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Energy and Water Conservation Assessment of the Radiochemical Processing Laboratory (RPL) at Pacific Northwest National Laboratory

SR Johnson
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May 2014

Pacific Northwest NATIONAL LABORATORY

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Richland, Washington99352

EISA Assessment Summary

This report summarizes the results of an energy and water conservation assessment of the Radiochemical Processing Laboratory (RPL) at Pacific Northwest National Laboratory (PNNL). The assessment was performed in October 2013 by engineers from the PNNL Building Performance Team with the support of the dedicated RPL staff and several Facilities and Operations (F&O) department engineers. The assessment was completed for the Facilities and Operations (F&O) department at PNNL in support of the requirements within Section 432 of the Energy Independence and Security Act (EISA) of 2007. EISA requires comprehensive energy and water evaluations on the top 75% of a site's total covered facility energy use. EISA requires an assessment similar to a Level 1 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) energy audit, which consists of an initial building walkthrough and identification of energy and water conservation measures (ECMs and WCMs). This report covers these requirements. A Level 1 energy audit also requires re/retro commissioning opportunity identification, which F&O is covering in a separate effort.

The model simulation and engineering analysis did not return many large life cycle cost effective capital improvements, which was expected because the Radiochemical Process Laboratory (RPL) is a Hazard Category-II Nuclear Facility with a unique nuclear science and technology mission that requires following specific operational and maintenance (O&M) guidelines. The mandatory O&M guidelines that require running RPL ventilation equipment continuously, irrespective of the day of the week or holidays, eliminate the typical building ECMs that can be deployed. In addition, the energy unit costs are relatively low for the area and craft labor costs are high which results in undesirable paybacks. Additionally, to carry out the facility's mission, the 1953 building has been renovated over the years. Approximately $50M has been invested in facility life extension and upgrades; now housing more than 87 laboratories, 16 hot cells, 160 fume hoods and 25 glove boxes for work with radioactive materials. In FY13, RPL was designated by DOE as a High Performance Sustainable Building (HPSB), the first DOE Office of Science nuclear laboratory to achieve such status. HPSB designation is based on five guiding principles for existing buildings: integrated design, optimized energy use, water conservation, enhanced indoor environmental quality, and reduced environmental impact of materials.

Table 1 and **Table 2** summarize the results of the assessment by ECM or WCM category. The retrofit candidates include building envelope; lighting; heating, ventilation and air conditioning (HVAC); other; and water. The detailed results for each ECM and WCM type can be found in the main body of this report. Table 1 lists those ECMs that are economically feasible and considered a high priority to RPL, while Table 2 are those ECMs and WCMs that are either not cost-effective or are not considered a high priority for RPL. Some of these "best practice" measures were included despite the fact that the high labor costs ranked them economically less desirable; these ECMs/WCMs should be considered when the equipment and/or system requires replacement.

If F&O implemented all the cost-effective energy- and cost-reducing projects identified in Table 1, they could save 16,058 MMBtu and $131,921 per year. This represents a 48% reduction of energy use at RPL based on energy consumption during September 2012 – August 2013 with a simple payback period of 4. 9 years. However, prior to embarking on a retrofit campaign, it is recommended that additional comprehensive evaluations (i. e. capital cost and savings assessments) be completed for all these projects due to the unique hazards (radiological, asbestos, and beryllium) associated with the facility.

Table 1. Summary of Suggested ECMs

Measure	Total Energy Savings (MMBtu/yr)	Total Water Savings (Kgal/yr)	Annual Energy Cost Savings ($/yr)	Annual O&M Savings ($/yr)	Total Annual Savings ($/yr)	Capital Costs	Simple Payback (yr)
Building Envelope							
Install Second Floor Vestibule	210	0	$1,919	$0	$1,919	$22,968	12. 0
Lighting							
Replace Exit Signs	1	0	$8	$743	$751	$8,064	10. 7
Replace HLRF Lighting	4	0	$89	$398	$487	$8,083	16. 5
HVAC							
Convert High Pressure Steam System to Hot Water[1]	7,109	0	$57,418	$-4,351	$53,067	$524,680	9. 9
Apply Temperature Setback	3,544	0	$25,103	$0	$25,103	$200	0. 0
Install VFDs on Supply and Exhaust Fans	5,190	0	$50,594	$0	$50,594	$79,994	1. 6[2]
Total	16,058	0	$135,131	$-3,210	$131,921	$643,989	4. 9

If F&O implemented all the energy and water cost-reducing projects identified in Table 2, they could save an additional 2,298 MMBtu, 155 thousand gallons of water, and $35,624 per year. This represents a 7% reduction of energy and 31% water use at RPL.

[1] High level assessment based on converting a central steam plant to a decentralized hot water system

[2] The energy savings was determined by the FEDS model based on adding variable frequency drives (VFD)s to the existing supply and exhaust fans; however, this ECM is superseded by another more detailed analysis which recommended new fans and VFDs with harmonic filters. This approach took into account RPL's long term mission ensuring a life expectancy of 30+ years for the exhaust system while mitigating any harmonic disturbances.

Table 2. Additional ECMs and WCMs for Consideration

Measure	Total Energy Savings (MMBtu/yr)	Total Water Savings (Kgal/yr)	Annual Energy Cost Savings ($/yr)	Annual Water Cost Savings ($/yr)	Annual O&M Savings ($/yr)	Total Annual Savings ($/yr)	Capital Costs	Simple Payback (yr)
Building Envelope								
Upgrade South Windows	50	0	$403	$0	$0	$403	$27,234	67. 6
Upgrade Roof Insulation	957	0	$9,555	$0	$0	$9,555	$293,619	30. 7
Lighting								
Lighting Occupancy Sensors	716	0	$18,057	$0	$0	$18,057	$162,180	9. 0
Replace T12 Lighting	2. 5	0	$23	$0	$65	$88	$7,308	83. 0
HVAC								
HVAC Small Motor Upgrades	505	0	$6,097	$0	$0	$6,097	$302,508	49. 6
Other								
Smart Power Strips	52	0	$472	$0	$0	$472	$21,143	44. 8
Water								
Toilet Replacement	0	81	$0	$346	$0	$346	$7,431	21. 5
Urinal Replacement	0	21	$0	$90	$0	$90	$4,527	50. 1
Faucet Replacement	14	42	$219	$179	$0	$398	$188	0. 5
Showerhead Replacement	4	11	$70	$48	$0	$118	$167	1. 4
Total	2,298	155	$34,896	$663	$65	$35,624	$826,305	23. 2

Table 3 displays the totals from Table 1 and Table 2.

Table 3. Totals from all Measures Evaluated

Measure	Total Energy Savings (MMBtu/yr)	Total Water Savings (Kgal/yr)	Annual Energy Cost Savings ($/yr)	Annual Water Cost Savings ($/yr)	Annual O&M Savings ($/yr)	Total Annual Savings ($/yr)	Capital Costs	Simple Payback (yr)
Recommended Measures	16,058	0	$135,131	$0	$-3,210	$131,921	$643,989	4. 9
Measures for Consideration	2,298	155	$34,896	$663	$65	$35,624	$826,305	23. 2
Total	18,356	155	$170,027	$663	$-3,145	$167,545	$1,470,294	8. 8

Acronyms and Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	building automation system
BOCC	Building Operation Control Center
BPA	Bonneville Power Administration
CFL	compact fluorescent lamp
CRREL	Cold Regions Research and Engineering Laboratory
CUP	central utilities plant
CY	calendar year
DSOM	Decision Support for Operations and Maintenance
ECAM	Energy Charting and Metrics Tool
ECM	energy conservation measure
EISA	Energy Independence and Security Act
ESPC	energy savings performance contract
EUI	energy use intensity
F&O	Facilities and Operations
FEDS	Facility Energy Decision System
gpf	gallons per flush
gpm	gallons per minute
GSA	U. S. General Services Administration
HLRF	High Level Radiochemistry Facility
hp	horse power
HPS	high-pressure sodium
HVAC	heating, ventilation and air conditioning
JCI	Johnson Controls Inc.
Kgal	thousand gallons
kWh	kilowatt-hours
LCC	life-cycle cost
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LTHW	low temperature hot water
Mgal	million gallons
MMBtu	million British thermal units
MSA	Mission Support Alliance
NG	natural gas
NPV	net present value
O&M	operation and maintenance

PNNL	Pacific Northwest National Laboratory
RPL	Radiochemical Process Laboratory
SIOH	supervision, inspection, and overhead
SIR	savings-to-investment ratio
VAV	variable-air volume
VFD	variable-frequency drive
WCH	Washington Closure Hanford
WCM	water conservation measure
WUI	water use intensity

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1.0 EISA Assessment Process

A combination of audits, modeling, and other analysis was used to assess the potential for energy and water conservation measures at the Radiochemical Processing Laboratory (RPL). In addition, the engineers from the Building Performance Team relied on and fully appreciated the efforts of the knowledgeable facilities staff such as Scott Colby, Tony Lechelt, John Logan, Marc Berman, Shan Belew, Steve Hultman, and former facility staff member Ron Underhill. In addition, RPL's dedicated staff was able to provide accurate key drawings, flow diagrams, system reports and provide up to date equipment condition.

1.1 Walkthrough Audits

The assessment team performed a walkthrough of RPL during the week of October 21, 2013, to conduct the building audit. During this visit, the assessment team collected energy and water information from the facility for input into the Facility Energy Decision System (FEDS) model (PNNL 2013) and other analysis tools. Additional information was gathered to estimate conditions in the laboratory areas of the facility that could not be accessed. The audit sheet used during the audit is shown in Appendix C.

In addition to the walkthrough, several other sources of information were gathered to assess the condition of the building. These information sources included as-built and modified drawings, specifications, and utility bills.

1.1.1 Existing Building

The Radiochemical Process Laboratory (RPL) is a Hazard Category-II Nuclear Facility operated by Pacific Northwest National Laboratory (PNNL). RPL celebrated its 60th anniversary in 2013. It was built in 1953 and known as Building 325, but was renamed the Radiochemical Processing Laboratory in 1996. RPL has been transformed into a cornerstone for the PNNL nuclear science and technology mission. Since 2006, approximately $50M has been invested in facility life extension and upgrades. The facility now houses more than 87 laboratories, 16 hot cells, 160 fume hoods and 25 glove boxes for work with radioactive materials. In FY13, RPL was designated by DOE as a High Performance Sustainable Building (HPSB), the first DOE Office of Science nuclear laboratory to achieve such status. HPSB designation is based on five guiding principles for existing buildings: integrated design, optimized energy use, water conservation, enhanced indoor environmental quality, and reduced environmental impact of materials.

RPL has a total square footage of 144,820and has a full basement and one above grade floor, both with office, laboratory, and mechanical space. A second floor mezzanine consists of offices and mechanical space. In addition, the building has an adjacent high-bay laboratory with a few offices. An approximate breakdown of the building is 31% laboratory space, 11% office space, and 58% common space (hallways, storage, and mechanical space). **Figure 1** is an aerial view of the facility with the boiler annex, filter building, second floor, and high-bay lab spaces outlined in green.

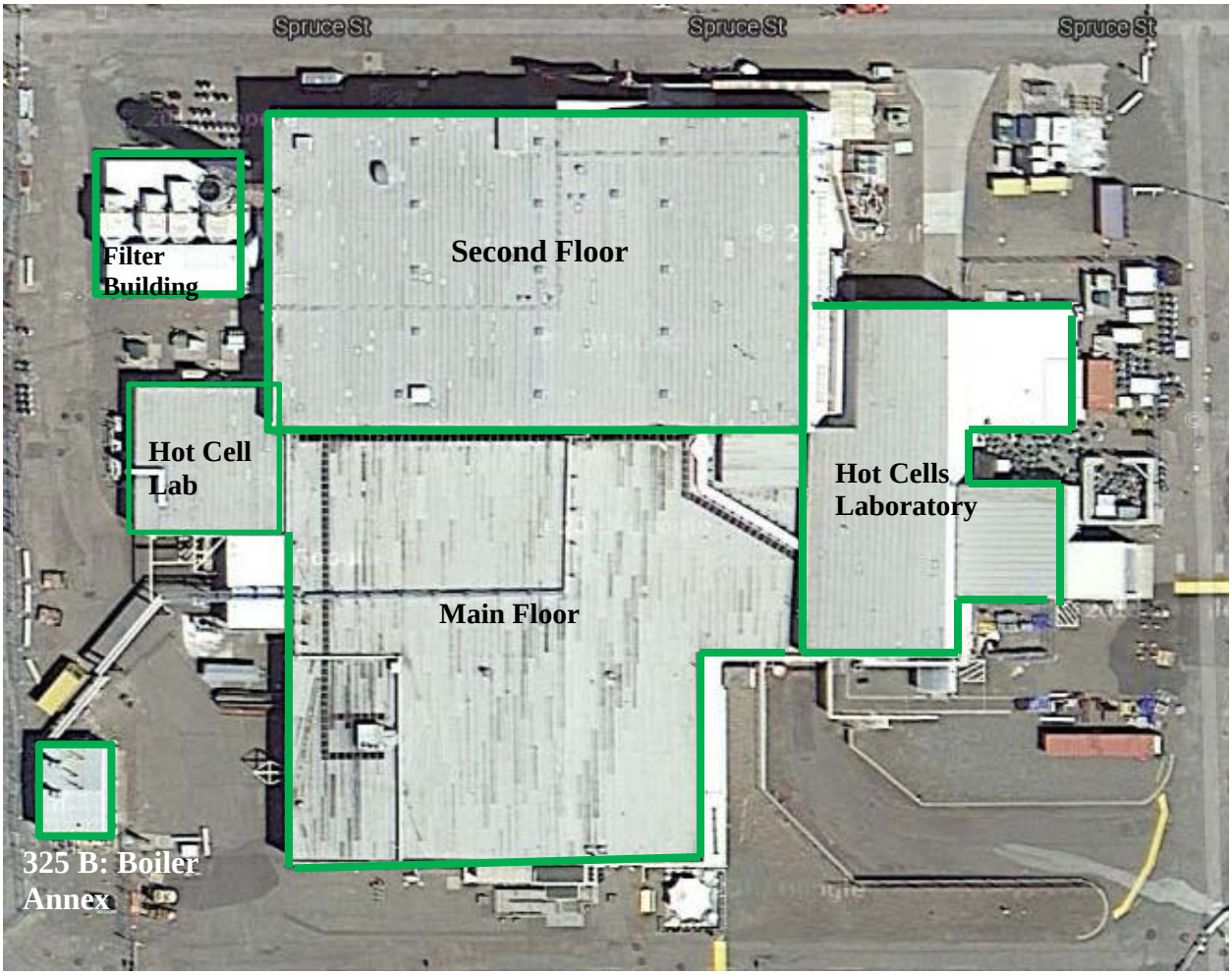

Figure 1. PNNL's Radiochemical Processing Laboratory

There are four supply fans located on the second floor. The fans are ducted into a common building supply air plenum, and three of them deliver between 135,000 and 140,000 cfm, pulling 100% outdoor air with one unit in standby. Each air handler is equipped with an outside air isolation damper, a hot water preheat coil, heat recovery coil, cooling coil, and a reheat coil. The fans are equipped with outside air isolation dampers and discharge air isolation dampers that are designed to close when the respective fan is off. The equipment is estimated to be original equipment installed in 1953, except the reheat coils that were installed in 1982. Unfortunately, according to a recent inspection[3,] many of the old dampers are not completely sealing; thus causing conditioned air to leak out of the building.

