Economic Dispatch and SCADA for Diesel Efficiency Improvements*

2009 International Wind-Diesel Workshop
Ottawa, Ontario, Canada
June 2, 2009

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A project funded by the US DOE National Energy Technology Lab (NETL) through the Arctic Energy Technology & Development Laboratory (AETDL)

* The economic dispatch analysis presented here for Kongiganak, Alaska was for data collected between Jan 2003 and Dec 2003. An economic dispatch system has been implemented at Kongiganak since 2005.

Economic Dispatch for Diesel Efficiency Improvements

- Introduction
- Objective
- DEG Model
- System Description
- Economic Dispatch
- Payback Analysis
- Conclusions

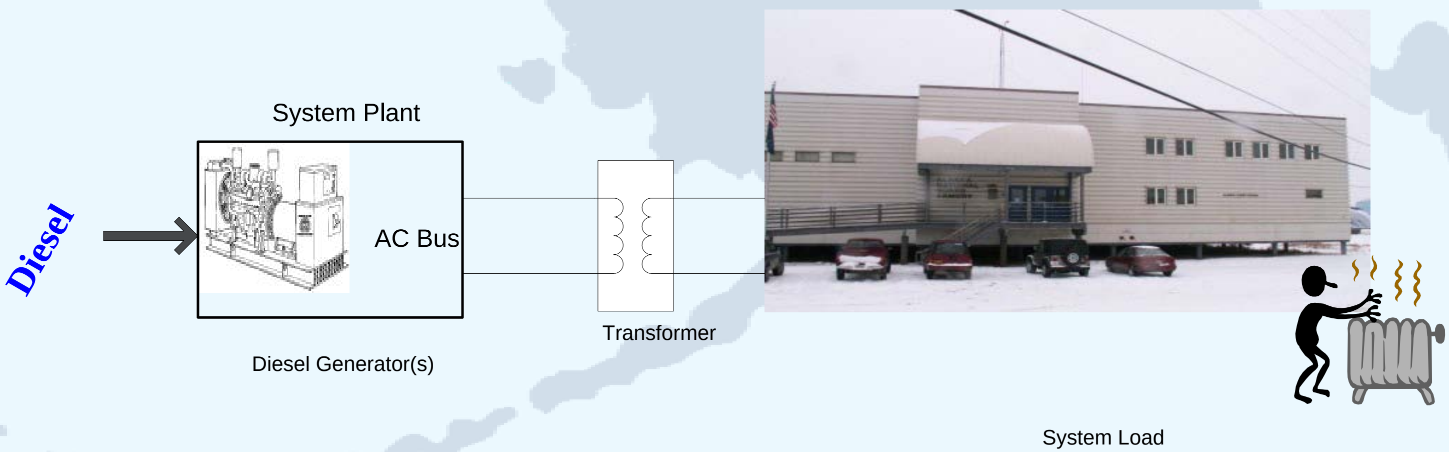
http://www.akenergyauthority.org/aearemotemon.html

University of Alaska Fairbanks Diesel Electric Generator

UAF UNIVERSITY OF ALASKA FAIRBANKS

Introduction: *DEG Efficiency*

- A DEG’s engine efficiency is directly proportional to the electric load.
- An increase in electrical loads causes an increase in operating efficiency due to the engine operating closer to its rated output.
- Lower ambient air temperature can increase engine efficiency due to rejecting heat to a lower temperature.
- However, lower ambient air temperature can also reduce engine efficiency due to a number of cold climate considerations such as lower fuel, engine oil, and coolant operating temperatures.



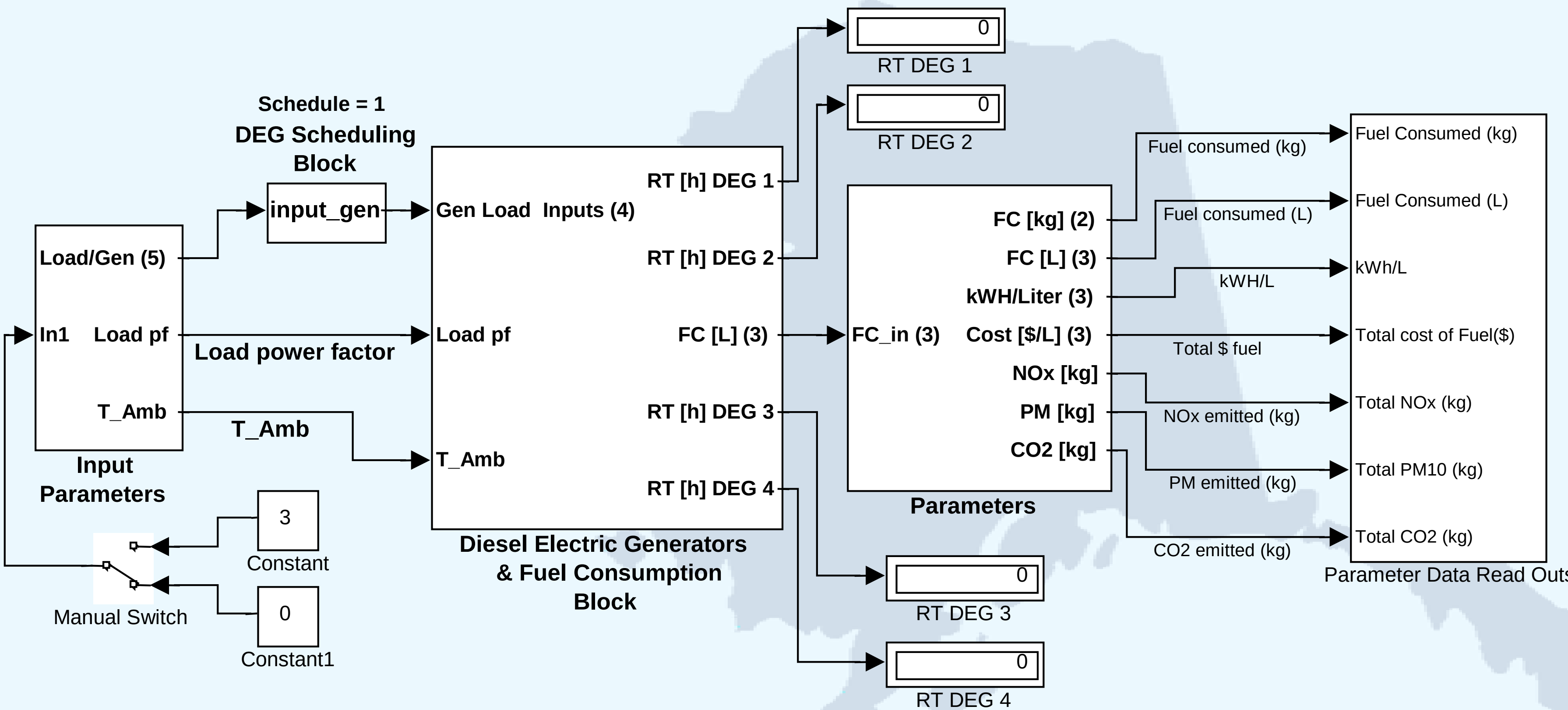
Objective/Goal: *Project*

- Investigate the relationship between village electrical loads, ambient air temperatures, efficiency, and operational lifetime of DEGs.

