functions. This consistency suggests that lighting and equipment are crucial operational components, irrespective of seasonal changes.

Fans and pumps show relatively steady energy consumption throughout the year, although there are slight fluctuations. This consistent usage likely supports ongoing HVAC system operations and other necessary building functions.

The monthly consumption breakdown for this equipment that uses electricity is shown in Figure 3.9.

Electricity Consumption (kWh) - view table

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating													
Cooling	0.0	23.51	324.25	3433.22	14527.36	26916.61	31247.5	31364.17	20832.81	8610.94	1733.18	246.11	139259.66
Interior Lighting	16652.28	15102.08	17127.56	15501.86	17127.56	16452.39	10016.25	10380.06	15977.11	16652.28	16452.39	16177.0	183618.81
Exterior Lighting													
Interior Equipment	31036.39	28084.72	31438.89	29515.83	31438.89	30320.83	19453.61	19721.94	29918.33	31036.39	30320.83	30633.89	342920.56
Exterior Equipment													
Fans	1172.6	1066.41	1177.37	1173.6	1323.94	1377.45	1136.27	1157.37	1378.58	1284.2	1149.83	1167.47	14565.08
Pumps	818.11	706.98	544.85	281.08	157.88	71.28	54.03	64.29	104.4	203.36	413.25	747.19	4166.7
Heat Rejection													
Humidification													
Heat Recovery													
Water Systems													
Refrigeration													
Generators													
Total	49679.37	44983.7	50612.92	49905.6	64575.62	75138.56	61907.66	62687.83	68211.23	57787.18	50069.48	48971.65	684530.81

Fig. 3.9 Electricity Consumption (Kwh) over months table

Heating, fueled by natural gas, demonstrates a distinct seasonal pattern in Alumni Hall, closely aligned with Chicago's climate. Usage is minimal during the warmer months from May through September, when heating is typically not required. Conversely, there is a significant surge in consumption during the colder months, particularly in January, February, and December, reflecting the need for heating during Chicago's frigid winters. The modest upticks in March, April, October, and November correspond to the milder transitional weather, highlighting the responsiveness of the heating system to changes in outdoor temperatures. The heating consumption can be seen in Figure 3.10.

Natural Gas Consumption (MBtu) - view table

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Heating	28.79	24.77	19.29	7.94	3.03	0.62	0.67	0.81	0.99	4.25	13.58	26.31	131.06

Fig. 3.10 Natural Gas Consumption (MBtu) over months table

In summary, the analysis highlights substantial seasonal variability in heating and cooling, which are the primary drivers of energy consumption changes throughout the year. Meanwhile, interior lighting and equipment maintain a steady demand, underscoring their importance to building operations. The data from exterior lighting and other categories contribute minimally, suggesting either controlled usage or efficient management practices. This comprehensive view of energy consumption aids in identifying key areas for improving energy efficiency, particularly in optimizing heating and cooling systems to adapt to seasonal needs.

In the context of energy management and sustainability, it is critical to continue monitoring and improving these indicators to reduce energy consumption and operating costs, as well as to minimize the building's environmental impact.

3.6.3 Sensitivity Analysis

The sensitivity analysis for Alumni Hall provides valuable insights into how changes in various variables impact overall energy consumption. This analysis was conducted using the sensitivity calculation formula by Hoffman and Gardener (1983), which determines the percentage change in the objective function (energy consumption) for a one percent change in each variable.

The sensitivity analysis is depicted in Table 3.11, highlighting the maximum and minimum energy consumption values for each variable, as well as their sensitivity percentages.

$$\text{sensitivity} = \frac{Y_{\max} - Y_{\min}}{Y_{\max}}$$

Table 3.11 Sensitivity Analysis for Alumni Hall

Variable	**Max**	**Min**	**Sensitivity**
Heating	416,150.00	4,070.00	99%
Cooling	116,675.25	169.51	100%
Interior Lighting	22,326.63	12,456.15	44%
Exterior Lighting	-	-	0%
Interior Equipment	104,203.44	68,467.96	34%
Exterior Equipment	-	-	0%
Fans	4,107.60	2,978.68	27%
Pumps	2,069.45	9.69	100%
Heat Rejection	-	-	0%
Humidification	-	-	0%
Heat Recovery	-	-	0%
Water Systems	-	-	0%
Refrigeration	-	-	0%
Generators	-	-	0%

Heating (99% Sensitivity): Energy consumption for heating in Alumni Hall is highly sensitive to changes, with a 99% sensitivity. This implies that small variations in heating requirements can significantly affect the overall energy consumption.

Cooling (100% Sensitivity): Cooling has the highest sensitivity at 100%, indicating complete dependency on this variable. Even slight changes in cooling needs have a direct and proportional impact on energy consumption.

Interior Lighting (44% Sensitivity): Interior lighting has a moderate sensitivity, with a 44% change in energy consumption. It remains a significant factor but to a lesser extent compared to heating and cooling.

Other Variables (0% Sensitivity): Exterior Lighting, Exterior Equipment, Heat Rejection, Humidification, Heat Recovery, Water Systems, Refrigeration, and Generators show no sensitivity. This suggests that changes in these variables have negligible impacts on energy consumption.

The sensitivity analysis reveals that cooling and heating are the most influential variables affecting energy consumption in Alumni Hall. Interior lighting also plays a significant role, though to a lesser extent. The results suggest that optimizing these key variables can lead to substantial improvements in energy efficiency for Alumni Hall. Other variables have minimal impact and may not be as critical for energy-saving strategies.

Chapter 4

Individual Analysis on RETScreen

This chapter of the research project focuses on analyzing an institutional building at the Illinois Institute of Technology (IIT) campus as a representative of all buildings on campus, given that 30 out of the 42 buildings are of this type. Alumni Hall will serve as the representative model for this analysis. This analysis is crucial due to the significant number of institutional buildings and their substantial energy consumption.

In this chapter, the analysis will be conducted using RETScreen. In the next chapter, a more extensive analysis will be performed using OpenStudio.

The insights gained from this focused analysis will contribute to developing actionable recommendations for enhancing the energy efficiency and sustainability of all institutional buildings on the IIT campus, aligning with the broader goals of the IIT Energy Master Plan.

4.1 Facility Analysis

The analysis of energy and emissions performance for a commercial/institutional educational facility is illustrated through a comprehensive overview of fuel consumption and emissions intensity.

Firstly, the data and graph on fuel consumption highlight the energy use intensity (EUI) of the facility. The facility has an actual and archetype size of 35,172 ft^2. The benchmark for EUI, derived from ASHRAE standards, stands at 20.16 kWh/ft^2, with a typical minimum of 13.66 kWh/ft^2 and a maximum of 36.88 kWh/ft^2. Currently, the base case EUI is 16.99 kWh/ft^2, which is lower than the benchmark but higher than the

typical minimum. A target has been set for the year 2050, aiming for a 50% reduction in EUI, bringing it down to 8.49 kWh/ft². This reduction translates to an annual fuel consumption decrease from 597,473 kWh to 298,737 kWh, thereby saving 298,737 kWh. All of this information is displayed in Figure 4.1.

In simpler terms, the facility aims to cut its energy use per square foot by half, resulting in significant energy savings and reducing overall energy consumption by nearly 300,000 kWh annually. This ambitious goal demonstrates a strong commitment to improving energy efficiency and reducing operational costs.

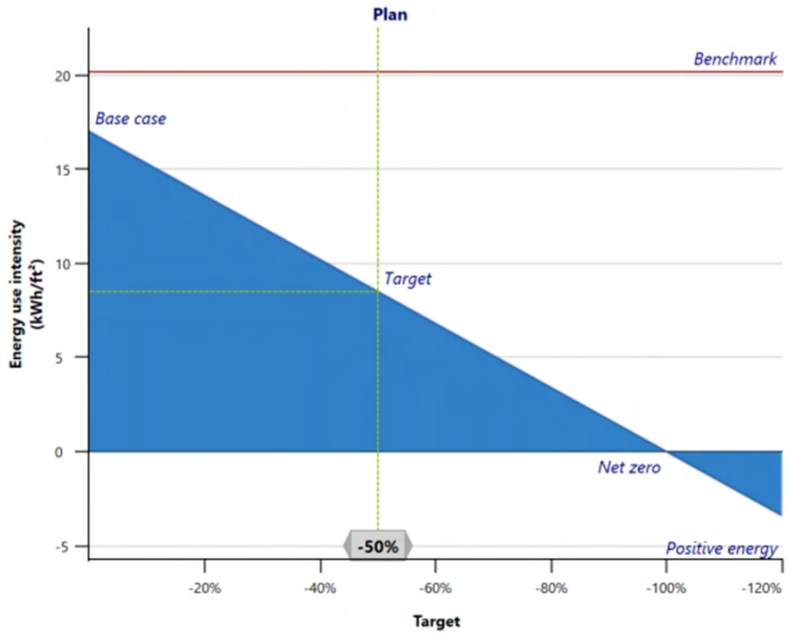


Fig. 4.1 Projected Energy Use Intensity Reduction for Alumni Hall

In terms of emissions intensity, the provided data and graph depict the facility's performance against typical benchmarks. The benchmark for emissions intensity, again based on ASHRAE standards, is 0.005 tCO2/ft², with a minimum of 0.001 tCO2/ft² and a maximum of 0.01 tCO2/ft². The current emissions intensity for the base case is 0.004 tCO2/ft². For the year 2050, the facility has set a target to reduce emissions intensity by 90%, which would lower it to 0.0004 tCO2/ft². This ambitious target results in a significant annual emissions reduction from 134 tCO2 to 13.4 tCO2, saving 121 tCO2. All of this information is illustrated in Figure 4.2.

In other words, the facility aims to reduce its carbon emissions per square foot by 90%, resulting in a dramatic drop in overall emissions. This effort is equivalent to cutting down 120 tons of carbon emissions annually, marking a substantial move towards sustainability and environmental responsibility.

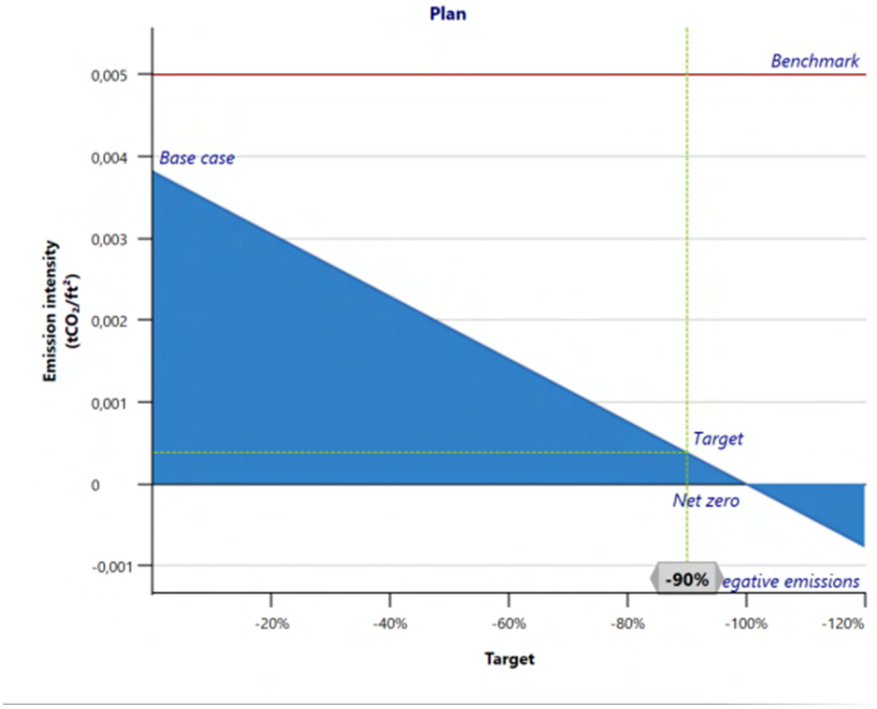


Fig. 4.2 Projected Emissions Intensity Reduction for Alumni Hall

These benchmarks and targets, aligned with ASHRAE standards, ensure that the facility's goals are both realistic and ambitious, promoting significant improvements in energy efficiency and reductions in carbon footprint. The graphs visually emphasize the progress towards these targets, showcasing the potential for substantial savings and enhanced sustainability within the facility. This approach not only benefits the environment but also positions the facility as a leader in energy and emissions management.

4.2 Energy Analysis

4.2.1 Fuel & Schedules

This section explores the energy sources and operational schedules utilized by the Illinois Institute of Technology (IIT) campus. Detailed are the primary fuels, including natural gas and electricity, along with their respective rates and uses. Additionally, the heating and cooling schedules designed to optimize energy efficiency and comfort for the campus occupants are outlined. This comprehensive understanding of fuels and schedules provides insight into IIT's energy management strategies, supporting the campus's commitment to sustainability and efficiency.

4.2.1.1 Fuel

The Illinois Institute of Technology (IIT) campus utilizes a diverse mix of energy sources to meet its electricity and heating needs. A significant portion of the campus's energy consumption is dedicated to maintaining a comfortable and operational environment for its students, faculty, and staff.

One of the primary fuels used at the IIT campus is natural gas. This fuel is utilized for various purposes, including heating and electricity generation. Based on the provided data, the details of natural gas usage are as follows:

* **Fuel Type:** Natural gas
* **Fuel Rate:** \$0.30 per cubic meter (m^3)
* **Heating Value:** 53.9 MJ/kg
* **Fuel Rate per Energy Unit:** \$0.03 per kWh

The use of natural gas is essential for the campus's heating requirements, providing a reliable and cost-effective source of energy. The heating value of natural gas ensures that it can efficiently meet the campus's demand, maintaining a stable supply of energy throughout the year.

In addition to natural gas, the IIT campus also relies on electricity for a wide range of applications, from lighting and powering electronic devices to supporting laboratory equipment and infrastructure. The electricity consumption details are as follows:

* **Electricity Rate:** \$0.10 per kilowatt-hour (kWh)

The annual rate for electricity consumption at the campus is set at \$0.10 per kWh. This rate reflects the cost of electricity supplied to the campus, which is managed to ensure an uninterrupted and efficient energy supply for all campus activities.

In summary, the combination of natural gas and electricity provides IIT with a flexible and resilient energy strategy. By leveraging natural gas for heating and a stable electricity rate for various operational needs, the campus can effectively manage its energy costs while ensuring a reliable energy supply for its community. This approach supports the campus's commitment to sustainability and energy efficiency.

4.2.1.2 Schedules

The Illinois Institute of Technology (IIT) campus has a well-defined schedule for its heating and cooling systems to ensure optimal energy efficiency and comfort for its occupants. The following details describe the temperature settings and occupancy rates for both occupied and unoccupied periods.

The temperature settings for the IIT campus are managed based on whether the spaces are occupied or unoccupied. The settings are as follows:

* **Occupied:**
    - **Temperature - space heating:** 22°C
    - **Temperature - space cooling:** 22°C
* **Unoccupied:**
    - **Temperature - space heating:** 20°C
    - **Temperature - space cooling:** 26°C

The occupancy rate varies throughout the week, with different daily hours for occupied and unoccupied periods. The details are as follows:

* **Occupancy Rate:**
    - Weekdays (Monday-Friday): 15 hours/day
    - Weekends (Saturday and Sunday): 0 hours/day

Annually, this results in a total of 3,911 occupied hours, accounting for 44.6% of the year. Moreover, the heating and cooling seasons are also defined, with a heating/cooling changeover temperature of 18°C, a heating season length of approximately 218.7 days, and a cooling season length of 146 days. These schedules ensure that energy consumption is optimized while maintaining a comfortable environment for all occupants.

