The University of Michigan

Building Efficiency Studies

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Building Efficiency Study Report

PREPARED BY:

SMITHGROUP
500 Griswold Street, Suite 1700
Detroit, Michigan 48226

Project Numbers:11540.000
&12158.000

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SMITHGROUP

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CONTENTS

Art & Architecture Building Energy Efficiency Study

Couzens Residential Hall Building Energy Efficiency Study

Art & Architecture Building Energy Efficiency Study

Executive Summary

Introduction

This initial Building Efficiency Study focused on the original Art & Architecture Building (A&A Bldg.), circa 1971, for strategies to significantly minimize energy use and carbon impacts. Another goal of this study is to set up a high-level effective process that can be repeated across a range of university building types and uses to identify how much energy efficiency can be gained and carbon impacts reduced.

The Art & Architecture Building was evaluated for Energy Conservation Measures (ECM) that were applicable to this type of structure and building use. Note the recent addition, circa 2017, was not included within this study. The Art & Architecture Building houses studio, workshop, lab, classroom, and administrative spaces. ECM strategies included mechanical and electrical building systems, the building enclosure, walls, and roof, as well as various combinations of these same systems. The architectural and engineering team visited the building, collected existing utility data, and reviewed the existing drawings. Their initial task was to determine how the current building is performing to set a benchmark for comparison. Based on the team's review, Art & Architecture Building is a prime candidate for significant renovations that would greatly reduce energy consumption and reduce ongoing carbon impacts. Following the high-level process for the study, a simplified energy model (also known as a shoebox model) was employed to compare the original building energy performance against the proposed ECM energy performance. Shoebox energy modeling is a computer simulation of the built environment that is widely used throughout the architectural and engineering industries.

Scope
The team developed eleven (11) individual ECMs and three (3) combined ECMs. The (11) ECMs include four (4) HVAC (Heating Ventilating Air Conditioning); two (2) electrical and five (5) architectural. Energy and cost were evaluated for each ECM. The following is an overview of each of the ECMs:

HVAC Systems ECMs (Heating, Ventilating, Air Conditioning)
The current Art and Architecture Building mechanical systems include in-building natural gas-fired steam boilers, Dual-Duct air handling systems, and in-building electric centrifugal chiller cooling.

The boilers and air handling systems are considered “high-entropy” systems today, because considerable energy is lost due to heat transfer over high temperature differences (i.e., burning fossil fuel to produce 1,900°F flames to produce 275°F steam to heat spaces to 75°F —when 100°F water would suffice) and moving and mixing disparate air streams (i.e., pushing 100°F Hot Duct air and 55°F Cold Duct air long distances—only to blend them to maintain comfortable temperatures in the occupied areas of the building that today are achievable by other means using far less energy).

The primary ways by which new HVAC systems can reduce energy use and carbon impacts compared to the original systems include: using water or environmentally safe refrigerants to move local cooling/heating energy in lieu of high-horsepower fans, reusing the energy in the building to the extent possible for conditioning outside air and for local heating/cooling in lieu of using only “new” energy sources, and relying on a low-entropy campus system to handle the building’s net heating and cooling loads.

The four HVAC ECM were developed, exploring the most viable and cost-effective options currently available. Note that all the mechanical ECMs assume that a central campus plant is available to provide heating and cooling water. Costs associated with constructing the central plant are not included since a separate team is studying such plants.

- HVAC-1 DOAS, Chilled Beams
    - This ECM is to replace the existing building HVAC systems with Dedicated Outdoor Air Systems (DOAS) for ventilation and Chilled Beams for local cooling and heating.
    - Chilled Beams provide zone-based cooling using chilled water (CHW) coils, and it takes less energy to transport cooling capacity via water than in systems using all air like the existing building HVAC system. The CHW used is at relatively high temperature (typically 58°F) which takes less energy to produce than low-temperature (e.g., 44°F) chilled water and can better leverage central plant services.
    - For heating, the Chilled Beam coils circulate a relatively low temperature (e.g., 100°F) heating hot water, which is compatible with the central plant being

separately studied (anticipating 120°F heating water supply in winter and likely 100°F in summer).
  - Chilled Beams use the pressure of primary air distributed from the DOAS unit to induce room air over the CHW coil. This also reduces energy compared to fan-powered systems.
  - The use of chilled beams allows code-required, conditioned, reduces 100% outside ventilation air to be provided by a separate DOAS, which reduces the amount of transported air to be moved by central fans. The DOAS unit will judiciously use lower-temperature CHW (i.e., 44°F) from the central plant to dehumidify humid outside air.
  - The DOAS also provides better temperature & humidity control, because it can be focused on ventilation air needs and not local heating and cooling needs, and it employs efficient energy wheels to recover in-building energy in lieu of tapping new sources.
  - Additionally, this system is easier to fit into the building ceiling space, since much smaller central system ductwork is required.
  - Modifications to floor and roof structure to support adjacent work will be required.
  - Modifications to the existing roof due to adjacent work will be required.
  - Modifications to the existing ceilings and walls due to adjacent work will be required.
    Modifications to the existing fire suppression system due to adjacent work will be required.

- HVAC-2 DOAS, Chilled Boxes & Chilled Beams
  - This ECM is to replace the existing building HVAC systems with Dedicated Outdoor Air Systems (DOAS) for ventilation, and Chilled Boxes for the majority of local cooling and heating zones but Chilled Beams for small zones.
  - The Chilled Boxes provide the same function as the Chilled Beams in ECM HVAC-1, using the same water temperatures. But they are essentially fan-powered boxes, using efficient, variable-speed, Electrically Commutated Motor (ECM) fans to move air over dry (i.e., sensible cooling-only) local cooling coils, in lieu of induction chilled beams utilizing DOAS supply air.
  - Chilled Boxes cost less to install for mid- and larger-size zones because they provide more cooling per unit vs. chilled beams. Therefore, chilled boxes cover a larger area and less units are required to serve the same area which reduces the overall installation cost. The Chilled Boxes would be used in the studios and large classroom spaces.
  - The DOAS unit would be similar to that in ECM HVAC-1, though slightly smaller, since Chilled Beams in large and high-heat-gain zones often require a bit more DOAS air supply flow to meet room air induction needs than the rooms need for ventilation alone, and local fans in Chilled Boxes eliminate that constraint. As

  - such, the savings in DOAS/ventilation energy is greater than what the local fans consume.
  - Chilled Boxes require more maintenance because of the local fans and filters employed. Modifications to floor and roof structure to support adjacent work will be required.
  - Modifications to the existing roof due to adjacent work will be required.
  - Modifications to the existing ceilings and walls due to adjacent work will be required.
  - Modifications to the existing fire suppression system due to adjacent work will be required.

- HVAC-3 DOAS, Chilled Sails, and Destratification Fans
  - This ECM is to replace the existing building HVAC systems with Dedicated Outdoor Air Systems (DOAS) for ventilation, and Chilled Sails with Ceiling Destratification Fans for local cooling and heating.
  - Chilled Sails plus Destratification Fans couple the radiant cooling and heating effects of a standard radiant ceiling panel with enhanced surface area and an enhanced convective heat transfer component for increased performance and higher comfort.
  - They are like Chilled Beams in that no local fan is required, no local filter is provided, and they are limited in peak cooling capacity.
  - The DOAS system would be the same as for HVAC-2 (i.e., smaller than for Chilled Beams), with ventilation air being the sole factor for sizing.
  - Significantly, however, ceiling destratification fans allow equal or greater occupant comfort because the temperature of the space can be set higher due to the air movement which provides a cooling effect. This slight increase in space cooling temperature saves considerable energy by allowing cooling equipment to work more efficiently.
  - However, chilled sails and destratification fans are not always practical to implement for a given space. Further study during design would be needed to determine the extent of implementation possible. Modifications to floor and roof structure to support adjacent work will be required.
  - Modifications to the existing roof due to adjacent work will be required.
  - Modifications to the existing ceilings and walls due to adjacent work will be required.
  - Modifications to the existing fire suppression system due to adjacent work will be required.

- HVAC-4 DOAS, with Water-Source Variable Refrigerant Flow (VRF) local heating and cooling
    - This ECM is to replace the existing HVAC Building systems with Dedicated Outdoor Air Systems (DOAS) for ventilation, and Variable Refrigerant Flow fan coils for local cooling and heating.
    - The local VRF fan coils will be served by centralized, water-source VRF heat pump units that are connected to the central energy plant warm and cool water systems.
    - Refrigerant is transported between the heat pumps and a network of indoor fan coils equipped with refrigerant coils. The amount of refrigerant to each fan coil is varied to match the heating and cooling load, which is more efficient than on/off type refrigerant control. Sophisticated controls allow heating and cooling energy to be swapped between separate zones to the location needed.
    - This means heating and cooling would be moved between building spaces to the extent possible before excess heating or cooling load must be taken from or added to the central plant systems.
    - In this unique application, net heat rejection from the building (i.e., for a net cooling load) will go to the central plant *heating* hot water return pipe (employing heat pumps' ability to efficiently move heat in a "high-lift," or slightly higher-temperature-output mode), thus helping the central plant *create* a heating resource that other buildings on the central plant system can use year-round.
    - Similarly, net heating demand in the building (i.e., for a net heating load), will be extracted from the central plant *chilled* water return pipe, thus helping the central plant create a cooling resource that other buildings on the central system can use year-round. In effect, this means the central plant warm and cool water systems are only taxed for DOAS loads, while VRF loads are transferred in a way that *reduce* central plant loads.
    - This innovative synergy between building VRF compressors and new central plant energy systems is what boosts this ECM's carbon reduction to a remarkable 77%, versus the base building. (Note, a "low-lift" HVAC-4A option was also considered without this feature, though it was dropped as less effective.)
    - VRF systems are highly engineered systems that use proprietary replacement parts, require more sophisticated maintenance staff, and are less flexible for future architectural modifications.
    - However, their energy and carbon reduction advantages are exemplary.
    - Modifications to floor and roof structure to support adjacent work will be required.
    - Modifications to the existing roof due to adjacent work will be required.
    - Modifications to the existing ceilings and walls due to adjacent work will be required.
    - Modifications to the existing fire suppression system due to adjacent work will be required.

Electrical Systems ECMs (Electrical)

- ELECT-1 PV
    - This ECM is to install a roof-mounted Photovoltaic (PV) system of the maximum practical capacity given the available roof area.
    - The significant benefit of this is that it utilizes the expansive natural asset of the building's flat-roof solar exposure to offset an appreciable portion (close to half) of the renovated building's remaining electrical power needs.
    - It also helps shade the roof from the hot summer sun.
    - PV capacity could also be pursued through photovoltaic carports or at a central plant or an off-site scale, parking lots are subject to becoming future building sites, and central plant projects struggle to access building-based solar assets such as large flat roofs.
    - Existing roof systems modifications including structural reinforcing will be required to support the added weight and repair roof at installation points.
    - Roof tie off protection will be installed to provide permanent safety.
    - Ceilings will be replaced that are impacted by structural reinforcing.

- ELECT-2 LED
    - This ECM is to replace existing light fixtures with improved fixtures equipped with LEDs (Light Emitting Diodes).
    - Energy savings would accrue not only on the basis of slightly higher energy efficiency at the LED *sources* (i.e., compared to LED retrofit components in original fixtures), but in appropriately redesigning the lighting distribution and intensity per current standards and opportunities (i.e., compared to the limitations of the original light fixture types and spatial distribution).
    - New LED systems would also include controls that adjust lighting levels to compensate for daylight and would turn off lights when spaces are unoccupied.
    - Modifications to floor and roof structure to support adjacent work will be required.
    - Modifications to the existing roof due to adjacent work will be required.
    - Modifications to the existing HVAC and fire suppression system due to adjacent work will be required.

Arch Systems ECMs (Architecture)

- ARCH-1 New Curtain wall
  - Replace the existing curtain wall, which meets current energy code performance requirements, with a more energy efficient system. The existing curtain wall accounts for the majority of windows in the building and is typically large expanses of glass on the building. The existing curtain wall system is a single glazed system which preforms worse. A new modern curtain wall will allow the system to lose less heat to the exterior in the winter and will reduce the amount of heat entering the building in the summer.
  - Structure near each window will need to be investigated and modified to allow for the attachment of the new system. This will require selective demolition at each window opening.
  - Adjacent systems such as roofing may need to be repaired if they are integrated into the curtain wall system.
  - Depending on the placement and proximity of Mechanical, Electrical, and Plumbing, some systems may need to be moved or recalibrated due to the area of construction.
  - Interior finishes near the construction area will likely need to be repaired and cleaned.

- ARCH-2 High Performance Curtain Wall
  - Replace the existing curtain wall with a system that is better than current code in performance. As stated in ARCH-1 the existing curtain wall system performs less than a contemporary system. However, for this ECM the curtain wall will be a very high performing system. While ARCH-1 will help reduce the amount of energy to heat and cool the building, this ECM will provide increased energy efficiencies.
  - Similar to ARCH-1 interior finishes, Structural, Mechanical, Electrical, and Plumbing work will be required.

- ARCH-3 High Performance Skylights
  - Replace the existing skylights with high performance glazing. The existing skylights run east-west along corridors and studio spaces. They are uninsulated with single pane glass allowing for additional heat loss during the winter, and heat gain in the summer. Contemporary skylights can now utilize insulating glass and insulation can be added to the frame that connects them to the building and provides a much more energy efficient system.
  - In addition to the additional impacts listed in ARCH-1, there will be additional roofing work required to maintain air and water tightness where the roof meets the skylight.

- ARCH-4 10% Existing Glazing Reduction
  - Remove 10% of building glazing and infill with a solid energy efficient exterior wall system. Glass typically allows more heat gain or loss than a contemporary wall system. While on site it was observed that many of the studios had curtains that were closed, potentially due to too much exterior light entering the space. There were also areas where exterior lighting could be reduced due to the activities that were occurring in that space such as kiln rooms. While it is not recommended to eliminate exterior daylight from any one space, an estimated 10% of glass could likely be reduced from around the building. In the areas where the glass would be reduced, an insulated wall system that does not let any light in would fill the space where the glass originally occurred. This insulated wall system could be spandrel glass or wall infill depending on location of the infill and if the ARCH-5 is selected. By adding this insulated portion of wall, the room will become more comfortable to occupants near the wall and will increase the thermal efficiency of that portion of the wall.
  - The construction of the infill will impact both interior and exterior construction in order to integrate with the existing construction.
  - Main structural elements, Mechanical, Electrical, Plumbing and Roofing, will likely be unaffected as most of the work will be installed in the established opening.

- ARCH-5 Reskin building with new exterior veneer, high performance curtain wall and skylights, and reduce glazing by 10%.
  - The existing wall utilizes common construction practices for the time it was built. This means that the insulation value for the existing wall is quite low. Additionally, the existing building does not have a continuous means to limit the amount of exterior air that can enter the building.
  - Removing the existing brick that is on the building will allow the installation of an air barrier on the existing building. By reducing the amount of air that can come in and out of the building, the mechanical system can heat and cool spaces more efficiently. Air barriers control reduce the air leakage into and out of the building envelope. . The amount of air leakage has a direct influence on the amount of heat that can bypass the insulation. By reducing the amount of air that can come in and out of the building, the mechanical system can heat and cool spaces more efficiently. Additionally, Air Barriers reduce water infiltration into the building and reduce the risk of condensation in the wither, both functions will help protect the existing structure from long term water damage.
  - Removing the brick will also allow new insulation to be installed. Adding new insulation on the exterior of the building will significantly increase the energy efficiency of the exterior wall. This will also make the spaces within the building that are located on an exterior wall more comfortable to the users.
  - Because removing the existing brick is a significant undertaking, and will likely impact the curtain wall framing, it is the perfect opportunity to replace the curtain wall with high performance systems and reducing the amount of glazing.
  - Replacing the skylights with higher performing glass would also be recommended at this time because it would be the last poor performing system on the building envelope.

- This ECM has the potential to have a limited impact to the occupied space within the building during the time of construction. However due to the unknown variables there is a possibility that significant disruption to the occupied space may be required. This level of disruption will not be known until selective demolition of the existing wall has taken place and reviewed by a structural engineer.
- All major systems within the exterior wall will likely be impacted by the ECM including the Structure, Mechanical, Electrical, Plumbing. While not all systems will be impacted the same, the change to the wall is significant, and in field conditions may require the alteration, moving, or recalibrating of these systems.
- In addition to the above grade structural improvements that may be required, there will be structural impacts to the foundation. This will be based on the weight and attachment system of the new exterior wall veneer.
- Roofing and waterproofing will require some modifications to allow the new air and water barrier to integrate with the existing systems. Air and water tightness are critical to the longevity and efficiency of a building, so new systems should be integrated with the existing.
- Due to the extensive construction from the exterior, some site work will be required to remove any damage from the construction.
- This EMC has a lot of unknown variables including the condition of the existing structure and interior part of the existing wall. To capture these unknowns, the following ARCH-5 Alternatives were created. Each address either an aesthetic choice or a structural limitation.
    - ARCH-5 Alt 1 Brick Reskin, High Perf Curtain wall & Skylights, 10% Glazing Reduction
        - Remove existing brick exterior and replace with new energy efficient brick enclosure.
            - By removing the existing brick installation of a continuous air barrier will be much easier. This is because the existing inner wall can be cleaned and repaired to increase the chances of a good installation.
            - Adding insulation to the existing wall will make the system thicker. By removing the existing brick, this additional thickness will be reduced which will likely be easier for the existing structure to accommodate.
            - Installing new brick after the installation of the air barrier and insulation will allow the building to maintain a look that is similar to what it is now and will also increase the thermal performance of the wall assembly.
        - Replace existing curtain wall and skylights (See explanation in ARCH-2-3)
        - Reduce glazing by 10% (See explanation in ARCH-4)
    - ARCH-5 Alt 2 Rainscreen Reskin, High Perf Curtain wall & Skylights, 10% Glazing Reduction

        - Remove existing brick exterior and replace with a rainscreen exterior wall system.
            - This Alt is like ALT 1, however removing the brick gives an opportunity for a wall to be replaced with a system that is aesthetically different from brick. This will not change the thermal performance of the new wall assembly but could change the visual identity of the building.
        - Replace existing curtain wall and skylights (See explanation in ARCH-2-3)
        - Reduce glazing by 10% (See explanation in ARCH-4)
    - ARCH-5 Alt 3 Metal Panel Over Existing Brick, High Perf Curtain wall & Skylights, 10% Glazing Reduction
        - Install insulation and new metal panels over existing brick exterior.
        - Instead of removing the existing brick there is a potential that the brick could be left in place. This will likely reduce the installation schedule.
            - The additional thickness of the wall, caused by keeping the existing brick, will push the weight of the rain screen system out further than previous options. Because the weight will be cantilevered out further from the structure, the system will likely need to be constructed of lighter materials. Allowable weight can be calculated after the structure has been fully evaluated.
        - Replace existing curtain wall and skylights (See explanation in ARCH-2-3)
        - Reduce glazing by 10% (See explanation in ARCH-4)

Three scenarios were then developed where various ECMs were combined to maximize energy use reduction and reduce carbon impacts:

Combined ECMs

ECM Scenario A is the combination of the following three components
- HVAC 2 - DOAS, Chilled Boxes
- ARCH2 - High Performance Curtain Wall
- ELEC 2 – LED
- This ECM reflects a combination of ECMs that the team estimated would typically be done under current UM Design Guidelines during a building renovation

This combined set of ECM will provide energy and CO2 reductions from the existing conditions of 34% energy savings; CO2 reduction of 985 tons/year; Energy Use Intensity (EUI) of /sf 115kBTU/sf a saving of 60kBTU/sf per year and total energy cost saving per year of $92,072

ECM Scenario B is the combination of the following components
- HVAC 4 - VRF (high lift)
- ARCH 5 - Brick Re-skin, High Performance Curtain Wall and Skylights, 10% Glazing Reduction
- ELEC 1 and ELEC 2 - LED, PV

This combined set of ECM will provide energy and CO2 reductions from the existing conditions of 89% energy savings; CO2 reduction of 2,516 tons/year; Energy Use Intensity (EUI) of /sf 19kBTU/sf a saving of 156kBTU/sf per year and total energy cost saving per year of $232,396

This ECM reflects a combination of ECMs selected to produce the maximum reduction in carbon.

ECM Scenario C is the combination of the following components
- HVAC 4 - VRF (high lift)
- ARCH 5 - Brick Re-skin, High Performance Curtain Wall, and Skylights, 10% Glazing Reduction
- ELEC 2 – LED
- This ECM combination is the same as ECM B but with no PV.

This combined set of ECM will provide energy and CO2 reductions from the existing conditions of 77% energy savings; CO2 reduction of 1,646 tons/year; Energy Use Intensity (EUI) of /sf 41kBTU/sf a saving of 134kBTU/sf per year and total energy cost saving per year of $106,745

Opinion of Probable Costs

This study calculates simple payback in years as the difference between the Project Cost divided by the Annual Energy Cost savings. To determine the Project Cost, the team sought to estimate the total cost of the project. In Exhibit 6 – Costs Analysis, the Opinion of Probable Cost (OPC) is an estimate of the construction cost. Construction cost is the amount paid to a contractor (i.e., General Contractor or Construction Manager) to build the project, including the material costs, the labor costs, and the contractor's overhead & profit. Also, because this study seeks to estimate the construction cost for a future project, an allowance was included for material & labor escalation. Given the preliminary nature of this study, a design contingency was included. As noted above, in addition to Construction Cost, there are other expenses that would be necessary to complete any of these potential ECM projects. These additional expenses include things like "Related Construction" (e.g., new/revised utility and City connections, etc.), Owner's contingencies (e.g., Construction Contingency, etc.), professional fees, and miscellaneous expenses. Based on experience with previous projects, the study assumes that other expenses would be 35% of the estimated construction costs. *This 1.35 factor included construction contingency, which is why the OPC notes that it contains 0% for construction contingency.*

The opinion of probable costs may be perceived as high when considering a specific ECM or even a combined ECM. However, the detailed estimate included in the appendix show the extent of construction work that is required for each ECM and the combined ECM scenarios. It should also be noted that the simple paybacks provided here-in assume the existing system(s) do not need to be replaced. This produces long simple paybacks. A comparative example would be replacing your home furnace when not broken solely for the purpose of gaining the benefit of improved energy efficiency. However, during a major renovation, the simple payback would be calculated based upon the cost difference to install a more energy-efficient system verses a system that just meets current energy code requirements, resulting in shorter simple paybacks. The opinion of cost detail includes scope of work beyond just the direct components of the ECM. Other building infrastructure and existing conditions will be affected by the work required to implement the ECM. This includes structural upgrades, roofing repair or replacement, reworking or replacing mechanical, electrical, plumbing components, and replacing interior finishes.

It is also important to highlight what is not included in the project's costs proposed by this study:

- Any improvements beyond those described in the study which does not include improvements to the recent addition completed in 2017.
- Escalation beyond the two years that was included in the estimate. Additional escalation may be appropriate depending on the timeframe for implementation.
- Phasing and/or temporarily other measures to facilitate the continued use and occupancy of the building during construction.
- Any costs to temporally relocate the building occupants, furniture, or equipment.
- Metering and monitoring beyond what is typical for a comparable UM building.

The below tables summarize the Project Cost and Simple Payback for the ECMs listed in the above Scope section.

