Elliott Bay Design Group
Architectural & Engineering Services for the Marine Industry
5305 Shilshole Avenue NW, Suite 100 · Seattle, WA 98107 · t 206.782.3082 · f 206.782.3449
www.ebdg.com

Energy Audits for Fishing Vessels*

Acronyms & Definitions

BHP	=	Brake Horse Power
Btu	=	British thermal unit (↑ temp. 1 lb. water, 1°F)
Btuh	=	British thermal unit per hour
ECO	=	Energy Conservation Opportunities
FO	=	Fuel Oil (Used interchangeably as #2 Diesel Fuel)
hph	=	Horse Power per hour
kW	=	kilo Watt (1000 watts)
kWh	=	kilo Watts per hour
ULSDO	=	Ultra Low Sulfur Diesel Oil
NEMA	=	National Electrical Manufacturers Association
ROI	=	Return on Investment
SMCR	=	Specified (Specific) Maximum Continuous Rating (80%-85%, typ.)
~	=	Approximately
≡	=	Equivalent to

Conversions - (Typical values, and general rules of thumb…..)

- 1 gallon #2 MDO = 137k to 142k Btu
- 1 gallon #2 ULSDO = 1.2% less than #2 MDO
- 1kW = 1.341 hp
- 1kWh = 3,413 Btu
- 1 hph = 2,545 Btu
- 1 ton (refrigeration) = 12,000 Btuh
- 1 ton refrigeration requires ~ 1 kW (1.341 hp) in commercial AC systems.

Common Mechanical and Electrical Efficiencies

Electrical:

Generators / Large Alternators	-	95%
Small Engine Alternators	-	40% to 85% (Speed dependent)
Small Engine Alternators	-	55% to 85% (Full speed output)
Lead Acid Batteries	-	85% to 95% (Discharge rate dependent)
Rectifiers & Inverters	-	85% to 90%
Standard Electric Motors	-	80% to 90% (1 hp to 50 hp)
Premium Efficiency Motors	-	82% to 95%

*All information contained herein is to be used at you own peril and risk. No warranties are expressed or implied w/regard to its use, applicability, or accuracy.

Common Mechanical and Electrical Efficiencies, cont.

Mechanical:

Drive Belts	-	(Discussed below)
Centrifugal Pumps	-	40% to 70% (<200 gpm)
Hydraulic Pumps/Motors	-	85%
Diesel Engines	-	40%

Note: Electrical power derived through an engine driven alternator is not free. It comes as a direct result of consuming fuel within the engine to drive the alternator. With a typical engine efficiency of 40%, a belt efficiency of 98% and an alternator efficiency of 55%, this leads to an overall energy conversion efficiency of only 21%. Assuming a fuel cost of $4.00/gal, this leads to an on-board electrical power cost of $0.51/kWh, or roughly 6 times a typical household utility rate in Seattle WA, in 2011.

General Energy Equations

- Energy Cost per Year (calculated) = Energy Price ($/kWh) x Weighted average power consumed (kWh) x Average Operating Hours per year
- Input Power Measurements: (3-phase, AC Power)

$$Pi = \left(V\ x\ I\ x\ PF\ x\ \sqrt{3}\ \right) / 1000$$

Where:

Pi	=	Three Phase power in kW
V	=	RMS voltage, mean line to line of 3-phases
I	=	RMS current, mean of 3-phases
PF	=	Power factor as a decimal

- For DC:
    - Power (watts) = Amps x Voltage (x efficiency as applicable)

A motor's Power Factor is a function of both motor size and most importantly, a function of percentage of full load amperage. PF's are maximum at and above 75% full load amperage. At 75% full load amperage, the following are good estimates for motor PF's:

Motor Size(hp)	PF
5-10	70
15-30	75
40-75	80
100-125	84

Hydraulic System Rules of Thumb

- Hydraulic (fluid power) hp = (psi x gpm)/1714
- 1 hp of drive (for a hydraulic pump)produces ~ 1 gpm at 1500 psi

- Heat generated by flowing oil across a valve:
    - 1 hp = 2,545 btu / hr
    - 1 btuh = 1.5 x psi x gpm