4.2.2 Equipment

This section examines the heating and cooling systems utilized at the Illinois Institute of Technology (IIT) campus, detailing the prioritization and enhancements of these systems to improve energy efficiency.

4.2.2.1 Heating System

The heating system was prioritized over the cooling system due to Chicago's predominantly cold climate throughout the year. Maintaining the cooling system was essential to avoid unnecessary expenses, but it did not require the same level of focus.

To enhance the seasonal efficiency of the heating system between the base case and proposed case, a systematic approach was employed based on the provided data and the calculated heating power requirement for the building.

To determine the heating power required for the building, the total area of the building needs to be calculated. The building has two floors, each with an area of 1480 square meters. Thus, the total area is:

$$\text{Total Area} = \text{Area per floor} \times \text{Number of floors} = 1480\,\text{m}^2 \times 2 = 2960\,\text{m}^2$$

Using a general estimate of 100 watts per square meter for heating power, the total heating power required is:

$$\text{Heating Power} = \text{Total Area} \times 100\,\text{W/m}^2 = 2960\,\text{m}^2 \times 100\,\text{W/m}^2 = 296,000\,\text{W} = 296\,\text{kW}$$

To enhance the seasonal efficiency of the heating system between the base case and proposed case, a systematic approach was employed based on the provided data and the calculated heating power requirement for the building.

A comparison was made between the existing heating system at Alumni Hall (base case) and a proposed upgraded system. The exact details of the base case are not known but have been supposed for this analysis. The base case represents the current heating setup, while the proposed case involves the selection of a more efficient model.

In the base case, the heating system had a capacity of 284.76 kW and operated with a seasonal efficiency of 75%, using natural gas as the fuel type. The system comprised two units, each with a heating COP of 3.3.

For the proposed case, the capacity was increased to 304 kW, and the seasonal efficiency was significantly improved to 90%. The proposed system also used natural gas, maintaining the same fuel rate and number of units. The new system had a heating COP of 4.7. The initial incremental cost was $130 per kW, for a total cost of $39,520.

The proposed case's heating COP of 4.7 indicates a significant improvement over the base case's COP of 3.3. The Coefficient of Performance (COP) is a measure of a heating or cooling system's efficiency, defined as the ratio of useful heating provided to the energy consumed. A higher COP means greater efficiency. This means that for every unit of energy consumed, the proposed system provides more heat, leading to higher efficiency and lower energy costs.

The proposed case's seasonal efficiency of 90% is a substantial improvement over the base case's 75%. This increase in efficiency means that the proposed system converts a higher percentage of the energy consumed into useful heating over the course of the heating season. As a result, the proposed system reduces energy waste and operational costs while providing more effective heating.

By improving the seasonal efficiency from 75% to 90%, the heating power requirement was recalculated to reflect these efficiency gains. The heating power needed in the proposed case was reduced as follows:

$$\text{Heating Power (high-efficiency)} = \text{Heating Power (base case)} \times \frac{\text{Efficiency (base case)}}{\text{Efficiency (proposed case)}}$$

$$\text{Heating Power} \approx \text{Heating Power} \times \frac{0.75}{0.90} \approx \text{Heating Power} \times 0.833$$

This significant reduction in heating power demonstrated the efficiency gains achieved through the proposed upgrades. By implementing these systematic upgrades and optimizations, the seasonal efficiency of the heating system for the building was significantly improved, leading to substantial energy savings and reduced operational costs.

4.2.2.2 Cooling System

As stated in the previous section, the focus of this project was primarily on the heating systems due to their more frequent use throughout the year and the lower occupancy during the summer term. The previous heating systems used for the design also have cooling system functions. To avoid additional expenses, it was decided to keep the existing cooling system.

The design of the cooling system involved selecting a reciprocating compressor for the rooftop unit. The seasonal efficiency for this system is represented by the Seasonal Coefficient of Performance (COP), which is 4.0. This value was applied to both the base and proposed cases to maintain consistency and control costs.

In summary, the cooling system design maintains the same efficiency level as the existing system. The cooling system operates with natural gas as the fuel type, at a fuel rate of \$0.30/m^3. The choice to keep the existing system aligns with the project's objective to improve heating efficiency without making the proposal unnecessarily expensive.

4.2.3 End-Use

This section provides an analysis of the end-use energy systems for Alumni Hall at the Illinois Institute of Technology (IIT) campus. It includes detailed evaluations of the building envelope, ventilation, lighting, electrical equipment, hot water systems, and pumps for heating and cooling. The analysis utilizes the RETScreen software for energy cost estimation and proposes enhancements to improve energy efficiency and reduce operational costs.

4.2.3.1 Building Envelope

The building envelope for Alumni Hall at the Illinois Institute of Technology (IIT) campus was designed to optimize energy efficiency and thermal comfort. This section outlines the configuration of the building envelope using the RETScreen software for energy cost estimation.

The base case assumed continuous operation (24/7) with a roof area of 1,480 square meters and an R-value of 13.89 for insulation. The proposed case increased the R-value to 20, resulting in improved insulation performance.

The proposed case resulted in significant energy savings compared to the base case. Heating energy consumption was reduced from 7,245 kWh to 5,031 kWh, and cooling energy consumption decreased from 1,841 kWh to 1,278 kWh. This translates to energy savings of 2,214 kWh (30.6%) for heating and 563 kWh (30.6%) for cooling, as shown in the energy saved column in Table 4.1

The incremental initial cost for the insulation upgrade in the proposed case was $16,000. Despite this initial investment, the substantial reduction in energy consumption highlights the long-term benefits and cost-effectiveness of improving the building envelope's insulation.

By enhancing the roof insulation and maintaining the same operational schedule, the proposed case achieved significant improvements in energy efficiency. These findings will inform the final design and performance evaluations as the project progresses.

Table 4.1 Building envelope for Base vs Proposed case

	Base case	**Proposed case**
Building north (°)	0	0
Schedule	24/7	24/7
Roof Area (m^2)	1,480	1,480
R-value (m^2 - °C/W)	13.89	20
Incremental initial costs ($)	0	16,000
Incremental O&M savings ($)	0	0
System selection	Heating & cooling	Heating & cooling
Heating system	Heating System	Heating System
Heating (kWh)	7.245	5.031
Cooling system	Cooling System	Cooling System
Cooling (kWh)	1.841	1.278

4.2.3.2 Ventilation

The ventilation system for Alumni Hall at the Illinois Institute of Technology (IIT) campus was designed to optimize energy efficiency and maintain indoor air quality. This section outlines the configuration of the ventilation system using the RETScreen software for energy cost estimation.

The airflow rate of 2,000 CFM was estimated based on the building's total area of 2,960 square meters (1,480 m^2 per floor, with two floors), ensuring adequate ventilation for the entire space.

In the base case, the ventilation system operated continuously (24/7) with no heat recovery, resulting in higher energy consumption for both heating and cooling. The proposed case utilized an occupancy-based schedule.

The proposed case significantly reduced energy consumption, with a 55.4% reduction in heating energy (from 15,185 kWh to 6,779 kWh) and a 67.8% reduction in cooling energy (from 3,858 kWh to 1,244 kWh). The energy saved column in Table 4.2 highlights these reductions, showing 8,406 kWh saved for heating and 2,615 kWh saved for cooling.

By shifting from continuous operation to an occupancy-based schedule and incorporating heat recovery, the proposed ventilation system achieved considerable energy efficiency

improvements. These findings will guide the final design and performance evaluations as the project progresses.

Table 4.2 Ventilation usage Base vs Proposed case

	Base case	**Proposed case**
Schedule	24/7	Schedule
Flow (cfm)	2,000	2,000
Fresh air (%)	20%	20%
System reheat	No	No
System selection	Heating & cooling	Heating & cooling
Fan control	Schedule	Schedule
Ventilation control	Schedule	Schedule
Intake air damper leakage	Medium	Medium
Heat recovery efficiency (%)	0%	0%
Incremental initial costs ($)	0	0
Heating system	Heating System	Heating System
Heating (kWh)	15.185	6.779
Cooling system	Cooling System	Cooling System
Cooling (kWh)	3.858	1.244

4.2.3.3 Lighting

The lighting system estimation for Alumni Hall at the Illinois Institute of Technology (IIT) campus was designed to enhance energy efficiency and maintain optimal illumination levels. This section outlines the configuration of the lighting system using the RETScreen software for energy cost estimation.

The base case utilized fluorescent T5 lamps operating continuously (24 hours/day) with a total of 400 fixtures. In contrast, the proposed case implemented LED lighting, which significantly improved energy efficiency. Both configurations maintained the same illumination level of 500 lux for the classroom space type.

In the proposed case, the LED lighting system reduced the electricity load per fixture and the operating hours were adjusted to 16 hours/day. These changes resulted in substantial energy savings. The base case consumed 140,160 kWh, whereas the proposed case reduced consumption to 87,133 kWh, achieving an energy savings of 53,027 kWh or 37.8%.

The incremental initial cost for upgrading to LED lighting was $600, with additional operational and maintenance savings of $100. Despite the initial investment, the proposed lighting system's efficiency improvements and reduced operating hours contributed to significant energy savings and cost-effectiveness.

By upgrading to LED lighting and optimizing operating hours, the proposed case achieved significant energy efficiency improvements. These findings will guide the final design and performance evaluations as the project progresses (see Table 4.3).

Table 4.3 Lighting System Base vs Proposed case

	Base case	**Proposed case**
Space type	Classroom	Classroom
Illumination level (Lux)	500	500
Description	Fluorescent T5	LED
Manufacturer	GE	MaxLite
Model	3000K, 35W	3500K, 32.3W
Efficiency (lm/W)	95.7	106
Electricity load per lamp (W)	35	32.3
Miscellaneous losses (W)	5	5
Electricity load per fixture (W)	40	37.3
Number of fixtures - suggested	400	388
Number of fixtures	400	400
Number of lamps - total	400	400
Illumination level - variance (%)	0%	3.3%
Operating hours (h/d)	24	16
Incremental initial costs ($)	0	600
Incremental O&M savings ($)	0	100
Electricity (kWh)	140.160	87.133

4.2.3.4 Electrical Equipment

The electrical equipment estimation for Alumni Hall at the Illinois Institute of Technology (IIT) campus was designed to optimize energy usage and reduce operational costs. This section outlines the configuration of the electrical equipment using the RETScreen software for energy cost estimation.

The base case scenario included various electrical devices such as TVs, projectors, computers, computer monitors, and standby losses, operating with typical electricity loads and duty cycles (see Table 4.4). In the proposed case, the operating hours and electricity loads were optimized, along with the implementation of more energy-efficient equipment (see Table 4.5).

The proposed case significantly reduced energy consumption, achieving a 54.2% energy savings. The base case consumed 38,472 kWh, whereas the proposed case reduced consumption to 17,619 kWh. These savings were achieved through measures such as reducing the electricity load of TVs from 250W to 60W and optimizing the duty cycle and operating hours for other equipment.

The incremental initial cost for upgrading the electrical equipment was $4,400. Despite this initial investment, the substantial reduction in energy consumption highlights the long-term benefits and cost-effectiveness of improving the electrical equipment efficiency.

By upgrading to more energy-efficient electrical equipment and optimizing their operating parameters, the proposed case achieved significant improvements in energy efficiency. These findings will guide the final design and performance evaluations as the project progresses.

Table 4.4 Electricity Load for Base Case

Description	**Quantity**	**Operating hours (h/yr)**	**Load (W)**	**Duty cycle (%)**
TV	2	80	250	100%
Projector	30	400	200	100%
Computer	50	1,600	200	75%
Monitor	50	1,600	30	75%
Standby losses	1	7,160	3.105	100%

Table 4.5 Electricity Load for Proposed Case

Description	Quantity	Operating hours (h/yr)	Load (W)	Duty cycle (%)
TV	2	80	60	100%
Projector	30	400	200	100%
Computer	50	1,120	200	75%
Monitor	50	1,120	30	75%
Standby losses	1	7,160	775	100%

4.2.3.5 Hot Water

The hot water system estimation for Alumni Hall at the Illinois Institute of Technology (IIT) campus was designed to optimize energy usage primarily by changing the hot water system. This section outlines the configuration of the hot water system using the RETScreen software for energy cost estimation.

In the base case, the hot water system serves an office with 300 occupants, operating with an assumed daily hot water use of 798 liters and a fixed temperature of 40°C. The proposed case reduced the assumed daily hot water use to 400 liters by implementing more efficient water usage strategies, maintaining the same water temperature.

The proposed case achieved significant energy savings, reducing heating energy consumption from 9,901 kWh to 4,963 kWh, which translates to a savings of 4,938 kWh or 49.9%. The incremental initial cost for upgrading the system was $600.

Despite the initial investment, the substantial reduction in energy consumption highlights the long-term benefits and cost-effectiveness of improving the hot water system. These findings will guide the final design and performance evaluations as the project progresses.

4.2.3.6 Pumps for Heating/Cooling

The pump system for heating and cooling at Alumni Hall at the Illinois Institute of Technology (IIT) campus was designed to optimize energy efficiency and reduce operational costs. This section outlines the configuration of the pump system using the RETScreen software for energy cost estimation.

In the base case, the system utilized a standard efficiency motor with a capacity of 2.2 kW, operating at 84.6% efficiency at full load and 83.8% under operating conditions. The pump operated with a throttling flow control type and variable flow range, resulting in an annual energy consumption of 8,081 kWh.

The proposed case upgraded to a premium efficiency motor with the same capacity but improved efficiency levels: 90.2% at full load and 89.3% under operating conditions.

Additionally, the flow control type was changed to variable speed, enhancing the system's overall efficiency.

These upgrades resulted in a substantial energy savings of 64.9%, reducing the annual energy consumption to 2,837 kWh. The energy saved amounted to 5,243 kWh. The incremental initial cost for the proposed upgrades was $5,000, which is justified by the significant reduction in energy consumption and operational costs.

By upgrading to a premium efficiency motor and implementing variable speed control, the proposed case achieved significant improvements in energy efficiency. These findings will guide the final design and performance evaluations as the project progresses, as seen in Table 4.6.

Table 4.6 Motor and Pump Efficiency Base vs Proposed case

	Base case	**Proposed case**
Motor		
Type	Standard efficiency	Premium efficiency
Capacity (kW)	2.2	2.2
Efficiency - full load (%)	84.6	90.2
Load factor (%)	70	70
Efficiency - operating conditions (%)	83.8	89.3
Motor shaft power load (kW)	1.5	1.5
Pump		
Efficiency (%)	75	75
Fluid load - full flow (kW)	1.2	1.2
Flow type	Variable	Variable
Flow range	Low	Low
Flow control type	Throttling	Variable speed
Operating hours (h/yr)	5,450	5,450
Incremental initial costs ($)		5,000
Number of pumps	1	1
Electricity (kWh)	8,081	2,837

4.2.4 Optimize Supply

This section addresses the integration of renewable energy systems into Alumni Hall at the Illinois Institute of Technology (IIT) campus. It includes three main subsections, each focusing on a different renewable energy technology: solar water heaters, solar air heaters, and photovoltaic power systems. These technologies are evaluated using the RETScreen software for their potential to enhance energy efficiency and sustainability at the facility.

