Mechanical Solution

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In order to arrive at a highly efficient solution to an architectural design, it is important to examine ways to save time and money in every major system within the shell of the building. Previously, methods to improve efficiency from a structural perspective were discussed. Here, the focus shall be on the mechanical system of the building.

Figure 6 below is an overall view of the solution to the mechanical aspect of the improvements on efficiency. The structure on the rooftop with the large garage-type door on the front is a mechanical penthouse that has been designed to house two boilers and two chillers which will serve the entire new portion of the building.

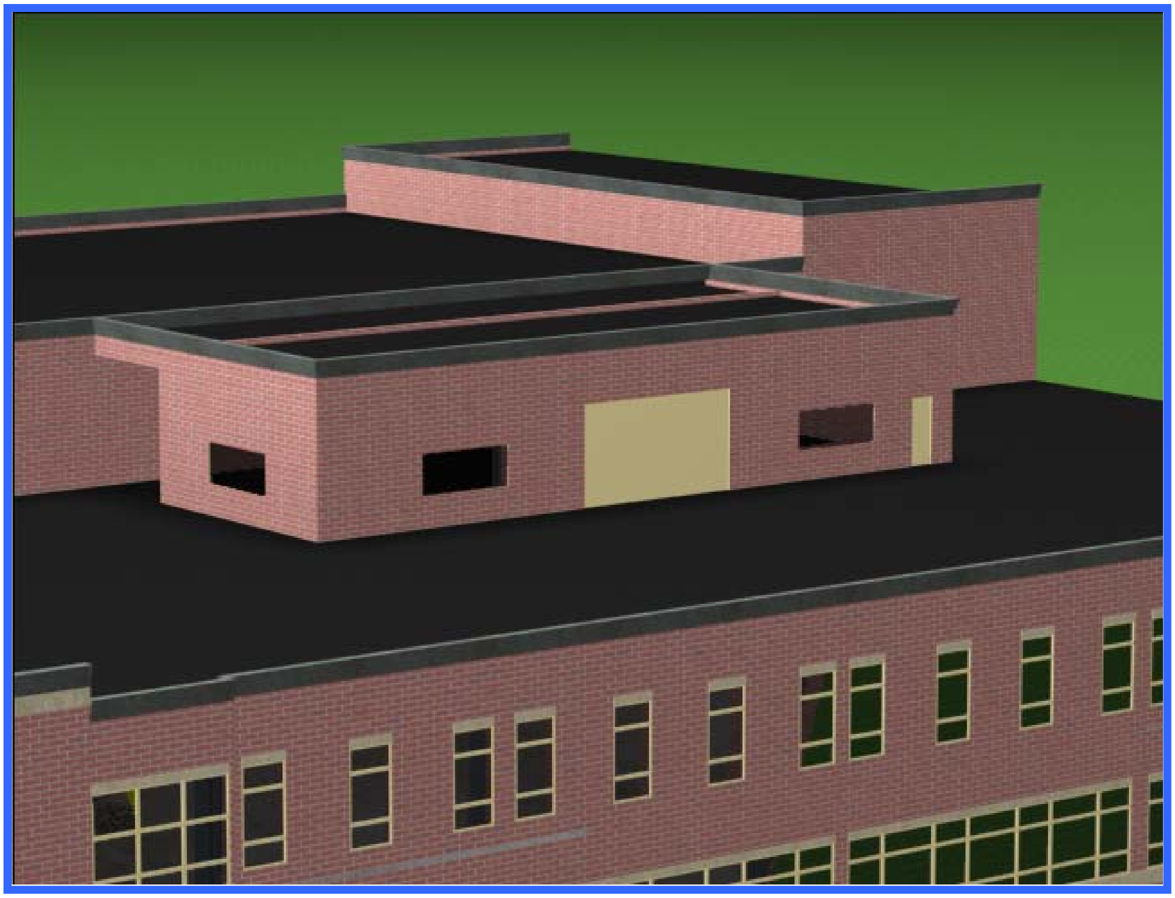


Figure 6: *Three-dimensional rendering of the newly designed mechanical penthouse which houses two boilers and two chillers. This figure shows how the penthouse fits in architecturally with the rest of the facade.*

In order to fully appreciate the impact of moving this mechanical equipment all the way to the rooftop from its current location on the ground floor, it is important to consider the chilled water piping configuration and the complexities of routing pipes through several floors and partitions.