General Lighting System Equations and Rules of Thumb

- Lighting Efficacy: Light Energy Intensity (Lumens) / Power In (Watts)
- Lighting Costs = (Total watts x # of hours x energy cost)
    - Total watts = (bulb wattage x # of bulbs)
    - # of hours = # of hours each bulb is on
    - Energy Cost =
        - Rate per kWh local utility charges (~ $0.083 kWh - Seattle; ~ $0.094 - Sitka)
        - Rate determined using is either determined fixtures x $ per /kW #of bulbs x bulb wattage(s) x total wattage
- Incandescent vs. Florescent vs. Compact Florescent (CFL) vs. Light Emitting Diode (LED)
- 60 w IC bulb ≡ 900 lumens ; 75 w IC bulb ≡ 1200 lumens ; 100 w IC bulb ≡ 1750 lumens
- 20 w CFL bulb ≡ 1200 lumens
- IC bulbs require 3-4 times the amount of watts, to produce the same amount of lumens as a CFL bulb.
- LED's are more efficient than CFL and extremely long lived; technology is coming along rapidly.
- Relative bulb energy costs and (commercially rated) lives: (Standard Florescent bulbs = a score of 100, and is the benchmark against which others are compared; i.e. a smaller number is better…..)
    - IC bulbs = 412
    - SFL = 100 (10 x life of IC)
    - CFL = 102 (10 x life of IC)
    - T8 FL = 74 (10 x life of IC)
    - Mercury Vapor = 149 (24k hours)
    - Metal Halide = 90 (10k to 20k hours)
    - High Pressure Sodium = 65 (24k hours)
    - Low Pressure Sodium = 44 (18k hours)

Electrical Costs to Generate Power w/onboard Generators

- Establish the price of fuel ($/gallon) delivered to the vessel.
- Establish Generator Load Profile and FO Costs/kW generated. (Example below is for a 10 kW Generator, $4/gal FO, and $.)

Cost of Energy Aboard					
Price of fuel ($/gallon)		$ 4.00			
Rated size of generator (kW)		10			
Hour load profile		24	kW	gal/hr	$/kW-hr
Time generator is off (hrs)		6	0	0.00	$ -
Time at 0% of rated load (hrs)		0.25	0	0.18	$ -
Time at 25% of rated load (hrs)		1	2.5	0.45	$ 0.72
Time at 50% of rated load (hrs)		10	5	0.63	$ 0.50
Time at 75% of rated load (hrs)		1	7.5	0.80	$ 0.43
Time at 100% of rated load (hrs)		5.75	10	1.00	$ 0.40

- Note that gal/hr in the Load Profile chart above is based on the values provided in the next chart (FO consumed vs. load percentage, based on generator size).
- $/kW-hr values above are determined with the following equation:

$$\frac{FO\ Cost\left(\frac{\$}{gal}\right)\ x\ \frac{gal}{hr}\ x\ time\ at\ rated\ load\ (hrs)}{kW\ (at\ each\ load\ level)\ x\ \ time\ at\ rated\ load\ (hrs)}$$

- Chart below provides estimates for FO consumption of various generator sizes, at partial loads. When possible, actual measurements (fuel consumed vs. power produced) should be used for these values. Alternatively, use manufacturers' curves.

Generator Size (kW)	1/4 Load (gal/hr)	1/2 Load (gal/hr)	3/4 Load (gal/hr)	Full Load (gal/hr)
10	**0.45**	**0.63**	**0.8**	**1**
20	**0.6**	**0.9**	**1.3**	**1.6**
30	**1.3**	**1.8**	**2.4**	**2.9**
40	**1.6**	**2.3**	**3.2**	**4**
60	**1.8**	**2.9**	**3.8**	**4.8**
75	**2.4**	**3.4**	**4.6**	**6.1**
100	**2.6**	**4.1**	**5.8**	**7.4**
125	**3.1**	**5**	**7.1**	**9.1**
135	**3.3**	**5.4**	**7.6**	**9.8**
150	**3.6**	**5.9**	**8.4**	**10.9**

- Estimate or otherwise establish a generator maintenance cost per kWh produced. EBDG uses between $0.01 and $0.035 per kWh produced. This example uses **$0.02 / kWh.**
- The next chart provides tabulated calculated values based on the information contained above.

