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Picatinny Arsenal

3000 Area Laboratory Complex Energy Analysis

DR Brown
JK Goddard

May 2010

Pacific Northwest
NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

In response to a request by Picatinny Arsenal, the Pacific Northwest National Laboratory (PNNL) was asked by the Army to conduct an energy audit of the Arsenal's 3000 Area Laboratory Complex. The objective of the audit was to identify life-cycle cost-effective measures that the Arsenal could implement to reduce energy costs. A relatively quick "level 1" audit of the facilities was conducted by PNNL staff on December 7-8, 2009. This audit focused on developing calibrated models of the Complex heating and cooling loads, a qualitative assessment of the condition of existing major equipment, and the cost-effectiveness of converting to building-level boilers and replacing existing building-level chillers.

The analysis conducted by PNNL implicitly assumed that current ventilation and humidification practices would continue. Prior to moving forward with any retrofits, PNNL recommends that the Arsenal review the laboratory HVAC needs for current and prospective missions. In particular, the safety of building-level boilers needs to be revisited.

The 3000 Area Laboratory Complex consists of a combination of laboratory and office space in each of buildings 3022, 3024, 3028, and 3029. These buildings conduct research, development, and testing on energetic materials, which puts a premium on safety considerations. The laboratory space requires 100% outside air 24 hours a day, 365 days a year. In addition, this air must be conditioned to a target relative humidity of 50% in both winter and summer to yield consistent experimental conditions and minimize the possibility of static electricity discharge. Finally, the laboratory ventilation rate is much higher than for typical office space. Steam is provided to each of the buildings by two central boilers in building 3013 via an above-ground distribution system. Each building is served by one or two chillers with supplemental cooling in a handful of rooms provided by air-cooled direct expansion (DX) equipment.

Key observations and recommendations from the audits are as follows.

- Given the age, condition, and/or capacity shortfall of the existing chillers, all should be replaced.
- Given the age and the condition of the existing air handling equipment in Building 3028, new air-handling units, controls, and mezzanine level ducting are recommended.
- The air-handling units and ducting in the remaining buildings are in good shape, but the controls are not working well and are dated, so should be replaced.

The Facility Energy Decision System (FEDS) software was used in combination with spreadsheet calculations to develop a model of energy use for the 3000 Area Laboratory Complex, including its central boiler plant and distribution system. The recommendations resulting from the energy and economic evaluation are as follows.

- Replace the existing building-level chillers with new building-level centrifugal water-cooled chillers.
- Replace the existing central boilers and distribution piping serving the entire complex with new building-level boilers.

Annual energy and boiler makeup water savings are estimated to result in a payback period of 7.6 years on an investment of $1.3 million.

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Introduction

In response to a request by Picatinny Arsenal, the Pacific Northwest National Laboratory (PNNL) was asked by the Army to conduct an energy audit of the Arsenal's 3000 Area Laboratory Complex. The objective of the audit was to identify life-cycle cost-effective measures that the Arsenal could implement to reduce energy costs. The specific facilities included in the audit were buildings 3022, 3024, 3028, and 3029. The central boiler plant in building 3013, which serves these four buildings, was also included in the audit. A "level 1" audit of the facilities was conducted on December 7-8, 2009 by PNNL staff Daryl Brown and James Goddard. The visit was hosted by Nick Stecky, the Arsenal's energy manager, with support from several other Arsenal staff familiar with the Complex.

Laboratory Complex Overview

The 3000 Area Laboratory Complex consists of a combination of laboratory and office space in each of the four buildings. Buildings 3022 and 3024 are physically connected, as are buildings 3028 and 3029. An aerial view of the facilities, including the boiler plant, is shown in Figure 1. As can be seen in Figure 1, building 3022 forms a U-shape. Construction records indicate that building 3022 is actually comprised of three different buildings that were built at different times. The west and south wings of this building are entirely office space, while the east wing is a mixture of laboratory and office space, as are buildings 3024, 3028, and 3029. Summary dimensional characteristics of the buildings are listed in Table 1.

