Mueller Laboratory Renovation: Final Report

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Construction Management Option
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Executive Summary

Roof deck reinforcement beams to help carry the load of new air handler units can be installed on top of the roof deck instead of underneath. This design choice will provide a better quality product, save money, and decrease allow the air handler units to be installed 20 days earlier than otherwise possible.

Asbestos is present in floor tiles in the renovation. Disturbances to the tile from the renovation could create unsafe working conditions. Pennsylvania law requires the abatement of the asbestos containing material given the quantity found on the project. Increasing the abatement crew size accelerates the schedule without significant changes in cost.

The renovation’s current worksite is disorganized. Moving the site to a more open, flatter area to the south has a wealth of benefits. Material can be stored more neatly, deliveries are easier, and contractor parking is expanded.

Recycling opportunities are limited for the project due to the distance needed to travel to recycling centers. A scrapyard is close enough for relatively straightforward recycling of large scrap metal. Selling the large quantities of metal scrap will more than pay for the extra equipment needed to recycle metal on the project.

While LED downlight fixtures are efficient, using Edison-base fixtures and screw-in LED bulbs may make sense. Initial cost is lower and system replacement or upgrade is as easy as changing a light bulb. Screw-in bulbs perform nearly identically to hard-wired fixtures, and sometimes even perform better.

The overall recommendations are as follows:
It is recommended that the roof reinforcement be moved to the top of the roof deck.
The abatement of asbestos should be assigned more crews to decrease the duration.
The project’s worksite would benefit greatly from going south, not west.
Effective recycling remains difficult to achieve on a renovation such as this one.
Screw-in LED bulbs should be used instead of hard-wired LED fixtures.

Project Background

The Mueller Laboratory building on the Penn State University Park campus was built in 1963. Fifteen years after its construction that it was given its current title, in honor of Erwin W. Mueller, a Penn State faculty member from 1952-1977. Dr. Mueller was the first person to experimentally observe atoms, and developed several high precision microscopes to study them.

In the 51 years since it was built Mueller Laboratory had not undergone a significant renovation. Notably, in 2001 Penn State professor of ecology Christopher Uhl led a team of grad students in exposing the shortcomings of the Mueller building, ultimately releasing a document titled "The Mueller Report" detailing inefficiencies in the building.

Finally, in 2012, Penn State chose to begin the renovation of the Mueller building. Robert Bloom, Facilities Project Manager for Penn State's Office of Physical Plant was chosen as project leader. Priorities included full renovation of labs on four of the building's seven floors, overhauling the laboratory exhaust system, replacing the outdated mechanical and electrical systems, and installing a new fire sprinkler system. Overall 75,482 square feet of the building will be renovated. Although much of the building’s interior will be gutted, the building's facade will not change extensively during the renovation. The only outwardly visible addition to the building will be four brick-wrapped HVAC chases. Stantec, which has a State College office, was chosen to do the design drawings.

Penn State collected bids for the project in fall of 2013. Barton Malow was selected as the CM firm, with a team led by Scott Mull. Starting in May of 2014, the renovation is schedule to be completed in August of 2015, in time for the start of the fall semester. By its completion roughly 18 million dollars will have been spent on the renovation.

Many pieces of the building's renovation will make it more sustainable. An overhauled HVAC system will both be more efficient. Connecting to campus chilled water will benefit from the economy of scale, saving energy. And improved electrical distribution will minimize loses.

Project Details

There are five main components of the renovation: new mechanical systems, new electrical systems, new interior finishes, building enveloped maintenance, and improved accessibility and safety.

The primary component of the renovation is a complete overhaul of the mechanical systems. The HVAC system will be almost completely replaced, from air handlers, to ductwork, to control systems. The new system will include VAV and constant volume air distribution. Additionally the building will be connected to campus-supplied chilled water, with connections run to each of the labs. Also, many components of the building's plumbing system need replacement. The domestic hot water converter and its associated piping are reaching the end of their service life. Laboratory waste drains are original to the building and leak in spots. And even the bathroom fixtures and piping are aging and worn. As such, much of the plumbing system will be replaced during the renovation.

Another large component of the renovation will be the replacement of the building's electrical system. The switchgear and transformers of the building are all original to the building. Also, the panel and breaker boxes that supply the labs are at near capacity. Furthermore, many of the lighting fixtures in the building run on old, inefficient ballasts, at 120 volts. And finally, the emergency power feeders to the building have proved to be inadequate during power outages. Because of the shortcomings of the entire electrical system, virtually all of it will be replaced in the renovation.

Interior finishes makes up the third most costly component of the renovation. Carpet, floor tiles, and seamless laboratory floors are to be installed. In addition to flooring, select interior doors and hardware and laboratory furniture are to be replaced.

Another piece of the renovation is maintenance of the building envelope. The warranty on the building's roof system expired in 2004, and will thus be replaced. Also, some of the mortar joints of the brick exterior are failing, and so selective repointing of the bricks will be done during the renovation.

Last, but not least, are accessibility and safety improvements. The building has no sprinkler system. The stairway guardrails, fire alarms, and exits signs no longer comply with current codes and standards. There are not enough laboratory eyewash stations, and many of those present are of poor quality. Also, both elevators in the building are original to the building, and lack fire extinguishers or emergency phones. Braille labeling is positioned incorrectly. All of these problems will be corrected in the renovation.

Roof Reinforcement

One of the main tasks of the Mueller Laboratory renovation is the updating of the mechanical system. This includes installation of 4 new roof-top exhaust fans and 3 new air handler units (AHUs). In order to support these larger, heavier fans and AHUs the roof deck needs to be reinforced. To accomplish this, the project plans call for 25 steel W-shape beams to be installed underneath the roof deck, as shown below.

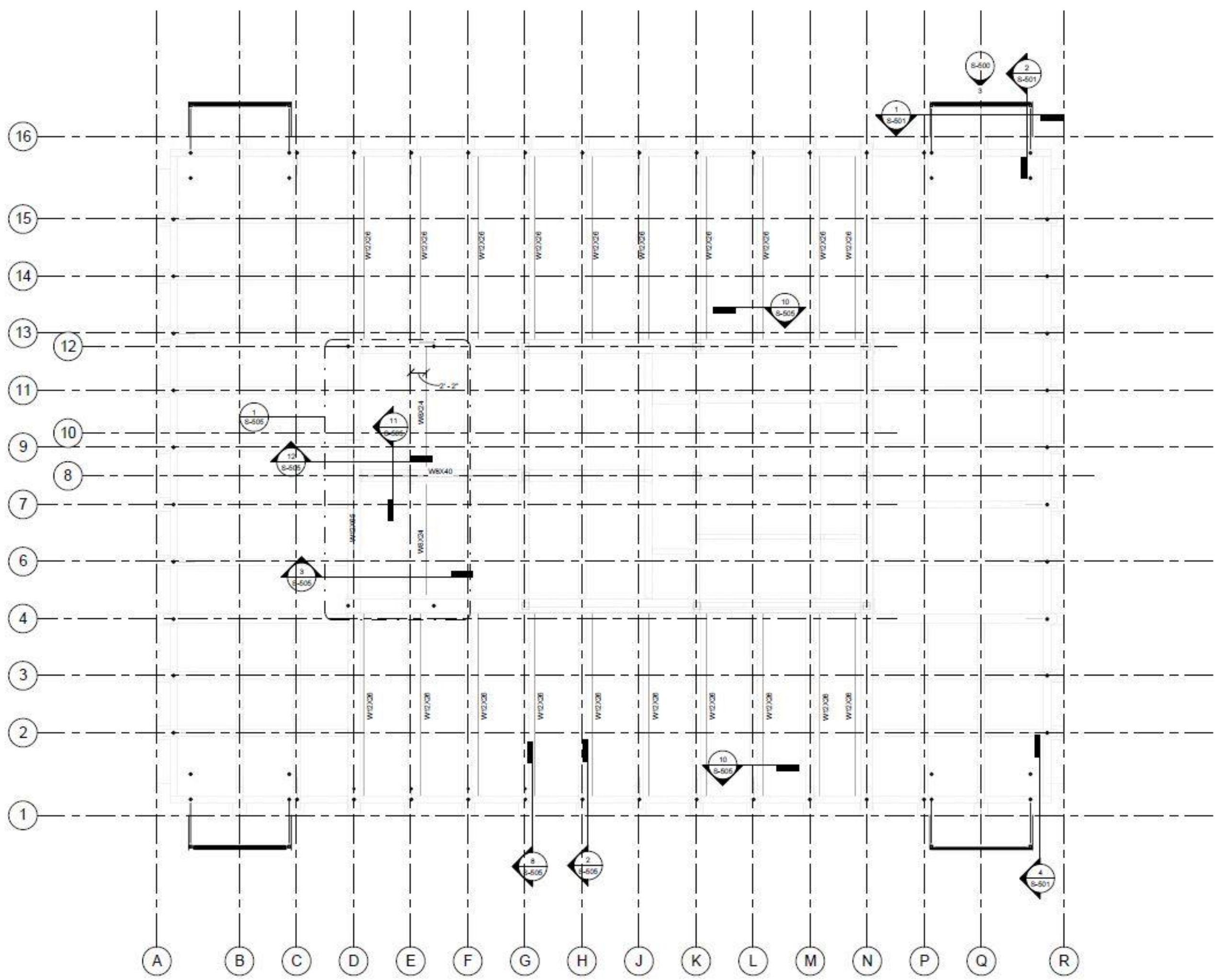


Figure 1: Current roof reinforcement plan. (From project structural plans)

Sections 10 and 12, shown below, shows how the reinforcing steel will be installed underneath the roof deck.

