Supplementary Materials for Comparison of Greenhouse Gas Emission Assessment of Solar and Energy Efficiency Improvements at Small Water Resource Recovery Facilities

Matthew Thompson[1] and Bruce Dvorak[2,*]

[1] HDR Inc., Omaha, NE 68106, USA; matthew.thompson@hdrinc.com
[2] Department of Civil and Environmental Engineering, University of Nebraska-Lincoln, Lincoln, NE 68588, USA
* Correspondence: bdvorak1@unl.edu

*Correspondence author email: bdvorak1@unl.edu, phone: +1(402)-472-3431

Table S1. Monthly electricity solar generation and facility load data for case study A.

Start	End	Delivered from Grid	Net Excess (this is what was delivered TO the grid)	Solar Generaton	Total Plant Load
1/1/2018	1/31/2018	73416	-11570	37,482	99,328
2/1/2018	2/28/2018	63774	-19533	43,602	87,843
3/1/2018	3/31/2018	55705	-38939	67,012	83,777
4/1/2018	4/30/2018	51236	-40908	66,374	76,702
5/1/2018	5/31/2018	51941	-52127	89,703	89,517
6/1/2018	6/30/2018	46207	-56507	102,311	92,011
7/1/2018	7/31/2018	44833	-64385	109,907	90,355
8/1/2018	8/31/2018	45056	-51464	86,174	79,765
9/1/2018	9/30/2018	44534	-38878	67,039	72,695
10/1/2018	10/31/2018	55833	-23175	47,462	80,120
11/1/2018	11/30/2018	64658	-12027	32,447	85,078
12/1/2018	12/31/2018	66802	-10598	31,360	87,564
Sum		**663,995**	**(420,111)**	**780,873**	**1,024,755**

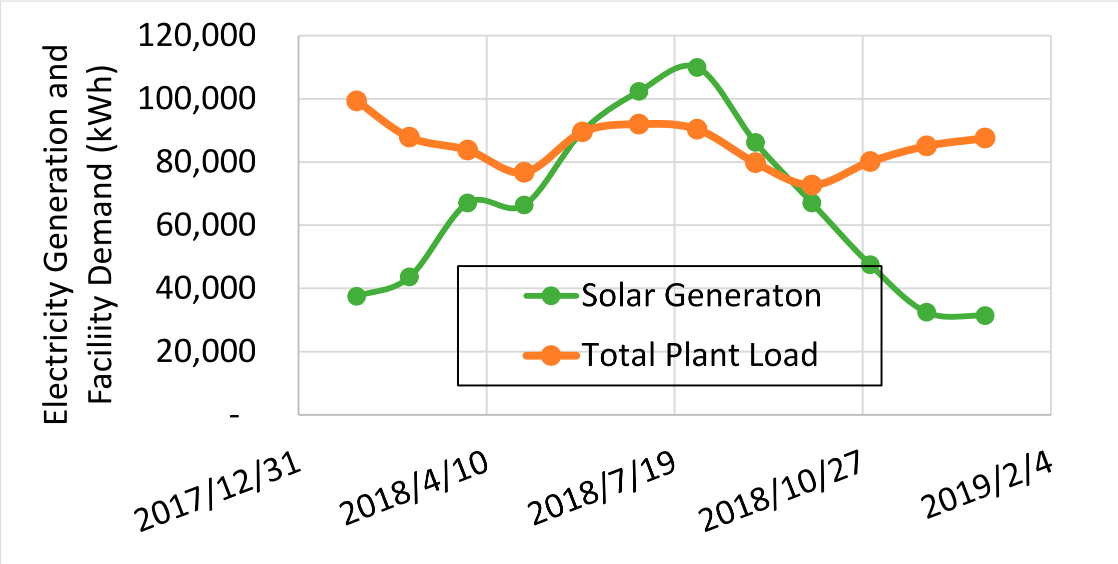


Figure S1. Monthly electricity solar generation and facility load plotted over time

Table S2. Summary of forecasted carbon intensity of grid electricity under difference renewable energy adoption scenarios (NREL).

Carbon Intensity of Grid Electricity (kg CO2/MWH)			
Year	co2_rate_avg_load_enduse		
	Midcase	Low Case	High Case
2020	375.4	366.5	373.8
2022	398.5	383.8	401
2024	384.8	344.2	396.9
2026	392.2	276.2	386.7
2028	349.3	257.1	406.4
2030	354.7	181.9	332.9
2032	339	132.7	335.9
2034	413.6	135.3	403.7
2036	379.8	135.1	407.6
2038	318.5	121.2	404.7
2040	242.6	123.3	413.7
2042	238.1	110.1	375.9
2044	189.7	82.9	263.5
2046	180.7	69	152.9
2048	164.2	75.9	148.2
2050	135.2	76.9	129.8

Table S3. Summary of Energy Efficiency Improvements recommended in assessments.

