# Technical Report Two

Building and Plant Energy Analysis Report

**National Rural Utilities Cooperative Finance Corporation (NRUCFC) Headquarters Building**
**Sterling, VA**

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**10.26.2011**

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# Executive Summary

The purpose of Technical Assignment Two is to perform a block load and energy use estimate of the National Rural Utilities Cooperative Finance (NRUCFC) Headquarters Building using a computer-based method. The new headquarters building is 120,000 square foot office building that will also house a fitness center, café, and executive lounge. The three-story above grade building is located on a 42-acre lot in Sterling, VA, about 10 miles north of the Dulles International Airport, at the intersection of Route 28 & 7. The headquarters is LEED® Gold certified.

To determine the loads and the energy use of the building, TRANE Trace 700 was used. A block load method was used to determine both the loads and energy consumption. The building loads were compared to ASHRAE Pocket Guide values and were found to be much lower than the standard's values. The large difference is believed to be because of errors in modeling the systems as they are designed and because block load method was used as opposed to a space-by-space method, which would have been more accurate.

Using the same model, energy consumption, operating costs and emissions were calculated. The calculated values were compared to national average of buildings with similar square footage and function. The electrical consumption exceeded the national average while the natural gas consumption was roughly half the national average.

# Mechanical Systems Overview

### Primary Cooling

Two 210 ton electric centrifugal chillers are located in the first floor central plant. They incorporate oil-free compressors to increase part-load efficiency. Six "ice on coil" storage tanks will circulate 25% ethylene glycol solution through the chillers. Two induced draft cooling towers are located on the roof. The central plant and piping has been configured to allow for future expansion and serve as the central plant for other buildings.

### Primary Heating

Two high efficiency natural gas-fired condensing boilers are located in the mechanical penthouse and serve as the primary heating source. They will circulate water to the terminal units with a hot water heat feature. The heating plant is also configured for future expansion.

### Atrium Heating and Cooling

A combination of radiant flooring and ventilation units serve as the heating and cooling for the three story atrium. A water to water heat pump serves the radiant flooring while three ground source heat pumps ventilate the space. Both systems are connected to the geothermal well located in the parking lot.

### Office Space Heating and Cooling

Four central air handling units, located on the roof, serve as the heating and cooling for the office spaces, supplying to the zones shown in Figure 1. The perimeter spaces are ventilated by fan powered boxes with a hot water coil. Interior spaces are ventilated by VAV boxes.

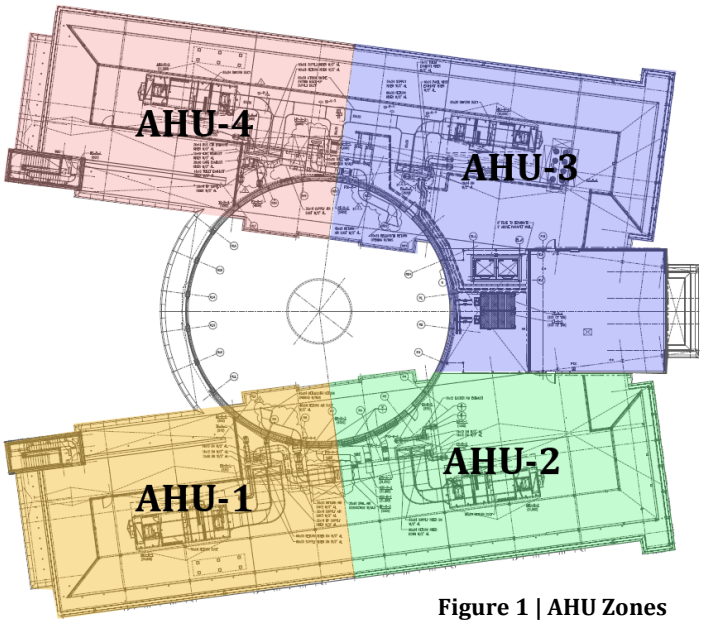


**Figure 1 | AHU Zones**

# Design Load Estimation

## Block Assumptions

### Weather Data

Weather data from the ASHRAE Handbook of Fundamentals for Washington, D.C. was used for the load and energy simulation. The project location of Sterling, VA is approximately 30 miles from Washington D.C. and experiences similar weather conditions. Table 1 provides a summary of the weather design conditions used in the simulation.

| Table 1 \| ASHRAE Weather Data \| Washington, D.C. | | | |
|---|---|---|---|
| **ASHRAE Values** | **Outdoor DB ($^{o}$F)** | **Outdoor WB ($^{o}$F)** | **Design Indoor DB ($^{o}$F)** |
| **Summer Design Cooling (0.4%)** | 93.2 | 75.1 | 75.2 |
| **Winter Design Heating (99.6%)** | 9.6 | - | 71.8 |

### Occupancy

Occupancy for each space was determined from the design documents provided by the project team and therefore the ASHRAE Occupant Densities were not used.

### Lighting Loads

Lighting loads were assumed on a Watt per square foot basis. Because of the variety in lighting fixtures used throughout the building, the lighting power densities were taken from ASHRAE Standard 90.1-2007 to simplify the model. If exact values based on the fixtures were used for each space, a more accurate model could be generated.

### Electrical Loads

Electrical Loads were assumed on a Watt per square foot basis. For spaces with large equipment loads, a larger density was assumed.

### Ventilation

The ventilation rates were assumed on cfm per person rate for regularly occupied spaces like offices or conference rooms or a cfm per square foot rate for spaces such as corridors and storage areas. The occupancy classifications from ASHRAE Standard 62.1-2007 were used to determine the rates for the different spaces.