- Methods of improving the efficiency and operational lifetime of these power systems are:
    - Load the DEGs closer to their rated capacity (Generator Scheduling)
    - Employ heat recovery (Thermal Loads)
    - Utilize turbochargers. (Improving Combustion Process)
    - Engine Controllers (Electronic Load-based Fuel Injection)

- **Demonstrate how economic dispatch could be used in conjunction with other methods to improve the efficiency and operational lifetime of DEGs in Alaska rural villages.**

DEG Model: *Overall Model*



DEG Model: *DEG Block Detail*

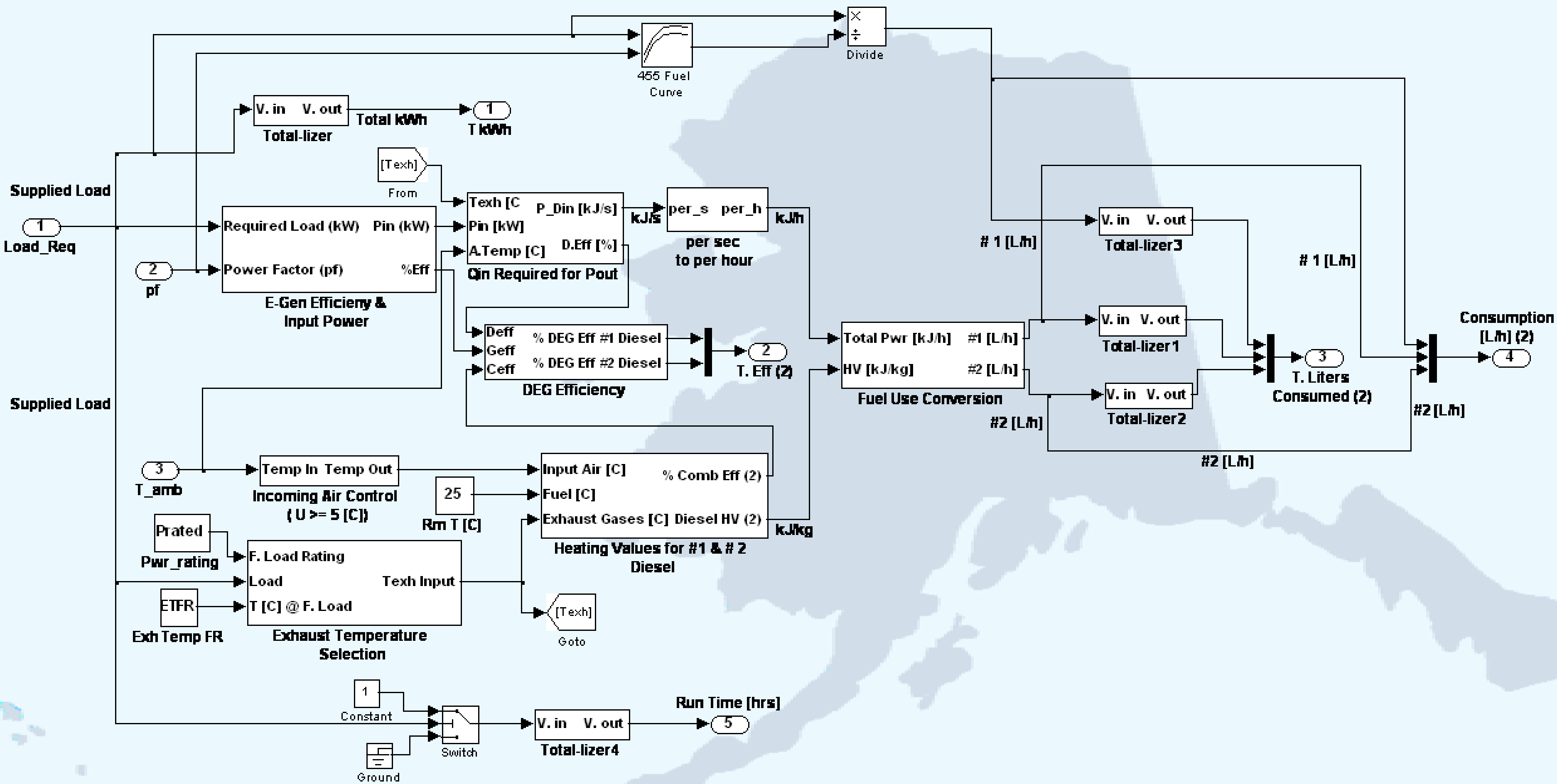
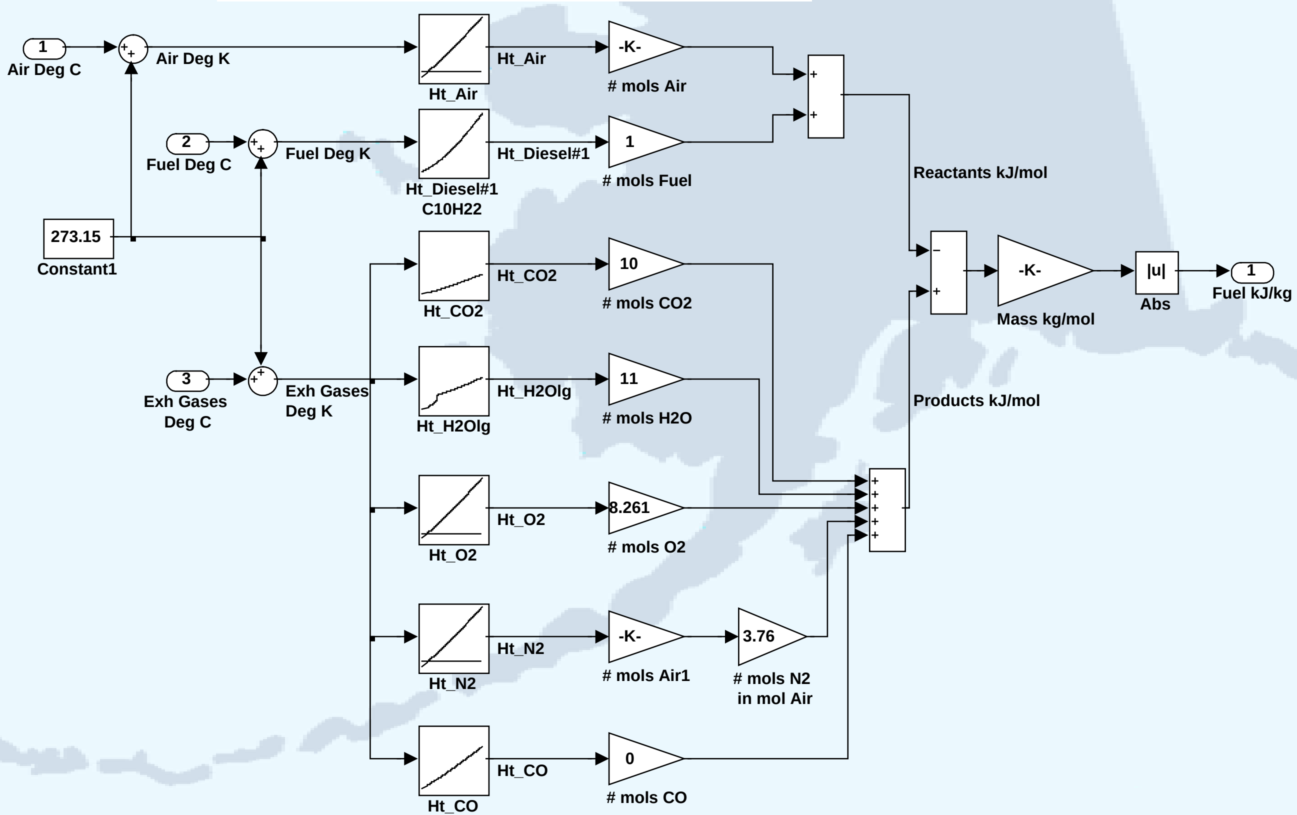


Table 4.1: Comparison table of simulation heating values to referenced values.

