DEVELOPMENT OF A WEB-BASED EMISSIONS REDUCTION CALCULATOR FOR RETROFITS TO MUNICIPAL WATER SUPPLY AND WASTE WATER FACILITIES

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ABSTRACT

Four areas in Texas, involving 16 counties, have been designated by the United States Environmental Protection Agency (EPA) as non-attainment areas because ozone levels exceed the National Ambient Air Quality Standard (NAAQS) maximum allowable limits. These areas face severe sanctions if attainment is not reached by 2007. Four additional areas, involving 25 counties, in the state are also approaching national ozone limits (i.e., affected areas).

In 2001, the Texas State Legislature formulated and passed the Texas Emissions Reduction Plan (TERP), to reduce ozone levels by encouraging the reduction of emissions of NOx by sources that are currently not regulated by the state. Ozone results from photochemical reactions between oxides of nitrogen (NOx) and volatile organic compounts (VOCs) in the presence of sunlight. An important part of this legislation is the State's energy efficiency program, which includes reductions in energy use and demand that are associated with the adoption of the 2000 International Energy Conservation Code (IECC 2000), including the 2001 Supplement (IECC 2001) which represents one of the first times that the EPA is considering State Implementation Plan (SIP) credits from energy conservation and renewable energy– an important new development for building efficiency professionals, since this could pave the way for documented procedures for financial reimbursement for building energy conservation from the state's emissions reductions funding.

This paper presents the procedures developed and used to calculate the electricity savings from potential retrofits to municipal water supply and waste water facilities. The methodology integrates the ASHRAE Inverse Model Toolkit (IMT) [1] used for weather normalization, a peak-extractor for calculating peak-day electricity savings and the use of the EPA's Emissions and Generations Resource Integrated Database (eGRID [2]) for calculating potential NO_x emissions reductions for the electric utility provider associated with the user.

INTRODUCTION

In 2001, the Texas State Legislature formulated and passed Senate Bill 5 to further reduce ozone levels by encouraging the reduction of emissions of NOx by sources that are currently not regulated by the state, including area sources (e.g., residential emissions), on-road mobile sources (e.g., all types of motor vehicles), and non-road mobile sources (e.g., aircraft, locomotives, etc.)[3]. An important part of this legislation is the evaluation of the State's new energy efficiency programs, which includes reductions in energy use and demand that are associated with specific utility-based energy conservation measures, and implementation of the International Energy Conservation Code (IECC), published in 2000 as amended by the 2001 Supplement (IECC 2000; 2001). In 2001 thirty-eight counties in Texas were designated by the EPA as either non-attainment or affected areas[4]. In 2003, three additional counties were classified as affected counties[5], bringing the

[1] IMT, the inverse modeling toolkit is a FORTRAN 90 application for regression modeling of building energy use. Its development was sponsored by ASHRAE 1050-RP in support of ASHRAE GPC-14. IMT is capable of identifying traditional linear, least-squares regression models. it is also capable of identifying special change-point and variable-base degree-day models that have been shown to be especially useful for modeling building energy use.

[2] E-GRID, ver. 2, is the EPA's emissions and generation resource integrated database. This publicly available database can be found at *www.epa.gov/airmarkets/egrid/*.

[3] In the 2003 Texas State legislative session, the emissions reductions legislation in Senate Bill 5 was modified by House bill 3235, and House Bill 1365. In general, this new legislation strengthens the previous legislation, and did not reduce the stringency of the building code or the reporting of the emissions reductions.

[4] The sixteen counties designated as non-attainment counties include: Brazoria, Chambers, Collin, Dallas, Denton, El Paso, Fort Bend, Hardin, Harris, Jefferson, Galveston, Liberty, Montgomery, Orange, Tarrant, and Waller counties. The twenty-two counties designated as affected counties include: Bastrop, Bexar, Caldwell, Comal, Ellis, Gregg, Guadalupe, Harrison, Hays, Johnson, Kaufman, Nueces, Parker, Rockwall, Rusk, San Patricio, Smith, Travis, Upshur, Victoria, Williamson, and Wilson County.