Average load		5	kW
Fuel consumed per 24 hours (gallons)		13.345	gallons
Cost of fuel per 24 hours		$ 58.72	
kW-hr in 24 hours		118	
Cost of maintenance per 24 hours		$ 2.35	
Cost to operate per day		$ 61.07	
Cost per kW-hr		$ 0.52	

- Average Load is determined by multiplying each of the six load point times by its respective kW produced (for example 11.66 hrs. x 0 kW produced), summing all six of those values, and then dividing that total the total number of hours (24 in this example).
- FO consumed in 24 hours is determined similarly by multiplying each of the six load point times by its respective gal/hour value, and adding up those six numbers.
- Cost of fuel consumed in 24 hours = Cost of FO ($/gal) x FO consumed in 24 hrs (determined above) x an added "fudge factor" to account for FO leaks, evaporation, fuel degradation through various means, filters, hoses, and other materials and handling costs, etc. This example uses a 10% "fudge factor."
- kW-hr in 24 hours is the numerator of the Average Load calculation. It represents the sum total of the kWh produced by the gen set in 24 hours.
- Cost of Maintenance per 24 hours is the total kWh produced in 24 hours (determined immediately above) x the measured or assumed hourly cost to maintain the gen set.
- Cost to operate per day (24 hrs) is the cost of FO + the cost of maintenance.
- Cost per kWh (or kW-hr) is the cost to operate per day divided by the total kWh generated in 24 hours.

Determine FO costs per kW generated, based off actual measurements (fuel consumed vs. power produced) or Mfgrs. Curves.

Electric Motors

- Maximum efficiency for electric motors is ~ 75% of rated load. Operating motors above or below this maximum efficiency point wastes energy.
- Operating motors below 50% rated load dramatically decreases motor efficiency.
- NEMA premium efficiency motors use 1.5% to 4.5% less electricity for the same output, compared to "old style" standard efficiency motors.

General Ventilation Equations and Rules of Thumb

- Minimum engine room air supply should be at least 1.5 x total air consumption of main engines, auxiliary engines, boiler, etc. at all maximum SMCRs.
- Minimum engine room ventilation air should be 1.75 x SMCR; 2.0 x SMCR is preferred.
- Roughly 50% of required engine room ventilation air should be directed at the engine intakes.
- For every 10° increase / decrease in engine room temperature, fuel consumption will increase / decrease by ~ 0.7%. (Note: Operating in Arctic conditions typically requires pre-heating combustion air to avoid excessive firing pressures and potentially damaging the engine.)

Financial Analysis of Energy Conservation Opportunities

- Basic /Fundamental approach is identical to how a businessperson's banker looks at the "numbers" when asked for a capital loan. It boils down to analysis of a discounted series cash flows.

    - What is the ECO going to cost you initially to implement?
    - What are your anticipated annual "net returns" from that investment?
    - What is your "cost of money"?
        - Include FO cost escalation factor
        - General inflation factor
        - Risk
        - History
    - What is the time frame over which we are evaluating this?
- From this analysis, ROI, Pay Back Period – and if deciding between two different ECOs – possibly the NPV of the investment is determined.
- These three (3) financial metrics are weighed and compared against the alternative costs of making no changes (leaving the status quo), and other operational and business considerations, to arrive at an action decision.

General ECO Equations and Rules of Thumb

Drive Belts:

- Typical Efficiencies:
    - V-Belt Drives - 95%
    - PolyV or Cogged Belt Drives - 97%
    - Timing Belt Drives - 98%
    - Flat Belt Drives - 98% - 99%
- Losses are affected by entering and leaving losses of the belt with the pulley, hysteresis energy dissipation from straight to curved spans in the belt path, slippage, and heat generation.
- Cog belts can improve transmission efficiency by as much as 2.5% over a v-belt or joined v-belt and are comparably priced with high quality v-belts.
- Synchronous belt drives require special sheaves, which increase the cost of the belt drive; however, efficiency is improved by as much as 6% as the result of less slippage and cooler operating temperature.