Currently, the mechanical equipment is located in the northeast corner of the new portion of design, area E. This is represented by the gold square in Figure 7. This system is designed so that the chilled water is pumped from the chiller to the cooling tower, which is located on the roof level in the northeast portion of area C and designated with a blue circle. As one can see, the pipes carrying the water must be pumped horizontally a distance of approximately 280 feet, and, most importantly, a vertical distance of three levels, or approximately 45 feet. The vertical change in elevation is one of the most crucial factors when sizing the primary pump in this open system between the chillers and the cooling tower. With the effects of atmospheric pressure, the pump must be significantly larger to overcome this height differential.

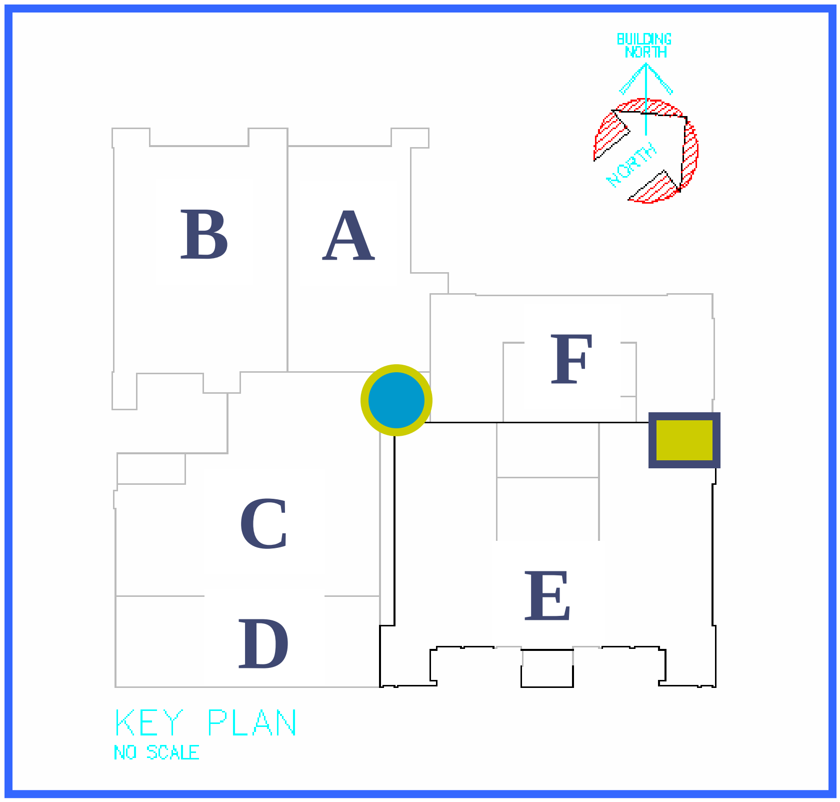


Figure 7: *This figure shows the layout of the entire project. Area E is the portion of new design, and the focus of this research. The square indicates the location of the original mechanical room, and the circle represents the location of the cooling tower.*

With this in mind, the primary pump shall be the focus of any potential cost savings from moving the mechanical equipment from the ground floor mechanical room to the newly designed penthouse on the roof. Similarly, although not quantified, the reduction in piping coordination from the chillers to the cooling tower shall be the focus when considering any potential construction time savings. It is expected that the amount of labor shall be decreased due to the elimination of the vertical piping runs.

Prior to performing any detailed calculations to determine the total savings for choosing this altered mechanical system, it is important to understand what exactly is being dealt with. The information presented here in Table 7 is a summary of the major pieces of equipment that will be affected in this mechanical redesign.

As seen here, this building is served by two water cooled centrifugal chillers and two gas/oil burning wet back boilers. As noted earlier, the new cooling tower is to be placed on the northeast corner of area C, just left of the new design, area E.

Chillers

Symbol	Tons	EWT	LWT	Evap. GPM	Evap. Water AP	Evap. FF	Remarks
CHL-1	400	55°F	45°F	960	MAX. 15.0 FT	0.0001	Water Cooled Cetrifugal Chiller 460V/3 Φ, 302 FLA

Boilers

Symbol	Type	Fuel	G.P.H. Oil	Gas CFH	HP		Remarks
B-1	Firetube	Natural Gas/#2 Fuel Oil	60	8369	200		Burner - 10 HP - 460V/3 Φ

