

Use of Preheated Combustion Air for Industrial Heating Equipment And Boilers



Prepared for California Energy Commission (CEC)

Prepared By:

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(A Sempra Energy Utility)**

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Executive Summary

This technical description describes a calculator tool that will allow a user to estimate annual energy savings and associated money (US Dollars) savings and reduction in CO₂ emissions through the use of preheated combustion air for industrial heating applications and boilers. The savings are estimated for a case where heat from flue (or exhaust) gases is used to preheat combustion air that is used in the burners installed on a heating system such as a furnace, oven, heater, dryer, melters etc. and industrial boilers. The calculator estimates the annual expected energy savings in terms of million (MM) Btu/year. It also estimates energy cost reduction using a given cost of energy used for the application and number of operating hours per year. The calculator also gives reduction in CO₂ emission resulting from combustion of natural gas.

Primary objective of the calculator is to identify energy savings potential in industrial heating operations to make a go/no go decision on additional detailed engineering and economics analysis. The user is required to give data or values for several operating parameters which can be measured or estimated from normal operating conditions using available records or actual measurements. All data should be collected at typical or average unit operating conditions.

Calculator results should be considered preliminary estimates of energy savings potential and a starting point for detail technical and economic analysis. Accuracy of the results is expected to be within plus or minus 5 percent.

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1. Description of the topic or subject area

This work paper describes a calculator tool that will allow the user estimate annual energy (fuel) savings, reduction in CO₂ emission and energy cost savings (\$/year) with use of preheated combustion air in fuel fired burners installed on a heating equipment (boiler, furnace, oven, heater, dryer etc.). This calculator covers a case when a heat exchanger (commonly known as a recuperator, an air preheater or regenerator) is used to transfer the heat in the flue gas for preheating the combustion air for the heating equipment mentioned above. A schematic depiction of a combustion air preheater using a recuperator to extract heat from the flue gases is shown in Exhibit 1.

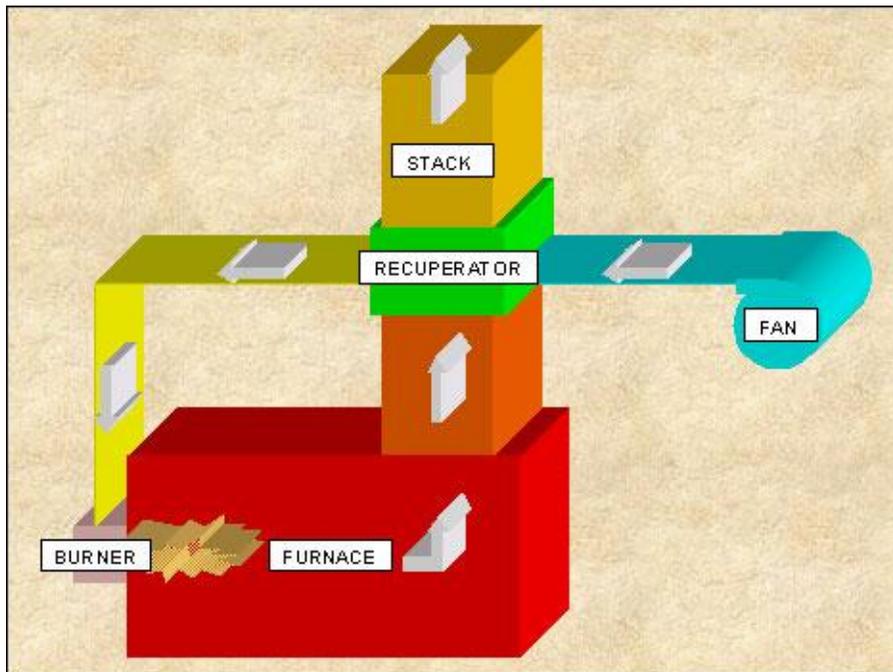


Exhibit 1: Combustion air preheat schematic using a recuperator

Another type of air preheating system used for industrial process heating is known as regenerative system. A regenerative system is one in which a pair of burners are directly connected to heat exchangers. A system using regenerative burners is shown in Exhibit 2.

