# **Data Validation**



# **Isentropic Efficiency**

703E Isentropic Efficiency vs. Flow (Manufacturer Provided)						
	Power Flow Rate (hp) (lbm/hr) Exhaust (Btu/lb) Entrance (Btu/lbm) Isentropic (Btu/lbm) Isentr					lsentropic Efficiency
Max	1187	50000	1140	1200	1079	0.499
Average	767	35000	1144	1200	1079	0.461
Min	322	20000	1159	1200	1079	0.338



# **Campus Heating Requirement**

 $CHR = \dot{m} \times (h_{boiler \ exit} - h_{condensate \ tank})$ 

CHR	7/
ṁ	=
h <sub>boiler exit</sub>	=
h <sub>condensate</sub>	=

Campus heating requirement (Btu/hr) mass flow rate of steam (lbs/hr) Enthalpy of steam exiting boiler (1,195 Btu/lbm) Enthalpy of condensate returning from campus(180.1 Btu/lbm)

Month	Campus Heating Requirement (Btu/hr)	
January	4.65E+07	
February	3.99E+07	
March	3.52E+07	
April	3.12E+07	
May	2.29E+07	
June	1.69E+07	
July	2.23E+07	
August	2.41E+07	
September	1.96E+07	
October	2.82E+07	
November	3.64E+07	
December	4.25E+07	

# Boiler Efficiency (Btu/BDT)

#### $BTU/BDT = (\dot{m} \times (h_{boiler \ exit} - h_{boiler \ entry}))/Fuel Input$

Month	Btus/BDT (by month)		
January	12700000.000		
February	12460000.000		
March	13090000.000		
April	12340000.000		
May	13970000.000		
June	9830000.000		
July	12570000.000		
August	13070000.000		
September	15840000.000		
October	13760000.000		
November	12110000.000		
December	13240000.000		

Campus I
(Btu/hr)
mass flov
produced
Enthalpy
(1,195 Bt
Enthalpy
boiler (19

Campus heating requirement
(Btu/hr)
mass flow rate of steam
produced by biomass (lbs/hr)
Enthalpy of steam exiting boiler
(1,195 Btu/lbm)
Enthalpy of condensate entering
boiler (199 Btu/lbm)