The RPL exhaust system is composed of four belt driven fans that run at a constant speed of 1178 revolutions per minute (RPM). The exhaust fans also are equipped with vortex inlet dampers for flow control and have inlet and outlet dampers that close when the fan is off. During normal operations, three exhaust fans run continuously, and one is held in standby. Building exhaust passes through primary

[3] Ayers. W.S.. 2011.Engineering Study of Ventilation Supply and Exhaust Systems in the Radiochemical Process Laboratory.S663633-RPT-PM-001, Revision 0. Pacific Northwest National Laboratory, Richland, WA. December 2011.

HEPA filters located in close proximity to the rooms they serve and then passes through 4 Final HEPA banks located in the Filter Building. All four HEPA banks are normally on-line. Each bank is equipped with inlet and outlet isolation dampers to allow for taking the bank out of service for maintenance. The RPL exhaust system was modified in 1982. The modification involved the addition of heat recovery to the building, including the addition of heat recovery coils in the discharge air stream of each exhaust fan.

Building 325BA is a boiler annex building that is located outside of the RPL building. It houses two Cleaver Brooks packaged steam boilers (model # CB-700-125-150). The boilers were installed as part of a 25year energy savings performance contract (ESPC) installed in 1997. The fire-tube boilers burn natural gas (NG) fuel and are designed to operate at a pressure of 150 psi maximum. They are 125 hp, which indicates that they output ~ 4313 lbs. /hr. [4] of saturated steam, with a rated input of ~ 5,103 kBtu/hr of NG. According to the boiler manufacturer, they have an average efficiency of 80% across the range of firing rates; however the nameplate efficiency is 82% and the boiler operator claimed 84%, which was a conservative value used in the FEDS analysis. Based on the natural gas consumption in 2013 and confirmed by the boiler operator, one boiler is typically in standby mode, and the operation of the boilers are alternated. Although the consumption of fuel is weather dependent, the annex building also houses a Cleaver Brooks (45,000 gallon) water conditioner, a CB dearerator (8,000 lbs. /hr. capacity), a condensate tank, three feed water pumps and two condensate pumps. The operation of all the pumps is alternated; yet the pump run time hours indicate that some months the condensate pumps don't run at all or very little, indicating little to no condensate is being returned to the boiler.

Originally, the system was designed to provide high pressure and low pressure steam, but during the audit, the low pressure steam system was turned off, and building engineers stated that it may remain off for the cooling Season which ends October 31st. The primary user of the low pressure steam is the supply fan #5 (SF-5). The high pressure steam is converted to hot water and primarily used for preheat and reheat coils for space heating. The operating pressure the day of the audit was ~ 100 psig, but has since been dropped to approximately between 80 psig.

To cool the facility, two 300-ton chillers provide chilled water to the cooling coils in the main supply units. This system also provides cooling water for the second floor offices. Select spaces on the first floor have additional booster cooling coils that receive chilled water from the 300 ton units. In addition, there is a process chiller to provide cooling to the basement offices and select lab spaces and equipment, and an office chiller which provides cooling water for 4 fan coil units that serve first floor offices at the south end of the building. A small 10,350 cfm air handler, with 11 variable-air volume (VAV) units, is located on the second floor to supply the second floor ventilation, electric heating, and distribute the chilled water from the 300-ton central chillers.

1.2 Analysis Tools and Inputs

A FEDS model was developed for RPL and all fuels and equipment were accounted for. FEDS is a fuel-neutral, technology-independent software tool developed by PNNL that provides a comprehensive method to quickly and objectively identify energy improvements that offer maximum life-cycle cost (LCC) savings. FEDS determines an optimum set of cost-effective retrofits from a current database of hundreds of proven technologies. FEDS does not include building-integrated renewable energy conservation measures (ECMs) at this time. FEDS can be used to perform comprehensive assessments

[4] 1 Boiler Horsepower = evaporation of 34.5 lbs. of water at 212°F into steam as 212°F

using other sources of capital (e. g. , energy savings performance contract or utility financing) with distinct economic inputs. If desired, the PNNL energy team can re-run the FEDS software using site-specific alternative financing options and reassess the results. This reassessment was not requested, thus not performed and included in this report; however, a re-run of Feds was requested after the preliminary set of measures were reviewed to bring the estimates more in line with "actual" costs at a Category 2 nuclear facility. The revised Feds model included a fully burdened craft charge out rate and an escalation factor that reflects the challenges of working in a facility such as RPL facility that contains asbestos, radioactive materials, and beryllium.

The FEDS model was calibrated using the local weather and utility data for September 2012 – August 2013. More information on the calibration processes is included in Appendix B. The models were then run to estimate annual HVAC, lighting, service hot water, and miscellaneous end-use loads based on typical meteorological weather year, and to identify cost-effective retrofits. For retrofits not included in the FEDS model, such as irrigation and plug load reduction, other spreadsheet analysis tools were used. These other analysis tools were developed for the military's EISA assessment program and have been peer reviewed and used by other entities outside of PNNL.

Retrofit costs and savings estimates for ECMs were developed for projects that are LCC effective given the utility rates and current loads. ECMs screened for include:

- Boiler and Chiller Plant Improvements
- Service Hot Water
- Lighting Improvements
- Building Envelope Modifications
- Chilled Water Distribution Systems
- Refrigeration
- Electric Motors and Drives
- Renewable Energy Systems
- Water and Sewer Conservation Systems
- Appliance/Plug-Load Reduction

In addition to this report, F&O will receive a complete record of the FEDS input and output files, as well as the Excel documentation for projects. The FEDS input files consist of the relevant building and equipment data collected and the assumptions made to perform the complex engineering analysis. The FEDS output files contain considerably more detail in support of project development.

1.2.1 Utility Rates

Over the past several years, Mission Support Alliance (MSA) has provided RPL with Bonneville Power Administration (BPA) electricity; however, at the end of calendar year 2013, the electrical service for the Hanford 300 Area was transitioned over to the City of Richland. Unfortunately, the transition was not as smooth as hoped, and some meter reading issues were discovered for the months of November and December 2013. Likewise, MSA (a company that is responsible for the transmission and distribution of the BPA electricity on the Hanford Site) had some problems with their final September and October (2013) meter readings. Thus, it was recommended that analysis use 12 months' worth of historical data, which represented stable, "more accurate" costs and consumption figures, from September 2012 thru August 2013. The rates used for the analysis are discussed below.

Beginning November 3, 2013, the City of Richland replaced MSA, to provide electricity to RPL. RPL will be billed for electricity according to the City of Richland's Schedule 24 (Large General Service, for customers with a maximum demand between 300 and 1,000 kW). As of January 1, 2013, the rate schedule has a demand charge of $5. 85/kW an energy charge of 3. 12¢/kWh, and a power factor charge. These charges do not vary by time of day or season, and there is no ratchet used in the determination of billing demand (i. e. , the measured peak demand in a given month is the billing demand for that month, modified for power factor lower than 0. 95). FEDS uses the rate schedule parameters in the LCC. Other analysis tools use a blended rate, and $0. 3112/kWh was used for the period of Sept. 2012 – Aug. 2013. The electrical consumption for this same time period was 7,313,573 kWh which includes the main RPL building, the chiller and the boiler annex.

The 300 Area is billed from a Cascade Natural Gas, Inc. natural gas meter that serves as the master meter for the entire 300 area. The RPL natural gas allocation comes from the PNNL gas meter located outside the RPL steam annex building. The effective rate for calendar year 2013 was $0. 662/therm, and the total usage based on calendar year 2013 was 81,343 therms.

The water and sewer services are provided by the City of Richland. These rates have varied considerably in the past, so similar to the electrical rates above, the basis for the rates and consumption were recommended by the PNNL Utility Program Manager. The recommended rate for this analysis is the rate charged to Washington Closure Hanford (WCH) for the 300 Area which is $1. 05/ccf ($1. 404/Kgal) for water and $2. 15/ccf ($2. 87/Kgal) for sewer.

In addition, as part of the 1997 ESPC contract, Johnson Controls Inc. (JCI) is responsible for the operation and maintenance (O&M) of the boiler annex. The O&M cost paid to JCI varies from year to year but was $19,469 per month for FY13, for an annual fee of $233,628 and $14,010 per month for FY14, which will be adjusted, as required, based on the gas consumption later in the year. This seems excessive and as more of the buildings in the 300 area become obsolete and are demolished, this cost may increase, unless renegotiated.

2.0 RPL Energy and Water Conservation Measures

The following section describes the ECMs identified and recommended during the assessment. Interactive effects are also evaluated as part of the optimization process so that energy savings are not double counted or undercounted. **Table 4** includes a summary of the energy savings, O&M savings and LCC economics. This table includes measures that were determined to be cost-effective.

Table 4. Expanded Summary of Measures by End Use

ECM Measure	Total Energy Savings (MMBtu/yr)	Total Water Savings (Kgal/yr)	Annual O&M Cost Savings ($/yr)	Annual Energy Cost Savings ($/yr)	Total Annual Savings ($/yr)	Capital Costs	Simple Payback (yr)
Lighting							
Replace Exit Signs	1		$743	$8	$751	$8,8064	10. 7
Replace HLRF Lighting	2		$398	$89	$487	$8,083	16. 5
Building Envelope							
Install Second Floor Vestibule	210			$1,919	$1,919	$22,968	12. 0
HVAC							
Convert Steam System to Hot Water[5]	7,019		($5,100)	$57,418	$53,067	$524,680	9. 9
Apply Temperature Setback	3,544			$25,103	$25,103	$200	0. 0
Install VFDs on Supply and Exhaust Fans	5,190			$50,594	$50,594	$79,994	1. 6[6]
Total	**16,049**	**0**	**($3,959)**	**$135,131**	**$131,923**	**$643,989**	**4. 9**

[5] High level assessment based on converting a central steam plant to a decentralized hot water system

[6] The energy savings were determined by the FEDS model based on adding variable frequency drives (VFD)s to the existing supply and exhaust fans; the capital cost and payback were hand calculated based on these savings. However, this ECM is superseded by another more detailed analysis which recommended new fans and VFDs with harmonic filters. This approach took into account RPL's long term mission ensuring a life expectancy of 30+ years for the exhaust system while mitigating any harmonic disturbances.

2.1 Measures Identified Using FEDS

The FEDS simulation did not return many large capital retrofits, which was expected because the RPL energy unit costs are relatively low with high craft labor costs to safely implement upgrades.

To carry out the unique mission of RPL, there are mandatory operational requirements that must be met such as the large supply and exhaust fan systems serving the RPL lab spaces must run continuously, irrespective of the day of the week or holidays. Likewise, the fume hoods ventilation also operate continuously because of radiological and chemical hazards in the labs and hoods. Thus, typical building energy conservation measures involving curtailing HVAC equipment runtimes cannot be deployed at RPL.

The following sections identify the energy and water conservation measures (ECMs and WCMs) and include an assessment of the existing conditions in the affected group of buildings, a description of each ECM or WCM, and a summary of the economics.

2.1.1 Replace Exit Signs with Electroluminescent Exit Signs

RPL has 34 LED exit signs throughout the facility. Because these fixtures need to be on, regardless of occupancy, it is recommended that these fixtures be upgraded to a more efficient technology such as electroluminescent as funding permits. It is calculated that this retrofit yields a cost savings of $751, with a simple payback of 10. 7 years and a SIR of 1. 6.

2.1.2 Replace Metal Halide Lighting in HLRF

A majority of the High Level Radiochemistry facility (HLRF) space is lit by 11 metal halide fixtures. It was suggested by RPL staff that all the lighting in HLRF needs a comprehensive redesign and replacement including not just the High Bay but also room 604, the 603 manipulator shop, and the truck lock (610).