[5] These counties are Henderson, Hood and Hunt counties in the Dallas – Fort Worth area.

total to forty-one counties (sixteen non-attainment and twenty-five affected counties). On February 2004, the TCEQ issued a document entitled "Incorporating Energy Efficiency/Renewable Energy (EE/RE) Projects into the SIP: A Guide for Local Entities", which provides guidance on how political subdivisions can assist the TCEQ in taking credit for emissions reductions from energy efficiency measures implemented at the political subdivision level. According to this TECQ guidance energy efficiency, renewable energy and no-emission distribuited generation strategies that may be considered for inclusion as SIP measures comprise, but is not limited to, the Utility Water and Wastewater Energy-Related Improvements. This paper is a response to that guide and describes a methodology to assess the potential emissions reduction from the electricity savings from the implementation of retrofit measures to city-wide, water/waste water distributions.

METHODOLOGY

The methodology developed in this study evaluates the potential emission reductions from retrofitting water supply and waste water distribution systems using a two-step regression method: one step to relate the gallons of water pumped or waste water treated to ambient temperatures, and a second step that relates the gallons of water pumped or waste water treated to the electricity consumed during a given period. The model that was developed uses pre- and post-retrofit monthly utility billing data (i.e., electricity use and gallons of water or waste water processed), and daily weather data corresponding to the billing period. These data are then processed with the ASHRAE Inverse Method Toolkit (IMT) analysis software (Kissock et al. 2003; Haberl et al. 2003) in a two-step procedure to evaluate the performance of the water or waste water pumping system, and any weather dependence using average daily temperatures. Both pre-retrofit and post-retrofit data are weather normalized to the 1999 base year , so the evaluation of the potential savings can be performed using base-year weather conditions. Finally the potential annual and peak ozone period emissions reductions are determined using the EPA's eGRID, emissions and generation resource integrated database[6].

Municipal Water/Waste-water Analysis Description

When the user submits their municipal water and waste-water project for analysis, the emissions calculator performs a series of calculations, as indicated in Figure 1. For each analysis, the user is required to enter 12 pre-retrofit utility bills and 12 post-retrofit utility bills, as shown in Table 1, including the monthly water pumped and electricity used by the pumps that either supplied the water or handled the waste water[7].

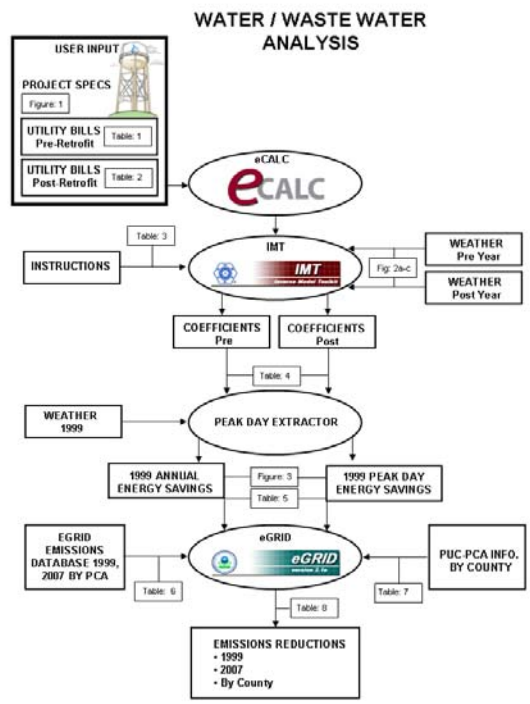

Figure 1. Municipal water and waste-water analysis flowchart.

To perform the appropriate weather normalization of the potential energy savings, ASHRAE's Inverse Model Toolkit (Kissock et al. 2002) is used in a two-step analysis. In the first step of the analysis, IMT is used to determine the statistical relationship between the pre-retrofit electricity used by the pumps and the water produced (i.e., municipal water supply system) or waste-water processed. This same process is then repeated for the post-retrofit period. In the second step of the analysis, IMT is used to develop change-point linear models for the pre-retrofit and post-retrofit periods

[6] The peak day savings calculations are required by the EPA for the prediction of NOx emissions reductions on a peak ozone day, which can represent a specific peak day during the base year (i.e., August 19th, 1999), or an average day across the ozone episode period (i.e., July 15th to September 15th for Texas).

[7] In this example analysis data from the City of College station from 2002 was reduced by 10% and then reported as 2003 data.

using corresponding averages of the NOAA weather data from the nearest weather location.

Table 1. Pre-Retrofit and post-retrofit monthly electricity bills for water use and pumping electric load (corresponding, respectively, to the Table 1 and Table 2 of the municipal water and waste-water analysis flowchart).