	ART & ARCHITECTURE INDIVIDUAL ECM STRATEGIES									
	Energy Conservation Measure	**EUI** (kBtu/sf)	**% Energy Savings**	**CO2** (tons/year)	**% CO2 Savings**	**Annual Energy Cost**	**Annual Energy Cost/SF**	**% Cost Savings**	**Project Cost***	**Simple Payback** (Years)
Existing Condition	**NA**	**175**	**-**	**3,251**	**-**	**$ 338,377**	**$ 1.46**	**-**	**-**	**-**
HVAC Systems	**HVAC-1** DOAS, Chilled Beams	**136**	**22%**	**2,566**	**21%**	**$ 270,858**	**$ 1.17**	**20%**	**$ 55,566,000**	**823**
	HVAC-2 DOAS, Chilled Boxes & Chilled Beams	**129**	**26%**	**2,478**	**24%**	**$ 264,866**	**$ 1.14**	**22%**	**$ 54,831,600**	**746**
	HVAC-3 DOAS, Chilled Sails, Destrat Fans	**98**	**44%**	**2,019**	**38%**	**$ 225,756**	**$ 0.98**	**33%**	**$ 58,378,050**	**518**
	HVAC-4 DOAS, Water-Source VRF (high-lift transfer)	**49**	**72%**	**1,910**	**41%**	**$ 275,688**	**$ 1.19**	**19%**	**$ 61,956,900**	**988**
ELECT Systems	**ELECT-1** PV	**153**	**13%**	**2,381**	**27%**	**$ 212,726**	**$ 0.92**	**37%**	**$ 16,152,750**	**129**
	ELECT-2 LED	**173**	**1%**	**3,128**	**4%**	**$ 319,115**	**$ 1.38**	**6%**	**$ 17,346,150**	**901**
ARCH Systems	**ARCH-1** New Curtain Wall	**168**	**4%**	**3,070**	**6%**	**$ 316,423**	**$ 1.37**	**6%**	**$ 18,835,200**	**858**
	ARCH-2 High Performance Curtain Wall	**164**	**6%**	**3,012**	**7%**	**$ 310,565**	**$ 1.34**	**8%**	**$ 22,512,600**	**809**
	ARCH-3 High Performance Skylights	**173**	**1%**	**3,191**	**2%**	**$ 331,494**	**$ 1.43**	**2%**	**$ 4,126,950**	**600**
	ARCH-4 10% Existing Glazing Reduction	**170**	**3%**	**3,137**	**4%**	**$ 325,487**	**$ 1.41**	**4%**	**$ 1,482,300**	**115**
	ARCH-5 - Alt 1 Brick Reskin, High Perf Curtain Wall & Skylights, 10% Glazing Reduction	**141**	**19%**	**2,595**	**20%**	**$ 269,151**	**$ 1.16**	**20%**	**$ 40,729,500**	**588**
	ARCH-5 - Alt 2 Rainscreen Reskin, High Perf Curtain Wall & Skylights, 10% Glazing Reduction	**141**	**19%**	**2,595**	**20%**	**$ 269,151**	**$ 1.16**	**20%**	**$ 39,756,150**	**574**
	ARCH-5 - Alt 3 Metal Panel Over Existing Brick, High Perf Curtain Wall & Skylights, 10% Glazing Reduction	**141**	**19%**	**2,595**	**20%**	**$ 269,151**	**$ 1.16**	**20%**	**$ 38,568,150**	**557**

Natural Gas Rate: $3.40/Mcf
Electricity Rate: $0.086/kWh
*Project Cost based on Walbridge Cost Estimate V2 dated 6/2/2020

Table A: Individual ECM Strategies

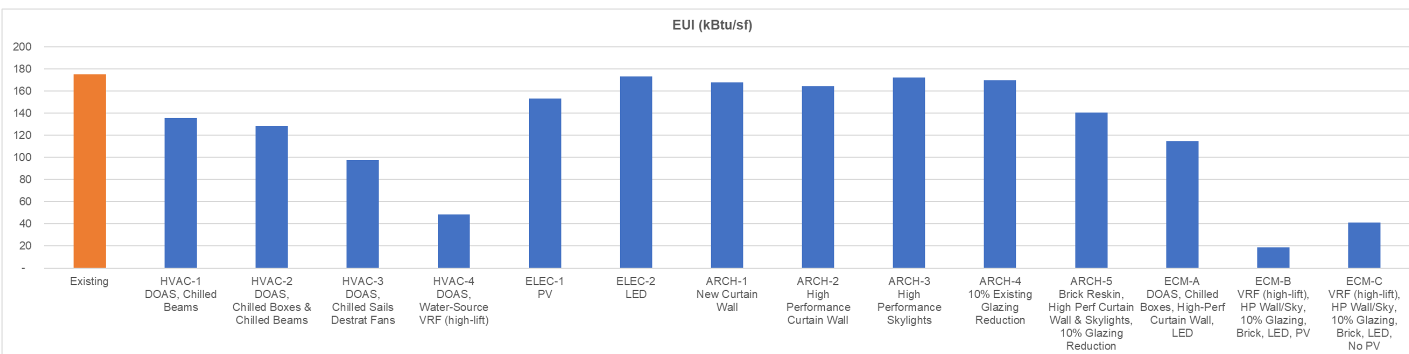
ART & ARCHITECTURE COMBINED ECM STRATEGIES										
Energy Conservation Measure	**Description**	**EUI** (kBtu/sf)	**% Energy Savings**	**CO2** (tons/year)	**% CO2 Savings**	**Annual Energy Cost**	**Annual Energy Cost/SF**	**% Cost Savings**	**Project Cost**	**Simple Payback** (Years)
Existing Condition	Dual Duct AHU, Cooling Towers, Chillers, Steam Boilers, Lighting at 0.8 W/sf, Original Envelope at 0.75 CFM/sf leakage factor	**175**	**-**	**3,251**	**-**	**$ 338,377**	**$ 1.46**	**-**	**-**	**-**
Combined ECM-A HVAC-2, ARCH-2, ELEC-2	DOAS, Chilled Boxes, High-Perf. Curtain Wall, LED	**115**	**34%**	**2,266**	**30%**	**$ 246,305**	**$ 1.06**	**27%**	**$ 87,879,600**	**954**
Combined ECM-B HVAC-4, ARCH-5, ELEC-1, ELEC-2	VRF (high-lift), HP Wall/Sky, 10% Glazing, Brick, LED, PV	**19**	**89%**	**735**	**77%**	**$ 105,981**	**$ 0.46**	**69%**	**$ 114,238,350**	**492**
Combined ECM-C HVAC-4, ARCH-5	VRF (high-lift), HP Wall/Sky, 10% Glazing, Brick, LED, No PV	**41**	**77%**	**1,605**	**51%**	**$ 231,632**	**$ 1.00**	**32%**	**$ 107,558,550**	**1,008**

Natural Gas Rate: $3.40/Mcf
Electricity Rate: $0.086/kWh
*Project Cost based on Walbridge Cost Estimate V2 dated 6/2/2020

Table B: Combined ECM Strategies

A summary of the Shoe Box Energy Model results can be found below, and in Exhibit 5:

EUI (kbtu/sf/yr)	Existing	HVAC-1 DOAS, Chilled Beams	HVAC-2 DOAS, Chilled Boxes & Chilled Beams	HVAC-3 DOAS, Chilled Sails Destrat Fans	HVAC-4 DOAS, Water-Source VRF (high-lift)	ELEC-1 PV	ELEC-2 LED	ARCH-1 New Curtain Wall	ARCH-2 High Performance Curtain Wall	ARCH-3 High Performance Skylights	ARCH-4 10% Existing Glazing Reduction	ARCH-5 Brick Reskin, High Perf Curtain Wall & Skylights, 10% Glazing Reduction	ECM-A DOAS, Chilled Boxes, High-Perf Curtain Wall, LED	ECM-B VRF (high-lift), HP Wall/Sky, 10% Glazing, Brick, LED, PV	ECM-C VRF (high-lift), HP Wall/Sky, 10% Glazing, Brick, LED, No PV
Interior Lighting	7.9	7.9	7.9	7.9	7.9	7.9	5.0	7.9	7.9	7.9	7.9	7.9	5.0	5.0	5.0
Receptacle Equipment	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Space Heating	132.9	101.1	94.3	66.8	13.2	132.9	134.5	128.7	126.1	131.2	129.3	107.1	82.1	10.5	10.5
Space Cooling	7.8	4.9	5.9	4.5	4.5	7.8	7.4	6.5	6.3	7.4	7.2	4.9	6.2	4.1	4.1
Heat Rejection	2.4	1.1	1.3	1.0	0.9	2.4	2.3	2.0	1.9	2.2	2.2	1.5	1.4	0.9	0.9
Interior Central Fans	12.4	6.9	5.8	5.1	5.1	12.4	12.2	10.9	12.3	11.9	11.5	7.8	6.2	5.1	5.1
Interior Local Fans	-	-	0.4	-	4.5	-	-	-	-	-	-	-	0.6	2.9	2.9
Exhaust Fans	1.8	4.4	3.7	3.3	3.3	1.8	1.8	1.8	0.9	1.8	1.8	1.8	4.0	3.3	3.3
Pumps	1.1	0.3	0.3	0.2	0.3	1.1	1.0	0.9	-	1.0	1.0	0.6	0.3	0.2	0.2
PV	-	-	-	-	-	(22.1)	-	-	-	-	-	-	-	(22.1)	-
Total (kBtu/sf/yr)	**175**	**136**	**129**	**98**	**49**	**153**	**173**	**168**	**164**	**173**	**170**	**141**	**115**	**19**	**41**
Savings		**23%**	**27%**	**44%**	**72%**	**13%**	**1%**	**4%**	**6%**	**2%**	**3%**	**20%**	**34%**	**89%**	**77%**
Elec (Mmbtu)	9,530	7,781	7,745	7,000	10,933	4,544	8,717	8,781	8,625	9,306	9,124	7,539	7,366	4,199	9,184
Nat Gas (Mmbtu)	29,916	22,773	21,222	15,029	34	29,916	30,286	28,979	28,391	29,535	29,107	24,112	18,479	47	47
Elec ($)	$ 240,195	$ 196,120	$ 195,217	$ 176,433	$ 275,575	$ 114,544	$ 219,722	$ 221,317	$ 217,391	$ 234,565	$ 229,962	$ 190,019	$ 185,661	$ 105,828	$ 231,479
Nat Gas ($)	$ 98,182	$ 74,738	$ 69,649	$ 49,322	$ 113	$ 98,182	$ 99,393	$ 95,106	$ 93,175	$ 96,929	$ 95,524	$ 79,132	$ 60,644	$ 153	$ 153
Total Energy Cost ($)	**$ 338,377**	**$ 270,858**	**$ 264,866**	**$ 225,756**	**$ 275,688**	**$ 212,726**	**$ 319,115**	**$ 316,423**	**$ 310,566**	**$ 331,494**	**$ 325,487**	**$ 269,151**	**$ 246,305**	**$ 105,981**	**$ 231,632**
Elec (metric tons CO2)	1,663	1,358	1,352	1,221	1,908	793	1,521	1,532	1,505	1,624	1,592	1,316	1,285	733	1,603
Nat Gas (metric tons CO2)	1,588	1,209	1,126	798	2	1,588	1,607	1,538	1,507	1,567	1,545	1,280	981	2	2
Total Carbon (metric tons CO2)	**3,251**	**2,566**	**2,478**	**2,019**	**1,910**	**2,381**	**3,128**	**3,070**	**3,012**	**3,191**	**3,137**	**2,595**	**2,266**	**735**	**1,605**



Project Overview

Existing Floor Plans

Floor plans from the shoebox energy model are shown below. The shoebox model simplifies building geometry and program to rapidly iterate design options. Note that the addition is coded in dark grey because it was not analyzed in the study. Rather, the addition was modeled as an adjacent building for solar analysis.

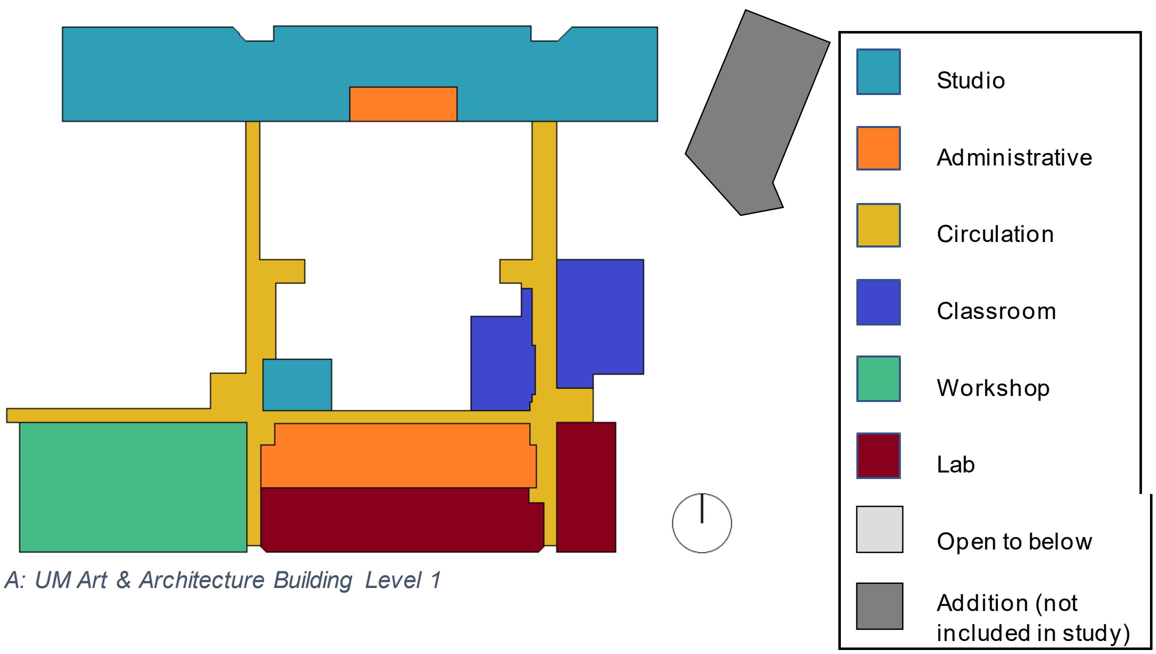
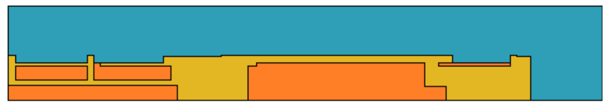


Figure A: UM Art & Architecture Building Level 1



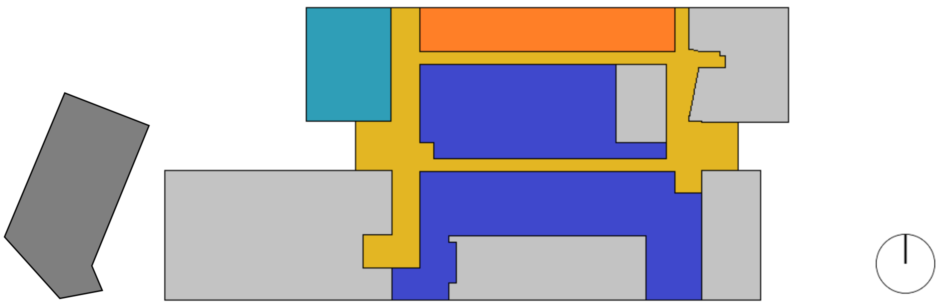


Figure B: UM Art & Architecture Building Level 2

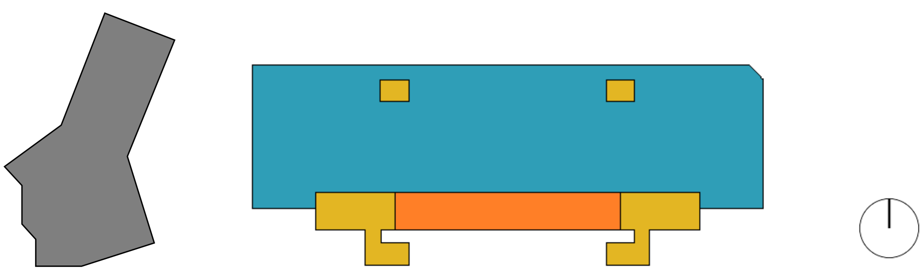


Figure C: UM Art & Architecture Building Level 3

A benchmarking study comparing the energy use intensity (EUI) of buildings of similar program on the University of Michigan Ann Arbor campus reveals that the to the Art & Architecture Building stands in the middle of its peers in terms of energy consumption (See Exhibit 3). However, as measured by the Commercial Buildings Energy Consumption Survey (CBECS), the Art & Architecture Building consumes nearly 50% more energy than the average college/university building in the United States.

Project Goals

Goal 1: Provide high-level energy and carbon assessment for Art & Architecture Building

Goal 2: Provide energy audit and ECM analysis for Art & Architecture Building, in line with UM Plant Blue sustainability goals of reducing greenhouse gas emissions by 25 percent.

> University of Michigan – Ann Arbor Sustainability Goal Reporting Guidelines:
> Goal #1: Reduce Scope 1 & 2 Greenhouse Gas Emissions by 25%
>
> > *"As an institution comprised of nearly 400 buildings covering over 37 million square feet, the University of Michigan (U-M) requires a significant amount of energy to meet the educational, research, and operational needs of the campus. An innovational leader, U-M strives to set the standards for sustainability, both in the classroom and through its physical operations. Announced in the fall of 2011, U-M aims to reduce its scope 1 and 2 greenhouse gas emissions from FY2006 levels by 25% by 2025. Achieving a goal such as this will require the development of new technology, improvement of existing technology, and behavioral changes within the University community."*

Goal 3: Create an assessment framework for other buildings/campus regions

Data Collection and Benchmarking

- Historic Climate Analysis for Ann Arbor – See Exhibit 1.
  - Shoebox model outputs reflect historic climate data
- Future Climate Analysis for Ann Arbor – See Exhibit 2.
- Benchmarking – See Exhibit 3.
- UM Office of Campus Sustainability Energy Database Analysis – See Exhibit 4.

Existing Conditions & Parallel Studies

Existing Conditions

The following assumptions were made as the existing conditions for the UM Art & Architecture Building energy model inputs:

Design Category	Description of Existing Systems	Source
Envelope	Air Tightness: Leaky/Loose (0.75 cfm/sf of envelope) Curtainwall: U-Factor 1.75, SHGC 0.70 Insulated metal panel: R-Value 12 Sloped Roof: R-Value 10 Flat Roof: R-Value 20 Brick Wall: R-Value 3.22 Soffit: R-Value 9.5 Skylights: U-Factor 1.3, SHGC 0.70	System description derived from existing drawings Performance of wall system derived from code compliance at year of construction
Mechanical Engineering	Ventilation: Thirty-eight (38) Constant volume dual duct air handling units Cooling: Two (2) 500-ton cooling towers at 38.2 gpm/ton; Two (2) 350-ton centrifugal chillers (5.2 COP) Heating: Three (3) 7,000-MBH steam boilers at 80% efficiency	System description derived from field observation and historic drawing sets Performance of mechanical system derived from code compliance at year of installation
Electrical Engineering	Lighting: 0.61 W/sf	System description derived from field observation Lighting power density derived from code compliance at year of installation
Schedule	See Exhibit 5	University of Michigan Facilities Representatives

Table: Existing Conditions District Improvements

Integral Group is in the process of creating a district energy master plan, which to date includes:

- Geothermal heat exchange and the reuse of as much building energy as possible
- Low Temperature Hot Water (LTHW(at 120°F for Art & Architecture Building and as many systems as possible (for cooling dominant campuses with ample availability of low-grade thermal energy sources/ sinks (i.e. geo-exchange) and the plant based on single stage lift heat recovery chillers)
- Medium Temperature Hot Water (MTHW) at 145°F would likely be required for campuses with heating dominant demand and more constrained availability of low-grade thermal energy sources/ sinks requiring two-stage lift HRCHs
- High Temperature Hot Water (HTHW) at 180°F would likely be required for the Central Campus where availability of low-grade thermal energy sources is limited. This will require combustion-based plant using biofuels.

Analysis

Included in Analysis

The following were included in the building energy analysis:

- Basic building geometry and programming
- Mechanical systems per existing drawings and code compliance at year of installation[1]
- Lighting systems per existing drawings and code compliance at year of installation
- Envelope per existing drawings and code compliance at year of installation
- Plug load, lighting, people, and mechanical equipment schedules per University of Michigan input

Excluded from Analysis

The following were excluded from the building energy analysis:

- Load shedding: Energy benefit of load shedding is generally understood and is intended to be part of the design process rather than analysis
- Change of occupancy and scheduling: Building upgrades preferred to have minimal impact on curriculum
- Process loads: Process loads are not sub-metered; therefore, a realistic assumption could not be provided. Additionally, it is assumed process load will not change with future building upgrades.

[1] For example, actually efficiency of newly-replaced steam boilers unknown, but modeled at 80% per 2012 (year of installation) energy code

ECM Summary

	ART & ARCHITECTURE ECM SUMMARY									
	Energy Conservation Measure	Description	Energy Reduction Potential	Carbon Reduction Potential	Central Plant Integration	First Cost	Life Cycle Cost	Comfort / Productivity Value	Disruption and Relocation	Exterior Elements Committee
HVAC Systems	**HVAC-1** DOAS, Chilled Beams	Minimize fan energy for Chilled Beam / Box system approach	Medium	Medium	Uses 120F HHW, 45F CHW	$$$	$$$	++	+++	-
	HVAC-2 DOAS, Chilled Boxes & Chilled Beams	Maximize investment while gaining viable separation of ventilation and cooling loads	Medium	Medium	Uses 120F HHW, 45F CHW	$$$	$$$	++	+++	-
	HVAC-3 DOAS, Chilled Sails, Destrat Fans	Maximize local cooling efficiency by reducing fan load and raising comfortable space temp	High	High	Uses 120F HHW, 45F CHW	$$$	$$	+++	+++	-
	HVAC-4 DOAS, Water-Source VRF (high-lift transfer)	Connect to and assist Central Plant by moving heat into HHWR for cooling, and removing heat from CHWR for heating	Very High	High	Helps Make 120F HHW, 45F CHW	$$$	$$$	+	+++	-
ELEC Systems	**ELECT-1** PV	Practical Maximim Rooftop Photovoltaic Panel capacity	Medium	Medium	Microgrid Potential	$	$	++	-	-
	ELECT-2 LED	Redesign interior lighting and lighting control systems complete with space utilization function	Low	Low	NA	$	$$	-	+	-
ARCH Systems	**ARCH-1** New Curtain Wall	Remove existing Curtain Wall system and replace with standard two pane glazing with contemporary Low-E coating	Low	Low	NA	$$	$$$	++	++	+
	ARCH-2 High Performance Curtain Wall	Remove existing Curtain Wall system and replace with three pane glazing with contemporary Low-E coating	Low	Low	NA	$$	$$$	+++	++	+
	ARCH-3 High Performance Skylights	Remove existing skylight system and replace with standard two pane glazing with contemporary Low-E coating	Low	Low	NA	$	$$$	+	++	+
	ARCH-4 10% Existing Glazing Reduction	Reduce the square footage of exterior glazing based on building utilization	Low	Low	NA	$	$	-	++	+
	ARCH-5 Brick Reskin, High Performance Curtain Wall & Skylights, 10% Glazing Reduction	Remove existing face brick and install new air/water barrier. Install new high performance Curtain Wall and Skylights.	Medium	Medium	NA	$$$	$$$	+++	+++	+

Table C: ECM Summary

Description of Energy Conservation Measures

ECM HVAC-1:

Replace existing heating, ventilating, and air conditioning (HVAC) systems in original building with dedicated outdoor air systems (DOAS) units and chilled beams, operating with 42-44°F chilled water for DOAS in dehumidifying season, 58°F for chilled beams (ideally a separate, year-round service from central plants), and heating hot water at 120°F (central plant targeted supply temperature). Reuse medium-pressure duct mains (cold, hot) as feasible, typical for all HVAC ECMs

- Energy Reduction – separates ventilation and temperature control, cuts reheat load
- Carbon Reduction – commensurate with energy reduction
- Comfort Enhancement – comfort and productivity increase due to supply air temperature being closer to room air temperature

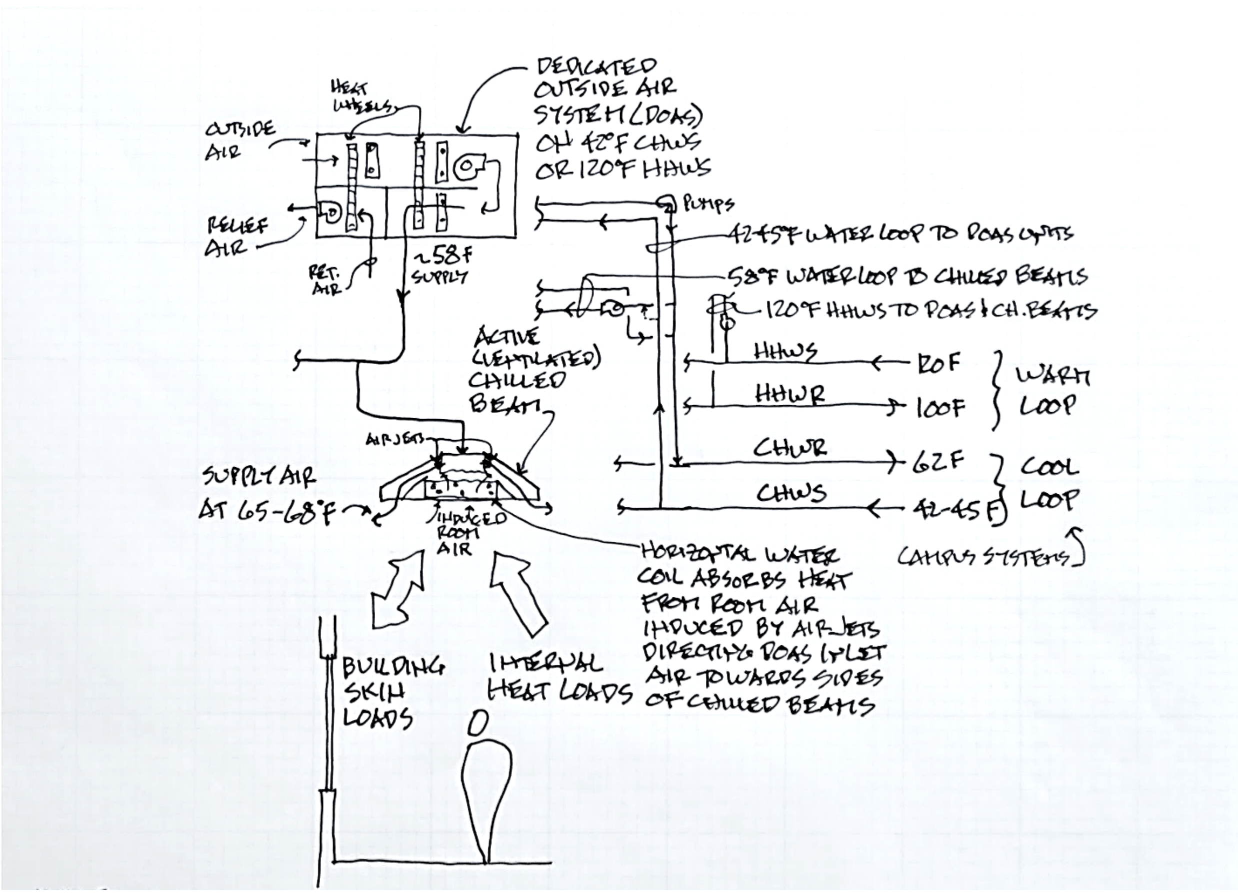


Figure D: HVAC ECM-1

ECM HVAC-2:

Replace existing HVAC systems with DOAS units and chilled boxes for larger areas and chilled beams for smaller areas (e.g., individual offices or small huddle rooms), operating with 42-44°F chilled water for DOAS, 58°F for chilled beams, and heating hot water at 120°F. More effective in first cost, fewer units overhead.