4.2.4.1 Solar Water Heater Integration

The primary function of the solar water heater system for Alumni Hall at the Illinois Institute of Technology (IIT) campus is to harness solar energy to efficiently meet the hot water demands of the facility. This section outlines the configuration of the solar water heater system using the RETScreen software for energy cost estimation.

In the base case, hot water is supplied by an electric water heater, consuming 4,963 kWh annually to maintain a temperature of 40°C. The proposed case incorporates a solar water heater system to significantly reduce electricity consumption.

The proposed solar water heater system utilizes glazed collectors with a fixed solar tracking mode at a 25-degree slope. This system includes three solar collectors with a total area of 7 square meters and a storage capacity of 644 liters. An efficient heat exchanger with 80% efficiency is integrated into the system to optimize thermal energy transfer.

The proposed system achieved significant energy savings, reducing the electricity required for heating from 4,963 kWh to zero, as the solar water heater meets 66.3% of the annual hot water demand. This translates to energy savings of 3,289 kWh annually. The initial cost for implementing the solar water heater system was estimated at $6,930.

By integrating a solar water heater, the proposed case achieved substantial reductions in electricity consumption, leveraging renewable energy to meet hot water needs. These findings will guide the final design and performance evaluations as the project progresses.

As detailed in Table 4.7, the specifications of the solar water heating system give a detailed overview of its components and performance metrics.

Table 4.7 Solar Water Heater Design Specifications

Solar Water Heating System Specifications	
Solar tracking mode	Fixed
Slope (°)	25
Azimuth (°)	0
Type	Glazed
Gross area per solar collector (m^2)	2.32
Aperture area per solar collector (m^2)	2.31
Fr (tau alpha) coefficient	0.69
Fr UL coefficient ($(W/m^2)/°C$)	4.2
Temperature coefficient for Fr UL ($(W/m^2)/°C^2$)	0.01
Number of collectors - suggested	2
Number of collectors	3
Solar collector area (m^2)	7
Capacity (kW)	4.9
Miscellaneous losses (%)	2%
Storage	Yes
Storage capacity / solar collector area (L/m^2)	93
Storage capacity (L)	644
Heat exchanger	Yes
Heat exchanger efficiency (%)	80%
Miscellaneous losses (%)	1%
Electricity rate ($/kWh)	0.10
Initial costs ($/$m^2$-aperture)	1,000
Incremental initial costs - total ($)	6,930

4.2.4.2 Solar Air Heater Integration

The primary function of the solar air heater system for Alumni Hall at the Illinois Institute of Technology (IIT) campus is to harness solar energy to efficiently meet the heating demands of the facility. This section outlines the configuration of the solar air heater system using the RETScreen software for energy cost estimation.

In the base case, the building relies entirely on a conventional heating system with an annual energy consumption of 130,675 kWh. The proposed case incorporates a solar air heater system designed to reduce the energy required from the conventional heating system.

The proposed solar air heater system includes transpired plate collectors with a total collector area of 200 square meters. The system is designed to preheat the ventilation air before it enters the building, thereby reducing the load on the conventional heating system, as detailed in Table 4.8.

Table 4.8 Load characteristics

Load characteristics		
Facility type	Commercial/Institutional	
	Base case	**Proposed case**
Indoor temperature (°C)	21	21
Air temperature - maximum (°C)	20	20
R-value - wall (m^2 °C/W)	13.9	13.89
Design airflow rate (m^3/h)	6,480	6,480
Operating days per week - weekdays (d/w)	5	5
Operating hours per day - weekdays (h/d)	16	16
Operating days per week - weekends (d/w)	2	2
Operating hours per day - weekends (h/d)	16	16
Heating (kWh)	134,390	134,390

The energy savings achieved by the proposed solar air heater system are substantial. The proposed system reduced the annual energy consumption from 130,675 kWh to 107,847 kWh, resulting in a total energy saving of 22,828 kWh, or 17.5%. The solar air heater delivers 22,042 kWh of heating annually, and an additional 786 kWh is saved through recaptured building heat loss, as shown in Table 4.9.

Table 4.9 Resource assessment and solar radiation data

Month	**Daily solar radiation - horizontal ($kWh/m^2/d$)**	**Daily solar radiation - tilted ($kWh/m^2/d$)**	**Heating delivered (kWh)**
January	1.58	2.21	3,160,912
February	2.41	2.53	3,297,035
March	3.38	2.68	3,786,991
April	4.37	2.86	3,916,009
May	5.23	2.93	295,722
June	5.82	3.04	0
July	5.73	3.08	0
August	4.95	3.04	0
September	4.11	3.04	0
October	2.80	2.59	2,657,772
November	1.63	1.81	2,498,942
December	1.28	1.67	2,428,476
Annual	**3.61**	**2.62**	**22,041,860**

The initial cost for implementing the solar air heater system was estimated at $14,000. Despite this initial investment, the significant reduction in energy consumption and operational costs highlights the long-term benefits and cost-effectiveness of integrating solar air heating into the building's HVAC system.

By leveraging solar energy to meet a significant portion of the heating demand, the proposed case achieved substantial improvements in energy efficiency. These findings will guide the final design and performance evaluations as the project progresses, as detailed in Table 4.10.

Table 4.10 Solar air heater specifications for proposed case

Solar Air Heater	
Solar tracking mode	Fixed
Slope (°)	90
Azimuth (°)	45
Type	Transpired-plate
Design objective	High temperature rise
Solar collector colour	Black
Solar collector absorptivity	0.94
Performance factor	1
Solar collector area (m^2)	200
Capacity (kW)	140
Solar collector shading - season of use (%)	10%
Wind sheltering - season of use (%)	30%
Electricity rate ($/kWh)	0.10
Initial costs ($)	14,000
Heating delivered (kWh)	22,042
Building heat loss recaptured (kWh)	786

4.2.4.3 Photovoltaic Power

The photovoltaic (PV) system for Alumni Hall at the Illinois Institute of Technology (IIT) campus was designed to harness solar energy to generate electricity, thereby reducing reliance on grid electricity and lowering operational costs. This section outlines the configuration of the PV system using the RETScreen software for energy cost estimation.

In the base case, the building relies entirely on grid electricity. The proposed case incorporates a photovoltaic system with a power capacity of 148 kW, utilizing 865 solar panels with a capacity factor of 19%.

The proposed PV system generates significant energy savings by producing 246,331 kWh of electricity annually. This reduces the reliance on grid electricity and results in

substantial energy cost savings. The initial cost for implementing the PV system was estimated at $281,200, with annual operational and maintenance savings of $3,700.

The energy saved by the proposed PV system amounts to 246,331 kWh annually. This translates to a significant reduction in electricity costs and a positive environmental impact by reducing greenhouse gas emissions.

By integrating a photovoltaic system, the proposed case achieved substantial improvements in energy efficiency and cost savings. These findings will guide the final design and performance evaluations as the project progresses.

As detailed in Table 4.11, the photovoltaic integration specifications provide an overview of the system's components and performance metrics.

Table 4.11 Photovoltaic Integration in Alumni Hall

Photovoltaic	
Power capacity (kW)	148
Manufacturer	
Model	
Number of units	865
Capacity factor (%)	19%
Initial costs ($/kW)	1,900
Initial costs ($)	281,200
O&M costs (savings) ($/kW-year)	25
O&M costs (savings) ($)	3,700
Energy saved (kWh)	246,331

4.3 Results

This section of the research project presents a comprehensive analysis of energy savings and financial viability for Alumni Hall at the Illinois Institute of Technology (IIT) campus. The first subsection details the energy-saving measures implemented across various systems, highlighting the significant reductions in energy consumption. The subsequent subsection examines the financial viability of these measures, evaluating their cost-effectiveness and economic feasibility to determine the overall sustainability of the proposed solutions.

4.3.1 Energy Savings

This section of the research project focuses on analyzing an institutional building at the Illinois Institute of Technology (IIT) campus as a representative of all buildings on campus, given that 30 out of the 42 buildings are of this type. Alumni Hall serves as the representative model for this analysis. This analysis is crucial due to the significant number of institutional buildings and their substantial energy consumption.

The energy-saving measures implemented at Alumni Hall encompass various systems, including heating, cooling, building envelope, ventilation, lighting, electrical equipment, hot water, pumps, and renewable energy sources. Overall, these measures result in significant energy savings, with the total energy savings amounting to 396,720 kWh annually. The most substantial contributions come from the photovoltaic system (186,713 kWh), followed by lighting upgrades (140,160 kWh), and solar air heater improvements (130,675 kWh) (Figure 4.3).

The table illustrates the energy savings achieved through these measures. Heating systems, including domestic hot water, save a combined 140,576 kWh. The cooling system shows no significant energy savings, indicating it was not a primary focus of the upgrades. Building envelope improvements save 22,425 kWh annually, while ventilation upgrades contribute an additional 47,006 kWh in energy savings.

Lighting upgrades provide significant energy savings of 140,160 kWh annually, demonstrating the effectiveness of transitioning to more efficient lighting solutions. Electrical equipment upgrades save 38,472 kWh annually, showcasing the benefits of using more energy-efficient devices and optimizing their operating parameters.

The hot water system improvements result in energy savings of 9,901 kWh annually. The pumps for heating and cooling systems contribute 8,081 kWh to the overall energy savings. The solar water heater saves 19,000 kWh, and the solar air heater adds another 130,675 kWh to the total energy savings. Lastly, the photovoltaic system provides the most substantial energy savings of 186,713 kWh annually.

Show: Energy / Energy - base case	Heating kWh	Cooling kWh	Electricity kWh	Simple payback yr	Include measure?
Heating					
Heating System				None	☑
Domestic hot water				None	☑
Cooling					
Cooling System					☑
Building envelope					
Building envelope	0	22.425		1.082,3	☑
Ventilation					
Ventilation	0	47.006		Immediate	☑
Lights					
Lights			140.160	0,1	☑
Electrical equipment					
Electrical equipment			38.472	2,1	☑
Hot water					
Hot water	9.901			None	☑
Pumps					
Heating/Cooling			8.081	9,5	☑
Heating					
Solar water heater	0			19,0	☑
Solar air heater	130.675			None	☑
Power					
Photovoltaic				13,4	☑
Total	**140.576**	**69.431**	**186.713**	**19,4**	

Fig. 4.3 Energy savings for measures at Alumni Hall

In the graph from Figure 4.4, it is highlighted the energy savings across different systems by comparing the base case, proposed case, and the total fuel saved. The proposed measures significantly reduce energy consumption compared to the base case. The graph shows that the photovoltaic system contributes the largest share of electricity savings, followed by lighting upgrades and improvements in ventilation. Heating, cooling, and other systems also show reductions, though to a lesser extent. This comprehensive reduction in energy use underscores the effectiveness of the proposed measures in achieving significant overall energy savings.

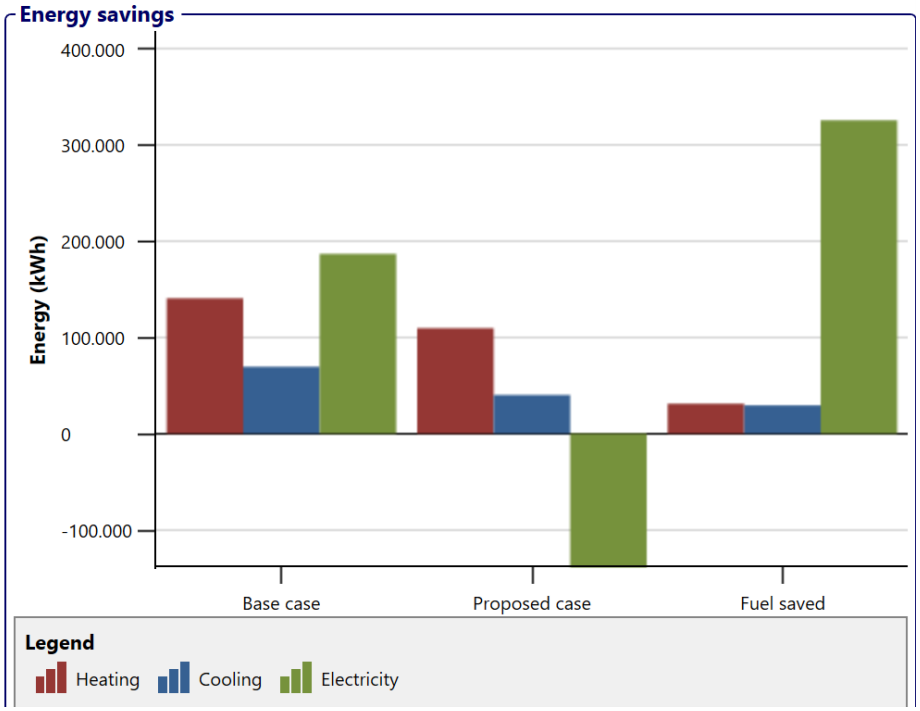


Fig. 4.4 Comparison of energy consumption between the base case and proposed case

In the graph from Figure 4.5 a summary of the fuel savings is provided. It shows a notable reduction in energy consumption when transitioning from the base case to the proposed case, particularly emphasizing the fuel saved. The base case relies heavily on both natural gas and electricity, as indicated by the blue and green bars, respectively. In the proposed case, there is a marked decrease in the use of natural gas and a slight reduction in electricity usage. The "Fuel saved" section of the graph clearly illustrates the substantial overall reduction in energy consumption, reinforcing the significant impact of the implemented energy-saving measures. This visual representation makes it evident how effective these measures are in reducing the reliance on traditional energy sources and enhancing overall efficiency.

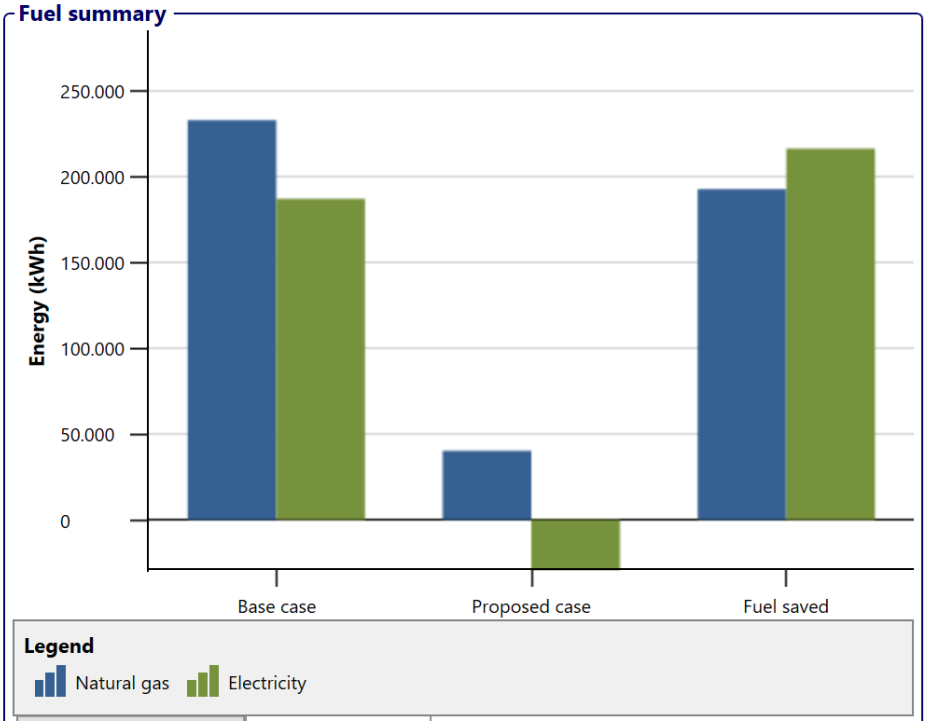


Fig. 4.5 Fuel summary showing energy savings from transitioning to the proposed case

In conclusion, the energy-saving measures at Alumni Hall yield substantial energy savings across various systems, with the total energy savings amounting to 396,720 kWh annually. These findings will inform actionable recommendations for enhancing the energy efficiency and sustainability of all institutional buildings on the IIT campus, aligning with the broader goals of the IIT Energy Master Plan.