### Wall Construction

The wall type for exterior walls was generalized to save time. It was assumed that all walls were face brick, 4" light weight concrete and 6" insulation. From this TRACE output a U-factor of .0403. The walls however do vary. On the east side and part of the north and south walls are mainly brick while the west walls and the other part of the north and south walls are primarily glass with shading devices. The glazing was also assumed to be consistent throughout the building and was given an assumed U-factor of .214. The glazing percentage was assumed to be 40%, the maximum allowed by ASHRAE Standards. It was also assumed that shading devices were used on the glazing.

### Schedules

Schedules were not assigned in TRACE to be able to find the max load that the building would consume if they were to operate continuously for 24 hours.

A summary of the TRANE Trace templates with all assumptions can be found in Appendix A.

## System Load Analysis Results

Table 2 summarizes the results of the load analysis performed in TRANE Trace 700. The values of the design loads from the engineer were unknown so the results are compared to the ASHRAE Pocket Guide check figures. The calculated values are roughly four times lower than the average check figure for refrigeration. Loads for each space could have been underestimated for each piece of equipment was not accounted for within each space. The percentage of glass used for the exterior spaces was assumed and modeled as 40%, based on ASHRAE's maximum requirement, but there is more glazing used on the exterior walls but the exact value was unknown, which could have led to the discrepancy in the results. In order to get the most accurate results, each room would have to be modeled with all its design conditions and not with the block load assumptions used. Additionally, all the systems used in the NRUCFC Headquarters building were not modeled. The four main air handlers and the heat pump that serves the atrium and main lobby were modeled but the heat pump that serves the stairways and the radiant flooring in the atrium was not modeled.

**Table 2 | System Load Results**

| System | Cooling ($ft^2$/ton) | Heating (BTU/h-$ft^2$) | Total Supply Air (cfm/$ft^2$) |
|---|---|---|---|
| **AHU-1** | 1020.88 | 28.78 | 0.80 |
| **AHU-2** | 897.80 | 31.80 | 1.06 |
| **AHU-3** | 1088.00 | 26.93 | 0.75 |
| **AHU-4** | 843.10 | 32.52 | 0.90 |
| **HP-3** | 70.40 | 110.84 | 1.77 |
| **ASHRAE Guide** | 280.00 | - | 1.0-1.6 |

# Annual Energy Consumption and Operating Costs

The annual energy consumption and operating costs were modeled using the same TRANE Trace model used for the heating and cooling loads. The cooling plant was modeled as two water cooled chillers with cooling towers for absorption chillers. The ice storage tank was neglected. The heating plant was modeled as two natural gas fired boilers. An energy analysis was performed by the design engineer using a combination of eQUEST, TRANE Trace, and Excel. The analysis was unavailable for comparison. No schedule was provided so it was assumed that everything was operating 24 hours a day, 7 days a week.

## Energy Consumption

Table 3 below shows a breakdown of energy consumption by system. Figure 1 shows the same results. The lighting and receptacle loads appear to consume the most energy annually and the cooling energy consumption appears to be larger than the heating load. The results are inaccurate. The primary heating should be the largest consumer of energy. The lighting and receptacle values could be off because they are scheduled to be 100% available when in reality the lighting would be on occupancy schedules and the receptacle load would consume the most energy during normal work hours. Also, due to unfamiliarity with the modeling software the heating and cooling plants may not be modeled as designed. Mircoturbines and a photovoltaic array were not modeled as part of the energy analysis. They would have led to a reduction in energy consumption for the lighting and receptacle loads.

**Table 3 |Energy Consumption**

| System | Electric Consumption (kWh) | Gas Consumption (kBtu) | Water Consumption (1000 gallons) | Total Building Energy (kBtu/yr) | % of Total Building Energy |
|---|---|---|---|---|---|
| **Primary Heating** | | **1,601,655** | | **1,601,655** | **15.4%** |
| **Primary Cooling** | **504,574** | | **1,616** | **1,722,111** | **16.6%** |
| Cooling Compressor | 349,405 | | | 1,192,518 | 11.5% |
| Tower/Cond Fans | 41,552 | | 1,616 | 141,818 | 1.4% |
| Condenser Pump | 104,857 | | | 357,878 | 3.5% |
| Other Clg Accessories | 8,760 | | | 29,898 | 0.3% |
| **Auxiliary** | **98,576** | | | **336,439** | **3.2%** |
| Supply Fans | 17,633 | | | 60,182 | 0.6% |
| Pumps | 80,942 | | | 276,257 | 2.7% |
| **Lighting** | **891,231** | | | **3,041,772** | **29.3%** |
| **Receptacle** | **1,075,234** | | | **3,669,774** | **35.4%** |
| **Totals** | **2,569,615** | **1,601,655** | **1,616** | **10,371,751** | **100.0%** |

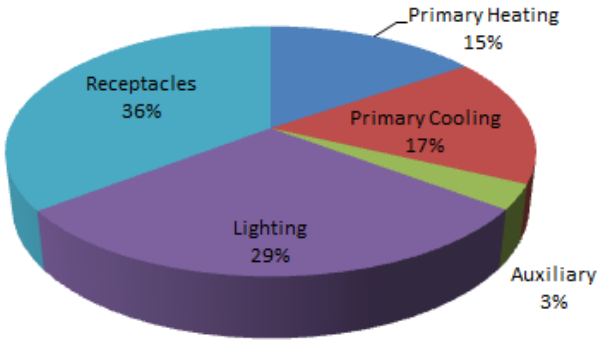


**Figure 1 | Energy Consumption**

## Building Energy Costs

The energy and natural gas rates for Virginia were used and are shown in Table 4 below. The values were taken from the US Energy Information Administration because no actual utilities bills were available.