- Energy Reduction – similar to HVAC-1, slightly higher local fan load
- Carbon Reduction – commensurate with energy reduction
- Comfort Enhancement – comfort and productivity increase due to supply air temperature being closer to room air temperature

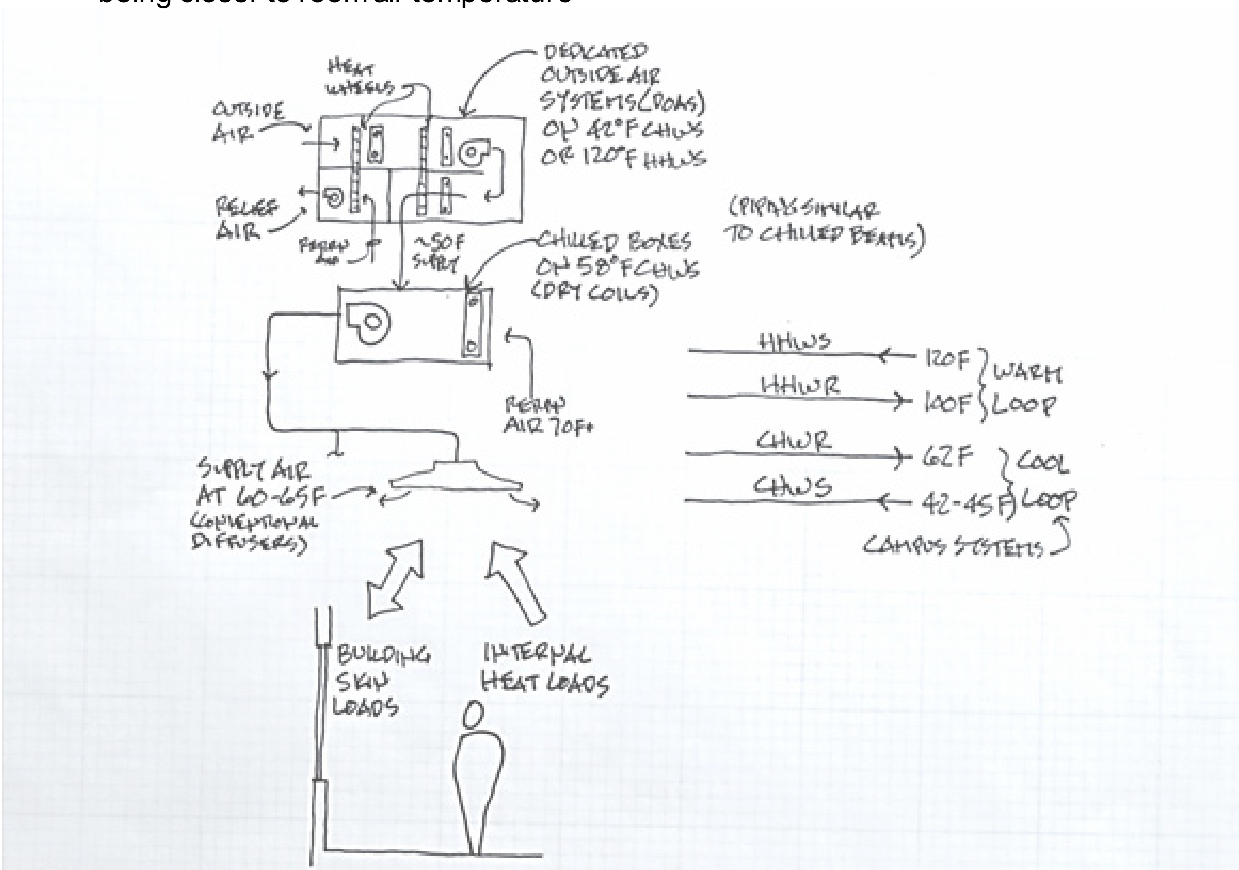


Figure E: ECM HVAC-2

ECM HVAC-3:

Replace existing HVAC systems with DOAS units and chilled sails/radiant panels/passive chilled beams and destratification fans, operating with 42-44°F chilled water for DOAS, 58°F for chilled sails, and heating hot water at 120°F, with chilled sails minimizing pump energy and destratification fans further reducing central plant energy, both by augmenting chilled sail heat transfer and accommodating significantly warmer summer dry-bulb setpoints with the associated adiabatic cooling effect.

- Energy Reduction – highest reduction, given less fan load and higher space dry bulb
- Carbon Reduction – highest
- Comfort Enhancement – highest, air temperature close to room temperature, plus radiant temperature control

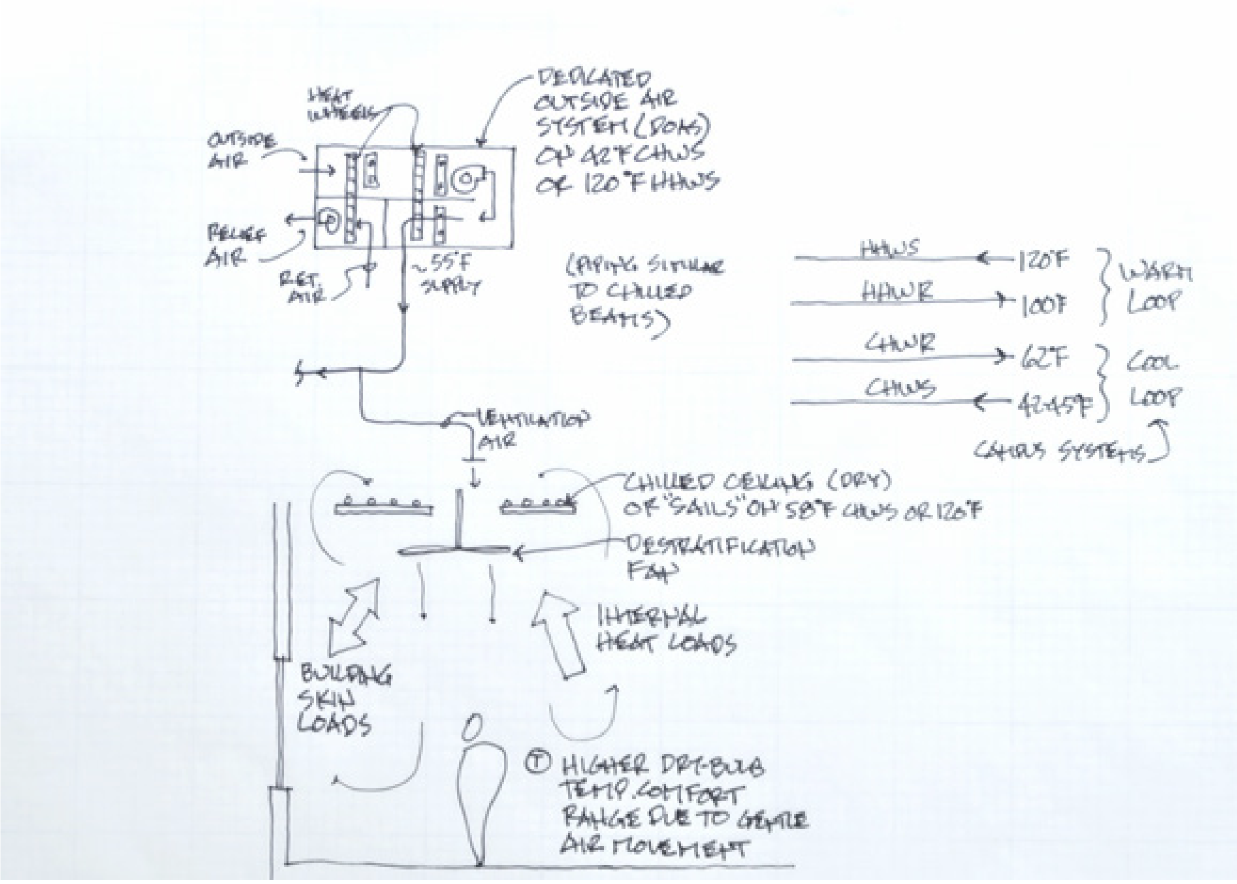


Figure F: ECM HVAC-3

ECM HVAC-4:

Replace existing HVAC systems with DOAS and water-source variable refrigerant flow (VRF) systems, with a net-energy building water loop that recirculates heat within the building, then rejects excess heat in summer to the return side of the heating hot water site system (with that system possibly operating at lower temperatures in summer at 90°F heating hot water return), and takes heat in winter from the return side of the chilled water site system at 58°F. This presents the central plant with a negative load in both seasons, while avoiding dual-compression effects between buildings and plants. Domestic hot water heating is accomplished with a conventional or trans-critical CO2 heat pump, also working off of the chilled water return. It also increases building resiliency, in that it can operate off of either warm or cool loop from the central plant if one is built before the other, or one goes down.

- Energy Reduction – with the stated goal being to “see how far building loads can be reduced,” this approach drops them to below zero (i.e., actually helping the central plant, as seen from the central plant warm loop and cool loop).
- Carbon Reduction – commensurate with energy reduction
- Comfort Enhancement – comparable to variable air volume (VAV) system

ECM HVAC-4A (low-lift heat rejection to the “easy” campus loop was considered only to understand the EUI delta compared to the high-lift approach of HVAC-4)[2]:

Replace existing HVAC systems with DOAS and water-source VRF systems, with a net-energy building water loop that recirculates heat within the building, then rejects excess heat in summer to the return side of the chilled water site system at 58°F, and taking heat from the heating hot water return system at 100°F, presenting the central plant with the next best thing to negative loads, that being not using any supply water capacity for either system, only return water, which increases Central Plant Coefficients of Performance. Domestic Hot Water is heated with a trans-critical CO2 heat pump, working off of the chilled water return.

- Offers the same phasing- and redundancy-based resiliency as ECM HVAC-4.
- Energy Reduction – strong at building level and at central plant level
- Carbon Reduction – commensurate with energy reduction
- Comfort Enhancement – comparable to VAV system

[2] Energy and costing analysis for HVAC-4A not included in study due to large deficit in energy savings compared to HVAC-4

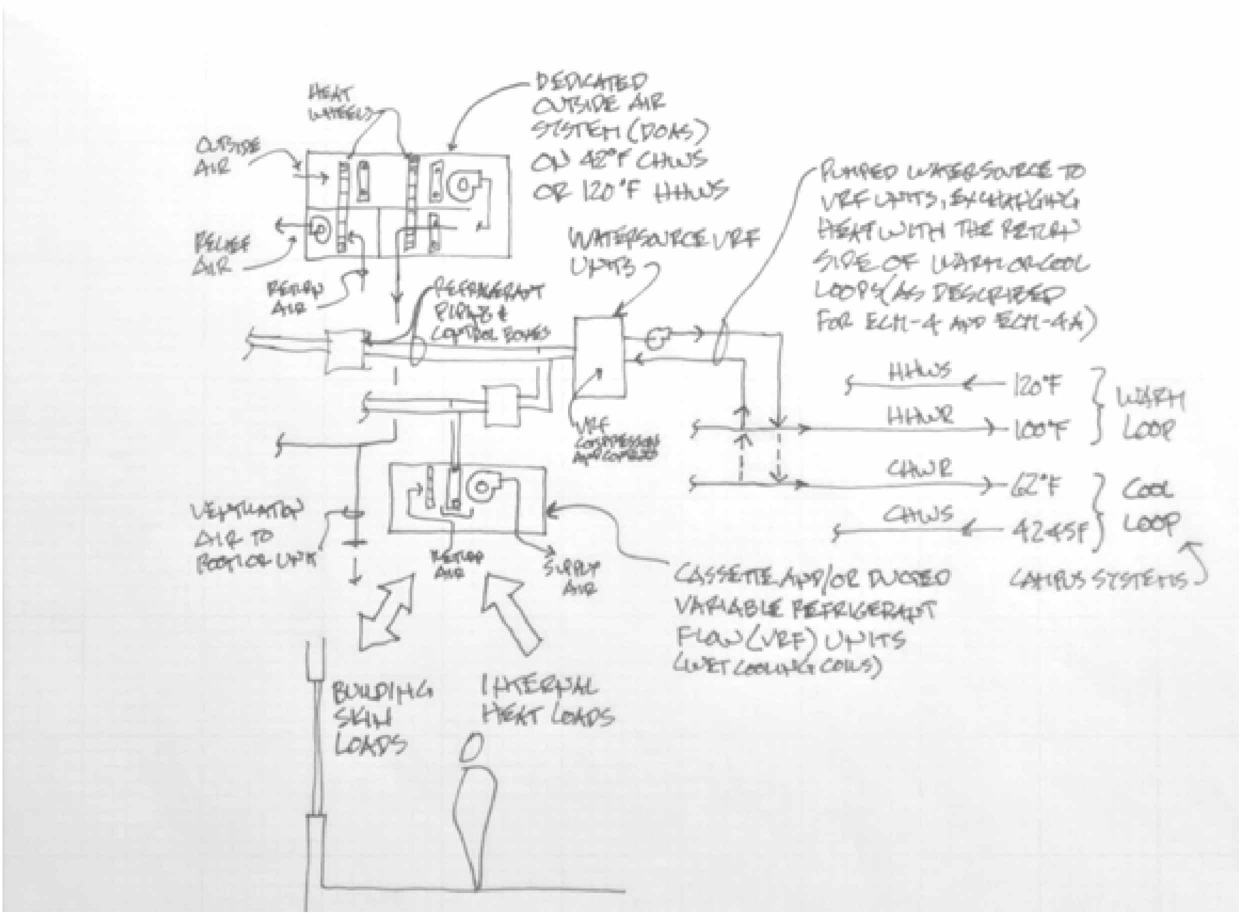


Figure G: ECM HVAC-4,4A

ECM ARCH-1:

Replace existing curtain wall with standard systems that meet code requirements. Glazing will utilize double pane glazing with one low emissivity (Low-E) coating and filled with air.

- U-Factor 0.38
- SHGC 0.23

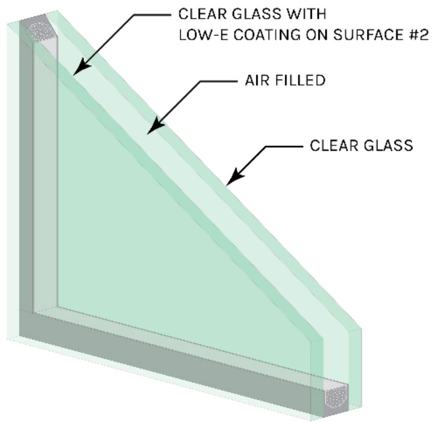


Figure H: ECM ARCH-1

ECM ARCH-2:

Replace existing curtain wall with high performance systems. Gazing will utilize triple pane glazing with two Low-E coatings filled with argon.

- U-Factor 0.24
- SHGC 0.20

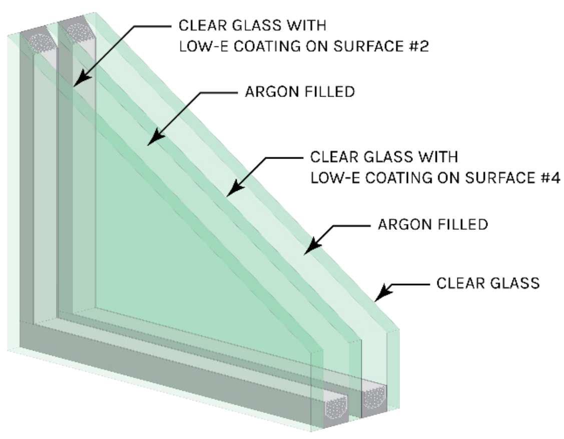


Figure I: ECM ARCH-2

ECM ARCH-3:

Replace existing skylight system with high performance systems. Glazing will utilize double pane gazing with one Low-E coating and argon. Glazing system can be tuned per elevation and program.

- U-Factor 0.35
- SHGC 0.23

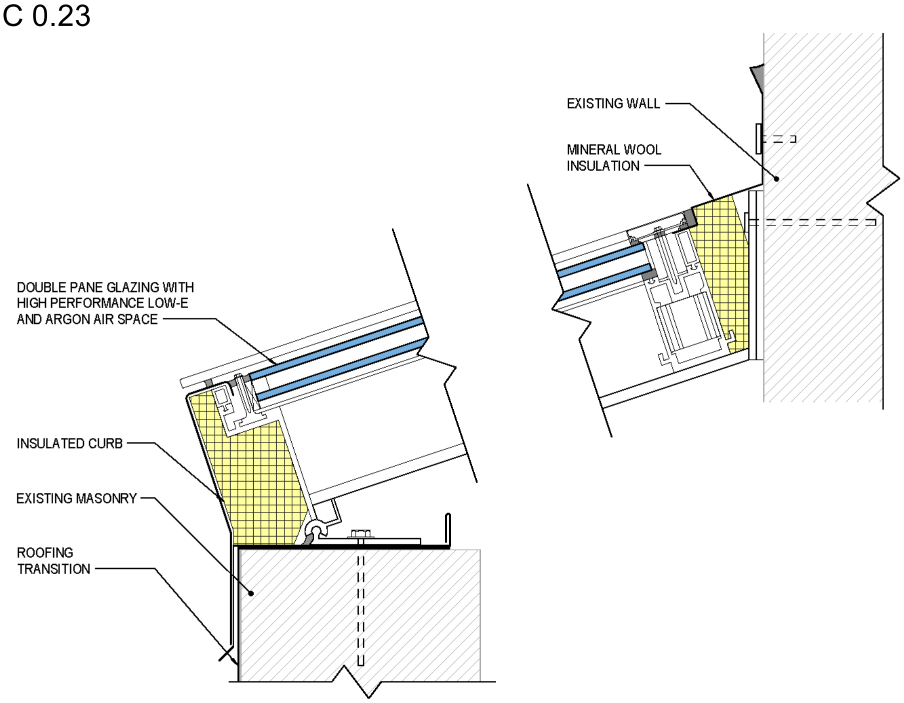


Figure J: ECM ARCH-3

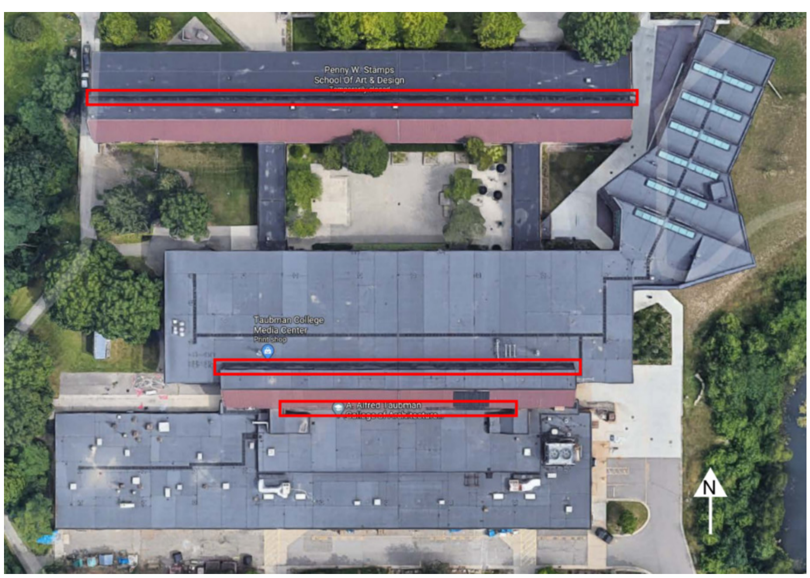


Figure Q: Location of Skylights

ECM ARCH-4:

Reduce the square footage of exterior glazing based on building utilization.

- A 10% reduction in window area minimum is estimated based on observations and existing glazing performance. This percentage could increase based on future space utilization and planning strategies.

If ARCH-4 is selected alone it is assumed that the infill will be a glazing spandrel and will perform similar to the existing opaque wall assembly.

If ARCH-4 is selected with ARCH-5 infill will be similar to that of the new wall assembly.

- A 10% reduction of glazing when combined with ARCH-5 will also be a reasonable minimum. While glazing will appear clearer, the visible light transmission will be comparable to what is currently installed.

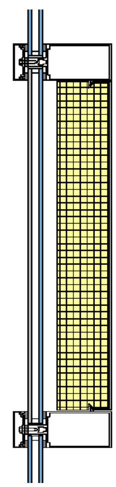


Figure R: ECM ARCH-4

ECM ARCH-5:

Total reskin or over clad above grade wall systems

All reskin/over clad options target the same performance

- Effective opaque wall assembly R-Value 20.
- Increase air tightness of building from an estimated 0.75 cfm/sf of envelope to 0.56 cfm/sf of envelope.

All reskin/over clad options will also include the following ECMs.

- Replace existing curtain wall with the system described in ECM ARCH-2.
- Replace existing skylights with system described in ECM ARCH-3.
- Optimize window to wall ratio per ECM ARCH-4.

No work to existing roof system except for the tie in for new air barrier system. Connecting the new air barrier system to existing systems is critical to maintain air and water tightness of the envelope.

Alternative Architectural ECMs:

The following are three (3) alternate methods of constructing ECM ARCH-5. Selection between these alternates will require intrusive investigation of existing systems to determine feasibility of each. The condition of the existing structure and its capacity is an unknown variable. It is possible that additional structure will be required to support the installation. Ideally existing concrete masonry unit (CMU) walls will remain in place; however, additional structure may require CMU to be partly or fully removed. The selection of which alternate will affect schedule, disruption, and cost, but energy efficiency will be the same for all three alternates.

Alternative 1 – Remove existing enclosure and reskin building with brick.

- Inspect and repair existing CMU and floor slabs. Evaluate for structural capacity to determine if brick ledges and lintels can be adequately supported and that existing CMU can resist wind loads per current code.
- Install vapor permeable fluid applied air barrier on prepared surface of CMU. Tie new air barrier system into existing roof and below grade systems.
- Install new brick ledges and lintels to accommodate deeper brick cavity.
- Install 3.5” of extruded polystyrene ultra-insulation.
- Install new brick.

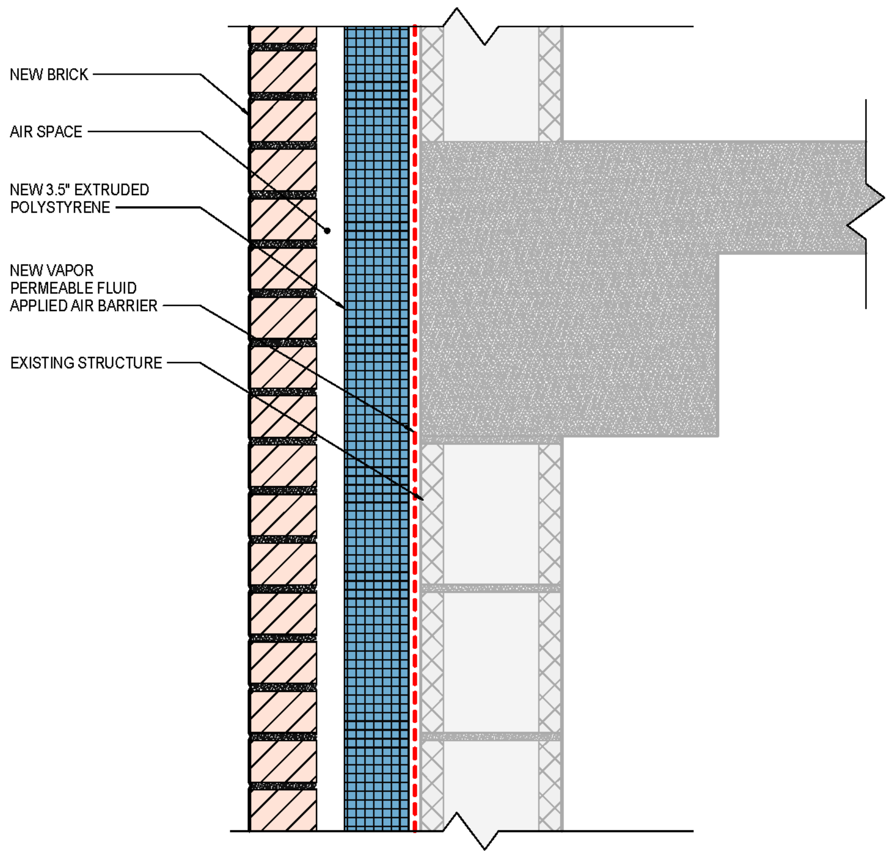


Figure S: Architectural Alternative 1

Alternate 2 - Remove existing enclosure and reskin with alternate rainscreen veneer.

- Remove existing brick.
- Inspect and repair existing CMU and floor slabs. Evaluate for structural capacity to determine if CMU can resist wind loads per current code in addition to the rainscreen deadload.
- Install thermally broken clips and rails required for supporting veneer. If CMU is determined to not have the capacity to support the veneer, additional structure supported by the building's main structural system may be required.
- Install vapor permeable fluid applied air barrier on prepared surface of CMU. Tie new air barrier system into existing roof and below grade systems.
- Install 4.5" of mineral wool insulation.
- Install new veneer such as aluminum composite panels.
- If a heavy weight veneer is desired, sizing of structure will likely become more substantial.