# Average Flow Rate Per Month

data         DELVERED         DELVERD         DELVERD         WOD         GAS         USAGE         STEAM           1/1/2013         4         50.16         1.234,000         0         0         1.234,000           1/2/2013         8         109.70         1.271,000         0         69         1.271,000           1/3/2013         11         135.47         1.170,000         90,000         1.226         1.260,000           1/4/2013         10         122.93         1.065,000         32,000         467         1.097,000           1/6/2013         0         0.00         1.075,000         0         0         1.075,000           1/6/2013         7         87.23         946,000         0         0         1.075,000           1/4/2013         7         87.23         946,000         0         0         967,000           1/4/9/2013         7         98.55         1.150,000         30,000         445         1.180,000           1/11/2013         5         63.20         1.244,000         0         1.233,000         1.249,000           1/14/2013         11         1.249,501         1.160,000         7.453         1.246,075           1/14							
DELIVERED         DELIVERED         WOOD         GAS         USAGE         STEAM           1/1/2013         4         50.16         1.234.000         0         0         1.234.000           1/2/2/2013         8         109.70         1.271.000         90.000         1.226         1.260.000           1/4/2/2013         10         129.30         1.065.000         32.000         467         1.097.000           1/6/2013         5         62.29         1.099.000         0         0         1.075.000           1/6/2013         0         0.00         1.075.000         0         0         1.075.000           1/6/2013         7         87.23         946.000         0         0         967.000           1/1/2/2013         7         87.23         946.000         0         0         967.000           1/1/2/2013         7         98.56         1.150.000         30.000         445         1.180.000           1/11/2/2013         5         63.20         1.244.000         0         1.330.000           1/11/2/2013         8         101.82         1.303.000         0         1.249.000           1/11/2/2013         12         163.74         1.10	date	LOADS	CEDAR	STEAM BY	STEAM BY	GAS	TOTAL
1/1/2013         4         50.16         1.234,000         0         0         1.234,000           1/2/2013         8         109.70         1.271,000         9         0         1.271,000           1/3/2013         11         135.47         1.170,000         90,000         1.226         1.260,000           1/4/2013         10         129.30         1.065,000         32,000         467         1.097,000           1/6/2013         0         0.00         1.075,000         0         0         1.075,000           1/4/2013         10         115.59         1.022,000         0         0         1.075,000           1/1/2013         7         87.23         946,000         0         0         946,000           1/1/2013         7         87.53         1.150,000         30,000         445         1.180,000           1/1/2013         5         63.20         1.244,000         0         103         1.244,000           1/11/2013         8         101.82         1.303,000         0         0         1.330,000           1/14/2013         11         124.85         1.176,000         90,000         1.249         1.246,000           1/14/2013 <th></th> <th>DELIVERED</th> <th>DELIVERED</th> <th>WOOD</th> <th>GAS</th> <th>USAGE</th> <th>STEAM</th>		DELIVERED	DELIVERED	WOOD	GAS	USAGE	STEAM
1/2/2013         8         109.70         1.271.000         0         69         1.271.000           1/3/2013         11         135.47         1.170.000         90.000         1.226         1.280.000           1/6/2013         10         129.30         1.065.000         32.000         467         1.097.000           1/6/2013         0         0.00         1.075.000         0         0         1.099.000           1/6/2013         10         115.59         1.022.000         0         0         1.075.000           1/7/2013         10         115.59         1.022.000         0         0         946.000           1/9/2013         7         87.23         946.000         0         0         967.000           1/10/2013         7         98.56         1.150.000         30.000         445         1.180.000           1/11/2013         5         63.20         1.244.000         0         1.33.000         1.244.000           1/14/2013         11         124.95         1.176.000         90.000         1.239         1.194.000           1/14/2013         12         163.74         1.104.000         90.000         1.239         1.194.000         1.414/2013 <th>1/1/2013</th> <th>4</th> <th>50.16</th> <th>1,234,000</th> <th>0</th> <th>0</th> <th>1,234,000</th>	1/1/2013	4	50.16	1,234,000	0	0	1,234,000
1/3/2013       11       135.47       1.170.000       90.000       1.226       1.280.000         1/4/2013       10       129.30       1.065.000       32.000       467       1.097.000         1/6/2013       5       6.2.29       1.099.000       0       0       1.075.000         1/6/2013       0       0.00       1.075.000       0       0       1.075.000         1/7/2013       10       115.59       1.022.000       0       0       1.022.000         1/8/2013       7       87.23       946.000       0       0       967.000         1/9/2013       7       100.69       967.000       0       0       967.000         1/10/2013       7       89.56       1.150.000       30.000       445       1.180.000         1/11/2013       5       63.20       1.244.000       0       103       1.244.000         1/11/2013       8       101.82       1.303.000       0       0       1.303.000         1/11/2013       12       163.74       1.104.000       90.000       1.239       1.134.000         1/11/2013       6       67.50       646.675       600.000       7.463       1.246.675      <	1/2/2013	8	109.70	1,271,000	0	69	1,271,000