DEG Model: *Fuel Heating Value*

Parameter	Reference Heating Value kJ/kg (Btu/lbm) [13] Higher	Lower	Simulated Heating Value (@ STP) kJ/kg (Btu/lbm)
# 1 Diesel $C_{10}H_{22}$	47640 (20490)	44240 (19020)	44580 (19166.2)
#2 Diesel $C_{12}H_{26}$	45500 (19600)	42800 (18400)	44450 (19109.3)

Combustion Equation for Decane (C10H22): @ AF=20
C10H22 + 15.5*(O2 +3.76*N2) --> 10*CO2+11*H2O+0*CO+0*O2+15.5*3.76*N2



System Description: *Kongiganak*

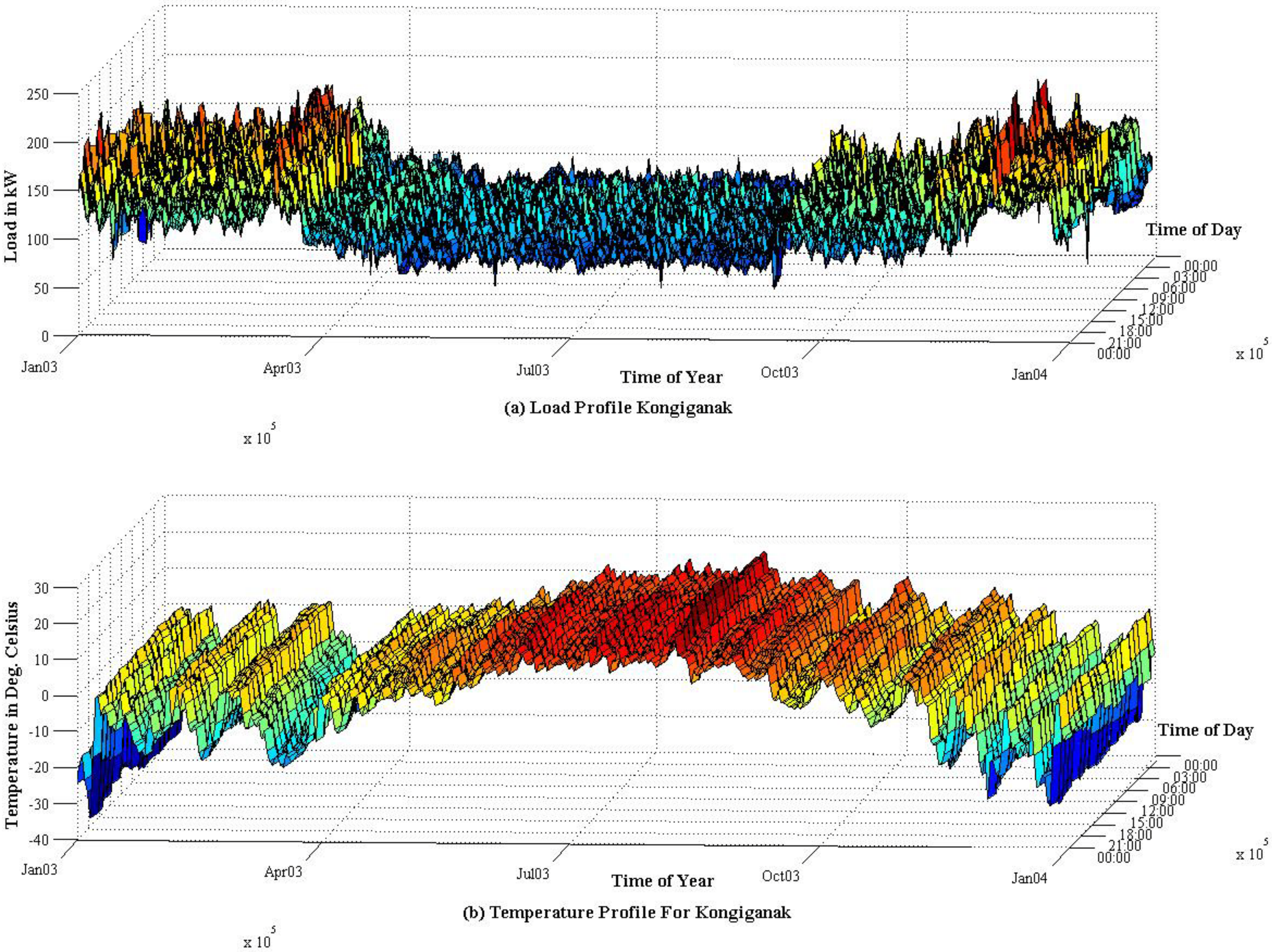
- **Kongiganak's location**
  - 59.880000° (North) Latitude
    -163.054000° (West) Longitude
  - marine climate zone
  - Precipitation averages 22 inches, with 43 inches of snowfall annually
  - Temperatures range from:

    -14.4 °C to 13.9 °C (6 °F to 57 °F)

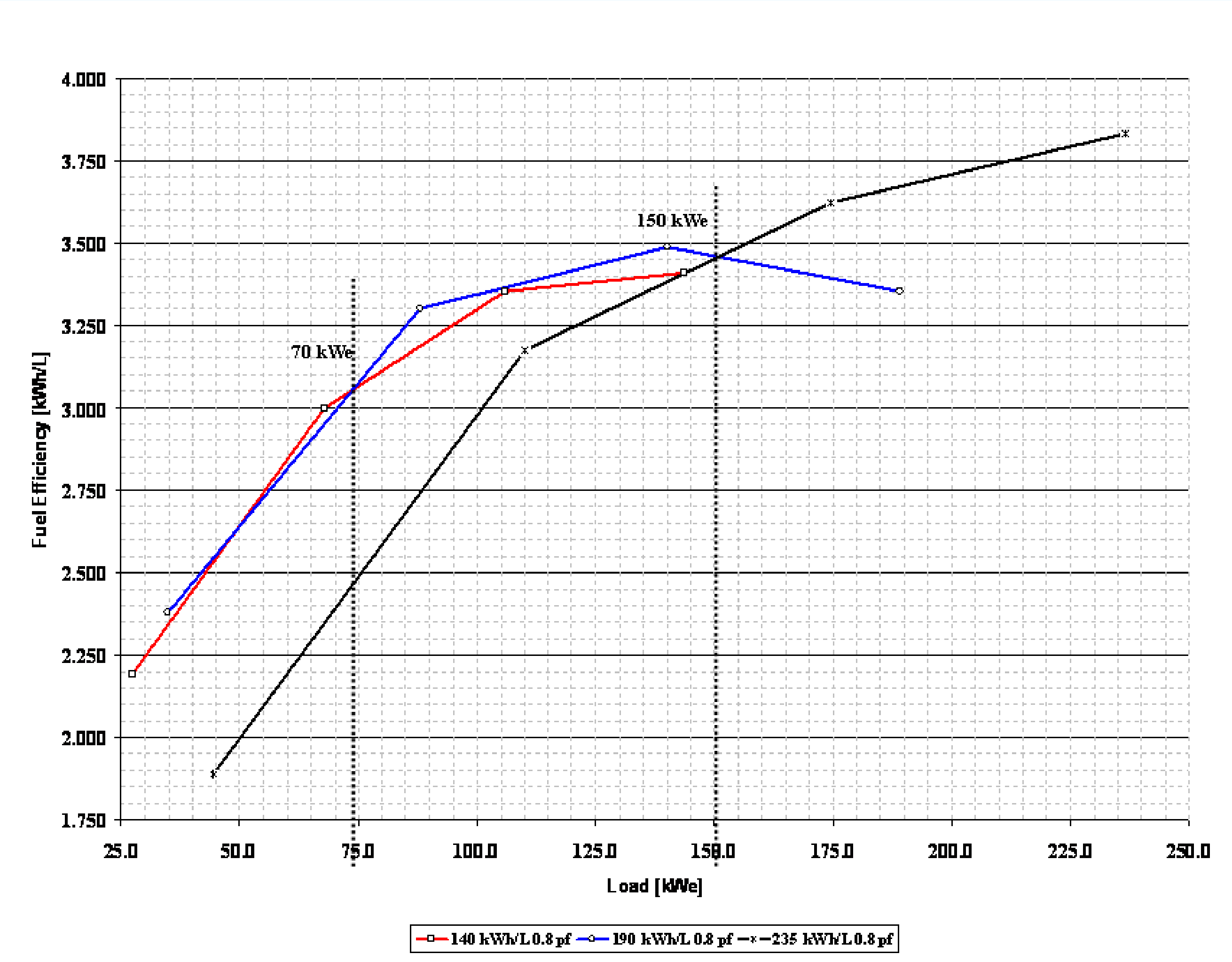
http://www.commerce.state.ak/dca/commdb/CF_CIS.html