Facility ID	Rec ID	Improvement type	Process area	Rec Name	Design Flow (MGD)	Average Flow (MGD)
15	9	BLDG		Improve building insulation		3.36
17	9	BLDG		Improve building insulation	0.75	0.174
18	9	BLDG		Improve building insulation	0.27	0.11
3	2	BLDG		Lighting	0.28	0.302
4	2	BLDG		Lighting	0.106	0.064
6	2	BLDG		Lighting	1.00	0.26
7	2	BLDG		Lighting	0.255	0.12
8	2	BLDG		Lighting	0.35	0.16
9	2	BLDG		Lighting	0.04	0.0325
13	2	BLDG		Lighting		0.195
14	2	BLDG		Lighting	1.8	1.2
2	2	BLDG		Lighting	3.71	1.86
15	2	BLDG		Lighting		3.36
16	2	BLDG		Lighting	13.1	10.6
18	2	BLDG		Lighting	0.27	0.11
19	2	BLDG		Lighting	0.168	0.076
20	2	BLDG		Lighting	0.12	0.06
18	11	BLDG		Occupancy sensors	0.27	0.11
16	10	TP	ST	Downsize Aeration Blower	13.1	10.6
11	6	TP	ST	Timer on secondary aeration		0.122
1	1	TP	ST	VFD on Secondary Aeration		0.70
2	1	TP	ST	VFD on Secondary Aeration	3.71	1.86
6	5	TP	SM	Improve BFP / Digestion operation	1.00	0.26
8	5	TP	SM	Improve BFP / Digestion operation	0.35	0.16
12	7	TP	SM	Improve Sludge Blower Operations		0.054
16	7	TP	SM	Improve Sludge Blower Operations	13.1	10.6
19	3	TP	SM	Install aerobic digester cover	0.168	0.076
20	3	TP	SM	Install aerobic digester cover	0.12	0.06
5	3	TP	SM	Timer on aerobic digester blower	0.33	0.2
10	3	TP	SM	Timer on aerobic digester blower	0.125	0.101
19	3	TP	SM	Timer on aerobic digester blower	0.168	0.076
20	3	TP	SM	Timer on aerobic digester blower	0.12	0.06
14	8	TP	SM	VFD on aerobic digestion	1.8	1.2
6	4	TP		Premium Efficiency Motor	1.00	0.26
14	4	TP		Premium Efficiency Motor	1.8	1.2

Table S3. (cont.)

Facility ID	Energy Saved (kWh/year)	Energy Intensity Offset (kWh/MG)	Implementation Cost ($)	Energy Cost ($/kWh)	Energy Cost Savings ($/year)	Payback Period (years)
15	9,404 therms/year		$ 22,557	$0.61 /therm	$5,716	3.9
17	2,824	44	$ 4,075	$ 0.063	$188	23
18	41,982	1,046	$ 1,773		$498	3.6
3	7,300	66	$ 1,311	$ 0.04	$ 278.00	4.7
4	438	19	$ 308	$ 0.08	33	9.3
6	4152	44	$ 1,935	$ 0.09	374	5.2
7	1030	24	$ 425	$ 0.07	$ 82	5.2
8	4300	74	$ 1,380	$ 0.06	$ 260	5.3
9	72.9	6	$ 30	$ 0.07	$ 5	6.0
13	1,960	28	$ 230	$ 0.096	$ 270	0.9
14	8000	18	$ 6,660	$ 0.070	$ 1,225	5.4
2	10,972	8	$ 5,620	$0.040	$1,017	5.5
15	663	1	$ 421	$ 0.045	$ 119	3.5
16	28,295	7	$ 2,807	$ 0.049	$1,899	1.5
18	907	23	$ 80		$73	1.1
19	1,847	67	$ 2,150	0.107	$103	20.9
20	4,350	199	$ 2,267	0.089	$292	7.8
18	3,807	95	$ 861		$320	2.7
16	917,950	237	$ 111,600	$ 0.049	$59,550	1.9
11	15470	347	$ 1,020	$ 0.096	$ 1,490	0.7
1	226,058	885	$ 25,400	$ 0.07	$ 15,825	1.9
2	718,320	1,058	$ 155,000	$ 0.04	$ 47,523.00	3.3
6	108424	1,143	$ 600	$ 0.09	$ 5,105.00	0.1
8	58140	996	$ 600	$ 0.06	$ 3,600	0.2
12	6,800	345	$ 600	$ 0.096	$655	0.9
16	430,444	111	$ 690	$ 0.049	$21,092	0.0
19	4,862	175	$ 990	0.107	$361	2.7
20	3,580	163	$ 990	0.089	$160	6.2
5	47500	651	$ 410	$ 0.07	$ 3,300.00	0.1
10	13820	375	$ 170	$ 0.082	$ 1,130	0.2
19	5,105	184	$ 305	0.107	$546	0.6
20	3,770	172	$ 305	0.089	$336	0.9
14	103914	237	$ 40,000	$ 0.070	$ 7,236	5.5
6	3285	35	$ 3,775	$ 0.09	340	11.1
14	7500	17	$ 1,300	$ 0.070	$ 360	3.6

Table S3. (cont.)

Facility ID	Carbon impact of infrastructure (kg CO2eq)	Carbon Offset (kg CO2eq/year)	Carbon Payback Period (year)	Net Life Cycle Offsets (kg CO2eq)	Net GWP Intensity Offset (kg CO2eq/MG)	Carbon Reduction per investment cost (kg CO2eq/$)
15		49,907		998,146	40.69	44
17		1,962	-	39,244	30.90	10
18		29,170	-	583,410	726.54	329
3	30.2	5,072	0.006	101,416	45.94	77
4	7.1	304	0.023	6,080	13.09	20
6	44.5	2,885	0.015	57,654	30.38	30
7	9.8	716	0.014	14,304	16.33	34
8	31.7	2,988	0.011	59,724	51.13	43
9	0.7	51	0.014	1,012	4.27	34
13	5.3	1,362	0.004	27,232	19.13	118
14	153.2	5,559	0.028	111,020	12.67	17
2	129.3	7,624	0.017	152,345	11.22	27
15	9.7	461	0.021	9,204	0.38	22
16	64.6	19,660	0.003	393,142	5.08	140
18	1.8	630	0.003	12,602	15.69	158
19	49.5	1,283	0.039	25,618	46.17	12
20	52.1	3,023	0.017	60,398	137.90	27
18	19.8	2,645	0.007	52,885	65.86	61
16	3550.978	637,822	0.006	12,752,894	164.81	114
11	0	10,749	-	214,981	241.39	211
1	1,337.4	157,073	0.009	3,140,115	614.50	124
2	8,224.7	499,113	0.016	9,974,029	734.57	64
6	0	75,337	-	1,506,732	793.85	2511
8	0	40,398	-	807,952	691.74	1347
12	0	4,725	-	94,497	239.72	157
16	0	299,087	-	5,981,737	77.30	8669
19	0	3,378	-	67,566	121.78	68
20	0	2,488	-	49,750	113.58	50
5	352.8	33,005	0.011	659,739	451.88	1609
10	235.2	9,603	0.024	191,817	260.16	1128
19	205.8	3,547	0.058	70,737	127.50	232
20	176.4	2,620	0.067	52,214	119.21	171
14	1,978.4	72,203	0.027	1,442,080	164.62	36
6	455	2,283	0.199	45,196	23.81	12
14	325	5,211	0.062	103,900	11.86	80