| Table 4 \| Utility Rates | |
|---|---|
| Electricity ($/kWh) | .0821 |
| Natural Gas ($/1000 $ft^3$) | 10.63 |

### Monthly Utility Costs

Based on the utility rates in Table 4, monthly operating costs were generated. Figure 2 below shows the monthly operating cost for both electricity and natural gas. The natural gas peaks during the winter months when the heating load is the greatest. The electric load peaks during the summer months when the cooling load is the greatest.

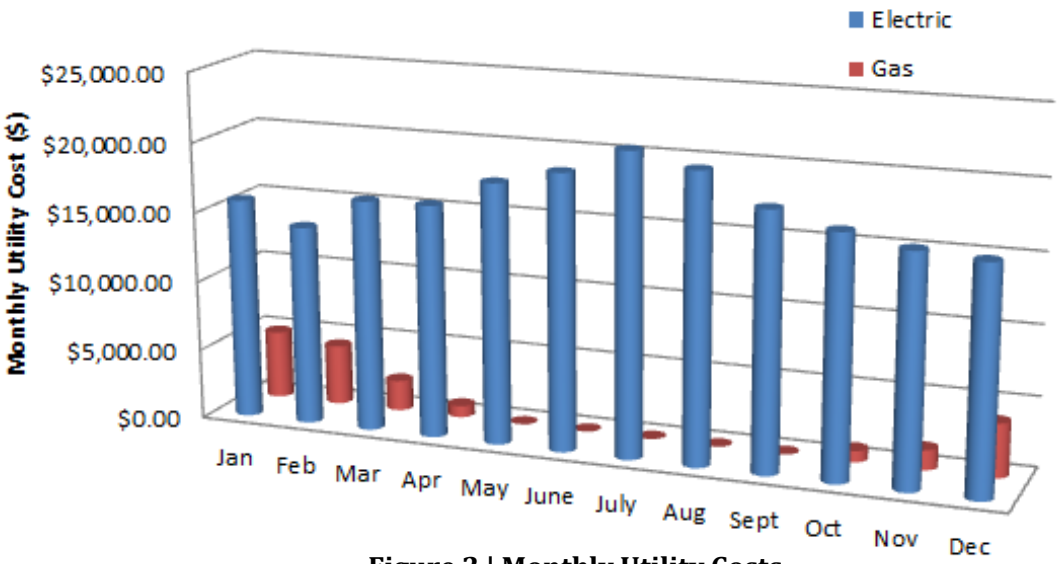


**Figure 2 | Monthly Utility Costs**

### Annual Energy Costs

The annual total operating cost is approximately $229,191.44 per year and $2.38 per square foot. The annual operating cost is higher than it should be due to modeling errors. As previously mentioned, if the additional on-site energy producing systems were modeled the utility costs would be lower both annually and monthly. Compared to Commercial Buildings Energy Consumption Survey (CBECS) tables (found in Appendix B) provided by the U.S. Energy Information Administration (EIA), the NRUCFC Headquarters building exceeds the national averages in terms of electrical energy use but is well under the average for natural gas as shown in Table 5 below.

| Table 5 \| Energy Consumption (kBtu/ft$^2$) | |
|---|---|
| **Electricity** | |
| Calculated | 91.2 |
| 100,001 to 200,000 ft$^2$ Buildings | 57.7 |
| Office Buildings | 58.9 |
| **Gas** | |
| Calculated | 16.6 |
| 100,001 to 200,000 ft$^2$ Buildings | 36.5 |
| Office Buildings | 32.8 |

## Building Emission Rates

The emission rates for pollutants have been calculated based on the total energy consumption determined from the block load model previously discussed. The results for the NRUCFC Headquarters building pollutants can be found in Table 6 below. The emission factors were taken from tables provided by the National Renewable Energy Laboratory (NREL) which can be found in Appendix C.

| Table 6 \|Pollution Emission Rates | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Pollutant** | **Electricity** | | | **Natural Gas** | | | **Total Pollutants (lbs/yr)** |
| | **Emission Factor (lb/kWh)** | **Electric Consumption (kWh/yr)** | **Electric Total (lb/yr)** | **Emission Factor (lb/1000 ft$^3$)** | **Gas Consumption (1000 ft$^3$/yr)** | **Gas Total (lbs/yr)** | |
| $CO2_e$ | 1.40E+00 | 2,569,615 | 3,597,461 | 1.97E+00 | 1,560 | 3,072 | 3,600,533 |
| **CO2** | **1.33E+00** | **2,569,615** | **3,417,588** | **1.96E+00** | **1,560** | **3,057** | **3,420,645** |
| $CH_4$ | 2.52E-02 | 2,569,615 | 64,754 | 4.00E-05 | 1,560 | 0 | 64,754 |
| $N_2O$ | 2.81E-05 | 2,569,615 | 72 | 4.00E-05 | 1,560 | 0 | 72 |
| **$NO_x$** | **2.67E-03** | **2,569,615** | **6,861** | **1.78E-03** | **1,560** | **3** | **6,864** |
| **$SO_x$** | **8.04E-03** | **2,569,615** | **20,660** | **1.01E-05** | **1,560** | **0** | **20,660** |
| CO | 9.74E-04 | 2,569,615 | 2,503 | 1.50E-03 | 1,560 | 2 | 2,505 |
| TNMOC | 8.77E-05 | 2,569,615 | 225 | 9.82E-05 | 1,560 | 0 | 226 |
| Lead | 1.02E-07 | 2,569,615 | 0 | 9.01E-09 | 1,560 | 0 | 0 |
| Mercury | 3.24E-08 | 2,569,615 | 0 | 4.16E-09 | 1,560 | 0 | 0 |
| **PM-10** | **7.25E-05** | **2,569,615** | **186** | **1.35E-04** | **1,560** | **0** | **187** |
| Solid Waste | 1.47E-01 | 2,569,615 | 377,733 | - | - | - | 377,733 |