1/4/2013         10         129.30         1.065,000         32,000         467         1.097,000           1/5/2013         5         62.29         1.099,000         0         0         1.099,000           1/6/2013         0         0.00         1.075,000         0         0         1.075,000           1/7/2013         10         115,59         1.022,000         0         0         1.022,000           1/9/2013         7         87.23         946,000         0         0         966,000           1/9/2013         7         100,69         967,000         0         0         967,000           1/10/2013         7         98,55         1.150,000         30,000         445         1.180,000           1/11/2013         5         63,20         1.244,000         0         57         1.268,000           1/11/2013         8         101,82         1.303,000         0         0         1.333,000           1/14/2013         11         124,95         1.176,000         90,000         1.249         1.266,000           1/14/2013         12         163,74         1.104,000         90,000         1.239         1.194,000           1/14/2013	1/3/2013	11	135.47	1,170,000	90,000	1,226	1,260,000
1/5/2013         5         62.29         1.099,000         0         0         1.095,000           1/6/2013         0         0.00         1.075,000         0         0         1.075,000           1/7/2013         10         115.59         1.022,000         0         0         1.022,000           1/8/2013         7         87.23         946,000         0         0         946,000           1/9/2013         7         100.69         967,000         0         0         946,000           1/11/2013         7         98.56         1.150,000         30,000         445         1.180,000           1/11/2013         3         31.64         1.229,000         0         57         1.268,000           1/11/2013         3         31.64         1.209,000         0         0         1.303,000           1/11/2013         11         124.95         1.176,000         90,000         1.239         1.194,000           1/11/2013         12         163.74         1.104,000         90,000         1.249         1.246,675           1/11/2013         12         23.38         1.029,000         1.281         1.299,429           1/18/2013         0	1/4/2013	10	129.30	1,065,000	32,000	467	1,097,000
1/6/2013         0         0.00         1.075,000         0         0         1.075,000           1/7/2013         10         115.59         1.022,000         0         0         1.022,000           1/8/2013         7         87.23         946,000         0         0         967,000           1/10/2013         7         98.56         1.150,000         30,000         445         1.180,000           1/11/2013         5         63.20         1.244,000         0         103         1.244,000           1/12/2013         3         31.64         1.269,000         0         57         1.269,000           1/14/2013         11         124.95         1.176,000         90,000         1.249         1.266,000           1/14/2013         12         163.74         1.004,000         90,000         1.239         1.194,000           1/14/2013         12         163.74         1.004,000         1.249         1.266,000           1/14/2013         12         163.74         1.004,000         1.239         1.194,000           1/16/2013         2         23.38         1.029,000         1.281         1.299,429           1/118/2013         2         23.38	1/5/2013	5	62.29	1,099,000	0	0	1,099,000
1/7/2013         10         115.59         1.022.000         0         0         1.022.000           1/8/2013         7         87.23         946,000         0         0         946,000           1/9/2013         7         100.69         967,000         0         0         967,000           1/10/2013         7         98.56         1.150,000         30,000         445         1.180,000           1/11/2013         5         63.20         1.244,000         0         103         1.246,000           1/11/2013         8         101.82         1,303,000         0         0         1,303,000           1/14/2013         11         124.95         1.176,000         90,000         1.249         1.266,000           1/14/2013         12         163.74         1.104,000         90,000         1.249         1.266,000           1/16/2013         6         67.50         646,675         600,000         7.463         1.246,675           1/11/2013         4         52.36         412,429         887,000         11.281         1.299,429           1/18/2013         7         91.73         1.079,000         0         0         1.079,000           1/	1/6/2013	0	0.00	1,075,000	0	0	1,075,000
1/8/2013         7         87.23         946,000         0         0         946,000           1/9/2013         7         100.69         967,000         0         0         967,000           1/10/2013         7         98,56         1.150,000         30,000         445         1.180,000           1/11/2013         5         63.20         1.244,000         0         103         1.244,000           1/13/2013         8         101.82         1.303,000         0         0         1.303,000           1/14/2013         11         124,955         1.176,000         90,000         1.249         1.266,000           1/15/2013         12         163,74         1.104,000         90,000         1.239         1.194,000           1/16/2013         6         67,50         646,675         600,000         7,463         1.246,675           1/17/2013         4         52,36         412,429         887,000         11.281         1.299,429           1/18/2013         2         23,38         1.029,000         33,000         441         1.184,000           1/20/2013         7         91,73         1.079,000         0         0         1.017,000	1/7/2013	10	115.59	1,022,000	0	0	1,022,000
1/9/2013         7         100.69         967,000         0         0         967,000           1/10/2013         7         98.56         1.150,000         30,000         445         1.180,000           1/11/2013         5         63.20         1.244,000         0         103         1.244,000           1/12/2013         3         31.64         1.269,000         0         57         1.269,000           1/14/2013         11         124.95         1.176,000         90,000         1.249         1.266,000           1/14/2013         12         163.74         1.104,000         90,000         1.249         1.246,675           1/16/2013         6         67.50         646,675         600,000         7.463         1.246,675           1/17/2013         4         52.36         412,429         887,000         11,281         1.299,429           1/18/2013         2         23.38         1.029,000         3.000         10         0.099,000           1/20/2013         7         91.73         1.079,000         0         0         1.079,000           1/21/2013         7         101.77         1.151.000         33,000         4411         1.184,000      <	1/8/2013	7	87.23	946,000	0	0	946,000