Examples of Energy Efficiency Recommendations detailed in Reports from Technical Assistance Providers:

EXAMPLE 1: Aeration Improvement

5.0 Energy Efficiency Assessment Recommendations

The assessment recommendations presented in the following section are organized from the highest savings to the lowest. For each recommendation, the rates for electricity usage and electricity demand used were **$0.040/kWh** and **$0.105/kWh** (or **$21/kW**), respectively.

5.1 AR No. 1: Install an Automated Dissolved Oxygen Control System on the Aeration Process

Recommended Action

It is recommended that the facility installs an automated dissolved oxygen (DO) control and variable frequency drive (VDF) system to adjust the level of aeration provided to the basins. It is estimated that the current system costs the plant around $115,000/yr. The estimated savings, implementation cost, and simple payback of this recommendation are summarized in Table 5.1-1. The implementation cost includes the rebate from NPPD's VFD Incentive program, which is further discussed in the Cost of Implementation section. Significant electrical demand savings may also be realized from the installation of this application but are not included in this analysis.

Table 5.1-1: AR No. 1 Recommendation Summary

Annual Electricity Usage Savings	Electrical Demand Savings	Annual Cost Savings	Implementation Cost	Simple Payback
718,320 kWh	82 kW/month	$47,523	$155,000	3.3 years

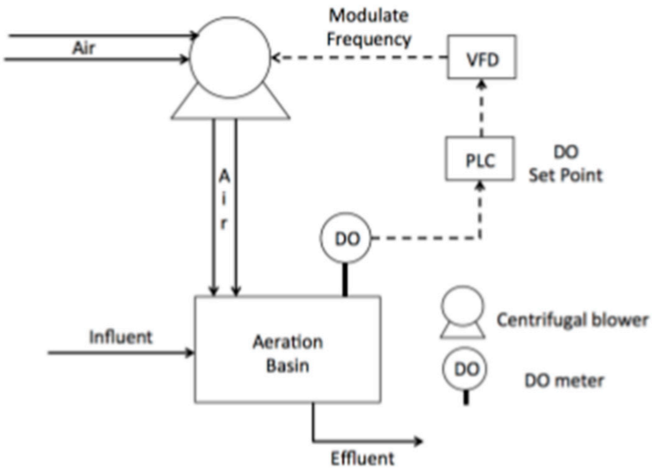
Background

The [redacted] WWTP currently employs a fine bubble diffuser for the aeration of wastewater. Air is supplied by use of one of three centrifugal blowers to the aeration basins. The blowers supply air to either one of the two aeration basins. One basin has 1,000 fine bubble sock diffusers and a 2.5 million gallon capacity; the other basin has 8,000 fine bubble disc diffusers and a capacity of 1 million gallons. Currently, the blowers operate at a near constant rate, with the ability for the air supply to be adjusted automatically with use of an inlet air control value that adjusts based on the air temperature. However, this is not as effective for energy savings as a VFD would be. There are no dissolved oxygen sensors present in the basins and effluent DO levels are measured manually.

Figure 5.1-1 shows the effluent DO levels recorded by the SCADA system. The operator noted that the aeration basins are currently over aerated, operating at higher DO levels than needed, and therefore consuming more energy than necessary. Figure 5.1-1 shows that the effluent DO levels far exceed the necessary amount of 2-3 mg/L. A line at 3 mg/L graphing the minimum DO levels necessary, gives a visualization of how far DO levels within the basin exceed required DO levels. In exception to a few weeks, the DO levels are typically greater than 6 mg/L and can rise close to the maximum saturation level of oxygen in water.

Figure 5.1-1: Aeration Basin Effluent DO Levels Measured Over Time

An automated DO/VFD control system could be installed to optimize process control of the system, allowing reduced energy usage of the blower. Figure 5.1-2 shows an example schematic of the proposed DO/VFD control system. A DO meter would read the DO levels in the aeration basin and then would be reported to a programmable controller (PLC) which would compare the reading to the desired DO set point and then communicate what proper VFD operating frequency would be needed to provide sufficient air for processing. The appropriate VFD setting would then control the quantity of air supplied to the basin by the blower. The DO meter would read the new DO levels in the basin, and adjustments would continue to be made based on DO levels until the desired set point is achieved. This system would allow for constant monitoring of DO levels and adjustment to the blower output. It should be noted that the installation of the DO probes could be difficult because of the distance from the blower building to the basin; radios may be necessary to transmit the signal.