- **Power demand is supplied by:**
  - one 235 kWe John Deere® 6125AF
  - one 140 kWe John Deere® 6081TF
  - two 190 kWe John Deere® 6081AF

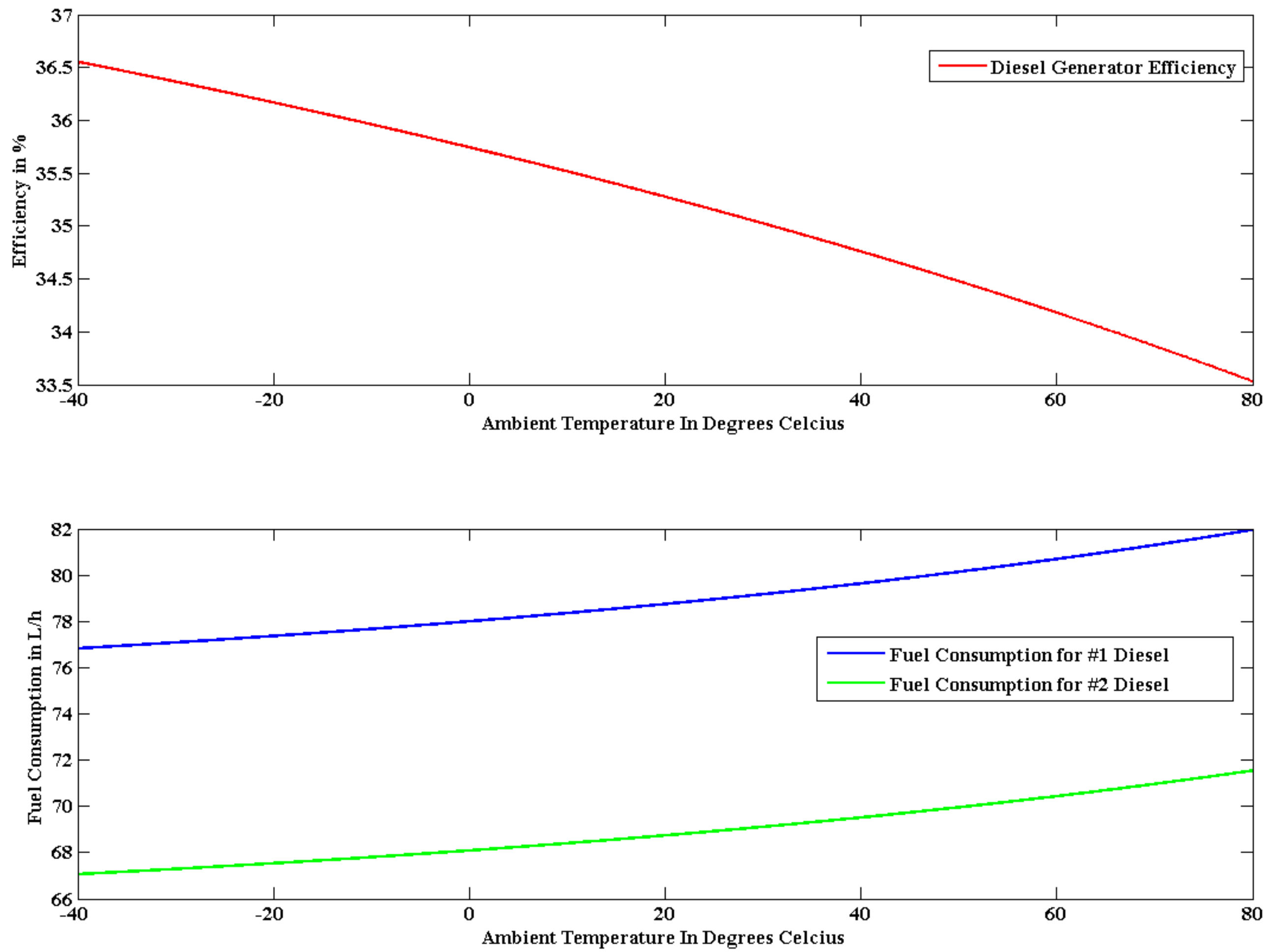
Annual Village Load (top) and Temperature (bottom) Profiles: *Kongiganak, AK (Jan 03-Dec 03)*



John Deere DEG Fuel Efficiency: *Load vs. kWh/L (0.8 pf)*



Ambient Air Temp vs. Efficiency:
190 kWe DEG (80% rated output)



(b) 190 ekW Diesel Generator Fuel Consumption vs Ambient Inlet Air Temperature Curves at 80% Rated Output

Economic Dispatch Analysis for DEG Load/Temp Profile: ***Kongiganak System****

- **Pre-Configured Control (PCC)**:
  - switching on DEGs in an increasing generation sequence to meet the increased demand
  - results in overall efficiency higher than operating all DEGs with even load distribution, but not optimal
- **Economic Dispatch (ED)**:
  - use any combination of generators to match the load based on determining the highest efficiency operating point
  - higher efficiencies expected to reduce:
    - **fuel consumption**
    - **operating time**
    - **costs**
    - **emissions**
    - **maintenance**

* The economic dispatch analysis presented here for Kongiganak, Alaska was for data collected between Jan 2003 and Dec 2003. An economic dispatch system has been implemented at Kongiganak since 2005.

Economic Dispatch Analysis for DEG Load and Temperature Profile: ***Kongiganak System***

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- Each scenario run for both #1 and #2 Diesel with two temperature cases:
  - Case 1: no change in average ambient air temperature
  - Case 2: 3 °C (5.4 °F) change in average ambient air
- Efficiency and fuel consumption values at load and ambient temperature points were interpolated from the efficiency curves.

Economic Dispatch Analysis for DEG Load and Temperature Profile: ***Kongiganak System***

- PCC vs. ED: #1 Diesel

Parameter (for #1 Diesel)	Simulation / Scenario Data							
	PCC Control		Temperature Change Comparison	ED Control		Temperature Change Comparison	Control Scheme Comparison	
Ambient Temp Change in [°C]	0	3	-	0	3	-	0	3
Load energy- kWh	919433.5378	919433.5378	-	919433.5378	919433.5378	-	-	-
Fuel consumed- L (gal)	489808.0 (129,393.6)	490559.0 (129,591.9)	**751.0** (198.4)	442987.0 (117,024.8)	443891.6 (117,263.7)	**904.6** (239.0)	-46821.0 (-12,368.8)	**-46667.3** (-12,328.2)
Efficiency of engine- kWh/L (kWh/gal)	1.8771 (7.0956)	1.8743 (7.0847)	-0.0029 (-0.0109)	2.0755 (7.8455)	2.0713 (7.8295)	-0.0042 (-0.0160)	0.198 (0.750)	0.197 (0.745)
Total annual cost of fuel	0	0						
at $1.082/L ($3.50/gal)	$529,972.2	$530,784.8	$812.6	$479,311.9	$480,290.7	$978.8	-$50,660.3	-$50,494.1
at $1.3209/L ($5.00/gal)	$646,987.4	$647,979.3	$992.0	$585,141.5	$586,336.4	$1,194.9	**-$61,845.9**	**-$61,642.9**
NO_X emitted- ton_m (lbs)	12260.7 (27,030.2)	12279.5 (27,071.7)	18.80 (41.44)	11088.7 (24,446.4)	11111.4 (24,496.3)	22.64 (49.92)	-1172.01 (-2,583.8)	-1168.16 (-2,575.4)
PM_{10} emitted- kg (lbs)	92.2 (203.3)	92.4 (203.6)	0.14 (0.31)	83.4 (183.9)	83.6 (184.2)	0.17 (0.37)	-8.82 (-19.4)	-8.79 (-19.4)
CO_2 emitted- kg (lbs)	1105963.9 (2,438,230.2)	1107659.6 (2,441,968.6)	1695.69 (3,738.34)	1000244.2 (2,205,158.5)	1002286.9 (2,209,661.7)	2042.65 (4,503.27)	-105719.70 (-233,071.8)	-105372.74 (-232,306.9)
Annual fuel savings			**-0.153%**			**-0.204%**	**9.559%**	**9.513%**

