THE UNIVERSITY OF TEXAS AT AUSTIN

Department of Utilities & Energy Management

Method for Calculating CO_2 Emissions for Campus Energy Streams

August 23rd, 2010

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Summary

This report outlines the methodology used by the Utilities & Energy Management Department to determine the CO_2 emission rates for the generation of electricity, chilled water, and heating steam utilized on the UT main campus. This methodology is then applied to monthly averages for the prior year from August 2009 through July 2010 to generate metrics for the carbon intensity of each energy stream. These metrics are applied to Welch Hall as an example of determining a building's carbon footprint.

Energy Generation and CO_2 Emissions on Campus

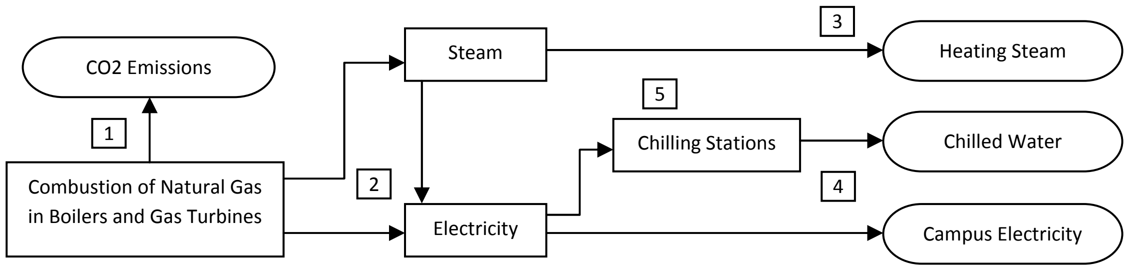
Buildings on the University of Texas at Austin main campus receive all of their electricity, heating and cooling from the combined heating and power (CHP) plant and chilling stations on campus operated by the Utilities & Energy Management Department. The three primary energy streams, electricity, chilled water, and heating steam, are the end results of multiple processes which all begin with the combustion of natural gas.

Natural gas is a fossil fuel which emits carbon dioxide (CO_2) when burned. For a large variety of reasons, measuring and understanding the amount of CO_2 emitted directly or indirectly by a process has gained significant attention and has become a standard metric for comparing the sustainability and efficiency of energy saving projects. Knowing the rate that CO_2 is being emitted for each energy stream on campus, combined with the metered data on how much energy a campus building is using, allows a building's carbon footprint to be evaluated and provides for more informed decisions on how to reduce the overall carbon emissions on campus. For example, knowing the difference between CO_2 rates for kilowatt-hours and ton-hours would allow you to determine whether changing out the lights in a building or improving the air conditioning system would have a greater reduction in CO_2 emissions.

Energy generation is complex and swayed by a number of variables including peak campus demand, time of day, ambient weather conditions and equipment availability. For simplicity in determining CO_2 emission rates in this report, we will narrow these impacting variables down to only two: type of energy produced, and time of year. This simplification works for averaging monthly or annual CO2 emissions based on energy consumption, however will begin to become inaccurate for daily averages and very unreliable for hourly or real-time emissions. The methodology to determine monthly averages is the same for determining real-time CO2 emissions, however the complexity and size of the real-time dataset becomes unwieldy for this report.

Converting Natural Gas to Energy

The following diagram summarizes energy production on campus:



The three energy streams on the right (heating steam, chilled water, and campus electricity, measured in kWh, ton-hrs, and lbs, respectively) are the primary three types of energy consumed by campus buildings. The first stage to produce these streams is to combust natural gas, point 1 on the diagram. This first step is the only place where CO_2 is released; all other steps are transformations from one energy type to another, each having an associated efficiency where energy is lost. How much energy is flowing from one process to the next, the ratio between each split, and the efficiency of each process can change dramatically and depends on the variables mentioned earlier.

With the goal to determine how much of that initial CO_2 is related to the resulting energy streams, we must generalize each transformation process and assign an efficiency and ratio. Doing this can be listed as several steps:

1. The combustion of natural gas emits CO_2.
2. The combustion of natural gas produces steam in boilers and electricity from gas turbine generators. Most of the steam is used to make electricity in steam turbines.
3. Some of the steam is sent to campus for space heating and water heaters.
4. Most of the electricity is sent to campus for lighting, computers, labs, pumps, etc.
5. Some of the electricity (up to 50% on the hottest days) is sent to chilling stations, where it is converted to chilled water and pumped to each building for air conditioning.