To reduce the energy consumption in the majority of the HLRF area, and allow the lighting level to remain the same, the metal halide fixtures should be replaced by 3F32ST8 fixtures. Switching the metal halide lights for super T8s is expected to yield an electrical savings of 7 MMBtu per year. However, the decrease in the lighting load also decreases the amount of heat added to the space. Therefore, the heating load to the HLRF space will increase approximately 3 MMBtu per year, resulting in a total energy savings of 4 MMBtu per year. This measure has a simple payback of 16. 5 years and a SIR of 1. 0.

2.2 Measures Identified Outside of FEDS

The following additional measures were identified for more analysis beyond the FEDS model. These measures included: (1) adding a second floor vestibule, (2) conversion from steam to hot water, and (3) temperature setbacks.

2.2.1 Add a Second Floor Vestibule for Office Area

It is recommended that a vestibule be added for the second floor entrance door # 211, **Figure 2.** The intent of a vestibule is to reduce infiltration of air, thereby addressing energy conservation and comfort

issues for occupants located near the entrance door. Vestibules can reduce the infiltration losses (or gains) from wind and stack effects by creating an air lock entry. It was noted by RPL staff that there may be an additional benefit to reworking the 2nd floor door by adding a vestibule. The rework of the door will allow the proximity card reader to move the inside door. The exterior door has been a serious maintenance issue because as the weather gets warm the door warps from heat and sometimes doesn't latch, resulting in security issues and added maintenance cost; thus removal of the proximity system reader from the outside door should curtail maintenance costs.

This is a main entrance on the west side of the building for office spaces serving approximately 59 occupants. Two vestibules were added on the first floor on the east and west side of the building within the last 6 months. These additions have reduced drafts, stabilizing the building pressure.

Figure 2. Second Floor Vestibule Location

Table 5 shows a breakdown of savings anticipated from installing a vestibule on the second floor, with a total energy savings of 209. 9 MMBtu per year and $1,919 per year (See Appendix E for the assumptions and calculations). These savings result in a simple payback period of approximately 12 years.

Table 5. Savings from Installing a Second Floor Vestibule

Heating Source	Heating Energy Savings (MMBtu/yr)	Cooling Energy Savings (MMBtu/yr.)	Total Annual Cost Savings ($/yr.)	Capital Cost	Simple Payback (yrs.)
Electric	197. 89	12. 02	$1,919. 42	$22,968	12. 0

2.2.2 Convert steam system to hot water

The 25-year ESPC ends in approximately 8 years. In the next few years, it would be prudent to develop a strategy that would complement the RPL mission, and include favorable negotiation of the disposition of existing assets. Over the years, investments have been made to extend the life of the RPL facility and upgrade the operational processes. However, a considerable portion of the remaining equipment and systems are old and in need of major repairs or replacement. Further, based on current operation, it seems that the high pressure steam system originally installed is no longer required, and to be efficient, the pressures and temperatures should only be as high as required for the end use. High pressure steam systems result in higher heat losses, and require a complex condensate system. The steam and condensate systems are subject to steam trap problems and piping and pump corrosion, which tends to reduce or eliminate the amount of condensate return to the boilers, driving up costs. Based on the run time hours of the condensate pumps, it appears this is the case.

A high level simulation was performed in FEDS to confirm the idea of converting the central steam plant to a hot water system. The model assumes a method to accomplish this is to decentralize the plant and place the boilers, in this case a hot water boiler near the consumer. Thereby gaining boiler efficiency and reducing lines losses; yet adding a slight increase in operations and maintenance (O&M) costs (estimated by FEDs to be $5100/year) since the boilers will then be managed by RPL instead of the ESPC contract. Regardless of the exact strategy to convert from steam to hot water, it is recommended to continue with the incremental dropping of the steam pressures (as the astute RPL operations staff have initiated) to a lower pressure; yet without introducing operational problems, and make future modifications to eliminate the direct steam consumers beginning with the low pressure consumers by:

- Remove the supply fan #5 (SF-5) system and enable shutting down the low pressure steam leg that routes through basement from second floor, along with associated pumps and steam traps. This would eliminate a $5,000 to $10,000 fee associated with handling and dumping the condensate because of its' potential to be radioactive waste. About $1K is spent to test the condensate before sending to waste treatment, and this testing is repeated at least five times per heating season.

- An alternative for the areas that are fed by SF-5 and any other active steam consumers would need to be investigated. However, some of the steam consumers have been eliminated, for example, the RPL staff have stated that the craft shop (room 206) RTU has a steam preheat coil is no longer active and was abandoned in place.

- It is recommended that the large supply fans be reviewed to determine is they have enough capacity to cover the common areas fed by SF-5, which would require extending ducts, and adding zone reheat and re-cool coils as needed with zone control. It is also possible that the small chiller system located on the SW corner of the building that presently serves the front office/lobby areas could provide the chilled water for cooling coils. Using these existing sources would keep the capital and O&M costs down.

Once the low pressure steam is eliminated, a path to convert the remaining steam system from high pressure steam to hot water can be considered and evaluated. Currently, the high pressure steam is converted to hot water via heat exchangers for heating coils; thereby introducing a potential loss of anywhere from 1% to 3%, so ideally, they should be eliminated. If the heat exchangers are needed or

desired for isolation purposes, larger buildings can use plate-and-frame heat exchangers, which because of their large surface area to volume ratios, are economical for low temperature hot water (LTHW) applications; these LTHW systems are defined per Cold Regions Research and Engineering Laboratory (CRREL) Report by Army Corp of Engineers (Phetteplace).

The existing CB steam boilers were expected to be in the range of 80% to 84% efficient when installed in 1997; therefore, it is very unlikely that they are operating that efficiently now. Further, based on 2013 gas consumption, only one boiler is required (with one in standby) and that boiler operates on average, less than 50% of the time. Although this is an average and weather dependent, the water consumption into the annex confirms that the boilers are underutilized.

The option to retrofit the existing boilers to hot water has been considered by Johnson Controls Inc. (JCI). Cole Industrial has provided a quote in 2011 to JCI for $22,000; which inflated to 2015 (~ 3% per year) would be $25,000 to retrofit the boiler only, with no other labor or equipment (such as pumps and piping, valves, etc.) included, and the efficiency of the boiler would be the same as today ~ 80% or lower. This option has a low initial cost for the boiler retrofit; but after modifying the system to accommodate the hot water instead of steam; the costs would rise considerably. In addition, if the manufacturer cannot guarantee optimal boiler efficiency and/or the option requires an extension of the ESPC contract, it is not expected to be a viable alternative.

It is recommended to consider a new boiler, such as a condensing boiler. Using hot water has many advantages and given the right conditions (hot water return temperatures below 140°F) a condensing boiler can provide ~ 95% efficiency. Based on the existing range of the hot water set points, it appears that a condensing boiler may be an appropriate choice for RPL. It is understood that there are many factors to address to make the conversion; for instance the preheat and reheat coils in the main supply air handlers may need to be replaced if the existing coils are scaled but new coils would not only provide better heat transfer but would reduce pressure drop across the coils. Therefore, a thorough evaluation would have to be undertaken, but the enhanced system efficiencies could provide a good payback and the reduction of O&M costs associated with the elimination of equipment and a simplified system would provide additional benefits.

Ideally a new small boiler could be located close to the process (second floor mechanical room) to facilitate allow cost installation, reduction of line losses, and potential elimination of extra equipment (less O&M); however, RPL is a unique facility that has operating criteria that only allows for a limited amount of flammable gases within the building. Therefore, any boiler would have to reside in the boiler annex or another similar building built to house the small boiler(s). Even though there will still be line losses associated with the boiler upgrade, there will be less of a loss since there will be less of a temperature difference between what is inside and outside of the steam/water lines.

Based on the measured data that indicates a smaller boiler would be sufficient to meet RPL needs, Cleaver Brooks recommended a CB ClearFire C 2,500 MBtu[7]. However, in this boiler family, the range goes as high as 5,000 MBtu, and there are many other models and manufacturers to choose from for this technology.

A condensing boiler assessment was conducted for GSA in 2010. The assessment replaced two natural-gas-fired non-condensing fire-tube boilers with four boilers of the 2500 MBtu size. The

[7] http://www.cleaver-brooks.com/Products-and-Solutions/Boilers/Commercial-Condensing/ClearFire-C/Index.aspx

condensing boilers were shown to operate at ~ 93. 5% efficiency and had reduced natural gas consumption by ~14%. The results were shown in two options:

- The Retrofit option: when the existing boilers have considerable life remaining so replacement is optional; replacing with condensing boilers led to a SIR of 0. 25
- The Replace at End of Life option: the existing boilers are at the end of their useful economic life and need to be replaced; replacing with condensing boilers led to a SIR of 1. 78[8]

To simulate this measure in FEDS, the boiler system was set up as a central plant to account for losses in the steam to hot water conversion and the losses in the lack of condensate return. After the model was calibrated to the provided utility data, the model was adjusted by abandoning the central plant to make up for the line losses in the current system. This analysis method[9] resulted in an energy savings of 7,019 MMBtu per year and $53,067 per year, with a simple payback of 9. 9 years. These savings would be the result of upgrading to a boiler with an efficiency of at least 84%

Thus, the strategy for RPL would include a review of existing assets, the ESPC contract terms, and operating process tactics. If an assessment of condensing boilers is implemented, there are several reports with guidelines (Office of the Deputy Prime Minister) to assist in the evaluation, and GSA has lessons learned support the cost effectiveness of this type of upgrade (GSA).

2.2.3 Temperature Setbacks

RPL's HVAC system is currently on PNNL's building automation system (BAS) through the Building Operation Control Center (BOCC). It was discovered during a meeting at BOCC in January, that the zone temperature setbacks had been overridden to 70°F, which also disallows the zone temperatures to change during unoccupied periods. These zone setbacks should be periodically reviewed and verified. Currently, BOCC sets all PNNL building zone temperatures according to **Table 6**.

Table 6. Suggested Building Temperature Set Points

	Heating Season	Cooling Season
Occupied Hours	68°F	72°F
Unoccupied Hours	60°F	80°F

Unlocking the fixed set point of 70°F, and re-implementing the above temperature set points is expected to save approximately 3,544 MMBtu per year and $25,103 per year.

Upon further investigation it was suggested that one of the zones had their heating setbacks overridden because the space took too long to recover from the nighttime setback. This should be investigated and insufficiencies in the zone infrastructure be corrected so in the future setbacks can be implemented that can save energy. Further, engage in discussions with PNNL energy experts to determine if other options such as advanced BAS code could be employed to produce energy savings.

[8] http://www.gsa.gov/portal/mediaId/163539/fileName/GPG_Condensing_Boiler_-_FINAL_DRAFT_4-15-13_508.action; downloaded 2/26/2104

[9] This method uses a high efficiency gas boiler, not a condensing boiler.

It is also recognized that other strategies simulating setbacks are being used effectively, such as during the cooling season, the chillers are turned off when the outside air temperatures drop below a target set point (typically 78 deg.). These strategies are implemented to maintain the building temp at 72 ±7 °F, while making sure that special lab spaces with sensitive equipment that could experience calibration shifts due to changes in the room temperature are not detrimentally affected.

2.2.4 Add Variable-Frequency Drives (VFDs) for Supply and Exhaust Fans

Installing VFDs, such as those proposed for the four large exhaust fans (150 hp each) and all four large supply fans (60 hp each) were evaluated using the FEDs model. The savings for VFD-driven equipment is from the summed savings of running (4) parallel ducted systems in tandem and the resulting power that results from the Affinity Laws (cube reduction in power for each RPM% reduction). In addition, the VFDs would enable a change in the operation of the fans; to run the fans at lower speeds decreasing pressure drop across coils and filters, which should make the heat recovery system work better. The latter benefits were not accounted for the FEDs model.

There are also other inherent benefits that FEDs was unable to estimate in the savings and payback calculations that should result in reduced capital replacement and O&M costs; such as:

- The elimination of air leakage past the non-running supply and exhaust fans.
- The reduction of wear on the fans, due to the ability to run all supply and exhaust fans at lower RPMs. These benefits include reduced wear on motor windings, bearings, shafts, belts and pulleys; extending equipment life.

Although FEDS cannot quantify all benefits of an ECM, it is a tool that can determine cost effective energy efficiency measures in an all-encompassing manner. The FEDS analysis for the installation of VFDs estimated a reduction in electricity of 7,047 MMBtu, with an increase in natural gas usage of 1,856 MMBtu for a total energy savings of approximately 5,190 MMBtu per year and $50,594 per year[10].

After using FEDs to generate savings and a payback for this ECM, it was brought to our attention that an evaluation had been completed in September of 201311 which concluded that to meet RPL's long term mission it would be better to replace the supply and exhaust fans, while adding VFDs with harmonic filters. This comprehensive approach ensures a life expectancy of 30+ years for the exhaust system while mitigating any harmonic disturbances. This alternative would cost $1. 6 to $1. 9 million, with an annual savings of $87, 716 resulting in a 15-20 year payback.

Both FEDS and the "Alternative Analysis" evaluation determined that this type of ECM would result in significant savings. However, since the FEDS model cannot adequately address issues such as harmonics it is recommended that all the ECMs/WCMs proposed are re-evaluated considering long term goals, unique hazards, infrastructure life expectancy and any other specific characteristics associated with the facility.

[10] These savings are evaluated with the assumption that the previous measures have been implemented to avoid "double counting" savings throughout the analysis. Installing VFDs with RPL in its current condition shows a savings of 4,162 MMBtu per year and $41,009 per year.