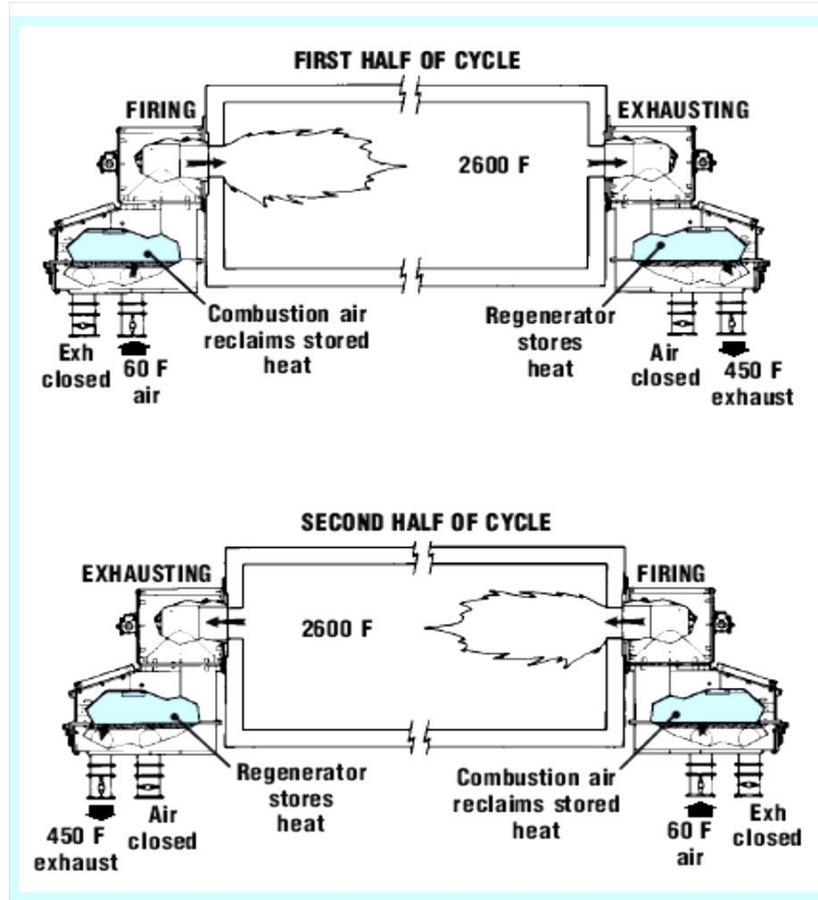


Exhibit 2: Combustion air preheating using regenerative urners (source: North American Mfg. Company)

For large boilers it is common to use a rotary wheel type air preheater in which a rotating heat transfer media is passes through the flow of exhaust gases and combustion air alternatively. A typical design is shown in Exhibit 3. The rotary wheel system offers very high surface area and a compact design for large boilers. Use of such a device is uncommon for high temperature furnaces and ovens.