4.3.2 Financial Viability

In terms of energy saving, everything was viable, but now it is necessary to study the financial viability. The financial assessment provides insights into the cost-effectiveness and economic feasibility of the proposed measures.

The financial viability of the energy-saving measures implemented at Alumni Hall is assessed by examining incremental initial costs, fuel cost savings, operations and maintenance (O&M) savings, and simple payback periods. The total initial cost for these measures is $454,110, with annual fuel cost savings of $27,049, indicating a mix of short-term and long-term investments.

Heating systems, including the domestic hot water system, have high initial costs of $125,380 and negative fuel cost savings, making them financially unviable. Similarly, building envelope improvements incur an initial cost of $16,000 with minimal fuel cost savings of $14.8, resulting in a payback period of over 1,082 years, suggesting that these

measures, while improving energy efficiency, may not be financially viable in the short term.

Conversely, the ventilation system shows immediate financial benefits with no initial cost and annual fuel cost savings of $192, providing an immediate payback. Lighting upgrades, with an initial cost of $600, result in significant annual savings of $5,303 and a payback period of only 0.1 years, making them highly financially viable. Electrical equipment upgrades, costing $4,400, offer annual fuel cost savings of $2,085 and a payback period of 2.1 years. The heating/cooling pumps, with an initial cost of $5,000 and savings of $524 annually, have a payback period of 9.5 years.

Renewable energy systems, such as solar water and air heaters, have higher initial costs of $6,930 and $14,000, respectively, with long payback periods or negative fuel cost savings, suggesting their financial viability depends on long-term perspectives and potential incentives. The photovoltaic system, although having a high initial cost of $281,200, provides significant annual fuel cost savings of $24,633 and a payback period of 13.4 years, indicating long-term financial viability.

All this information can be seen in Figure 4.6:

Show: Finance / Energy - base case	Incremental initial costs $	Fuel cost savings $	Incremental O&M savings $	Simple payback yr	Include measure?
Heating					
Heating System	0	-3.849	0	None	☑
Domestic hot water	125.380	-40,5	0	None	☑
Cooling					
Cooling System	0	0	0		☑
Building envelope					
Building envelope	16.000	14,8	0	1.082,3	☑
Ventilation					
Ventilation	0	192	0	Immediate	☑
Lights					
Lights	600	5.303	100	0,1	☑
Electrical equipment					
Electrical equipment	4.400	2.085	0	2,1	☑
Hot water					
Hot water	600	-162	0	None	☑
Pumps					
Heating/Cooling	5.000	524	0	9,5	☑
Heating					
Solar water heater	6.930	365	0	19,0	☑
Solar air heater	14.000	-2.017	0	None	☑
Power					
Photovoltaic	281.200	24.633	-3.700	13,4	☑
Total	**454.110**	**27.049**	**-3.600**	**19,4**	

Fig. 4.6 Financial Viability for measures at Alumni Hall

Additionally, the cost analysis table (Figure 4.7) breaks down the financial details further. The total initial cost is reaffirmed at $454,110. In the first year, the total annual costs, including O&M costs, fuel costs, and debt payments, amount to $35,881. The annual savings and revenue from fuel cost savings total $24,429. This results in a net yearly cash flow of -$11,452 for the first year, highlighting the initial financial outlay and the gradual path to achieving savings.

Costs | Savings | Revenue

Initial costs

Incremental initial costs	100%	$	454.110
Total initial costs	**100%**	**$**	**454.110**

Yearly cash flows - Year 1

Annual costs and debt payments

O&M costs (savings)	$	3.600
Fuel cost - proposed case	$	-2.620
Debt payments - 15 yrs	$	34.901
Total annual costs	**$**	**35.881**

Annual savings and revenue

Fuel cost - base case	$	24.429
GHG reduction savings	$	0
CE production revenue	$	0
Total annual savings and revenue	**$**	**24.429**

Net yearly cash flow - Year 1	**$**	**-11.452**

Fig. 4.7 Breakdown of Costs, Saving and Revenues

Figure 4.8 provides a detailed overview of the financial viability metrics. The internal rate of return (IRR) and modified internal rate of return (MIRR) for both equity and assets are negative, indicating financial challenges. The net present value (NPV) is -$166,466, and the annual lifecycle savings are -$18,236, further highlighting the long-term financial hurdles. The benefit-cost ratio (B-C ratio) is -0.22, and the debt service coverage is 0.69, indicating a need for careful financial planning and potential external support or incentives.

Financial viability

Pre-tax IRR - equity	%	-2,6%
Pre-tax MIRR - equity	%	-0,06%
Pre-tax IRR - assets	%	-7,2%
Pre-tax MIRR - assets	%	-4,7%
Simple payback	yr	19,4
Equity payback	yr	> project
Net Present Value (NPV)	$	-166.466
Annual life cycle savings	$/yr	-18.236
Benefit-Cost (B-C) ratio		-0,22
Debt service coverage		0,69
GHG reduction cost	$/tCO$_2$	201

Fig. 4.8 Financial Viability metrics

Due to the unfavorable financial viability of the project, it is essential to evaluate specific measures for inclusion or exclusion to optimize the project's financial outcomes. Below is a detailed evaluation of each measure based on initial costs, fuel cost savings, incremental O&M savings, simple payback periods, and recommendations:

Measures to Include

* **Lights:** Initial cost of $600 with fuel cost savings of $5,303 and $100 in O&M savings. Payback period of 0.1 years, making it highly attractive.
* **Electrical Equipment:** Initial cost of $4,400 with fuel cost savings of $2,085. Payback period of 2.1 years, providing a reasonable return.
* **Ventilation:** No initial cost with fuel cost savings of $192 and immediate payback. Highly cost-effective.
* **Photovoltaic:** Initial cost of $281,200 with fuel cost savings of $24,633. Payback period of 13.4 years, recommended for long-term benefits.

Measures to Exclude

* **Heating System:** No initial cost but negative fuel savings of -$3,849. No payback period, financially unviable.
* **Domestic Hot Water:** Initial cost of $125,380 with negative fuel savings of -$40.5. No payback period, should be excluded.
* **Hot Water:** Initial cost of $600 with negative fuel savings of -$162. Financially unfeasible.
* **Solar Air Heater:** Initial cost of $14,000 with negative fuel savings of -$2,017. No payback period.

Measures to Consider with Caution

* **Building Envelope:** Initial cost of $16,000 with minimal fuel savings of $14.8, resulting in a payback period of 1,082.3 years. May offer non-financial benefits.
* **Heating/Cooling Pumps:** Initial cost of $5,000 with fuel savings of $524, leading to a payback period of 9.5 years. Consider for potential operational benefits.
* **Solar Water Heater:** Initial cost of $6,930 with fuel savings of $365, resulting in a payback period of 19 years. May be included for sustainability goals.

Due to the unfavorable financial metrics, several measures were excluded to improve the project's viability. These excluded measures include the solar water heater, solar air heater, and the existing heating system, domestic hot water system, and hot water systems. While these measures were successful in saving significant amounts of energy, they were not financially feasible. For instance, the solar water heater and solar air heater required high initial investments and offered long payback periods with negative fuel cost savings, making them unviable in the short term. Similarly, the heating system and domestic hot water systems, despite their substantial energy savings, did not present a financially attractive proposition due to their high initial costs and negative fuel cost savings.

By removing these high-risk investments, the financial viability of the project has improved significantly, as reflected in the updated financial viability table (Figure 4.9). The revised metrics now show a pre-tax IRR of 11.8% for equity and 1.3% for assets, and a net present value (NPV) of $29,689. The annual lifecycle savings are now positive at $3,252, with a benefit-cost ratio of 1.3 and a debt service coverage ratio of 1.3, indicating a more sustainable financial outlook for the project.

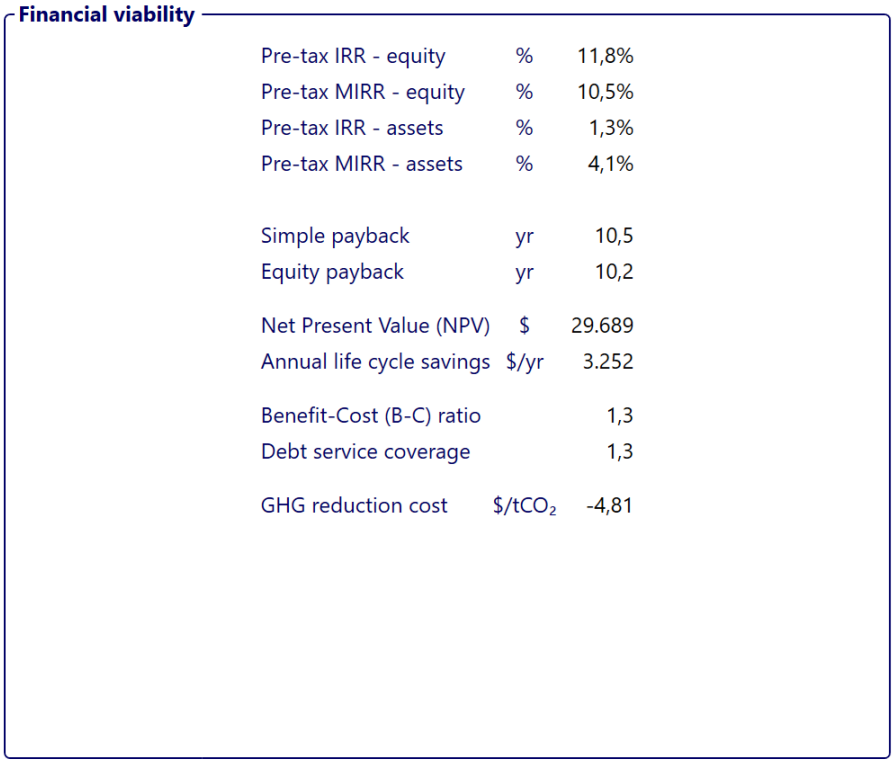


Fig. 4.9 Financial Viability Metrics After Excluding Unfeasible Investments

The financial assessment of energy-saving measures at Alumni Hall reveals that while ventilation and lighting upgrades are highly viable with quick payback periods, systems like heating and domestic hot water improvements are financially unviable due to high costs and minimal savings. Renewable energy systems have mixed viability, with photovoltaic systems being beneficial long-term despite high initial costs. Overall, the project's financial feasibility requires careful selection of measures.

4.3.3 Emission Analysis

The implementation of the final set of energy-saving measures at Alumni Hall has led to a significant reduction in greenhouse gas (GHG) emissions. The RETScreen Emission Analysis table and accompanying chart illustrate the impact of these measures on GHG emissions.

The base case electricity system for Illinois, USA, shows a GHG emission factor of 0.329 kgCO2/kWh, excluding transmission and distribution (T&D) losses. With T&D losses included, the GHG emission factor increases to 0.354 kgCO2/kWh, accounting for 7.0% losses.

In the base case, Alumni Hall's GHG emissions amount to 118 tonnes of CO2 annually. The proposed case, which includes the implemented energy-saving measures, significantly

reduces GHG emissions to 5.2 tonnes of CO2 annually. This results in a gross annual GHG emission reduction of 113 tonnes of CO2, representing a 95.6% decrease in emissions.

The Figure 5.5 visually demonstrates this reduction, showing a substantial drop in emissions from the base case to the proposed case.

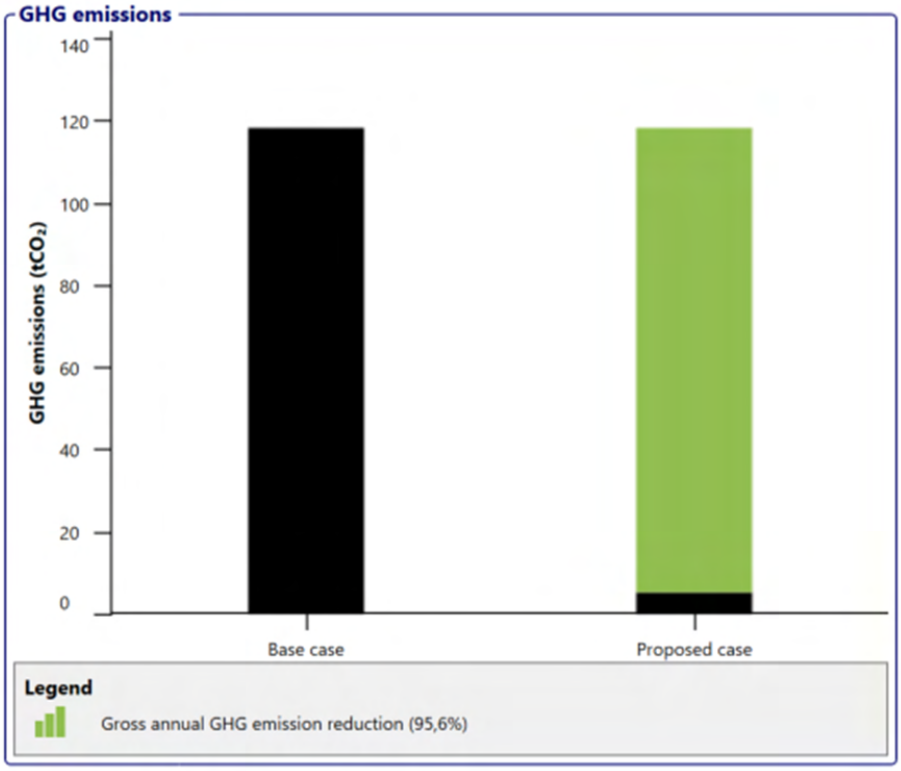


Fig. 4.10 GHG Emission Reduction Analysis for Alumni Hall

In addition to the direct emissions reduction, the analysis also provides various equivalences to help contextualize the impact of these savings, as shown in Figure