Anticipated Savings

Calculations were performed to determine the energy and cost savings possible with this recommendation. Several requirements must be considered when identifying the maximum power reduction of the blower. There must be enough oxygen supplied to the aeration basin for the breakdown of organic matter and inorganic compounds such as ammonia. The air supply must also be sufficient to adequately mix the contents of the basin and prevent settling that would lead to anoxic conditions in the basin. Lastly, the power supplied to the blower can only be reduced so far before the blower begins to have difficulty operating due to a condition called surging. This limit is referred to as the surge point.

Oxygen Requirements

The aeration process must supply enough air to meet the carbonaceous biochemical oxygen demands (CBOD). In other words, enough oxygen must be supplied to allow the bacteria to biodegrade the organic matter in the wastewater, producing water and carbon dioxide in the process. Oxygen is also necessary for bacteria to oxidize the ammonia in the wastewater, producing a final product of nitrate. The energy required to operate the blower at the necessary air supply level was modeled based on current pollutant loadings and operating water temperatures measured weekly at the plant. These measurements were gathered from the plant's SCADA system. Pollutant loadings are shown in Figure 5.1-3 and 5.1-4. Figure 5.1-3 shows the influent CBOD loadings, and Figure 5.1-4 depicts the influent ammonia loadings. The loadings are based on multiplying the flowrate by the concentration of contaminant measured. In some cases the pollutant loadings were based on grab samples and not composite samples, however the plant staff had expressed that Infiltration and Inflow (I&I) has been largely addressed in the town and the wastewater is largely sourced from residential and commercial users. Based on this, they believed the concentration may not very too much throughout the day and thus this data may be fairly representative.

Figure 5.1-3: Influent CBOD Loading

Figure 5.1-4: Influent Ammonia Loading

As will be discussed later in this section, the amount of dissolved oxygen in water is dependent upon the temperature of the water. Figure 5.1-5 shows how the temperature of the water has varied. The CBOD loading, ammonia loading, and temperature can all affect the oxygen requirements and dissolved oxygen levels within the basin.

Figure 5.1-5: Temperature of Effluent Water

Data obtained from the plant's SCADA records was used for modeling. This included influent flowrates of wastewater, CBOD and ammonia concentration, and the wastewater temperature. Based on these parameters, the required oxygen (RO) was calculated. Data from the past year is shown in Appendix 7.3, along with more detailed calculations. The calculations were performed on a basis of weekly data. If multiple data points were collected during 1 week, those values were averaged over the time period.

A sample calculation of a single data point is shown following the equation given below. The following equations were sourced from Tchobanoglous et al. (2014). The oxygen requirements for aeration are:

$$RO = 1.1 * (LCBOD_0 - LCBOD) + 4.6 * (LNH_0 - LNH)$$

$$4{,}471\ \frac{lbs\ O_2}{day} = 1.1\frac{lbs\ O_2}{lbs\ LCBOD} * (2{,}542\frac{lbs\ LCBOD}{day} - 0\frac{lbs\ LCBOD}{day}) + 4.6\frac{lbs\ O_2}{lbs\ LNH} * (364\frac{lbs\ LNH}{day} - 0\frac{lbs\ LNH}{day})$$

Where,

RO - Required oxygen for removal of CBOD and ammonia ($\frac{lbs\ O_2}{day}$)

1.1 - Amount of oxygen required to breakdown the CBOD. Value is taken from the Scottsbluff Plant Improvements Specification for the Grid Aeration System ($\frac{lbs\ O_2}{lbs\ LCBOD}$)

$LCBOD_0$ - Current CBOD influent loading. CBOD loading is the concentration of CBOD multiplied by the volume flow rate of wastewater. Both CBOD and flow rate values were gathered from the WWTP's SCADA system ($\frac{lbs\ LCBOD}{day}$)

$LCBOD$- Desired CBOD effluent loading, assigned value of 0 ($\frac{lbs\ LCBOD}{day}$)

4.6 - Amount of oxygen required to oxidize ammonia. Value taken from the Scottsbluff Plant Improvements Specification for the Grid Aeration System ($\frac{lbs\ O_2}{lbs\ LNH}$)

LNH_0 - Current ammonia influent loading gathered from SCADA system. Ammonia loading is the concentration of ammonia multiplied by the volume flow rate of wastewater. ($\frac{lbs\ LNH}{day}$)

LNH - Desired ammonia effluent loading, assigned value of 0 ($\frac{lbs\ LNH}{day}$)[2]

The oxygen transfer rate (OTR) is dependent upon the design specification of the configuration used for supplying air to the basin, as well as the field environmental conditions. This parameter was set equal to the required oxygen rate (RO) and used in calculations below. The concentration of oxygen in the water is a function of temperature. Data from the Engineering Toolbox[2] was used to calculate the oxygen concentration in water of specific temperatures. The following expression can be used to describe the oxygen transfer rate:

$$OTR = RO = SOTR * \left(\frac{\beta * C_{st} - C_{basin}}{C_{st20}}\right) * \theta^{T-20} * \alpha * FO$$

Where,

$SOTR$ - Standard oxygen transfer rate of oxygen required ($\frac{lbs\ O_2}{day}$)

β - Ratio of the oxygen saturation in wastewater to freshwater. Value taken from the Scottsbluff Plant Improvements Specification for the Grid Aeration System (0.98)

C_{st}- Oxygen concentration in freshwater at the field temperature and altitude. The equation used for this value is found in Appendix 7.3. It was calculated with data from the Engineering ToolBox[1]. Temperatures recorded from the SCADA system were used to find the specific oxygen concentrations $(\frac{mg}{L})$

C_{basin} - Desired oxygen concentration in the basin, assigned value of 3 mg/L $(\frac{mg}{L})$