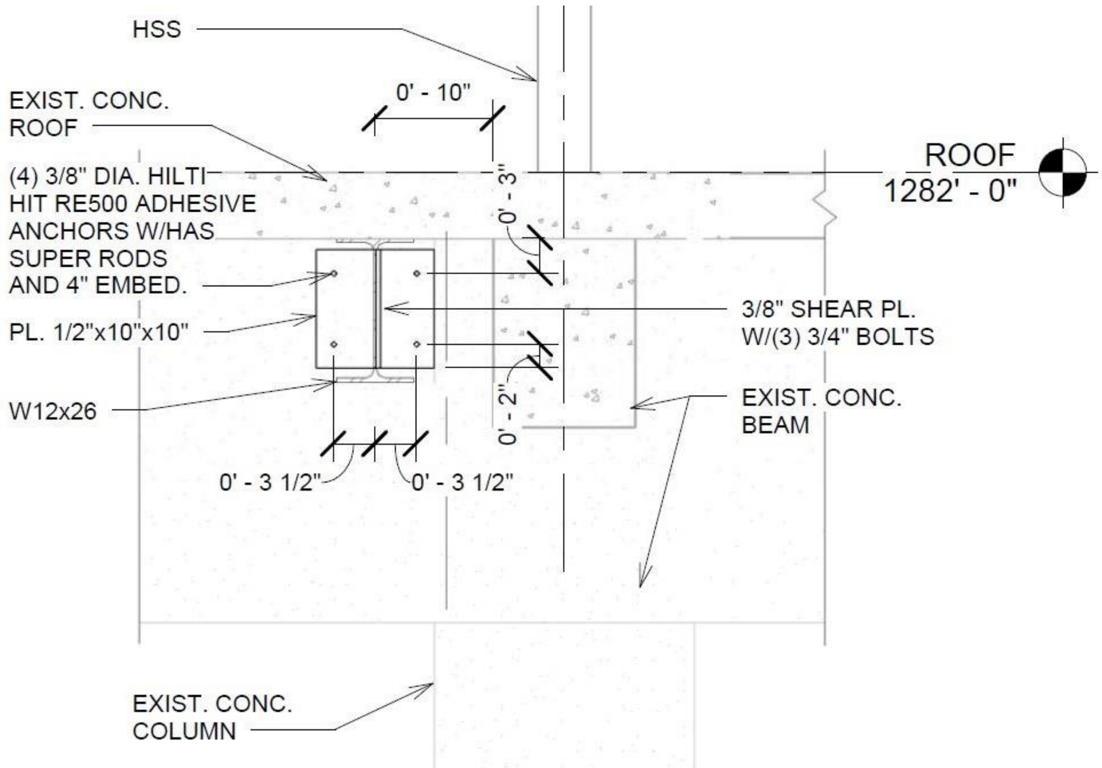


Figure 2: Section 10, detail of current roof reinforcement plan. (From project structural plans)

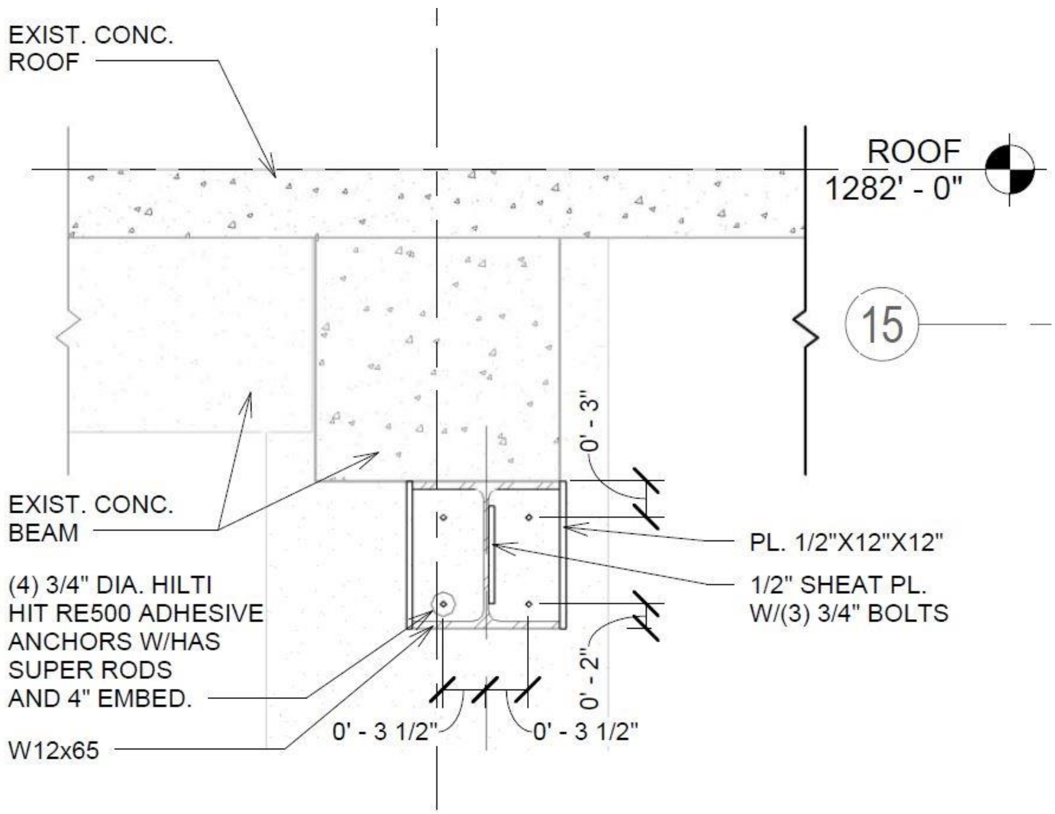


Figure 3: Section 12, detail of current roof reinforcement plan. (From project structural plans)

Complete demolition of the 6th floor must take place to allow access to the underside of the roof deck. Demolition was scheduled to take 10 days. This demolition can only take place after asbestos abatement has taken place on the 6th floor. Abatement of the asbestos was also scheduled to take 10 days. The schedule for the 6th floor is shown below.

6TH FLOOR		210	30-Jun-14	20-Apr-15
6F-01010	Owner Vacates Floor	0		30-Jun-14*
6F-01020	Erect Temporary Barriers and Lab Bench Protection	5	01-Jul-14	07-Jul-14
6F-02240	MEP Cut, Cap, Make Safe for Abatement/Demo	5	08-Jul-14	14-Jul-14
6F-02250	Demo Lab Casework; Set Up Abatement	5	08-Jul-14	14-Jul-14
6F-02290	Abatement	10	15-Jul-14	28-Jul-14
6F-02320	MEP Cut, Cap, Safe, Drop for Bulk Demo	10	29-Jul-14	11-Aug-14
6F-02340	Rough Demolition	10	12-Aug-14	25-Aug-14
6F-22020	Remove MEP Stub Ups Thru Floor	5	26-Aug-14	01-Sep-14
6F-22030	U/S Drain Connections/Core Drilling	5	26-Aug-14	01-Sep-14
6F-22040	OH Storm Piping R/I	30	26-Aug-14	06-Oct-14
6F-05100	Install Steel Reinforcing Below Roof Slab	10	26-Aug-14	08-Sep-14

Figure 4: 6th floor schedule showing install of steel reinforcing. (From project schedule)

Thus, in total, 20 days of preparation are needed before installation of the roof reinforcing steel can begin. This is nearly a full month of schedule time. To speed up construction, there are two options: eliminate the need to access the underside of the roof deck, or speed up the abatement/demolition process. The latter option will be discussed later in this report. The first option will be discussed here.

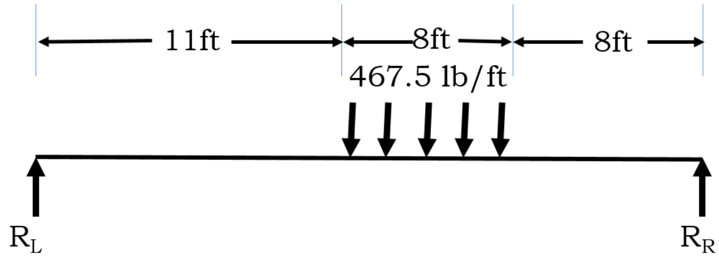
The current plant calls for steel reinforcing beams to be placed under the roof deck, or underneath concrete beams supporting the roof deck. These beams, in conjunction with the roof deck and deck beams, support the weight of the AHUs. Calculations for the sizing of these beams has been performed by the project's structural engineer. These beams take up part of the load of the AHUs and transfer it to large concrete beams, which in turn transfer the load to the building's columns. As such the connections of the ends of the steel reinforcing beams to the existing concrete beams must be able to resist a maximum of 2077.8 lbs of shear force, as demonstrated below.

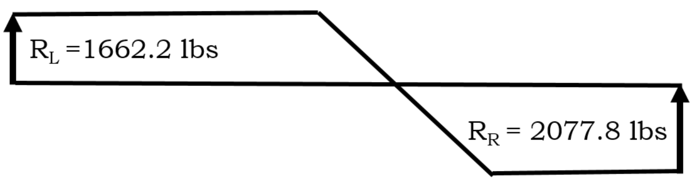
AHU load on beam:

AHU weight	# of supporting beams	Weight/beam
18700 lbs	5	3740 lbs

3740 lbs/8 ft = 467.5 lbs/ft

Free body diagram:





$M_O = 0 = R_R*(0) +3740*(12) – R_L*(27) = 0$

$R_L*(27) = 44,880$

$R_L = 1662.2$

$F_Y = 0 = R_L – 3740 + R_R = 0$

$1662.2 – 3740 + R_R = 0$

$R_R = 2077.8$

The 2 kips of shear is well within the capacity of the specified ¾ bolts, which have a minimum shear strength of 12 kips. However, if the steel reinforcing beams are instead placed on top of the roof deck, instead of underneath it, the need for high strength connections on the end of the beams is eliminated. Placing the steel on top of the roof deck still transfers the load directly to the supporting concrete beams and columns. Furthermore, there are several reinforcing beams that were to be placed directly underneath concrete beams. Moving this supporting steel to the top instead has zero effect on the structural calculations of the reinforcing. Additionally, moving the reinforcing steel to the top of the roof allows it to be placed exactly where it will support the AHUs best, as shown below.