[11] Alternatives Analysis, Building 325 Exhaust and Supply Fan VFD Installation; S704539-TECH-PM-001; Revision 0, September 2013

2.3 Additional ECMs and WCMs for Consideration

The following section describes areas that were evaluated but not included in the main project list because they were either low priority or not cost effective. These projects may become cost-effective as energy prices increase, spaces are renovated, and building infrastructure and/or equipment are replaced at end of life. **Table 7** displays the expected savings and project costs for each measure.

Table 7. Additional ECMs and WCMs for Consideration

Measure	Total Energy Savings (MMBtu/yr)	Total Water Savings (Kgal/yr)	Annual Energy Cost Savings ($/yr)	Annual Water Cost Savings ($/yr)	Annual O&M Savings ($/yr)	Total Annual Savings ($/yr)	Capital Costs	Simple Payback (yr)
Building Envelope								
Upgrade South Windows	50	0	$403	$0	$0	$403	$27,234	67. 6
Upgrade Roof Insulation	957	0	$9,555	$0	$0	$9,555	$293,619	30. 7
Lighting								
Lighting Occupancy Sensors	716	0	$18,057	$0	$0	$18,057	$162,180	9. 0
Replace T12 Lighting	2. 5	0	$23	$0	$65	$88	$7,308	83. 0
HVAC								
HVAC Small Motor Upgrades	505	0	$6,097	$0	$0	$6,097	$302,508	49. 6
Other								
Smart Power Strips	52	0	$472	$0	$0	$472	$21,143	44. 8
Water								
Toilet Replacement	0	81	$0	$346	$0	$346	$7,431	21. 5
Urinal Replacement	0	21	$0	$90	$0	$90	$4,527	50. 1
Faucet Replacement	14	42	$219	$179	$0	$398	$188	0. 5
Showerhead Replacement	4	11	$70	$48	$0	$118	$167	1. 4
Total	2,298	155	$34,896	$663	$65	$35,624	$826,305	23. 2

2.3.1 Install Commercial Style, High Performance Aluminum Frame Double Pane Argon/Low-Gain Windows

The facility has two sets of windows on the south face of the building, as shown in **Figure 3**. South Face of RPL The same type of windows are in a few other locations around the building, as seen on the left side of **Figure 3**. During the audit, these windows were defined as having aluminum frames, double pane, with a reflective coating. It is recommended to replace these windows with a higher performance window to help reduce infiltration rates and solar gains.

Figure 3. South Face of RPL

2.3.2 Increase Roof Insulation

Although the current condition of the roof insulation was not measured during the audit, FEDS was able to estimate the roof insulation R-value based on the construction and age of the building. It is estimated that the current insulation has an average R-value of 8. 90, and that it should be increased to an R-value of 19. 0. This complements the fact that during the walk down of the building it was observed that the building roof and envelope was old and leaky. In addition, we were informed that the roof had been repaired over the years in several locations.

2.3.3 Lighting Occupancy Sensors

Currently, there are a few lighting occupancy sensors in limited areas at RPL. However, during the walkthrough audit, it was observed that many locations were lit while unoccupied. However, according to the RPL staff, some of these spaces may already be configured for occupancy sensors; thus there may be other reasons for the observations made during the walk down of the facility. It is possible some of the occupancy sensors may have failed, not functioning properly, have been over ridden or set-up for a significantly long period of vacancy. It is recommended to periodically check the sensors to ensure proper operation, timer setting and/or automatic configuration.

In addition, the hourly profile (explained in detail in Appendix A) reveals that there is only a slight variation in electrical load during different times of the day, indicating that a large majority of the building load remains constant, regardless of when the building is occupied. Although it is recognized that the primary reason for the constant building load is the continuous running of the large exhaust and supply fans, installing lighting occupancy sensors throughout the remainder of the facility will assist in reducing lighting utilization and electrical load.

2.3.4 Replacing T12 Lighting Fixtures

During the walkthrough audit, auditors counted approximately 20 T12 fixtures throughout the facility. After performing an analysis on the replacement of the T12 lights, a replacement to a more efficient lighting source was determined to not be cost effective at this time, largely in part because of the low utility rate and low quantity of fixtures. However, it is suggested to replace these fixtures as they wear out, or as the light bulbs burn out.

2.3.5 HVAC Motor Upgrade

The plan to sustain RPL‘s infrastructure should include upgrading older equipment to more efficient equipment. The average age for HVAC motors is approximately 20 years, which is the time when motor replacement should be considered. When purchasing a new motor, energy efficiency should be a major consideration; Rewinding is also an option, but usually not as effective at gaining major efficiency improvements as a new motor. Although there is a capital cost associated with a new motor, the annual energy cost of running a motor is usually many times greater than its initial purchase price. For example, even at the relatively low energy rate of $0. 04/kWh, a typical 20-horsepower (hp) continuously running motor uses almost $6,000 worth of electricity annually, about six times its initial purchase price.

The following are motor upgrade suggestions to improve efficiency:

1. Upgrade the motors for the two preheat pumps
2. Upgrade the motors for the two heat recovery pumps
3. Upgrade the motors for the two reheat pumps
4. Upgrade the motors for the four large exhaust fans
5. Upgrade the motors for the four large supply fans

Motor Master+ International (V 1. 1. 5) was used to determine motor replacement savings. The full outputs from Motor Master can be reviewed in Appendix F. **Table 8** displays a summary of the approximate savings from replacing the motors listed above. Note: The motors chosen for comparison experience the highest savings. Less expensive motors may be selected for quicker payback periods. Also, these numbers were calculated based on average annual run-times. Some motors may experience more or less of a savings depending on their use during seasonal and shoulder months.

Table 8. Savings Summary for HVAC Motor Replacement

Current Motor	Size (hp)	Qty.	Current Efficiency Rating	Replacement Efficiency Rating	Replacement Motor Cost[12]	Total Energy Savings (kWh/yr)	Total Cost Savings ($/yr)	Simple Payback Period (yr)
Pre Heat Pumps								
US Motor	30	1	90%	93. 4%	$7,797	5,638	$233	11. 15
Lincguard	50	1	91. 7%	93. 2%	$5,952	4,233	$174	11. 40
Reheat Pumps								
Lincguard	50	2	91. 7%	93. 2%	$15,594	8,466	$348	11. 15
Heat Recovery Pumps								
US Motor	30	2	90%	93. 4%	$11,904	11,276	$466	11. 40
Supply Fans								
Westinghouse Motor	60	4	90%	94. 7%	$151,635	62,704	$2,584	22. 05
Exhaust Fans								
Lincguard	150	4	94. 1%	95. 9%	$109,626	55,632	$2,292	14. 14
Totals					**$302,508**	**147,949 kWh/yr.**	**$6,097 per yr.**	**49. 6 yrs.**

[12] Motor costs are dependent on Motor Master's 2010 figures for the purchase cost of a motor and cost of installation, plus 15% was added to that figure to account for supervision, inspection, and overhead (SIOH) and to reflect 2013 market prices. The values from Motor Master have also been escalated by a factor of 2.5 to align with project costs at RPL.

2.3.6 Workstation Occupancy-Controlled Power Strips

During the walkthrough audits, the assessment team noticed opportunities to save energy by installing occupancy-controlled (or "smart") power strips at workstations[13]. Smart power strips have a combination of controlled outlets (which turn off devices that are not being used) and uncontrolled outlets (which continuously deliver power to their devices).

Load-sensing strips have a master outlet (always on) to which a selected device is connected to monitor loads. The load sensor detects the decrease in current that occurs when the master outlet's device goes into standby mode. When the master outlet's device (e. g. , a computer) enters standby mode or is manually turned off by the user, the peripheral devices (e. g. , monitor, speakers, printer, and scanner) plugged into controlled outlets are automatically turned off. Peripheral devices for which the user never wants power to be automatically disconnected can be plugged into the uncontrolled (always on) outlets. **Figure 4** shows an example of a load-sensing smart power strip.

Figure 4. Example Load-Sensing Power Strip

The number of office workstations was estimated by combining the information gathered during the walkthrough with the PNNL Map Information Tool and querying the number of people who work in each building. The load-sensing strips are only being suggested in offices, not in the laboratories, but there may be an opportunity in the laboratories once the power strips are piloted in the offices.

Recommendations for installing smart power strips are as follows:

- install 53 workstation smart power strips in the first floor office spaces
- install 50 workstation smart power strips in the second floor office spaces
- install 40 workstation smart power strips in the basement office spaces.

Conservative estimates of savings were used to estimate the LCC for this project and it was assumed that occupants would install their own power strips at their workstations. Because of the low utility rate, this project has an SIR below 1, but when bundled with other projects, it could be implemented.

2.3.7 Potable Water Use

The potable water use at RPL includes the domestic plumbing fixtures in 325, as well as the cold process water that feeds the steam boilers residing in 325A. Total water use in FY12 was 674 hundred cubic feet, or 504,263 gallons, based on billing information. The assessment team performed an engineering estimate of the annual domestic fixture water use at RPL based on the assigned number of

[13]The retrofit described here involves occupancy-based control of the workstation devices (e.g., computer, monitor, speakers, printer, and scanner).

building occupants, the known efficiency of the installed fixtures, and a range of assumed fixture uses per person per day (see Appendix D for additional description of the assumptions and calculations used to derive these estimates). Although some of the retrofits did not have favorable return on investment estimates they were all included to facilitate prioritizing which fixtures to replace when future upgrades are implemented. In addition, sub-metered data for the cold process water was provided so a water balance could be established for all the principal end uses at the time of the assessment.

Toilets are the largest component of the domestic water balance, accounting for 162 Kgal annually. The cold process water that includes the steam boilers also uses about 162 Kgal annually based on sub-metered data[14]. Bathroom faucets are the next largest water end-use representing 64 Kgal annually, followed by leaks/losses/other that account for roughly 50 Kgal per year (**Table 9**). These four uses comprise 87% of the total water consumption at RPL (**Figure 5**).

Table 9. Water Use by Major End-Use Category

Water Use Category	Average Water Use (gallons)	% of Total Use
Toilets	162,401	32%
Process/Steam Boilers	161,700	32%
Bathroom Faucets	63,570	13%
Leaks/Losses/Other	49,720	10%
Urinals	34,334	7%
Showers	27,905	5%
Kitchen Faucets	4,633	1%

[14] Insufficient information was available on the overall performance of the steam boiler system to develop any efficiency opportunities. Therefore, all of the conservation measures investigated were only for domestic plumbing fixtures.

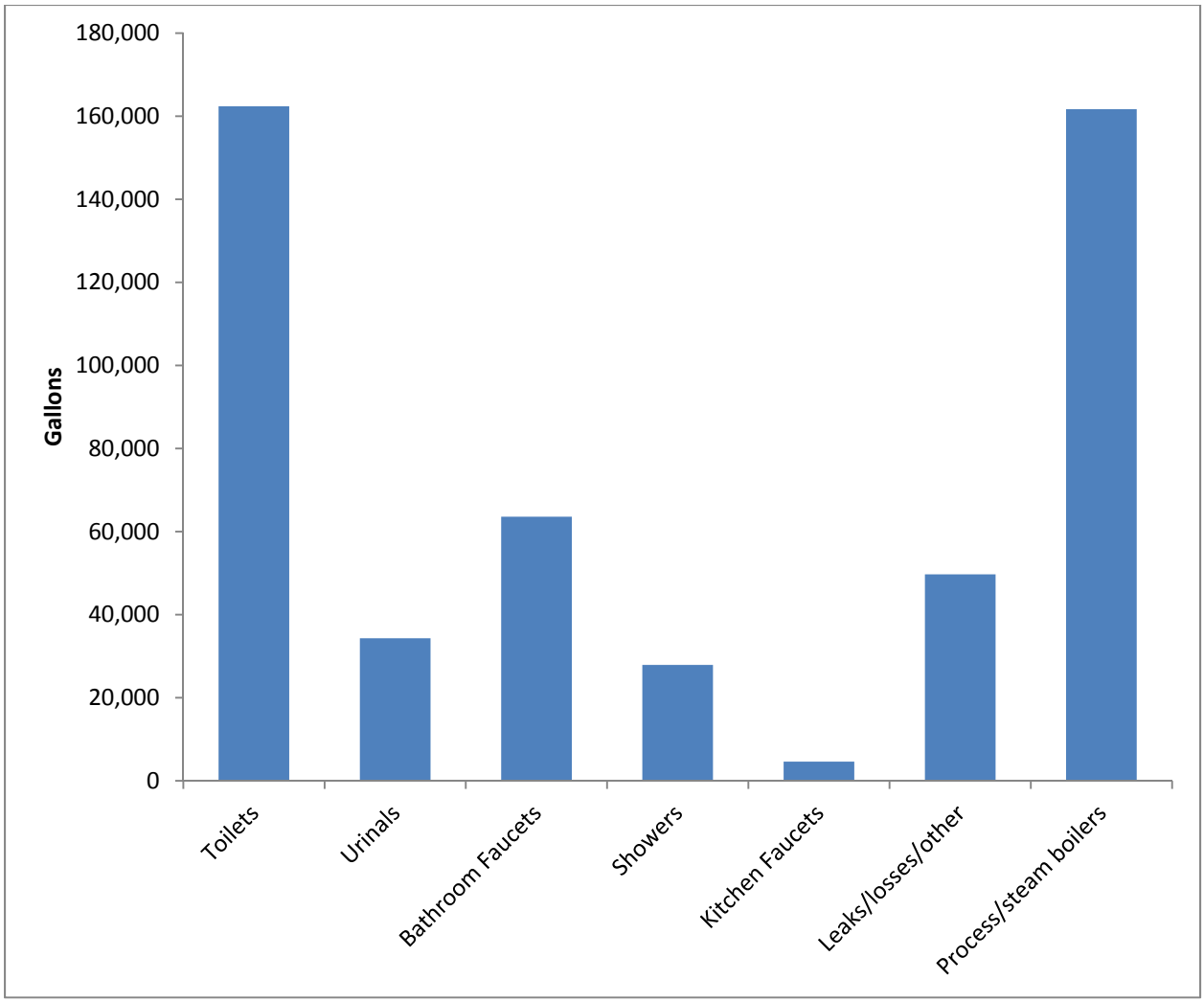

Figure 5. RPL Annual Water Use Breakout

During the walkthrough audits, the assessment team examined the domestic plumbing fixtures installed in the five men's restrooms and four women's restrooms throughout RPL. This included the restrooms in the HLRF area, as well as the fixtures in both the men's and women's locker rooms. Both locker rooms featured high efficiency toilets, faucets, and urinals, while the fixtures elsewhere in the building varied in their measured flow rates. To account for the difference between efficiency of the fixtures in the locker rooms and all of the other bathrooms, the building was divided into two use categories (the locker rooms, and all of the other bathrooms). Based on observed behavior during the walk-through audits, it was estimated that half the building occupants use the locker rooms while the other half use the remaining restrooms on a daily basis.