# Resources

ANSI/ASHRAE. (2007). Standard 62.1 - 2007, Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.

ANSI/ASHRAE. (2007). Standard 90.1 - 2007, Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating Refrigeration and Air Conditioning Engineers, Inc.

ASHRAE. Handbook of Fundamentals. Atlanta: ASHRAE, 2009.

ASHRAE. Pocket Guide. Atlanta: ASHRAE, 1997.

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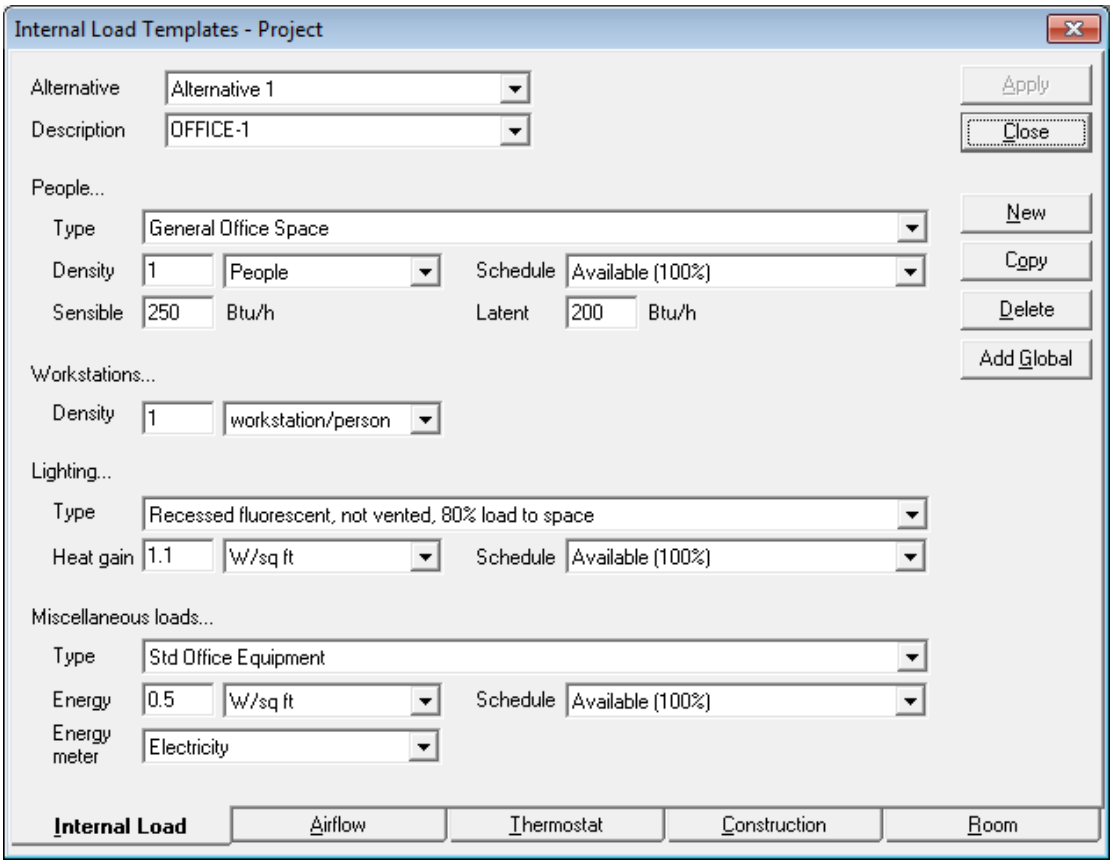
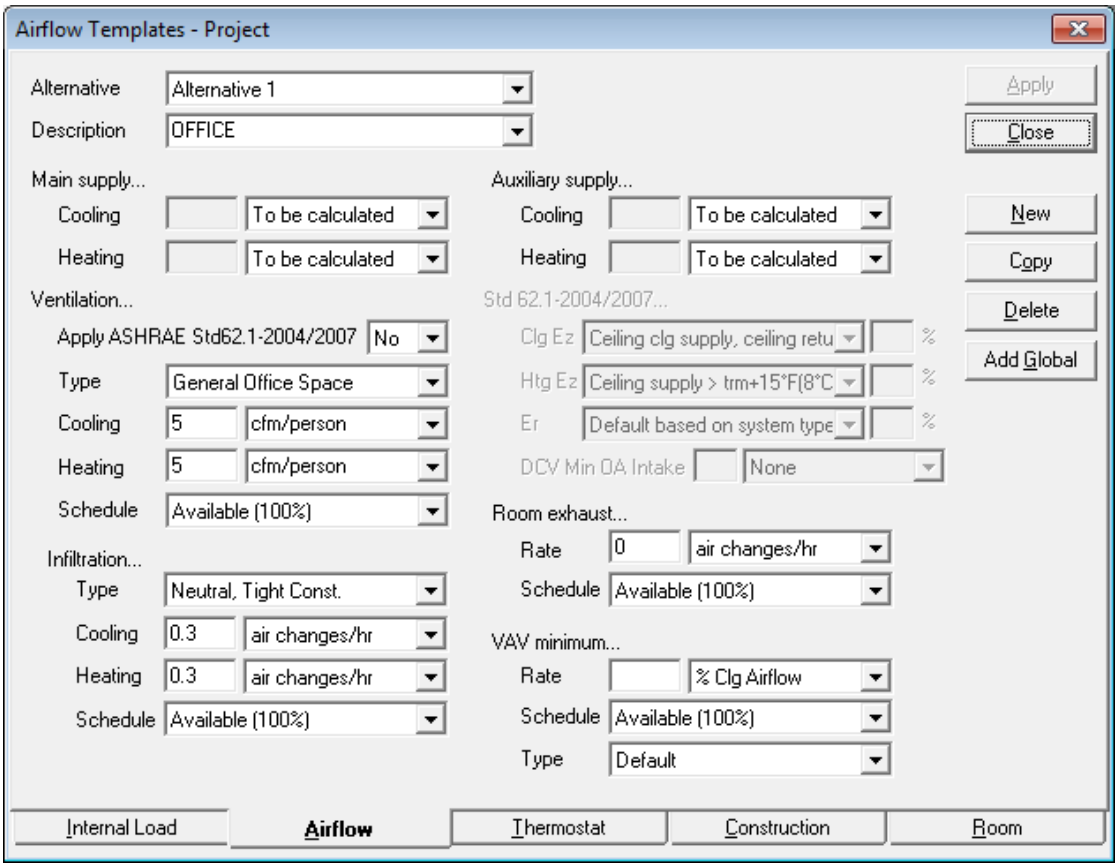
Sebesta Blomberg. Design Documents. Sebesta Blomberg, Arlington, VA