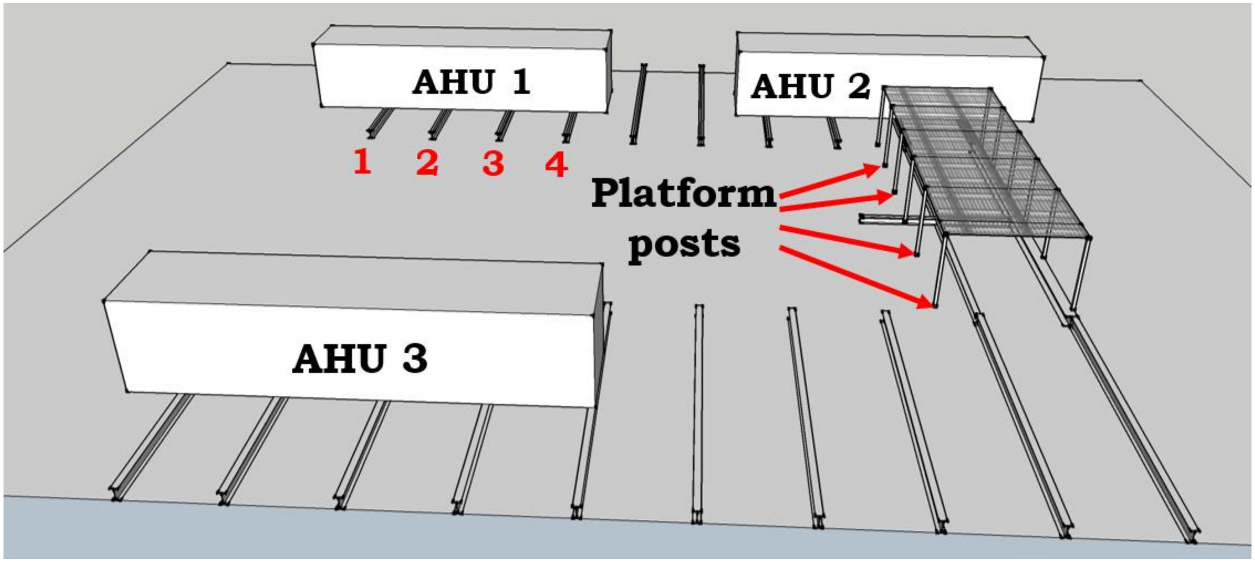


Figure 5: Current plan of reinforcing beam locations.

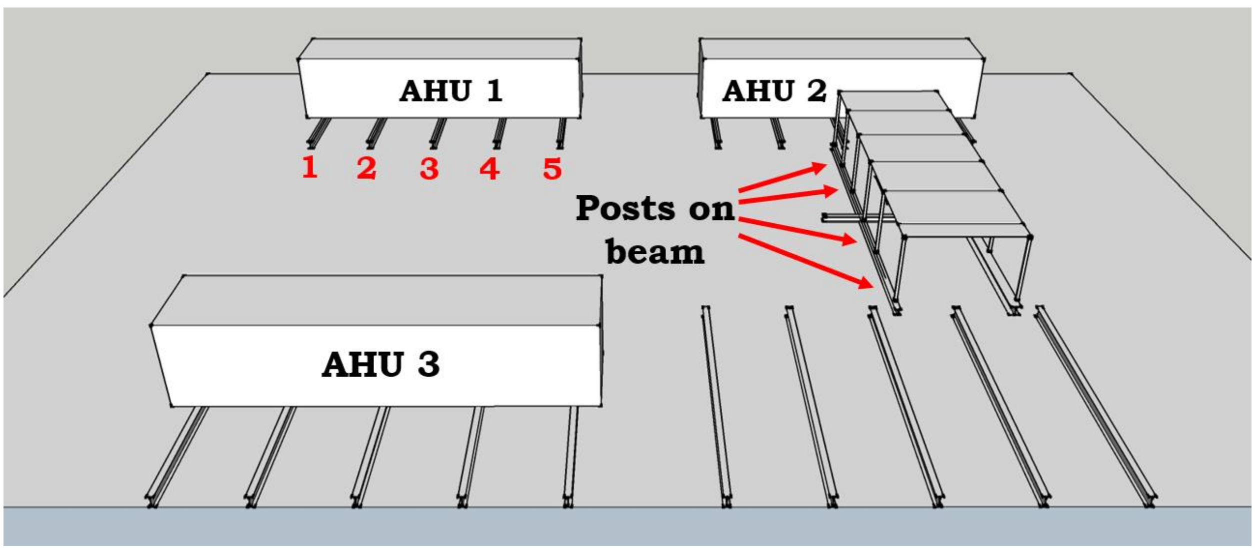


Figure 6: Proposed plan of new reinforcing beam locations.

This eliminates the need to work around the existing concrete roof deck support beams, and does not lower the ceiling height of the 6th floor.

This does raise the difficulty of securing the beams to the roof deck. Conveniently, however, the renovation project includes the replacement of the membrane roof system, as shown on the schedule below.

ROOF		140	01-Jul-14	12-Jan-15
RF-23020	Temp Tie-in of Existing AHU 1/4 to 5/6 Floor Make-up Air Duct	10	01-Jul-14	14-Jul-14
6F-05020	Erect Screen Wall Structure - Quad 1	10	07-Jul-14	18-Jul-14
6F-02300	Remove AHU 5/6	10	15-Jul-14	28-Jul-14
6F-05050	Erect Screen Wall Structure - Quad 2	5	21-Jul-14	25-Jul-14
6F-05060	Erect Screen Wall Structure - Quad 3	5	28-Jul-14	01-Aug-14
RF-23050	Install HRC/EF Roof Curb	5	29-Jul-14	04-Aug-14
6F-05080	Erect Screen Wall Structure - Quad 4	5	04-Aug-14	08-Aug-14
6F-07010	Replace Roofing Membrane - Quad 1	15	05-Aug-14	25-Aug-14
RF-23060	Set HRC/EF (1st half)	5	05-Aug-14	11-Aug-14
RF-23070	Tie-in Existing Exhaust Riser to Vekor Fans	10	12-Aug-14	25-Aug-14
RF-23080	Final Connections & Start-up - EF/HRC (1st half)	20	12-Aug-14	08-Sep-14
6F-08000	Install Metal Wall Panels - Quad 1	5	26-Aug-14	01-Sep-14
RF-23100	Install Distrib Duct - Quad 1	10	26-Aug-14	08-Sep-14
6F-08010	Install FRP Panels - Quad 1	5	02-Sep-14	08-Sep-14
6F-02390	Remove Existing HRC/EF	10	09-Sep-14	22-Sep-14
RF-23130	Install Curb for AHU-2	5	23-Sep-14	29-Sep-14
6F-07050	Replace Roofing Membrane - Quad 3	15	30-Sep-14	20-Oct-14
RF-23140	Set AHU-2	5	30-Sep-14	06-Oct-14
RF-23150	Final Connections & Start-up - AHU-2	20	07-Oct-14	03-Nov-14
6F-02510	Remove Chiller	10	17-Oct-14	30-Oct-14
RF-23160	Install Distrib Duct - Quad 3	10	21-Oct-14	03-Nov-14
6F-08030	Install Metal Wall Panels - Quad 3	5	21-Oct-14	27-Oct-14
6F-08040	Install FRP Panels - Quad 3	5	28-Oct-14	03-Nov-14
RF-23180	Install Curb for AHU-3	5	31-Oct-14	06-Nov-14
RF-23190	Connect Existing Supply Air Riser to AHU's	10	04-Nov-14	17-Nov-14
6F-07060	Replace Roofing Membrane - Quad 2	15	07-Nov-14	27-Nov-14
RF-23210	Set AHU-3	5	07-Nov-14	13-Nov-14

Figure 7: Roof schedule showing install of membrane roofing system. (From project schedule)

This means that the membrane roofing can be removed, the steel reinforcing beams can be bolted in place, and the new membrane roofing system installed around the steel beams. The AHUs and exhaust fans can then be installed directly on top of the steel reinforcing beams. For corrosion resistance all steel would need to be galvanized, just like the steel being used for the exhaust fan platform.

The result of installing the steel reinforcing beams is threefold. First, it removes the dependence the AHU placement has on the completion of the 6th floor demolition. Secondly it is cheaper since rooftop beams will be faster and safer to install, requiring no overhead. And thirdly, it allows the reinforcing steel to be placed exactly where it can best support the AHUs.

Asbestos Abatement

As discussed above, demolition on the floors being renovated must be preceded by asbestos abatement. Throughout Mueller Laboratory there are large areas of floor tile that contain asbestos. If this schedule abatement was deemed to be unnecessary then 40 days of schedule time could be saved.