The restroom faucets varied in rating from 0. 5 gallons per minute (gpm) to 2. 2 gpm with the most efficient fixtures featured in the locker rooms. These ratings were confirmed by measurement with a flow bag. (A flow bag is a plastic bag that is calibrated for 5 seconds of flow and is marked with 1-gpm increments.)A flow rate of 0. 5 gpm is appropriate for a public restroom faucet; therefore none of the high efficiency faucets in the locker rooms (**Figure 6**) were considered for retrofits. A total of 20 bathroom faucets were observed during the audits, 8 of which were present in the locker rooms. The 12

faucets in the regular restrooms are estimated to use 53 Kgal annually, while the more efficient faucets in the locker rooms are estimated to use less than 11 Kgal annually if each grouping is used daily by half of the building population. Two faucets were found to be missing aerators. One was in room 710 and the other was in room 605 in the HLRF area. The 12 faucets in the building restrooms were all evaluated for efficiency improvements. If they were replaced with high efficiency 0. 5-gpm units similar to those featured in the locker rooms, consumption would be reduced to 11 Kgal each year, saving RPL 42 Kgal annually in water use. This retrofit would cost $188 and save $398 annually in water and heating energy costs. The simple payback for this project is 0. 5 years (**Table 10**).

Figure 6. Efficient Locker Room Faucet

Figure 7. Inefficient Restroom Faucet

The showerheads in the locker room were rated at 2. 5 gpm (**Figure 8**). There were three showerheads in the men's locker room and three in the women's. All can easily be replaced with WaterSense[15] labeled replacements that use no more than 1. 5 gpm. That would reduce the estimated consumption by showers from 28 Kgal per year to less than 17 Kgal per year and would save over 4 million British thermal units (MMBtu) of hot water heating energy each year. The water use and LCC analysis assumes that 5% of the occupants shower daily. [16] The retrofit would cost $167 and save $118 in water and heating costs resulting in a simple payback of 1. 4 years (**Table 10**).

Figure 8. Showerheads Rated at 2. 5 gpm

Urinal efficiency varied from 0. 3 gallons per flush (gpf) to 0. 8 gpf based on unit ratings and time duration to flush. The higher efficiency units observed are in the men's locker room. A total of eight urinals were counted in RPL, three of which are present in the men's locker room. Water use from the five less efficient fixtures is estimated to be 25 Kgal per year, while the water use from the locker room units is 9 Kgal per year. Retrofits for the less efficient units with high efficiency 0. 125 gpf units will save 21 Kgal annually, or $90 in water costs. The capital cost of this retrofit is $4,527 resulting in a simple payback of 50 years (**Table 10**), which is not sufficient to make this feasible at this time. No projects to install more efficient urinals in the men's locker room were considered because they would achieve minimal savings.

Similar to bathroom faucets and urinals, the toilets at RPL varied in efficiency with 1. 0-gpf units observed in the locker rooms and 3. 5 gpf observed in the other restrooms. A total of 21 toilets were counted in the building with nine in the locker rooms. Water use from the thirteen less efficient units is estimated to be 128 Kgal annually while use in the locker rooms is estimated at 35 Kgal per year. No efficiency projects were considered for the locker rooms fixtures. Replacing the 13 less efficient toilets with 1. 28- gpf high-efficiency flushometer piston valve toilets is estimated to save 81 Kgal of water

[15] WaterSense is a U.S. Environmental Protection Agency program that tests and recognizes products for water efficiency, similar to the ENERGY STAR program for energy efficiency.

[16] 5% of the building population is about eight showers per day. Actual shower use may be higher or lower.

annually for a cost savings of $346. However, the economics are not attractive with a capital cost of the project at $7,431 and a simple payback of 21 years (**Table 10**).

Figure 9. Toilet in Room 706

Table 10. Plumbing Retrofits

Retrofit Description	# of Units	First Year Water Savings (Kgal)	Heat Energy Savings (MMBtu)	First Year Cost Savings	Retrofit Capital Cost	Simple Payback (yr)
Toilet Replacement	13	81	-	$346	$7,431	21. 5
Urinal Replacement	5	21	-	$90	$4,527	50. 1
Faucet Replacement	12	42	14	$398	$188	0. 5
Showerhead Replacement	6	11	4	$118	$167	1. 4
Totals	36	155	18	$952	$12,313	12. 9

2.4 Observations for Further Follow-Up

In addition to the projects quantified previously, three areas were identified for further investigation.

2.4.1 Non-Administrative Plug Load Reduction

The building may have other opportunities to optimize plug loads (reduce/turn off/seasonally and/or manage loads better etc.) that we did not fully investigate(for example, the heat trace system, which has a manual toggle switch and a thermostat for each heat trace zone/circuit). If the existing system components are working correctly, the heat trace cables are de-energized when the temperature rises above the thermostat set point. The system can be manually shut down for the season by switching them off or locking the circuit breakers off. It was stated that this system was designed for a more automatic solution, but was not implemented.

It is apparent that the organization is well managed, and those involved in the operations and maintenance make every effort to manage energy consuming devices (plug loads/process loads), and that their due-diligence in this area will help sustain the already superb energy reductions seen over the last few years.

2.4.2 Add Variable Frequency Drives (VFDs) for Smaller Pumps/Motors

Some of the VFDs, such as those proposed for the four large exhaust fans (150 hp each) and all four large supply fans (60 hp each) were evaluated using the FEDs model, but some of the smaller models were not modeled in FEDs; yet should be considered to save additional energy while improving process control, and reducing mechanical stress (e. g. soft starts). In addition, since motors and VFDs need to be compatible, when replacing a motor, a VFD should be considered.

Centrifugal pumps run at a fixed speed yet could be improved if they had the means to modulate the speed; in other words, vary the flow to match the requirement. For instance, if operations call for 50% flow volume, and the flow can be modulated, then because of the affinity laws, only 12. 5% of the power would be needed to run the system at 100% volume. The power requirements decrease faster than the reduction in volume; thus, at lower volumes or off-peak conditions, significant energy can be saved. Therefore, it is recommended to evaluate adding VFDs to all applications, even those with inlet vanes, but especially the following:

- The two preheat motors/pumps
- The two heat recovery motors/pumps
- The two reheat motors/pumps

2.4.3 Renewable Energy

Given the low marginal charge for electricity at RPL, solar photovoltaic, solar thermal and solar hot water were not identified as cost effective at this time. As the technology costs decrease the cost effectiveness of these systems should be re-evaluated.

3.0 Bibliography

GSA. Condensing Boilers. Washington D. C. December 2012. http://www. gsa. gov/portal/content/163495.

Office of the Deputy Prime Minister. Guide to the Condensing Boiler Installation Assessment Procedure for Dwellings. London. April 2005. https://www. gov. je/SiteCollectionDocuments/Planning%20and%20building/ID%20AssessmentGuidetoCondensingBoilerInstallationinDwellings%2020100910%20mm. pdf

Phetteplace, Gary. 1995. Efficiency of Steam and Hot Water Heat Distribution Systems. Cold Regions Research and Engineering Laboratory. Hanover, New Hampshire. September 1995. http://www. crrel. usace. army. mil/library/crrelreports/CR95_18. pdf; downloaded 2/25/2014

Appendix A

Hourly Profile Analysis

Appendix A

Hourly Profile Analysis

Power readings from PNNL's Decision Support for Operations and Maintenance (DSOM) building monitoring system were plotted in the Energy Charting and Metrics Tool (ECAM). The charts below represent 1 year: September 1, 2012 to August 31, 2013. This date range was chosen to coincide with the most accurate and recent utility data provided.

Figures A. 1 and A. 2 show the building occupants arrive between 5:15AM and 6:00AM on weekdays, and the building is unoccupied around 6:00 PM on weekdays. However, the base load on weekdays (~750 and 760 kWh) is 90% of the peak consumption (~830 kWh). This indicates that the majority of equipment is not setback or shutdown during any unoccupied periods.

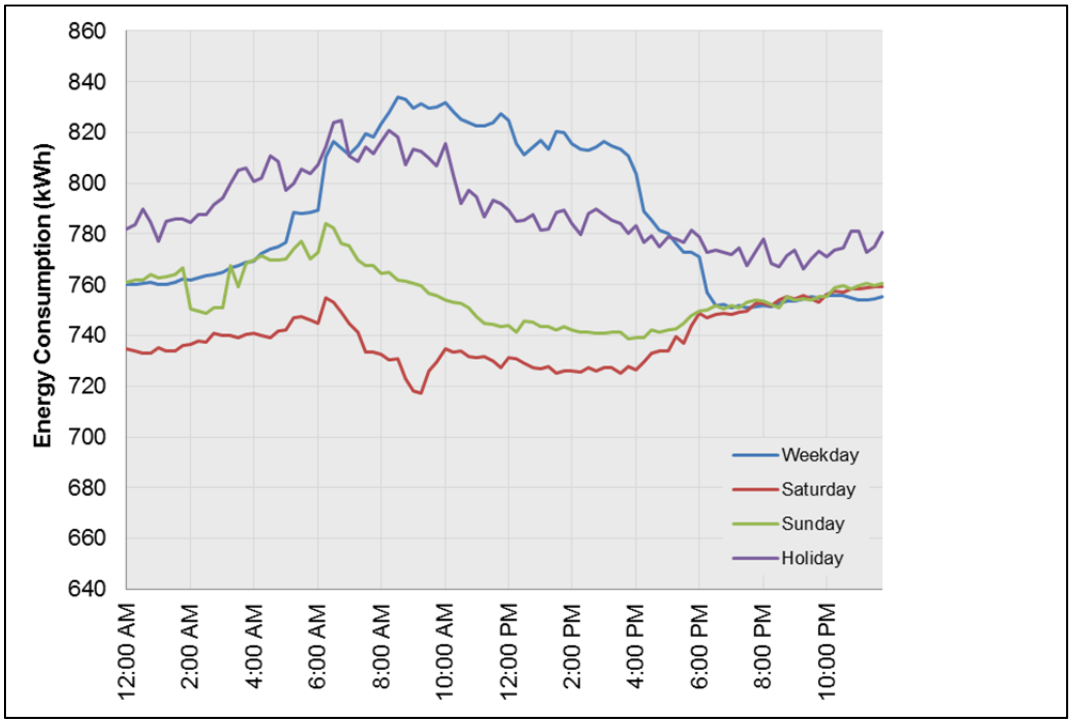

Figure A. 1. RPL Load Profile by Day Type

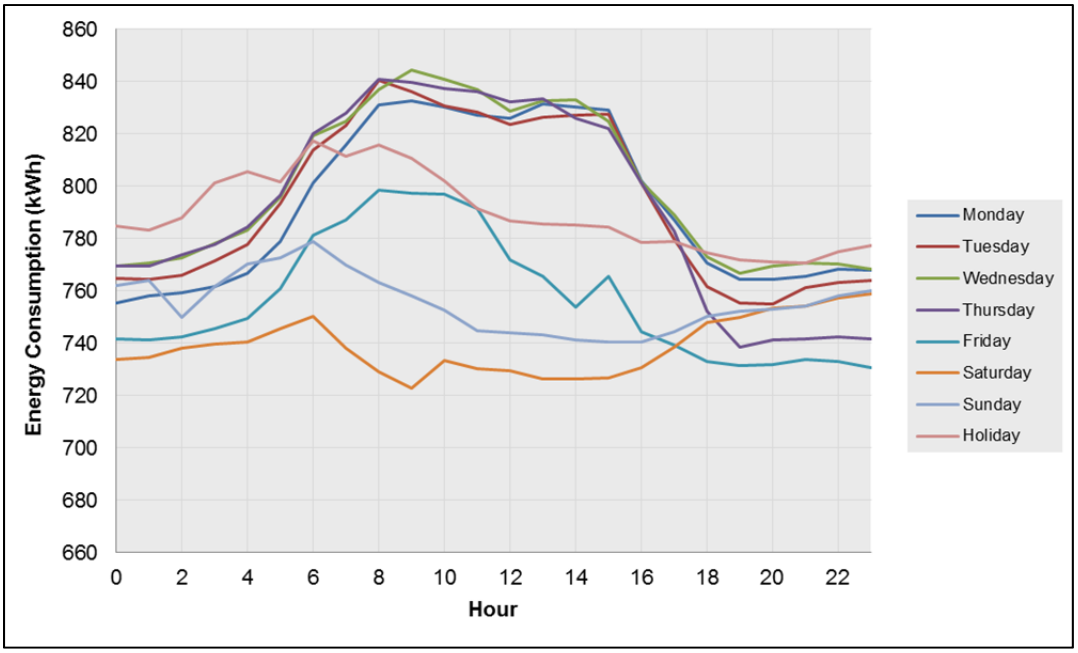

Figure A. 2. RPL Load Profile by Day of Week

Figures A. 3 and A. 4 demonstrate the building load as a function of outdoor air temperature for weekdays and weekends, respectively. There is a corresponding model fitting the data for each case, which will be discussed below. Both figures show the building being heated when the outdoor air temperature reaches 65°F, indicating there is no temperature setback during the weekend. In addition, the data for both figures have a narrow variation, signifying the load characteristics of the building are consistent from day to day.