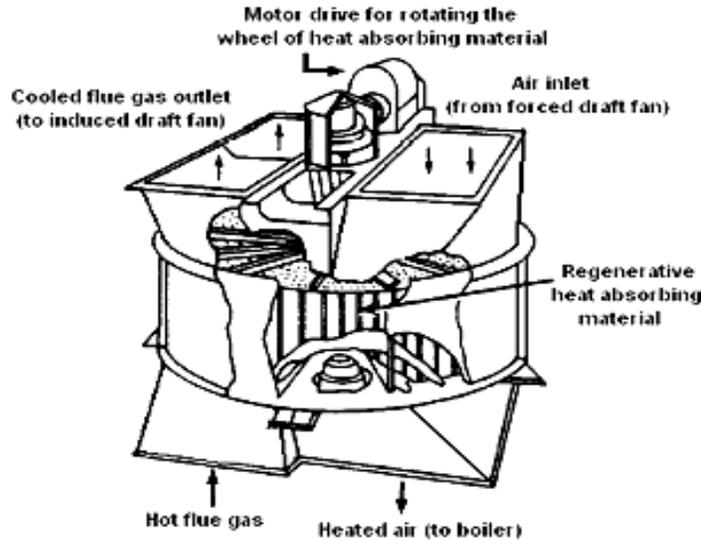


Exhibit 3: Rotary wheel type air preheater

Combustion air preheating is commonly used for the high temperature processes such as chemical processing, petroleum refining, metal, glass industries etc. It is also used for specific lower temperature processes such as steam generation, drying and non-metal heating processes where the flue gas volumes are very high, usually in terms of hundreds of cubic feet per minute (CFM).

This calculator estimates the expected annual energy savings at a specified set of furnace¹ operating conditions. The focus of the Technical Guide discussion is on industrial process heating units that use heat exchangers to transfer heat from its exhaust or flue gases to its combustion air used in the burners. The annual energy savings from preheating combustion air depends on the flue gas temperature, combustion air preheat temperature, and amount of excess air present in the flue gasses. The excess air or amount of oxygen in the flue gases represents amount of mass flowing through the furnace stack.

This calculator requires certain measured data related to the average furnace performance and cost of energy in terms of \$/Million (MM) Btu using natural gas as fuel. Changes in combustion air temperature (and resulting savings) is reported in the “modified” column and gives changes in the furnace energy input (or use), CO₂ emission, and Dollar savings. The data requirements are discussed in a following section.

Calculated results should be considered as a good representation of the savings when the natural gas composition changes within a limited range. The results are also considered as good approximation for hydrocarbon gaseous fuels. However these results should not be considered representative when the fuel composition includes a large amount of inert gases such as nitrogen (N₂), water vapor (H₂O), carbon dioxide (CO₂) etc. It is necessary to give detail of the fuel gas composition when such fuels are used. *It is not recommend to use this calculator if fuel composition is considerably different from the commonly used natural gas in California.* Use of additional engineering or expert help is recommended for such cases.

¹ In this Technical Guide, the term “furnace” is frequently used as convenient shorthand for the more precise “process heating equipment (furnace, oven, kiln, heater, etc.) or process boiler”.

The calculation methodology and equations used are based on the output of equilibrium combustion models and tables of physical properties; they are good approximations to the calculation results of the Process Heating Assessment and Survey Tool (PHAST)².

2. Impact of the energy saving step (activity) on energy savings and CO₂ reduction

This calculator allows a user to estimate energy savings that can be achieved with the use of preheated combustion air when the air is heated by using heat from the exhaust gases from a heating system. A reduction in the consumption of commonly used fossil fuels such as natural gas (which is the most commonly used industrial fuel for California industries) results in the reduction of formation of CO₂.

The reduction in CO₂ emissions is directly proportional to the reduction in energy use or energy savings achieved with the use of natural gas. According to the U.S. Environmental Protection Agency (EPA) estimates (Reference 5), combustion of natural gas used in USA, produces 116.39 lbs. of CO₂ for one million Btu heat input. For convenience most calculations use 117 lbs. CO₂ emission per million Btu heat input from natural gas. If the natural gas composition is available, it is advisable to carry out detail combustion calculations to estimate actual value of CO₂ produced by the combustion of natural gas. Reduction in CO₂ emission is calculated by using value of reduction in energy (heat) used for the furnace.

This calculator is designed to give results assuming that the process uses natural gas as fuel. The actual savings in fuel consumption, associated energy costs, and reduction of CO₂ emissions depends on several operating parameters. These parameters include:

- Average firing rate or fuel used per hour
- Temperature of exhaust gases leaving a furnace or boiler
- Amount of excess air used for combustion as represented by presence of oxygen (on dry basis) in exhaust gases.
- Number of operating hours per year
- Average temperature of combustion air after it is preheated using the proposed heat recovery system.
- Cost of fuel in terms of \$ per MM Btu

The energy savings and corresponding CO₂ reduction can vary from 5% for low temperature processes to as high as 30% for high temperature processes.