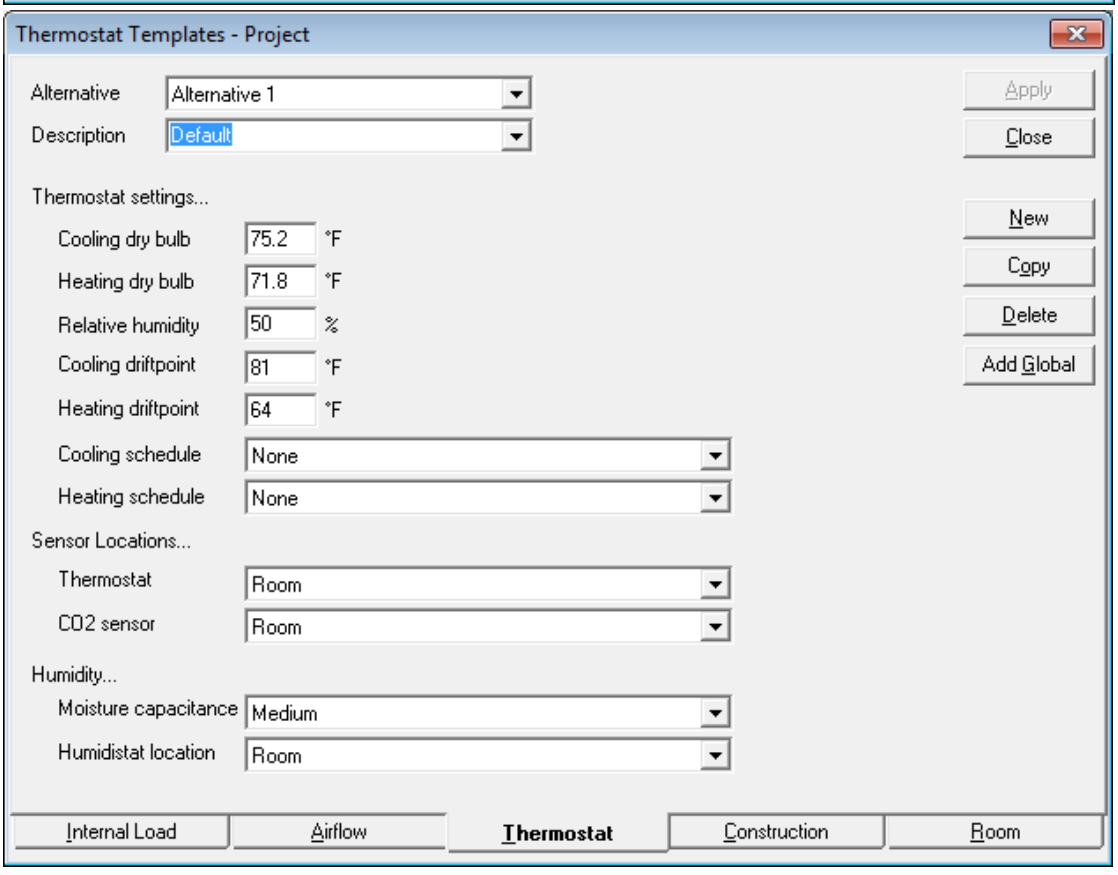
U.S. Energy Information Administration. "Table E2A. Major Fuel Consumption (Btu) Intensities by End Use for All Buildings, 2003." 2003. U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. 24 October 2010 <http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003pdf