1/10/2013         7         98.56         1.150,000         30,000         445         1.180,000           1/11/2013         5         63.20         1.244,000         0         103         1.244,000           1/12/2013         3         31.64         1.269,000         0         57         1.269,000           1/13/2013         8         101.82         1.303,000         0         0         1.303,000           1/14/2013         11         124.95         1.176,000         90,000         1.249         1.266,000           1/15/2013         12         163.74         1.104,000         90,000         1.239         1.194,000           1/16/2013         6         67.50         646,675         600,000         7.463         1.246,675           1/18/2013         2         23.38         1.029,000         13.000         159         1.042,000           1/20/2013         7         91.73         1.079,000         0         0         1.099,000           1/21/2013         7         101.77         1.151,000         33,000         441         1.184,000           1/22/2013         7         96.98         1.123,000         0         0         1.049,000	1/9/2013	7	100.69	967,000	0	0	967,000
1/11/2013         5         63.20         1,244,000         0         103         1,244,000           1/12/2013         3         31.64         1,269,000         0         57         1,269,000           1/13/2013         8         101.82         1,303,000         0         0         1,303,000           1/14/2013         11         124.95         1,176,000         90,000         1,239         1,194,000           1/15/2013         12         163.74         1,104,000         90,000         1,239         1,194,000           1/16/2013         6         67.50         646,675         600,000         7,463         1,246,675           1/17/2013         4         52.36         412,429         887,000         11,281         1,299,429           1/18/2013         2         23.38         1,029,000         3,000         159         1,042,000           1/19/2013         7         91.73         1,079,000         0         0         1,099,000           1/22/2013         7         96.98         1,123,000         0         0         1,019,000           1/22/2013         7         106.31         1,014,000         0         0         1,014,000	1/10/2013	7	98.56	1,150,000	30,000	445	1,180,000
1/12/2013         3         31.64         1,269,000         0         57         1,269,000           1/13/2013         8         101.82         1,303,000         0         0         1,303,000           1/14/2013         11         124.95         1,176,000         90,000         1.249         1,266,000           1/15/2013         12         163.74         1,104,000         90,000         1,239         1,194,000           1/16/2013         6         67.50         646,675         600,000         7,463         1,246,675           1/17/2013         4         52.36         412,429         887,000         11,281         1,299,429           1/18/2013         2         23.38         1,029,000         13,000         159         1,042,000           1/19/2013         7         91.73         1,079,000         0         0         1,099,000           1/20/2013         0         0.00         1,099,000         0         0         1,0179,000           1/21/2013         7         101.77         1,151,000         33,000         441         1,184,000           1/22/2013         7         106.31         1,014,000         0         0         1,014,000 <tr< th=""><th>1/11/2013</th><th>5</th><th>63.20</th><th>1,244,000</th><th>0</th><th>103</th><th>1,244,000</th></tr<>	1/11/2013	5	63.20	1,244,000	0	103	1,244,000
1/13/2013         8         101.82         1,303,000         0         0         1,303,000           1/14/2013         11         124.95         1,176,000         90,000         1,249         1,266,000           1/15/2013         12         163.74         1,104,000         90,000         1,239         1,194,000           1/16/2013         6         67.50         646,675         600,000         7,463         1,246,675           1/17/2013         4         52.36         412,429         887,000         11,281         1,299,429           1/18/2013         2         23.38         1,029,000         13,000         159         1,042,000           1/19/2013         7         91.73         1,079,000         0         0         1,079,000           1/20/2013         0         0.00         1,099,000         0         0         1,029,000           1/21/2013         7         101.77         1,151,000         33,000         441         1,184,000           1/23/2013         7         106.31         1,014,000         0         0         1,014,000           1/25/2013         6         81.97         1,061,790         0         0         1,061,790      1	1/12/2013	3	31.64	1,269,000	0	57	1,269,000
1/14/2013         11         124.95         1,176,000         90,000         1,249         1,266,000           1/15/2013         12         163.74         1,104,000         90,000         1,239         1,194,000           1/16/2013         6         67.50         646,675         600,000         7.463         1,246,675           1/17/2013         4         52.36         412,429         887,000         11,281         1,299,429           1/18/2013         2         23.38         1,029,000         13.000         159         1,042,000           1/19/2013         7         91.73         1,079,000         0         0         1,099,000           1/20/2013         0         0.00         1,099,000         0         0         1,099,000           1/21/2013         7         101.77         1,151,000         33,000         441         1,184,000           1/23/2013         7         96.98         1,123,000         0         0         1,014,000           1/24/2013         8         111.64         918,000         0         0         1,061,790           1/25/2013         6         81.97         1,061,790         0         0         917,000	1/13/2013	8	101.82	1,303,000	0	0	1,303,000