The Pennsylvania Department of Environmental Protection (DEP) requires that "friable" asbestos containing material be removed prior to demolition or renovation. "Friable" asbestos is defined by the DEP as "asbestos containing material that is likely to release fibers through normal handling." It goes on to explain that "any material that may be destroyed, broken or reduced to powder through normal hand pressure is considered friable." Since the asbestos-containing floor tiles in Mueller are in good condition they can be considered non-friable. At this point it seems that abatement is not necessary.

However, the DEP continues with their definition. It states that "non-friable materials may also become friable if they are subjected to sanding, grinding, cutting, drilling or abrading." In the Mueller renovation there will be a number of cuts and core drillings made through the floor to allow pipe and ductwork to run vertically through the building. Thus, where cutting and drilling is to occur, abatement will be necessary.

But the DEP also gives guidelines for the required scope of abatement. They state that if the asbestos containing material exceeds 160 square feet, then full abatement is required before demolition of renovation can proceed. The Mueller renovation encompasses 75,482 square feet, and has far more than 160 square feet of asbestos containing tile. As such, asbestos abatement is a legal requirement of this renovation.

Since asbestos abatement is necessary, reducing its duration to the minimum necessary is desirable, so that demolition and renovation can proceed quickly. Duration and cost calculations are show below

Square footage of renovation	75,482 square feet

Single crew calculations:

Production rate of abatement of one crew	250 square feet/hr
Total duration of abatement	301 hours = 37.74 days
Cost per hour of abatement, one crew working	$125
Total cost of abatement	$37,625

Two crew calculations:

Production rate of abatement of two crews	500 square feet/hr
Total duration of abatement	151 hours = 18.87 days
Cost per hour of abatement, two crews working	$250
Total cost of abatement	$37,750

Predictably, doubling the crew size doubles the hourly rate, but at the same time halves the duration of the task. This results in roughly the same cost for both one crew and two crews. Since the cost is the same but the duration is halved, it makes sense to assign two crews to the asbestos abatement on this renovation.

Site Logistics

The current site plan for the Mueller renovation concentrates most of the equipment, material, and contractor space on the west side of the building. Access is from the northwest corner, off of Curtain Road. However, there are several shortcomings with using the west side of the site as the main storage, parking, and work area for the project. The diagram below shows the current site plan for the Mueller Laboratory renovation.

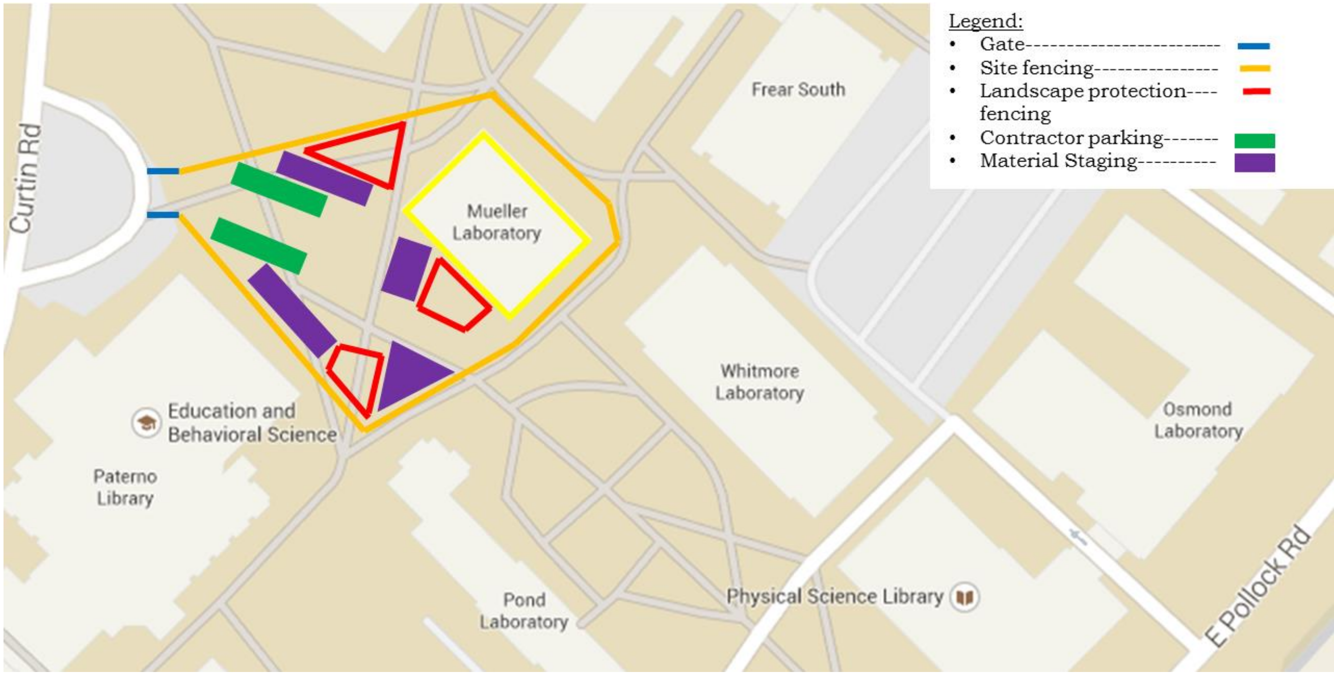


Figure 8: Current Mueller Laboratory renovation site plan. (Map from Google Maps)

While the site fencing encompasses a generous work area, several factors cut down on the amount of usable space. First is the presence of three islands of trees that must be protected, as seen in the picture below.

Figure 9: Fenced in areas with trees to be protected.

Since the Penn State University Park campus functions as an arboretum, all significant trees must be protected throughout the construction process. This requires fencing around these trees within the project perimeter fencing. These tree islands are fenced off for the duration of the project, constricting the worksite and reducing what area can be used for material staging and contractor parking.

A second factor is the lack of suitable material staging area. The purple triangular region in the site plan, shown above, is a material staging that is on a considerable slope, as seen below.

Figure 10: Material storage on slope.

Any tall items, such as stored mechanical equipment, would be in danger of falling over or sliding if placed on this slope. Thus, this area is delegated to lengths of pipe and other short items. This wastes valuable staging space. Furthermore, this necessitates storing the large mechanical equipment in the only open, flat space on the site, by the front gate. These pieces of stored equipment in turn displace contractor parking, creating a bottleneck at the site entrance gate, as shown in the picture below.

Figure 11: Stored mechanical equipment displacing contractor parking.

Storing the mechanical equipment also displaced other equipment as well, meaning the mortar mixer and stored scaffolding get placed in the only remaining open space, the center of the jobsite This further hinders the movement of JLG lifts and other equipment. Additionally, semi-trailers have no place to be unloaded without blocking either some of the 14 contractor park spaces or the dumpster, as shown below.

Figure 12: Stack of scaffolding and mortar mixer forced to center of site. Semi-trailer blocks the dumpster.

In all, the jobsite is congested and disorganized, as seen in the panorama below.

Figure 13: Panorama of existing job site.

At a glance, the using the west side as the main storage and work area, though clearly not ideal, seems to make sense compared to the alternatives. The north side of the building has even more trees, meaning no crane can be placed there. The north east side has a nearby open space, but no way access it with deliveries, and with more trees in between it and the project. This can be seen in the picture below.

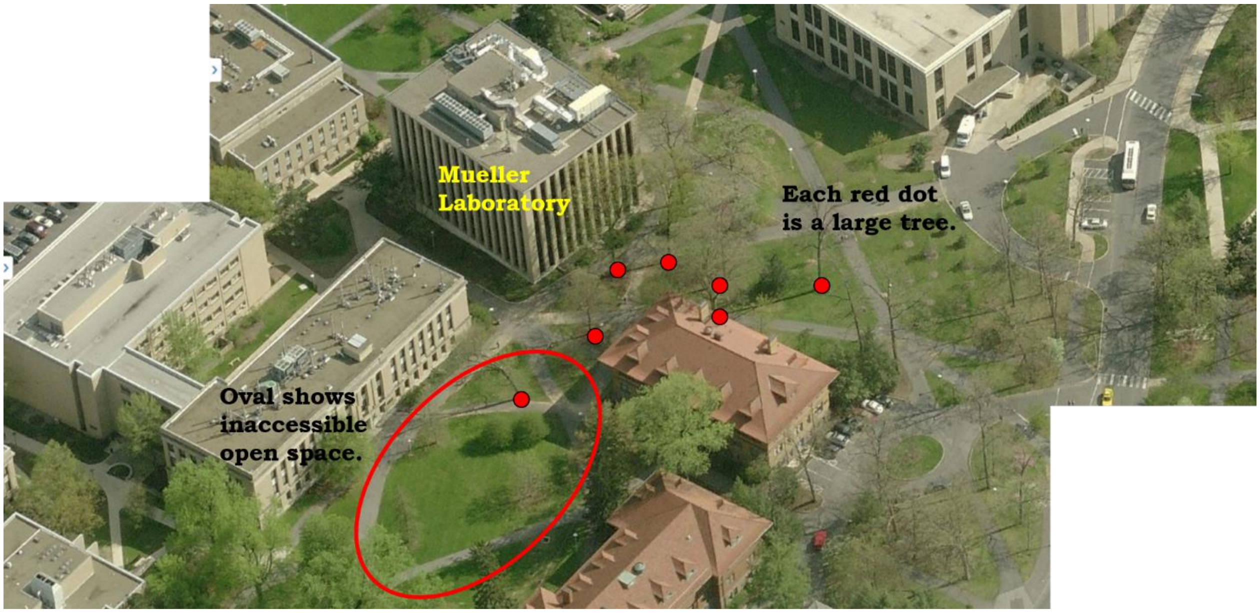


Figure 14: Congestion of area north and east of Mueller Laboratory. (Aerial image from Bing Maps)

The east side is steep and bottlenecked by two adjacent buildings, and thus not a viable option. However, the south side holds much promise in being a superior material storage and work area as it has few trees, is next to an access road, as seen below.