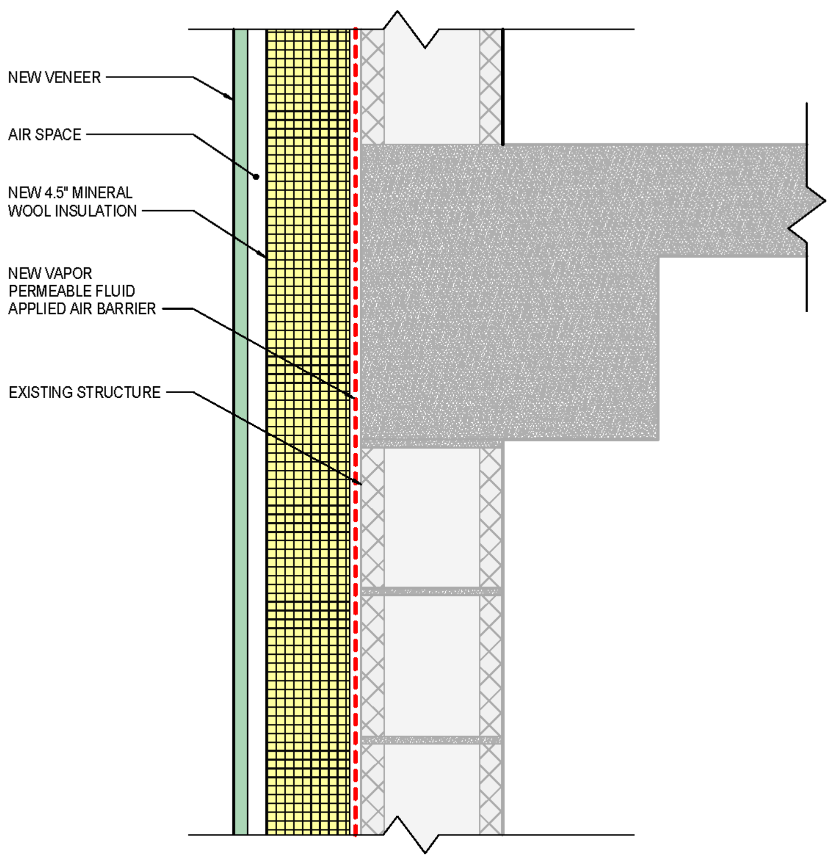


Figure T: Architectural Alternative 2

Alternate 3 – Leave existing brick in place and provide over cladding

- Inspect and repair existing brick. Evaluate brick, CMU, and floor slabs to determine if they can resist wind loads per current code in addition to the rainscreen deadload.
- Install brick stabilization ties as required.
- Install vapor permeable fluid applied air barrier. Tie new system into existing roof and below grade systems.
- Install thermally broken clips and rails
  - If brick and CMU is determined to not have the capacity to support the veneer, additional structure supported by the building's main structural system may be required. Selective removal of brick may be required for attachment of this system.
- Install 4.5" of mineral wool insulation.
- Install new veneer such as aluminum composite panels.
- If a heavy weight veneer is desired, sizing of structure will likely become more substantial.

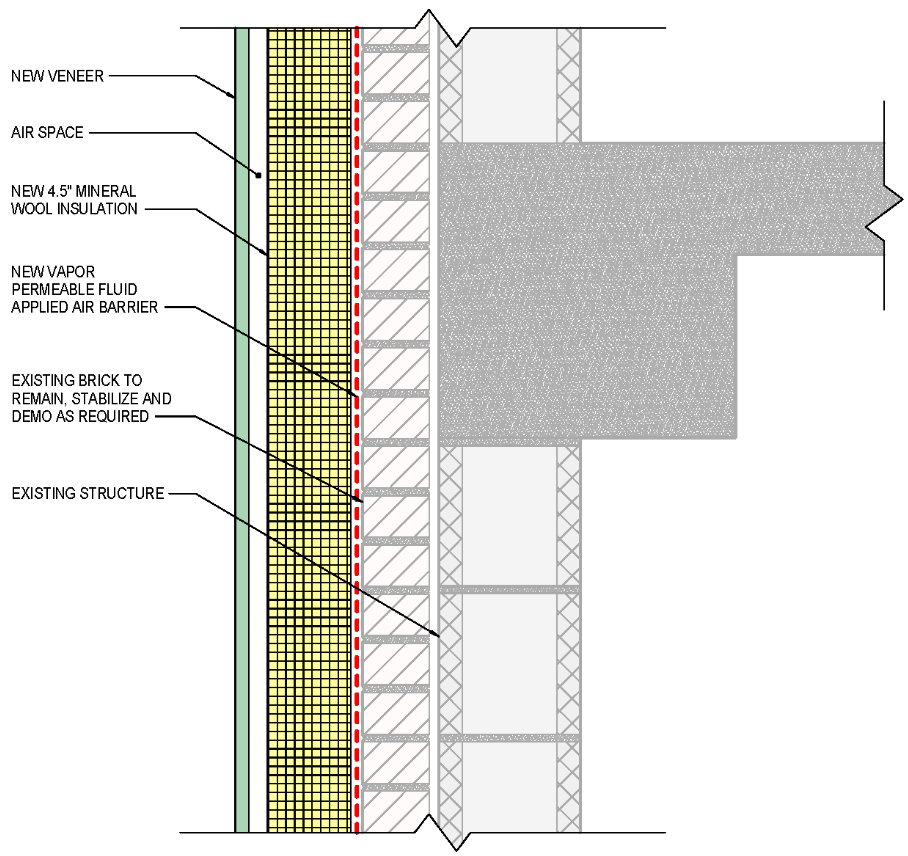


Figure U: Architectural Alternative 3

ECM ELEC-1:

Maximize photovoltaic (PV) capacity on the Art & Architecture roof, which offers large and flat rectangular areas and south-sloped areas. A dramatic reduction in EUI is expected, since this is only a 2 & 3-floor building, begging for a show-case opportunity.

- The PV system shall include provisions for fall protection to allow the array to be closer to the roof edge.
- Some of the existing mechanical equipment will be removed or relocated to maximize roof area for PV array.
- The sloped metal roofs (two locations) will be replaced with new standing seam metal roofs and covered in PV modules.
- The PV array size/rating would be 1.25 MW dual tilt, ballast mounted array with string inverters.

Figure V: ECM ELEC-1

ECM ELEC-2:

Remove all existing lighting fixtures and replace with new high-efficacy light-emitting diode (LED) lighting fixtures and controls. We envision a comprehensive review of both quality and quantity of fixtures paired with network lighting controls, vacancy sensors and daylight harvesting sensors. Therefore, this is not just a one-for-one fixture replacement.

- ASHRAE Standard 90.1-2013 (Energy Standard for Buildings Except Low-Rise Residential Buildings) allowance for a school/university building is 0.87 W/SF.
- Target lighting power density (LPD) for the renovated building would be 30% below the ASHRAE 90.1 allowance or 0.61 W/SF.
- Energy Reduction – Slight improvement over existing LEDs
- Carbon Reduction – Slight improvement over existing
- Comfort Enhancement – Opportunity for further enhancement and performance

Combined ECMs
The following is a combination of aforementioned ECMs that were modeled for energy and cost analysis:

Combined ECM-A

- ECM HVAC-2: DOAS, Chilled Boxes
- ECM ARCH-2: High-Perf. Curtain Wall
- ECM ELEC-2: LED

Advantages/Disadvantages:

The chilled box system has the advantages of hydronic piping and fan terminals with dry coils, which require only conventional maintenance. It relies primarily on large equipment in central plants and significant pumping between building and plant, which concentrates equipment replacement to fewer locations, but requires significant pumping between the plant and building to do so. (The DOAS aspect is similar for each of the combined ECMs.)

New lighting fixtures and controls improve not only energy performance, but also functional light levels throughout the facility for improved occupant comfort. Daylight harvesting controls will dim and/or turn lighting off when sufficient daylight is present.

Replacing the curtain wall is less invasive than other architectural ECMs. It will provide a higher level of human comfort near vertical glazing systems along with the energy benefits, but increased performance will affect a smaller percentage of the exterior envelope when compared to ECM ARCH-5.

Combined ECM-B

- ECM HVAC-4: VRF (high-lift)
- ECM ARCH-5 (note this includes window [ECM ARCH-2] and skylight [ECM ARCH-3] replacement): High Performance (HP) Wall/Sky, 10% Glazing, Brick
- ECM ELEC-2: LED
- ECM ELEC-1: PV

Advantages/Disadvantages:

Generally, a VRF system requires skilled maintenance and may warrant costly system updates at times of building renovations. This VRF system performs more refrigeration locally, which has the advantage of more granular management/synergy in heat transfer, less pumping between building and central plant, relying on the central plant only for net energy transfer, in a unique way that the plant sees as reducing its load rather than increasing it. However, VRF suppliers include some proprietary differences, they require extensive local refrigeration piping, more locations to address in an end-of-life condition, and the potential for more regulation of refrigerant.

A photovoltaic (PV) system provides an on-site renewable source of energy with a large reduction in EUI. The proposed racking would be a ballast system to avoid roof penetrations. The PV would require little annual maintenance. The downside of PV is the high initial cost.

Replacing the entire building skin is highly invasive, and there are many unknowns related to the condition of the existing structure, but replacing the skin will provide a building that has a higher resistance to air and water infiltration with very strong energy benefits.

Combined ECM-C:

- ECM HVAC-4: VRF (high-lift)
- ECM ARCH-5 (note this includes window [ECM ARCH-2] and skylight [ECM ARCH-3] replacement): HP Wall/Sky, 10% Glazing, Brick
- No PV

Advantages/Disadvantages:

Generally, a VRF system requires skilled maintenance and may warrant costly system updates at times of building renovations. This VRF system performs more refrigeration locally, which has the advantage of more granular management/synergy in heat transfer, less pumping between building and central plant, relying on the central plant only for net energy transfer, in a unique way that the plant sees as reducing its load rather than increasing it. However, VRF suppliers include some proprietary differences, they require extensive local refrigeration piping, more locations to address in an end-of-life condition, and the potential for more regulation of refrigerant.

Replacing the entire building skin is highly invasive, and there are many unknowns related to the condition of the existing structure, but replacing the skin will provide a building that has a higher resistance to air and water infiltration with very strong energy benefits.

Life Cycle Cost

The Life Cycle Cost (LCC) Analysis is a very high-level study intended for comparison purposes. It is a method for assessing the total cost of ownership in present value terms which takes into account all costs of acquiring, owning, and disposing of a building or building system. Important information regarding cost model content and assumptions is listed below:

- 1.35 Factor utilized for soft costs to convert estimated construction costs into project costs; construction contingency is part of 1.35 factor
- Estimates include 5% for construction escalation per year for two years
- Suggested 2.5% inflation rate (UM) for the duration of the payback period replaced with US Department of Energy Escalation Projections (Exhibit 7)
- Estimates assume UM Cost of Money at 3%, this is the estimated average cost of borrowing.
- Current campus utility rates.
  - Natural Gas Rate: $3.40/Mcf
  - Electricity Rate: $0.086/kWh
- 30 Year lifespan of all equipment, with a project start date of 2022
- Estimates exclude maintenance costs associated with systems upgrades
- Estimates assume General Contractor format for construction
- Estimates assume no relocation
- Estimate assumes building is fully vacated throughout renovation
- Estimate should be understood as high-level and for comparative purposes; not for project use

ECM-A:

- Project Cost = $87,879,600
- Total Life Cycle Cost = $95,848,168 (Refer to Exhibit 8 for detailed analysis)
- Risk: The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion. The system concepts are known proven systems that mitigates the risks associated with the energy and performance evaluations.

ECM-B:

- Project Cost = $114,238,350
- Total Life Cycle Cost = $120,530,681 (Refer to Exhibit 8 for detailed analysis)
- PV Maintenance: The local climate experiences enough precipitation to self-clean the PV modules and periodic cleaning/washing is not required. An annual inspection of the system is recommended. The annual inspection includes visually inspecting modules, inverters, wiring and other balance of system (BOS) components. Replacing deficient components, tightening wiring connections and removing debris in and around the array are some of the tasks that may be required to maintain the system. Overall, maintenance costs for an annual inspection should be approximately $4,000.

- Risk: The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion. The new enclosure system with this option includes more risk associated with unforeseen existing conditions regarding the integrity of the existing structural system that could support the new enclosure.

ECM-C:
- Project Cost = $107,558,550
- Total Life Cycle Cost = $115,744,291 (Refer to Exhibit 8 for detailed analysis)
- The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion. The new enclosure system with this option includes more risk associated with unforeseen existing conditions regarding the integrity of the existing structural system that could support the new enclosure.

Life Cycle Cost Summary (1)			
Energy Conservation Measure	**Project Cost**	**Life Cycle Cost**	**Total CO2 (3)**
Existing Bldg. Condition	-	(2)	97,530
ECM-A	$87,879,600	$95,848,168	67,980
ECM-B	$114,238,350	$120,530,681	22,050
ECM-C	$107,558,550	$115,744,291	48,150

(1) 30-year life cycle
(2) Not provided as not comparable to ECM A, B, C.
(3) 30-year total CO2 emissions in tons (lower values are better). An approximation provided for comparative purposes only; does not adjust for reductions in CO2 emissions associated with DTE electricity production anticipated to occur over the 30-year period.

Couzens Residence Hall Building Energy Efficiency Study

Executive Summary

Introduction

This study was commissioned by the President's Commission on Carbon Neutrality (PCCN) to evaluate the existing Couzens Residential Hall (Couzens), circa 1926 with a major renovation in 2011, and identify Energy Conservation Measure (ECM) strategies to reduce energy demand and associated carbon emissions as low as possible. The design team started by visiting the building, collecting existing utility data, and reviewing the existing drawings. Their initial task was to determine how the current building was performing, to set a benchmark for comparison. Due to the major renovation in 2011 and potential future renovations to the site utilities, the team analyzed several approaches for Couzens that could be applied to similar building types that may not have had a recent renovation.

Then the team developed nineteen (19) individual ECMs, and six (6) combined ECMs that were evaluated, and cost estimated. The ECM strategies included mechanical and electrical building systems, the building enclosure itself, as well as various combinations of the individual ECMs. All ECM's are within the Couzens building and not adjacent sites or buildings. A summary of the ECMs is contained in Table A (individual) and Table B (combined) on pages 6 & 7 of the report. More in-depth descriptions of each of the ECMs can be found on pages 9-29, including explanatory graphics. The combined ECMs were as follows:

- ECM Scenario A: This ECM reflects a combination of ECMs that the team estimated would typically be done under current UM Design Guidelines during a building renovation.
- ECM Scenario B: This ECM reflects a combination of ECMs selected to produce the maximum reduction in carbon.
- ECM Scenario C: This ECM combination is the same as ECM B but with no renewable energy, photovoltaics (PV).
- ECM Scenario D: This ECM combination aims to reduce project costs and still achieve a healthy carbon reduction result. This combination includes the same HVAC ECM's as B & C but only PV for electrical and solar shading for architectural.
- ECM Scenario E: This ECM combination aims to reduce project costs and still achieve a healthy carbon reduction result without PV or solar shading.
- ECM Scenario F: This ECM combination aims to produce the maximum reduction in carbon utilizing the existing campus infrastructure without any renewable energy (PV).

To be judicious with the budget and schedule allocated for the study, shoebox (simplified) energy modeling was employed to compare the original building energy performance with the proposed ECM energy performance.

Project Costs

To determine the estimated Project Costs of the various scenarios, the team worked with a Construction Manager to develop high-level construction cost estimates (see Exhibit 6 – Costs Analysis, the Opinion of Probable Cost (OPC). Although the OPCs could be perceived as high when comparing specific ECMs to various benchmarks, it is important to consider that these estimates consider the specific existing conditions at Couzens and include the full scope of associated work in Couzens to implement the ECMs. The full scope of this associated work is detailed in the Report and Appendix and provides a comprehensive understanding of the full scope of associated construction work that is required to implement each ECM. The total estimated Project Costs for the scenarios include the estimated construction costs, related construction costs (such as hazardous materials abatement and City utilities costs), contingencies, and professional fees and therefore represents the total costs anticipated to implement the various ECMs and bundled ECM scenarios.

Analysis of the ECMs

As noted, the study looked at the simple payback for each of the ECMs. The study calculated simple payback in years as the difference between the Project Cost divided by the Annual Energy Cost savings. The simple paybacks assumed the existing system(s) did not need to be replaced, which is reasonable given that the building recently underwent a major renovation. This assumption produces long simple paybacks. A comparative example would be replacing your home's windows solely for the purpose of gaining the benefit of improved energy efficiency. The EUI (energy use per square foot per year) was calculated for each of the ECMs. The most promising and compatible discipline ECMs were combined and then analyzed via a very high-level Life Cycle Cost (LCC) analysis for comparative purposes, see pages 43-45 of the report. LCC is a method for assessing the total cost of ownership in present value terms, which considers all costs of acquiring, owning, and disposing of a building or building system. The tables below summarize the results of the Simple Payback and Life Cycle Costs analysis for each of the ECM scenarios.

COUZENS INDIVIDUAL ECM STRATEGIES

	Energy Conservation Measure	EUI (kBtu/sf)	% Energy Savings	CO2 (tons/year)	% CO2 Savings	Annual Energy Cost	Annual Energy Cost/SF	% Cost Savings	Project Cost*	Simple Payback (Years)	CO2 Avoided (Cost/ton)
Existing Condition	NA	98.4	-	1,420	-	$ 151,956	$ 0.66	-	-	-	-
HVAC Systems	**HVAC-1A-1 Existing** Centralized Water Source Heat Pump	61.8	37%	1,364	4%	$ 180,671	$ 0.78	-19%	$ 2,971,350	103	$ 53,060
	HVAC-1A-2 Future [1] Centralized Water Source Heat Pump	61.6	37%	1,364	4%	$ 180,901	$ 0.78	-19%	$ 3,285,900	114	$ 58,677
	HVAC-1B-1 Existing De-Centralized Water Source VRF Fan Coils	54.4	45%	1,152	19%	$ 150,314	$ 0.65	1%	$ 30,863,700	18,796	$ 115,163
	HVAC-1B-2 Future [2] De-Centralized Water Source VRF Fan Coils	53.6	46%	1,130	20%	$ 147,113	$ 0.64	3%	$ 31,178,250	6,438	$ 107,511
	HVAC-1C Existing/Future De-Centralized Air Source VRF Fan Coils (supplement heat)	61.3	38%	1,355	5%	$ 179,585	$ 0.78	-18%	$ 32,186,700	1,165	$ 495,180
	HVAC-1D Existing/Future De-Centralized Air Source VRF Fan Coils	61.3	38%	1,356	5%	$ 179,724	$ 0.78	-18%	$ 32,680,800	1,177	$ 510,638
	HVAC-2 OA Preheat Using CHW	96.2	2%	1,400	1%	$ 150,730	$ 0.65	1%	$ 785,700	641	$ 39,285
	HVAC-3 Preheat domestic hot water with Sanitary Flow	94	4%	1,381	3%	$ 149,547	$ 0.65	2%	$ 533,250	221	$ 13,673
	HVAC-4 De-Centralized Ground Source Heat Pumps	75.8	23%	1,330	6%	$ 159,686	$ 0.69	-5%	$ 13,009,950	1,683	$ 144,555
	HVAC-6 Residential Rm Space Temp Set-Back	96.8	2%	1,421	0%	$ 158,830	$ 0.69	-5%	$ 645,300	94	$ 645,300
ELECT Systems	**ELEC-1** PV	93.8	5%	1,285	10%	$ 132,462	$ 0.57	13%	$ 4,708,800	242	$ 34,880
	ELEC-2 lighting efficiency upgrade	97.3	1%	1,342	5%	$ 138,971	$ 0.60	9%	$ 6,623,100	510	$ 84,912
	ELEC-3 Submetering	97.3	1%	1,360	4%	$ 142,273	$ 0.61	6%	$ 2,601,450	269	$ 43,358
ARCH Systems	**ARCH-1** High Performance Windows	94.4	4%	1,371	3%	$ 147,365	$ 0.64	3%	$ 9,936,000	2,164	$ 202,776
	ARCH-2 Solar Shading	98.6	0%	1,421	0%	$ 151,867	$ 0.66	0%	$ 1,814,400	20,387	$ 1,814,400
	ARCH-3 Flat Roof Insulation	96.4	2%	1,398	2%	$ 150,211	$ 0.65	1%	$ 2,743,200	1,572	$ 124,691
	ARCH-4 Reinsulate from the interior	87.4	11%	1,305	8%	$ 142,893	$ 0.62	6%	$ 21,176,100	2,337	$ 184,140
	ARCH-5 Remove Interior Insulation and Reskin Block	77.6	21%	1,203	15%	$ 134,948	$ 0.58	11%	$ 51,232,500	3,012	$ 236,094

Natural Gas Rate: $3.40/Mcf
Electricity Rate: $0.086/kWh
*Project Cost based on Walbridge Cost Estimate dated 12/14/2020
HVAC-5 Not used
Mechanical ECM's: Existing utilizes the current central campus plant to provide heating and cooling of water. Future assumes utilizing chilled water from a furture campus geo-exchange district
1 . From Walbridge Estimate include cost of HVAC ECM 1A-2 + HVAC ECM 1A-1
2. From Walbridge Estimate include cost of HVAC ECM 1B-2 + HVAC ECM 1B-1

Table A: Individual ECM Strategies

COUZENS COMBINED ECM STRATEGIES											
Energy Conservation Measure	Description	EUI (kBtu/sf)	% Energy Savings	CO2 (tons/year)	% CO2 Savings	Annual Energy Cost	Annual Energy Cost/SF	% Cost Savings	Project Cost	Simple Payback (Years)	CO2 Avoided (Cost/ton)
Existing Condition		98.4	-	1,420	-	$ 151,956	$ 0.66	-	-	-	-
Combined ECM-A HVAC-1A-2 , ELEC-2	"Typical" UM approach to a renovation project	58.8	40%	1,283	10%	$ 169,276	$ 0.73	-11%	$ 10,152,000	586	$ 74,102
Combined ECM-B HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ELEC-2, ELEC-3, ARCH-5	Maximize carbon reduction and provide renewable energy	32.5	67%	597	58%	$ 73,429	$ 0.32	52%	$ 63,082,800	803	$ 76,650
Combined ECM-C HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-5	Maximize carbon reduction	37.0	62%	732	48%	$ 92,922	$ 0.40	39%	$ 60,825,600	1,030	$ 88,409
Combined ECM-D HVAC-1A-2 , HVAC-2, HVAC-3, HVAC-6, ELEC-1, ARCH-2	Balanced approach to achieve healthy carbon reduction while minimizing costs including renewable energy	45.4	54%	978	31%	$ 128,372	$ 0.55	16%	$ 9,213,750	391	$ 20,846
Combined ECM-E HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6	Balanced approach to achieve healthy carbon reduction while minimizing costs	50.1	49%	1,115	21%	$ 148,222	$ 0.64	2%	$ 4,684,500	1,255	$ 15,359
Combined ECM-F HVAC-1B-1, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-1, ARCH-2, ARCH-3, ARCH-4,ARCH-5	Maximize carbon reduction utilizing existing campus infrastructure without renewable energy	32.9	67%	611	57%	$ 75,383	$ 0.33	50%	$ 99,812,250	1,303	$ 123,377

Natural Gas Rate: $3.40/Mcf
Electricity Rate: $0.086/kWh
*Project Cost based on Walbridge Cost Estimate V2 dated 12/14/2020

Table B: Combined ECM Strategies

Life Cycle Cost Summary (1)			
Energy Conservation Measure	**Project Cost**	**Life Cycle Cost**	**Total CO2 (3)**
Existing Bldg. Condition	-	(2)	42,598
ECM-A	$10,152,000	$13,517,722	38,499
ECM-B	$63,082,800	$66,863,258	17,924
ECM-C	$60,825,600	$64,852,582	21,973
ECM-D	$9,213,750	$11,828,049	29,335
ECM-E	$4,684,500	$7,462,359	33,458
ECM-F	$99,812,250	$105,065,305	18,330

(1) 30-year life cycle
(2) Not provided as not comparable to ECM A, B, C, D, E, F.
(3) 30-year total CO2 emissions in tons (lower values are better). An approximation provided for comparative purposes only; does not adjust for reductions in CO2 emissions associated with DTE electricity production anticipated to occur over the 30-year period.

Conclusion
There are opportunities to significantly reduce the carbon emissions of Couzens.

This study looked at options using the existing campus infrastructure and a new potential campus infrastructure. The central plant is a big undefined context to reduce energy and carbon. This study addressed some of the existing and future options under consideration for the central plant transformation. However, the timing and commitment of the transformation is still evolving. Clarity of a single compelling strategy that can be applied to other buildings has not emerged, in part because Couzens is a newly renovated building which contributed to some energy improvements that older buildings would not have as a baseline. The most opportune time to include efficient systems is when replacement is required. The marginal costs of improvement can have a reasonable payback period. The fact that Couzens had been recently renovated to a level comparable to meet current UM guidelines for energy and sustainability increases the payback timeline.

The combined scenarios were largely impacted by the HVAC ECM options. Scenario B that uses a centralized water source heat pump and renewable energy shows results similar to scenario F that uses a de-centralized water sourced VRF fan coils and no renewable energy. Both of these options provided the most energy and carbon reductions.

ECM Descriptions

The following is an overview of each of the ECMs:

HVAC Systems ECMs (Heating, Ventilating, Air Conditioning)

The Couzens mechanical system was recently renovated (~10 years ago). Couzens mechanical systems are fed by the existing campus utilities including low pressure steam (from the CPP), chilled water (chiller plant is in Moscher-Jordan), and domestic hot water (from the CPP). The system includes local heating hot water heat exchangers which serve other buildings utilizing the campus steam and providing heating hot water at 180°F. The residence rooms (~378) are served by individual two pipe fan coil units and the apartments (~6) are served by 4 pipe fan coil units. There are three air handling units serving the common areas with variable-air-volume (VAV) boxes and perimeter heat including a dedicated air handling unit serving the laundry. There are two energy recovery units with perimeter heat that supply air to the residence hall corridors and provide toilet make up air. There are unit heaters in stairwells, mechanical rooms, vestibule, and penthouses.

The primary ways by which new HVAC systems can reduce energy use and carbon impacts compared to the existing systems include: using water or environmentally safe refrigerants to move local cooling/heating energy in lieu of high-horsepower fans, reusing the energy in the building to the extent possible for conditioning outside air and for local heating/cooling in lieu of using only “new” energy sources, and relying on a low-entropy campus system approach for the building’s net heating and cooling loads.

The HVAC ECM were developed, exploring the most viable and cost-effective options currently available. Note that the first set of mechanical ECMs assume that the existing central campus plant is available to provide heating and cooling water. The second set of ECMs assume that the central plant has been updated and the plant will provide chilled water from a future campus geo-exchange district and medium temperature heating hot water from a future campus geo-exchange district (not domestic hot water) to Couzens. Costs associated with revising the central plant are not included since a separate team is studying potential revisions to the existing central plant.