1/15/2013         12         163.74         1.104,000         90,000         1.239         1.194,000           1/16/2013         6         67.50         646,675         600,000         7,463         1.246,675           1/17/2013         4         52.36         412,429         887,000         11.281         1.299,429           1/18/2013         2         23.38         1,029,000         13,000         159         1,042,000           1/19/2013         7         91.73         1,079,000         0         0         1,099,000           1/22/2013         7         101.77         1,151,000         33,000         441         1,184,000           1/23/2013         7         106.31         1,014,000         0         0         1,014,000           1/24/2013         8         111.64         918,000         0         0         1,061,790           1/25/2013         6         81.97         1,061,790         0         0         1,036,000           1/25/2013         6         81.97         1,061,790         0         0         1,036,000           1/28/2013         5         67.73         1,036,000         0         0         1,036,000	1/14/2013	11	124.95	1,176,000	90,000	1,249	1,266,000
1/16/2013         6         67.50         646,675         600,000         7,463         1,246,675           1/17/2013         4         52.36         412,429         887,000         11,281         1,299,429           1/18/2013         2         23.38         1,029,000         13,000         159         1,042,000           1/19/2013         7         91.73         1,079,000         0         0         1,099,000           1/20/2013         0         0.00         1,099,000         0         0         1,099,000           1/21/2013         7         101.77         1,151,000         33,000         441         1,184,000           1/23/2013         7         96.88         1,123,000         0         0         1,014,000           1/24/2013         8         111.64         918,000         0         0         1,061,790           1/25/2013         6         81.97         1,061,790         0         0         917,000           1/26/2013         4         61.20         917,000         0         0         998,000           1/28/2013         5         67.73         1,063,000         0         0         998,000           1/28/2013	1/15/2013	12	163.74	1,104,000	90,000	1,239	1,194,000
1/17/2013         4         52.36         412,429         887,000         11,281         1,299,429           1/18/2013         2         23.38         1,029,000         13,000         159         1,042,000           1/19/2013         7         91.73         1,079,000         0         0         1,079,000           1/20/2013         0         0.00         1,099,000         0         0         1,099,000           1/21/2013         7         101.77         1,151,000         33,000         441         1,184,000           1/22/2013         7         96.98         1,123,000         0         0         1,014,000           1/24/2013         8         111.64         918,000         0         0         1,061,790           1/25/2013         6         81.97         1,061,790         0         0         1,061,790           1/26/2013         4         61.20         917,000         0         0         998,000           1/28/2013         5         67.73         1,036,000         0         0         1,036,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6	1/16/2013	6	67.50	646,675	600,000	7,463	1,246,675
1/18/2013         2         23.38         1.029,000         13,000         159         1.042,000           1/19/2013         7         91.73         1.079,000         0         0         1.079,000           1/20/2013         0         0.00         1.099,000         0         0         1.099,000           1/21/2013         7         101.77         1.151,000         33,000         441         1.184,000           1/22/2013         7         96.98         1.123,000         0         0         1.123,000           1/23/2013         7         106.31         1.014,000         0         0         1.014,000           1/24/2013         8         111.64         918,000         0         0         1.061,790           1/26/2013         6         81.97         1.061,790         0         0         1.061,790           1/26/2013         4         61.20         917,000         0         0         998,000           1/28/2013         5         67.73         1.036,000         0         0         1.036,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6	1/17/2013	4	52.36	412,429	887,000	11,281	1,299,429
1/19/2013         7         91.73         1.079,000         0         0         1.079,000           1/20/2013         0         0.00         1.099,000         0         0         1.099,000           1/21/2013         7         101.77         1.151,000         33,000         441         1.184,000           1/22/2013         7         96.98         1.123,000         0         0         1.123,000           1/23/2013         7         106.31         1.014,000         0         0         1.014,000           1/24/2013         8         111.64         918,000         0         0         918,000           1/25/2013         6         81.97         1.061,790         0         0         917,000           1/26/2013         4         61.20         917,000         0         0         917,000           1/28/2013         5         67.73         1,036,000         0         998,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.63	1/18/2013	2	23.38	1,029,000	13,000	159	1,042,000
1/20/2013         0         0.00         1,099,000         0         0         1,099,000           1/21/2013         7         101.77         1,151,000         33,000         441         1,184,000           1/22/2013         7         96.98         1,123,000         0         0         1,123,000           1/23/2013         7         106.31         1,014,000         0         0         1,014,000           1/24/2013         8         111.64         918,000         0         0         918,000           1/25/2013         6         81.97         1,061,790         0         0         1,061,790           1/26/2013         4         61.20         917,000         0         0         917,000           1/27/2013         0         0.00         998,000         0         0         998,000           1/28/2013         5         67.73         1,036,000         0         0         991,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.	1/19/2013	7	91.73	1,079,000	0	0	1,079,000