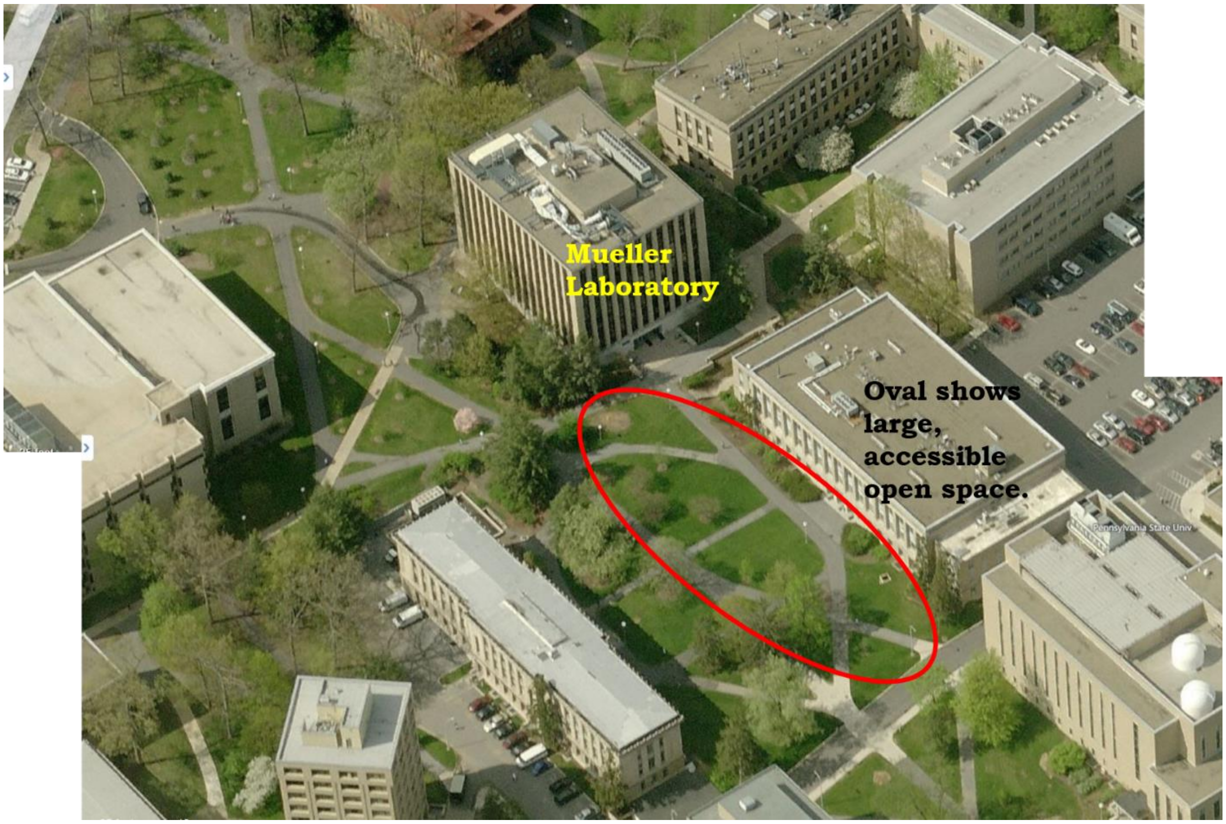


Figure 15: Open area south of Mueller Laboratory. (Aerial image from Bing Maps)

My proposal is to move contractor parking and material staging to the south of Mueller Laboratory, as shown in the diagram below.

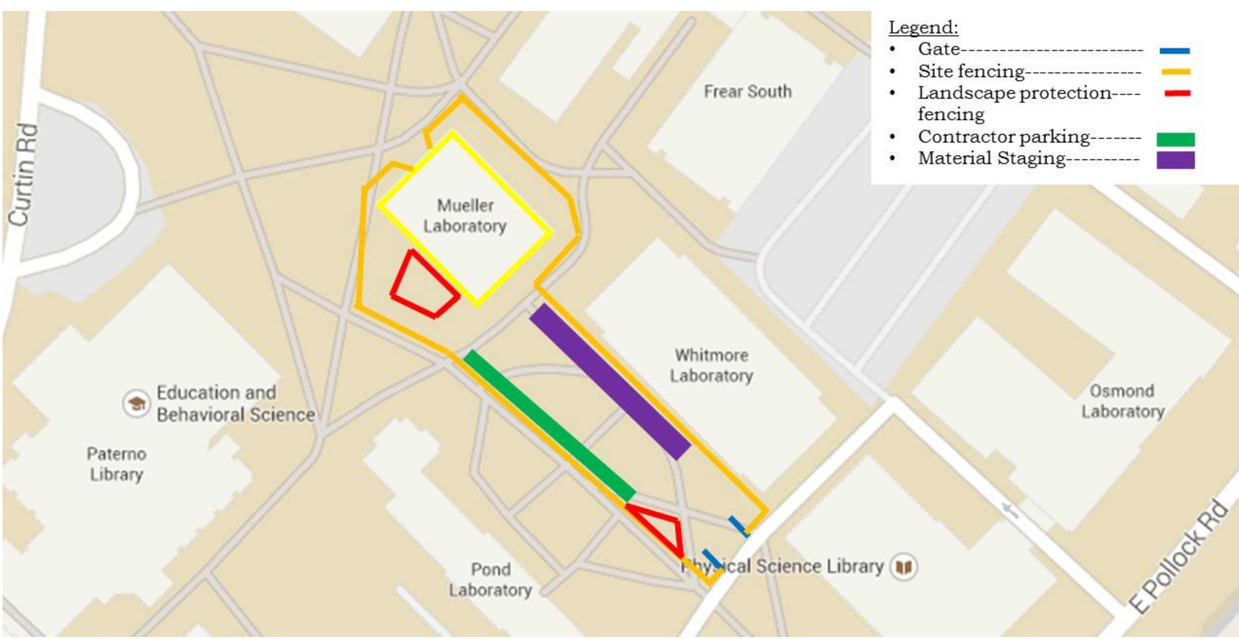


Figure 16: Proposed site plan. (Map from Google Maps)

In this plan the site is accessed from the south, using the laboratory access road that runs between Whitmore and Davey Laboratories. The front entrance of Whitmore Laboratory, adjacent to the proposed work site, would be blocked, but the north, east, and south entrances would all remain open, allowing ample access for Whitmore's occupants.

There are a number of advantages to moving the work site to the south. First is the minimization of protected tree islands. The three fenced-in areas from the original plan has been reduced to two, and only one that greatly impacts the work space. Then new tree island in the space to the south of Mueller would include only two sizeable trees, as shown in the picture below looking toward Mueller from the proposed new entrance gate.

Figure 17: Area for proposed work site.

Fortunately these trees are at the edge of the proposed site, and will not greatly limit usable area. These two trees can be protected with fencing just as the trees next to Mueller Laboratory are, with site fencing. The few small ornamental trees closer to Mueller can be temporarily transplanted to another location, as occurred on the current plan.

The detailed site plan shown below depicts a number of other advantages to moving the work site south.

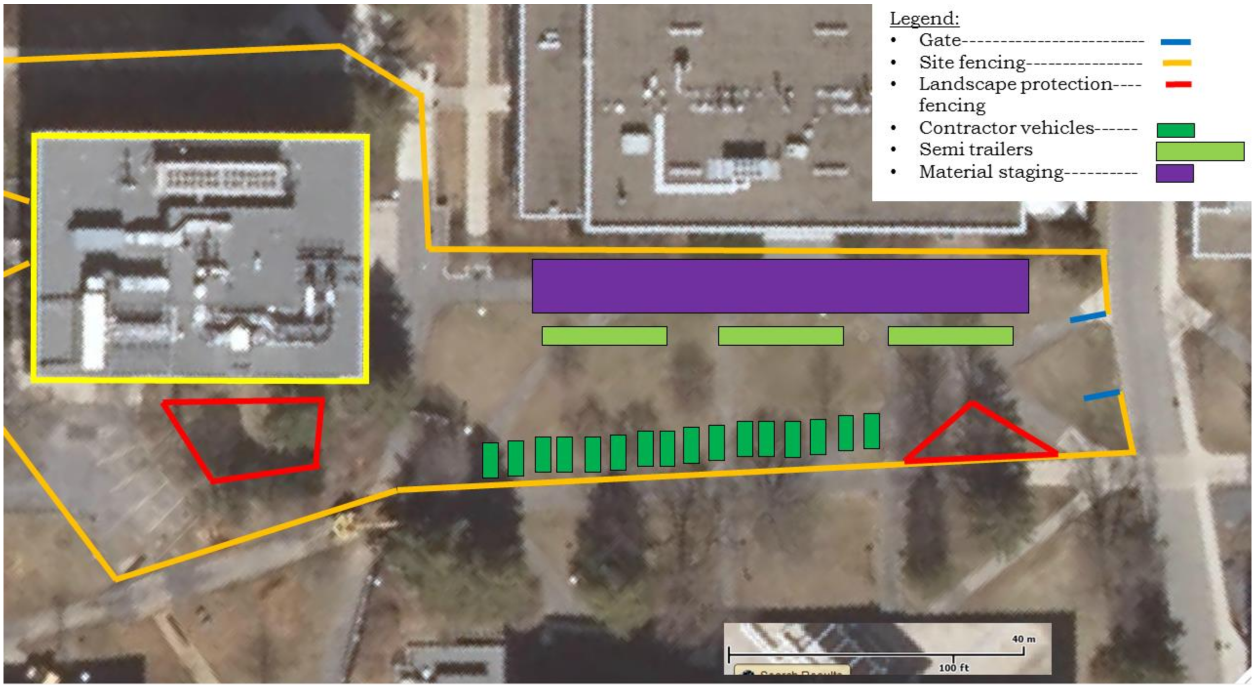


Figure 18: Detailed proposed site plan.