Step 1 – CO2 Emissions from Natural Gas

Natural gas is purchased (and therefore metered) not by volume but by the amount of energy contained, measured in MMBTU (million British thermal units). The Environmental Protection Agency has released tables of emissions factors for a variety of fuels and combustion sources, including the combustion of natural gas in a gas turbine, in a document they refer to as **AP 42**. Table 3.1-2a of *Chapter 3: Stationary Internal Combustion Sources*[1] lists a value of 110 lbs of CO_2 per MMBTU of natural gas combusted. This value is for near complete (99.5%) combustion of natural gas in a gas turbine, and would also suffice for the power plant's fired boilers utilizing flue-gas recirculation.

Using this ratio of 110 $lbs_{CO2}/MMBTU_{gas}$ it is possible to determine the total CO_2 emissions of the power plant. The following steps refine this total number down into the contribution from each energy stream.

Step 2 – Generation of Steam and Electricity

Natural gas for combustion is measured along with the total steam and electricity produced, however an exact determination of how much of that natural gas went into the production of steam and how much went into the production of electricity is extremely complex, especially considering a portion of that steam goes back into the generation of electricity. The EPA's Combined Heat and Power Partnership developed methods for calculating CHP efficiency[2] that simplify this method by assuming a constant thermal efficiency for generating steam and determining an effective electric efficiency based on the total fuel consumed and steam and electricity produced. The equation looks like:

$$\varepsilon_{EE} = \frac{W_E}{Q_{FUEL} - \sum(\frac{Q_{TH}}{\propto})}$$

Where:

ε_{EE} is effective electric efficiency
W_E is total electric generation
Q_{FUEL} is total fuel consumed
Q_{TH} is total thermal product (steam)
$\propto$ is thermal efficiency of steam production

Q_{FUEL}, W_E and Q_{TH} are directly measured, with Q_{TH} representing the steam sent to campus, not the total steam produced by the boilers. In this case Q_{TH} ignores the steam used to generate electricity and only looks at the thermal energy being sent to campus as an energy stream.

Figuratively, the above equation works by first subtracting the fuel needed to generate campus steam from the total fuel used, and then allocating the remaining fuel as that required to produce electricity. While the steam efficiency holds relatively steady, electrical efficiency varies significantly more due to load levels and ambient weather conditions.

Steps 3 & 4 – Steam and Electricity to Campus

At this point, we know the fuel required to produce campus steam, and the fuel required to generate electricity. Step 1 told us the amount of CO_2 emitted from the fuel, and applied to Step 2 will evaluate the CO_2 emitted to generate steam and electricity. For the year 2009, this looks like:

Past Year (August 2009 to July 2010) Averages	**Fuel Required**	**CO2 Emitted**
Campus Steam (lbs)	0.012 $MMBTU_{FUEL}/lbs_{STEAM}$	0.134 lbs_{CO2}/lbs_{STEAM}
Electricity (kWh)	0.009 $MMBTU_{FUEL}/kWh$	0.96 lbs_{CO2}/kWh

Step 5 – Chilled Water Generation

Chilled water is generated in four chilling stations on campus, each consisting of several chillers of varying age and efficiency. These chilling stations are fully electric, taking the electricity generated at the power plant and producing chilled water, measured in ton-hours. Once again, how efficiently these stations transform electricity into chilled water is dependent on the demand, weather, time of day, available units, etc.