C_{st20}- Oxygen concentration in freshwater at 20 °C (9.2 $\frac{mg}{L}$)[1]

α - Constant dependent upon the aeration type, in this case, fine bubble diffuser. Value taken from the Scottsbluff Plant Improvements Specification for the Grid Aeration System (0.41)

FO - Fouling factor associated with reduced performance of the diffuser system. Value found from the ratio of the effective flux ratio of unused diffusers to used diffusers in the Scottsbluff Plant Improvements Specification for the Grid Aeration System (0.9)

θ- Arrhenius constant for correcting system operating temperature. Value taken from the Scottsbluff Plant Improvements Specification for the Grid Aeration System (1.024)

T- Temperature of water in the basin. Values gathered from SCADA (°C)

The SOTR is also used in the calculation of the required flowrate of air (W). After rearranging the above equation, the equation for $SOTR$ can be substituted into the equation for W.

$$SOTR = \frac{RO}{\left(\frac{\beta * C_{st} - C_{basin}}{C_{st20}}\right) * \theta^{T-20} * \alpha * FO}$$

$$17{,}720\ \frac{lbs\ O_2}{day} = \frac{(4{,}471\ \frac{lbs\ O_2}{day})}{\frac{(0.98) * (10.34\ \frac{mg}{L}) - (3\ \frac{mg}{L})}{(9.20\ \frac{mg}{L})} * 1.024^{(14.7°C - 20°C)} * (0.41) * (0.9)}$$

The standard required mass flowrate of air to be supplied by a blower in order to meet oxygen requirements for effective treatment is described by the following expression:

$$W = \frac{SOTR}{CF * SOTE}$$

$$385{,}000\ \frac{lbs\ air}{day} = \frac{(17{,}720\ \frac{lbs\ O_2}{day})}{(0.23\ \frac{lbs\ O_2}{lb\ air}) * (0.2)}$$

Where,

W - Standard air flow rate of air required from the blower $(\frac{lbs\ air}{day})$

CF - Mass fraction of oxygen in air ($0.23 \frac{lbs\ O_2}{lb\ air}$)[3]

$SOTE$ - Standard oxygen transfer efficiency of the fine bubble diffuser system, which is a function of the diffuser depth within the digester. Value taken from the Scottsbluff Plant Improvements Specification for the Grid Aeration System (0.20)

The energy requirement of the blower associated with providing this standard air supply at a specific inlet air temperature, overall blower efficiency, and inlet and discharge pressure can be expressed with the following expression. The value of $5.25 \times 10^{-6} \frac{day}{lbs*s}$ is a conversion factor.

$$P = \frac{W * R * T_A}{MW_{air} * n * e_b * e_m * e_v} * [(\frac{p_2}{p_1})^n - 1]$$

$$72.6\ kW = \frac{(385{,}000 \frac{lbs\ air}{day}) * (8.314 \frac{J}{mol * K}) * (9.29 + 273)K}{(28.97 \frac{g}{mol\ air}) * (1.395) * (0.70) * (0.95) * (0.97)} * (5.25 \times 10^{-6} \frac{day}{lbs * s}) * [(\frac{1.306\ atm}{1\ atm})^{1.395} - 1]$$

Where,

P - Operating power of the blower (kW)

R - Universal gas constant ($8.314 \frac{J}{mol*K}$)[4]

T_A - Inlet air temperature of the blower (K)[5]

MW_{air} - Molecular weight of air ($28.97 \frac{g}{mol\ air}$)[6]

n - The binomial coefficient (1.395)[7]

e_b - Efficiency of the blower. Value taken from the Houston Services Industries, Inc. Installation, Operation and Maintenance Manual. (0.70)

e_m- Efficiency of the motor gathered from the nameplate (0.95)

e_v- Efficiency of the 250 HP VFD (0.97)[8]

p_1 - Absolute inlet pressure assumed to be atmospheric (atm)

p_2 - Absolute outlet pressure. Found by adding the blower outlet pressure operating condition of 5.2 psi to atmospheric pressure (atm)

The previous expressions can be used in conjunction with plant operating data and typical operating performance data of a fine bubble diffuser systems to relate the energy requirements of the blower to the dissolved oxygen concentration within the basin. The average power requirement of the blower to provide the needed oxygen is 90 kW. Calculations are shown in Appendix 7.3.

Mixing Requirements

It is a requirement that sufficient aeration is provided to prevent settling of sludge. The required air supply rate for proper mixing of a fine bubble diffusion system is approximately 30 SCFM/1000 ft^3 basin[9]. The assumption was made that the basins would not be filled to capacity, and therefore, the smaller of the two basin sizes, 1 million gallons, was used for the calculation. The required air flowrate for maintaining proper mixing within a full digestion basin is approximately 4,000 SCFM. This corresponds to a power requirement of 86 kW. Calculations are shown in Appendix 7.3.

Blower Turndown Capacity

Another key operating condition that must be met is supplying enough discharge pressure from the blower to overcome head loss throughout the system. It is estimated that the blower cannot be reduced past 70% of its operating capacity, as shown by the blower curve found in the Houston Service Industries Installation, Operation and Maintenance manual for the multistage centrifugal blowers. In terms of air supplied this corresponds to 3610 SCFM. This is because the blower will deliver a reduced discharge pressure at these operating conditions and will be unable to achieve the required pressure to pump air through the system, causing the blower to surge. The system is constrained by the pressure requirement and cannot achieve lower operating conditions without restructuring the overall system design. This pressure requirement corresponds to a power supply of 105 kW to the blower. Only two weeks in the past year had oxygen requirement levels that demanded a higher operating power than the minimum turndown capacity of the blower. This makes the turndown capacity the limiting factor for the proposed system.