Most notable is the single, large material staging area. Locating all the material and equipment to be installed in a single location allows for maximum order and efficiency. Material can be readily accessed without the need to move contractor vehicles or other stored equipment. Also, this material staging area is on a uniform, low-grade slope, instead of the steep grade of the existing site, as seen in the topographic map below.

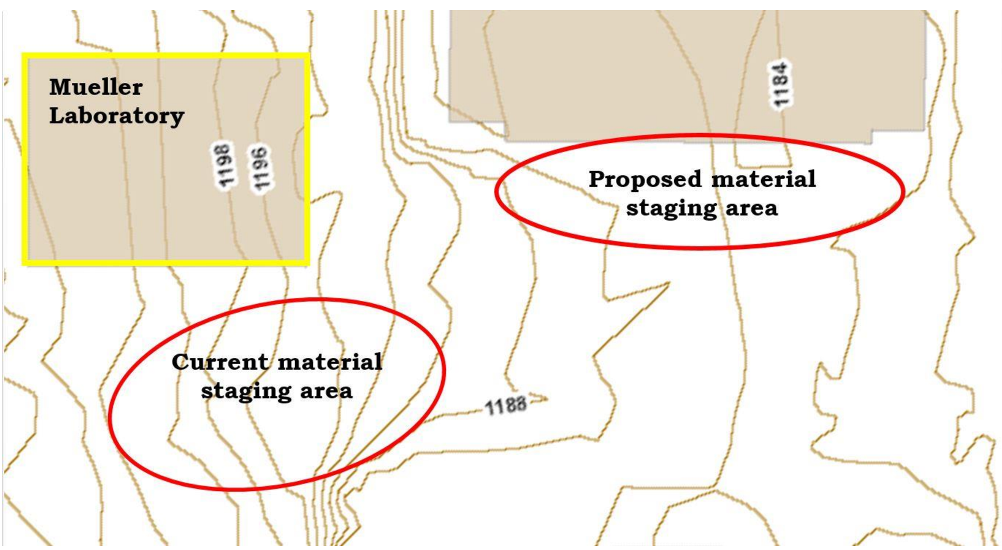


Figure 19: Site topographic map. (Map from gissites.co.centre.pa.us/CentreGISPublic/index.html)

The current material staging area drops nearly 14 feet in over a distance of 140 feet, averaging a 10% grade. The proposed staging area drops only 8 feet over a distance of 200 feet, for an average 4% grade, less than half of the current staging area. This flatter grade allows for more efficient storage of material, easier access to material and equipment, and safer conditions for workers on the site.

The proposed job site area also can comfortably receive 3 tractor trailers at a time. These trailers can be parked directly alongside the material storage area, simplifying unloading of trailers. Furthermore, these trailers would not block contractor parking, nor congest the worksite.

Another benefit to moving the job site southward is the increase in contractor parking. The proposed site plan comfortably can hold 16 vehicles without interfering at all with material staging space or trailer delivery space. This is an increase of 2 parking spaces as compared to the current plan, while at the same time creating a less congested work site.

There are other smaller advantages as well. One is the proximity of the south site's gate to a fire hydrant. This, and the openness of the site, would allow for a truck wash station to be easily set up. This would help to prevent tracking soil out of the site, keeping the campus roads cleaner and safer. A final benefit is the simplification of Mueller Laboratory's south side entrance renovation. In the current plan the entrance is closed to erect steel, then opened for several months, then closed again to install roofing. If the work site is moved to the south, the south entrance can be renovated all at one time. This also allows the north entrance to stay open for the duration of the project, minimizing the disturbance on the building's occupants.

Thus, moving the job site southward has numerous benefits over the current site plan. It allows for a more organized, safer site. Site space for material, equipment, and vehicles would all be increased. And the site's capacity for accepting deliveries would be expanded as well.

Recycling opportunities

A major part of any renovation is demolition. Debris from demolition can include drywall, metal studs, electrical wiring, lighting fixtures, ceiling tiles, and more. Demolition during the Mueller Laboratory renovation includes all these debris, as well as air handler units, exhaust fans, ductwork, and pipe. Minimizing what debris end up in landfills is not only a popular trend in the construction industry, but also a mandate for all Penn State construction projects. Section 8.11 of Penn State's general conditions for construction contracts states that "The contractor is required to recycle and/or salvage 75% of construction, demolition, and land clearing waste." To that end, Penn State specifically seeks to recycle or reuse the following materials:

- Cardboard
- Clean dimensional wood
- Beverage and food containers
- Brick and CMU
- Ferrous and non-ferrous metals
- Recyclable Plastic
- Gypsum wallboard
- Asphalt and concrete paving
- Ceiling Tile
- Carpeting
- Existing Windows
- Used equipment oil
- Useable appliances

The Mueller renovation seems to be a perfect candidate for recycling. Debris from demolition are in line with what Penn State wants to recycle. However, actual recycling opportunities are limited. Useable laboratory equipment can be resold, both reducing landfill waste and earing some revenue. Demolished and scrap metal from plumbing and HVAC pipes, ductwork, air handler units, and exhaust fans can be taken to a nearby scrapyard. But there are no general construction debris recyclers in the area. The closest facility is Construction, Demolition, Recycling, Inc., (CDR) in Southampton, PA, near Philadelphia. They offer off-site sorting and recycling of construction debris, but are 198 miles from University Park. Another recycler is Armstrong Commercial Ceilings and Walls. Armstrong recycles used ceiling tiles and new tile cutoffs, but their Lancaster recycling center is 136 miles from University Park. Finally, a USA Gypsum plant located near Lancaster, PA, recycles new drywall cutoffs. But their facility is 135 miles from University Park. At 6 miles/gallon, a semi-truck would use 33 gallons of diesel fuel transporting a single truckload of construction debris to CDR. If sustainability is the goal of recycling, burning such a high quantity of fossil fuels negates the positive impact of keeping construction debris out of landfills. Similarly, 23 gallons of fuel would be needed to reach Armstrong or USA Gypsum. None of these recyclers are close enough for them to be cost effective options.

However, there is a scrap metal dealer, Danny's Metals of Altoona, PA, that is only 42 miles from University Park, shown on the map below.

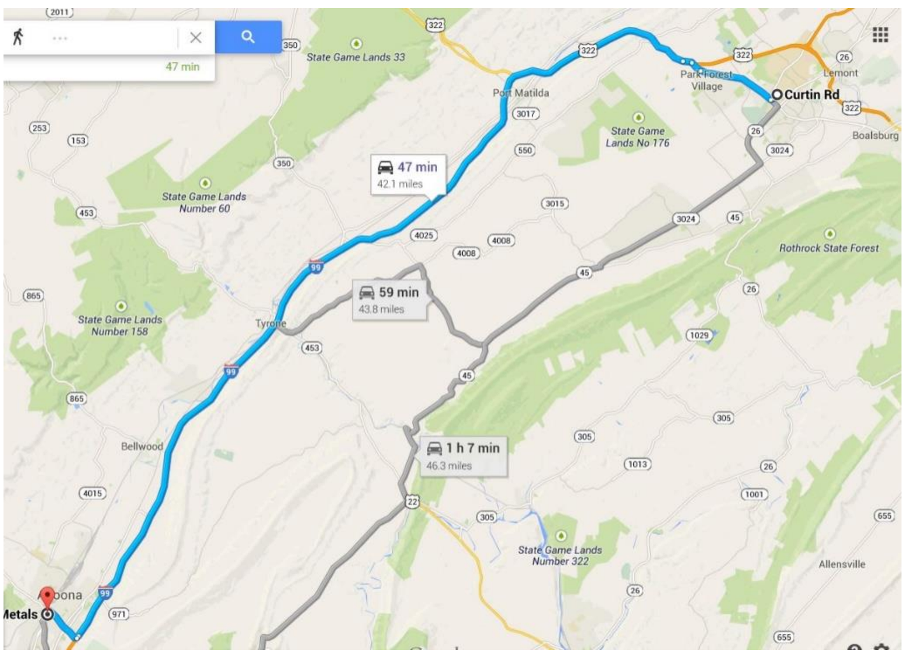


Figure 20: Distance to Danny's Metals. (Map from Google Maps)

This requires only 7.2 gallons of fuel to reach. Their facility also offers pickup services. Additionally they pay cash for scrap metal, another source of revenue for the project. This makes recycling scrap metal easy and economically wise, especially for large pieces such as the old air handler units and exhaust fans.

The rest of the metal debris from the project are more difficult to divert from the landfill. A separate dumpster would be needed for demolished ductwork and pipe lengths so that they could be taken to the scrap dealer. This would take up more space on an already crowded job site. But if room for a dumpster could be found, several types of debris can easily be recycled. First, it is relatively easy to set aside demolished ductwork pieces and sections of pipe for recycling, due to their large size. Other metal demolition debris such as lighting fixtures and electrical wire and conduit could be put in the same dumpster as the ductwork and pipe to be hauled to the scrapyard. Smaller debris that are mixed with other waste, such as metal studs and smaller pipe sections would be more difficult to recycle. Also, smaller debris are difficult to get to a dedicated recycling dumpster. Note the picture of the renovation site below.