1/21/2013       7       101.77       1,151,000       33,000       441       1,184,000         1/22/2013       7       96.98       1,123,000       0       0       1,123,000         1/23/2013       7       106.31       1,014,000       0       0       1,014,000         1/24/2013       8       111.64       918,000       0       0       918,000         1/25/2013       6       81.97       1,061,790       0       0       1,061,790         1/26/2013       4       61.20       917,000       0       0       917,000         1/27/2013       0       0.00       998,000       0       0       998,000         1/28/2013       5       67.73       1,036,000       0       0       1,036,000         1/29/2013       9       123.06       991,000       0       0       991,000         1/30/2013       6       82.28       873,000       14.000       212       887,000         1/31/2013       8       89.63       866,000       0       0       866,000       14.879,000       24.411       34.188,894	1/20/2013	0	0.00	1,099,000	0	0	1,099,000
1/22/2013         7         96.98         1,123,000         0         0         1,123,000           1/23/2013         7         106.31         1,014,000         0         0         1,014,000           1/24/2013         8         111.64         918,000         0         0         918,000           1/25/2013         6         81.97         1,061,790         0         0         918,000           1/26/2013         4         61.20         917,000         0         0         917,000           1/27/2013         0         0.00         998,000         0         0         917,000           1/28/2013         5         67.73         1,036,000         0         0         998,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.63         866,000         0         0         866,000           Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894	1/21/2013	7	101.77	1,151,000	33,000	441	1,184,000
1/23/2013       7       106.31       1,014,000       0       0       1,014,000         1/24/2013       8       111.64       918,000       0       0       918,000         1/25/2013       6       81.97       1,061,790       0       0       1,061,790         1/26/2013       4       61.20       917,000       0       0       917,000         1/27/2013       0       0.00       998,000       0       0       998,000         1/28/2013       5       67.73       1,036,000       0       0       1,036,000         1/29/2013       9       123.06       991,000       0       0       991,000         1/30/2013       6       82.28       873,000       14,000       212       887,000         1/31/2013       8       89.63       866,000       0       0       866,000         Jan Totals       194       2531.88       32,309,894       1,879,000       24,411       34,188,894	1/22/2013	7	96.98	1,123,000	0	0	1,123,000
1/24/2013       8       111.64       918,000       0       0       918,000         1/25/2013       6       81.97       1,061,790       0       0       1,061,790         1/26/2013       4       61.20       917,000       0       0       917,000         1/27/2013       0       0.00       998,000       0       0       998,000         1/28/2013       5       67.73       1,036,000       0       0       998,000         1/29/2013       9       123.06       991,000       0       0       991,000         1/30/2013       6       82.28       873,000       14,000       212       887,000         1/31/2013       8       89.63       866,000       0       0       866,000         Jan Totals       194       2531.88       32,309,894       1,879,000       24,411       34,188,894	1/23/2013	7	106.31	1,014,000	0	0	1,014,000
1/25/2013       6       81.97       1,061,790       0       0       1,061,790         1/26/2013       4       61.20       917,000       0       0       917,000         1/27/2013       0       0.00       998,000       0       0       998,000         1/28/2013       5       67.73       1,036,000       0       0       998,000         1/29/2013       9       123.06       991,000       0       0       991,000         1/30/2013       6       82.28       873,000       14,000       212       887,000         1/31/2013       8       89.63       866,000       0       0       34,188,894         Mverage:       1042255       60613       50013       50013       50013       50013       50013	1/24/2013	8	111.64	918,000	0	0	918,000
1/26/2013         4         61.20         917,000         0         0         917,000           1/27/2013         0         0.00         998,000         0         0         998,000           1/28/2013         5         67.73         1,036,000         0         0         998,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.63         866,000         0         0         34,188,894           Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894	1/25/2013	6	81.97	1,061,790	0	0	1,061,790
1/27/2013         0         0.00         998,000         0         0         998,000           1/28/2013         5         67.73         1,036,000         0         0         1,036,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.63         866,000         0         0         866,000           Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894	1/26/2013	4	61.20	917,000	0	0	917,000
1/28/2013         5         67.73         1,036,000         0         0         1,036,000           1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.63         866,000         0         0         34,188,894           Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894	1/27/2013	0	0.00	998,000	0	0	998,000
1/29/2013         9         123.06         991,000         0         0         991,000           1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.63         866,000         0         0         866,000           Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894	1/28/2013	5	67.73	1,036,000	0	0	1,036,000
1/30/2013         6         82.28         873,000         14,000         212         887,000           1/31/2013         8         89.63         866,000         0         0         866,000           Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894	1/29/2013	9	123.06	991,000	0	0	991,000
1/31/2013         8         89.63         866,000         0         0         866,000           Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894           Average:         1042255         60613         60613         60613         60613         60613	1/30/2013	6	82.28	873,000	14,000	212	887,000
Jan Totals         194         2531.88         32,309,894         1,879,000         24,411         34,188,894           Average:         1042255         60613         6	1/31/2013	8	89.63	866,000	0	0	866,000
Average: 1042255 60613	Jan Totals	194	2531.88	32,309,894	1,879,000	24,411	34,188,894
			Average:	1042255	60613		
Flow Rate: 43427 2526			Flow Rate:	43427	2526		