Pre-Retrofit			
Month	days	Water Consumption [gallon]	Electricity Consumption by pumping [kWh]
Jan-02	31	216,252,688	18,103
Feb-02	28	205,583,052	14,027
Mar-02	31	232,927,565	35,381
Apr-02	30	285,786,522	37,225
May-02	31	396,652,055	62,360
Jun-02	30	354,282,824	69,070
Jul-02	31	312,277,562	94,847
Aug-02	31	422,068,375	104,995
Sep-02	30	364,414,294	78,636
Oct-02	31	283,223,385	39,474
Nov-02	30	227,389,529	17,183
Dec-02	31	205,176,729	16,559

Post-Retrofit			
Month	days	Water Consumption [gallon]	Electricity Consumption by pumping [kWh]
Jan-03	31	205,440,054	15,388
Feb-03	28	195,303,900	11,923
Mar-03	31	221,281,186	30,074
Apr-03	30	271,497,196	31,641
May-03	31	376,819,452	53,006
Jun-03	30	336,568,683	58,710
Jul-03	31	296,663,684	80,620
Aug-03	31	400,964,956	89,246
Sep-03	30	346,193,579	66,841
Oct-03	31	269,062,216	33,553
Nov-03	30	216,020,052	14,606
Dec-03	31	194,917,892	14,075

As shown in Figure 1, IMT then produces pre-retrofit and post-retrofit coefficients (see Figure 2 and Table 3) that are used to determine the annual energy use in 1999 and the 1999 peak day energy use for the Ozone Episode Day (August 19, 1999), as shown in Figure 2. In Table 1, as an example, electricity use and the gallons of water pumped data from the City of College Station, TX for a pre-retrofit period (2002) and a hypothetical post-retrofit period (2003) is provided. For each of these periods the data are processed twice by the IMT. First, in the upper graphs of Figure 2, IMT was used to determine the weather-normalized water use for the city using a 3-parameter change-point linear model against average billing period temperature for the 2002 pre-retrofit (left graph), and 2003 post retrofit period (right graph). Next, thru IMT it is determined the performance of the facility using a 4-parameter change-point linear analysis that regressed the electricity use against the corresponding gallons of water that were pumped during the corresponding period.

Table 2. Example of IMT input file (corresponding to the Table 3 of the municipal water and waste-water analysis flowchart).

```
Path and name of input data file = dataWWW.prn
Value of no-data flag = -99
Column number of group field = 4
Value of valid group field = 1
Residual file needed (1 yes, 0 no) = 1
Model type (1:Mean,2:2p,3:3pc,4:3ph,5:4p,6:5p,7:MVR,8:HDD,9:CDD) = 5
Column number of dependent Y variable = 3
Number of independent X variables (0 to 6)  = 1
Column number of independent variable X1 = 2
Column number of independent variable X2 = 0
Column number of independent variable X3 = 0
Column number of independent variable X4 = 0
Column number of independent variable X5 = 0
Column number of independent variable X6 = 0
```

Table 3. Example of the output coefficients from IMT (corresponding to the Table 4 of the municipal water and waste-water analysis flowchart).

```
*********************************************
 ASHRAE INVERSE MODELING TOOLKIT (1.9)

*********************************************
    Output file name = IMT.Out

*********************************************
    Input data file name = DAILY2.dat
    Model type =           3P Cooling
    Grouping column No =     5
    Value for grouping =     1
    Residual mode =          1
    # of X(Indep.) Var =     1
    Y1 column number =       6
    X1 column number =    9
    X2 column number =    0 (unused)
    X3 column number =    0 (unused)
    X4 column number =    0 (unused)
    X5 column number =    0 (unused)
    X6 column number =    0 (unused)

*********************************************
    Regression Results
           N =      12
          R2 =      0.835
       AdjR2 =      0.835
        RMSE =       1.0560
     CV-RMSE =     11.006%
           p =     -0.346
          DW =      2.682 (p>0)
          N1 =       3
          N2 =       9
   -------------------------------------
         Ycp =       6.9610 (       0.4799)
          LS =       0.0000 (       0.0000)
          RS =       0.1864 (       0.0262)
         Xcp =      55.0408 (       0.6926)
   -------------------------------------
```