Figure 21: Dumpsters on the worksite.

The dumpster in the foreground is not easily accessible, and far from the building. If two smaller dumpsters were put in this location, one for landfill waste and one for scrap metal, the scrap dumpster might go unused. Putting the dumpster this far from the demolition work means that workers have to pre-sort their waste before bringing it to the dumpster, or sort it at the dumpster. This takes time, and thorough sorting would not be assured.

The picture below demonstrates another difficulty. A demolition debris chute can be seen running to a single dumpster. This means that none of the waste from the upper floors can be sorted into landfill waste and recyclable categories.

Figure 22: Second dumpster with trash chute.

Sorting construction debris is easiest done as demolition and construction work is going on. It is far easier to toss a ceiling tile rail or pipe cutoff into a dedicated recycling bin or wagon than it is to sort through construction debris afterward and pull out the recyclable items. If this dedicated bin could then be dumped into a trash chute that fed into a recyclables-only dumpster, then recycling would be trivial. However, this requires the rental of a second dumpster and a second trash chute. A 50 foot trash chute costs $700 to rent for four weeks.

Scaffolding				
	Size	Day	Week	4 Weeks
Trash Chute	50'	115.00	305.00	700.00

NOTE: Prices displayed do not include sales tax or damage waiver.

Figure 23: Cost of trash chute rental. (From BestLine.com)

If the chute is needed for ten months, having a second trash chute for a recycling dumpster would cost the project an extra $7525.

$$10\ months \times \frac{4.3\ weeks}{1\ month} \times \frac{\$700}{4\ weeks} = \$\mathbf{7525}\text{ chute rental cost}$$

Comparatively, purchasing a trash chute would only cost $7235.

$$75'\text{chute} \times \frac{12\text{ inches}}{1\text{ foot}} \times \frac{1\text{ section}}{31\text{ inches}} = 29\text{ sections}$$

$$29\text{ sections} \times \frac{\$200}{1\text{ section}} = \$5800$$

$$\$5800\text{ chute}$$

$$+\$635\text{ hopper}$$

$$+\$800\text{ mount}$$

$$= \$\mathbf{7235}\text{ chute purchase cost}$$

Thus, purchasing instead of renting a second trash chute is the most economical.

In addition, a second dumpster is needed. Costs are as follows.

$$10\text{ months} \times \frac{4.3\text{ weeks}}{1\text{ month}} \times \frac{\$13.5}{1\text{ week}} = \$580.50$$

$580.50 extra fee

+$810.72 base price

= $**1391.22** total dumpster rental cost

Thus, the total cost of a second trash chute and a second dumpster rental is:

$1391 dumpster rental

+$7235 trash chute purchase

= $**8626 Total Cost**

This is a considerable cost to incur for recycling. However, if the revenue gained from selling the scrap metal can offset this cost, purchasing a trash chute and renting a second dumpster may make sense. The break-even point must first be calculated. Scrap steel is worth $0.11 per pound.

$8626 Chute and Dumpster cost

÷ $0.11 per lb scrap steel

=78,418 lbs scraps steel

Thus, 78,418 pounds of scrap steel would need to be collected from the project in order to pay for the dumpster and trash chute costs. Using data from the ductwork and AHUs being installed, the approximate weight of ductwork and AHUs being removed can be estimated, as seen below.

9751 lbs duct being installed on 1st floor

× 3 for 1st, 5th, 6th floor

=29,253 lbs scrapped duct weight

18700 lbs per AHU

× 3 being installed

=56,100 lbs scrapped AHU weight

29,253 lbs duct weight

+ 56,100 lbs AHUs

=85,353 lbs Mech scrap weight

Thus, the target weight of scrap metal of 78,418 is easily reached. Furthermore, large quantities of plumbing pipe scrap will be generated by demolition. This pipe can also be sold as scrap. Additionally the electrical wiring, conduit, and lighting fixtures being removed will add to the scrap metal total. Electrical wiring will be copper or aluminum, which commands a higher scrap price than steel, further increasing the revenue gained from recycling metal.

Thus, recycling metal is both easy and financially viable. The close proximity of the scrap dealer, combined with the profitability of selling the scrap metal, and the benefit of keeping many tons of waste out of landfills make recycling metal on the Mueller renovation a wise choice.

LED Downlight Comparison

Throughout the Mueller renovation the existing fluorescent lighting fixtures are being replaced with LED fixtures. LEDs can provide the same lumen output as fluorescent but at lower wattages, meaning they are cheaper to run and waste less energy as heat, minimizing their contribution to the building's heating load. Additionally, LED fixtures can last for 50,000 hours without failure, far longer than fluorescents. In recent years LED fixtures have gotten very close to approximating the performance of incandescent and fluorescent fixtures in lumen output, color temperature, and color rendering index (CRI). However, LED fixtures continue to improve year by year. Fixtures installed as little as 5 years ago can quickly become obsolete, as is the case when working with cutting edge technology.

If in the future a fixture in Mueller Laboratory needs replacement, either due to defect or to improve the lighting performance of the building, an electrician is needed to disconnect the old fixture and install a new fixture. Doing this for a large number of fixtures can be expensive and time consuming.

Fixture replacement requires an electrician, but changing a lightbulb does not. Screw-in Edison-base LED bulbs can be changed in seconds by anyone. For the Mueller renovation, installing Edison-base socketed recessed downlights, instead of the specified hard-wired LED recessed downlights, would provide a number of benefits.

First, the project's specifications so there is data to compare to. The Mueller renovation specifies a four inch and two six inch CREE downlights, as seen below.

LIGHT FIXTURE SCHEDULE							
TYPE	DESCRIPTION	LAMP	LUMEN OUTPUT	Efficacy	MOUNTING	MANUFACTURER	MODEL
L-1	2x4 RECESSED TROFFER	LED	5089 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR24-50L-40K
L-1A	2x4 RECESSED TROFFER	LED	5089 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR24-50L-40K
L-1AE	2x4 RECESSED TROFFER	LED	5089 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR24-50L-40K
L-1E	2x4 RECESSED TROFFER	LED	5089 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR24-50L-40K
L-2	2x4 RECESSED TROFFER	LED	4024 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR24-40L-40K
L-2A	2x4 RECESSED TROFFER	LED	4024 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR24-40L-40K
L-2E	2x4 RECESSED TROFFER	LED	4024 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR24-40L-40K
L-3	2x2 RECESSED TROFFER	LED	3284 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR22-32L-40K
L-3E	2x2 RECESSED TROFFER	LED	3284 lm	81 lm/W	RECESSED	CREE OR EQUAL	CR22-32L-40K
L-4	1x4 RECESSED TROFFER	LED	4346 lm	81 lm/W	RECESSED	LIHTONIA OR EQUAL	TL4-43L-RW-A12-D46-LP840
L-4E	1x4 RECESSED TROFFER	LED	4346 lm	81 lm/W	RECESSED	LIHTONIA OR EQUAL	TL4-43L-RW-A12-D46-LP840
L-5	T-BAR LIGHT	LED	743 lm	81 lm/W	RECESSED	T-BAR SMARTLIGHT OR EQUAL	TBSL-HN-2-15-D-U-W
L-5A	T-BAR LIGHT	LED	743 lm	81 lm/W	RECESSED	T-BAR SMARTLIGHT OR EQUAL	TBSL-HN-2-15-D-U-W
L-5E	T-BAR LIGHT	LED	743 lm	81 lm/W	RECESSED	T-BAR SMARTLIGHT OR EQUAL	TBSL-HN-2-15-D-U-W
L-6	RECESSED DOWNLIGHT	LED	655 lm	14 lm/W	RECESSED	CREE OR EQUAL	KR4-9L-40K-120V
L-6E	RECESSED DOWNLIGHT	LED	655 lm	14 lm/W	RECESSED	CREE OR EQUAL	KR4-9L-40K-120V
L-7	RECESSED DOWNLIGHT	LED	1053 lm	14 lm/W	RECESSED	CREE OR EQUAL	KR6-13L-40K-120V
L-7E	RECESSED DOWNLIGHT	LED	1053 lm	14 lm/W	RECESSED	CREE OR EQUAL	KR6-13L-40K-120V
L-8	RECESSED DOWNLIGHT	LED	1652 lm	14 lm/W	RECESSED	CREE OR EQUAL	KR6-20L-40K-120V
L-8E	RECESSED DOWNLIGHT	LED	1652 lm	14 lm/W	RECESSED	CREE OR EQUAL	KR6-20L-40K-120V

Figure 24: Project lighting schedule. (From project electrical plans)

Separate LED bulbs with Edison bases were found that matched the performance of the CREE fixtures as closely as possible. The performance of these bulbs is listed in the following table, beneath the performance data of the CREE fixtures.

	Wattage	**Lumens**	**CRI**	**CRT**
CREE 4" LED fixture	*13*	*665*	*90*	*4000*
CREE 6" LED fixture 1	*18*	*1250*	*90*	*4000*
CREE 6" LED fixture 2	*30*	*1664*	*90*	*4000*
LED bulb 1	13	700	92	2700
LED bulb 2	20.8	1250	94	2700
LED bulb 3	26	1650	82	4000

	Bulb name:
LED bulb 1	Green Creative 13 watt LED BR30
LED bulb 2	Feit LEDR56/827 Led Retrofit Kit 5/6-Inch
LED bulb 3	LED26DP38S840/40

Comparing the 4" CREE to LED bulb 1, both run at the same wattage. The bare LED bulb has 6.4% higher lumen output, and has a higher CRI. It also has a lower CRT, meaning its light will appear warmer.