# Monthly Fuel Requirement

 $\begin{array}{l} \textit{Biomass Fuel Requirement} = \\ ((\dot{m} \times (h_{boiler\ exit} - h_{boiler\ entry}))/(Btus/BDT)) \times \textit{FR} \times \textit{MOH} \end{array}$ 

Fuel Requirement	=	BDTs of fuel
ṁ	=    h	total mass flow rate of steam (lbs/hr)
h <sub>boiler exit</sub>	<b>H</b>	Enthalpy of steam exiting boiler (1,195 Btu/lbm)
h <sub>boiler entry</sub>	=	Enthalpy of condensate entering boiler (199 Btu/lbm)
Btus/BDT	41111	See 'Boiler Efficiency'
FR	±////	Ratio of biomass to natural gas used by month

 $*(1 - FCR) \times \dot{m}$  will yield the quantity of steam produced by natural gas for each month. Then, the Fuel Cost Ratio in the following table can be used to determine the cost of natural gas.

# Monthly Fuel Requirement

January					
STEAM BY	STEAM BY		T200		
WOOD	COSL	GAS	0031		
32,309,894	\$134,189.64	1,879,000	\$13,426.05		
FCR 1.72					

 $Fuel Cost Ratio = \frac{Cost of NG \times Steam by Wood}{Cost of Biomass \times Steam by NG}$ 

Month	Fuel ratio	Fuel cost ratio NG/BDT	
January	0.945	1.7204	
February	0	0	
March	0.9366	1.9872	
April	0.9597	2.2478	
May	0.9305	2.5462	
June	0.9098	1.834	
July	0.967	1.9719	
August	0.9994	2.0267	
September	0.9975	3.0091	
October	0.8808	1.7595	
November	0.9366	1.5935	
December	0.9642	2.1314	

#### **Modified Flow Rate**

$$\dot{m} = \frac{CHR}{h_{turbine\ exit} - h_{condensate\ tank}}$$

CHR	<i> </i>	Campus heating requirement (Btu/hr)
ṁ	=/////	Flow rate adjusted for turbine (lbs/hr)
h <sub>turbine exit</sub>	( <i>+</i> /////	Enthalpy of steam exiting turbine (1,130-1,160 Btu/lbm)
h <sub>boiler entry</sub>	<i>Ħ</i> /////	Enthalpy of condensate tank(180.1 Btu/lbm)

\*In developing the value of  $h_{turbine exit}$  an isentropic efficiency of 65% was used. The resulting modified flow rate was then used to recalculate a new isentropic efficiency for each month. The new isentropic efficiency was in turn used to generate a new flow rate. In other words, an iteration process was used to obtain the actual flow rate.