It is generally believed that combustion air preheating should be recommended for higher temperature process, where the exhaust gas temperature is higher than 1000 deg. F. However it should be noted that the savings can be substantial for large energy consuming systems or systems with a large volume of exhaust gases. Examples of cases where it is advisable to consider combustion air preheating are drying processes, steam generators (boilers), process air heaters etc.

² The PHAST model was developed as part of a formal partnership agreement between the Department of Energy and the Industrial Heating Equipment Association. Dr. Arvind Thekdi, E3M, Inc. was the project manager for the development of PHAST and has provided the program logic for the calculators under a separate contract to the Gas Company.

Annual energy cost savings depend on the cost of energy expressed as Dollar (\$) per MM Btu and energy savings estimated using the calculator.

3. Discussion on the technical approach and the calculations

The energy savings and associated CO₂ emission reduction are calculated for most commonly used hydrocarbon fuels such as natural gas. The savings are calculated for a system in which heat from exhaust or flue gases is used to preheat combustion air as shown in Exhibit 4 below. In these calculations the system heat demand consisting of several areas of heat requirement in a typical heating system (listed in the figure) remains constant. In these calculations, the energy required to heat the product remains constant.

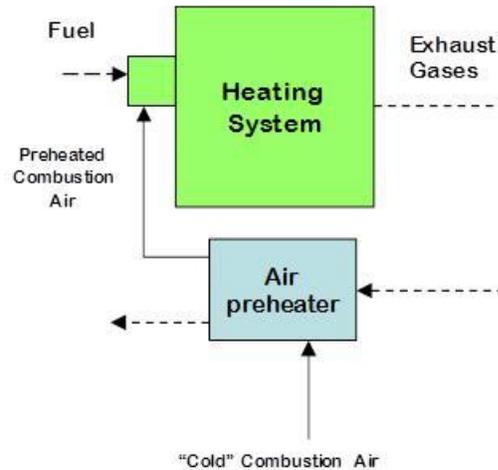


Exhibit 4: Combustion air preheating using heat from flue gases

The savings are based on changes in reduction in heat content of the exhaust gases and will increase “available heat” through the recycling of the heat from the exhaust to the combustion air.

The term available heat is defined as the difference between the heat input and the heat content of exhaust gases leaving the furnace. This term is usually expressed as percentage (%) and represents the amount of heat that remains in a furnace as a fraction or percentage of the heat input to the furnace.

Available heat expressed in terms of percentage is given as

H_f = Furnace heat demand

H_{av} = Available heat (%)

H_{in} = heat input in the furnace (Btu/hr)

H_{ex} = heat content of exhaust gases leaving the heating system or furnace (Btu/hr)

Avht(%) = Percent available heat

With use of preheated combustion air, we can consider two different operating conditions. One in which the combustion air is temperature lowered (T_{ac}) and another where combustion air temperature is raised (T_{ah}). Correspondingly the heat input will be H_{inc} and H_{inh} , and the available heat will be Avht_c(%) and Avht_h(%). Note that in each case the furnace heat demand is constant at H_f . For each case heat content is H_{exc} and H_{exh} respectively.

Hence,

The available heat expressed in terms of % or Avht(%) depends on the following variables:

- Fuel composition
- Exhaust gas temperature
- Combustion air temperature
- Percent Oxygen (dry) in the exhaust gases.

Available heat can be calculated by using combustion calculations for a given fuel. For the preheated combustion air calculator tool such calculations use a typical natural gas composition as used in California and USA.

The gas composition used for the calculations in the preheated combustion air tool is given below.