Figure 5.1-6 shows the power necessary for each requirement: power needed to provide the necessary amount of air, and therefore oxygen; the necessary amount of air to mix the aeration tank, and the minimum turndown capacity of the blower. The minimum turndown capacity of the blower has the highest power requirement. There cannot be less power than 105 kW provided to the blower. This power restriction was used to calculate the potential savings. Savings were estimated based on reducing the current operating power to the highest calculated power value, which was often the minimum turndown capacity of the blower. This would result in a monthly reduction of 82 kW in operating power of the blower. This would correspond to a reduced electrical usage of 718,000 kWh per year. The calculations for the monetary savings of this recommendation in the month of April 2018 are shown below. The same method is used to find the cost savings from the past 12 months. The total annual cost savings are found to be approximately $47,500; extensive monthly calculations are shown in Appendix 7.3.

Electricity Savings: $82\ kW * \frac{24\ hours}{day} = \frac{1{,}968\ kWh}{day}$

Annual Electrical Savings: $\frac{1{,}968\ kWh}{day} * \frac{365\ days}{year} = \frac{718{,}320\ kWh}{year}$

New Total Usage: $233{,}600\ kWh - \left(\frac{1{,}968\ kWh}{day} * \frac{30\ days}{month}\right) = 174{,}560\ kWh$

*There were 30 days in April of 2018

New Demand Cost: $\left[(382.3\ kW - 82\ kW) * 200\ hours * \frac{\$0.0944}{kWh}\right] = \$5{,}669.66$

New Electricity Usage Cost:

$$\{174{,}560\ kWh - [(382.3\ kW - 82\ kW) * 200\ hours]\} * \frac{\$0.0364}{kWh} = \$4{,}167.80$$

*April is a winter month, therefore the demand rate is \$0.0944/kWh and the electricity rate is \$0.0364/kWh

Cost Savings:

$$\$15{,}014.45 - \frac{\$5{,}669.66 + \$4{,}167.80 + \$150 + \$125}{0.88} = \$3{,}523.02$$

*See Section 4.1 for sources of \$150, \$125, and 0.88 values

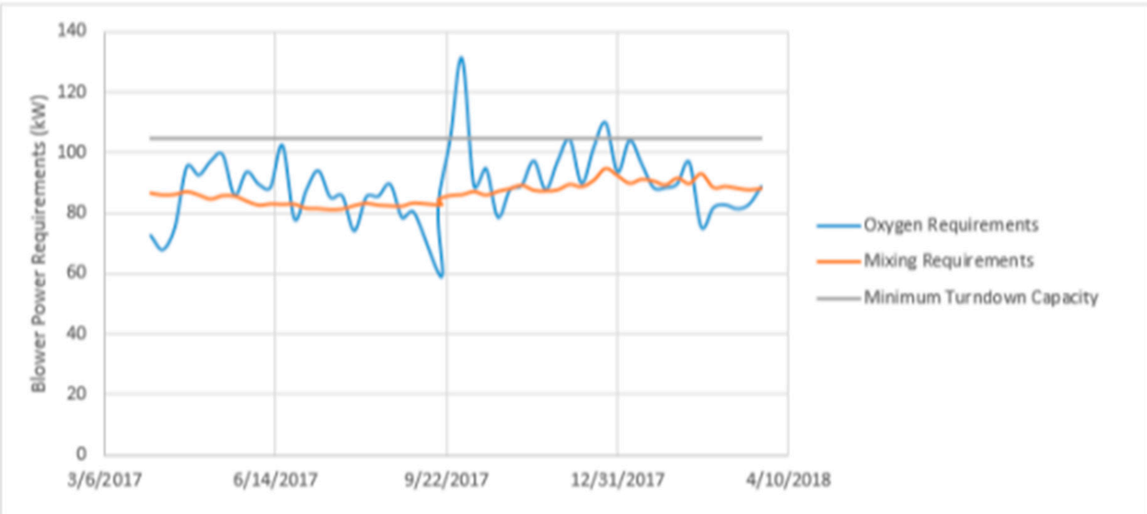


Figure 5.1-6: Comparison of Blower Power Requirements

Implementation Cost and Simple Payback

The cost of implementation for installing the automated system was based on a quote from a vendor. The total cost estimate included the following: installing three new 250 hp VFDs; one air conditioner to cool the VFDs; one new air flow meter installed in the discharge piping to the aeration basins; a dissolved oxygen analyzer with two probes to be installed in the aeration basins; programming of PLC; configuration of VFDs and SCADA interface; and system design, drawings, assembly, testing, startup and training. This all totaled to \$150,000-180,000. It was noted that the airflow meter may not be necessary.

Another possibility to reduce the capital cost would be to take advantage of Nebraska Public Power District's (NPPD) EnergyWise Variable Frequency Drive Incentive Program. This program offers a $30 per horsepower incentive on VFDs up to 200 hp on centrifugal pumps and fans. This could potentially reduce the capital cost by $18,000 for all three VFDs, taking it from $150,000-180,000 down to $132,000-162,000. The NIAC is recommending a budgetary estimate of $155,000 for the entire system.

Since the annual cost savings from this recommendation would be $47,523, the payback period using this estimate would be 3.3 years.

EXAMPLE 2: Lighting Improvement

5.3 AR No. 3: Install Occupancy Sensors

Recommended Action

Based on the information provided by Hastings Utilities and the data collected during the assessment, it is suggested that occupancy sensors be installed throughout the plant. There are currently four different types of lighting fixtures throughout the plant, T12, T8, and T5 fluorescents, and LED fixtures. A majority of these are either T8 or T5 fluorescents, the most efficient fluorescent bulbs. It is not recommended that the facility install LED fixtures due to their high initial capital cost. It is recommended that occupancy sensors be installed throughout the plant.