Economic Dispatch Analysis for DEG Load and Temperature Profile: ***Kongiganak System***

- <u>PCC vs. ED</u>: #2 Diesel

Parameter (for #2 Diesel)	Simulation / Scenario Data							
	PCC Control		Temperature Change Comparison	ED Control		Temperature Change Comparison	Control Scheme Comparison	
Ambient Temp Change in [°C]	0	3	-	0	3	-	0	3
Load energy- kWh	919433.5378	919433.5378	-	919433.5378	919433.5378	-	-	-
Fuel consumed- L (gal)	427570.7 (112,952.2)	428225.9 (113,125.3)	**655.2** (173.1)	386641.7 (102,139.9)	387431.1 (102,348.4)	**789.3** (208.5)	-40928.9 (-10,812.3)	**-40794.8** (-10,776.8)
Efficiency of engine- kWh/L (kWh/gal)	2.1504 (8.1284)	2.1471 (8.1159)	-0.0033 (-0.0124)	2.3780 (8.9888)	2.3732 (8.9705)	-0.0048 (-0.0183)	0.228 (0.860)	0.226 (0.855)
Total annual cost of fuel	0	0						
at $1.082/L ($3.50/gal)	$462,631.5	$463,340.4	$709.0	$418,346.4	$419,200.4	$854.0	-$44,285.1	-$44,140.0
at $1.3209/L ($5.00/gal)	$564,778.1	$565,643.6	$865.5	$510,715.1	$511,757.7	$1,042.6	**-$54,063.0**	**-$53,885.9**
NO_X emitted- ton_m (lbs)	10275.5 (22,653.7)	10291.3 (22,688.4)	15.75 (34.72)	9291.9 (20,485.2)	9310.9 (20,527.0)	18.96 (41.81)	-983.61 (-2,168.5)	-980.40 (-2,161.4)
PM_{10} emitted- kg (lbs)	77.3 (170.4)	77.4 (170.6)	0.12 (0.26)	69.9 (154.1)	70.0 (154.3)	0.11 (0.25)	-7.40 (-16.3)	-7.40 (-16.3)
CO_2 emitted- kg (lbs)	926894.0 (2,043,449.1)	928314.4 (2,046,580.5)	1420.41 (3,131.46)	838167.7 (1,847,841.3)	839878.8 (1,851,613.6)	1711.12 (3,772.37)	-88726.31 (-195,607.8)	-88435.60 (-194,966.9)
Annual fuel savings			**-0.153%**			**-0.204%**	**9.572%**	**9.526%**

Installation Costs for Two Economic Dispatch Control Schemes: ***Kongiganak System***

(a)Generator Control Automation Upgrade for a Three-Machine Plant (Buckland)

	Installed Cost ($)	
Item	**Option 1**	**Option 2**
PLC/ Communications Hardware	26,625	33,571
PLC/ Communications Software	16,206	23,153
Plant Wiring	4,630	9,261
Transducer Installation	3,473	5,788
Setup and Commissioning	6,946	9,261
Total without RTED Software	**$57,880**	**$81,034**
RTED Software	27,783	27,783
Total with RTED Software	**$85,663**	**$108,817**

(b)Generator Control Automation Upgrade for a Four-Machine Plant (Kong)

	Installed Cost ($)	
Item	**Option 1**	**Option 2**
PLC/ Communications Hardware	35,501	44,762
PLC/ Communications Software	21,609	30,870
Plant Wiring	6,174	12,348
Transducer Installation	4,630	7,718
Setup and Commissioning	9,261	12,348
Total without RTED Software	**$77,175**	**$108,046**
RTED Software	37,044	37,044
Total with RTED Software	**$114,219**	**$145,090**

Net Present Value Analysis for Economic Dispatch Control Scheme: ***Kongiganak System***

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$$NPV = \sum_{j=1}^{n} \frac{values_j}{(1+rate)^j} - \sum Cost_{initial}$$

Kongiganak NPV for the PCC and ED control schemes using #1 diesel.

Variable	Net Present Value at Different Average Fuel Costs Utilizing Control Schemes ($)			
	$1.082/L ($3.50/gal)		$1.3029/L ($5.00/gal)	
	PCC	ED	PCC	ED
Option 1				
Annual Fuel Savings (PV)	2,945,969	992,965	3,596,423	1,212,206
Installation Cost	77,175	114,219	77,175	114,219
Net Present Value	2,782,989	849,825	3,414,498	1,099,724
Option 2				
Annual Fuel Savings (PV)	2,945,969	992,965	3,596,423	1,212,206
Installation Cost	108,046	145,090	108,046	145,090
Net Present Value	2,752,118	818,954	3,383,627	1,031,809

Kongiganak NPV for the PCC and ED control schemes using #2 diesel.

Variable	Net Present Value at Different Average Fuel Costs Utilizing Control Schemes ($)			
	$1.082/L ($3.50/gal)		$1.3029/L ($5.00/gal)	
	PCC	ED	PCC	ED
Option 1				
Annual Fuel Savings (PV)	2,571,549	868,007	3,139,333	1,059,659
Installation Cost	77,175	114,219	77,175	114,219
Net Present Value	2,419,474	728,506	2,970,721	914,576
Option 2				
Annual Fuel Savings (PV)	2,571,549	868,007	3,139,333	1,059,659
Installation Cost	108,046	145,090	108,046	145,090
Net Present Value	2,388,603	697,635	2,939,850	883,705

Payback Analysis for Economic Dispatch Control Scheme: ***Kongiganak System***

$$Payback = \frac{\sum Cost_{initial}}{Savings}$$

Kongiganak payback period for the PCC and ED control schemes using #1 diesel.

Variable	Payback Period at Different Average Fuel Costs Utilizing Control Schemes (yrs)			
	$1.082/L ($3.50/gal)		$1.3029/L ($5.00/gal)	
	PCC	ED	PCC	ED
Option 1				
Annual Fuel Savings ($/yr)	150,301	50,660	183,487	61,846
Installation Cost ($)	77,175	37,044	77,175	37,044
Payback Period (yrs)	0.51	0.73	0.42	0.60
Option 2				
Annual Fuel Savings ($/yr)	150,301	50,660	183,487	61,846
Installation Cost ($)	108,046	37,044	108,046	37,044
Payback Period (yrs)	0.72	0.73	0.59	0.60

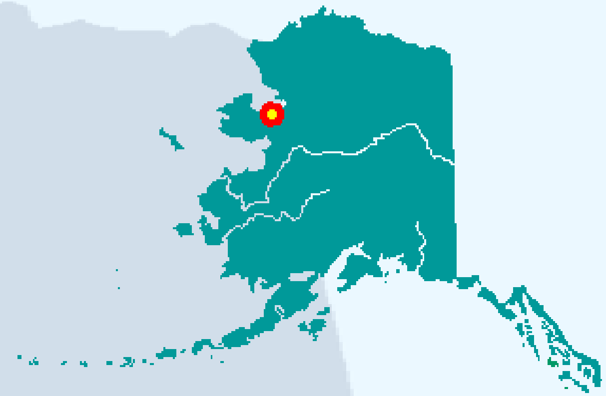
Kongiganak payback period for the PCC and ED control schemes using #2 diesel.