Fuel Gas Analysis (See note below)		
Gas composition	By volume	Adjusted by volume
CH4	94.00%	94.009%
C2H6	2.07%	2.070%
N2 and other inert	1.50%	1.500%
H2	0.01%	0.010%
C3H8	0.42%	0.420%
C4H10 + CnH2n	0.28%	0.280%
H2O	0.00%	0.000%
CO	1.00%	1.000%
CO2	0.71%	0.710%
SO2	0.00%	0.000%
O2	0.00%	0.000%
Total of fuel components	99.99%	100.000%
Difference	0.01%	0.00%

Note: The fuel gas composition is in volume %. The higher hydrocarbons in fuel are treated as same as C4H10 and all other inert gases are treated as N2.

Exhibit 5: Composition of Natural Gas Used for Calculations.

For this calculator, the “higher heating value” or “gross heating value” for the fuel is used. The Higher or Gross heating value for natural gas with the composition shown in Exhibit 5 is 1,011 Btu/scf. Natural gas heating value may vary from as low as 970 Btu/scf to as high as 1200 Btu/scf. However 1000 Btu/scf is considered as a “normal” heating value of natural gas. Note that minor discrepancies in the heating value have very little effect on the savings achieved with changes.

It is recognized that the natural gas composition may vary somewhat during the year or from location to location. However a series of calculations show that variation in natural gas composition has very small effect on available heat expressed as percentage of the heating value. Therefore available heat changes are within a narrow range and error in its value is relatively small. The error for the available heat value would be within plus or minus 5%. In this case we advise the user that the accuracy of the estimate will be in the same order of magnitude (±5%) with use of this calculator. A separate calculator is available to calculate exact value of available heat when the fuel composition is known or the natural gas composition is significantly different from that stated in Exhibit 5.

Further discussion on available heat and effect of fuel is discussed in references 1 and 2.

Reduction in energy or heat used for a furnace with use of preheated combustion air can be estimated by calculating changes in available heat when air temperature is changed for the burners. The following equations show the calculation method used for this calculator.

Annual savings can be expressed in terms of Btu per/year or Therms per year or Million (MM) Btu/year by using appropriate equations given below.

The CO₂ savings can be calculated by using the fuel combustion calculations or by using the EPA guidelines for CO₂ generation calculations. Reference 5 gives details of US EPA guidelines.

4. Instruction on use of each calculator

The combustion air preheating calculator requires following input parameters to describe the user and to estimate the savings. Exhibit 5 shows the user information screen and Exhibit 6 shows the calculator screen.

The following list summarizes the user inputs that are required. The user should collect this information before use of this calculator-tool.

- Company name, plant location and address
- Customer name and contact information
- Heating equipment description (where the energy saving measure is applied)

- Equipment type (furnace, oven, kiln, heater, boiler)
- Equipment use (e.g., textile drying, aluminum melting, food processing.)
- Flue gas temperature (hot-side inlet to heat exchanger) (°F)
- Oxygen in flue gas (% , dry basis)
- Combustion air temperature (cold-side inlet to heat exchanger) (°F)
- Current fuel energy input (Btu/hr)
- Fuel (energy cost) in terms of \$/per MM Btu
- Number of operating hours per year

The calculator gives following results.

- Excess air in flue gases
- Available heat for the furnace
- Heat (energy) used per year (MM Btu/year)
- Heat (energy) savings per year (MM Btu/year)
- Energy cost savings per year (\$/year)
- CO₂ savings per year (tons/year)

The first section requires information for the user, the equipment, process etc. The second section of the calculator is used for collecting the necessary data and reporting the estimated savings.

There are two columns for the calculator. The “Current” column represents the conditions or data collected as average values for each of the parameters. Details of the data are given below. Data for the “Modified” conditions represents values of each of the inputs after the suggested measure (use of preheated combustion air in this case) is implemented. For this calculator in most cases the only input parameter that will change is combustion air temperature with all other values remaining constant.