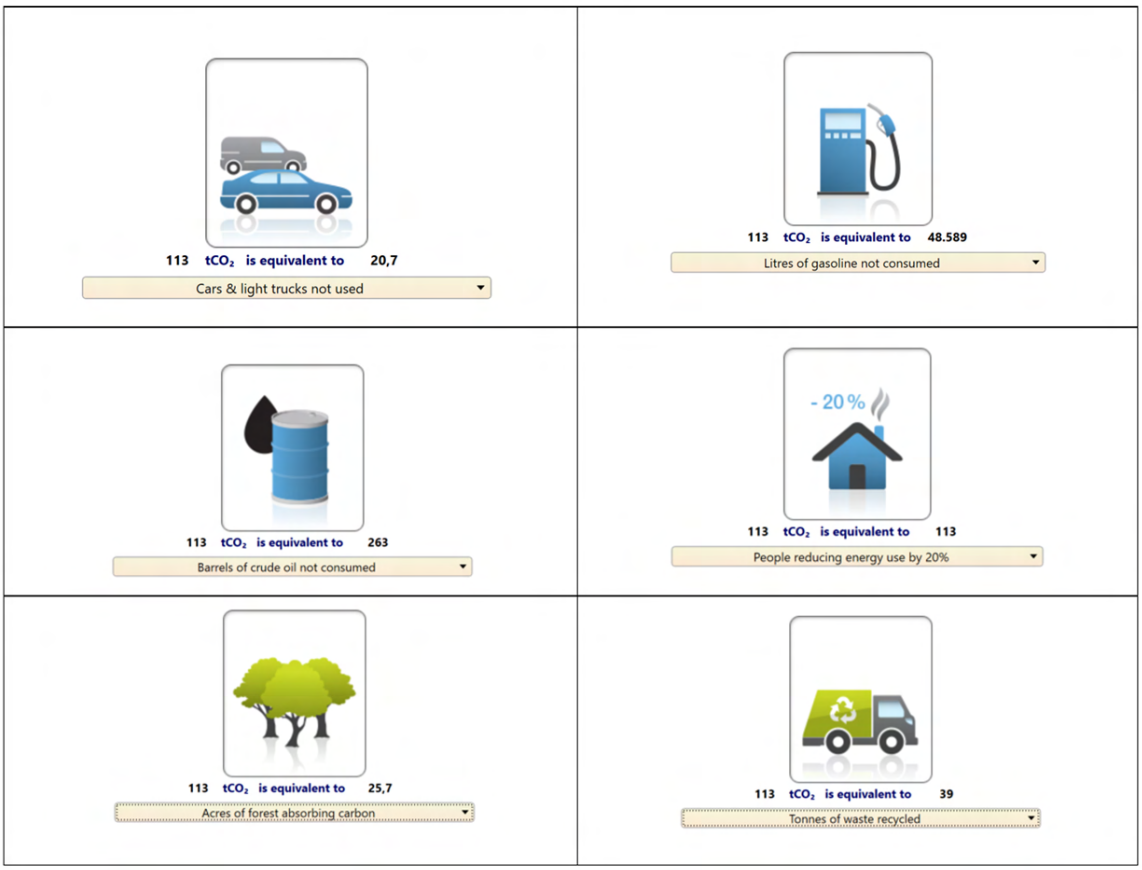


Fig. 4.11 Equivalences of GHG emissions saved

In summary, the final set of energy-saving measures at Alumni Hall not only improves energy efficiency but also achieves significant environmental benefits by drastically reducing GHG emissions. This aligns with the broader sustainability goals of the Illinois Institute of Technology and contributes to global efforts to mitigate climate change.

Chapter 5

Campus-Wide Analysis

This chapter focuses on conducting a comprehensive analysis of renewable energy integration across the Illinois Institute of Technology (IIT) campus. Given the diversity and energy demands of the campus buildings, this analysis is essential for understanding the potential for renewable energy adoption and its impact on campus sustainability.

The analysis will evaluate the feasibility and potential benefits of various renewable energy sources using the RETScreen software. RETScreen provides a robust platform for conducting detailed energy audits, feasibility studies, and performance analyses. This tool will enable us to assess the economic and environmental impacts of integrating renewable energy technologies into the campus infrastructure.

In addition to the RETScreen analysis, this chapter will incorporate findings from various research efforts focused on the campus's existing infrastructure. This includes examining the steam distribution network, chilled water systems, roof conditions, and shaded areas across the campus. These elements are crucial for determining the optimal locations and configurations for renewable energy installations.

By leveraging RETScreen and incorporating detailed research on the campus's existing infrastructure, this chapter aims to provide actionable insights into how renewable energy can enhance the energy efficiency and sustainability of IIT's campus. The findings will contribute to the broader goals of the IIT Energy Master Plan, supporting the university's commitment to reducing its carbon footprint and achieving greater energy independence. The subsequent chapters will build on these insights, exploring more detailed analyses and implementation strategies for renewable energy projects across the campus.

5.1 Climate data

The RETScreen software retrieves weather data specific to the location where it is deployed, sourcing information from reputable outlets such as NASA. This data is visualized in Figures 5.1 and 5.2.

Subsequently, this weather data is utilized to compute the energy requirements for heating and cooling the facility. It includes various parameters for each month of the year, such as air temperature, relative humidity, precipitation, solar radiation, atmospheric pressure, wind speed, earth temperature, heating degree-days, and cooling degree-days.

Both Figures 5.1 and 5.2 display the weather data pertinent to the Illinois Institute of Technology location, located on 10 W 35th Street, in Chicago, Illinois. They outline monthly climatic data for heating and cooling design in buildings. It displays average air temperatures, relative humidity, precipitation, daily solar radiation, atmospheric pressure, wind speed, and earth temperature.

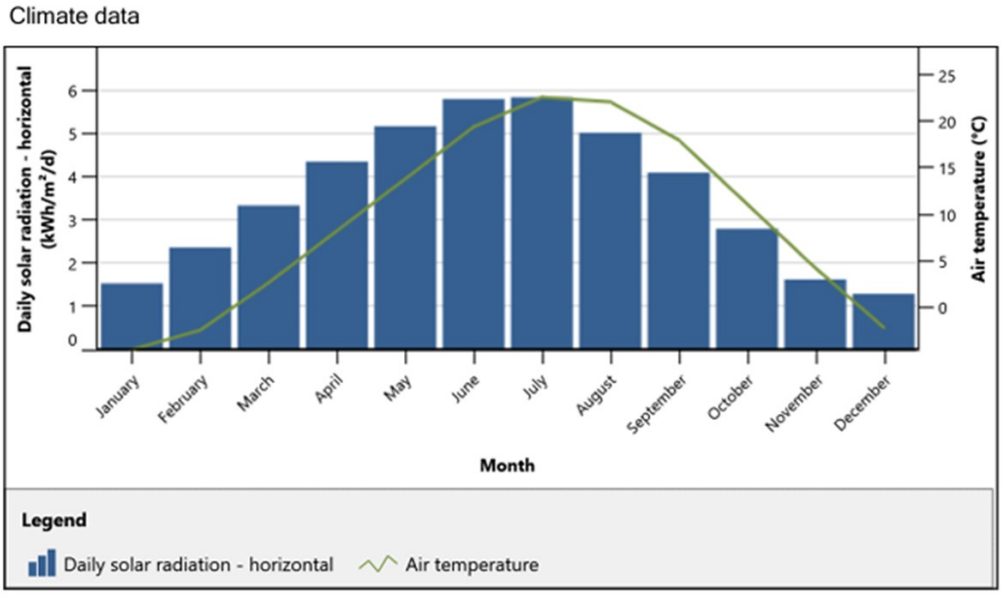


Fig. 5.1 Solar Radiation across the Year

Heating degree-days and cooling degree-days are provided, indicating energy needed to heat or cool. Key design temperatures include a heating design temperature of -8.4°C, a cooling design temperature of 29.0°C, and an earth temperature amplitude of 21.9. These figures are essential for designing efficient HVAC systems, reflecting the area's seasonal temperature fluctuations and corresponding energy demands.

	Heating design temperature			-8,4					
	Cooling design temperature			29,0					
	Earth temperature amplitude			21,9					
Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	-4,6	85,9%	48,98	1,53	99,4	6,1	-3,8	701	0
February	-2,5	82,8%	46,20	2,36	99,4	5,8	-2,1	574	0
March	2,6	79,5%	61,69	3,33	99,3	5,7	2,6	477	0
April	8,2	77,1%	89,40	4,34	99,1	5,5	7,8	294	0
May	13,8	76,6%	105,40	5,16	99,1	4,8	13,1	130	118
June	19,4	75,7%	99,30	5,79	99,1	4,1	18,7	0	282
July	22,6	73,5%	98,58	5,83	99,2	3,8	22,4	0	391
August	22,1	72,5%	105,40	5,01	99,3	3,7	22,1	0	375
September	18,0	71,1%	82,50	4,09	99,3	4,4	18,1	0	240
October	11,1	74,0%	84,32	2,79	99,3	5,2	11,4	214	34
November	4,2	80,1%	76,50	1,62	99,4	5,8	4,7	414	0
December	-2,2	85,3%	56,11	1,29	99,4	5,8	-1,3	626	0
Annual	9,5	77,8%	954,38	3,60	99,3	5,0	9,5	3.430	1.440

Fig. 5.2 Weather Conditions across the Year

5.2 Building Overview and Description

The aim of this section is to provide a comprehensive overview and description of the buildings on the Illinois Institute of Technology (IIT) campus, as depicted in the accompanying diagram (Figure 5.3). This diagram illustrates almost all the buildings on the IIT campus and how they are interconnected through the smart grid system. The smart grid employs a loop configuration that includes High-Reliability Distribution System (HRDS) smart switches and various renewable energy sources such as solar panels and wind turbines. This interconnected system ensures efficient distribution and reliable power delivery across the campus, enabling quick isolation of faults and minimizing downtime.

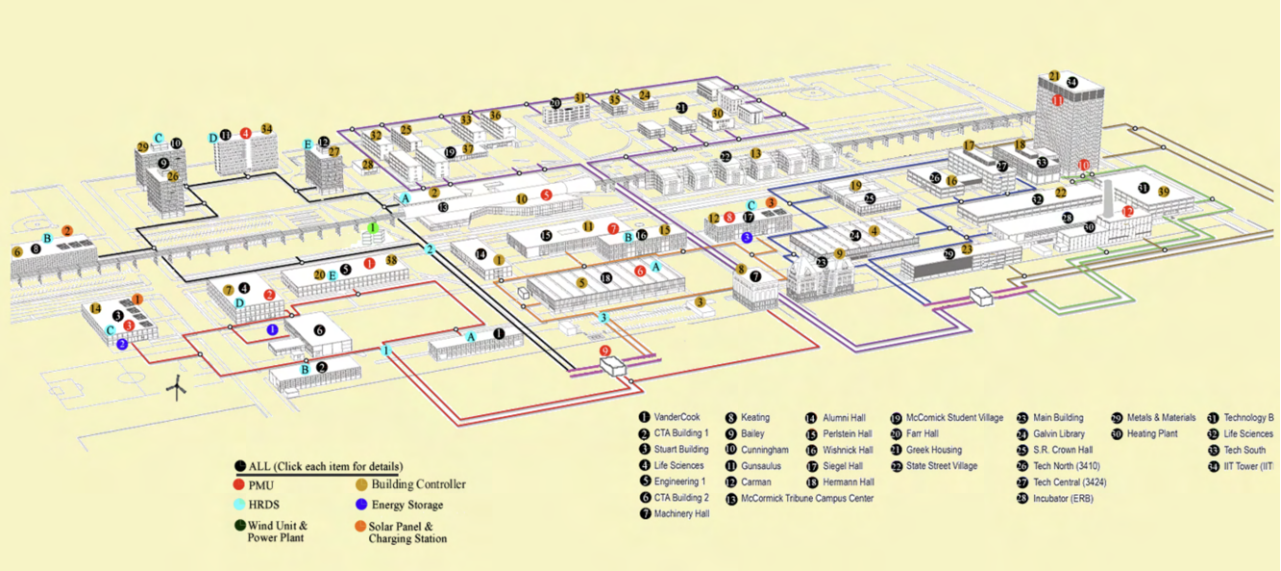


Fig. 5.3 IIT Campus Buildings and their Interconnection

Reprinted from "IIT Microgrid," by Illinois Institute of Technology, n.d., Illinois Institute of Technology

Thus, the focus of this section is the classification of buildings at the Illinois Institute of Technology (IIT) as presented in the accompanying Table 5.1. The buildings are categorized into different types such as Religious, Education, Residential, Industrial, and Transport. Each building is identified by its name, address, and size in square feet. These buildings encompass a wide range of facilities including chapels, research buildings, student centers, music colleges, libraries, residences, and more. They are primarily situated along streets such as S. State, S. Wabash, S. Michigan, and S. Dearborn.

These buildings are integral to the energy efficiency analysis undertaken as part of this project. They will be analyzed using RETScreen, a software tool for energy efficiency and renewable energy feasibility analysis.

This comprehensive table provides valuable insight into the campus infrastructure at IIT, forming the basis for further examination and evaluation in this project section.

Table 5.1 IIT Building Classification

Type	Building Name	Address	Size (ft²)
Religious	Chapel	65 E. 32ND	4,137
Education	Crown	3360 S. STATE	53,900
	3410	3410 S. STATE	37,374
	3424 Central	3424 S. STATE	80,660
	3424 South	3424 S. STATE	81,658
	Life Science Research Building	35 W. 34TH	103,000
	Stuart Building	10 W. 31ST	79,788
	McCormick Tribune	3200 S. WABASH	33,182
	Cunningham	3100 S. MICHIGAN	74,103
	McCormick Student	3241 S. WABASH	142,373
	Carman	60E. 32ND	74,103
	Gunsaulus	3140 S. MICHIGAN	82,898
	IIT Tower	10 W. 35TH	382,636
	Main Building	3300 S. FEDERAL	67,836
	Chemical Research Building	3440 S. DEARBORN	141,328
	Machinery Hall	100 W. 33RD	29,375
	Wishnick	3255 S. DEARBORN	61,512
	Perlstein Hall	3255 S. DEARBORN	51,775
	Alumni Hall	3201 S. DEARBORN	35,172
	Hermann Union Building	3141 S. FEDERAL	112,640
	Engineering Research Building	55 W. 34TH	46,632
	Life Sciences Building	3110 S. STATE	107,068
	Engineering Building 1	10 W. 32ND	145,056
	Vandercook College of Music	3140 S. FEDERAL	35,172
	Siegel	3301 S. DEARBORN	61,512
	Galvin Library	35 W. 33RD	92,609
	Keating	3040 S. WABASH	64,524
	Bailey	3101 S. WABASH	74,013
Residential	ASA	3340 S. MICHIGAN	15,616
	TRI	3360 S. MICHIGAN	13,336
	AEP	3350 S. MICHIGAN	15,616
	FARR	3300 S. MICHIGAN	24,802
	Law House	3330 S. MICHIGAN	15,616
	PKS	3366 S. MICHIGAN	12,876
	PKP	3333 S. WABASH	12,876
	ASP	3361 S. WABASH	12,402
	SPE	3341 S. WABASH	15,616
	DTD	3349 S. WABASH	18,360
Industrial	Metals Building	3350 S. FEDERAL	63,802
	Heating Plant	3430 S. FEDERAL	24,316
Transport	CTA 1	3120 S. DEARBORN	24,662
	CTA 2	3100 S. FEDERAL	20,115

5.3 Energy Analysis on RETScreen

This chapter focuses on conducting a comprehensive analysis of renewable energy integration across the Illinois Institute of Technology (IIT) campus using the RETScreen software. Given the diversity and energy demands of the campus buildings, this analysis is essential for understanding the potential for renewable energy adoption and its impact on campus sustainability.

The analysis will evaluate the feasibility and potential benefits of various renewable energy sources. RETScreen provides a robust platform for conducting detailed energy audits, feasibility studies, and performance analyses. This tool will enable us to assess the economic and environmental impacts of integrating renewable energy technologies into the campus infrastructure.