Existing Campus Infrastructure HVAC- ECMs

- HVAC-1A-1, Centralized Water Source Heat Pump
    - This ECM is to provide a high-lift heat pump (in the basement) to serve the building’s heating needs in low to moderate heating conditions.
    - The existing fan coils, air handling units, energy recovery units, perimeter heat, and terminal units would remain.
    - Assumed 80% of peak heating load would be served by high lift heat pump boosting 58°F CHWR to 140°F, the remaining 20% of peak capacity would be served by the existing heating hot water heat exchangers at 180°F HHW which is served by the campus steam.
    - Cooling to remain from campus CHW plant.
    - This ECM assumes chilled water from the central plant is being utilized by other buildings throughout the heating season. The exact load and chilled water availability would need to be further investigated and confirmed.
    - Most of the work would be in unoccupied spaces (basement/mechanical rooms).
    - There would be tie ins to the existing chilled water and heating hot water systems located in the basement. The location of the basement provides an opportunity for minimal impact to the shutdown of utilities.
    - This option provides an eco-friendly alternative because it removes heat from the chilled water plant transferring it to meet the building heating needs. This helps the central chilled water plant create a cooling resource that other buildings on the central system can use. This system also reduces the demand on the central steam plant.

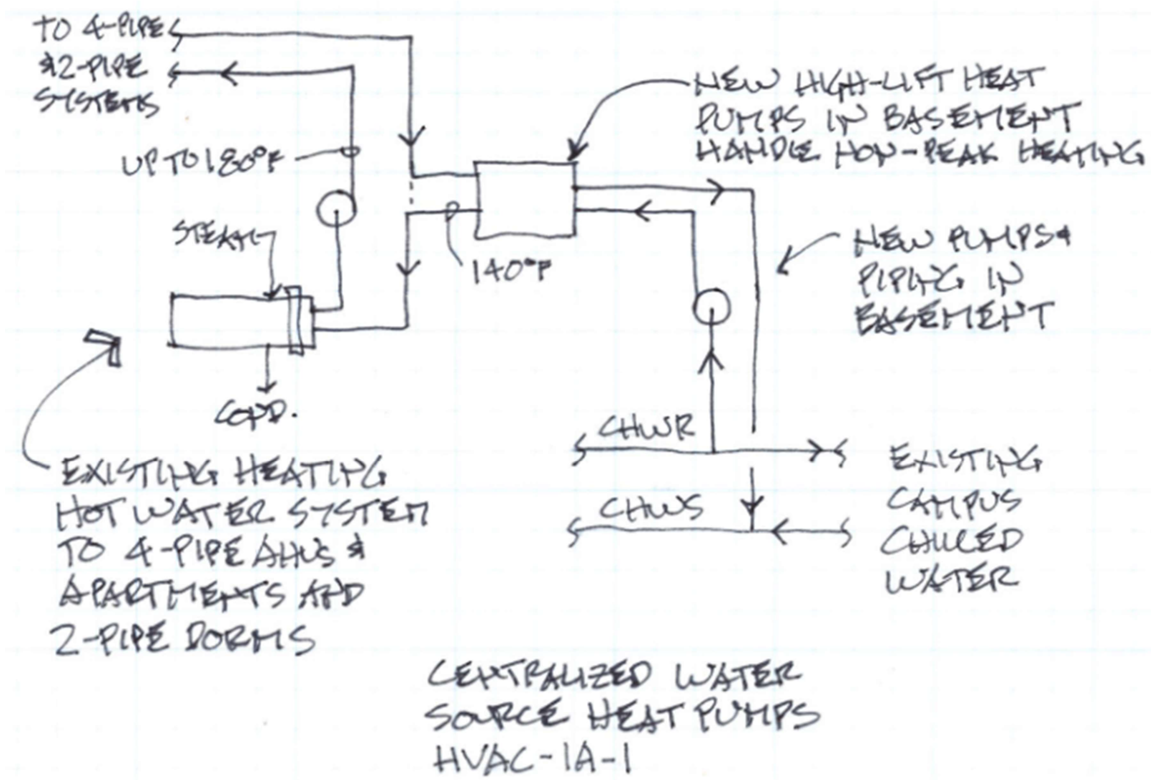


Figure HVAC-1A-1: Centralized Water Source Heat Pump

- HVAC-1B-1, De-Centralized Water Source Variable Refrigerant Flow (VRF) Fan Coils
    - Replace existing systems with water cooled VRF systems. Fan coil units would be replaced with VRF fan coil units, air handling units would be replaced with Dedicated Outside Air System (DOAS) units and VAV boxes would be replaced with VRF fan coil units/cassettes.
        - Perimeter heat would be removed to the extent possible keeping all cabinet and unit heaters and potentially perimeter heat in lobby spaces. Further analysis would be required to determine extent feasible to remove.
    - The local VRF fan coils will be served by centralized, water-source VRF heat pump units that are connected to the central energy plant warm and cool water systems.
    - The system would utilize Chilled Water Return (CHWR) for the source (58F) for both heating and cooling. It would remove heat to CHWR (downstream of the point of intake, in a campus line with robust flow that passes by the Couzens Building) during cooling and remove heat to Chilled Water Supply (CHWS) during heating.

- One disadvantage is that this would allow for double compression during cooling (at campus level and building level).
- This ECM assumes chilled water from the central plant is being utilized by other buildings throughout the heating season. The exact load and chilled water availability would need to be further investigated and confirmed.
- VRF systems are highly engineered systems that use proprietary replacement parts, require more sophisticated maintenance staff, and are less flexible for future architectural modifications.
- The air handling unit coils and energy recovery coils would be modified as required to connect to the VRF heat pumps.
- Modifications would be required throughout the building including the resident's room, pipe shafts, mechanical rooms, ceilings of common areas.
- VRF systems are eco-friendly systems, because the heating and cooling would be moved between building spaces to the extent possible before excess heating or cooling load must be taken from or added to the central plant systems.

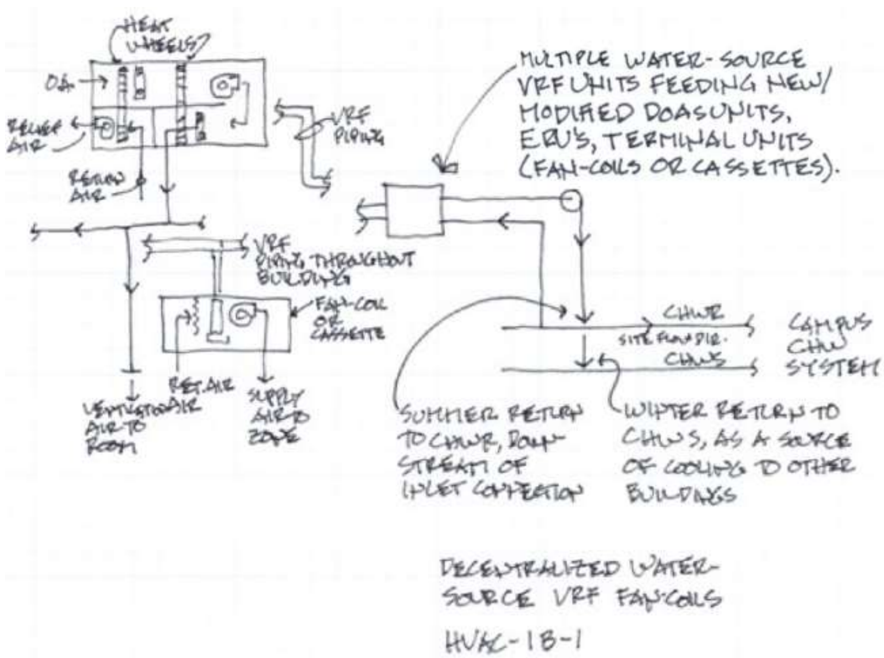


Figure HVAC-1B-1: De-Centralized Water Source VRF Fan Coils

- HVAC-1C De-Centralized Air Source VRF Fan Coils (supplemental heat)
  - Replace existing systems with air cooled VRF systems. Fan coil units would be replaced with VRF fan coil units, air handling units would be replaced with DOAS unit and VAV boxes would be replaced with VRF fan coil units/cassettes. New

perimeter heat (finned tube) would be provided throughout and would be selected for 140F Heating Hot Water Supply (HHWS) (the future condition) and served by existing campus steam via 180F HHW.
  - Modifications would be required throughout the building including the resident's room, pipe shafts, mechanical rooms, ceilings of common areas.
  - An area for the air-cooled units, has not been identified. However, anticipate additional modifications to support these units.
  - Air-cooled VRF are energy efficient systems as a result of the heating and cooling that would be moved between building spaces to the extent possible and limit the central plant connections required except for connections to the perimeter heat.

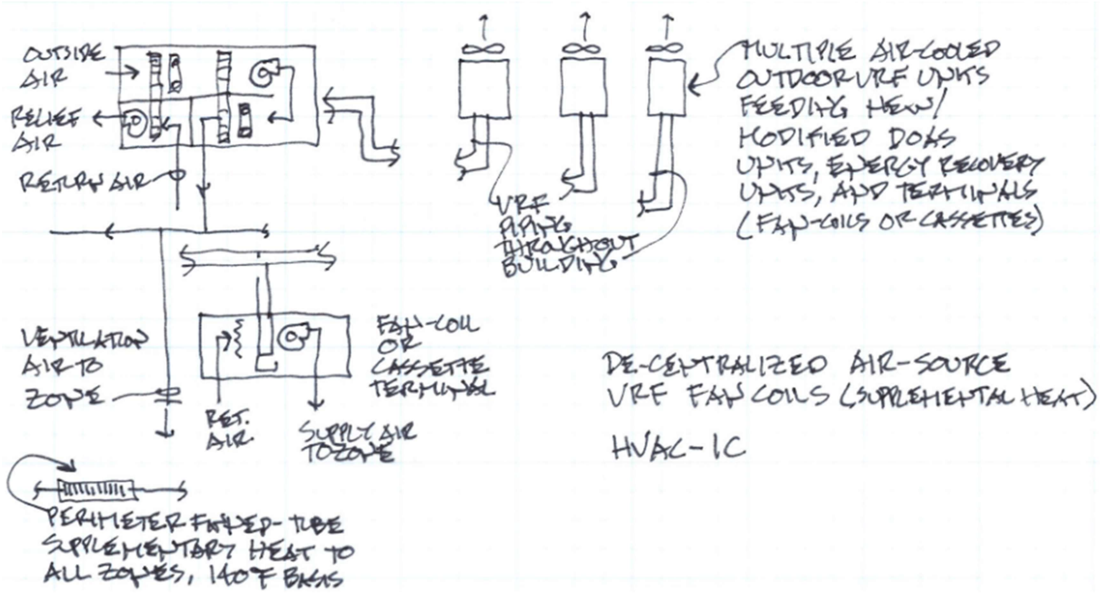


Figure HVAC-1C: De-Centralized Air Source VRF Fan Coils (supplemental heat)

- HVAC-1D De-Centralized Air Source VRF Fan Coils
  - Replace existing systems with air cooled VRF systems. Similar to 1C, but the VRF system would provide all the heat in lieu of perimeter heat.
  - Air cooled VRF is technically capable of providing heat in this climate; however, various projects have demonstrated it has had several short comings. Air source VRF systems typically lose capacity and efficiency at low ambient temperatures. The system would need to be further investigated to evaluate risks, prior to implementation.
  - Air-cooled VRF are energy efficient systems because the heating and cooling would be moved between building spaces to the extent possible and limit the central plant connection.

- HVAC-2 OA Preheat Using CHW
  - Preheat the outside air for the airlanding units and energy recovery units using chilled water return while making chilled water for the campus.
  - Modifications will be required in the basement, penthouse, and a chase from the basement to the penthouse. It is recommended this work take place in the summer months when not in use.
  - This ECM assumes chilled water from the central plant is being utilized by other buildings throughout the heating season. The exact load and chilled water availability would need to be further investigated and confirmed.
  - This is an energy efficient option because it removes heat from the chilled water plant transferring it to meet the building heating needs. This helps the central chilled water plant create a cooling resource that other buildings on the central system can use. This system also reduces the demand on the central steam plant.

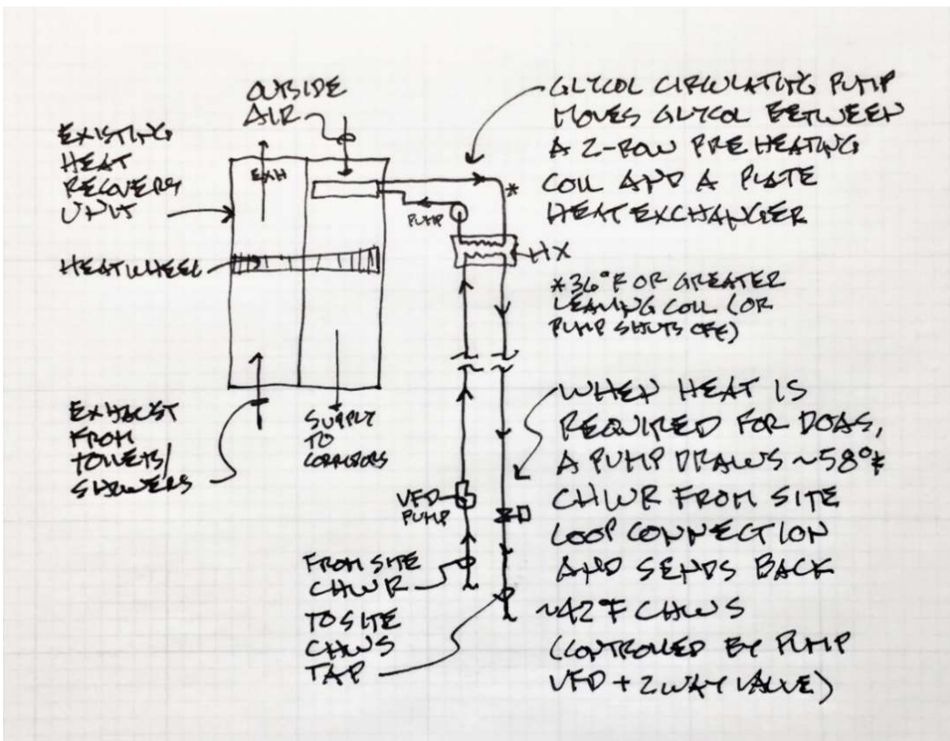


Figure HVAC-2: Example of OA Preheat System Using CHW

- HVAC-3 Preheat domestic Hot Water with Sanitary Flow

- ECM Not applicable when using campus domestic hot water

- HVAC-4 De-Centralized Ground Source Heat Pumps
  - Provide geothermal wells and heat pumps for heating and cooling of residential rooms. There would be a tie into central utilities to reject heat as required.
  - Replace fan coil units with water source heat pumps. Existing air handling units and downstream devices would remain.
  - Modifications would be required throughout the building including the resident's rooms, mechanical rooms, and site.
  - This was not taken to the next level because it is being investigated under another study at a campus level.

- HVAC-5 Not Used

- HVAC-6 Residential Room Space Temperature Set-Back
  - Use existing lighting occupancy sensors to set back space temperatures in residential rooms.
  - Tie in occupancy sensors to existing Siemens controllers.
  - Modifications would be limited to wiring within residential rooms.
  - A potential shortcoming for this option is that the system could react as if the space was unoccupied while the occupants were not moving (i.e. sleeping). There are options such as manual overrides to overcome this issue, but they come with other limitations. Further discussion would be required before installation.

  - This is an energy efficient option because it reduces the HVAC load when spaces are unoccupied.

Future Campus Infrastructure HVAC-ECMs

- HVAC-1A-2, Centralized Water Source Heat Pump
  - The system would remain relatively the same with the deletion of steam and the addition of medium temperature heating hot water (MTHHWS).
  - The exception would be during peak heating conditions the heat pumps would boost 140F MTHHWS to 175F/180F. Most of the heating would be provided by the high lift heat pumps boosting 58F CHWR to 140F. Cooling to remain from campus CHW plant.

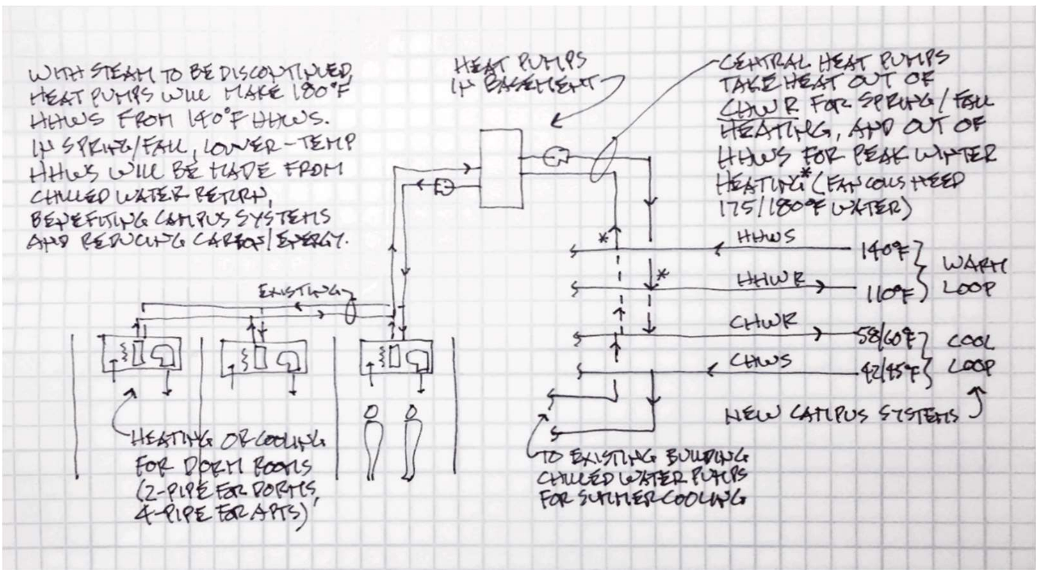


Figure HVAC-1A-2: Example of Centralized Water Source Heat Pump

- HVAC-1B-2, De-Centralized Water Source VRF Fan Coils
  - The system would remain relatively the same with the deletion of steam and the addition of medium temperature heating hot water (MTHHWS).
  - The source water would be modified to use a low entropy (cross flow) approach (free heat from 58F CHWR and rejection to 110F MTHHWR)
- HVAC-1C De-Centralized Air Source VRF Fan Coils (supplemental heat)
  - The system would remain the same. The MTHHWS would replace the steam/ building HHW system.
- HVAC-1D De-Centralized Air Source VRF Fan Coils
  - No change

- HVAC-2 OA Preheat Using CHW
  - No change

- HVAC-3 Preheat Domestic Hot Water with Sanitary Flow
  - Preheat domestic water with shower and/or laundry sanitary flow.
  - Provide heat exchanger on existing sanitary lines within basement.
  - Modifications would be limited to basement.
  - This is an energy efficient options because it utilizes “waste” heat to preheat the domestic water.

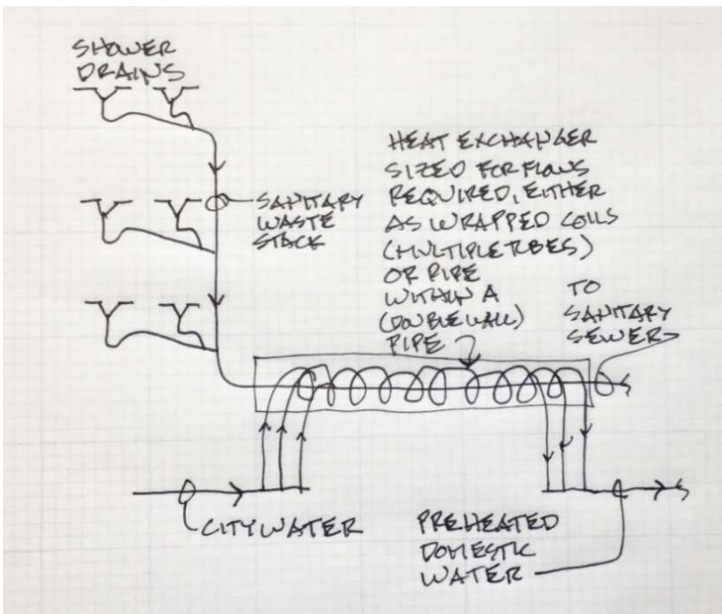


Figure HVAC-3: Example of Preheat Domestic Hot Water System

- HVAC-4 De-Centralized Ground Source Heat Pumps
  - The system would remain the same. The MTHHWS would replace the steam system including the building HHW system.

- HVAC-5 Not Used

- HVAC-6 Residential Room Space Temperature Set-Back
  - No change

Electrical Systems ECMs (Electrical)

- ELECT-1 PV
  - This ECM is to install a roof and exterior façade mounted photovoltaic (PV) system of the maximum practical capacity given the available roof area.
  - The significant benefit of this is that it utilizes the expansive natural asset of the building's solar exposure to offset a portion of the building's power needs.
  - It also helps shade the roof from the hot summer sun.
  - The PV system consists of three mounting methods. First, is the traditional flat roof ballast type mounting/racking system. Second is a sloped racking system fastened to the slate roof. Lastly, are external "sun shades" mounted above the punched windows at the south façade.
  - Major existing roof systems modifications including structural reinforcing are not anticipated.
  - Roof tie off protection is not required on the flat roofs since the roof includes a parapet of adequate, however, ties off or another form of fall protection would be required at the sloped slate roofs.
  - Some exterior construction will be required to route conduits from the roof and punched windows to the interconnection point in the basement.
  - The combined PV array DC rating is 236.9 kW with an annual energy yield of 226,666 kWh.

Figure ELEC-1: PV System

- ELECT-2 Lighting Efficiency Upgrade
    - This ECM is to replace existing fluorescent light fixtures with highly efficient LED (light emitting diodes) sources. The upgrades would be a one-for-one fixture replacement. Fixture quantity and distribution would remain as is.
    - Most of the building does have automatic controls. However, there is an opportunity to modify the controls in three ways. One is to add auto off controls where currently not present. Two is to add daylight harvesting controls where there is access to natural daylight. And three is to modify the current time of day scheduled controls to allow lighting fixtures to turn off during period of vacancy.

- ELECT-3 Submetering
    - Given the function and use of the facility, the energy consumption is heavily influenced by student occupant energy habits. Raising occupant awareness about energy use and carbon could potentially help to increase energy savings and lower carbon production.
    - Submetering of energy use and load types will enable the university staff and students to understand their impact on energy and carbon footprint at a granular level.
    - There are two options of submetering. Option one is to replace existing panelboards with "title 24" style panels premanufactured for load segregation and submetering load classifications (e.g., lighting, HVAC, plugs and appliances). This option involves replacing 40 panelboards. Option two is to submeter loads by floor only. This option includes leaving the existing panelboards intact and only adding appropriate submeters per floor. This would include adding 53 submeters. In either option, IP-based remote monitoring and connection to the building management system (BMS) is included.
    - Option two was priced as the basis of design.

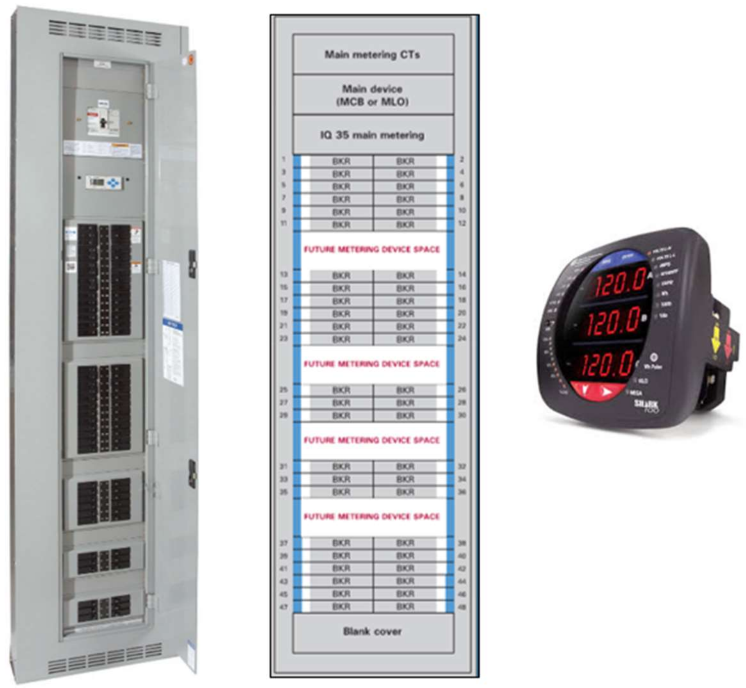


Figure ELEC-3: Submetering

Arch Systems ECMs (Architecture)

- ARCH-1 New High-Performance Windows
    - New modern fenestration systems reduce heat loss to the exterior in the winter and will reduce the amount of heat entering the building in the summer.
    - Replace the existing curtain wall and window systems with a system that exceeds the performance of typical energy efficient systems. The existing systems appear to be common for the time of the previous renovation, completed in 2011, with a single thermal break and insulated glazing units.
        - Performance of new systems are based on triple glazed units with argon filled cavities and two Low-E coatings. Framing system are based on ultra-thermal performance systems that include thermal breaks greater than ¼”.
            - Punched Windows
                - U-Factor: 0.34
                - SHGC:0.26
                - VLT: 47%
            - First Floor Curtain Wall
                - U-Factor: 0.31
                - SHGC: 0.25
                - VLT: 56%
    - Wall construction near each window will need to be investigated and repaired to allow for the attachment of the new system. This may require selective demolition at each window opening.
    - Selective demolition of masonry veneer will be required to allow for new fenestration to tie into the air and water plane of existing assembly.
    - Interior finishes near the construction area will likely need to be repaired and cleaned.