Circulating Pumps

Symbol	GPM	FT. Head	HP	RPM	Voltage		Remarks
CP-1	850	105	40	1750	460V/3 Φ		Base Mounted; Cetrifugal; End Suction; Hot Water; VFD
CP-2	1920	100	60	1750	460V/3 Φ		Base Mounted; Cetrifugal; End Suction; Chilled Water; Secondary Loop; VFD
CP-3	960	50	20	1750	460V/3 Φ		Base Mounted; Cetrifugal; End Suction; Chilled Water; Primary Loop
CP-4	2400	60	50	1750	460V/3 Φ		Base Mounted; Cetrifugal; End Suction; Condenser Water
CP-5	40	80	2	1750	460V/3 Φ		Inline; Pool Water Heating (DH-1)

Cooling Tower

Symbol	GPM	EWT	LWT	EAT	FANS		
					HP	RPM	Voltage
CT-1	2400	95°F	85°F	95/78	(2) - 50		460V/3 Φ
					(2) - 15		460V/3 Φ

Table 7: *This table is a summary of the major pieces of equipment that will be affected in this mechanical system re-design. The largest circulating pump, CP-4, will be the main focus for cost analysis.*

This table also indicates that the largest primary condenser pump was sized based on 60 feet of total head loss, which is due to things like static pressure drops (height differentials), frictional losses (coils, heat exchangers, etc.), and any other pressure drop that may occur due to piping configuration and layout. Placing the boilers and chillers in the rooftop mechanical penthouse will eliminate the need for such a high-powered primary pump since the total head loss will not include the height differential from the ground floor all the way to the roof (approximately 45 feet). And, as previously noted, incorporating this rooftop mechanical penthouse will greatly decrease the time it takes to route and install all of the piping from the chiller to the cooling tower since it will be more of a direct route between them.

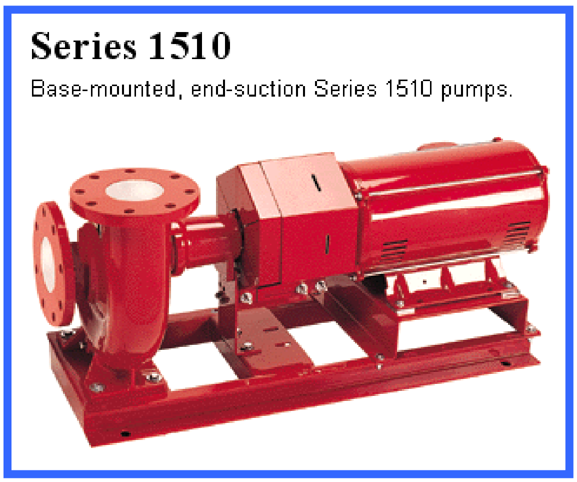
Cost Savings from Specifying a Smaller Primary Pump

The following equation can be used to determine the new required horsepower of the primary condensing pump. Note that V is taken directly from Table 7, as it will not change throughout the design. H is the new feet of head loss which does not include the height differential of 45 feet. A conservative estimate for the efficiency of the pump is assumed to be 0.8, and is only used as a means for calculating a trial value for the horsepower.

$$\dot{W}_s = \frac{\dot{m}\omega}{\eta} = \frac{\rho\dot{Q}\omega}{\eta} = \frac{\rho\dot{Q}Hg}{\eta g_c}$$

$$H.P. = \frac{V(gal/\min) \times H(ft.head)}{3960 \times \eta(efficiency)} = \frac{2400 \times 15}{3960 \times 0.8} = 11.4HP$$

This equation yields a new required pump horsepower of 11.4 HP, which was originally 50 HP, as seen in Table 7. The next step once these parameters have been determined is to turn to an equipment manufacturer and specify a new pump from their given design aides. In this case, Bell & Gossett's website for online pump selection was chosen *(http://www.bellgossett.com/selectpumps.stm)*. This interactive website allows the user to input basic parameters, such as total flow rate and pump head, and will then provide several solutions in tabular form. Based on 2400 gpm and 15 ft head, Figure 8 below is a summary of the new pump that was specified.