However, it is important to note that the analysis conducted using RETScreen for this part was less precise than the individual analyses. Simulating 40 buildings within the given time constraints was not feasible, leading to a broader, less detailed examination. Nonetheless, the RETScreen analysis offers valuable insights into the general trends and critical factors to consider when designing the Energy Master Plan.

By leveraging RETScreen and incorporating detailed research on the campus's existing infrastructure, this chapter aims to provide actionable insights into how renewable energy can enhance the energy efficiency and sustainability of IIT's campus. The findings will contribute to the broader goals of the IIT Energy Master Plan, supporting the university's commitment to reducing its carbon footprint and achieving greater energy independence.

5.3.1 Fuel Consumption

The success of the Energy Master Plan is palpable through substantial reductions in fuel consumption, achieved by targeting both high-usage areas and implementing general campus-wide improvements. Notably, the Heating Plant, initially characterized by high energy usage, showcased a particularly impressive reduction, serving as a beacon for similar facilities.

A comprehensive examination of fuel consumption data across different facilities is presented through Figure 5.4, comparing the base case (pre-implementation of the Energy Master Plan) and the proposed case (anticipated outcomes post-implementation of energy-saving measures). Each facility is represented by three bars: the base case (blue), the proposed case (purple), and the resultant savings achieved (green).

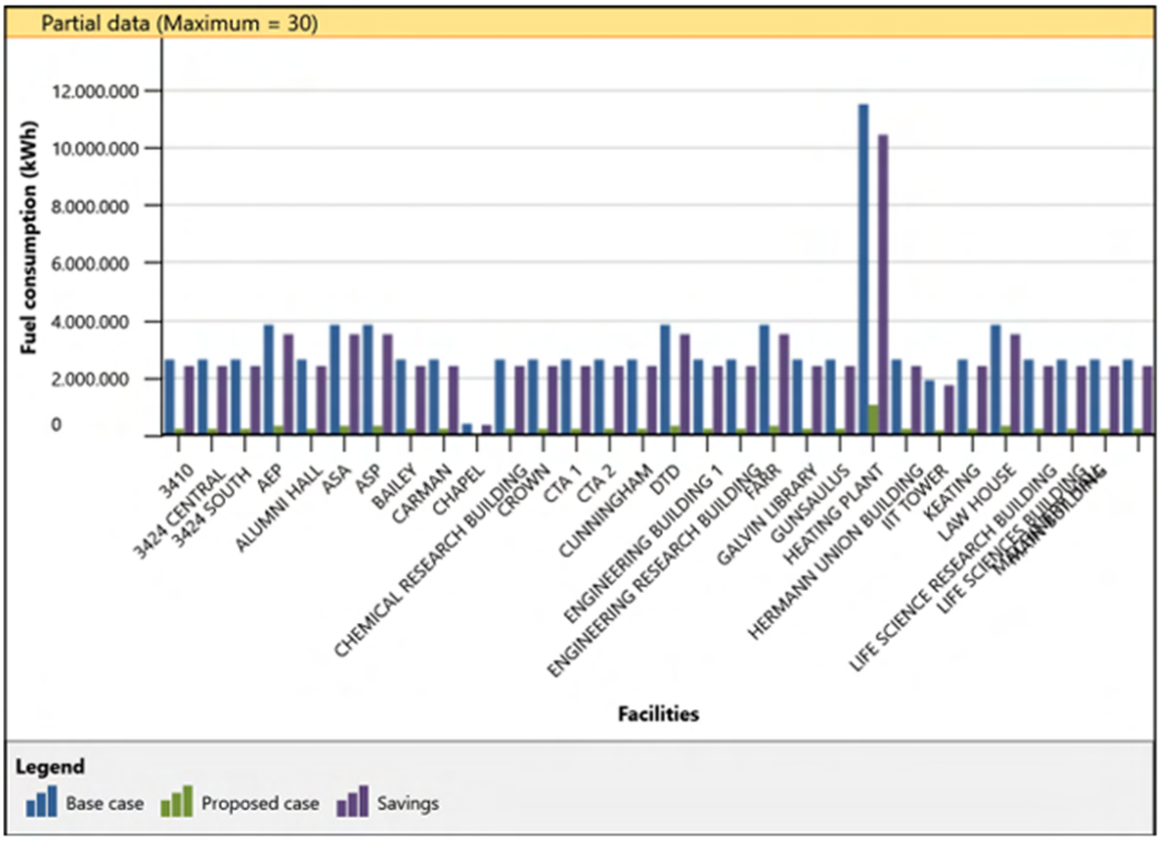


Fig. 5.4 Fuel Consumption of IIT Campus Buildings

Several key observations emerge from this analysis:

1. Across nearly all facilities, a discernible reduction in fuel consumption is evident from the base case to the proposed case, affirming the efficacy of the Energy Master Plan's measures.

2. The green bars, symbolizing savings, vividly illustrate the disparity between the base and proposed cases, with some instances showcasing substantial reductions in fuel consumption.

3. One facility notably exhibits exceptionally high fuel consumption in the base case, coupled with a significant reduction in the proposed case, resulting in noteworthy savings. Such a facility likely represents a substantial energy consumer, such as a heating plant or power station, thus presenting a prime opportunity for energy efficiency enhancements.

4. One facility notably exhibits exceptionally high fuel consumption in the base case, coupled with a significant reduction in the proposed case, resulting in noteworthy savings. Such a facility likely represents a substantial energy consumer, such as a

heating plant or power station, thus presenting a prime opportunity for energy efficiency enhancements.

5. Variations in the scale of savings among different facilities are apparent, with some demonstrating minor improvements while others indicate considerable reductions in fuel consumption.

6. The Partial data (Maximum = 30) notation suggests the existence of additional data beyond the graph's depiction, with only a subset of facilities presented. This hints at the broader scope of the Energy Master Plan's impact across the campus.

The graph in Figure 5.4 effectively delineates the influence of proposed energy-saving measures on fuel consumption, thereby facilitating the prioritization of efforts towards facilities with the greatest potential for savings.

5.3.2 GHG Emissions

The attainment of zero GHG emissions across all facilities signifies a triumphant transition to renewable energy sources and other energy-saving initiatives, underscoring Illinois Institute of Technology's unwavering commitment to realizing a carbon-neutral campus.

A graphical representation of the costs associated with reducing GHG emissions across various facilities as part of the Net Zero Plan for IIT is shown in Figure 5.5, which offers insightful observations:

1. Each bar on the graph corresponds to the cost incurred to achieve GHG reductions at individual facilities, denoted in thousands of dollars.

2. Variability in GHG reduction costs among facilities suggests discrepancies in the cost intensiveness of emission reduction endeavors across different locations.

3. Notably, one facility exhibits significantly higher costs associated with GHG reduction efforts compared to others. This disparity may imply either more ambitious emission reduction goals or greater challenges in mitigating emissions within that facility.

4. The majority of facilities display GHG reduction costs clustered within the mid-range of the graph's scale, indicating a relatively uniform approach to costs among these locations.

5. The notation Partial data (Maximum = 30) hints at the graph's subset representation within a larger dataset, suggesting a more comprehensive analysis encompassing additional facilities.

This graph serves as a valuable tool for pinpointing facilities necessitating greater investment to curtail GHG emissions, thus facilitating informed budget allocation and prioritization within the Net Zero Plan implementation. It offers a succinct snapshot of

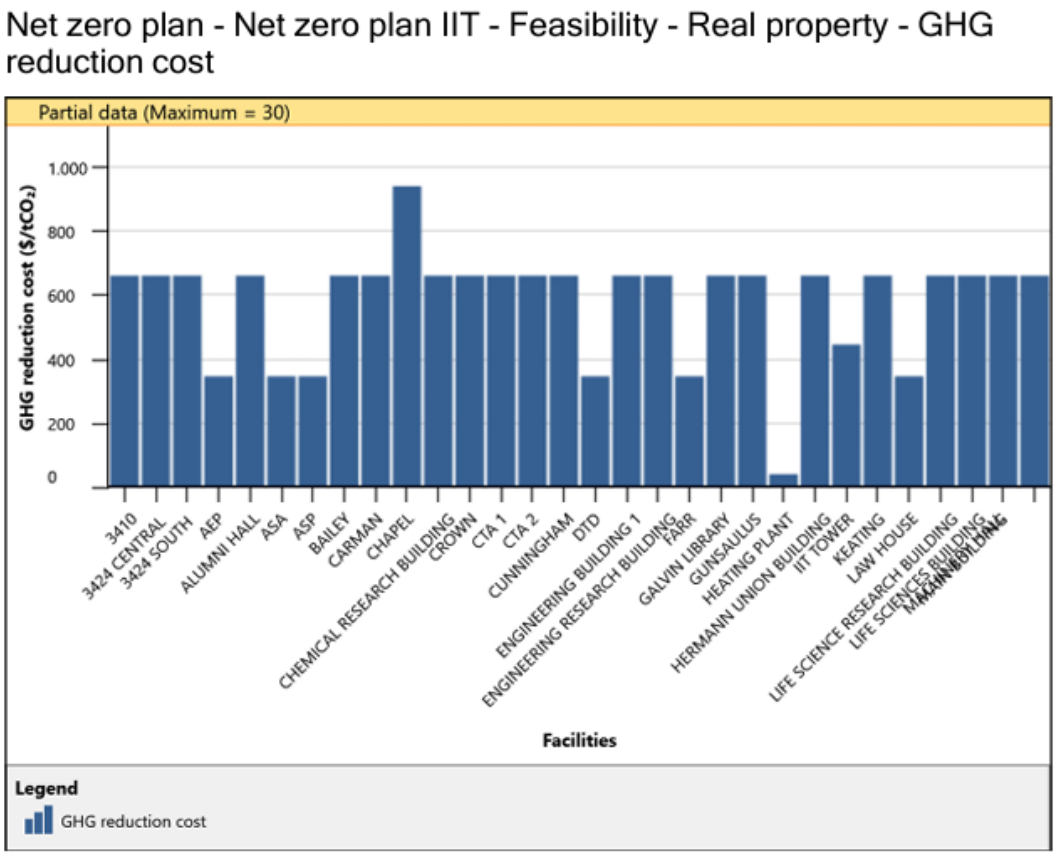


Fig. 5.5 GHG Emissions

the financial dimension of sustainability efforts, delineating where resources are allocated to achieve GHG reductions effectively.

5.3.3 Energy Use Intensity (EUI)

The purpose of this section is to conduct a comprehensive analysis of the Energy Use Intensity (EUI) across various facilities within the Illinois Institute of Technology (IIT) campus. EUI serves as a crucial metric for evaluating the energy performance and efficiency of buildings. This analysis aims to assess the effectiveness of energy-saving measures implemented across different types of facilities at IIT.

The table from Figure 5.6 details the EUI for various facilities and provides a comparison between the current or base case and the targeted or proposed case after the implementation of energy efficiency measures. EUI, measured in kWh/m², serves as a critical metric for assessing a building's energy performance. It is calculated by dividing

the total energy consumed by the building in one year (in kWh) by the total floor area of the building (in m²). Examining the table, several key insights emerge:

Facility name	Facility size m²	Energy use intensity			
		Benchmark kWh/m²	Base case kWh/m²	Target %	Proposed case kWh/m²
CHAPEL	384	120	252	-91%	22,8
ASA	1.451	137	278	-91,5%	23,6
AEP	1.451	137	278	-91,5%	23,6
TRI	1.239	137	278	-91,5%	23,6
PKS	1.196	137	278	-91,5%	23,6
ASP	1.152	137	278	-91,5%	23,6
SPE	1.451	137	278	-91,5%	23,6
DTD	1.706	137	278	-91,5%	23,6
LAW HOUSE	1.451	137	137	-91,5%	11,7
FARR	2.304	125	125	-91,5%	10,6
PKP	1.196	137	278	-91,5%	23,6
METALS/INFAC BUILDING	5.927			-90,8%	
HEATING PLANT	2.259			-90,8%	
IIT TOWER	35.548	245	160	-90,9%	14,5
GUNSAULUS	82.898	217	183	-91,4%	15,7
CARMAN	6.876	217	183	-91,4%	15,7
McCORMICK STUDENT VILLAGE	13.227	217	183	-91,4%	15,7
CUNNINGHAM	6.884	217	183	-91,4%	15,7
McCORMICK TRIBUNE CAMPUS CENTER	3.083	217	183	-91,4%	15,7
BAILEY	6.876	217	183	-91,4%	15,7
KEATING	5.994	217	183	-91,4%	15,7
GALVIN LIBRARY	8.604	217	183	-91,4%	15,7
SIEGEL	5.715	217	183	-91,4%	15,7
CROWN	5.007	217	183	-91,4%	15,7
3410	3.472	217	183	-91,4%	15,7
3424 CENTRAL	7.494	217	183	-91,4%	15,7
3424 SOUTH	7.586	217	183	-91,4%	15,7
LIFE SCIENCE RESEARCH BUILDING	9.569	217	183	-91,4%	15,7
STUART BUILDING	7.413	217	183	-91,4%	15,7
CTA 2	1.869	217	183	-91,4%	15,7
CTA 1	2.291	217	183	-91,4%	15,7
MACHINERY HALL	2.729	217	183	-91,4%	15,7
WISHNICK	5.715	217	183	-91,4%	15,7
PERLSTEIN HALL	4.810	217	183	-91,4%	15,7
ALUMNI HALL	3.268	217	183	-91,4%	15,7
HERMANN UNION BUILDING	10.465	217	183	-91,4%	15,7
ENGINEERING RESEARCH BUILDING	4.332	217	183	-91,4%	15,7
LIFE SCIENCES BUILDING	9.947	217	183	-91,4%	15,7
ENGINEERING BUILDING 1	13.476	217	183	-91,4%	15,7
VANDERCOOK COLLEGE OF MUSIC	3.268	217	183	-91,4%	15,7
MAIN BUILDING	6.302	217	183	-91,4%	15,7
CHEMICAL RESEARCH BUILDING	13.130	217	183	-91,4%	15,7

Fig. 5.6 Energy Use Intensity Analysis

* The "Base case EUI" column lists the current or existing EUI for each facility.
* The "Proposed case EUI" column outlines the targeted or proposed EUI after implementing specific energy-saving measures or upgrades.
* The "Benchmark kWh/m²" column provides a standard or reference EUI, serving as a goal or comparison point.
* The "Target %" column indicates the percentage difference between the base case and the proposed case, illustrating the degree of improvement or reduction in energy consumption aimed for each facility.

Notably, while some facilities exhibit significantly higher base EUI values compared to others, the proposed EUI reductions follow a consistent pattern across entries. The "Proposed case kWh/m²" values are markedly lower than the base case for all facilities, implying substantial improvements in energy efficiency if targets are met.

Furthermore, variations in the "Benchmark kWh/m²" suggest differing energy use standards or expectations based on the size and function of different types of facilities. For example, a chapel may have a lower benchmark (e.g., 120 kWh/m²) compared to an engineering research building (e.g., 217 kWh/m²), reflecting distinct energy needs and usage patterns.

This comprehensive analysis underscores the effectiveness of IIT's energy efficiency initiatives and highlights the university's commitment to sustainable campus operations.

5.3.4 Financial Viability

Despite the environmental benefits, the financial analysis shows a consistent pattern of long payback periods and negative Net Present Value (NPV) across campus facilities. This underlines the need for strategic financial planning to address the economic challenges posed by the sustainability measures.