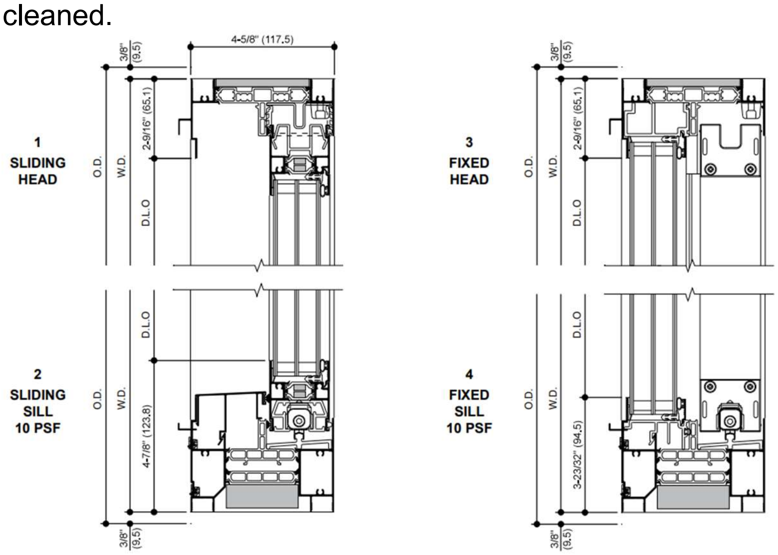


Figure ARCH-1: Example of High-Performance Window System

- ARCH-2 Solar Shading
  - Install solar shading devices over punched windows on south elevation. The addition of shading devices provides a small additional space for increased PV generation, and will reduce heat gain from the sun during the summer.
  - Selective masonry demolition may be required depending on investigation of existing brick masonry's capacity to hold external elements.
  - Wiring will pass through the building enclosure and connect to electrical system. Interior finishes will need to be patched and cleaned.
  - Shades would include PV panels as described in ELECT – 1.
    - 2' shades with minimal slope were assumed for initial run to determine general effectiveness.
    - This size was roughly based on one PV module.
    - When initial study came back with minor performance increase, no further optimization or refinement was studied.
      - This lack of increased building performance is likely tied to the relatively good solar performance of the existing windows, and the fact that the building energy use is heating dominated.

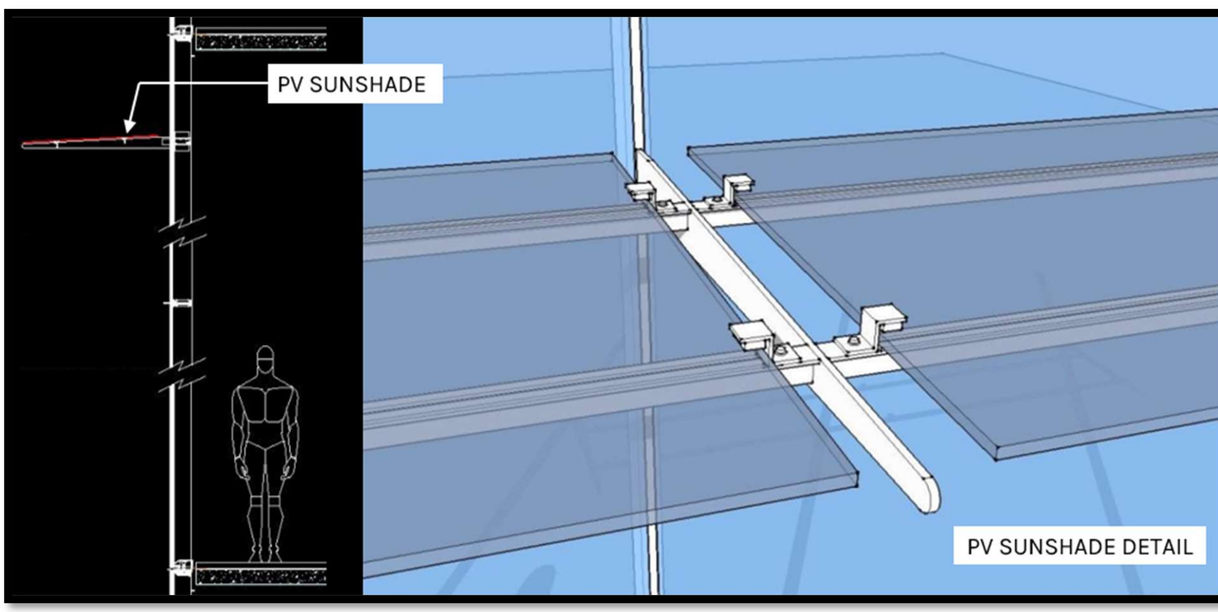


Figure ARCH-2: Example for PV Shading Device

- ARCH-3 Flat Roof Installation
  - Increase the insulation depth and replace existing roof membrane. While the existing roof membrane is between one third to one halfway through its anticipated life expectancy, reroofing with additional insulation will reduce heat gain in the summer and reduce heat loss in the winter.
  - Existing roof membrane, edge metal, terminations, flashing, and copings will be removed and inspected for potential reuse.
  - Additional insulation to be added to the assembly until the total thickness of the roof assembly is 6" before counting the thickness of any insulation that provides taper.
  - Some areas will require modifications to the edge metal and copings to allow for the additional thickness.
  - Selective demolition may be required in some locations to facilitate a minimum termination of 8" above the membrane surface at parapets and adjacent walls.

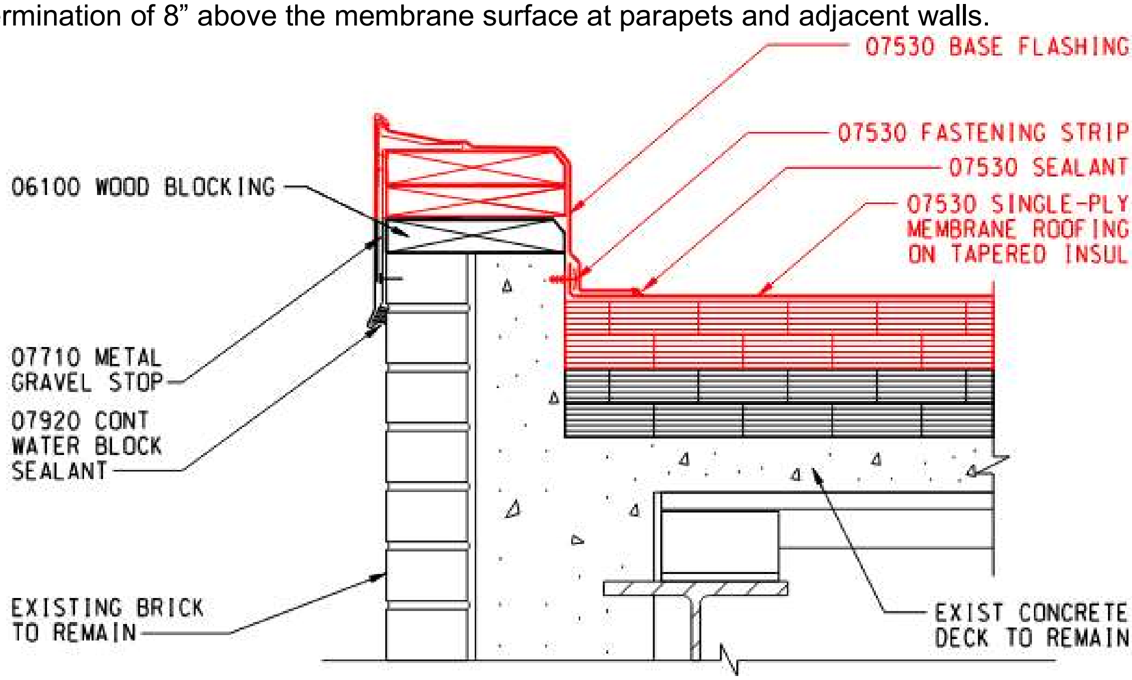


Figure ARCH-3: Add Insulation to Flat Roofs

- ARCH-4 Reinsulate from the Interior
    - Reinsulating from the interior with spray foam insulation will increase air tightness of the wall assembly and will allow for a reduction of thermal bridging at wall openings. Both will increase the assumed thermal performance of the assembly and increase thermal comfort of the space adjacent to the wall.
        - Existing air tightness and thermal bridging assumptions are based on drawings provided to SG. Actual air infiltration and thermal bridging may be better or worse than assumed.
    - Remove existing insulation and replace with spray foam insulation.
        - Existing insulation is assumed to be R-5/inch
            - This value is based on NRCA design value for polyisocyanurate. While NRCA is typically associated with roofing applications, they have done extensive research on the aging effects of polyisocyanurate and the effects of temperature on the thermal resistance.
            - Existing insulation is assumed to be taped per materials submitted. Taped joints are hard to install in a perfectly continuous manner and could open over time. Without visual inspection of joints, it is assumed that there is air infiltration.
        - Spray foam insulation has a higher thermal resistance than most rigid insulation materials and will increase air tightness of the wall assembly.
            - Insulation to be closed cell, 1.5” thick
            - Assume R-Value of 7.1/inch in R-Value
            - Additional R-value of 2 was assigned to account for new thermal continuity at heads and jambs of some windows.
            - Air infiltration reduced 25% in models.
    - Interior fishes, to be completely removed and remaining substrate to be prepared to receive spray foam insulation.
    - Insulation to be installed at the same thickness of existing insulation and completely covered from floor to underside of deck to provide a thermal barrier.
    - Additional selective demolition around windows may be required to tie air and thermal tightness plane of spray foam insulation with existing windows.
    - Electrical, plumbing, and mechanical, may need to be repaired, replaced, or recalibrated during construction due to the extent of demolition.
    - When calculating the change in wall performance, the majority of the savings was based on reduced air infiltration which was assumed to be reduced by 25%.

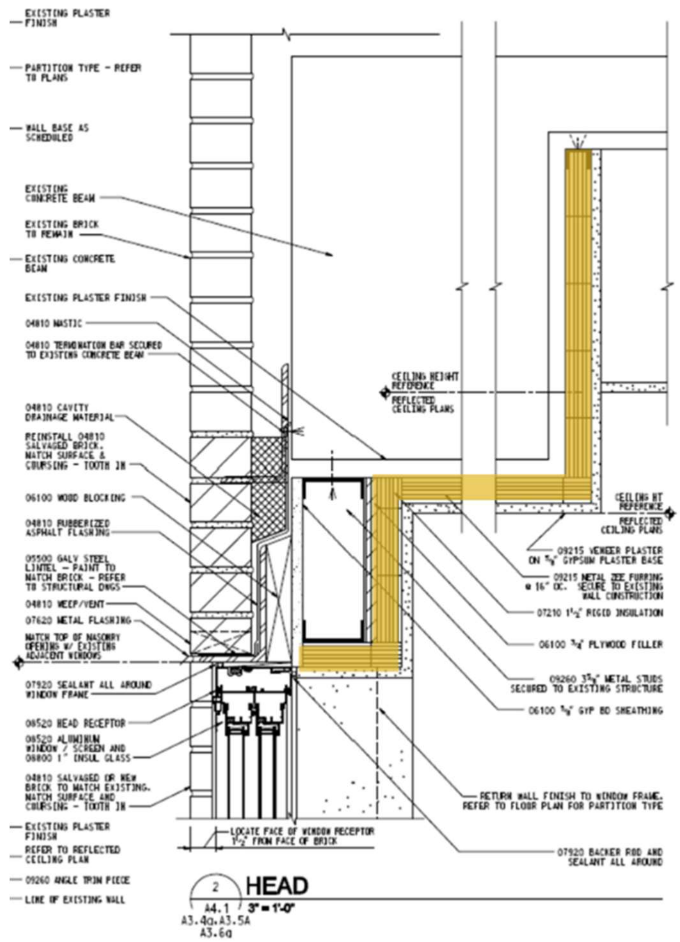


Figure ARCH-4: Existing Rigid Insulation Removed and Spray Foam Insulation Installed in its Place

- ARCH-5 Reskin Full Building
    - Providing a full building reskin that includes a new dedicated air barrier system and continuous insulation will reduce the heat transfer through the wall assembly and increase thermal comfort in the spaces adjacent to the exterior wall.
        - Providing continuous insulation exterior of the structure will allow for continuous insulation which increases the insulation's efficiency.
        - Providing a dedicated air barrier will reduce the amount of air that can bypass the insulation.
    - The previous renovation added insulation to the interior of the existing masonry construction. The effectiveness of interior insulation is limited by space, inherent thermal bridges in the structure, and alignment of fenestration systems within the wall assembly. Additionally, the existing building likely does not have a continuous means to limit the amount of exterior air that can enter the building.
    - Removing the existing brick that is on the building will allow the installation of an air/water barrier on the existing building reduces the amount of air that can come

in and out of the building. This not only helps increase occupant conform but also allows the mechanical system can heat and cool spaces more efficiently. Additionally, an air/water barrier can reduce water infiltration into the building and reduce the risk of condensation in the wither. Both functions will help protect the existing structure from long term water damage.

- After the removal of existing brick has completed, prepare existing building substrate to receive a fluid applied air/water barrier assembly. This assembly includes new flashings, and transitions to existing fenestration, roofing, and foundation waterproofing.

- Removing the brick will also allow new insulation to be installed. Adding new insulation on the exterior of the building will increase the energy efficiency of the exterior wall. This will also make the spaces within the building that are located on an exterior wall more comfortable to the users by increasing the radiant temperature of the exterior wall surfaces.
    - Install three inches of extruded polystyrene ultra and a nominal two-inch air space.
- During demolition of the exterior wall, it is also recommended that the interior insulation that was installed during the previous renovation be removed. This will have a significant impact on the ability to occupy the space during demolition and construction. The removal of the existing insulation will reduce the risk of condensation within the wall assembly and allow the air/water/vapor control layers to be conditioned by the interior space.
- All major systems within the exterior wall will likely be impacted by the ECM including the Structure, Mechanical, Electrical, Plumbing. While not all systems will be impacted the same, the change to the wall is significant, and in field conditions may require the alteration, moving, or recalibrating of these systems.
- In addition to the above grade structural improvements that may be required, there will be structural impacts to the foundation. This will be based on the weight and attachment system of the new exterior wall veneer.
- Roofing and waterproofing will require some modifications to allow the new air and water barrier to integrate with the existing systems. Air and water tightness are critical to the longevity and efficiency of a building, so new systems should be integrated with the existing.
- Due to the extensive construction from the exterior, some site work will be required to remedy any damage from the construction.
- This EMC has a lot of unknown variables including the condition of the existing structure and interior part of the existing wall.
- During demolition of existing masonry, brick should be removed in a manner to salvage and reuse as much of the existing brick as possible. Photographic logging of existing brick patterns and general coloration should take place prior to any demolition.
- Reinstall brick to replicate patterning and general coloration of the original building. Patterning on the existing building to be implemented on both the original building and additions, to unify the appearance of the masonry.
- Reinstall interior finishes.

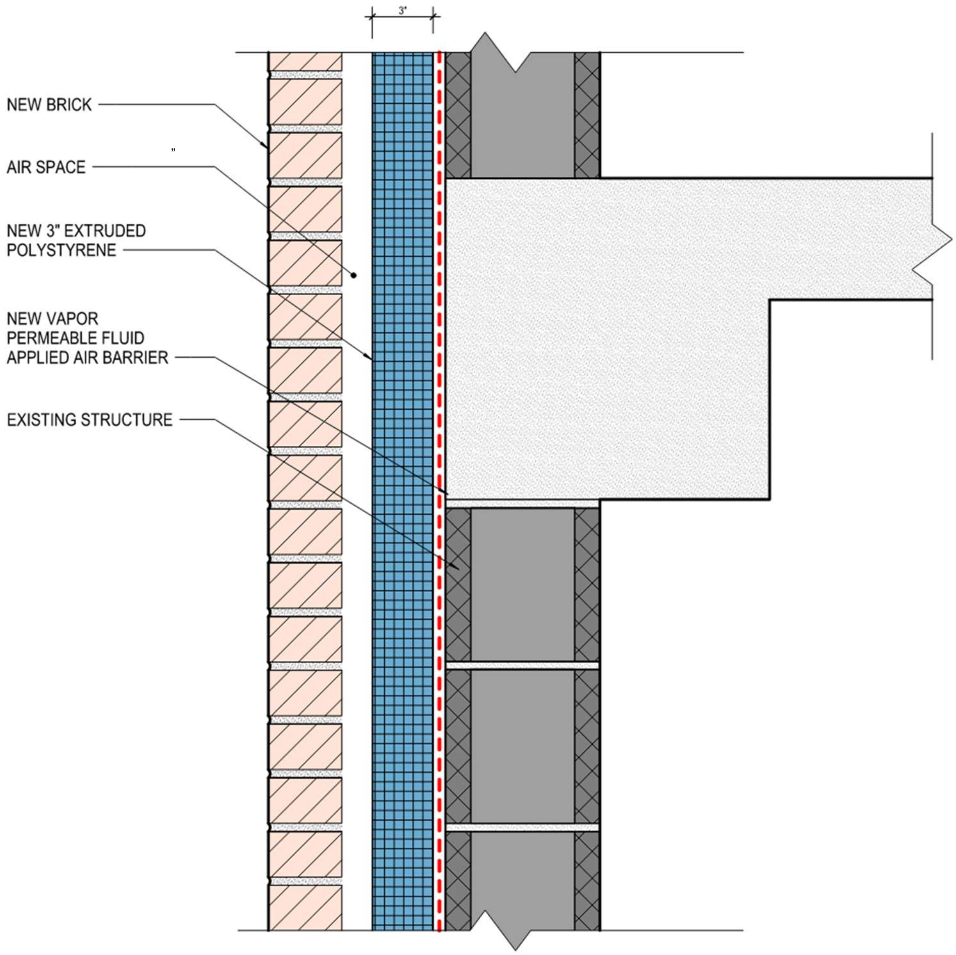


Figure ARCH-5: Reskin Exterior Wall, Remove Existing Interior Insulation

Six scenarios were then developed where various ECMs were combined to maximize energy use reduction and reduce carbon impacts:

Combined ECMs

The combined ECMs are provided with the future central utility plant

ECM Scenario A is the combination of the following components

- HVAC 1A -2– Centralized Water Source Heat Pump
- ELEC 2 – Lighting Efficiency Upgrade

This combined set of ECM will provide energy and CO_2 reductions from the existing conditions of 40% energy savings; CO_2 reduction of 137 tons/year; Energy Use Intensity (EUI) of /sf 58.8 kBTU/sf a saving of 39.6 kBTU/sf per year and total energy cost increase per year of $17,320.

ECM Scenario B is the combination of the following components

- HVAC 1A-2 – Centralized Water Source Heat Pump
- HVAC 2 – OA Preheat Using CHW
- HVAC 3 – Preheating Domestic Hot Water with Sanitary Flow
- HVAC 6 – Residential Room Space Temperature Set-Back
- ELEC 1 – PV
- ELEC 2 – Lighting Efficiency Upgrade
- ELEC 3 – Submetering
- ARCH 5 – Remove Interior Insulation and Reskin Brick

This combined set of ECM will provide energy and CO_2 reductions from the existing conditions of 67% energy savings; CO_2 reduction of 822 tons/year; Energy Use Intensity (EUI) of /sf 32.5 kBTU/sf a saving of 65.9 kBTU/sf per year and total energy cost saving per year of $78,527.

ECM Scenario C is the combination of the following components

- HVAC 1A -2– Centralized Water Source Heat Pump
- HVAC 2 – OA Preheat Using CHW
- HVAC 3 – Preheating Domestic Hot Water with Sanitary Flow
- HVAC 6 – Residential Rm Space Temp Set-Back
- ELEC 2 – Lighting Efficiency Upgrade
- ELEC 3 – Submetering
- ARCH 5 – Remove Interior Insulation and Reskin Brick
- This ECM combination is the same as ECM B but with no PV.

This combined set of ECM will provide energy and CO_2 reductions from the existing conditions of 62% energy savings; CO_2 reduction of 688 tons/year; Energy Use Intensity (EUI) of /sf 37.0 kBTU/sf a saving of 61.3 kBTU/sf per year and total energy cost saving per year of $59,034.

ECM Scenario D is the combination of the following components

- HVAC 1A -1– Centralized Water Source Heat Pump
- HVAC 2 – OA Preheat Using CHW
- HVAC 3 – Preheating Domestic Hot Water with Sanitary Flow
- HVAC 6 – Residential Room Space Temperature Set-Back
- ELEC 1 – PV
- ARCH 2 – Solar Shading

This combined set of ECM will provide energy and CO2 reductions from the existing conditions of 54% energy savings; CO2 reduction of 422 tons/year; Energy Use Intensity (EUI) of /sf 45.4 kBTU/sf a saving of 53.0 kBTU/sf per year and total energy cost saving per year of $23,583.

ECM Scenario E is the combination of the following components

- HVAC 1A -1– Centralized Water Source Heat Pump
- HVAC 2 – OA Preheat Using CHW
- HVAC 3 – Preheating Domestic Hot Water with Sanitary Flow
- HVAC 6 – Residential Room Space Temperature Set-Back
- This ECM combination is the same as ECM D but with no PV

This combined set of ECM will provide energy and CO2 reductions from the existing conditions of 49% energy savings; CO2 reduction of 305 tons/year; Energy Use Intensity (EUI) of /sf 50.1 kBTU/sf a saving of 48.3 kBTU/sf per year and total energy cost saving per year of $3,733.

ECM Scenario F is the combination of the following components

- HVAC 1B -1– De-Centralized Water Source VRF Fan Coils
- HVAC 2 – OA Preheat Using CHW
- HVAC 3 – Preheating Domestic Hot Water with Sanitary Flow
- HVAC 6 – Residential Room Space Temperature Set-Back
- ELEC 1 – PV
- ELEC 2 – Lighting Efficiency Upgrade
- ELEC 3 – Submetering
- ARCH 1 – New High-Performance windows
- ARCH 2 – Solar Shading
- ARCH 3 – Flat Roof Insulation
- ARCH 4 – Reinsulate from Interior
- ARCH 5 – Remove Interior Insulation and Reskin Brick

This combined set of ECM will provide energy and CO2 reductions from the existing conditions of 67% energy savings; CO2 reduction of 809 tons/year; Energy Use Intensity (EUI) of /sf 32.9 kBTU/sf a saving of 65.5 kBTU/sf per year and total energy cost saving per year of $76,573.

Opinion of Probable Costs
This study calculates simple payback in years as the difference between the Project Cost divided by the Annual Energy Cost savings. To determine the Project Cost, the team sought to estimate the total cost of the project. In Exhibit 6 – Costs Analysis, the Opinion of Probable Cost (OPC) is an estimate of the construction cost. Construction cost is the amount paid to a contractor (i.e., General Contractor or Construction Manager) to build the project, including the material costs, the labor costs, and the contractor's overhead & profit. Also, because this study seeks to estimate the construction cost for a future project, an allowance was included for material & labor escalation. Given the preliminary nature of this study, a design contingency was included. As noted above, in addition to Construction Cost, there are other expenses that would be necessary to complete any of these potential ECM projects. These additional expenses include things like "Related Construction" (e.g., new/revised utility and City connections, etc.), Owner's contingencies (e.g., Construction Contingency, etc.), professional fees, and miscellaneous expenses. Based on experience with previous projects, the study assumes that other expenses would be 35% of the estimated construction costs. *This 1.35 factor included construction contingency, which is why the OPC notes that it contains 0% for construction contingency.*

The opinion of probable costs may be perceived as high when considering a specific ECM or even a combined ECM. However, the detailed estimate included in the appendix show the extent of construction work that is required for each ECM and the combined ECM scenarios.   It should also be noted that the simple paybacks provided here-in assume the existing system(s) do not need to be replaced. This produces long simple paybacks. A comparative example would be replacing your home furnace when not broken solely for the purpose of gaining the benefit of improved energy efficiency. However, during a major renovation, the simple payback would be calculated based upon the cost difference to install a more energy-efficient system verses a system that just meets current energy code requirements, resulting in shorter simple paybacks. The opinion of cost detail includes scope of work beyond just the direct components of the ECM. Other building infrastructure and existing conditions will be affected by the work required to implement the ECM. This includes structural upgrades, roofing repair or replacement, reworking or replacing mechanical, electrical, plumbing components, and replacing interior finishes.

It is also important to highlight what is not included in the project's costs proposed by this study:

- Any improvements beyond those described in the study.
- Escalation beyond the two years that was included in the estimate. Additional escalation may be appropriate depending on the timeframe for implementation.
- Phasing and/or temporarily other measures to facilitate the continued use and occupancy of the building during construction.
- Any costs to temporally relocate the building occupants, furniture, or equipment.
- Metering and monitoring beyond what is typical for a comparable UM building.

The below tables summarize the Project Cost and Simple Payback for the ECMs listed in the above Scope section. This table includes all the individual ECMs and combined ECM's and ranks them in terms of the cost per ton of carbon avoided.