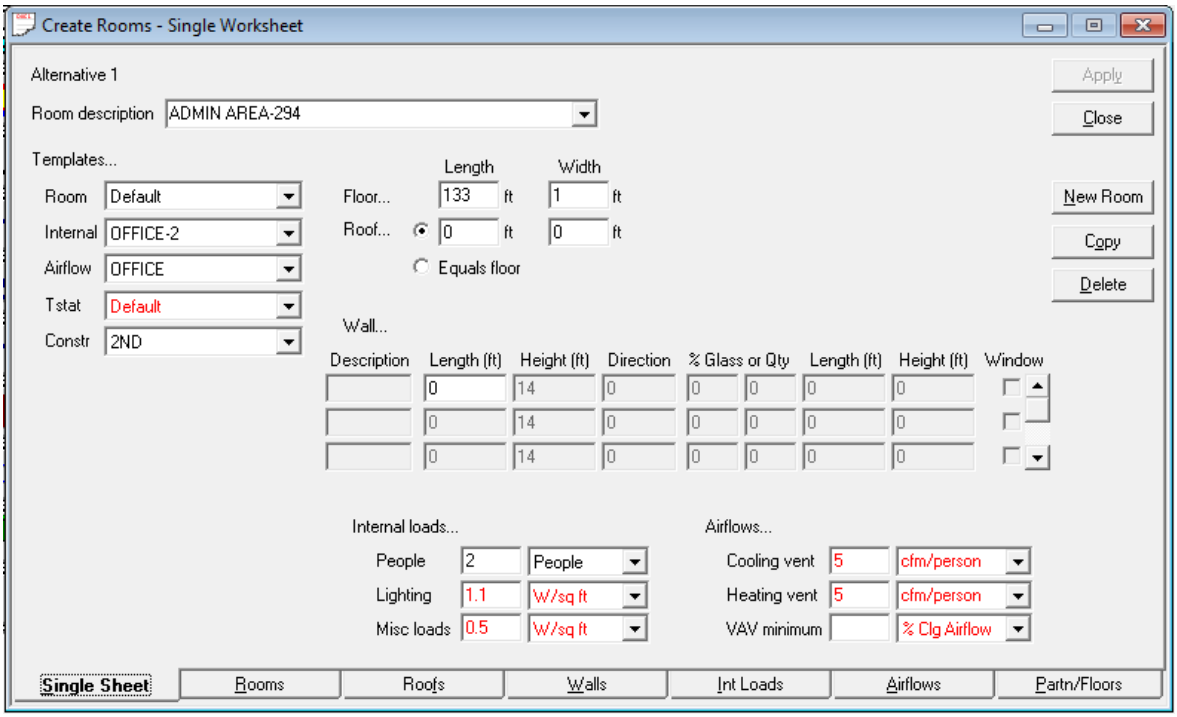
WSP Flack + Kurtz. Mechanical Design Documents. WSP Flack + Kurtz, New York City, NY