Laboratory Complex HVAC

The 3000 Area laboratories conduct research, development, and testing on energetic materials, which puts a premium on safety considerations. The laboratory space requires 100% outside air 24 hours a day, 365 days a year. In addition, this air must be conditioned to 70° F in the winter and 72° F in the summer, with a target relative humidity of 50% in both seasons to minimize the possibility of static electricity discharge. Finally, the laboratory ventilation rate is much higher than for typical office space. These requirements combine to result in a much higher than normal energy use per square foot of floor space.

Steam is provided to each of the buildings by two central boilers in building 3013 via an above-ground distribution system. The steam is used for sensible heating and humidification in the winter, reheating of dehumidified air in the summer, and building 3024’s service hot water needs year-round. Roughly half of the delivered steam is used for sensible heating. One-third is used for humidification, and most of the rest is used for reheating cooled and dehumidified air. No condensate is returned to the boiler plant.

Each building is served by one or two chillers with supplemental cooling in a handful of rooms provided by air-cooled direct expansion (DX) equipment. The west wing of building 3022 is cooled exclusively with DX equipment. Space conditioning is universally provided via air-handling units and ducting. Buildings 3028, 3029, and the east wing of 3022 have multi-zone air handlers with heating and cooling supplied to each of the zones, while single supply ducts are used in Building 3024 and the west and south wings of Building 3022. Terminal reheat is used in the laboratory portion of Building 3024. Building cooling equipment is summarized in Table 2.

Figure 1. Picatinny 3000 Area Laboratory Complex

Table 1. 3000 Area Laboratory Complex Building Dimensions

Building #	Square Feet	# Floors
3022-W	10,150	1
3022-S	15,550	2
3022-E	14,875	1
3024	14,800	1
3028	27,200	2
3029	19,900	2

Table 2. Laboratory Complex Cooling Equipment

Building	Equipment Types	# Units	Capacities, Tons	Air-side Systems
3022-E	Water-cooled chillers Split system DX	2 5	140 each ≈ 3 each	Multi-zone air handlers
3022-S	Shares 3022E chillers			Multi-zone air handlers
3022-W	Split system DX	7	≈ 5 each	Constant volume air handlers; split system DX cooling
3024	Air-cooled chiller	1	80	Constant volume air handler with chilled water coils
3028	Water-cooled chillers	2	140 each	Multi-zone air handlers
3029	Shares 3028 chillers			Multi-zone air handlers

HVAC Equipment Condition

Much of the HVAC equipment in the Complex needs to be replaced because it's not functioning well and is beyond its useful service life. The chillers serving buildings 3028 and 3029 are approximately 30 years old. The compressors on these chillers have been replaced once, but they have no unloading capability. This results in poor part-load efficiency with frequent starts and stops that are detrimental to equipment life. The chillers in building 3022 have compressors with unloading capability and are in better condition, but are still at least 20 years old. The chiller serving building 3024 is relatively new, but is too small to meet the building's peak cooling load and is inherently less efficient with its air-cooled condenser. The DX equipment serving the west wing of building 3022 is only 2 years old and in good condition. **Given the age, condition, and/or capacity shortfall of the existing chillers, all should be replaced.**

The air-handling units in building 3028 are rusting and leaking air. Insulation was missing on several ducts on the mezzanine level. Given the age and the condition of the equipment, new air-handling units, controls, and mezzanine level ducting are recommended. The existing equipment was designed for indoor use, but that on the mezzanine is sitting outside, albeit under an awning. Replacement mezzanine equipment and insulation should be designed for outdoor use. **The air-handling units and ducting in the remaining buildings are in good shape, but the controls are not working well and are dated, so should be replaced.**[1] The exception to this recommendation is the west wing of building 3022, where the HVAC equipment is only 1 or 2 years old.