Figure 25: The 4" CREE fixture. (Picture from Amazon.com)

Performance Specifications	
Replacement for:	BR30
Brightness (Lumens):	700
Color Temperature:	2700K
Color Accuracy (CRI):	92
Traditional Wattage Equivalent:	65 Watts
Power Consumption:	13 Watts
Voltage:	120 Volts
Dimmable:	Yes (See Compatibility List)
Moisture Rating:	Dry
Fixture Rating:	Open / Not Fully Enclosed
Base Type:	E26
EnergyStar Qualified	Yes - (See Rebates Page)
Dimensions / Additional Data	
Bulb Diameter:	3.74 in
Maximum Overall Length:	5.31 in
Product Weight:	8.32 ounces
Certifications:	UL
Product/Order Code:	13BR30G3DIM/927
Lifespan / Cost To Run	
Projected Life: @3 hrs/Day	40,000 Hrs
Yearly Energy Cost: 3 hrs/Day @ .11 kWh	$1.57

Figure 26: LED bulb 1 data. (Chart from EarthLED.com)

Figure 27: LED bulb 1. (Picture from Amazon.com)

The first 6” CREE fixture and LED bulb 2 are also similar. The bare bulb runs at 1.5% higher wattage for the same lumen output, but has a CRI 4 points higher than that of the CREE fixture. This bulb also has a lower CRT, a good quality for the lobby and bathroom spaces.

Figure 28: The 6" CREE fixture. (Picture from Amazon.com)

Performance Specifications	
Replacement for:	5" or 6" Downlight
Brightness (Lumens):	1250
Color Temperature:	2700K
Color Accuracy (CRI):	94
Traditional Wattage Equivalent:	120 Watts
Power Consumption:	20.8 Watts
Voltage:	120 Volts
Dimmable:	Yes (See Compatibility List)
Moisture Rating:	Damp
Fixture Rating:	Suitable for type IC, type Non-IC and Air Tight Housings
Base Type:	E26
EnergyStar Qualified	Yes (See Rebates Page)
Dimensions / Additional Data	
Bulb Diameter:	5.15 in
Maximum Overall Length:	4.2 in
Certifications:	UL
Product/Order Code:	LEDRT56/927
Lifespan / Cost To Run	
Projected Life: @3 hrs/Day	50,000 Hrs
Yearly Energy Cost: 3 hrs/Day @ .11 kWh	$2.47

Figure 29: LED bulb 2 data. (Chart from EarthLED.com)

Figure 30: LED bulb 2. (Picture from Amazon.com)

The second 6” CREE fixture nearly beats the selected LED bulb 3. Both have identical CRTs and run at within .8% lumen output of each other. However, the bare

LED bulb has a CRI of only 82, far worse than the CREE's 90. But the bare bulb partially redeems itself by running at only 26 watts instead of 30, a savings of 13%.

Figure 31: The Edison-socket fixture. (Picture from Amazon.com)

LED commercial indoor/outdoor PAR38 lamps

Directional Lamps (PAR)

Bulb Shape	Base Type	Watts	Order Code	Description	Volts	Case Qty**	MOL (In)	Lumens Initial	CBCP	Initial Color Temp	CRI	Wattage Equivalent	*Rated Life L70 (Hrs)	Dimmable	ENERGY STAR® Status	#Location Rating	Additional Information
Commercial PAR38 (Indoor/Outdoor)																	
PAR38	MED	12	90150	LED12DP382W83025	120	6	5.1	950	4400	3000	84	85W	25,000	Yes	★	Wet	Narrow Flood, 25° beam, White
			90151	LED12DP382W83035	120	6	5.1	950	2700	3000	84	85W	25,000	Yes	★	Wet	Flood, 35° beam, White
			90132	LED12DP382W82725	120	6	5.1	850	4000	2700	84	85W	25,000	Yes	★	Wet	Narrow Flood, 25° beam, White
			90133	LED12DP382W82735	120	6	5.1	850	2500	2700	84	85W	25,000	Yes	★	Wet	Flood, 35° beam, White
		18	90159	LED18DP38W830/25	120	6	5.1	1300	7600	3000	84	100W	25,000	Yes	★	Wet	Narrow Flood, 25° beam, White
			90160	LED18DP38W830/40	120	6	5.1	1300	2400	3000	84	100W	25,000	Yes	★	Wet	Flood, 40° beam, White
			90154	LED18DP38W827/25	120	6	5.1	1200	7000	2700	84	100W	25,000	Yes	★	Wet	Narrow Flood, 25° beam, White
			94453	LED18DP38W827/40	120	6	5.1	1200	2200	2700	84	100W	25,000	Yes	★	Wet	Flood, 40° beam, White
			90162	LED18DP38W840/25	120	6	5.1	1400	8200	4000	84	100W	25,000	Yes	★	Wet	Narrow Flood, 25° beam, White
			90163	LED18DP38W840/40	120	6	5.1	1400	2600	4000	84	100W	25,000	Yes	★	Wet	Flood, 40° beam, White
			22235	LED18DP38FL5K/TP	120	3	5.1	1500	3200	5000	84	100W	25,000	Yes	★	Wet	Flood, 40° beam, White
	MED	26	68183	LED26DP38S830/12	120	6	5.3	1500	24000	3000	82	130W	25,000	Yes	★	Wet	Spot, 12° beam, Silver
			68184	LED26DP38S830/25	120	6	5.3	1500	6800	3000	82	130W	25,000	Yes	★	Wet	Narrow Flood, 25° beam, Silver
			68185	LED26DP38S830/40	120	6	5.3	1500	3100	3000	82	120W	25,000	Yes	★	Wet	Flood, 40° beam, Silver
			68182	LED26DP38S840/40	120	6	5.3	1650	3200	4000	82	120W	25,000	Yes	★	Wet	Flood, 40° beam, Silver
			[illegible]	LED26DP38S835/12	120	6	5.3	1900	31000	3500	82	160W	25,000	Yes	★	Wet	Spot, 12° beam, Silver
			70591	LED26DP38S835/40	120	6	5.3	1900	4000	3500	82	160W	25,000	Yes		Wet	Flood, 40° beam, Silver
		28	15139	LED28P38S830/15	120	6	5.3	2400	20000	3000	82	130W	25,000	-	★	Dry	Spot, 15° beam, Silver

Figure 32: LED bulb 3 data. (Chart from GELighting.com)

Figure 33: LED bulb 3. (Picture from Amazon.com)

So the performance of the fixtures and bulbs is very similar, with only 6” CREE fixture 2 possibly edging out LED bulb 3 because of the bulb’s poor CRI. But a cost comparison will help the cause of the bare LED bulbs. The CREE downlights specified for the project cost from $157 to $204. In contrast, a recessed downlight fixture with an Edison-base socket costs $9, and a bare LED bulb costs $23 to $59, for a maximum total cost of $68.

	Price
CREE 4” LED fixture	*$157.14*
CREE 6” LED fixture 1	*$157.14*
CREE 6” LED fixture 2	*$204.29*
Can fixture	$8.67
LED bulb 1	$22.24
LED bulb 2	$25.24
LED bulb 3	$58.38

In total there are 60 downlights that can be installed with screw-in bulbs instead of hard-wired LEDs. The comparative costs of hard-wired and screw-in bulbs are seen below.

	Fixtures	Cost per fixture	CREE fixture total costs	Cost per screw-in bulb	Screw in bulb total costs	Difference in total costs
CREE 4”	2	$157	$314	$33	$66	$248
CREE 6” #1	48	$157	$7536	$36	$1728	$5808
CREE 6” #2	10	$204	$2040	$69	$690	$1350
				Total amount saved:		**$7406**

Thus, using screw-in bulbs results in a total of $7406 savings on installation costs.

An additional benefit of using screw-in bulbs is the ease of upgrade. Since LED technology advances rapidly, future bulbs will have better efficiency and performance. When bulbs that are more efficient or have a better CRI become available they can easily be installed in these screw-in socket fixtures to save money and provide better performance.

Recommendations

It is recommended that the roof reinforcement be moved to the top of the roof deck. The same structural capacity will be achieved for support of the air handler units. The steel installation will be easier since there will be no overhead work. There will be no need for jacks to lift the steel into position for it to be bolted in place. Also, the installation of the reinforcing steel will not have to wait for the 6^{th} floor asbestos abatement and rough demolition to be completed. This will allow the air handler units to be placed 20 days earlier, saving nearly a month of schedule time.

The abatement of asbestos should be assigned more crews to decrease the duration. Since Pennsylvania law does require full abatement of all asbestos containing material, the abatement should be performed as efficiently as possible. Assigning two crews instead of one doubles the production speed. This halves the duration of the abatement, resulting in the cost of two crews being nearly identical to the cost of one.

The project's worksite would benefit greatly from going south, not west. The current site on the west side of Mueller Laboratory is congested and disorganized. Moving the material staging area and contractor parking to the south of the building would allow material to be stored more neatly, simplify deliveries, and allow for more contractor parking.

Effective recycling remains difficult to achieve on a renovation such as this one. If the worksite is moved to the south, as recommended above, then additional provisions for recycling could be made. Additional dumpsters and trash chutes dedicated to recycling would be useful, but come at a price. The owner would have to decide at what cost recycling is worth it.

Screw-in LED bulbs should be used instead of hard-wired LED fixtures. Screw in bulbs are cheaper to purchase than hard-wired fixtures. Once installed, any defective units are easier to repair or replace than hard-wired fixtures. And when upgrades are desired, screw-in fixtures are easier and cheaper to upgrade, and generate less waste.

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