COUZENS ECM STRATEGIES

Energy Conservation Measure	EUI (kBtu/sf)	% Energy Savings	CO2 (tons/year)	% CO2 Savings	Annual Energy Cost	Annual Energy Cost/SF	% Cost Savings	Project Cost*	Simple Payback (Years)	CO2 Avoided (Cost/ton) ($)	CO2 Avoided (Cost/ton) (ranking)
Existing Condition Fan coil units, AHUS, ERUs, Campus LPS and CHW, Lighting at 1 W/sf	98.4	-	1,420	-	$ 151,956	$ 0.66	-	-	-	-	0
HVAC-3 Preheat domestic hot water with Sanitary Flow	94	4%	1,381	3%	$ 149,547	$ 0.65	2%	$ 533,250	4	$ 13,673	1
HVAC-1B-1 Existing De-Centralized Water Source VRF Fan Coils	54.4	45%	1,152	19%	$ 150,314	$ 0.65	1%	$ 30,863,700	205	$ 15,359	2
Combined ECM-E HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6	50.1	49%	1,115	21%	$ 148,222	$ 0.64	2%	$ 4,684,500	1,255	$ 15,359	3
Combined ECM-C HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-5	37.0	62%	732	48%	$ 92,922	$ 0.40	39%	$ 60,825,600	1,030	$ 20,846	4
HVAC-1C Existing/Future De-Centralized Air Source VRF Fan Coils (supplement heat)	61.3	38%	1,355	5%	$ 179,585	$ 0.78	-18%	$ 32,186,700	179	$ 495,180	5
Combined ECM-D HVAC-1A-2 , HVAC-2, HVAC-3, HVAC-6, ELEC-1, ARCH-2	45.4	54%	978	31%	$ 128,372	$ 0.55	16%	$ 9,213,750	391	$ 20,846	6
ELEC-1 PV	93.8	5%	1,285	10%	$ 132,462	$ 0.57	13%	$ 4,708,800	36	$ 34,880	7
HVAC-2 OA Preheat Using CHW	96.2	2%	1,400	1%	$ 150,730	$ 0.65	1%	$ 785,700	5	$ 39,285	8
ELEC-3 Submetering	97.3	1%	1,360	4%	$ 142,273	$ 0.61	6%	$ 2,601,450	18	$ 43,358	9
HVAC-1A-1 Existing Centralized Water Source Heat Pump	61.8	37%	1,364	4%	$ 180,671	$ 0.78	-19%	$ 2,971,350	16	$ 53,060	10
HVAC-1A-2 Future Centralized Water Source Heat Pump	61.6	37%	1,364	4%	$ 180,901	$ 0.78	-19%	$ 3,285,900	18	$ 58,677	11
Combined ECM-A HVAC-1A-2 , ELEC-2	58.8	40%	1,283	10%	$ 169,276	$ 0.73	-11%	$ 10,152,000	586	$ 74,102	12
Combined ECM-B HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ELEC-2, ELEC-3, ARCH-5	32.5	67%	597	58%	$ 73,429	$ 0.32	52%	$ 63,082,800	803	$ 76,650	13
ELEC-2 LED lighting and controls	97.3	1%	1,342	5%	$ 138,971	$ 0.60	9%	$ 6,623,100	48	$ 84,912	14
HVAC-1B-2 Future De-Centralized Water Source VRF Fan Coils	53.6	46%	1,130	20%	$ 147,113	$ 0.64	3%	$ 31,178,250	212	$ 107,511	15
Combined ECM-F HVAC-1B-1, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-1, ARCH-2, ARCH-3, ARCH-4,ARCH-5	32.9	67%	611	57%	$ 75,383	$ 0.33	50%	$ 99,812,250	1,303	$ 123,377	16
ARCH-3 Flat Roof Insulation	96.4	2%	1,398	2%	$ 150,211	$ 0.65	1%	$ 2,743,200	18	$ 124,691	17
HVAC-4 De-Centralized Ground Source Heat Pumps	75.8	23%	1,330	6%	$ 159,686	$ 0.69	-5%	$ 13,009,950	81	$ 144,555	18
ARCH-4 Reinsulate from the interior	87.4	11%	1,305	8%	$ 142,893	$ 0.62	6%	$ 21,176,100	148	$ 184,140	19
ARCH-1 High Performance Windows	94.4	4%	1,371	3%	$ 147,365	$ 0.64	3%	$ 9,936,000	67	$ 202,776	20
ARCH-5 Remove Interior Insulation and Reskin Brick	77.6	21%	1,203	15%	$ 134,948	$ 0.58	11%	$ 51,232,500	380	$ 236,094	21
HVAC-1D Existing/Future De-Centralized Air Source VRF Fan Coils	61.3	38%	1,356	5%	$ 179,724	$ 0.78	-18%	$ 32,680,800	182	$ 510,638	22
HVAC-6 Residential Rm Space Temp Set-Back	96.8	2%	1,421	0%	$ 158,830	$ 0.69	-5%	$ 645,300	4	$ 645,300	23
ARCH-2 Solar Shading	98.6	0%	1,421	0%	$ 151,867	$ 0.66	0%	$ 1,814,400	12	$ 1,814,400	24

Natural Gas Rate: $3.40/Mcf
Electricity Rate: $0.086/kWh
*Project Cost based on Walbridge Cost Estimate V2 dated 12/15/2020

Table C: ECM Strategies Ranked by Cost per Ton Carbon Avoided

Strategy Assessments

The assessment of ECM combined strategies depends on the parameters chosen for decision making.

Modeled energy savings vary from a 40% reduction to a striking 67% reduction, with a net building EUI of 32.5 kBtu/sf/yr.

Modeled carbon (CO_2) reduction savings vary from a 10% reduction to an impressive 58% reduction.

In terms of first cost, each of these strategies recognizes that the Couzens Residential Hall systems are at not at the end of their useful life and that the renovation would primarily be initiated to improve energy savings. Given that, the range in first cost of these strategies places the most energy-reducing and carbon-reducing strategy 600% higher in cost than that of the lowest strategy.

Schedule

- On average a 12-month to 14-month schedule is assumed for each ECM, including complete building vacancy.
- The budget and schedule are based on all engineering being complete prior to starting construction.
- The budgets are based on furniture and artwork being sheltered or moved out of building.
- 2 to 3 buildings could be completed concurrently with the existing local labor pool (This would also allow for lessons learned to be included is subsequent projects).
- If a phased approach is utilized temporary heating and cooling provisions would be required at additional cost not currently included in the cost models.
- Layout /use of building will be a factor in determining if a phased schedule should be implemented.
- A phased schedule approach could lead to a 24-month construction schedule.
- Environmental studies need to be completed during the engineering phase.
- Extensive commissioning requirements may have an impact on the schedule duration.
- The ECM equipment availability and lead times could impact the schedule.
- Consideration of the site confines – some sites may be more restrictive than others – lay-down and field offices, traffic control, material deliveries, etc.
- Cost of move-outs and the preparation of swing space should be considered. These are not currently part of the cost models.
- Life safety upgrades are not included in the cost models.

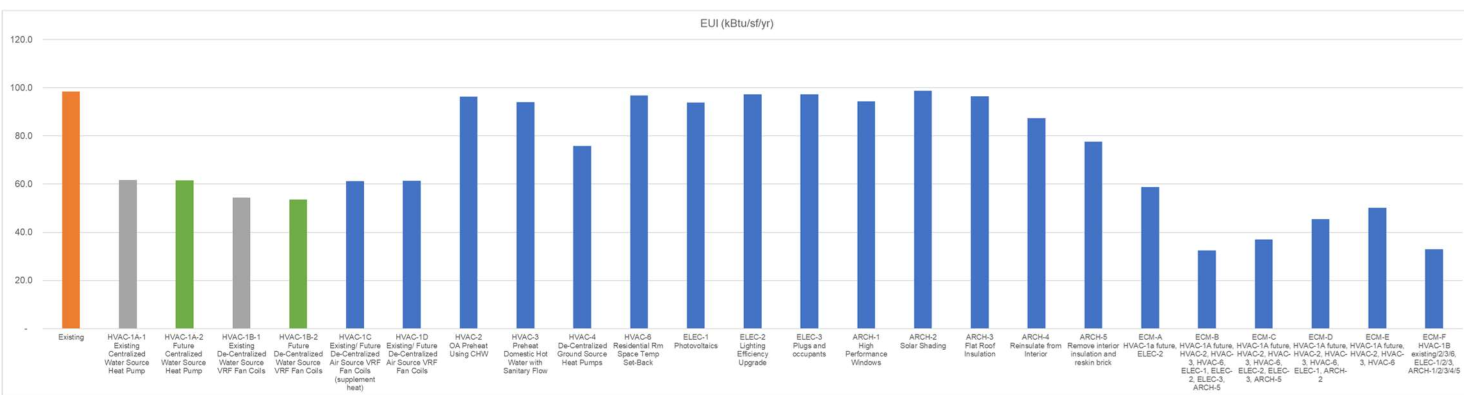
A summary of the Shoe Box Energy Model results can be found below, and in Exhibit 5:

kBtu	Existing	HVAC-1A-1 Existing Centralized Water Source Heat Pump	HVAC-1A-2 Future Centralized Water Source Heat Pump	HVAC-1B-1 Existing De-Centralized Water Source VRF Fan Coils	HVAC-1B-2 Future De-Centralized Water Source VRF Fan Coils	HVAC-1C Existing/ Future De-Centralized Air Source VRF Fan Coils (supplement heat)	HVAC-1D Existing/ Future De-Centralized Air Source VRF Fan Coils	HVAC-2 OA Preheat Using CHW	HVAC-3 Preheat Domestic Hot Water with Sanitary Flow	HVAC-4 De-Centralized Ground Source Heat Pumps	HVAC-6 Residential Rm Space Temp Set-Back	ELEC-1 Photovoltaics
Interior Lighting	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731
Receptacle Equipment	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177
Space Heating - NG	8,452,750	48,102	-	-	-	40	-	8,087,516	8,452,750	3,717,572	8,063,383	8,452,750
Space Heating - Electricity	-	2,207,151	2,222,569	1,145,737	1,144,671	2,428,463	2,431,117	-	-	1,064,167	-	-
Service Water Heating - NG	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	2,936,179	3,670,238	3,670,238	3,670,238
Space Cooling	397,049	397,140	397,119	361,300	283,083	288,473	290,675	397,099	397,049	381,130	398,621	397,049
Heat Rejection	204,467	204,473	204,465	121,349	72,038	80,362	80,651	204,466	204,467	113,404	202,818	204,467
Interior Central Fans	1,348,788	1,348,788	1,348,789	1,281,445	1,281,445	1,281,445	1,281,444	1,348,788	1,348,788	1,348,874	1,349,857	1,348,788
Interior Local Fans	249,525	249,555	249,544	348,874	348,912	348,173	348,541	249,485	249,525	230,459	373,147	249,525
Pumps	54,537	80,862	80,868	31,104	32,685	24,235	24,218	53,450	54,537	39,581	54,990	54,537
Renewables	-	-	-	-	-	-	-	-	-	-	-	773,384
Total	**16,573,262**	**10,402,217**	**10,369,500**	**9,155,955**	**9,028,980**	**10,317,337**	**10,322,792**	**16,206,950**	**15,839,203**	**12,761,333**	**16,308,962**	**15,799,878**

kBtu	ELEC-2 Lighting Efficiency Upgrade	ELEC-3 Plugs and occupants	ARCH-1 High Performance Windows	ARCH-2 Solar Shading	ARCH-3 Flat Roof Insulation	ARCH-4 Reinsulate from Interior	ARCH-5 Remove interior insulation and reskin brick	ECM-A HVAC-1A-2, ELEC-2	ECM-B HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ELEC-2, ELEC-3, ARCH-5	ECM-C HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-5	ECM-D HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ARCH-2	ECM-E HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6	ECM-F HVAC-1B-1, HVAC-2, HVAC-3, HVAC-6, ELEC-1/2/3, ARCH-1/2/3/4/5
Interior Lighting	1,228,242	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,228,242	1,228,242	1,228,242	1,756,731	1,756,731	1,228,242
Receptacle Equipment	439,177	69,560	439,177	439,177	439,177	439,177	439,177	439,177	69,560	69,560	439,177	439,177	69,560
Space Heating - NG	8,834,398	8,684,568	7,885,698	8,507,077	8,140,427	6,733,756	5,196,579	-	-	-	-	-	-
Space Heating - Electricity	-	-	-	-	-	-	-	2,326,152	377,284	377,284	1,005,252	1,005,252	377,287
Service Water Heating - NG	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	2,936,179	2,936,179	2,936,179	2,936,179	2,936,179
Space Cooling	366,086	364,689	350,310	389,185	390,278	377,300	364,513	366,044	117,644	117,644	395,400	403,062	161,150
Heat Rejection	188,637	191,792	185,636	202,771	200,750	192,248	181,919	188,604	46,110	46,110	191,710	196,524	76,280
Interior Central Fans	1,351,095	1,348,745	1,331,345	1,348,570	1,341,540	1,308,929	1,275,707	1,351,086	1,281,444	1,281,444	1,370,510	1,370,890	1,281,444
Interior Local Fans	259,747	251,361	227,933	249,120	239,525	188,702	131,885	259,799	162,659	162,659	253,309	254,663	162,789
Pumps	52,426	53,059	50,858	54,116	53,699	51,467	49,555	78,929	21,368	21,368	72,090	72,035	25,110
Renewables	-	-	-	-	-	-	-	-	773,384	-	773,384	-	773,384
Total	**16,390,046**	**16,390,743**	**15,897,926**	**16,616,985**	**16,232,365**	**14,718,548**	**13,066,304**	**9,908,271**	**5,467,106**	**6,240,490**	**7,646,974**	**8,434,513**	**5,544,657**

EUI (kBtu/sf/yr)	Existing	HVAC-1A-1 Existing Centralized Water Source Heat Pump	HVAC-1A-2 Future Centralized Water Source Heat Pump	HVAC-1B-1 Existing De-Centralized Water Source VRF Fan Coils	HVAC-1B-2 Future De-Centralized Water Source VRF Fan Coils	HVAC-1C Existing/ Future De-Centralized Air Source VRF Fan Coils (supplement heat)	HVAC-1D Existing/ Future De-Centralized Air Source VRF Fan Coils	HVAC-2 OA Preheat Using CHW	HVAC-3 Preheat Domestic Hot Water with Sanitary Flow	HVAC-4 De-Centralized Ground Source Heat Pumps	HVAC-6 Residential Rm Space Temp Set-Back	ELEC-1 Photovoltaics
Interior Lighting	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
Receptacle Equipment	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Space Heating - NG	50.2	0.3	-	-	-	0.0	-	48.0	50.2	22.1	47.9	50.2
Space Heating - Electricity	-	13.1	13.2	6.8	6.8	14.4	14.4	-	-	6.3	-	-
Service Water Heating - NG	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	17.4	21.8	21.8	21.8
Space Cooling	2.4	2.4	2.4	2.1	1.7	1.7	1.7	2.4	2.4	2.3	2.4	2.4
Heat Rejection	1.2	1.2	1.2	0.7	0.4	0.5	0.5	1.2	1.2	0.7	1.2	1.2
Interior Central Fans	8.0	8.0	8.0	7.6	7.6	7.6	7.6	8.0	8.0	8.0	8.0	8.0
Interior Local Fans	1.5	1.5	1.5	2.1	2.1	2.1	2.1	1.5	1.5	1.4	2.2	1.5
Pumps	0.3	0.5	0.5	0.2	0.2	0.1	0.1	0.3	0.3	0.2	0.3	0.3
Renewables	-	-	-	-	-	-	-	-	-	-	-	4.6
Total (kBtu/sf/yr)	**98.4**	**61.8**	**61.6**	**54.4**	**53.6**	**61.3**	**61.3**	**96.2**	**94.0**	**75.8**	**96.8**	**93.8**
Savings		**37%**	**37%**	**45%**	**46%**	**38%**	**38%**	**2%**	**4%**	**23%**	**2%**	**5%**
Elec (Mmbtu)	4,450	6,684	6,699	5,486	5,359	6,647	6,653	4,449	4,450	5,374	4,575	3,677
Nat Gas (Mmbtu)	12,123	3,718	3,670	3,670	3,670	3,670	3,670	11,758	11,389	7,388	11,734	12,123
Elec ($)	$ 112,170	$ 168,468	$ 168,856	$ 138,268	$ 135,068	$ 167,540	$ 167,679	$ 112,143	$ 112,170	$ 135,440	$ 115,322	$ 92,677
Nat Gas ($)	$ 39,786	$ 12,203	$ 12,045	$ 12,045	$ 12,045	$ 12,045	$ 12,045	$ 38,587	$ 37,377	$ 24,246	$ 38,508	$ 39,786
Total Energy Cost ($)	**$ 151,956**	**$ 180,671**	**$ 180,901**	**$ 150,314**	**$ 147,113**	**$ 179,585**	**$ 179,724**	**$ 150,730**	**$ 149,547**	**$ 159,686**	**$ 153,830**	**$ 132,462**
Elec (metric tons CO2)	777	1,166	1,169	957	935	1,160	1,161	776	777	938	798	642
Nat Gas (metric tons CO2)	643	197	195	195	195	195	195	624	604	392	623	643
Total Carbon (metric tons CO2)	**1,420**	**1,364**	**1,364**	**1,152**	**1,130**	**1,355**	**1,356**	**1,400**	**1,381**	**1,330**	**1,421**	**1,285**

EUI (kBtu/sf/yr)	ELEC-2 Lighting Efficiency Upgrade	ELEC-3 Plugs and occupants	ARCH-1 High Performance Windows	ARCH-2 Solar Shading	ARCH-3 Flat Roof Insulation	ARCH-4 Reinsulate from Interior	ARCH-5 Remove interior insulation and reskin brick	ECM-A HVAC-1a future, ELEC-2	ECM-B HVAC-1A future, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ELEC-2, ELEC-3, ARCH-5	ECM-C HVAC-1A future, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-5	ECM-D HVAC-1A future, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ARCH-2	ECM-E HVAC-1A future, HVAC-2, HVAC-3, HVAC-6	ECM-F HVAC-1B existing/2/3/6, ELEC-1/2/3, ARCH-1/2/3/4/5
Interior Lighting	7.3	10.4	10.4	10.4	10.4	10.4	10.4	7.3	7.3	7.3	10.4	10.4	7.3
Receptacle Equipment	2.6	0.4	2.6	2.6	2.6	2.6	2.6	2.6	0.4	0.4	2.6	2.6	0.4
Space Heating - NG	52.4	51.6	46.8	50.5	48.3	40.0	30.9	-	-	-	-	-	-
Space Heating - Electricity	-	-	-	-	-	-	-	13.8	2.2	2.2	6.0	6.0	2.2
Service Water Heating - NG	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	17.4	17.4	17.4	17.4	17.4
Space Cooling	2.2	2.2	2.1	2.3	2.3	2.2	2.2	2.2	0.7	0.7	2.3	2.4	1.0
Heat Rejection	1.1	1.1	1.1	1.2	1.2	1.1	1.1	1.1	0.3	0.3	1.1	1.2	0.5
Interior Central Fans	8.0	8.0	7.9	8.0	8.0	7.8	7.6	8.0	7.6	7.6	8.1	8.1	7.6
Interior Local Fans	1.5	1.5	1.4	1.5	1.4	1.1	0.8	1.5	1.0	1.0	1.5	1.5	1.0
Pumps	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.1	0.1	0.4	0.4	0.1
Renewables	-	-	-	-	-	-	-	-	4.6	-	4.6	-	4.6
Total (kBtu/sf/yr)	**97.3**	**97.3**	**94.4**	**98.6**	**96.4**	**87.4**	**77.6**	**58.8**	**32.5**	**37.0**	**45.4**	**50.1**	**32.9**
Savings	**1%**	**1%**	**4%**	**0%**	**2%**	**11%**	**21%**	**40%**	**67%**	**62%**	**54%**	**49%**	**67%**
Elec (Mmbtu)	3,885	4,036	4,342	4,440	4,422	4,315	4,199	6,238	2,531	3,304	4,711	5,498	2,608
Nat Gas (Mmbtu)	12,505	12,355	11,556	12,177	11,811	10,404	8,867	3,670	2,936	2,936	2,936	2,936	2,936
Elec ($)	$ 97,932	$ 101,726	$ 109,441	$ 111,903	$ 111,450	$ 108,749	$ 105,849	$ 157,231	$ 63,792	$ 83,286	$ 118,736	$ 138,586	$ 65,747
Nat Gas ($)	$ 41,038	$ 40,547	$ 37,925	$ 39,964	$ 38,761	$ 34,144	$ 29,100	$ 12,045	$ 9,636	$ 9,636	$ 9,636	$ 9,636	$ 9,636
Total Energy Cost ($)	**$ 138,971**	**$ 142,273**	**$ 147,365**	**$ 151,867**	**$ 150,211**	**$ 142,893**	**$ 134,948**	**$ 169,276**	**$ 73,429**	**$ 92,922**	**$ 128,372**	**$ 148,222**	**$ 75,383**
Elec (metric tons CO2)	678	704	758	775	772	753	733	1,089	442	577	822	959	455
Nat Gas (metric tons CO2)	664	656	613	646	627	552	471	195	156	156	156	156	156
Total Carbon (metric tons CO2)	**1,342**	**1,360**	**1,371**	**1,421**	**1,398**	**1,305**	**1,203**	**1,283**	**597**	**732**	**978**	**1,115**	**611**



Project Overview

Existing Floor Plans

Floor plans from the of the existing building are shown below. The shoebox used a similar plan model however a simplified building geometry and program to rapidly iterate design options.

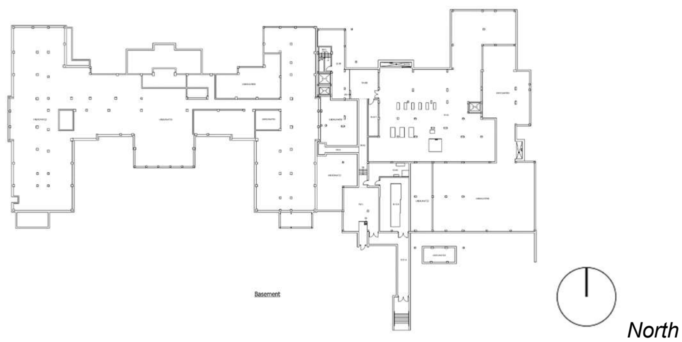


Figure A: Couzens Residential Hall Level Basement

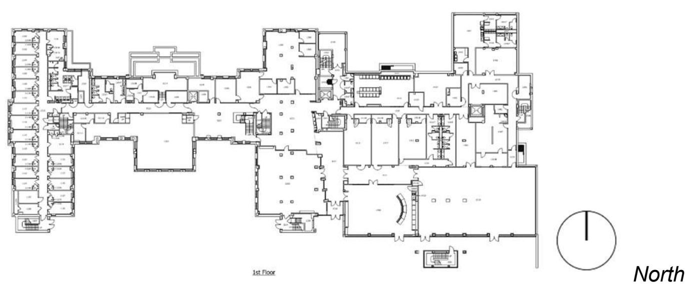


Figure B: Couzens Residential Hall Level 1

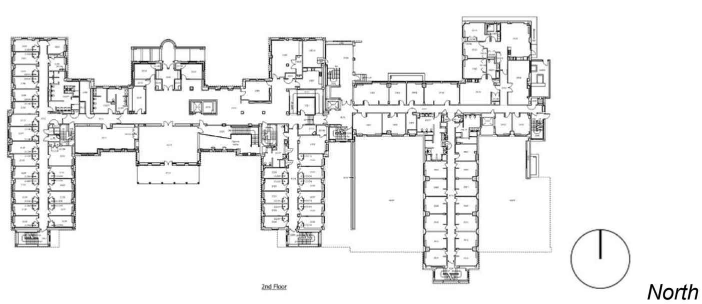


Figure A: Couzens Residential Hall Typical for Levels 2-5

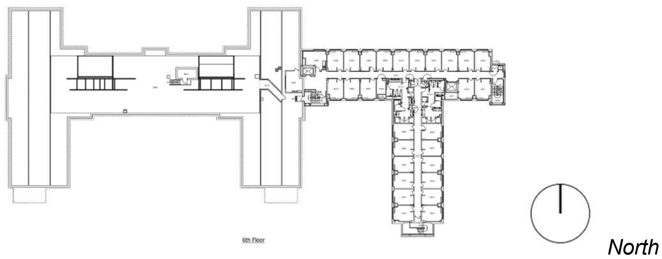


Figure G: Couzens Residential Hall Level 6

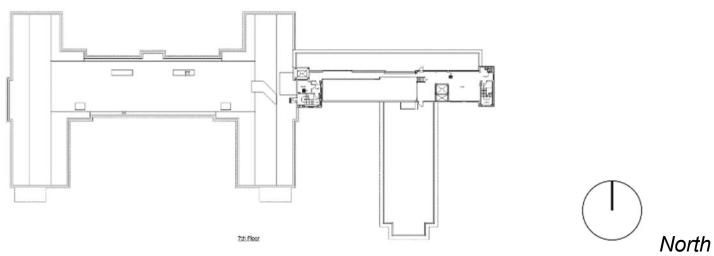


Figure H: Couzens Residential Hall typical for Levels 7-8

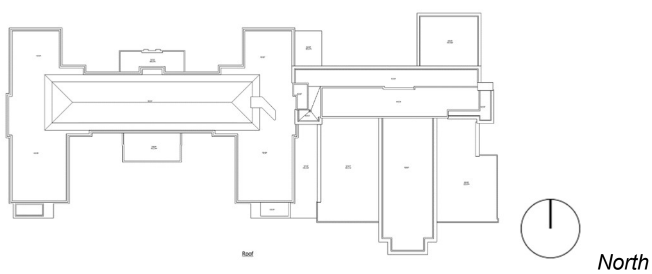


Figure K: Couzens Residential Hall Level Roof

Project Goals

Goal 1: Provide high-level energy and carbon assessment for Couzens Residential Hall

Goal 2: This study was commissioned by the President's Commission on Carbon Neutrality (PCCN) to evaluate the existing building and identify ECM strategies to reduce energy demand and associated carbon emissions as low as possible.

Goal 3: Build upon the previous assessment framework that can be applied for other buildings/campus regions.

Data Collection and Benchmarking

- Historic Climate Analysis for Ann Arbor – See Exhibit 1.
    - Shoebox model outputs reflect historic climate data
- Future Climate Analysis for Ann Arbor – See Exhibit 2.
- Benchmarking – See Exhibit 3.
- UM Office of Campus Sustainability Energy Database Analysis – See Exhibit 4.

A benchmarking study comparing the energy use intensity (EUI) of buildings of similar program on the University of Michigan Ann Arbor campus reveals that Couzens Residential Hall stands better than most of its peers in terms of energy consumption (See Exhibit 3). As measured by the Commercial Buildings Energy Consumption Survey (CBECS), Couzens Residential Hall consumes approximately 10% more energy than the average college/university building in the United States.

Existing Conditions & Parallel Study

Existing Conditions

The following assumptions were made as the existing conditions for the UM Couzens Building energy model inputs:

Design Category	Description of Existing Systems	Source
Envelope	Air Tightness: Leaky/Loose (0.80 cfm/sf of envelope) Curtain wall: U-Factor 0.37, SHGC 0.38 Punched Window Openings: U-Factor 0.42, SHGC 0.38 Punched Stair Windows: U-Factor 1.25 Flat Roof: R-Value 15 Typical Brick Wall: R-Value 11.33 Penthouse Wall on Addition: R-Value 14.49 Stair Tower Brick Walls: R-Value 4.13	System description derived from existing drawings
Mechanical Engineering	Ventilation Dorms/Apartments: DOAS FCUs with exhaust air energy recovery Ventilation Common Areas/Offices: VAV with reheat Cooling: One (1) 325-ton cooling tower at 38.2 gpm/ton; One (1) 325-ton screw chiller (5.5 COP) Heating: Two (2) 2,000-MBH steam boilers at 80% efficiency	System description derived from field observation and historic drawing sets Performance of mechanical system derived from code compliance at year of installation Steam, chilled water, hot water systems provided from central plant and relate to ECM's labeled "Existing".