Use Preheated Combustion Air for Burners (Calculator for Preheated Combustion Air)				
1	Company name	ABC Corporation		
2	Plant name or designation	LA Plant		
3	Plant address	12345 Main Street, Gabriel, CA 90878		
4	Contact name	Bob Smith		
5	Contact address	54321 First Street, North Warren, CA 90878		
6	Contact phone number and e-mail	Phone:	916-756-9923	E-mail: b.smith@abccorp.com
7	Date (format mm/date/year)	May 12, 2010		
Heating equipment description (where the energy saving measure is applied)				
8	Equipment type (e.g. furnace, oven, kiln, heater, boiler)	A furnace using a recuperator		
9	Equipment use (e.g., textile drying, aluminum melting)	Gas fired furnace used continuously		
10	Other comments if any	This is a preliminary evaluation for possible heat recovery and power generation using heat of exhaust gases.		

Exhibit 6: Required Information for the Calculator User

Line 1 – Name of the company

Line 2 – Name or known designation such as “main plant” or “secondary plant” if applicable.

Line 3 – Plant address

Line 4 – Contact name for the plant – This is the individual who is main contact and responsible for collecting and providing the required data or information.

Line 5 – Address for the contact person

Line 6 – Contact phone number and e-mail to be used for all future communications.

Line 7 – Date when the calculations are carried out.

Line 8 – Type of heating equipment. This can be an oven, a furnace, a boiler, heater etc. heating equipment where data is collected and the given energy saving measure is to be applied.

Line 9 – Description of the process or function for which the heating equipment is used. This can be name of the process such as drying, melting, water heating etc.

Line 10 – Additional information.

Use of Preheated Combustion Air			
Note: The combustion air is heated by using heat from flue or exhaust gases.			
		Current	New
11	Furnace flue gas temp. (°F)	1,000	1,000
12	Percent O ₂ (dry) in flue gases	2.09	2.09
13	% Excess air	9.89	9.89
14	Combustion air temperature (°F)	60	600
15	Fuel consumption (MM Btu/hr) - Avg. current	5.00	4.36
16	Volume of fuel gas scfh - based on fuel heating value	4,945.19	4,315.75
17	Available Heat (%)	67.75	77.63
18	Fuel savings (%)	Base	12.73%
19	No. of operating hours (hours/year)	6000	6000
20	Heat used per year (MM Btu/year)	30,000	26,182
21	Heat saved per year (MM Btu/year)	Base	3,818
22	Cost of fuel (\$/Million Btu)	\$ 6.00	\$ 6.00
23	Annual savings (\$/year)	Base	\$ 22,911
24	CO₂ savings (tons/year)	Base	225

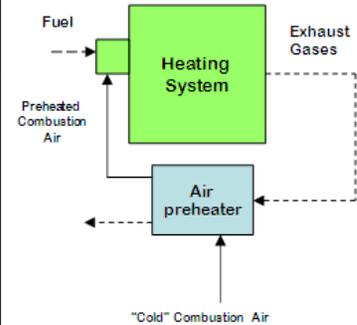


Exhibit 7: Example of calculator inputs and results

Line 11 – Furnace flue gas temperature. Give flue or exhaust gas temperature measured as close to the exit of the furnace as possible. The flue gas temperature should be taken when the furnace is operating at normal operating conditions. Readings taken at non-average production or operating conditions can give unreliable results. It is necessary to make sure that the flue gases are NOT mixed with cold air before the temperature is measured. Care should be taken to locate the thermocouple or temperature measurement sensor in the middle of the stack or area from where the flue gases are discharged. Measuring the temperature at the top of the stack or very close to the wall of the discharge duct can give erroneous reading. In almost all cases the flue gas temperature does not change by any meaningful value with use of preheated combustion air since the furnace zone temperatures are controlled to meet the required process conditions.

Line 12 – Percent oxygen (O₂) in flue gases. This value is obtained from flue gas analysis using commonly available combustion or flue gas analyzers. These meters give the flue gas analysis on dry basis. The sample for the gas analysis should be taken when the furnace is operating at normal operating conditions. Readings taken at non-average production or operating conditions can give unreliable results. It is necessary to make sure that the flue gases are NOT mixed with cold air before the temperature is measured. Care should be taken to locate the sampling probe in the middle of the stack or area from where the flue gases are discharged. Collecting the sample at the top of the stack or very close to the wall of the discharge duct can give erroneous reading. It is also necessary to make sure that there is no air leakage through the sampling port and the sampling probe when it is inserted in the stack or sampling location.