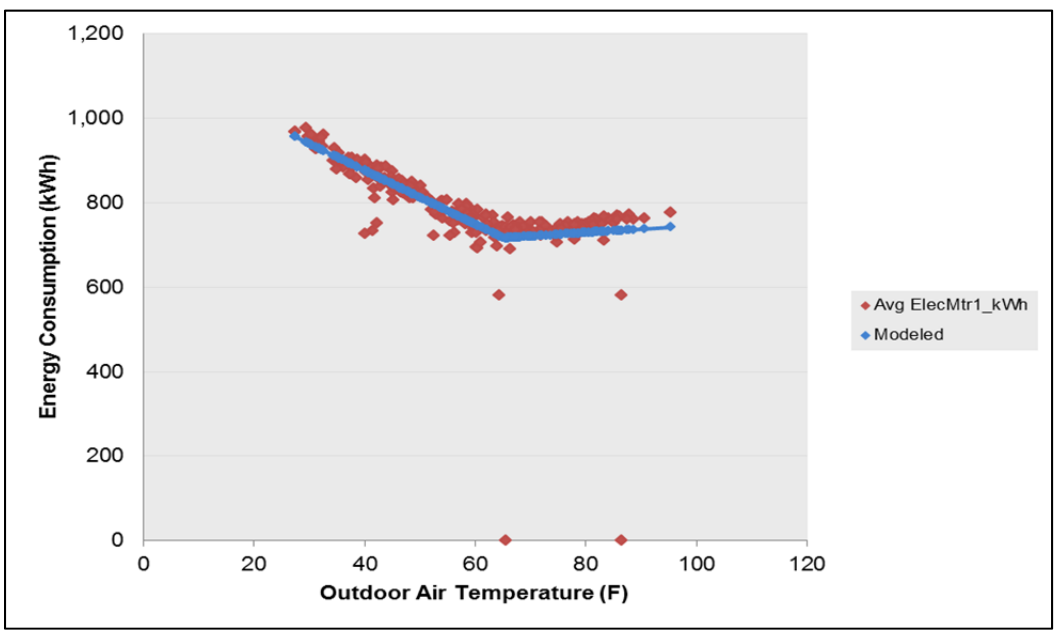

Figure A. 3. RPL Weekday Load Profile vs. Outdoor Air Temperature

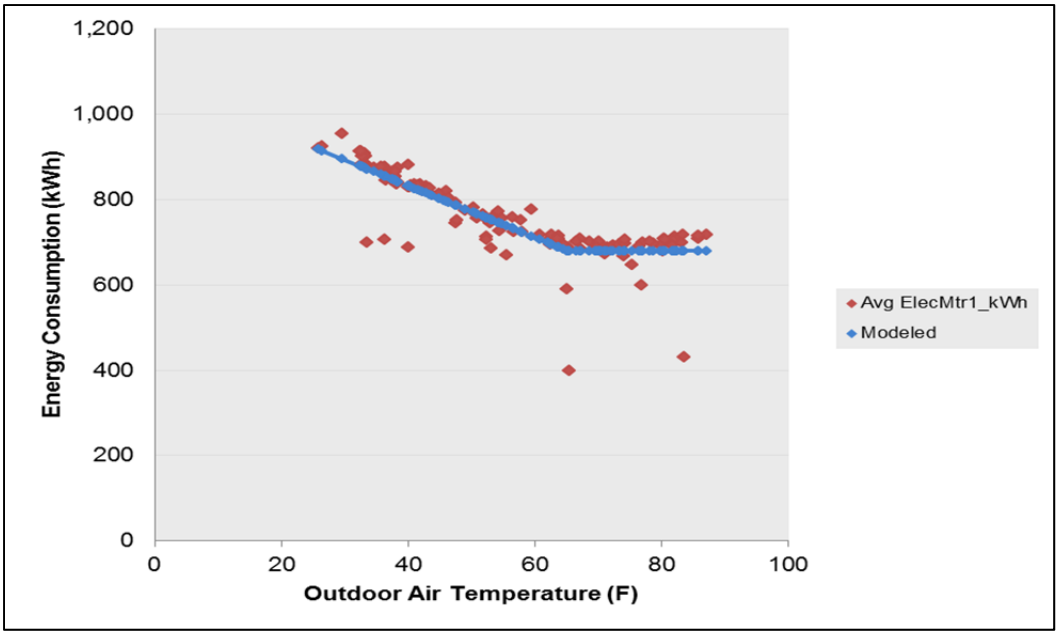

Figure A. 4. RPL Weekend Load Profile vs. Outdoor Air Temperature

Appendix B

FEDS Modeling, Calibration, and Outputs

Appendix B

FEDS Modeling, Calibration, and Outputs

B.1 Specialized FEDS Modeling Approach for RPL

After all of the building characteristics were entered in the FEDS model, the model was run to infer various characteristics that are generally estimated using the model because many times measurements are not available (i. e. , infiltration, percent outdoor air fraction). The operating parameters were examined and additional information was gathered from F&O staff to capture operating conditions in the RPL facility that differ significantly from the normal conditions that the model infers (i. e. , expects to be present) in a general laboratory/office building.

The first of these special operating conditions is that the ventilation exhaust air from the main building is used to assist in heating the ventilation supply air from the four large supply fans. Because the building brings in 100% outdoor air, this input had to be adjusted in FEDS to 70% to account for the heat recovery. This adjustment helps FEDS calculate a more accurate natural gas and steam usage because not 100% of the air that is being conditioned is at outdoor air temperature.

The second special condition was the strategy used to capture the use of the boilers and the heating of the main building. The boilers are located in the boiler annex, on the southwest external side of the main building. These boilers provide steam to the air-handling units, where the steam is then converted to hot water to be used by the air handlers to heat approximately 93% of the facility. A central plant scenario was then used in FEDS to account for any steam line losses and heat loss during the steam to hot water conversion. In addition, modeling the heating system as a central plant allowed for the ability to incorporate the substantial lack of condensate return.

B.2 FEDS Calibration

After information from the walkthrough audits and drawings is entered into FEDS, the model is calibrated to utility billing data (in this case, September 2012 through August 2013 electricity and natural gas consumption) so that the baseline case matches existing conditions in the buildings. If the baseline model is a reasonably close match with utility billing data, users can have a higher degree of confidence in the energy-saving retrofits generated by the model. Calibration results for Sept. 2012 through Aug. 2013 electricity consumption of RPL are shown in Table B. 1 and B. 2

Table B. 1. Building Electricity Calibration

Annual Electricity Consumption (all values in kWh)

FEDS Building Set	Actual	FEDS Calculation	% Difference
RPL	7,313,573	7,079,992	3%

The source of natural gas usage at RPL is in the boiler annex. Therefore, a single gas account serves the RPL facility. The FEDS building totals for natural gas are shown in Table B. 2.

Table B. 2. Natural Gas Calibration

Annual Natural Gas Consumption (all values in Therms)

FEDS Building Set	Actual (Utility Bill)	FEDS Calculation	% Difference
RPL	80,313	82,416	2%

B.3 FEDS Model Output

The following tables (Table B. 3 and B. 4) show the output of the FEDS baseline model for energy use at RPL.

Table B. 3. Energy-Use Intensity

	Electricity			Natural Gas		
FEDS Building Set	kWh	EUI (kWh/ 1,000 ft^2)	EUI (MMBtu/ 1,000 ft^2)	Therms	EUI (therms/ 1,000 ft^2)	EUI (MMBtu/ 1,000 ft^2)
RPL	3,982,672	27,501	94	101,978	704	70

Table B. 4. Energy Consumption by End-Use

	Electricity (kWh)			
FEDS Building Set	HVAC	Lighting	Motors/Misc	Hot Water
First Floor and Basement	2,333,435	510,850	712,255	5,489
Second Floor	19,345	50,871	52,379	1,542
% of Total	64%	15%	21%	0. 2%

Appendix C

Audit Forms Used During Walkthroughs

Site Name	Building Number/Name
Auditor Name	Date of Audit

BUILDING ENVELOPE

ROOF

Roof Type:	Deck Type (built-up)	Suspended Ceiling:
Built- up	Wood	Yes No
Pre-Engineered Metal	Concrete	Roof/Ceiling Insulation
Shingles/Shakes	Metal	Yes No Thickness:_____

FLOOR

Floor Type:	Ground Floor Carpet:	Floor Insulation:
Slab on Grade	Yes No	Yes No Thickness:_____
Crawlspace/Basement		

WALLS

Exterior Wall Type:	Frame Type:	Wall Insulation:
Wood Siding	Wood Frame	Yes No Thickness:_____
Masonry Façade	Masonry Frame	
Pre-Engineered Metal	Steel Frame	

WINDOWS

% Wall Area Glass:	# of Panes:	Frame Type:	Window Coverings:	Film Type:
	1	Wood/Vinyl	Tinting	Reflective
	2	Metal	Film	Low-e
	3	Thermal Break Metal	Shades/Blinds/Curtains	Super Low-e
			Gas Filled	

Is weather stripping/caulking worn, damaged, or missing?

Location:	Description:	Count (1st floor/upper floors):	Size:	Condition:
		/		
		/		

INTERIOR WORKSPACE

USE AREA DEFINITION

Use Area Description:	% of Building:	# of Floors:	Floor to Ceiling Height (ft.):	Floor to Floor Height (ft.):
1:				
2:				

OCCUPANCY

	Use Area 1		Use Area 2	
	Weekday	Weekend	Weekday	Weekend
Start				
End				
# Occupants (Occupied)				
# Occupants (Unoccupied)				
Seasonal variations in occupancy?				
Estimated % Men/Women:	Men:	Women:	Men:	Women:

IRRIGATION	Water supply: ____ potable ____ non-potable		
Planting type:	Mixed bed / turf only	**Turf Species:** cool/warm	**Native landscaping conversion potential?** Y / N
Mixed bed info:	protected / open / intense exposure	low / medium / high water demand	low / medium/ high density
Soil Type:	loam / sandy / clay	**Landscape Condition:**	stressed / average / high quality
Irrigation Equip:	rotor / spray / micro-spray / manual	**Irrigation Maintenance:** poor / average / high	**Irrigation Controls:** manual / clock / weather based
Irrigated Area (SF):	*SF can be mapped from GIS*	**Irrigation Schedule (days/wk; min/day):**	

Notes: (add information on type of existing plants)

LIGHTING

1. Lighting Technology Types: INC=Incandescent CFL=Compact Fluorescent FL=Fluorescent MV=Mercury Vapor MH=Metal Halide HPS=High Pressure Sodium LPS=Low Pressure Sodium, IND=Induction, LED= Light Emitting Diode
2. Size Definition: 2x4 3T8= 2' x 4' fixture, 3 T8 lamps 4-tube Biax=4BIAX

Technology Type[1]	**Fixture Description** (size[2], # lamps, wattage, reflectors, ballasts, application)	**Use Area /% of building**	**Fixture Density/Count**	**Mounting Method** (recessed, flush, pendant, etc.)	Usage (note sensors, schedule, controls)
Exit Signs					
Exit Signs					
Exterior					
Exterior					
Exterior					

If no occupancy sensors, note size of typical space, number of spaces & take a picture of the lighting in a typical space.

WATER

DOMESTIC HOT WATER

Use Area:	Fuel:	Heat Pump?	Dist./ Loop	Heating Capacity (MBtu/hr.)	Vintage	# of Tanks	Total Tank Capacity (gal.)	Efficiency (%)	Water Temp. (°F)

Note the presence of tank wraps, pipe insulation, etc.:

WATER FIXTURES

Location:

	Faucets:	Showers:	Toilets:	Urinals:	Notes/Conditions
# of fixtures Men's Restroom:					
# of fixtures Women's Restroom:					
Rated max flow/flush rate (gpm/gpf):					
Actual flow rate (F&S) /Sec per flush (FV T&U)					
Fixture type:	threaded / non-threaded	threaded wall mt gang	**tank/FV** floor / wall / floor w rear discharge	floor / wall discharge tube dia: ¾"____; 1¼"____	
Valve Type or Operation Type	sensor manual metered	hand-held	diaphragm piston sensor	diaphragm piston sensor	*Note if Delaney is the Mfg*

Location:

	Faucets:	Showers:	Toilets:	Urinals:	Notes/Conditions
# of fixtures Men's Restroom:					
# of fixtures Women's Restroom:					
Rated max flow/flush rate (gpm/gpf):					
Actual flow rate (F&S) /Sec per flush (FV T&U)					
Fixture type:	threaded / non-threaded	threaded wall mt gang	**tank/FV** floor / wall / floor w rear discharge	floor / wall discharge tube dia: ¾"____; 1¼"____	
Valve Type or Operation Type	sensor manual metered	hand-held	diaphragm piston sensor	diaphragm piston sensor	*Note if Delaney is the Mfg*

LAUNDRY

	# of Units	Make	Model No (photo)	Energy Star?	General Condition
Front Loaders				Y / N	excellent/good/poor
Top Loaders				Y / N	excellent/good/poor

Estimated loads per week per person:	**Notes:**

HVAC

HVAC Zones: Single (1) Perimeter w/halls (4) Central w/perimeter (5), Zone depth_____

HEATING

3. Heating Equip. Types: 1=Elec. Resistance baseboard 2=Forced air furnace 3=AHU/boiler 4=AHU/central steam/hw 5=Fan coils/boiler 6=Fan coils/central steam/hw/electricity 7=Radiator/boiler 8=Radiator/central steam/hw 9=Radiant/single bldg. boiler 10=Radiant/central steam/hw 11=Air source HP 12=Ground-coupled HP 13=Infrared

Equip. Type[3]:	Fuel:	Portion Served /Use Area:	Total Output Capacity:	# of Supply Units:	Vintage	Efficiency (%)	Notes:

COOLING

4. Cooling Equip. Types: 1=Window/wall units 2=Package/split DX 3=AHU/conventional chiller 4=AHU/central chilled water 5=AHU/absorption chiller 6=Fan coil/conventional chiller 7=Fan coils/absorption chiller 8=Fan coil/central chilled water 9=Evap. cooler 10=Air Source HP 11=Ground-coupled hp

Equip. Type[4]:	Fuel:	Portion Served /Use Area:	Total Output Capacity:	# of Supply Units:	Vintage	Nominal COP	Notes:

VENTILATION

5. Ventilation Control Modes: 1=Cycle 2=Constant 3=Constant occ. /cycle unocc. 4=Constant occ./off unocc. 5=no mechanical ventilation

System Type:	Constant Vol. (CV) Variable Air Vol. (VAV)		**Air Damper Type:** Fixed 2-Position Cont. modulated		
Ventilation Control Mode[5]:	Economizers	Terminal reheat	Fueled preheat	Fan Motor Location:	Outdoor Air %
	yes no	yes no	yes no	Air-stream Not	

Demand Control Ventilation? Active Dehumidification?