1510 8G

Flow Rate (GPM)	2400	Pump Head (Feet)	16
Speed (RPM)	1150	NPSHr (Feet)	n/a
Weight (lbs)	1140	Cost Index	100%
Suction Size (in.)	10	Suction Velocity (fps)	9.8
Discharge Size (in.)	8	Discharge Velocity (fps)	15.4
Impeller Size (in.)	10.375	Pump Efficiency (%)	67.24
Max. Flow (GPM)	2576	Duty Flow/Max Flow (%)	93.2
Flow @ BEP (GPM)	1606	Min. Rec. Flow (GPM)	401.5
Selected Motor Size (HP)	20	Selected Motor Size (kw)	14.91
Duty-Point Power (BHP)	14.49	Duty-Point Power (kw)	10.80
Maximum Power (BHP)	15.35	Maximum Power (kw)	11.45
Motor Manufacturer	US Prem Eff	Full Load Amps	24.30
Manufacturer Catalog Number	J480	Full Load Efficiency (%)	93.1
Frame Size	286T	Full Load Power Factor (%)	80.8

Generate Pump Curve
Calculate Operating Costs
Generate Submittal
Print Friendly Format
eMail This Pump Selection

Figure 8: *This figure shows the newly designed pump that was chosen from Bell & Gossett's website for online pump selection. As seen here, the new pump operates on 20 HP, compared to the original 50 HP pump.*

Note that the pump now operates on 20 HP as opposed to 50 HP previously. However, the efficiency of this pump is a bit lower than assumed, at a value of 67.24%. All other pump specifications can be seen in the chart in Figure 8.

To quantify the monetary savings from choosing this pump, the first item to determine is the average price of one kilowatt hour ($/kWh). This value varies from area to area, so a good source for determining average prices in a given location is the US Department of Energy's website *(http://www.eia.doe.gov/cneaf/electricity/st_profiles/pennsylvania.pdf)*. See Appendix C for a sample page from the DOE's website. From this site, it was determined that the average price for electricity in the state of Pennsylvania is approximately 8.01 cents/kWh. The following conversion equation can be used to determine the number of kWh used by this pump in a given year at the William Penn Senior High School:

$$HP \times 0.745 \times total \quad operating \quad hours = kWh$$

In order to use this equation, the total operating hours per year must be able to be approximated. It was conservatively determined that the pump would be in operation all year long for an average of 10 hours per day. Therefore, the total kWhs are computed as follows:

- 20HP x 0.745 x 365 days x 10 hours = **54,385 kWh**

Multiplying by the cost per kWh yields a total electricity cost of:

- 54,385 kWh x $0.0801/kWh = **$4,356**

The original cost of electricity (computed the same way but with a 50 HP pump) is approximately equal to $10,890 per year.

From this data, a total annual savings in electricity costs can be computed:

- ANNUAL SAVINGS = $10,890 - $4,356 = **$6,534** just for the pump.

Note that realistic monetary savings must be adjusted to consider *actual* operating hours per year, as this was simply an approximate scenario.

Mechanical Penthouse Design

Now that the total savings in electricity have been determined for the newly designed primary condenser pump, it is time to take a look at the actual space that will be housing the equipment. The floor plan shown here in Figure 9 is an overview of the layout and dimensions of the penthouse.