Variable	Payback Period at Different Average Fuel Costs Utilizing Control Schemes (yrs)			
	$1.082/L ($3.50/gal)		$1.3029/L ($5.00/gal)	
	PCC	ED	PCC	ED
Option 1				
Annual Fuel Savings ($/yr)	131,199	44,285	160,166	54,063
Installation Cost ($)	77,175	37,044	77,175	37,044
Payback Period (yrs)	0.59	0.84	0.48	0.69
Option 2				
Annual Fuel Savings ($/yr)	131,199	44,285	160,166	54,063
Installation Cost ($)	108,046	37,044	108,046	37,044
Payback Period (yrs)	0.82	0.84	0.67	0.69

System Description: ***Buckland***

- **Buckland’s location**
  - transitional climate zone
  - characterized by long, cold winters and cool summers
  - Temperatures range from -51°C to 29.5°C (-60°F to 85°F).

- **Power demand is supplied by:**
  - two 455 kWe CATERPILLAR® (CAT) 3456 DEGs
    - a primary
    - a backup
  - 175 kWe CAT DEG
    - used as a secondary for lower loads
    - for peak demands exceeding the primary DEG load capacity.

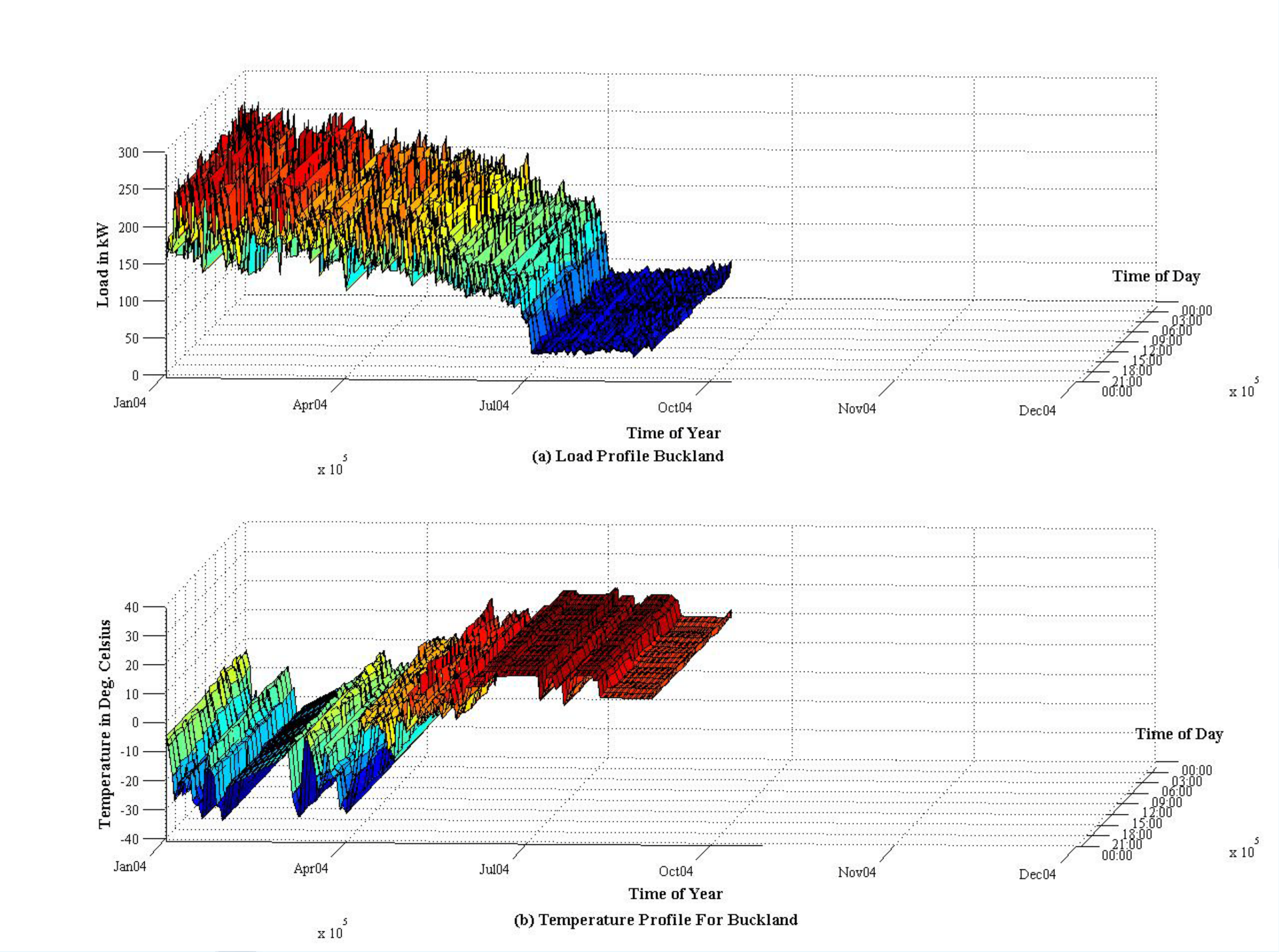


http://www.commerce.state.ak/dca/commdb/CF_CIS.html

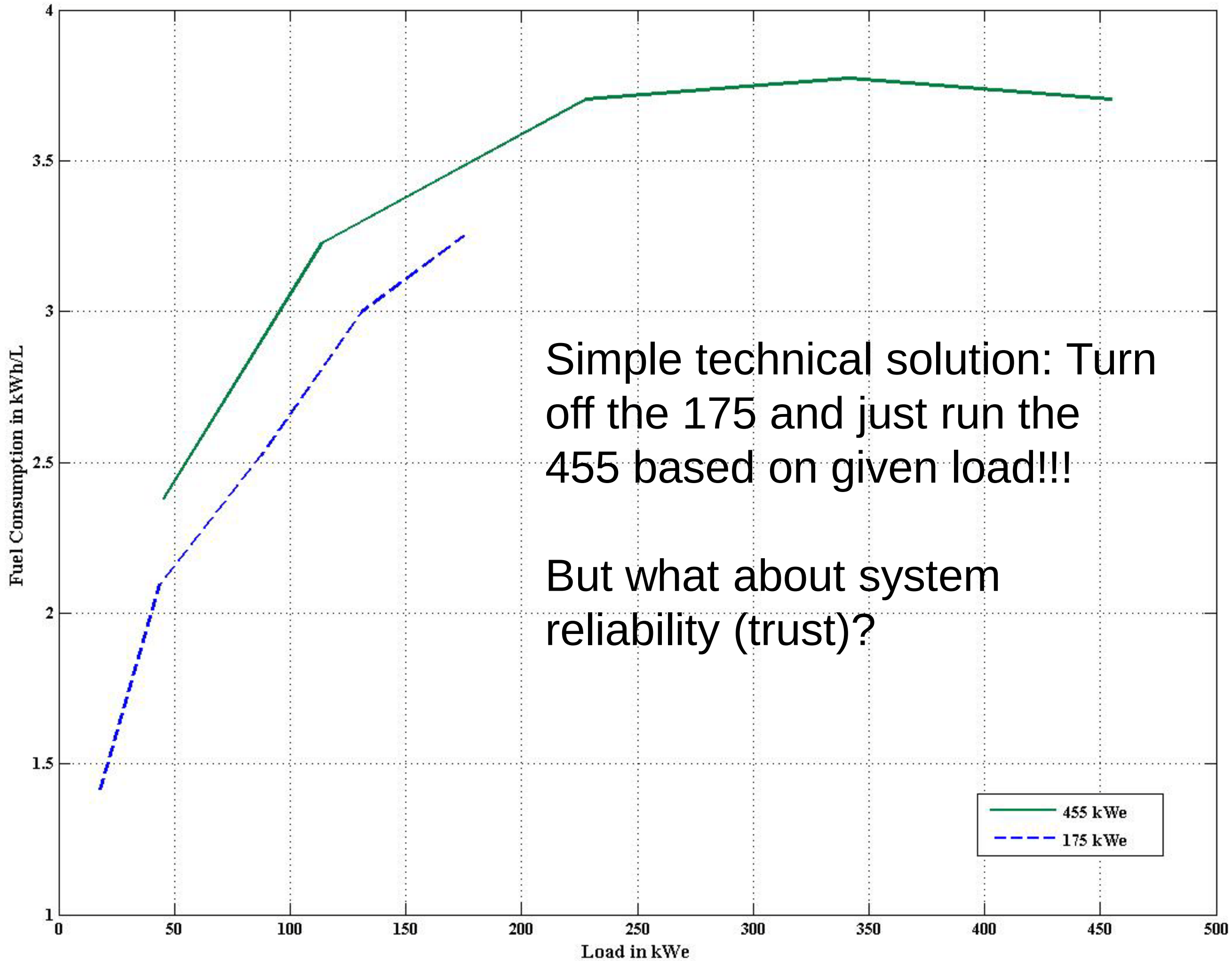
http://www.akenergyauthority.org/aearemotemon.html