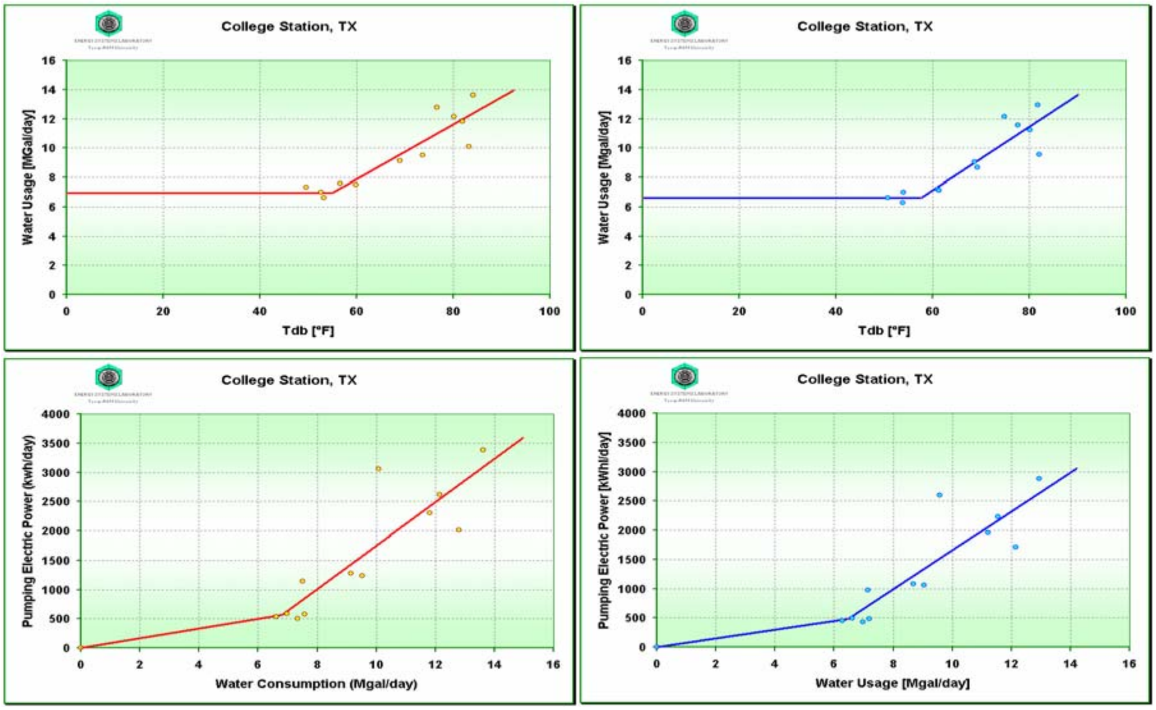

Figure 2. Pre-retrofit and pos-retrofit representation of the water use versus outside temperature and electricity use as a function of the water pumped models for the municipal water use (corresponding to the Figure 3 of the municipal water and waste-water analysis flowchart).