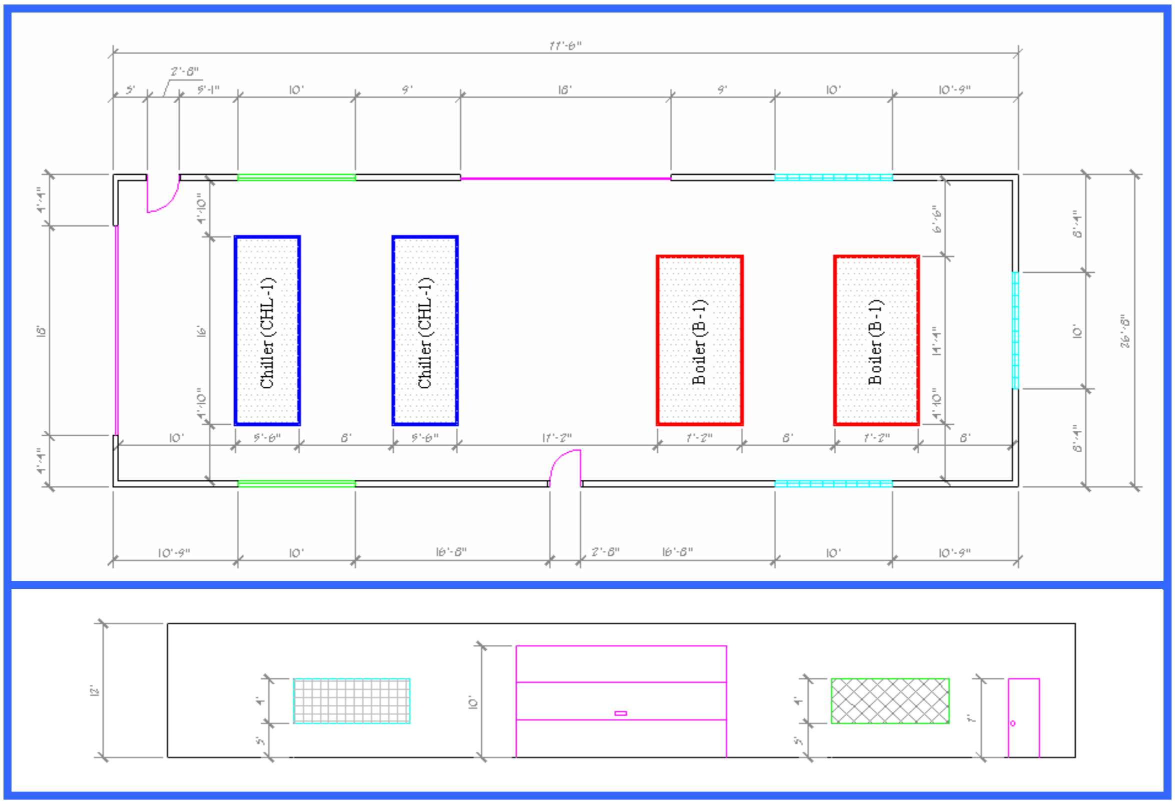


Figure 9: *This figure shows the floor plan and front elevation of the mechanical penthouse that was added to the roof to house the chillers and boilers.*

As seen here, the overall dimensions of the penthouse are 77'-6" x 26'-8". The perimeter of the penthouse conveniently lies directly on the edges of the structural bays beneath. Two large overhead doors have been incorporated into the penthouse design to allow for large equipment transportation into and out of the room. The light blue openings shown near the boilers represent louvered vents and the green openings near the chillers represent outward-blowing fans to control the air conditions of the space. Not shown on this plan is a code required chimney to allow the fuel-burning boilers to release their exhaust into the environment. In addition to the large overhead doors are 2 normal-sized doors for maintenance access and egress.

From an architectural perspective, the mechanical penthouse was designed to visually mesh with the existing facade. Many times, rooftop mechanical rooms are unsightly and

take away from the effect that the owner may have had in mind. Since the William Penn Senior High School is not a very tall building, anything located on the roof will be visible from street level. Therefore, the penthouse is clad with a brick veneer to match the brick used on the exterior walls.

Many of these design decisions directly affect the structure of the building as well. First and foremost, the framing under the penthouse and the region under the portion of the roof outside the penthouse that will hold equipment prior to being lifted on or off with a crane, is completely framed with wide flange beams. Prior to the addition of the penthouse, the entire roof was framed with open-web steel joists. With the boilers having an operating weight of 23,230 pounds each, and the chillers weighing in at 23,920 pounds per unit, the dead load on this portion of the roof is significantly higher than that of the rest of the roof. Because of this, wide flange members are more practical for this application.

Addressing Vibration Concerns Due to Rooftop Chillers

As in any system that may seem to save time and money during construction, this new mechanical design does not come without its own series of concerns. The major negative impact that the heavy equipment has on the building is noise generation. Now that the 23,000+ pound units are on the roof, the occupants in the spaces below may be unhappy with the vibrations that result from the equipment running, especially at startup. The subject of vibration isolation is a very complicated one, and is solved in a variety of ways. To be theoretically correct, a complete static AND dynamic analysis would be necessary to fully determine the oscillating loads that will be imposed on the structure from the equipment. However, there are many companies in the industry who manufacture products that are specially designed to isolate mechanical equipment by mounting them on springs.

To address the specific isolation needs for the William Penn Senior High School, this approach was taken. A company called Vibration Isolation has a website with all of their product information and specifications available to the designer. All spring mounts are rated up to a certain weight, most up to approximately 10,000 pounds per mount. Figure 10 shows the product that was chosen for the boilers and chillers in this mechanical penthouse.

Figure 10: *This figure shows Vibration Isolation product that is used to support the chillers and boilers in the mechanical penthouse and serves to reduce the noise level that is generated from the operating equipment.*

Since each of these spring mounts are rated up to 10,000 pounds each, it was considered to be acceptable to provide four mounts per unit, one at each corner. This specific product uses a synthetic material called neoprene, which provides additional cushioning and further reduces the vibrations generated from the equipment.