[1] Building 3029 was not included in the on-site walk-through audit. For energy modeling purposes, it was assumed to have features identical to building 3028 except for its external dimensions.

All laboratory space appears to be getting a constant high supply of air, 24 hours a day, 365 days a year. Energy modeling of the buildings and calibration to actual natural gas consumption in the central boiler plant indicates a ventilation rate of nearly eight air changes per hour on average. If the supply air flow rate could be matched with laboratory hood use, significant savings would occur if building staff were vigilant about turning off hood vents when not in use. Air-handling units dedicated to supplying air just to the hoods, as apparently was once done in building 3028, may allow the air supplied by the other air handlers to be reduced on nights and weekends. Follow-on discussion with laboratory personnel to better understand the temperature, humidity, and air exchange requirements would be necessary to make more specific operating and control recommendations.

Additional observations and recommendations are listed below:

- Night and weekend temperature setback should be used in the office areas.
- The 24/7 ventilation mode suggests that more efficient motors should be installed in the air handlers not being replaced and high efficiency motors should be specified in the air handlers that are replaced.
- There are five DX condenser units in the building 3022 attic. If these units can't be moved outside, then outside air should be provided to the attic in the summer.
- Chilled water was being supplied to the number 2 air-handler in building 3024 during the audit, even though it was a cold December day. This problem needs to be investigated.
- The two air-handlers in the downstairs mechanical room in building 3022 have economizer hardware, but need controls and sensors to allow them to work.

Energy Modeling

The Facility Energy Decision System (FEDS) software[2] was used in combination with spreadsheet calculations to develop a model of energy use for the 3000 Area Laboratory Complex including its central boiler plant and distribution system. Metered electricity consumption data were not available, but natural gas consumption at the boiler plant was known. Building (envelope, lighting, service hot water, and HVAC equipment) and boiler plant characteristics collected during the site audit were entered into the FEDS software along with weather data for calendar year 2008. The principle unknown was the average number of air changes per hour in the laboratory spaces. This value was varied until modeled natural gas consumption matched the actual natural gas consumption for the same year. Weather data for a typical meteorological year (TMY) was then used with the model for evaluating potential retrofits to the existing energy infrastructure. Building peak hourly and annual heating and cooling load data for TMY weather are presented in Table 3. Similar heating load data are shown in Table 4 for the boiler plant and its distribution system.

Although no metered electricity consumption data were available for the chillers, the peak cooling loads calculated are generally comparable to the installed capacity. Note that heating and cooling loads in the west and south wings of building 3022, which have no laboratories, are significantly less than for the other buildings. Also note that the calculated peak building load for building 3024 is about 50% higher than the 80-ton capacity of its chiller, which is consistent with what Arsenal staff reported during the December audit.

Table 3. 3000 Area Laboratory Complex TMY Building Heating and Cooling Loads

Building	Heating		Cooling	
	Peak MMBtu/hr	Annual MMBtu	Peak Tons	Annual Ton-Hours
3022-W	0.15	139	12	8,008
3022-S	0.16	117	17	14,504
3022-E	2.19	5,399	122	162,338
3024	2.14	5,465	118	154,382
3028	3.16	7,895	177	236,192
3029	2.32	5,829	130	172,859
Totals	10.12	24,844	575	748,283

[2] http://www.pnl.gov/FEDS/

Table 4. 3000 Area Laboratory Complex TMY Steam Heating Loads

	Peak MMBtu/hr	Annual MMBtu
Boiler Plant Natural Gas	14.62	40,293
Boiler Plant Output	11.70	32,234
Steam Piping Wall Loss	0.166	1,453
Steam Loss	0.392	3,433
Condensate Loss	1.02	2,504
Building Loads	10.12	24,844

Recommended Heating and Cooling Retrofits

The existing water-cooled reciprocating chillers were estimated to consume 1.1 kW/ton of cooling; the air-cooled chiller, although newer, is inherently less efficient, and was estimated to consume 1.5 kW/ton. In contrast, new water-cooled centrifugal chillers consume 0.5 kW/ton. **Although chiller replacement could be justified based on the age, condition, and capacity issues noted above, the electricity savings alone are also adequate to justify replacement.** New water-cooled centrifugal chillers including a new cooling tower, condenser piping and pumps, and chiller enclosure for building 3024 was estimated to cost $425,000 (not including design, SIOH[3], and contingency) and would save $57,000 per year for a 7.5 year payback of direct costs. The estimated direct costs for this option are presented in Table 5.