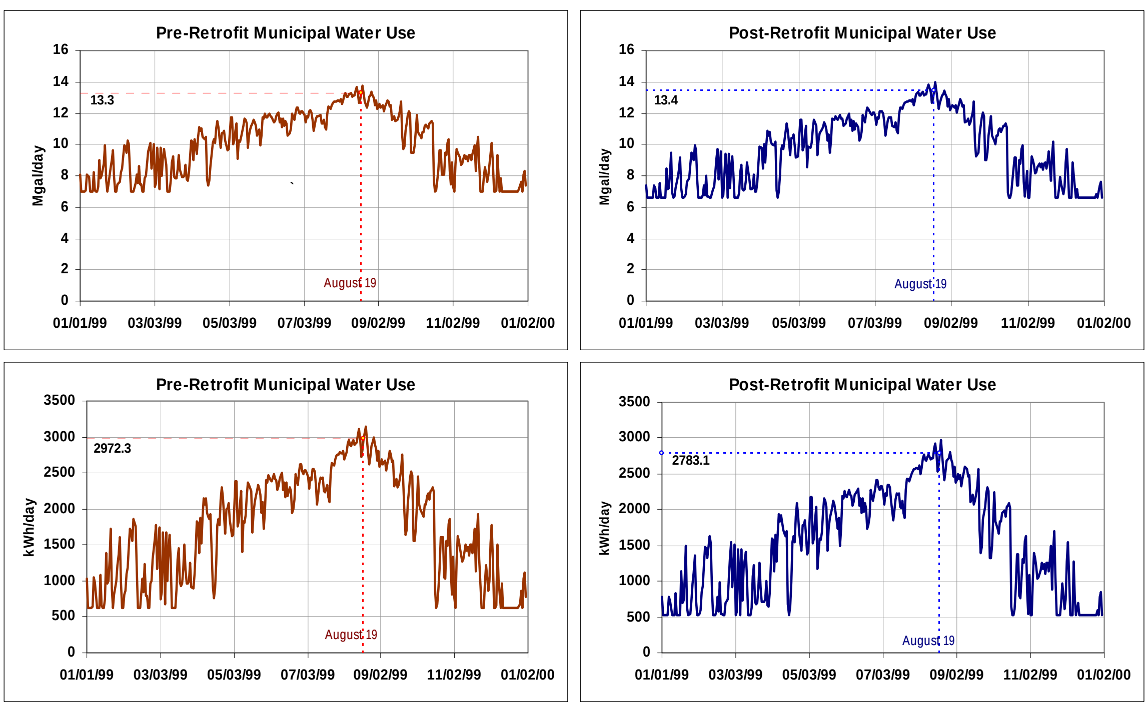

Figure 3. Peak output representation from eCALC's peak day extractor (corresponding to the Figure 3 of the municipal water and waste-water analysis flowchart).

Table 4. Example energy savings summary obtained from eCALC's peak day extractor (corresponding to the Table 5 of the municipal water and waste-water analysis flowchart).

75,521	kWh	Annual Energy Savings
199	kWh	OSDavg
189.22	kWh	OSDpkChosen

The pre-retrofit and post-retrofit water use (i.e., the gallons of water used, normalized for weather variations), and the system performance (i.e., the electricity used to pump the water) coefficients were then applied to the 1999 weather data to calculate the normalized savings for the 1999 base year as shown in Figure 3, which shows the normalized pre-retrofit daily municipal water use (upper left graph), and post-retrofit daily water use (upper right graph) varying from a low of 7 million gallons per day to a high of 14 million gallons per day. The lower graphs of Figure 3 show the normalized electricity used by the municipal pumping facilities for 1999, including the normalized daily pre-retrofit electricity use for 1999 (lower left graph), and normalized daily post-retrofit electricity use for 1999 (lower right graph). Also, indicated on these graphs is the normalized peak-daily electricity use for August 19, 1999, which is the peak Ozone Episode Day for 1999. Table 4 shows the normalized annual electricity savings for the 1999 base year, which includes 75,521 kWh/year, and 189 kWh/day on the peak Ozone Episode Day (OSD). Also shown is the average daily savings for the Ozone Season Period (i.e., July 15th through September 15th).

In the final step the emissions calculator calculates the potential savings of NO_x, using the USEPA's eGRID database. These results are then reported by eCALC, in a format that is similar to that shown in Figure 8 for residential and emailed to the user as HTML and XML files.

Municipal Water/Waste Water Supply Input Screens

The main eCALC screen is shown in Figure 4, this figure shows the choices for New Buildings (i.e., single-family, multi-family, office, retail); Community Projects (i.e., municipal buildings, street lights, traffic lights, water and waste water supply); and Renewables (i.e., solar PV, solar thermal, wind).

The user input screens for municipal water (water supply) and waste water retrofit projects begin with the general project input screen shown in Figure 5. When the user submits the type of project to the emissions calculator they are directed to the screen shown in Figure 6. This input screen asks for specific information about the beginning dates for the 12 months of pre-retrofit data and for the post-retrofit. After entering this information, the user can enter the pre-retrofit and post-retrofit data into the screen shown in Figure 7. When the user completes entering 12 periods of both the pre-retrofit and post-retrofit data, the project is submitted for analysis. At this point the emissions calculator report the potential emission reduction as in the Figure 8, which include the 1999 normalized annual pre and post-retrofit electricity use, as well as the average Ozone Season Day[8], and peak day electricity and emissions savings.

Figure 4. Main eCALC screen.

SUMMARY

This paper has described the methods that have been developed to compute annual and peak day NOx emissions reduction from retrofitting municipal water or waste-water pumping systems, and includes the procedures used to weather-normalize the calculated electricity production to the 1999 base year using ASHRAE's Inverse Model Toolkit (IMT). Additional information about these procedures can be found in Haberl et al. (2004a, b, c), by visiting the emissions calculator "ecalc.tamu.edu", or by visiting the Laboratory's Senate Bill 5 web site "eslsb5.tamu.edu".

[8] This value appears further down the printout that is mailed to the user, and therefore is not shown. The values shown in this figure are for display purposes, and include only values for NOx.