Table 5.3-1: AR No. 3 Recommendation Summary

AR Summary			
Annual Usage Savings	Annual Cost Savings	Implementation Cost	Simple Payback
52,800 kWh	$3,700	$2,500	0.7 years

Background

One of the biggest economic and environmental issues facing the current lighting situation at the wastewater plant is the fact that the lights are on approximately 10 times longer than they need to be. In addition to conserving electricity, installing occupancy sensors will also greatly reduce the number of hours maintenance staff need to spend changing lightbulbs. In order to make the following calculations, it was assumed that all lights throughout the plant are on for approximately 45 hours each week. It is also assumed that these lights only need to be on for 4 hours each week. These assumptions were based off of an estimate made by the plant superintendent. Installing the sensors would cause the lights to turn on only when the room is occupied reducing the electricity usage by approximately 90%. With a capital cost of approximately $125 per sensor, the initial investment will be $2,500, as shown in Table 5.3-1. The annual savings include energy savings, capital savings, and labor savings totaling approximately $3,700 annually. These calculations lead to a simple payback period of 0.7 years.

Based on plant superintendent's estimates, there is a significant quantity of energy that could be saved through the implementation of occupancy sensors throughout the plant. The installation of LED lights was also considered, but it was found to be more cost effective to simply install occupancy sensors as a majority of the lights installed are T8 fluorescent bulbs which are very efficient. Additionally, the lights are not in operation long enough for LED fixtures to be economically viable.

An inventory of all of the facility's lighting was taken during the assessment. Table 5.3-2 describes the lighting in each of the buildings. In order to improve clarity, there is a map of the facility in figure 5.3-1 showing the locations of each building, and the number of each type of light in the buildings.

Table 5.3-2: Lighting Inventory

Building	Bulb Type	Quantity (# of bulbs)	Wattage*	Annual Hours of Operation**
Grit Removal Building	T8	16	34 W	2,340 hr/year
	LED	1	20 W	
Solids Pump Station	T8	32	34 W	2,340 hr/year
RBC Building	T8	44	34 W	2,340 hr/year
	LED	4	20 W	
Trickling Filter Effluent Pump Station	T8	52	34 W	2,340 hr/year
Biosolids Storage Building	T8	52	34 W	2,340 hr/year
Influent Pump Station	T8	36	34 W	2,340 hr/year
	T5	20	28 W	
RAS/WAS Building	T8	72	34 W	2,340 hr/year
	T5	144	28 W	
Energy Recovery Unit Building	T12	27	40 W	2,340 hr/year
	T8	80	34 W	
Solids Complex/Digesters	T8	132	34 W	2,340 hr/year
	T5	52	28 W	

** The wattages for the bulbs are based on estimates given by maintenance staff (T12 – 40 W/bulb, T8 – 34 W/bulb, T5 – 28 W/bulb, LED – 20 W/fixture)*

*** Annual hours of operation based on the lights being on for 45 hours/week, 52 weeks per year*

Anticipated Savings

In order to calculate the anticipated savings from the installation of occupancy sensors, it is necessary to calculate the reduction in annual hours of operation. This can be done using the following equation:

$$\frac{Hours\ Saved}{Year} = (Current\ Weekly\ Hours - Necessary\ Weekly\ Hours) * 52\frac{weeks}{year}$$

Where,

- Current weekly hours are 45 hours/week
- Necessary Weekly Hours are 4 hours/week

$$\frac{Hours\ Saved}{Year} = (45\frac{hours}{week} - 4\frac{hours}{week}) * 52\frac{weeks}{year}$$

$$\frac{Hours\ Saved}{Year} = 2{,}132\frac{hours}{year}$$

$$Energy\ Savings\ (T12\ bulbs\ in\ ERUB) = 2{,}132\frac{hr}{year} * 40\frac{W}{T12\ bulb} * 27\ bulbs * \frac{1\ kWh}{1000\ W}$$

$$Energy\ Savings\ (T12\ bulbs\ in\ ERUB) = 2{,}303\frac{kWh}{year}$$

$$Energy\ Savings\ (T8\ bulbs\ in\ TFEPS) = 2{,}132\frac{hr}{year} * 34\frac{W}{T8\ bulb} * 52\ bulbs * \frac{1\ kWh}{1000\ W}$$

$$Energy\ Savings\ (T8\ bulbs\ in\ TFEPS) = 3{,}769\ \frac{kWh}{year}$$

$$Energy\ Savings\ (T5\ bulbs\ in\ IPS) = 2{,}132\frac{hr}{year} * 28\frac{W}{T5\ bulb} * 20\ bulbs * \frac{1\ kWh}{1000\ W}$$

$$Energy\ Savings\ (T5\ bulbs\ in\ IPS) = 1{,}194\ \frac{kWh}{year}$$

$$Energy\ Savings\ (LED\ Fixtures\ in\ RBC) = 2{,}132\frac{hr}{year} * 20\frac{W}{LED\ bulb} * 4\ bulbs * \frac{1\ kWh}{1000\ W}$$

$$Energy\ Savings\ (LED\ Fixtures\ in\ RBC) = 171\ \frac{kWh}{year}$$

This calculation must be done for each type of bulb (T12, T8, T5, and LED), and the results must be added together to obtain the total savings. At this point, the annual energy savings can be used to calculate the annual cost savings from installing occupancy sensors. This is done assuming a constant rate of \$0.056/kWh. It can be obtained from the following equation:

$$Energy\ Cost\ Savings = Energy\ Savings * \frac{\$0.056}{kWh}$$

Where,

- Energy savings is the total annual energy savings in (kWh/year)
- \$0.056/kWh is the average electricity rate