Additionally, the bar chart provided in Figure 5.6 offers insights into the total initial costs associated with the first proposed energy master plan for various facilities, analyzed using RETScreen—a software tool used to evaluate the viability, efficiency, and cost of renewable energy and energy efficiency projects. From the bar chart:

* The costs are measured in dollars, with the vertical axis (y-axis) representing the total initial costs, segmented in increments of $2,000,000.
* Each bar corresponds to a different facility, with the facility names listed along the horizontal axis (x-axis).
* Most facilities are projected to have initial costs falling between $1,000,000 and $4,000,000, as indicated by the heights of the bars.
* Notably, the IIT Tower stands out with a substantially higher initial cost, exceeding $10,000,000, making it an outlier compared to other facilities.
* The legend indicates that the blue bars represent "Total initial costs," confirming that these figures denote the anticipated upfront investment required for implementing energy efficiency measures at each facility.

Interpreting the visual data, one can infer that the energy master plan for the IIT Tower is significantly costlier than that of other facilities. This divergence could stem from various factors such as the tower's size, the complexity of proposed measures, or the state of its current infrastructure. Conversely, the consistent costs across other facilities suggest

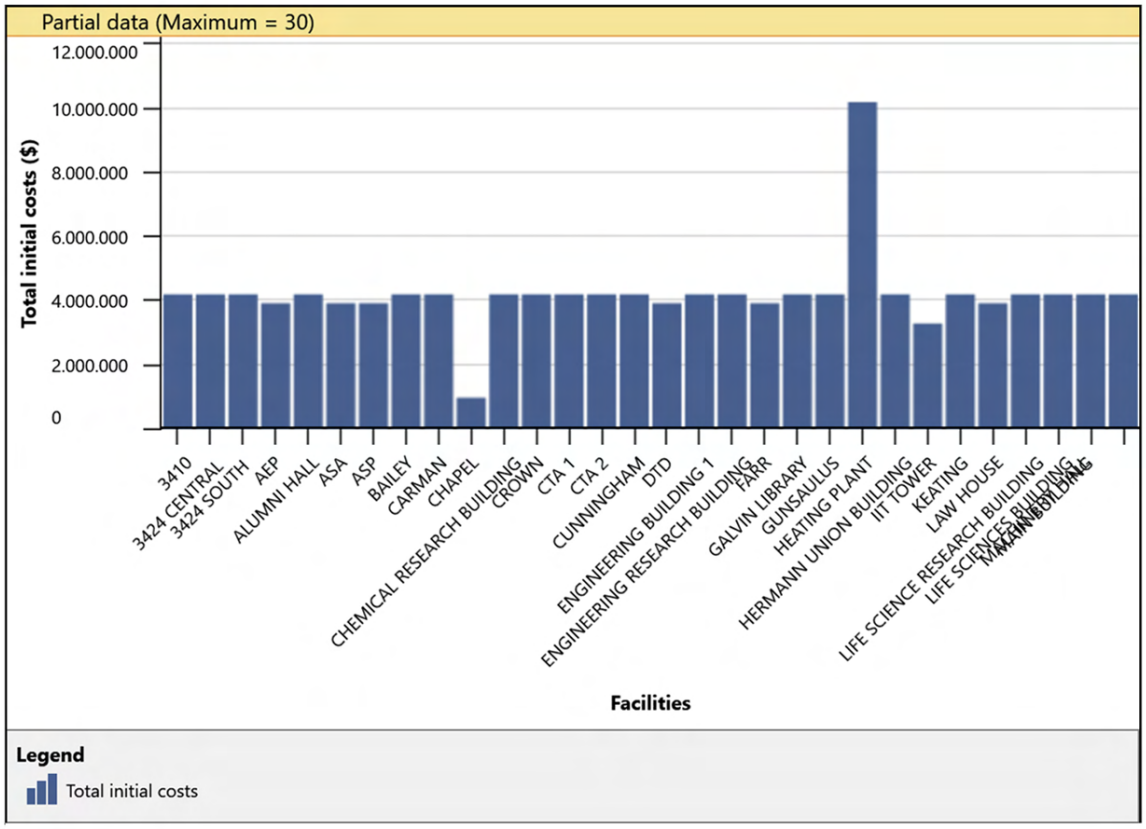
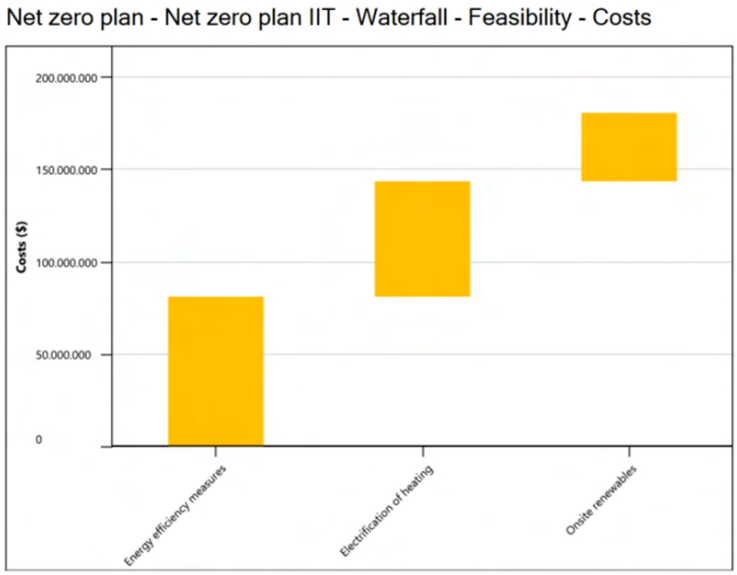


Fig. 5.7 Initial Investment Costs

a standardized approach to energy efficiency upgrades, although specifics regarding the reasons for cost discrepancies are not provided in this chart.

Figure 5.8 illustrates the costs associated with achieving a net zero plan for IIT, broken down into three main components: energy efficiency measures, electrification of heating, and onsite renewables. This waterfall chart provides a clear visualization of the cumulative sum, cost increase, and percentage for each component, highlighting the substantial investments required. The chart emphasizes that energy efficiency measures constitute the largest initial investment, followed by the electrification of heating and the implementation of onsite renewables. Understanding these financial requirements is crucial for strategic planning and prioritizing actions within the energy master plan.



Costs	Cumulative sum ($)	Increase ($)	Percentage (%)
Energy efficiency measures	81.167.601	81.167.601	44,9%
Electrification of heating	143.650.553	62.482.952	34,6%
Onsite renewables	180.773.953	37.123.400	20,5%
Total	180.773.953	180.773.953	100%

Fig. 5.8 Cost breakdown for achieving net zero at IIT

This analysis underscores the importance of strategic financial planning to navigate the economic challenges associated with sustainability measures, especially in cases where significant upfront investments are required.

5.4 Campus Building Interconnections

The interconnected nature of the Illinois Institute of Technology (IIT) campus buildings is crucial for ensuring efficient energy distribution, robust data communication, and integrated system management. By leveraging a smart grid system that incorporates High-Reliability Distribution System (HRDS) smart switches, renewable energy sources, and advanced monitoring technologies, IIT enhances its operational efficiency and sustainability. The interconnections between buildings enable seamless energy and data flow, promoting a resilient and adaptable infrastructure that can quickly respond to faults and maintenance needs. This chapter will explore the current state of IIT's building interconnections and propose enhancements to further optimize the campus's energy and communication networks.

5.4.1 Optimizing the Steam Distribution System

The steam distribution system at the Illinois Institute of Technology is a critical component of the campus's heating infrastructure. This system's efficiency, reliability, and

scalability are essential for maintaining a comfortable and operationally efficient campus environment. The current distribution system at IIT camous can be seen in Figure 5.11

Based on the schematic of the steam distribution system, several key improvements could be considered to enhance efficiency and reliability:

* **Minimize Sharp Turns**: The efficiency of a steam distribution system largely depends on the layout and design of the piping network. Smoothing out sharp turns into gradual curves can help reduce pressure drops and improve flow efficiency. Ideally, pathways should have minimal sharp bends and be as straight as possible to reduce heat loss, allowing for smoother steam flow and enhancing overall system performance.

* **Insulation Quality**: Ensuring all pipes are well-insulated minimizes heat loss, especially in areas exposed to lower ambient temperatures. Proper insulation can significantly reduce heating demands and improve the overall efficiency of the system.

* **System Redundancy**: Incorporating redundancy into the steam distribution system is essential for reliability. Implementing redundant paths for critical areas ensures continuous heating during maintenance or in case of faults. Parallel paths or loop configurations can ensure that if one section of the system is under maintenance or faces a fault, steam can still be routed through alternative pathways.

* **Streamlined Routing**: The system must adequately cover all areas requiring heating. Rerouting pipes more directly to their destinations can reduce the total length of piping needed, thus reducing heat loss and potential failure points. This involves ensuring that the main pipelines branch out to reach all necessary zones within the campus, providing uniform heating across all buildings and spaces.

* **Maintenance Access Points**: The layout should allow for easy maintenance access. Adding accessible maintenance and shut-off valves allows for easier repairs and minimal downtime. Maintenance and shut-off valves should be strategically placed and easily accessible to enable quick repairs without significant disruption to other operations.

* **Scalability for Future Expansion**: Scalability is another important consideration. Adding provisions for future expansions, like additional flange connections, simplifies extending the system to new areas. The steam distribution system should be designed with future expansion in mind, planning for potential extensions to new buildings or areas that may be developed.

* **Automation and Monitoring**: Incorporating smart monitoring systems can provide real-time data on system performance, detect leaks, and predict potential

failures. This proactive approach can help maintain the system's efficiency and reliability.

* **Energy Efficiency Audits**: Regular audits can identify areas where the system may be losing energy and suggest improvements. These audits are crucial for maintaining and enhancing the energy efficiency of the steam distribution system.

* **Pump and Valve Performance**: Ensuring pumps and valves are optimized for their tasks can lead to energy savings and better performance. Regular checks and maintenance of these components are essential for the system's overall efficiency.

* **Environmental Considerations**: Protecting the system from environmental factors, especially in outdoor or unheated spaces, can prevent issues like freezing and other impacts. This can ensure the system operates effectively in all conditions.

Analyzing and optimizing the steam distribution system at IIT is crucial for enhancing the campus's overall energy efficiency and reliability. By addressing factors such as efficiency, coverage, redundancy, scalability, and maintenance accessibility, IIT can ensure that its steam distribution system meets current demands and is prepared for future growth. Implementing these improvements will contribute to the sustainability goals outlined in the IIT Energy Master Plan, ensuring a more efficient and resilient energy infrastructure.

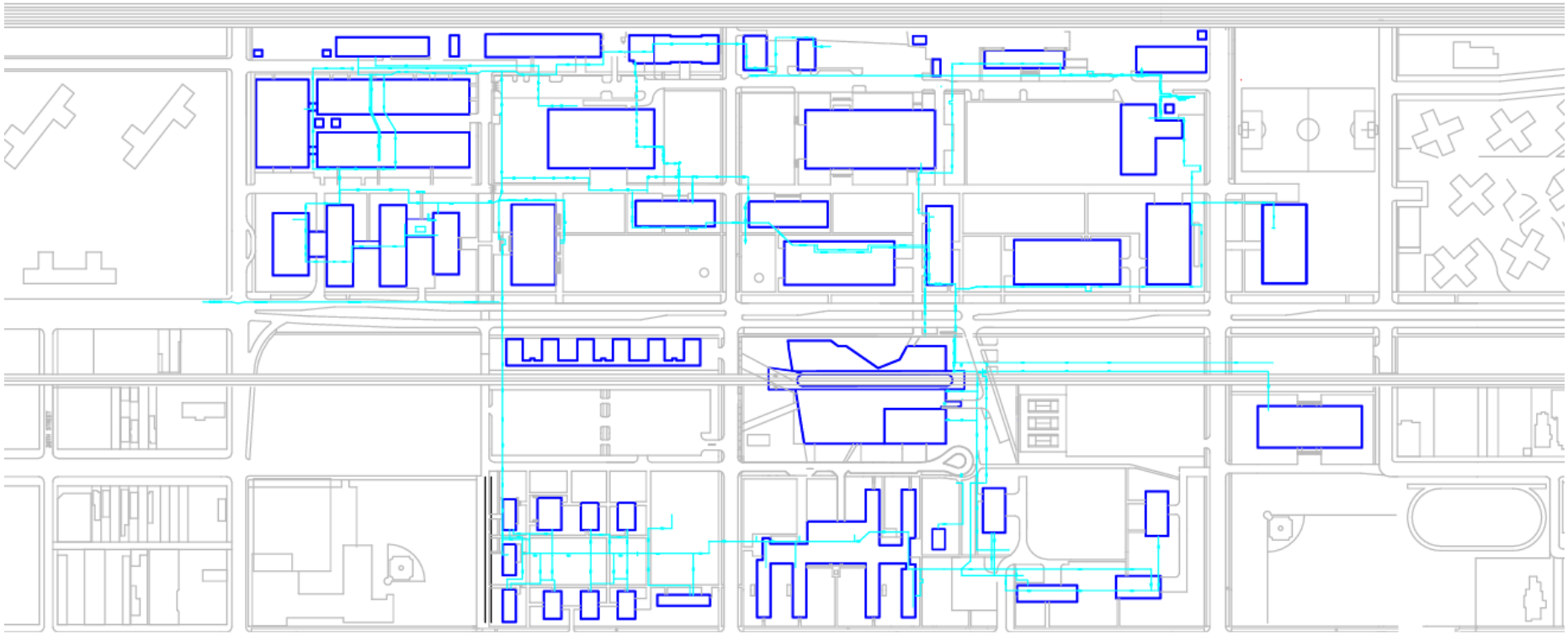


Fig. 5.9 Steam Distribution at IIT

5.4.2 Optimizing Roofs

The roof areas of buildings at the Illinois Institute of Technology (IIT) present significant opportunities for enhancing energy efficiency and integrating renewable energy solutions. With a substantial roof area of approximately 799,900 square feet, various measures can be implemented to optimize energy use and contribute to the campus's sustainability goals. This roof area is illustrated in Figure 5.10, which provides a map plan of IIT buildings.

* **Solar Panel Installation**: The large roof area provides an excellent opportunity for installing solar panels. By sizing the system according to the campus's energy needs, solar panels can significantly reduce electricity costs and carbon footprint. This renewable energy source can supply a considerable portion of the campus's electricity.

* **Green Roofing**: Implementing a green roof system, also known as a rooftop garden, can improve insulation, reduce the heat island effect, and manage stormwater. Green roofs provide additional thermal insulation, which helps in reducing heating and cooling demands. They also offer environmental benefits, such as increased biodiversity and improved air quality.

* **Roof Insulation Upgrade**: Enhancing roof insulation is a straightforward yet effective way to reduce heating and cooling demands. Proper insulation minimizes heat loss in winter and keeps buildings cooler in summer, leading to significant energy savings. This measure can be especially beneficial for older buildings where insulation may be inadequate.

* **Reflective Roofing Materials**: Using materials with high solar reflectance can help reduce the heat absorbed by the roof, thereby lowering cooling requirements. Reflective roofing materials, often referred to as cool roofs, reflect more sunlight and absorb less heat compared to standard roofing materials. This can result in lower energy consumption for air conditioning.