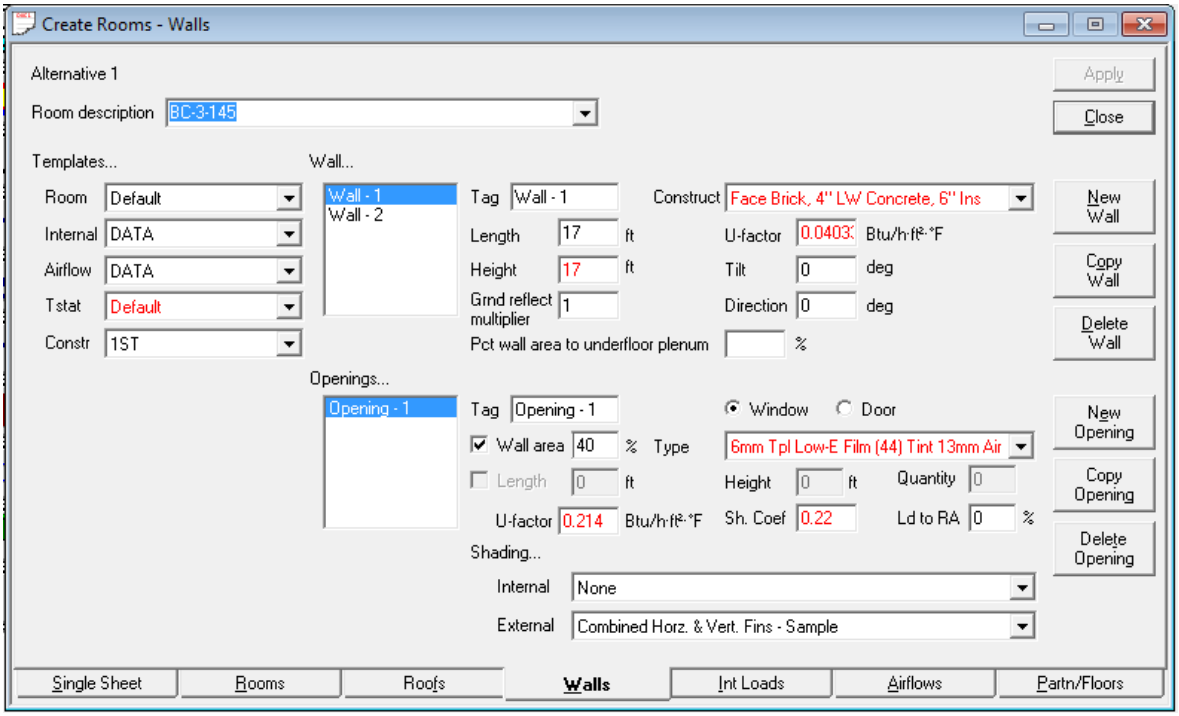
# Appendix A | TRANE Trace Templates




Airflow Templates - Project
Alternative
Alternative 1
Description
OFFICE
Apply
Close
Main supply...
Cooling
To be calculated
Heating
To be calculated
Auxiliary supply...
Cooling
To be calculated
Heating
To be calculated
New
Copy
Delete
Add Global
Ventilation...
Apply ASHRAE Std62.1-2004/2007
No
Type
General Office Space
Cooling
5
cfm/person
Heating
5
cfm/person
Schedule
Available (100%)
Std 62.1-2004/2007...
Clg Ez
Ceiling clg supply, ceiling retu
Htg Ez
Ceiling supply > trm+15°F(8°C
Er
Default based on system type
DCV Min OA Intake
None
Room exhaust...
Rate
0
air changes/hr
Schedule
Available (100%)
Infiltration...
Type
Neutral, Tight Const.
Cooling
0.3
air changes/hr
Heating
0.3
air changes/hr
Schedule
Available (100%)
VAV minimum...
Rate
% Clg Airflow
Schedule
Available (100%)
Type
Default
Internal Load
Airflow
Thermostat
Construction
Room


Thermostat Templates - Project
Alternative
Alternative 1
Description
Default
Apply
Close
Thermostat settings...
Cooling dry bulb
75.2
°F
Heating dry bulb
71.8
°F
Relative humidity
50
%
Cooling driftpoint
81
°F
Heating driftpoint
64
°F
Cooling schedule
None
Heating schedule
None
New
Copy
Delete
Add Global
Sensor Locations...
Thermostat
Room
CO2 sensor
Room
Humidity...
Moisture capacitance
Medium
Humidistat location
Room
Internal Load
Airflow
Thermostat
Construction
Room


Create Rooms - Single Worksheet
Alternative 1
Room description
ADMIN AREA-294
Apply
Close
Templates...
Room
Default
Internal
OFFICE-2
Airflow
OFFICE
Tstat
Default
Constr
2ND
Length
Width
Floor...
133
ft
1
ft
Roof...
0
ft
0
ft
Equals floor
New Room
Copy
Delete
Wall...
Description
Length (ft)
Height (ft)
Direction
% Glass or Qty
Length (ft)
Height (ft)
Window
Internal loads...
People
2
People
Lighting
1.1
W/sq ft
Misc loads
0.5
W/sq ft
Airflows...
Cooling vent
5
cfm/person
Heating vent
5
cfm/person
VAV minimum
% Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors


Create Rooms - Walls
Alternative 1
Room description
BC-3-145
Apply
Close
Templates...
Room
Default
Internal
DATA
Airflow
DATA
Tstat
Default
Constr
1ST
Wall...
Wall - 1
Wall - 2
Tag
Wall - 1
Construct
Face Brick, 4" LW Concrete, 6" Ins
Length
17
ft
U-factor
0.0403
Btu/h·ft²·°F
Height
17
ft
Tilt
0
deg
Grnd reflect multiplier
1
Direction
0
deg
Pct wall area to underfloor plenum
%
New Wall
Copy Wall
Delete Wall
Openings...
Opening - 1
Tag
Opening - 1
Window
Door
Wall area
40
%
Type
6mm Tpl Low-E Film (44) Tint 13mm Air
Length
0
ft
Height
0
ft
Quantity
0
U-factor
0.214
Btu/h·ft²·°F
Sh. Coef
0.22
Ld to RA
0
%
Shading...
Internal
None
External
Combined Horz. & Vert. Fins - Sample
New Opening
Copy Opening
Delete Opening
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors