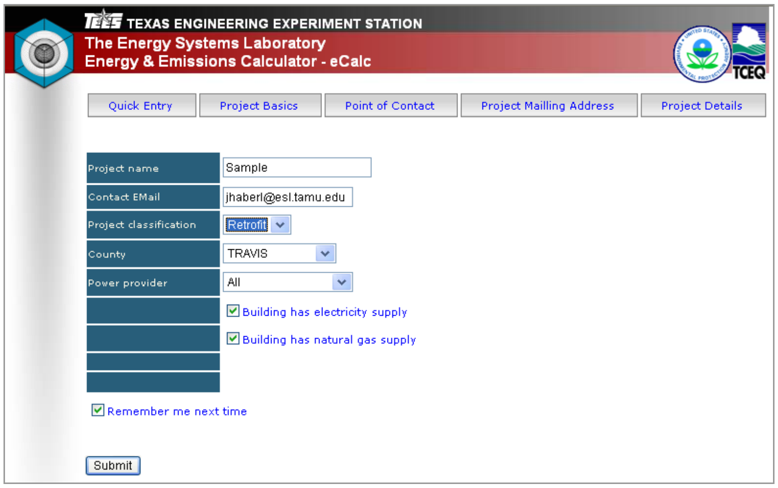

Figure 5. Project input screen -Municipal water or waste water retrofit data entry.

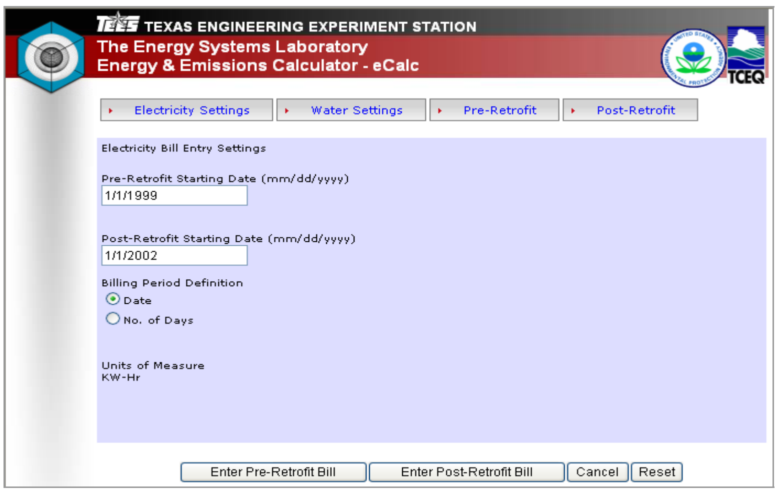

Figure 6. Project pre and post dates range screen -Municipal water or waste water data entry.

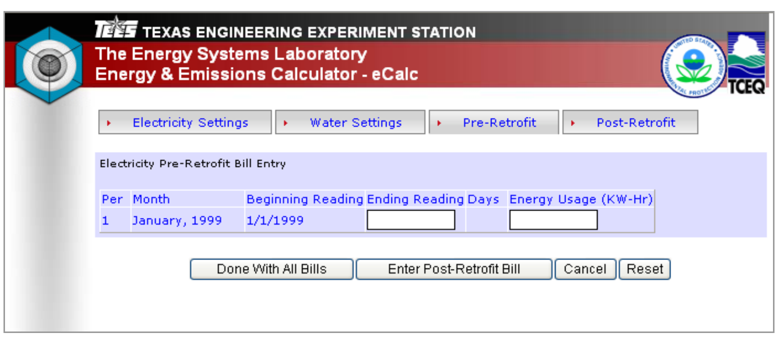

Figure 7. Project pre and post utility bill data screen -Municipal water or waste water retrofit data entry.

Preliminary test data, not for attribution or distribution

Report on Project 264: Andrew QA Test, TRAVIS

Project Information

Project ID	264
Job ID	65
County	TRAVIS
Project Name	Andrew QA Test
Project POC EMail	andrewniemann@tees.tamus.edu
Project Type	WS_BILL

1: ANNUAL Energy Savings

1.1: ANNUAL Energy Consumption

Consumption	Electricity (kWh)
Pre-Retrofit	634,333
After Retrofit	525,870

1.2: ANNUAL Energy: Savings (- implies increase in energy consumption)

Comparison	Electricity (kWh)
After Retrofit vs Pre-Retrofit	108,463

1.3: ANNUAL Emissions Savings (- implies increase in emissions)

1998

Comparison	Emissions (in lbs)		
	NOx	SOx	CO2
After Retrofit vs Pre-Retrofit	427.15	0.00	0.00

2007

Comparison	Emissions (in lbs)		
	NOx	SOx	CO2
After Retrofit vs Pre-Retrofit	37.33	0.00	0.00

Figure 8. Potential emission reduction from water use or water waste example as it is presented in the eCALC screen.

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