*Annual Village Load (top) and Temperature (bottom) Profiles: **Buckland, AK***

- Buckland's load profile and temperature profile from Dec '03 to Sept '04 is illustrated below.



CAT DEG Fuel Efficiency: *Load vs. kWh/L (0.8 pf)*

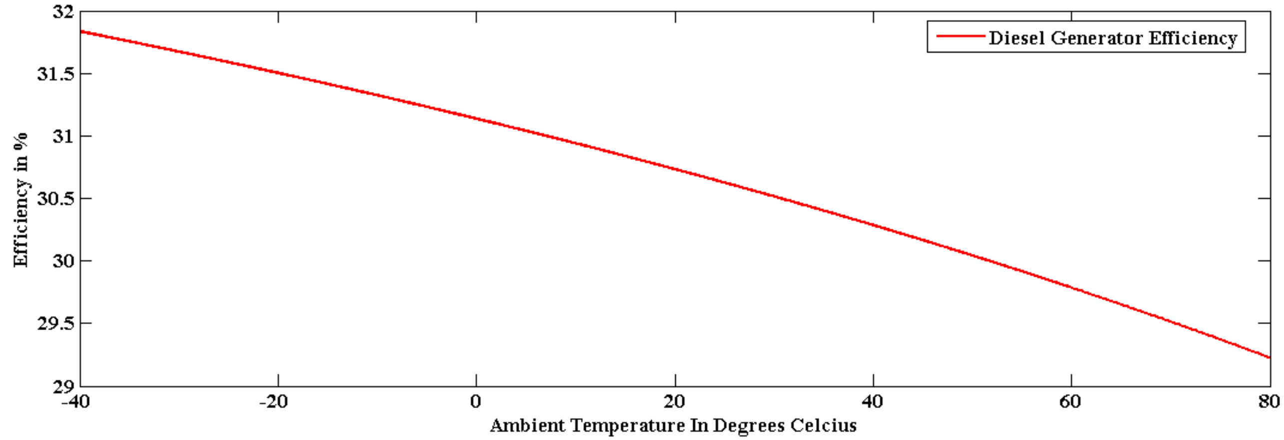


Diesel Generator Fuel Consumption vs Output (Manufacturer's Data) #2 Diesel

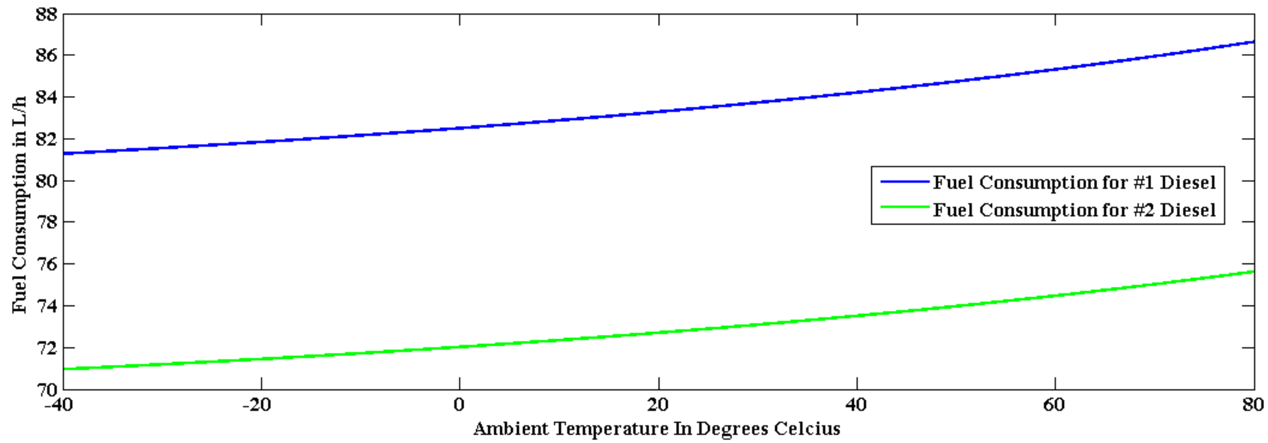
Simple technical solution: Turn off the 175 and just run the 455 based on given load!!!

But what about system reliability (trust)?

Ambient Air Temp vs. Efficiency:
175 kWe DEG (80% rated output)

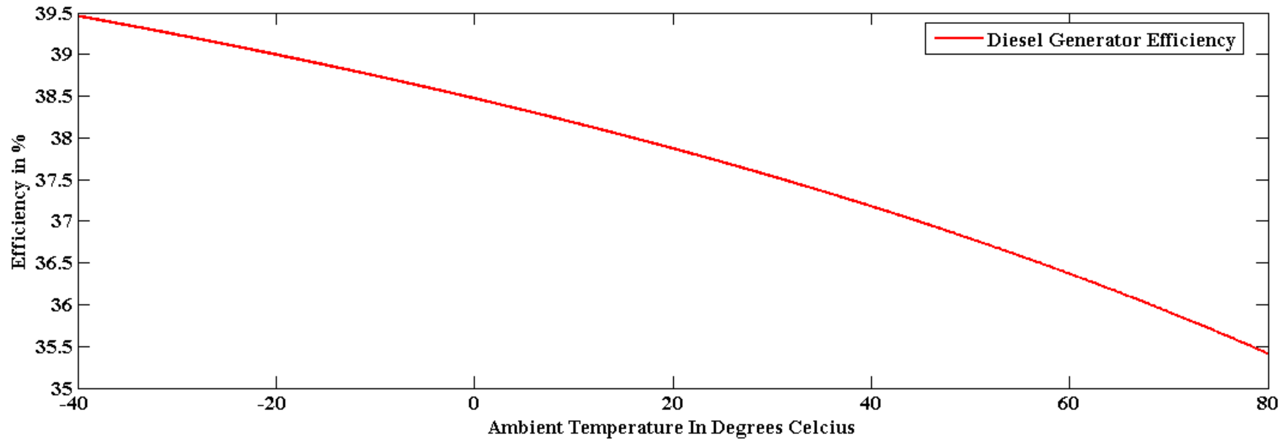


(a) 175 ekW Diesel Generator Efficiency vs Ambient Inlet Air Temperature Curves at 80% Rated Output