- Line 13 - % Excess air. This is a calculated value of excess air present in the flue gases. It is calculated for natural gas used as fuel. However the result is considered valid for different compositions of natural gas and for most hydrocarbon fuels.
- Line 14 – Combustion air temperature. For current condition the user should measure the combustion air temperature entering the burners. In many cases it is not possible to get exact air temperature at the burner and it is common to use air temperature entering the combustion air blower or ambient temperature around the air blower. For modified conditions one selects the desired and practical combustion air temperature. The air temperature depends on the type of equipment used such as a recuperator or regenerator or regenerative burners. The user should consult the furnace supplier and/or the burner suppliers and discuss their specific requirements to obtain correct value of the combustion air preheat temperature. It is suggested the user study suggestions given in References 1 and 2.
- Line 15 – Fuel consumption. This is the value of current fuel consumption expressed in terms of MM Btu/hour. This should be average value based on measurements of fuel use over a period of time or at “average” operating conditions. It is possible to get this value if the fuel consumption data is available for a certain period of time (monthly, annual etc.) for the furnace being considered. Note that the meter data, if used to calculate the fuel use, must be corrected for pressure and temperature at the meter and the heat input should be calculated using gross heating value of the fuel. For most commonly used or average quality natural gas a heating value of 1,020 Btu per standard cubic foot (scf) will be a good approximation.
- Line 16 – Volume of fuel gas. This is a calculated value based on gross heating value (average 1,011 Btu/std. cu. ft.)
- Line 17 – Available heat. This is a calculated value based on the data given above. The calculation uses “Available Heat” tool developed as part of the tool set and natural gas as fuel. The natural gas composition used for this calculation is same as given in Exhibit 6 above.
- Line 18 – Fuel savings. This term is calculated using available heat and heat input data for the preheated combustion air and the current conditions. The equations used for this calculation are discussed in a previous section.
- Line 19 – Number of operating hours. This represents annual operating hours at the average firing conditions given above.
- Line 20 – Heat used per year. This is calculated using values of fuel consumption and number of operating hours per year given above.
- Line 21 – Heat saved per year. This is the difference between heat used per year with the current air temperature and with use of preheated combustion air.
- Line 22 – Cost of fuel. The user gives cost of fuel expressed in terms of \$/MM Btu. The cost should include all charges related to use of fuel at “the burner tip”. This value can be obtained from the monthly or annual gas bill or total cost and annual fuel used.

Line 23 – Annual savings. This line gives estimated annual dollar savings resulting from reduced cost of fuel. It does not include any other savings or costs (negative savings) associated with use of preheated combustion air. In most cases any other savings or costs are small and often ignored.

Line 24 – Reduction in CO2 emission. The savings are calculated based on annual fuel savings assuming the fuel is natural gas. The savings are in Short (or US) tons and not in Metric tons.

Note: CO2 savings are based on use of natural gas as fuel for the heating equipment. A correction factor must be applied if any other fuel is used.

5. References

1. *North American Combustion Handbook*, Third Edition, 1986. Published by North American Mfg. Company, Cleveland, OH.
2. *Combustion Technology Manual*, Fifth Edition, 1994. Published by Industrial Heating Equipment Association, Cincinnati, OH.
3. *Improving Process Heating System Performance: A Sourcebook for Industry*, U.S. Department of Energy and Industrial Heating Equipment Association. Available on-line at www.eere.eenergy.gov/industry.
4. *Tip sheets and Technical Briefs*, published by The U.S. Department of Energy. Available on-line at www.eere.eenergy.gov/industry.
5. *Unit Conversions, Emission Factors and Other Reference Data*, published by the U.S. EPA, November 2004. Available on-line at <http://www.epa.gov/cpd/pdf/brochure.pdf>