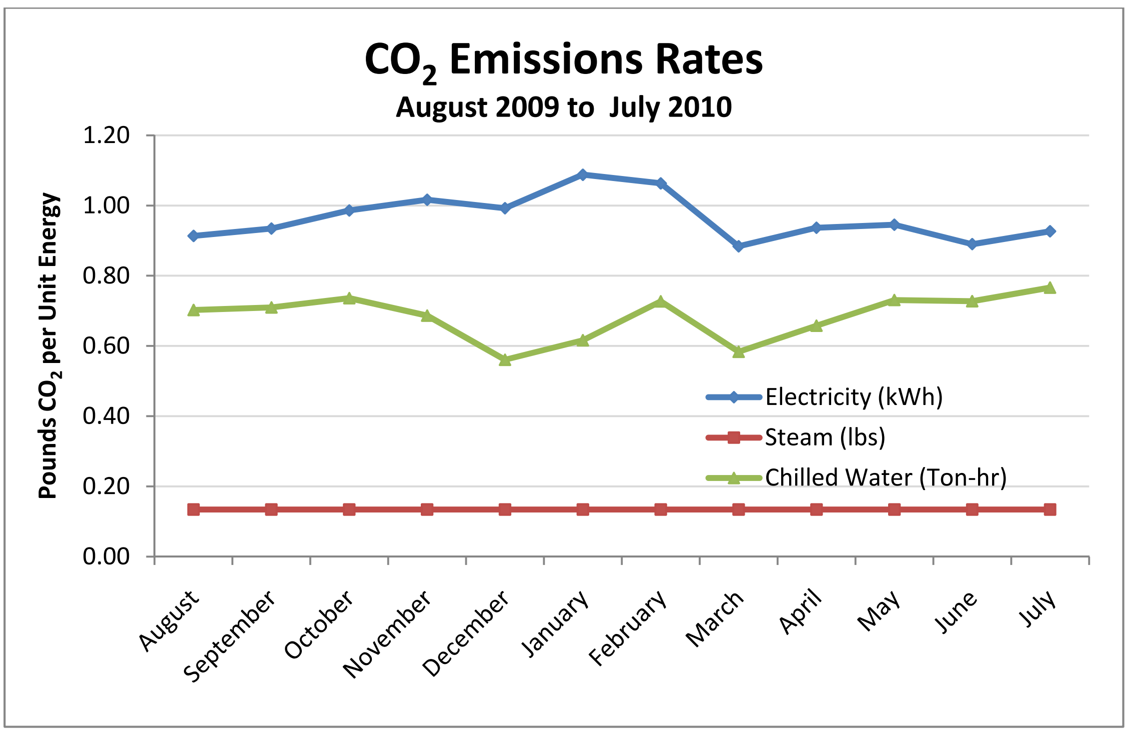
Chilling station efficiency is measured in kW/ton, and can range from 0.4 up to 1.0, depending on the station running. The past year average was 0.74 kW/ton, however an annual average does not take into account the wide seasonal swings and efficiency is better reported on at least a monthly basis. Knowing the overall kW/ton to generate chilled water, the MMBTU/kWh to generate electricity, and the $lbs_{CO2}/MMBTU$ in natural gas, a resulting $lbs_{CO2}/ton\text{-}hr$ can be calculated.

2009 Monthly Averages

The table below shows the monthly averages for the past year, from August 2009 through July 2010, based on the methodology just described.

Past Year	Electricity mmBTU/kWh	Electricity lbsCO2/kWh	Steam mmBTU/lb	Steam lbsCO2/lbSTEAM	Chilled Water kW/Ton	Chilled Water lbsCO2/Ton-hr
August 2009	0.0083	0.91	0.0012	0.134	0.77	0.70
September 2009	0.0085	0.93	0.0012	0.134	0.76	0.71
October 2009	0.0090	0.99	0.0012	0.134	0.75	0.74
November 2009	0.0092	1.02	0.0012	0.134	0.68	0.69
December 2009	0.0090	0.99	0.0012	0.134	0.56	0.56
January 2010	0.0099	1.09	0.0012	0.134	0.57	0.62
February 2010	0.0097	1.06	0.0012	0.134	0.68	0.73
March 2010	0.0080	0.88	0.0012	0.134	0.66	0.58
April 2010	0.0085	0.94	0.0012	0.134	0.70	0.66
May 2010	0.0086	0.95	0.0012	0.134	0.77	0.73
June 2010	0.0081	0.89	0.0012	0.134	0.82	0.73
July 2010	0.0084	0.93	0.0012	0.134	0.83	0.77
Weighted Avg	0.0090	0.99	0.0012	0.134	0.74	0.68

This data is presented graphically to demonstrate the monthly variations:



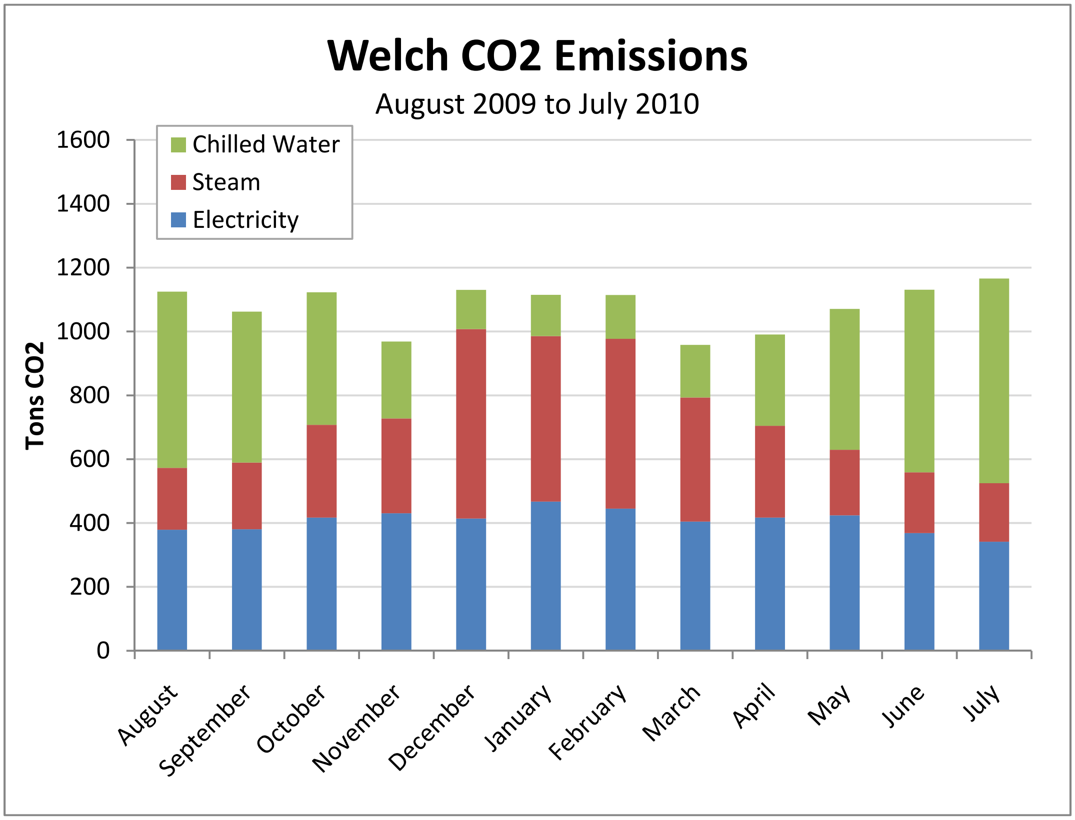
Evaluating the Carbon Footprint of a Building

By combining the CO_2 emission rates above with the metered energy usage for a building the total carbon emissions associated with that building's energy usage can be evaluated. As an example, below are the metered totals for a few months of energy usage at Welch Hall (WEL):

Welch	Electricity	Steam	Chilled Water
Past Year	kWh	lbs	ton-hrs
August 2009	829,941	2,895,690	1,570,985
September 2009	814,121	3,119,230	1,333,344
October 2009	846,079	4,333,980	1,128,734
November 2009	846,887	4,439,760	700,809
December 2009	834,652	8,856,360	439,261
January 2010	858,504	7,743,350	419,014
February 2010	837,290	7,943,510	376,722
March 2010	915,799	5,803,810	563,970
April 2010	890,116	4,294,750	869,213
May 2010	897,556	3,063,900	1,207,779
June 2010	828,089	2,844,720	1,572,641
July 2010	736,803	2,735,850	1,673,554

These totals can be multiplied by the respective 2009 CO_2 rates to obtain the associated tons of carbon dioxide emissions that resulted from generating energy for Welch, as shown below:

Welch	Electricity	Steam	Chilled Water	Total
Past Year	Tons CO2	Tons C02	Tons CO2	Tons CO2
August 2009	379	194	552	1125
September 2009	380	209	473	1062
October 2009	417	290	415	1123
November 2009	430	297	241	968
December 2009	414	593	123	1131
January 2010	467	519	129	1115
February 2010	445	532	137	1114
March 2010	405	389	165	958
April 2010	417	288	286	990
May 2010	424	205	441	1071
June 2010	368	191	572	1131
July 2010	341	183	641	1166



This shows that the total carbon emissions due to Welch's energy needs remain relatively steady from month-to-month, averaging 1080 tons of CO_2 per month. Electricity for lighting and equipment stays consistent as well, while missions related to heating steam decrease as the weather warms up into the summer, and conversely chilled water demand increases.

Conclusion

This method and the data presented is reliable and accurate enough for most situations encountered on campus, especially if looking into monthly or annual carbon savings related to planned or completed projects. However, it is still important to understand the assumptions involved:

1. *Constant CO_2 emissions factor*
   The EPA value is based on a constant HHV of 1020; realistically, this value fluctuates between +/- 3%, sometimes staying high or low for months at a time. This value also does not account for equipment start-ups and very low-load conditions.
2. *Constant steam efficiency*
   A steady steam generation efficiency is reasonable for monthly or greater averages, however it does not account for the daily swings associated with varying demand and equipment outages.
3. *Monthly averages*
   These monthly averages *cannot* be used for predicting swings in building occupancy during a

single day or even from week to week. This is especially true for chilled water production, with efficiencies that can swing by as much as 30% over a single day.

The first two assumptions can be addressed through a much more thorough energy balance of utilities, taking into account the efficiencies and run-times of each piece of equipment in the process. The 4th limitation is more easily addressed, and real-time values of CO_2 emissions can and have been calculated when necessary.

References:

[1] http://www.epa.gov/ttn/chief/ap42/ch03/index.html

[2] http://www.epa.gov/chp/basic/methods.html