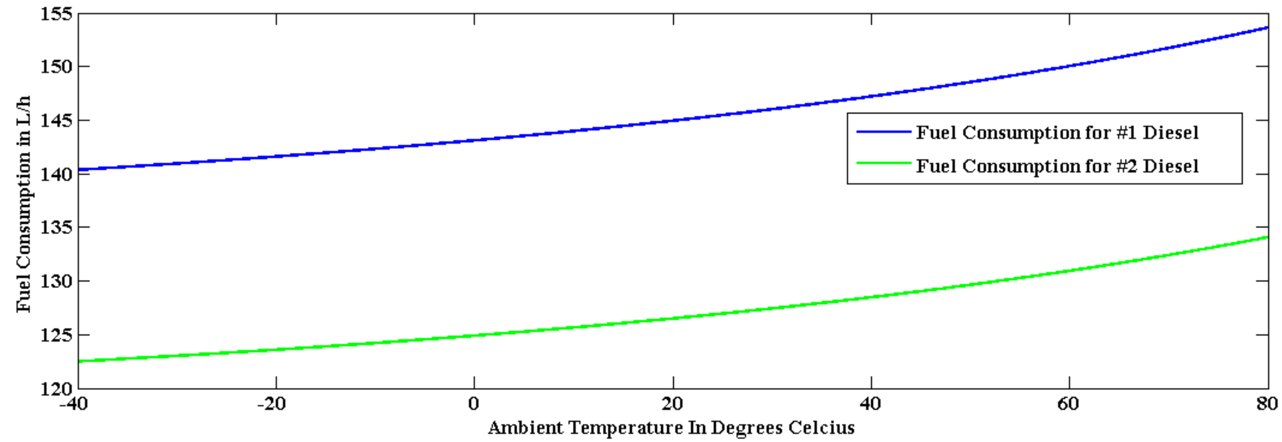


(b) 175 ekW Diesel Generator Fuel Consumption vs Ambient Inlet Air Temperature Curves at 80% Rated Output

Ambient Air Temp vs. Efficiency: *455 kWe DEG (80% rated output)*



(a) 455 ekW Diesel Generator Efficiency vs Ambient Inlet Air Temperature Curves at 80% Rated Output



(b) 455 ekW Diesel Generator Fuel Consumption vs Ambient Inlet Air Temperature Curves at 80% Rated Output

Economic Dispatch Analysis for DEG Load and Temperature Profile: *Buckland System*

- PCC vs. ED: #1 Diesel

Parameter (for #1 Diesel)	Simulation / Scenario Data							
	PCC Control		Temperature Change Comparison	ED Control		Temperature Change Comparison	Control Scheme Comparison	
Ambient Temp Change in [^oC]	0	3	-	0	3	-	0	3
Load energy- kWh	847624.2	847624.2	-	847624.2	847624.2	-	-	-
Fuel consumed- L (gal)	444286.2 (117,368.0)	444909.0 (117,532.5)	**622.8** (164.5)	352430.0 (93,102.1)	353093.7 (93,277.5)	**663.7** (175.3)	**-91856.2** (-24,265.8)	**-91815.3** (-24,255.0)
Efficiency of engine- kWh/L (kWh/gal)	1.9078 (7.2116)	1.9052 (7.2015)	-0.0027 (-0.0101)	2.4051 (9.0912)	2.4006 (9.0741)	-0.0045 (-0.0171)	0.497 (1.880)	0.495 (1.873)
Total annual cost of fuel								
at $1.082/L ($3.50/gal)	$480,717.6	$481,391.5	$673.9	$381,329.3	$382,047.4	$718.1	-$99,388.4	-$99,344.2
at $1.3209/L ($5.00/gal)	$586,857.6	$587,680.3	$822.7	$459,181.0	$460,045.8	$864.7	**-$127,676.5**	**-$127,634.5**
NO_X emitted- kg (lbs)	11121.2 (24,518.1)	11136.8 (24,552.5)	15.60 (34.39)	8821.9 (19,449.0)	8838.5 (19,485.5)	16.59 (36.57)	-2299.31 (-5,069.1)	-2298.32 (-5,066.9)
PM_{10} emitted- kg (lbs)	83.6 (184.4)	83.8 (184.7)	0.12 (0.26)	66.4 (146.3)	66.5 (146.6)	0.15 (0.33)	-17.29 (-38.1)	-17.26 (-38.1)
CO_2 emitted- kg (lbs)	1003177.8 (2,211,625.8)	1004584.1 (2,214,726.2)	1406.34 (3,100.44)	795770.0 (1,754,370.5)	797269.5 (1,757,676.3)	1499.50 (3,305.83)	-207407.76 (-457,255.3)	-207314.60 (-457,049.9)
Annual fuel savings			**-0.140%**			**-0.188%**	**20.675%**	**20.637%**

Economic Dispatch Analysis for DEG Load and Temperature Profile: ***Buckland System***

- <u>PCC vs. ED</u>: #2 Diesel

Parameter (for #2 Diesel)	Simulation / Scenario Data							
	PCC Control		Temperature Change Comparison	ED Control		Temperature Change Comparison	Control Scheme Comparison	
Ambient Temp Change in [°C]	0	3	-	0	3	-	0	3
Load energy- kWh	847624.2	847624.2	-	847624.2	847624.2	-	-	-
Fuel consumed- L (gal)	397645.1 (105,046.7)	398198.5 (105,192.9)	**553.4** (146.2)	307582.7 (81,254.7)	308161.9 (81,407.7)	**579.2** (153.0)	**-90062.4** (-23,792.0)	**-90036.6** (-23,785.2)
Efficiency of engine- kWh/L (kWh/gal)	2.1316 (8.0575)	2.1286 (8.0463)	-0.0030 (-0.0112)	2.7558 (10.4168)	2.7506 (10.3972)	-0.0052 (-0.0196)	0.624 (2.359)	0.622 (2.351)
Total annual cost of fuel								
at $1.082/L ($3.50/gal)	$430,252.0	$430,850.8	$598.7	$332,804.5	$333,431.2	$626.6	-$97,447.5	-$97,419.6
at $1.3209/L ($5.00/gal)	$525,249.5	$525,980.4	$730.9	$406,286.0	$407,051.0	$765.0	**-$118,963.4**	**-$118,929.4**
NO_X emitted- ton_m (lbs)	9556.4 (21,068.2)	9569.7 (21,097.5)	13.30 (29.31)	7391.9 (16,296.4)	7405.9 (16,327.1)	13.92 (30.69)	-2164.42 (-4,771.7)	-2163.79 (-4,770.3)
PM_{10} emitted- kg (lbs)	71.9 (158.5)	72.0 (158.7)	0.10 (0.22)	55.6 (122.6)	55.7 (122.8)	0.10 (0.23)	-16.28 (-35.9)	-16.28 (-35.9)
CO_2 emitted- kg (lbs)	862021.0 (1,900,428.8)	863220.6 (1,903,073.4)	1199.57 (2,644.61)	795770.8 (1,754,372.2)	668037.9 (1,472,769.7)	-127732.87 (-281,602.44)	-66250.28 (-146,056.7)	-195182.72 (-430,303.7)
Annual fuel savings			**-0.139%**			**-0.188%**	**22.649%**	**22.611%**

Conclusions

- The results indicate that loading has a significant impact on DEG efficiency.
- Simple economic dispatch for multiple DEG systems based on generator rated capacities and efficiency at given loads can increase system efficiency by better matching generator capacity to load.
- Results show a significant reduction in fuel consumption, operating time, and operating costs with short payback periods by implementing control with economic dispatch.

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