Solids Complex/Digesters Energy Cost Savings:

$$Energy\ Cost\ Savings = \left(9{,}568\frac{kWh[T8]}{year} + 3{,}104\frac{kWh[T5]}{year}\right) * \frac{\$0.056}{kWh}$$

$$Energy\ Cost\ Savings = \frac{\$710}{year}$$

Following the calculation of the total annual energy cost savings, the annual maintenance cost savings can be calculated. This will comprise a relatively major component of the savings due to the fact that the lifespans of the bulbs will be dramatically increased. While the nominal lifespan will not change, a 90% reduction in usage will result in a much longer lifespan. This will, in turn, reduce the amount of time maintenance will need to spend changing light bulbs. To begin, the reduction in the frequency at which bulbs must be changed is calculated.

Current burnouts/year is assumed to be 10% of bulbs. This is based on the fact that the average lifespan of each fluorescent bulb is approximately 20,000 hours. The lightbulbs are on for approximately 2,000 hours per year, leading to an average life of 10 years for each bulb. Assuming an equal number of bulbs are installed each year, 10% of the bulbs should burn out each year. New burnouts/year is assumed to be 1% of bulbs. This is because the annual usage will be decreased approximately 10-fold as described by plant personnel. This will reduce the number of bulbs that need to be changed by a factor of 10. The reduction in burnouts can be calculated in the following manner:

$$Reduction\ in\ Burnouts = \frac{Current\ burnouts}{year} - \frac{New\ burnouts}{year}$$

$$Reduction\ in\ Burnouts = (10\% - 1\%) * 764\ bulbs$$

$$Reduction\ in\ Burnout = 69\ \frac{bulbs}{year}$$

At this point, the annual capital cost of replacing bulbs can be calculated. These calculations will be done using the aforementioned reduction in burnout percentage. It will also be based off of the average cost per bulb of each respective type of bulb. The breakdown for bulb savings for each individual building can be found in Table 5.3-3.

$$Bulb\ Savings = Reduction\ in\ usage(\%) * \left(\#of\ bulbs * \frac{cost}{bulb}\right)$$

Where,

- Reduction in usage is the reduction in the frequency at which the light bulbs need to be changed
- # of bulbs*(cost/bulb) will need to be repeated for each type of bulb, and then all these will be added together.
- The cost of bulbs will be assumed to be constant at $2.00 for each T12, $4.00 for each T8, and $8.50 for each T5

Solids Complex/Digesters Bulb Cost Savings:

$$Bulb\ Savings = 0.09 * \left[\left(132\text{ T8 bulbs} * \frac{\$4}{\text{T8 bulb}}\right) + \left(52\text{ T5 bulbs} * \frac{\$8.50}{\text{T5 bulb}}\right)\right]$$

$$Bulb\ Savings = \frac{\$87}{year}$$

The average cost of maintenance can then be calculated. Note that the maintenance labor that is freed from build replacement can be used for other deferred maintenance that will have energy improvement benefits. This will show how much money will be saved in labor costs with the installation of occupancy sensors throughout the plant. Since LED bulbs are very energy efficient and do not require replacement often, the LED bulbs are assumed to have no annual bulb or labor cost savings. A breakdown of the labor savings for each individual room can be found in Table 5.3-3. This can be done using the following equation:

$$Labor\ Savings = Reduction\ in\ Burnouts(\%) * \#\ of\ bulbs * \left(\frac{hours}{bulb} * \frac{labor\ cost}{hour}\right)$$

Where,

- Reduction in burnouts is assumed to be 9%
- # of bulbs is the total number of bulbs present throughout the plant
- Hours/bulb is 0.167 hours/bulb (10 minutes/bulb)
- Labor cost is $32.81/hour

Solids Complex/Digesters Labor Cost Savings:

$$Labor\ Savings = 0.09 * 184\ bulbs * \left(0.167\frac{hours}{bulb} * \frac{\$32.81}{hour}\right)$$

$$Labor\ Savings = \frac{\$91}{year}$$

At this point, all the savings can be added together to obtain a total cost savings of installing occupancy sensors throughout the plant. A breakdown of total annual cost savings can be found in Table 5.3-3.

To calculate the total capital cost of installing the sensors it will be assumed that occupancy sensors cost $125 per piece. The number of sensors needed per building varies, and the exact breakdown can be found in Table 5.3-4.

$$Capital\ Cost = Number\ of\ sensors * \left(\frac{Cost}{Sensor} + Installation\ Time * Labor\ Rate\right)$$

Where,

- Number of sensors is the total number of sensors being installed throughout the plant
- Cost per sensor is $125/sensor
- Installation time is 1 hour/sensor
- Labor rate is $32.81/hour

Total Capital Cost:

$$Capital\ Cost = 16\ sensors * \left(\frac{\$125}{sensor} + \frac{1\ hour}{sensor} * \frac{\$32.81}{hour}\right)$$

$$Capital\ Cost = \$2{,}525$$

The simple payback period can be calculated by combining all the previously acquired information. The following sample calculation shows how the total simple payback period is calculated. These calculations can be applied to any individual room:

$$Payback\ Period = \frac{Capital\ Cost}{Energy\ Savings + Labor\ Savings + Bulb\ Savings}$$

$$Payback\ Period = \frac{\$2{,}525}{\frac{\$2{,}958}{year} + \frac{\$374}{year} + \frac{\$356}{year}}$$

$$Payback\ Period = 0.7\ years$$