Electrical Engineering	Lighting: 1.00 W/sf	Lighting power density derived from code compliance at year of installation
Schedule	See Exhibit 5	University of Michigan Facilities Representatives

Table: Existing Conditions District Improvements

The University of Michigan indicated that the district energy master plan for the area would include the following in approximately 10-15 years based on a parallel study regarding a future central plant which is assumed for ECM's labeled "Future":

- Medium Temperature Hot Water (MTHW) at 140°F returning at 110°F would be provided to Couzens.
- Chilled water would be provided to Couzens from the campus geo-exchange district.
- Steam and domestic hot water would no longer be provided.

Analysis

Included in Analysis

The following were included in the building energy analysis:

- Basic building geometry and programming
- Mechanical systems per existing drawings and code compliance at year of installation
- Lighting systems per existing drawings and code compliance at year of installation
- Envelope per existing drawings and code compliance at year of installation
- Plug load, lighting, people, and mechanical equipment schedules per University of Michigan input

Excluded from Analysis

The following were excluded from the building energy analysis:

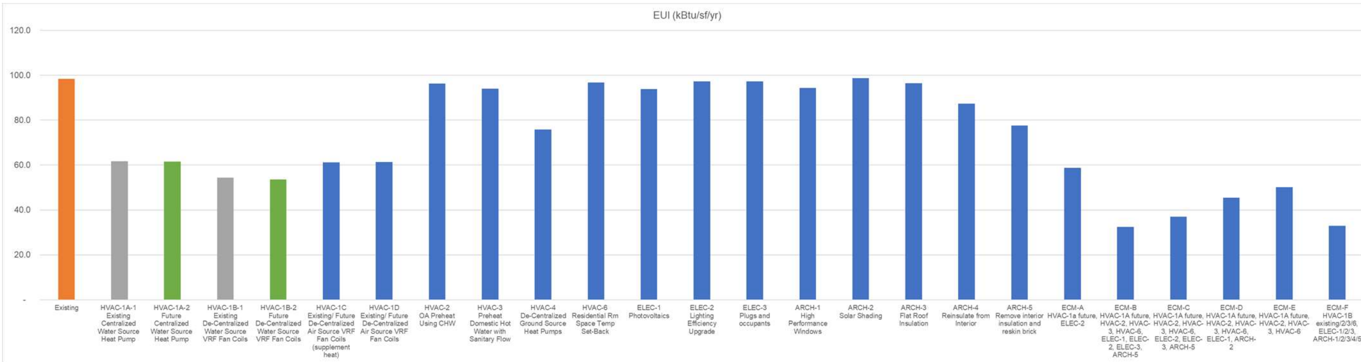
- Load shedding: Energy benefit of load shedding is generally understood and is intended to be part of the design process rather than analysis
- Change of occupancy and scheduling: Building upgrades preferred to have minimal impact on curriculum
- Process loads: Process loads are not sub-metered; therefore, a realistic assumption could not be provided. Additionally, it is assumed process load will not change with future building upgrades.

Results

A summary of the Shoe Box Energy Model results can be found below, and in Exhibit 5:

kBtu	Existing	**HVAC-1A-1 Existing** Centralized Water Source Heat Pump	**HVAC-1A-2 Future** Centralized Water Source Heat Pump	**HVAC-1B-1 Existing** De-Centralized Water Source VRF Fan Coils	**HVAC-1B-2 Future** De-Centralized Water Source VRF Fan Coils	**HVAC-1C Existing/ Future** De-Centralized Air Source VRF Fan Coils (supplement heat)	**HVAC-1D Existing/ Future** De-Centralized Air Source VRF Fan Coils	**HVAC-2** OA Preheat Using CHW	**HVAC-3** Preheat Domestic Hot Water with Sanitary Flow	**HVAC-4** De-Centralized Ground Source Heat Pumps	**HVAC-6** Residential Rm Space Temp Set-Back	**ELEC-1** Photovoltaics	**ELEC-2** Lighting Efficiency Upgrade	**ELEC-3** Plugs and occupants	**ARCH-1** High Performance Windows	**ARCH-2** Solar Shading	**ARCH-3** Flat Roof Insulation	**ARCH-4** Reinsulate from Interior	**ARCH-5** Remove interior insulation and reskin brick	**ECM-A** HVAC-1A-2, ELEC-2	**ECM-B** HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ELEC-2, ELEC-3, ARCH-5	**ECM-C** HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-5	**ECM-D** HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ARCH-2	**ECM-E** HVAC-1A-2, HVAC-2, HVAC-3, HVAC-6	**ECM-F** HVAC-1B-1, HVAC-2, HVAC-3, HVAC-6, ELEC-1/2/3, ARCH-1/2/3/4/5
Interior Lighting	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,228,242	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,756,731	1,228,242	1,228,242	1,228,242	1,756,731	1,756,731	1,228,242
Receptacle Equipment	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	439,177	69,560	439,177	439,177	439,177	439,177	439,177	439,177	69,560	69,560	439,177	439,177	69,560
Space Heating - NG	8,452,750	48,102	-	-	-	40	-	8,087,516	8,452,750	3,717,572	8,063,383	8,452,750	8,834,398	8,684,568	7,885,698	8,507,077	8,140,427	6,733,756	5,196,579	-	-	-	-	-	-
Space Heating - Electricity	-	2,207,151	2,222,569	1,145,737	1,144,671	2,428,463	2,431,117	-	-	1,064,167	-	-	-	-	-	-	-	-	-	2,326,152	377,284	377,284	1,005,252	1,005,252	377,287
Service Water Heating - NG	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	2,936,179	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	3,670,238	2,936,179	2,936,179	2,936,179	2,936,179	2,936,179
Space Cooling	397,049	397,140	397,119	361,300	283,083	288,473	290,675	397,099	397,049	381,130	398,621	397,049	366,086	364,689	350,310	389,185	390,278	377,300	364,513	366,044	117,644	117,644	395,400	403,062	161,150
Heat Rejection	204,467	204,473	204,465	121,349	72,038	80,362	80,651	204,466	204,467	113,404	202,818	204,467	188,637	191,792	185,636	202,771	200,750	192,248	181,919	188,604	46,110	46,110	191,710	196,524	76,280
Interior Central Fans	1,348,788	1,348,788	1,348,789	1,281,445	1,281,445	1,281,445	1,281,444	1,348,788	1,348,788	1,348,874	1,349,857	1,348,788	1,351,095	1,348,745	1,331,345	1,348,570	1,341,540	1,308,929	1,275,707	1,351,086	1,281,444	1,281,444	1,370,510	1,370,890	1,281,444
Interior Local Fans	249,525	249,555	249,544	348,874	348,912	348,173	348,541	249,485	249,525	230,459	373,147	249,525	259,747	251,361	227,933	249,120	239,525	188,702	131,885	259,799	162,659	162,659	253,309	254,663	162,789
Pumps	54,537	80,862	80,868	31,104	32,685	24,235	24,218	53,450	54,537	39,581	54,990	54,537	52,426	53,059	50,858	54,116	53,699	51,467	49,555	78,929	21,368	21,368	72,090	72,035	25,110
Renewables	-	-	-	-	-	-	-	-	-	-	-	773,384	-	-	-	-	-	-	-	-	773,384	-	773,384	-	773,384
Total	**16,573,262**	**10,402,217**	**10,369,500**	**9,155,955**	**9,028,980**	**10,317,337**	**10,322,792**	**16,206,950**	**15,839,203**	**12,761,333**	**16,308,962**	**15,799,878**	**16,390,046**	**16,390,743**	**15,897,926**	**16,616,985**	**16,232,365**	**14,718,548**	**13,066,304**	**9,908,271**	**5,467,106**	**6,240,490**	**7,646,974**	**8,434,513**	**5,544,657**

EUI (kBtu/sf/yr)	Existing	**HVAC-1A-1 Existing** Centralized Water Source Heat Pump	**HVAC-1A-2 Future** Centralized Water Source Heat Pump	**HVAC-1B-1 Existing** De-Centralized Water Source VRF Fan Coils	**HVAC-1B-2 Future** De-Centralized Water Source VRF Fan Coils	**HVAC-1C Existing/ Future** De-Centralized Air Source VRF Fan Coils (supplement heat)	**HVAC-1D Existing/ Future** De-Centralized Air Source VRF Fan Coils	**HVAC-2** OA Preheat Using CHW	**HVAC-3** Preheat Domestic Hot Water with Sanitary Flow	**HVAC-4** De-Centralized Ground Source Heat Pumps	**HVAC-6** Residential Rm Space Temp Set-Back	**ELEC-1** Photovoltaics	**ELEC-2** Lighting Efficiency Upgrade	**ELEC-3** Plugs and occupants	**ARCH-1** High Performance Windows	**ARCH-2** Solar Shading	**ARCH-3** Flat Roof Insulation	**ARCH-4** Reinsulate from Interior	**ARCH-5** Remove interior insulation and reskin brick	**ECM-A** HVAC-1a future, ELEC-2	**ECM-B** HVAC-1A future, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ELEC-2, ELEC-3, ARCH-5	**ECM-C** HVAC-1A future, HVAC-2, HVAC-3, HVAC-6, ELEC-2, ELEC-3, ARCH-5	**ECM-D** HVAC-1A future, HVAC-2, HVAC-3, HVAC-6, ELEC-1, ARCH-2	**ECM-E** HVAC-1A future, HVAC-2, HVAC-3, HVAC-6	**ECM-F** HVAC-1B existing/2/3/6, ELEC-1/2/3, ARCH-1/2/3/4/5
Interior Lighting	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	7.3	10.4	10.4	10.4	10.4	10.4	10.4	7.3	7.3	7.3	10.4	10.4	7.3
Receptacle Equipment	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	0.4	2.6	2.6	2.6	2.6	2.6	2.6	0.4	0.4	2.6	2.6	0.4
Space Heating - NG	50.2	0.3	-	-	-	0.0	-	48.0	50.2	22.1	47.9	50.2	52.4	51.6	46.8	50.5	48.3	40.0	30.9	-	-	-	-	-	-
Space Heating - Electricity	-	13.1	13.2	6.8	6.8	14.4	14.4	-	-	6.3	-	-	-	-	-	-	-	-	-	13.8	2.2	2.2	6.0	6.0	2.2
Service Water Heating - NG	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	17.4	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	21.8	17.4	17.4	17.4	17.4	17.4
Space Cooling	2.4	2.4	2.4	2.1	1.7	1.7	1.7	2.4	2.4	2.3	2.4	2.4	2.2	2.2	2.1	2.3	2.3	2.2	2.2	2.2	0.7	0.7	2.3	2.4	1.0
Heat Rejection	1.2	1.2	1.2	0.7	0.4	0.5	0.5	1.2	1.2	0.7	1.2	1.2	1.1	1.1	1.1	1.2	1.2	1.1	1.1	1.1	0.3	0.3	1.1	1.2	0.5
Interior Central Fans	8.0	8.0	8.0	7.6	7.6	7.6	7.6	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9	8.0	8.0	7.8	7.6	8.0	7.6	7.6	8.1	8.1	7.6
Interior Local Fans	1.5	1.5	1.5	2.1	2.1	2.1	2.1	1.5	1.5	1.4	2.2	1.5	1.5	1.5	1.4	1.5	1.4	1.1	0.8	1.5	1.0	1.0	1.5	1.5	1.0
Pumps	0.3	0.5	0.5	0.2	0.2	0.1	0.1	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.1	0.1	0.4	0.4	0.1
Renewables	-	-	-	-	-	-	-	-	-	-	-	4.6	-	-	-	-	-	-	-	-	4.6	-	4.6	-	4.6
Total (kBtu/sf/yr)	**98.4**	**61.8**	**61.6**	**54.4**	**53.6**	**61.3**	**61.3**	**96.2**	**94.0**	**75.8**	**96.8**	**93.8**	**97.3**	**97.3**	**94.4**	**98.6**	**96.4**	**87.4**	**77.6**	**58.8**	**32.5**	**37.0**	**45.4**	**50.1**	**32.9**
Savings		**37%**	**37%**	**45%**	**46%**	**38%**	**38%**	**2%**	**4%**	**23%**	**2%**	**5%**	**1%**	**1%**	**4%**	**0%**	**2%**	**11%**	**21%**	**40%**	**67%**	**62%**	**54%**	**49%**	**67%**
Elec (Mmbtu)	4,450	6,684	6,699	5,486	5,359	6,647	6,653	4,449	4,450	5,374	4,575	3,677	3,885	4,036	4,342	4,440	4,422	4,315	4,199	6,238	2,531	3,304	4,711	5,498	2,608
Nat Gas (Mmbtu)	12,123	3,718	3,670	3,670	3,670	3,670	3,670	11,758	11,389	7,388	11,734	12,123	12,505	12,355	11,556	12,177	11,811	10,404	8,867	3,670	2,936	2,936	2,936	2,936	2,936
Elec ($)	$ 112,170	$ 168,468	$ 168,856	$ 138,268	$ 135,068	$ 167,540	$ 167,679	$ 112,143	$ 112,170	$ 135,440	$ 115,322	$ 92,677	$ 97,932	$ 101,726	$ 109,441	$ 111,903	$ 111,450	$ 108,749	$ 105,849	$ 157,231	$ 63,792	$ 83,286	$ 118,736	$ 138,586	$ 65,747
Nat Gas ($)	$ 39,786	$ 12,203	$ 12,045	$ 12,045	$ 12,045	$ 12,045	$ 12,045	$ 38,587	$ 37,377	$ 24,246	$ 38,508	$ 39,786	$ 41,038	$ 40,547	$ 37,925	$ 39,964	$ 38,761	$ 34,144	$ 29,100	$ 12,045	$ 9,636	$ 9,636	$ 9,636	$ 9,636	$ 9,636
Total Energy Cost ($)	**$ 151,956**	**$ 180,671**	**$ 180,901**	**$ 150,314**	**$ 147,113**	**$ 179,585**	**$ 179,724**	**$ 150,730**	**$ 149,547**	**$ 159,686**	**$ 153,830**	**$ 132,462**	**$ 138,971**	**$ 142,273**	**$ 147,365**	**$ 151,867**	**$ 150,211**	**$ 142,893**	**$ 134,948**	**$ 169,276**	**$ 73,429**	**$ 92,922**	**$ 128,372**	**$ 148,222**	**$ 75,383**
Elec (metric tons CO2)	777	1,166	1,169	957	935	1,160	1,161	776	777	938	798	642	678	704	758	775	772	753	733	1,089	442	577	822	959	455
Nat Gas (metric tons CO2)	643	197	195	195	195	195	195	624	604	392	623	643	664	656	613	646	627	552	471	195	156	156	156	156	156
Total Carbon (metric tons CO2)	**1,420**	**1,364**	**1,364**	**1,152**	**1,130**	**1,355**	**1,356**	**1,400**	**1,381**	**1,330**	**1,421**	**1,285**	**1,342**	**1,360**	**1,371**	**1,421**	**1,398**	**1,305**	**1,203**	**1,283**	**597**	**732**	**978**	**1,115**	**611**



Many of the HVAC ECMs entail fuel switching (decarbonization). Relative to electricity, natural gas is very cheap for UM. The natural gas utility rate is 7.68x lower than the electricity rate. This utility rate difference between natural gas and electricity causes some ECMs to have a negative cost savings. The following are brief explanations of the results or ECMs that entail fuel switching.

- HVAC-1A-1 Existing entails fuel switching for the bulk of the heating load (80% of the building peak heat load) from natural gas to electricity (via heat pump with 3 COP). Energy and carbon savings are achieved however, the efficiency of the heat pump does not overcome the difference between the natural gas and electricity utility rates, causing the energy cost to increase.
- HVAC-1A-2 Future has a slightly higher energy cost compared to HVAC-1A-1 Existing, due to the additional fuel switching of the remaining heating load (20% of the building peak load) from natural gas to electricity (via heat pump with 2.5 COP). Further energy and carbon savings are achieved relative to HVAC-1A-1.
- HVAC-1B-1 Existing achieves more energy and carbon savings compared to the HVAC-1A alternatives. This is due to the heat pump acquiring free heat from the central cooling plant. The high efficiency of this system offsets the electric and natural gas utility rate difference and achieves a positive energy cost savings.
- HVAC-1B-2 Future achieves 2% more cost savings than HVAC-1B-1 Existing because it is able to reject heat to the MTHHW system at 110F rather than the central cooling plant (double compression).
- HVAC-1C and HVAC-1D are both air source VRF systems with lower efficiencies than the HVAC-1B alternatives which are water source VRF. HVAC-1C and HVAC-1D achieve energy and carbon savings compared to the existing case through the use of heat pumps, however, the difference in electricity and natural gas rates results in an energy cost increase.
- HVAC-4 entails the 1 to 1 replacement of the dorm room FCUs with WSHP terminals. The dorm room spaces account for 40% of the building. The remaining 60% of the building is served with VAV with HW reheat from the central plant. Therefore, only part of the heating load has been switched from natural gas to electricity. Energy and carbon savings are achieved, but due to the difference in electricity and natural gas rates, the energy cost increases

ECM Summary

	COUZENS ECM SUMMARY													
	Energy Conservation Measure	Description	Energy Reduction Potential	Carbon Reduction Potential	Central Plant Integration	First Cost	Life Cycle Cost	Comfort / Productivity Value	Timing / Synergy	Education Value	Disruption and Relocation	Exterior Elements Committee	Program Change Possibility	Other
HVAC Systems	**HVAC-1A-1** Existing Centralized Water Source Heat Pump	Use central heat pumps to heat without steam while making chilled water for campus	Medium	Medium	Uses 58F CHWR as heat source in spring/fall	$$	$$	-	+	+	+	-	+	
	HVAC-1A-2 Future Centralized Water Source Heat Pump	Use Variable Refrigerant Flow to recirculate/ exchange heat, campus loops only for peaks	Medium	Medium	Uses 58F CHWR as heat source in spring/fall	$$	$$	-	+	+	+	-	+	
	HVAC-1B-1 Existing De-Centralized Water Source VRF Fan Coils	Use Variable Refrigerant Flow to recirculate/ exchange heat, campus loops only for peaks	High	High	Net building cooling or heating load from campus	$$$	$$$	-	+	+	+++	-	+	
	HVAC-1B-2 Future De-Centralized Water Source VRF Fan Coils	Use Variable Refrigerant Flow to recirculate/ exchange heat, campus loops only for peaks	High	High	Net building cooling or heating load from campus	$$$	$$$	-	+	+	+++	-	+	
	HVAC-1C Existing/Future De-Centralized Air Source VRF Fan Coils (supplement heat)	Use Air-Cooled Variable Refrigerant Flow to recirculate/ exchange heat	High	High	Removes use of CHW system. Minimal steam/HHW usage for perimeter	$$$	$$$	-	+	+	+++	-	+	
	HVAC-1D Existing/Future De-Centralized Air Source VRF Fan Coils	Use Air-Cooled Variable Refrigerant Flow to recirculate/ exchange heat	High	High	Removes use of CHW and LPS/MTHW systems	$$$	$$$	-	+	+	+++	-	+	
	HVAC-2 OA Preheat using CHW	Preheat outside air with chilled water return while making chilled water for the campus	Low	Low	Uses 62F CHWR to produce 42F CHWS	$	$	-	+	+	+	-	+	
	HVAC-3 Preheat domestic hot water with Sanitary Flow	Preheat domestic hot water with heat from shower sanitary drains	Low	Low	Minimally reduces LPS usage	$	$	-	+	+	+	-	+	
	HVAC-4 De-Centralized Ground Source Heat Pumps	Use geothermal wells as net thermal source for heating and cooling residential halls	High	High	Reduces LPS/MTHW, CHW usage	$$$	$$$	-	+	+	++ (site)	-	+	
	HVAC-6 Residential Rm Space Temp Set-Back	Use lighting occupancy sensor to set back space temperatures	Medium	Medium	Reduces LPS/MTHW, CHW usage	$$	$$	-	+	+	+	-	+	
ELEC Systems	**ELEC-1** Photovoltaics	Practical Maximim Rooftop Photovoltaic Panel capacity	Medium	Medium	Microgrid Potential	$$	$	-	+	++	-	-	-	
	ELEC-2 Lighting Efficiency Upgrade	LED lighting and enhance lighting controls with auto off and daylighting	Medium	Medium	NA	$	$	+	+	+	+	-	-	
	ELEC-3 Submetering	Plug load control and comprehensive energy management targeting user habits	Low	Low	NA	$$	$	+	+	+++	+	-	-	
ARCH Systems	**ARCH-1** High Performance Windows	Remove existing Curtain Wall system and replace with triple glazing with high efficiency Low-E coatings and argon	Medium	Medium	NA	$$	$$	++	-	-	++	-	-	
	ARCH-2 Solar Shading	Install Solar Shades on South Facing Windows	Low	Low	NA	$$	$$	+	+	+	+	++	-	
	ARCH-3 Flat Roof Insulation	Replace existing roof insulation with R-30 minimum	Medium	Medium	NA	$$	$$	+	-	-	-	-	-	
	ARCH-4 Reinsulate from Interior	Replace existing wall insulation with spray foam insulation	Low	Low	NA	$$$	$$	+	-	+	+++	-	+	
	ARCH-5 Remove interior insulation and reskin brick	Remove existing brick and interior insulation and install new insulation and brick on exterior	Low	Low	NA	$$$	$$	+	-	+	++++	++++	+	

Table D: ECM Summary

Life Cycle Cost

The Life Cycle Cost (LCC) Analysis is a very high-level study intended for comparison purposes. It is a method for assessing the total cost of ownership in present value terms which considers all costs of acquiring, owning, and disposing of a building or building system. Important information regarding cost model content and assumptions is listed below:

- 1.35 Factor utilized for soft costs to convert estimated construction costs into project costs; construction contingency is part of 1.35 factor
- Estimates include 5% for construction escalation per year for two years
- Suggested 2.5% inflation rate (UM) for the duration of the payback period replaced with US Department of Energy Escalation Projections (Exhibit 7)
- Estimates assume UM Cost of Money at 3%, this is the estimated average cost of borrowing.
- Current campus utility rates.
    - Natural Gas Rate: $3.40/Mcf
    - Electricity Rate: $0.086/kWh
- 30 Year lifespan of all equipment, with a project start date of 2023
- Estimates exclude maintenance costs associated with systems upgrades
- Estimates assume General Contractor format for construction
- Estimates assume no relocation
- Estimate assumes building is fully vacated throughout renovation
- Estimate should be understood as high-level and for comparative purposes; not for project use

ECM-A:

- Project Cost = $10,152,000
- Total Life Cycle Cost = $13,517,722 (Refer to Exhibit 8 for detailed analysis)
- Risk: The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion. The system concepts are known proven systems that mitigates the risks associated with the energy and performance evaluations.

ECM-B:

- Project Cost = $63,082,800
- Total Life Cycle Cost = $66,863,258 (Refer to Exhibit 8 for detailed analysis)
- PV Maintenance: The local climate experiences enough precipitation to self-clean the PV modules and periodic cleaning/washing is not required. An annual inspection of the system is recommended. The annual inspection includes visually inspecting modules, inverters, wiring and other balance of system (BOS) components. Replacing deficient components, tightening wiring connections and removing debris in and around the array are some of the tasks that may be required to maintain the system. Overall, maintenance costs for an annual inspection should be approximately $4,000.

- Risk: The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion. The new enclosure system with this option includes more risk associated with unforeseen existing conditions regarding the integrity of the existing structural system that could support the new enclosure.

ECM-C:
- Project Cost = $60,825,600
- Total Life Cycle Cost = $64,852,582 (Refer to Exhibit 8 for detailed analysis)
- The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion. The new enclosure system with this option includes more risk associated with unforeseen existing conditions regarding the integrity of the existing structural system that could support the new enclosure.

ECM-D:
- Project Cost = $9,213,750
- Total Life Cycle Cost = $11,828,049 (Refer to Exhibit 8 for detailed analysis)
- The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion.

ECM-E:
- Project Cost = $4,684,500
- Total Life Cycle Cost = $7,462,359 (Refer to Exhibit 8 for detailed analysis)
- The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion.

ECM-F:
- Project Cost = $99,812,250
- Total Life Cycle Cost = $105,065,305 (Refer to Exhibit 8 for detailed analysis)
- The potential risk factors include the accuracy of the opinion of costs due to high level concept designs rather than detailed designs and existing condition observations, rather than detailed investigation or confirmation of quantities. These risks are mitigated by contingencies in the initial cost opinion. The new enclosure system with this option includes more risk associated with unforeseen existing conditions regarding the integrity of the existing structural system that could support the new enclosure.

Life Cycle Cost Summary (1)			
Energy Conservation Measure	**Project Cost**	**Life Cycle Cost**	**Total CO2 (3)**
Existing Bldg. Condition	-	-2	42,598
ECM-A	$10,152,000	$13,517,722	38,499
ECM-B	$63,082,800	$66,863,258	17,924
ECM-C	$60,825,600	$64,852,582	21,973
ECM-D	$9,213,750	$11,828,049	29,335
ECM-E	$4,684,500	$7,462,359	33,458
ECM-F	$99,812,250	$105,065,305	18,330

(1) 30-year life cycle
(2) Not provided as not comparable to ECM A, B, C, D, E, F.
(3) 30-year total CO_2 emissions in tons (lower values are better). An approximation provided for comparative purposes only; does not adjust for reductions in CO_2 emissions associated with DTE electricity production anticipated to occur over the 30-year period.