THERMOSTATS

	Set points (Use Area **1**/2)	**Setbacks** (Use Area **1**/2)	Dead band (Use Area 1/2)	Are thermostats programmable? Yes No
Summer	/	/	/	
Winter	/	/	/	

Notes: If no programable thermostats, count the number of zones that need them:

CONTROLS	
HVAC	
What are the control vendor(s) in the building?	
What is the age of the controls?	When was the last upgrade of software?
List equipment under control [Name (Qty)]	List equipt that is NOT under control [Name (Qty)]
Are the current controls operational? If no, explain.	
Is there access to the controls remotely? Or on site only?	

RETUNING				
HVAC				
What is the prominent type of heating at zone/room?	**HVAC Zones:** Single Multi-Zone	**Variable Frequency Drive:** Yes No	**Operational schedule:** Yes No	**Working Economizer:** Yes No
AIR HANDLERS				
AHU's controlled by BAS: Yes, how many?_____ No	**# of VAVs/Air Handler:**		**Discharge/supply air temp. set point:** Fixed Dynamic	
CHILLED WATER				
# of chilled water valves:	**Chilled water temp. set point:** Fixed Dynamic		**Chilled water pressure set point:** Fixed Dynamic	
HOT WATER				
# of hot water valves:	**Hot water temp. set point:** Fixed Dynamic		**Hot water pressure set point:** Fixed Dynamic	
Notes:				

OTHER ECM OPPORTUNITIES

HVAC ZONES

Could the building benefit from re-zoning to consolidate occupied areas?

Location:	Area of the space (sq. ft.):	Description:

ENVELOPE

Is an airlock or vestibule needed?

6. Vestibule Sizes: Small= <150 sq. ft. Medium= 150-300 sq. ft. Large= >300 sq. ft.

Location:	Size of vestibule needed[6]:	Average wind speed (mph):	# of occupants using the door:	Area of open door (sq. ft.):

Are there conditioned areas and non-conditioned areas that are not separated by barriers?

Location:	Est. Hours/Week Exposed:	Separator Type: Partition / Sliding Doors / Permanent Walls	Area of separation needed (sq. ft.):	# of separators needed:	Velocity of air infiltration (fpm):

PROBLEM TEMP./ INFILTRATION AREAS (hot/cold spots, space heaters, open windows, cracks)

Location:	Description (hot/cold spots, space heaters, open windows, cracks):

UNNECESSARY HEATING/COOLING

Are there unoccupied areas heated/cooled unnecessarily? (corridors, vestibules)

Location:	Area of the space (sq. ft.):	Description:

MISCELLANEOUS EQUIPMENT

Is there an opportunity to reduce the operating hours of exhaust hood fans?

Location:	Area of hood (sq. ft.):	Air flow velocity (fpm):	Motor HP:	# of hoods:	Estimated operating hours (hrs./wk.):	Estimated required operating hours (hrs./wk.):	Days/week in operation (days/wk.):

Miscellaneous equipment- note if irregular. Include description (type, fuel, capacity, utilization)

Description:	**Fuel:**	Capacity Density (kw, tons or Mbtu/hr.):

Notes:

MOTORS - Large Capacity Only

8. Enclosure Type: 1=Open Drip-Proof 2=Totally Enclosed Fan-Cooled 3=Explosion Proof 4= Totally Enclosed Non-ventilated

	Use Area 1	**Use Area 2**
Motor Identification:		
Rated Capacity (hp):		
# of motors of this type		
Synchronous speed (rpm):		
Enclosure[8]:		
Voltage:		
Nominal efficiency (%):		
Vintage (yr. of installation):		
Duty cycle vary by month	Yes No	Yes No
Notes		

KITCHEN						
Number of Staff in Kitchen:		**Meals served:**	B__/ L __ / D__	**# meals served/day:**		
	# of Units	**Make / Type**	**Model No (photo)**	**# hours or loads operated/day**	**Year installed**	**Condition/ Comments**
Dishwashing Machine		continuous / batch				Energy Star? Y / N
Pre-Rinse Spray Valve						Flow rate:
Tray Conveyor System						
Garbage Disposal						
Faucet		hand wash / prep sinks				Flow rate:
Ice Machine		air / water cooled				Energy Star? (tip: look for A or W in MN)
Food Steamer		boiler based / connectionless				Energy Star? *(check if pan is in bottom of unit)*

OTHER WATER USING PROCESSES (lab equipment, wash application)						
Equipment Type	# of Units	Make / Model No (photo)	Water Use Info (gpm; gal/unit)	Operating Schedule (hrs/wk;	% recycle	Condition/ Comments

RAINWATER HARVESTING (take photos)			
Potential Application	**Relative Proximity to Application:**	**Gutters**	**Notes**
irrigation / CT makeup/ fixture flushing / other:		Y / N	

Notes:

Appendix D

Domestic Fixture Water Use Estimate

Appendix D

Domestic Fixture Water Use Estimate

D.1 General Information

RPL assigned population: 154

Assume 67% men, 33% women (based on observed population dynamics during the walkthrough audit): 103 men, 51 women

D.2 Domestic Fixture Estimating Tool Inputs

Building Data

Building ID	RPL
Building Type	Administration
Number of Building Occupants, Weekdays	77
Number of Building Occupants, Weekend	20
Percentage Female Occupancy	33%
Percentage Male Occupancy	67%
Weeks Occupied per Year, Weekdays	52
Days Occupied per Work Week	5
Hours Occupied per Week Day	10
Weeks Occupied per Year, Weekend	52
Days Occupied per Weekend	2
Hours Occupied per Weekend Day	10

Estimating portion of the building population using regular restrooms

Water Data

Toilets in Building?	Y
Toilet Retrofit?	Y
Count of Toilets in Building	13
Primary Toilet Type	Flushometer
Flushometer Toilet Type	Floor Mount
Primary Flushometer Valve Type	Diaphragm
Avg Time to Flush Flushometer Toilets (sec)	8
Rated Flushometer Flush Rate (gpf)	2
	Average estimated rating
Urinals in Building?	Y
Urinal Retrofit?	Y
Count of Urinals in Building	5
Avg Time to Flush Urinals (sec)	6
Urinal Discharge Tube Diameter	3/4"
Rated Urinal Flush Rate (gpf)	1.5
	Average estimated rating
Bathroom Faucets in Building?	Y
Bathroom Faucet Retrofit?	Y
Count of Bathroom Faucets in Building	12
Primary Bathroom Faucet Type	Threaded
Avg Measured Bathroom Faucet Flow Rate (gpm)	2.4
Rated Bathroom Faucet Flow Rate (gpm)	2.2
	Missing aerator on one faucet in 710 and one faucet in 605.
Showerheads in Building?	N
Showerhead Retrofit?	N
Kitchen Faucets in Building?	N
Kitchen Faucet Retrofit?	N
Washing Machines in Building?	N
Washing Machine Retrofit?	N

Building Data

Building ID	Building Type
RPL Locker Rooms	Administration

Number of Building Occupants, Weekdays	Number of Building Occupants, Weekend
77	10

Percentage Female Occupancy	Percentage Male Occupancy
33%	67%

Weeks Occupied per Year, Weekdays	Days Occupied per Work Week	Hours Occupied per Week Day
52	5	10

Weeks Occupied per Year, Weekend	Days Occupied per Weekend	Hours Occupied per Weekend Day
52	2	10

Estimated half of the people in the building use the locker room restrooms

Water Data

Toilets in Building?	Y
Toilet Retrofit?	N
Count of Toilets in Building	9
Primary Toilet Type	Flushometer
Flushometer Toilet Type	Wall Mount
Primary Flushometer Valve Type	Piston
Avg Time to Flush Flushometer Toilets (sec)	3
Rated Flushometer Flush Rate (gpf)	1.28
(Notes)	
Urinals in Building?	Y
Urinal Retrofit?	N
Count of Urinals in Building	3
Avg Time to Flush Urinals (sec)	3
Urinal Discharge Tube Diameter	3/4"
Rated Urinal Flush Rate (gpf)	0.125
(Notes)	
Bathroom Faucets in Building?	Y
Bathroom Faucet Retrofit?	N
Count of Bathroom Faucets in Building	8
Primary Bathroom Faucet Type	Threaded
Avg Measured Bathroom Faucet Flow Rate (gpm)	0.5
Rated Bathroom Faucet Flow Rate (gpm)	0.5
(Notes)	
Showerheads in Building?	Y
Showerhead Retrofit?	Y
Count of Showerheads in Building	6
Primary Showerhead Type	Threaded Fixed
Avg Measured Showerhead Flow Rate (gpm)	2.5
Rated Showerhead Flow Rate (gpm)	2.5
Percentage of People Using Showers Daily, Weekdays	10%
Percentage of People Using Showers Daily, Weekends	10%
(Notes)	
Kitchen Faucets in Building?	Y
Kitchen Faucet Retrofit?	N
Count of Kitchen Faucets in Building	2
Primary Kitchen Faucet Type	Threaded
Avg Measured Kitchen Faucet Flow Rate (gpm)	2.2

D.3 Domestic Fixture Estimating Tool Results

Total Estimated Usage (gpy)	Total Retrofit Usage (gpy)	Total Water Savings (gpy)	Install Cost ($)	Heating Energy Savings (MMBTU)
292842.77	78206.28	155249.02	$ 12,314	17.93

Current Fixture	Fixture Type	Total Number of Fixtures	Existing Water Rate (gpm, gpf, gal/cycle/cuft)	Estimated Usage (gpy)	New Type of Fixture to be Installed	New Water Rate (gpm, gpf, or gal/load)	Retrofit Usage (gpy)	Water Savings (gpy)	Capital Cost ($)	Heating Energy Savings (MMBtu)	Water Cost Savings ($/year)	Energy Cost Savings ($/year)	Simple Payback (years)
Toilet	Diaphragm-valve, Floor Mount	13	3.5	127,655	HET flushometer piston valve and bowl	1.28	46,685	80,970	$ 7,431	0.00	$ 346.06	$ -	21.47
Urinal	Urinal	5	0.8	24,856	HEU - pint piston flushometer	0.13	3,728	21,128	$ 4,527	0.00	$ 90.30	$ -	50.14
Bathroom Faucet	Threaded	12	2.4	53,040	HE public lavatory faucet	0.50	11,050	41,990	$ 188	13.59	$ 179.47	$ 219.08	0.47
Toilet	Piston-valve, Wall Mount	9	1.0	34,746	No retrofit.								
Urinal	Urinal	3	0.3	9,478	No retrofit.								
Bathroom Faucet	Threaded	8	0.5	10,530	No retrofit.								
Showerhead	Threaded Fixed	6	2.5	27,905	HE WaterSense showerhead	1.50	16,743	11,162	$ 167	4.34	$ 47.71	$ 69.88	1.42
Kitchen Faucet	Threaded	2	2.2	4,633	No retrofit.								