Table 5. New Building Chillers Direct Cost Estimate

Item	Installed Cost, $k
4 water-cooled chillers; 120, 130, 140, & 180 ton	350
Bldg. 3024 cooling tower and condenser water pumps and piping	35
Bldg. 3024 mechanical room addition	15
Existing chiller removal allowance	25
Total Direct Cost	425

Another idea would be to build a new central chilled water plant near the location of the existing Building 3024 chiller. The four buildings could then be served by fewer larger chillers that would be even more efficient. The estimated cost for the new chiller plant, based on two 300-ton water-cooled centrifugal chillers, is $850,000, (not including design, SIOH, and contingency) as itemized in Table 6. The annual electricity savings would be about $60,000, resulting in an incremental payback period compared to new building chillers of 150 years for the direct cost alone![4] Clearly, a new central chiller plant cannot be justified based on energy savings.

Table 6. New Chiller Plant Direct Cost Estimate

Item	Installed Cost, $k
600 (2*300) ton centrifugal water-cooled chiller plant	650
1600 feet chilled water piping	200
Total Cost	850

[3]Construction supervision, indirect, and overhead costs.

[4] ($850k-$400k)/($60k/yr-$57k/yr) = 150 years

As shown in Table 4, **nearly one quarter of the steam energy leaving the current central boiler plant is estimated to be lost via heat conduction through the pipe and insulation, steam leaks at traps and other locations, and in the condensate that is not returned. All three of these loss mechanisms would be eliminated if building boilers were installed and condensate captured.** The installation of new boilers, mechanical room expansion, and an allowance for new condensate piping within the buildings is estimated to cost about $560,000 (see Table 7). Again, these capital cost estimates do not include design, SIOH, or contingency. The annual natural gas savings would be about $93k and the annual makeup water savings associated with returning condensate is estimated to be $26k. The additional net annual O&M costs associated with 4 distributed boilers instead of two central boilers was estimated to be about $9k. The resulting payback period for the direct costs is 5 years.

Table 7. Building Boiler Direct Cost Estimate

Item	**Installed Cost, $k**
Boilers	$435
Mechanical room additions	$75
Condensate piping allowance	$50
Total Cost	$560

Total project costs and economics for the installation of new building boilers and chillers are shown in Table 8. Here, a 30% markup has been included for design (10%), SIOH (6%), and contingency (14%). With a payback period of 7.6 years, this project is justified based on energy and O&M savings. **Natural gas is assumed to be available near the building mechanical rooms. If this is not the case, then the cost of extending natural gas lines to these rooms would need to be added to the estimates.**

Other Cost-Effective Retrofits

Necessitated by elimination of the central boiler plant for building 3024, but cost-effective for all buildings is the conversion from the existing (mostly electric) service water heating systems to natural gas water heating. The total capital cost, including design, SIOH, and contingency is estimated to be $20,000 for four natural-gas-fired service water heaters. The conversion from electricity to natural gas will save about $10,000 per year for a 2 year simple payback.

Table 8. Integrated Distributed Boiler and Chiller Project Economics

Item	$k
Replacement building chillers	$425
New building boilers	$560
Total net direct cost	$985
Design, SIOH and contingency @ 30%	$295
Total project cost	$1,280
Boiler annual energy savings	$93
Chiller annual energy savings	$58
Boiler makeup water annual savings	$26
Boiler O&M annual savings	($9)
Total annual savings	$168
Simple payback period, years	7.6