* **Roof Maintenance**: Regular cleaning and maintenance of the roof are essential for maximizing energy efficiency, particularly if solar panels are installed. Dirt and debris can reduce the efficiency of solar panels, so keeping the roof clean ensures optimal performance. Routine inspections can identify and address any issues that could compromise the roof's integrity and energy efficiency.

* **Wind Turbines**: If the location is suitable, small wind turbines could be another option to explore for renewable energy generation. Roof-mounted wind turbines can harness wind energy to generate electricity, complementing solar power and further reducing reliance on grid electricity.

* **Feasibility and Considerations**: Each of these options needs to be evaluated for feasibility, considering factors such as local climate, building regulations, the

structural capacity of the buildings, and financial considerations. Consulting with renewable energy specialists and building efficiency experts is essential to create a tailored plan that maximizes the benefits of these energy efficiency measures.

By implementing these strategies, IIT can significantly enhance the energy efficiency of its buildings and contribute to its sustainability goals. The optimization of roof areas for renewable energy and improved insulation supports the broader objectives of the IIT Energy Master Plan, ensuring a more sustainable and energy-efficient campus.

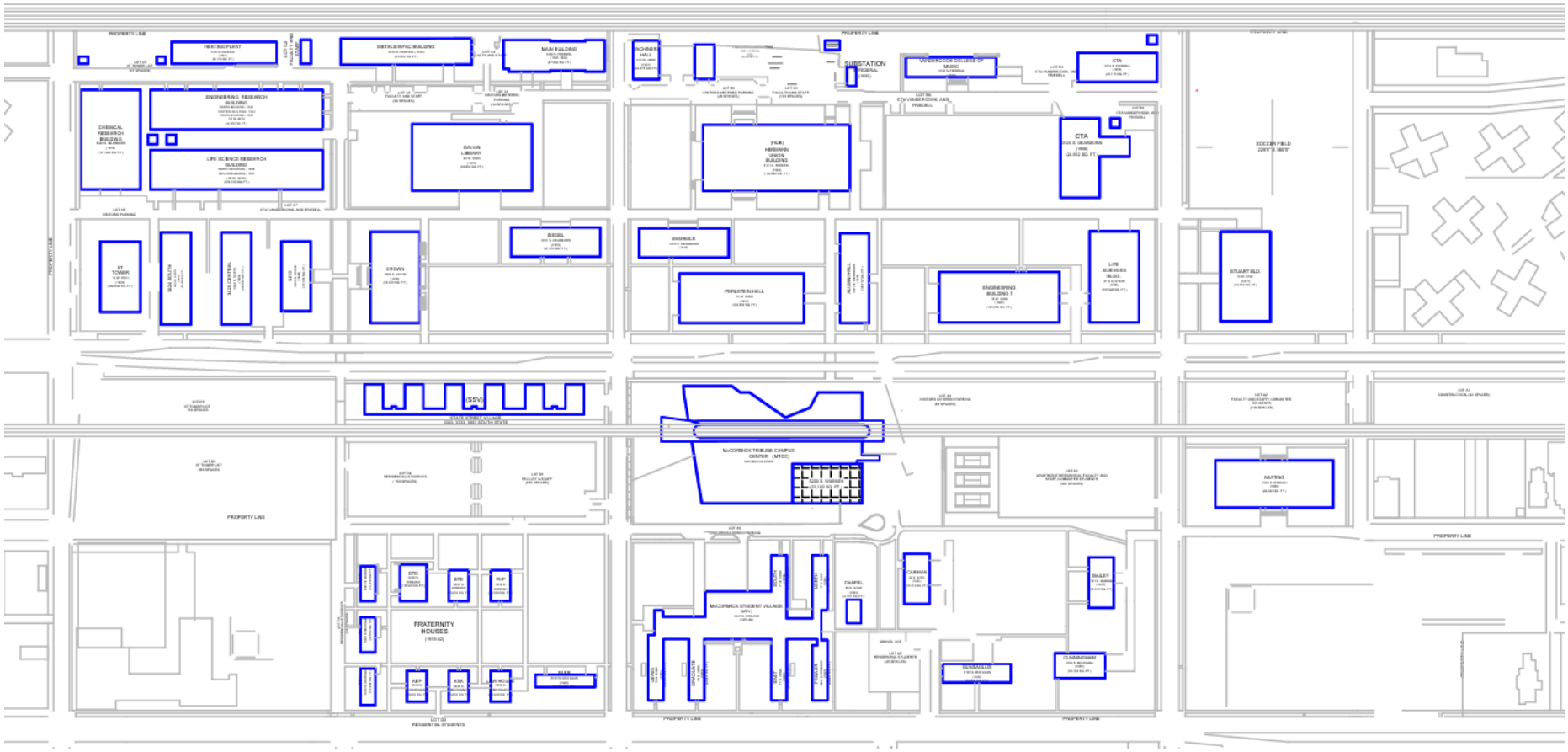


Fig. 5.10 IIT campus roof areas map

5.4.3 Optimizing Electrical and Telecom Systems

After studying in detail the campus electrical ducts, electrical and telecom systems, as shown in Figure 5.12, key strategies for optimization were identified:

* **Efficient Routing**: Wherever possible, routing should follow the shortest and straightest paths to minimize resistance and potential points of failure. Additionally, ensuring that electrical and telecom ducts do not overlap unnecessarily can prevent interference and ease maintenance.

* **Redundancy and Reliability**: Incorporate redundant pathways, especially for critical systems, to maintain functionality during maintenance or in case of failures. Implementing parallel lines where necessary can enhance reliability and provide alternative routes for power and data transmission.

* **Separation and Safety**: Maintain adequate separation between electrical and telecom systems to prevent electromagnetic interference and enhance safety. High-quality insulation and shielding materials should be used to protect against electrical faults and signal degradation.

* **Scalability and Future Proofing**: Design the infrastructure with provisions for future expansions, allowing easy integration of additional lines and equipment. Utilizing flexible conduits can accommodate future upgrades without significant rework.

* **Maintenance Accessibility**: Ensure that all ducts and conduits are easily accessible for maintenance and repairs to minimize downtime. Clearly marking all pathways and critical points within the ducts can aid in easy identification and maintenance.

* **Energy Efficiency**: Use high-efficiency cables and components to minimize power loss during transmission. Implementing smart monitoring systems to track energy usage, detect anomalies, and optimize the performance of electrical and telecom systems can further enhance energy efficiency.

* **Environmental Considerations**: Ensure that ducts are protected from extreme temperatures that could affect the performance of electrical and telecom systems. Measures should be implemented to protect against moisture ingress, which can cause short circuits and signal loss.



Fig. 5.11 Key strategies for optimizing electrical and telecom systems

By following these optimization strategies, the electrical and telecom infrastructure at IIT can be made more efficient, reliable, and scalable, supporting the campus's current needs and future growth.

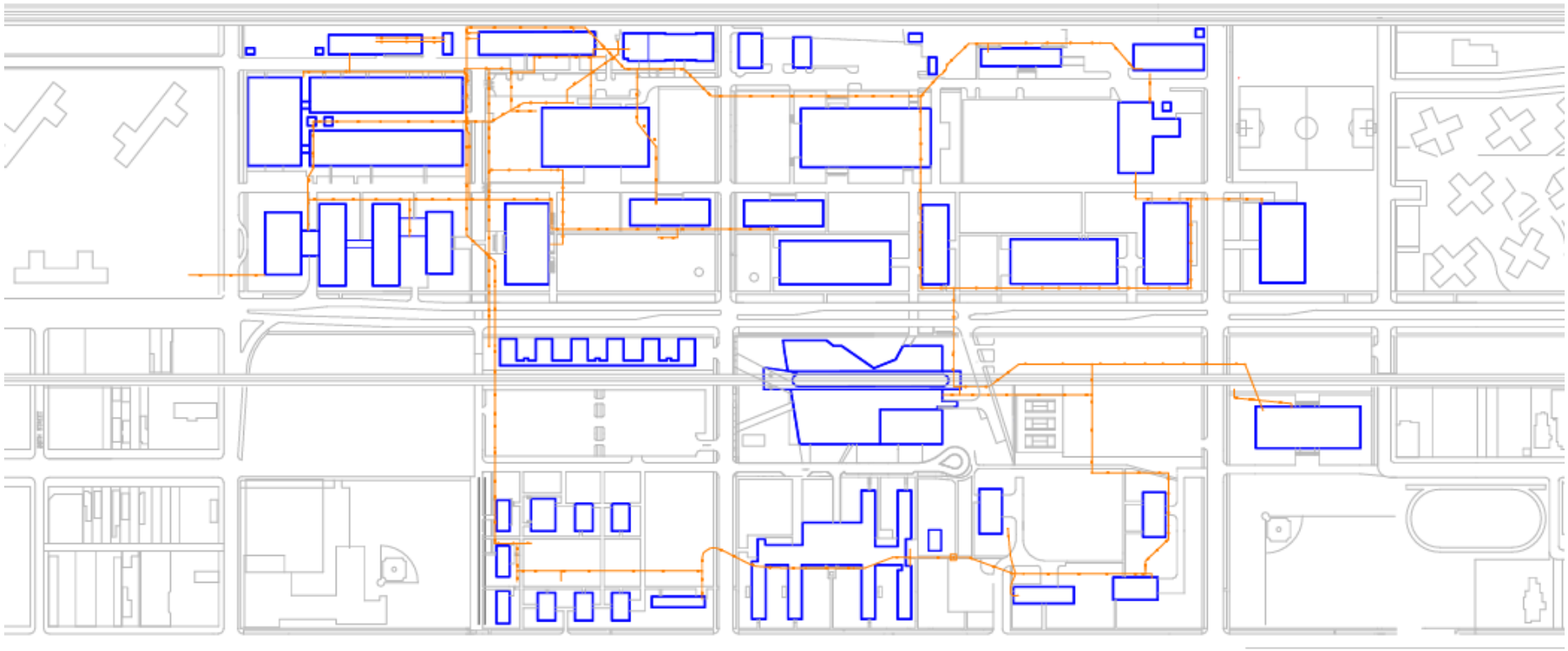


Fig. 5.12 Electrical and Telecom Distribution at IIT

5.5 The Sustainable Development Goals

The Energy Master Plan of the IIT campus plays a crucial role in advancing the Sustainable Development Goals (SDGs), which aim to create a more sustainable and equitable future. These goals focus on addressing global challenges by promoting sustainable practices among businesses and individuals, thereby facilitating a transition to a socially, economically, and environmentally sustainable world.

The development and implementation of the Energy Master Plan contribute significantly to three of the 17 Global Goals established by the United Nations: Affordable and Clean Energy (Goal 7), Industry, Innovation, and Infrastructure (Goal 9), and Responsible Consumption and Production (Goal 12).

5.5.1 Goal 7 - Affordable and Clean Energy

Although access to electricity has improved globally, the rising population is expected to increase energy demand, heightening the risks associated with continued dependence on fossil fuels. The Energy Master Plan addresses this challenge by prioritizing renewable energy investments on the IIT campus. By optimizing the efficiency and uptime of renewable energy systems—such as wind and solar installations—the plan ensures a steady supply of clean energy, significantly reducing the campus's carbon footprint. This initiative is particularly effective in optimizing the performance of renewable energy systems, and its approach could be applied not only across the entire college campus but also in clusters of buildings, significantly enhancing the efficiency and sustainability of energy use in various settings.

5.5.2 Goal 9 - Industry, Innovation, and Infrastructure

Aligned with Goal 9, which emphasizes the importance of resilient infrastructure and technological innovation, the Energy Master Plan promotes advanced solutions that improve energy efficiency and infrastructure resilience across the IIT campus. By incorporating state-of-the-art technologies into the campus's energy systems, the plan addresses both environmental and economic challenges while also supporting job creation within the renewable energy sector. This strategic approach illustrates how targeted infrastructure investments can drive sustainable industrial growth.

5.5.3 Goal 12 - Responsible Consumption and Production

Achieving sustainable development requires reducing the ecological footprint by transforming production and consumption patterns. The Energy Master Plan supports this

goal by promoting the efficient use of natural resources and minimizing waste through sustainable energy practices. By prioritizing responsible energy management and reducing the generation of toxic and polluting byproducts, the plan plays a crucial role in advancing responsible consumption and production on the IIT campus, contributing to a more sustainable and environmentally conscious community.

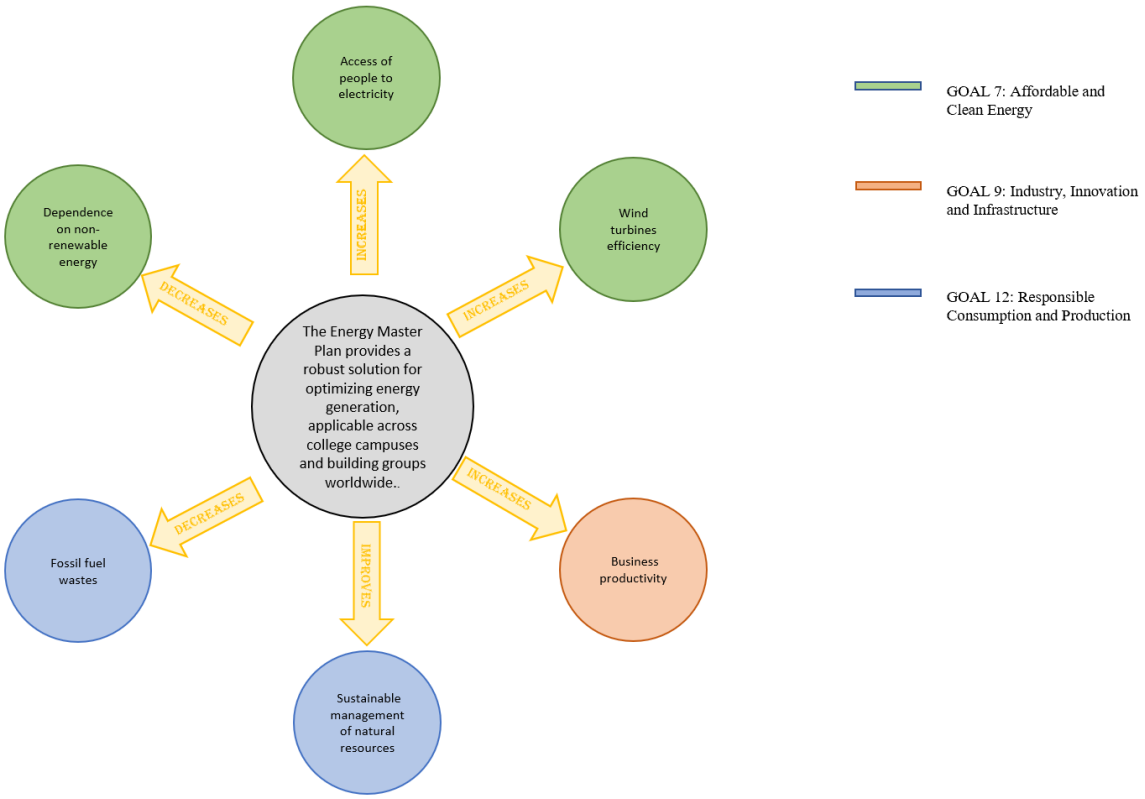


Fig. 5.13 Energy Master Plan Advancing SDG Goals

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