#### **Turbine Power Output**

$$\eta_{i.e.} = \frac{h_{entry} - h_{exit,actual}}{h_{entry} - h_{exit,isentropic}}$$

$$h_{exit,actual} = -\left(\frac{\eta_{i.e.}}{h_{entry} - h_{exit,isentropic}} - h_{entry}\right)$$

 $Power = \dot{m} \times \left(h_{turbine\ entry} - h_{turbine\ exit}\right) \times Conversion factor\left(\frac{Btu}{hr} to\ kW\right)$ 

### **Turbine Power Output**

Turbine Power Out (kW)				
	703E	K Frame		
January	855	1022		
February	677	831		
March	564	705		
April	474	604		
May	309	411		
June	208	287		
July	298	398		
August	332	439		
September	252	341		
October	411	532		
November	591	736		
December	746	905		

# **Fuel Costs**

Client Supplied Data								
Month	BDT Fuel Usage	BDT Fuel Cost	Natural Gas Usage (therms)	Natural Gas Fuel Cost	Total Fuel Costs			
January	2531.88	\$134,190.00	\$134,190.00 24411 \$13,426.0		\$147,615.64			
February	2113.1	\$109,881.00	0 \$0.00		\$111,994.30			
March	1839.02	\$93,790.00	21044 \$12,626.00		\$110,094.06			
April	1716.87	\$87,560.00	13766	\$8,260.00	\$99,254.11			
May	1140.19	\$58,150.00	18445	\$11,067.00	\$71,497.07			
June	426.65	\$21,759.00	95786	\$57,472.00	\$80,084.45			
July	1250.34	\$63,767.00	7144	\$4,286.00	\$70,554.02			
August	1349.31	\$68,815.00	131	\$79.00	\$71,592.43			
September	869.87	\$53,062.00	671	\$403.00	\$46,506.11			
October	1313.17	\$80,103.00	31792 \$19,075.00 \$88,6		\$88,673.01			
November	1985.62	\$121,123.00	21759	\$13,055.00 \$118,292.86				
December	2262.78	\$128,978.00	16993	\$10,196.00	\$130,123.34			

## **Fuel Costs**

#### Fuel Costs = Fuel Requirements × Fuel Rate

Cost per BDT	=	\$53
Cost per therm	=	\$0.60

\*Additional fuel requirements were calculated as the difference between the estimated fuel requirements for the turbine system minus the fuel requirements of the current system.

# Savings

#### \$0.0586/kWh

Turbine Revenue						
	703E	K Frame				
January	\$37,273	\$44,574				
February	\$26,668	\$32,710				
March	\$24,581	\$30,751				
April	\$20,007	\$25,491 \$17,928				
May	\$13,474					
June	\$8,766	\$12,099				
July	\$12,995	\$17,352				
August	\$14,476	\$19,127				
September	\$10,616	\$14,403				
October	\$17,925	\$23,179				
November	\$25,769	\$32,075				
December	\$32,505	\$39,455				

#### **Montana Validation**

#### UM Turbine Power Output vs. Flow Rate (2012)



#### **Montana Validation**

**Isentropic Efficiency vs. Flow Rate (2012)** 



### **Montana Validation**

Actual		Theoretical		% Difference
Flow	efficiency	Flow	efficiency	
8500	28.00%	8500	29.19%	4.15%
15500	44.00%	15500	56.02%	24.04%
18000	46.00%	18000	48.24%	4.76%
23000	47.00%	23000	53.93%	13.74%
26500	47.00%	26500	46.81%	0.40%
33000	41.00%	33000	52.63%	24.84%

Average Difference: 12%