LOCATION:		REGION NO.	Region 4-West	PROJECT NO.	
PROJECT TITLE:	FY__ Add low flow water fixtures ____			FISCAL YEAR	2013
ANALYSIS DATE:		ECONOMIC LIFE:	15 yrs		
		PREPARED BY:		PHONE #:	

1. INVESTMENT COSTS:

A. CONSTRUCTION COST	$ 12,314
B. SIOH (Supervision, Inspection & Overhead)	$ 739
C. DESIGN COST	$ 1,231
D. TOTAL COST (1A+1B+1C)	$ 14,284
E. SALVAGE VALUE OF EXISTING EQUIPMENT	$ -
F. PUBLIC UTILITY COMPANY REBATE	$ -
G. TOTAL INVESTMENT (1D-1E-1F)	$ 14,284

2. ENERGY SAVINGS (+)/COST(-)

DATE OF NISTR 85-3273-21 USED FOR DISCOUNT FACTORS: Sep-11

ENERGY SOURCE	COST $/MMBtu(1)	SAVING MMBtu/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECTRIC	$ 16.12	17.9	$ 288.96	11.8	$ 3,409.72
B. DISTILLATE	$ -	0.0	$ -	11.35	$ -
C. RESIDUAL	$ -	0.0	$ -	11.35	$ -
D. NAT. GAS	$ 6.62	0.0	$ -	12.96	$ -
E. PROPANE	$ -	0.0	$ -	12.44	$ -
F. OTHER	$ -	0.0	$ -	11.94	$ -
G. WATER (kgal)	$ 4.27	155	$ 663.53	11.94	$ 7,922.60
H. DEMAND SAVINGS				11.8	
I. TOTAL		173	$ 952.49		$ 11,332.32

3. NON-ENERGY SAVINGS (+) OR COST (-)

A. ANNUAL RECURRING (+/-)	$ -	
(1) DISCOUNT FACTOR (TABLE A-2)	11.94	
(2) DISCOUNTED SAVINGS/COST (3A X 3A1)		$ -

B. NON-RECURRING SAVINGS (+) OR COST (-) (TABLE A-1)

ITEM	SAVINGS(+) COST(-)(1)	YEAR OF OCCUR.(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS/COST(+/-)(4)
a.	$ -	1	0.97	$ -
b.	$ -	2	0.94	$ -
c.	$ -	3	0.92	$ -
d.	$ -	1	0.97	$ -
e.	$ -	1	0.97	$ -
f.	$ -	1	0.97	$ -
g.	$ -	1	0.97	$ -
h.	$ -	1	0.97	$ -
d. TOTAL	$ -			$ -

C. TOTAL NON-ENERGY DISCOUNTED SAVINGS (3A2+3B4d)	$ -
4. FIRST YEAR DOLLAR SAVINGS (2I3+3A+(3Bd1/YRS ECON LIFE)):	$ 952
5. SIMPLE PAYBACK (1G/4)	15.0 YEARS
6. TOTAL NET DISCOUNTED SAVINGS (2I5+3c):	$ 11,332
7. SAVINGS TO INVESTEMENT RATIO (SIR) 6/1G:	0.79

Appendix E

Assumptions for Second Floor Vestibule

The following assumptions were used to estimate the savings associated with a vestibule for the second floor office area. The assumptions also take into account that the building engineer measured the flow through the door which resulted in slightly lower and highly variable flows thru the door opening which was timed at 10 seconds from the initial opening to complete closure. In addition, because RPL has radiological and chemical hazards in the facility, the flow from the exhaust fans is considerably higher than the flow from the supply fans; causing a funneling effect when the door is open. This effect was deliberately not taken into account in the calculation to generate a conservative savings estimate.

Assumptions/Equations:

- Vestibule Required: Small <150 square feet (estimated)
- Annual average wind speed (Richland, WA)[1]=22 mph
- Number of occupants on second floor = 59 (Map Tool); conservatively assumed approximately half of the occupants use the door and average of 2 openings per occupant per day
- Average effective time door open= 6 seconds
- Door Size: 32 square feet
- Office hours: 40 hours per week,5 days per week,50 weeks per year
- 100% electrical heat
- Cooled by: air-cooled reciprocating chillers (closest to actual central air plant/screw chiller)
- Degree days based on Richland, Washington per National Climatic Data Center NCDC 1981-2010 Monthly Normals
- The SIOH (Supervision, Inspection and Overhead) and design costs were increased because RPL is a unique facility with radiological and chemical hazards requiring additional safety oversight.

Calculated air volumes through an open door using assumptions above as:

- Air volume thru an open door (cfm):

22 miles/hour*5280 feet/mile*(1hour/60 min)*32 square feet = 61,952 cfm

Frequency (F) of an open door - using the assumptions above:
F=30 occupants/day*2 openings/occupant*6 sec/opening/(3600 sec/hour)* 5 days/week=0. 5 hr. /wk.

Fuel consumption (E) = 1.08*cfm*DD*24*(F)/40 hr/week)* /(H*EFF);

- where cfm = cubic feet per minute of open door, as calculated above,
- where DD = degree days, annual heating/cooling
- where F = frequency of open door, as calculated above
- where H = conversion for fuel, as desired
- where EFF = annual efficiency of heating/cooling equipment

[1] http://www.usa.com/richland-wa-weather.htm#HistoricalWind Speed

LOCATION:		REGION NO.	Region 4-West	PROJECT NO.	
PROJECT TITLE:	FY__ Add Vestibule at ____			FISCAL YEAR	2013
ANALYSIS DATE:		ECONOMIC LIFE:	25 yrs		
		PREPARED BY:		PHONE #:	

1. INVESTMENT COSTS:

A. CONSTRUCTION COST	$ 7,920
B. SIOH (Supervision, Inspection & Overhead)	$ 950
C. DESIGN COST	$ 1,584
D. TOTAL COST (1A+1B+1C)	$ 10,454
E. SALVAGE VALUE OF EXISTING EQUIPMENT	$ -
F. PUBLIC UTILITY COMPANY REBATE	$ -
G. TOTAL INVESTMENT (1D-1E-1F)	$ 10,454

2. ENERGY SAVINGS (+)/COST(-)

DATE OF NISTR 85-3273-21 USED FOR DISCOUNT FACTORS: Sep-11

ENERGY SOURCE	COST $/MMBtu(1)	SAVING MMBtu/YR(2)	ANNUAL $ SAVINGS(3)	DISCOUNT FACTOR(4)	DISCOUNTED SAVINGS(5)
A. ELECTRIC	$ 22.86	83.1	$ 1,899.65	17.27	$ 32,807.03
B. DISTILLATE	$ -	-	$ -	17.19	$ -
C. RESIDUAL	$ -	-	$ -	17.19	$ -
D. NAT. GAS	$ -	-	$ -	20.36	$ -
E. PROPANE	$ -	-	$ -	18.62	$ -
F. OTHER	$ -	-	$ -	17.41	$ -
G. WATER					
H. DEMAND SAVINGS					
I. TOTAL		83	$ 1,899.65		$ 32,807.03

3. NON-ENERGY SAVINGS (+) OR COST (-)

A. ANNUAL RECURRING (+/-)	$ -
(1) DISCOUNT FACTOR (TABLE A-2)	19.6
(2) DISCOUNTED SAVINGS/COST (3A X 3A1)	$ -

B. NON-RECURRING SAVINGS (+) OR COST (-) (TABLE A-1)

ITEM	SAVINGS(+) COST(-)(1)	YEAR OF OCCUR.(2)	DISCOUNT FACTOR(3)	DISCOUNTED SAVINGS/COST(+/-)(4)
a.	$ -	1	0.97	$ -
b.	$ -	2	0.94	$ -
c.	$ -	3	0.92	$ -
d.	$ -	1	0.97	$ -
e.	$ -	1	0.97	$ -
f.	$ -	1	0.97	$ -
g.	$ -	1	0.97	$ -
h.	$ -	1	0.97	$ -
d. TOTAL	$ -			$ -

C. TOTAL NON-ENERGY DISCOUNTED SAVINGS (3A2+3B4d)	$ -
4. FIRST YEAR DOLLAR SAVINGS (2I3+3A+(3Bd1/YRS ECON LIFE)):	$ 1,900
5. SIMPLE PAYBACK (1G/4)	5.5 YEARS
6. TOTAL NET DISCOUNTED SAVINGS (2I5+3c):	$ 32,807
7. SAVINGS TO INVESTEMENT RATIO (SIR) 6/1G:	3.14

Appendix F
Motor Master+ International Outputs

Appendix F

Motor Master+ International Outputs

Motor Savings Analysis - Replace Existing

Page: 1

INPUTS

Motor Characteristics

	Existing Motor		Premium-Efficiency Motor	
Description:	Old Standard Efficiency		WEG Electric Motors - W22 - NEMA Premium SD - NEMA Design B	
Size (HP) / Speed (RPM) (Poles):	30.0 HP	1800 RPM	30.0 HP	1800 RPM
Enclosure / Voltage (Volts):	TEFC	440 Volts	TEFC	440 Volts
Load (%):	90.0		90.0	
Efficiency (%):	90.0		93.4	
Full load RPM:	0 RPM		0 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	Premium-Efficiency Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price ($/kWh):	0.0312
Purchase price ($):	N/A	2,095	Demand charge ($/kW/mo.):	5.85
Installation cost ($):	N/A	165	Power factor (%):	N/A
Motor rebate ($):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	10
Hours use/yr:	7000	7000		

RESULTS - SAVINGS

	Existing Motor	Premium-Efficiency Motor	Energy Savings	
Differential cost ($):		2,260	Energy (kWh/yr):	5,638
Energy use (kWh/yr):	156660	151022	Demand (kW):	0.8
Energy cost ($/yr):	4,888	4,712	Energy savings ($/yr):	176
Demand charge ($/yr):	1,571	1,515	Demand savings ($/yr):	57
Greenhouse Gas Emissions Reduction			Total savings ($/yr):	232
State:	Washington	tonnes CO2/yr:: 0.64	Simple payback (yrs):	9.7

30-hp US Motor used for Pre-Heat Pumps and Heat Recovery Pumps

Motor Savings Analysis - Replace Existing

INPUTS

Motor Characteristics

	Existing Motor		Energy-Efficient Motor	
Description:	Old Standard Efficiency		GE - Value Line TEFC - NEMA Design B	
Size (HP) / Speed (RPM) (Poles):	50.0 HP	1800 RPM	50.0 HP	1800 RPM
Enclosure / Voltage (Volts):	TEFC	460 Volts	TEFC	460 Volts
Load (%):	90.0		90.0	
Efficiency (%):	91.7		93.2	
Full load RPM:	0 RPM		0 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	Energy-Efficient Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price ($/kWh):	0.0312
Purchase price ($):	N/A	1,475	Demand charge ($/kW/mo.):	5.85
Installation cost ($):	N/A	250	Power factor (%):	N/A
Motor rebate ($):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	10
Hours use/yr:	7000	7000		

RESULTS - SAVINGS

	Existing Motor	Energy-Efficient Motor	Energy Savings	
Differential cost ($):		1,725	Energy (kWh/yr):	4,233
Energy use (kWh/yr):	256260	252027	Demand (kW):	0.6
Energy cost ($/yr):	7,995	7,863	Energy savings ($/yr):	132
Demand charge ($/yr):	2,570	2,527	Demand savings ($/yr):	42
Greenhouse Gas Emissions Reduction			Total savings ($/yr):	175
State:	Washington	tonnes CO2/yr:: 0.48	Simple payback (yrs):	9.9

50-hp Lincguard Motor used for Pre-Heat Pumps and Re-Heat Pumps

Motor Savings Analysis - Replace Existing

INPUTS

Motor Characteristics

	Existing Motor		Premium-Efficiency Motor	
Description:	Energy Efficient		WEG Electric Motors - NEMA Premium - IEEE-841 - NEMA Design B	
Size (HP) / Speed (RPM) (Poles):	60.0 HP	1200 RPM	60.0 HP	1200 RPM
Enclosure / Voltage (Volts):	TEFC	440 Volts	TEFC	440 Volts
Load (%):	90.0		90.0	
Efficiency (%):	90.0		94.7	
Full load RPM:	0 RPM		0 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	Premium-Efficiency Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price ($/kWh):	0.0312
Purchase price ($):	N/A	7,664	Demand charge ($/kW/mo.):	5.85
Installation cost ($):	N/A	280	Power factor (%):	N/A
Motor rebate ($):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	20
Hours use/yr:	7000	7000		

RESULTS - SAVINGS

	Existing Motor	Premium-Efficiency Motor	Energy Savings	
Differential cost ($):		7,944	Energy (kWh/yr):	15,676
Energy use (kWh/yr):	313320	297644	Demand (kW):	2.2
Energy cost ($/yr):	9,776	9,286	Energy savings ($/yr):	489
Demand charge ($/yr):	3,142	2,985	Demand savings ($/yr):	157
Greenhouse Gas Emissions Reduction			Total savings ($/yr):	646
State:	Washington	tonnes CO2/yr:: 1.78	Simple payback (yrs):	12.3

60-hp Westinghouse Motor for the Main Supply Fans

Motor Savings Analysis - Replace Existing

INPUTS

Motor Characteristics

	Existing Motor		Premium-Efficiency Motor	
Description:	Energy Efficient		Tatung - Super Max - NEMA Design B	
Size (HP) / Speed (RPM) (Poles):	150.0 HP	1800 RPM	150.0 HP	1800 RPM
Enclosure / Voltage (Volts):	TEFC	460 Volts	TEFC	460 Volts
Load (%):	90.0		90.0	
Efficiency (%):	94.1		95.9	
Full load RPM:	0 RPM		1780 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	Premium-Efficiency Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price ($/kWh):	0.0312
Purchase price ($):	N/A	10,338	Demand charge ($/kW/mo.):	5.85
Installation cost ($):	N/A	650	Power factor (%):	N/A
Motor rebate ($):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	20
Hours use/yr:	7000	7000		

RESULTS - SAVINGS

	Existing Motor	Premium-Efficiency Motor	Energy Savings	
Differential cost ($):		10,988	Energy (kWh/yr):	13,908
Energy use (kWh/yr):	749171	735263	Demand (kW):	2.0
Energy cost ($/yr):	23,374	22,940	Energy savings ($/yr):	434
Demand charge ($/yr):	7,513	7,374	Demand savings ($/yr):	139
Greenhouse Gas Emissions Reduction			Total savings ($/yr):	573
State:	Washington	tonnes CO2/yr:: 1.58	Simple payback (yrs):	19.2

150-hp Lincguard Motor for the Main Exhaust Fans

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