# Appendix B | CBECS Energy Consumption Tables

Released: September, 2008

## Table E7A. Natural Gas Consumption (Btu) and Energy Intensities by End Use for All Buildings, 2003

| | Total Natural Gas Consumption (trillion Btu) | | | | | Natural Gas Energy Intensity (thousand Btu/square foot) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Space Heating | Water Heating | Cook-ing | Other | Total | Space Heating | Water Heating | Cook-ing | Other |
| **All Buildings** | 2,100 | 1,420 | 348 | 164 | 168 | 43.3 | 29.3 | 7.2 | 3.4 | 3.5 |
| **Building Floorspace (Square Feet)** | | | | | | | | | | |
| 1,001 to 5,000 | 257 | 161 | 36 | 42 | 18 | 81.0 | 50.6 | 11.3 | 13.3 | 5.8 |
| 5,001 to 10,000 | 224 | 152 | 33 | 32 | 7 | 56.5 | 38.3 | 8.4 | 8.1 | 1.7 |
| 10,001 to 25,000 | 353 | 273 | 35 | 26 | 19 | 45.2 | 34.9 | 4.5 | 3.3 | 2.4 |
| 25,001 to 50,000 | 278 | 202 | 43 | 14 | Q | 42.2 | 30.6 | 6.5 | 2.1 | 3.0 |
| 50,001 to 100,000 | 277 | 192 | 47 | 14 | 25 | 36.9 | 25.6 | 6.2 | 1.8 | 3.3 |
| 100,001 to 200,000 | 275 | 187 | 58 | 10 | 20 | 36.5 | 24.8 | 7.7 | 1.3 | 2.7 |
| 200,001 to 500,000 | 211 | 138 | 44 | 11 | 17 | 35.8 | 23.4 | 7.5 | 1.9 | 2.9 |
| Over 500,000 | 224 | 115 | 52 | 14 | 42 | 37.5 | 19.3 | 8.7 | 2.4 | 7.0 |
| **Principal Building Activity** | | | | | | | | | | |
| Education | 268 | 207 | 37 | 5 | 19 | 38.1 | 29.5 | 5.2 | 0.7 | 2.7 |
| Food Sales | 39 | 27 | 2 | 8 | Q | 51.7 | 35.6 | 3.2 | 11.2 | Q |
| Food Service | 203 | 54 | 56 | 91 | Q | 145.6 | 39.0 | 40.0 | 65.4 | Q |
| Health Care | 243 | 136 | 74 | 10 | 23 | 95.3 | 53.6 | 28.9 | 3.8 | 9.1 |
| Inpatient | 204 | 103 | 71 | 9 | 21 | 113.2 | 56.8 | 39.4 | 5.2 | 11.9 |
| Outpatient | 38 | 34 | 3 | Q | Q | 51.8 | 45.6 | 3.5 | Q | Q |
| Lodging | 215 | 64 | 124 | 14 | Q | 50.4 | 15.0 | 29.2 | 3.3 | Q |
| Mercantile | 264 | 188 | 19 | 24 | 33 | 33.5 | 23.9 | 2.4 | 3.1 | 4.1 |
| Retail (Other Than Mall) | 91 | 84 | 3 | 3 | 2 | 31.9 | 29.3 | 1.0 | 0.9 | 0.7 |
| Enclosed and Strip Malls | 172 | 104 | 16 | 22 | 31 | 34.4 | 20.9 | 3.1 | 4.3 | 6.1 |
| Office | 269 | 230 | 13 | 3 | 23 | 32.8 | 28.1 | 1.6 | 0.3 | 2.8 |
| Public Assembly | 102 | 92 | 2 | 3 | Q | 37.5 | 33.8 | 0.9 | 1.0 | Q |
| Public Order and Safety | 29 | 15 | 10 | Q | Q | 45.0 | 24.1 | 15.1 | Q | Q |
| Religious Worship | 82 | 77 | 2 | 3 | Q | 31.2 | 29.1 | 0.9 | 1.0 | Q |
| Service | 139 | 119 | 2 | Q | 17 | 55.8 | 47.8 | 0.9 | Q | Q |
| Warehouse and Storage | 132 | 111 | 4 | Q | Q | 24.1 | 20.2 | 0.7 | Q | Q |
| Other | 87 | 72 | 2 | Q | 12 | 69.7 | 57.9 | 1.7 | Q | 9.4 |
| Vacant | 28 | 26 | Q | Q | Q | 23.7 | 22.0 | Q | Q | Q |
| **Year Constructed** | | | | | | | | | | |
| Before 1920 | 143 | 114 | 12 | 15 | Q | 51.7 | 41.0 | 4.4 | 5.5 | Q |
| 1920 to 1945 | 232 | 152 | 24 | 18 | 38 | 48.6 | 31.8 | 5.1 | 3.8 | 7.9 |
| 1946 to 1959 | 223 | 163 | 35 | 11 | 14 | 45.9 | 33.5 | 7.2 | 2.4 | 2.8 |
| 1960 to 1969 | 276 | 200 | 47 | 12 | 17 | 44.9 | 32.6 | 7.6 | 2.0 | 2.7 |
| 1970 to 1979 | 402 | 272 | 72 | 28 | 30 | 45.7 | 31.0 | 8.2 | 3.1 | 3.4 |
| 1980 to 1989 | 339 | 207 | 72 | 28 | 31 | 43.3 | 26.4 | 9.2 | 3.6 | 4.0 |
| 1990 to 1999 | 345 | 226 | 58 | 33 | 27 | 37.5 | 24.6 | 6.3 | 3.6 | 3.0 |
| 2000 to 2003 | 140 | 86 | 28 | 17 | 9 | 34.3 | 21.0 | 6.9 | 4.2 | 2.2 |
| **Census Region and Division** | | | | | | | | | | |
| Northeast | 462 | 332 | 51 | 34 | 45 | 45.5 | 32.7 | 5.1 | 3.3 | 4.4 |
| New England | 87 | 69 | Q | Q | 5 | 46.8 | 36.9 | 4.3 | 2.8 | 2.9 |
| Middle Atlantic | 375 | 263 | 44 | 29 | 39 | 45.2 | 31.7 | 5.2 | 3.5 | 4.7 |
| Midwest | 751 | 589 | 82 | 32 | 47 | 53.1 | 41.7 | 5.8 | 2.3 | 3.3 |
| East North Central | 567 | 452 | 62 | 23 | 30 | 54.8 | 43.7 | 6.0 | 2.2 | 2.9 |
| West North Central | 184 | 137 | 20 | 9 | Q | 48.5 | 36.2 | 5.4 | 2.4 | 4.5 |
| South | 527 | 291 | 129 | 68 | 38 | 34.5 | 19.1 | 8.4 | 4.5 | 2.5 |
| South Atlantic | 246 | 132 | 60 | 32 | 22 | 33.7 | 18.1 | 8.2 | 4.4 | 3.0 |
| East South Central | 107 | 69 | 25 | 8 | 5 | 42.6 | 27.4 | 10.0 | 3.3 | 1.8 |
| West South Central | 174 | 90 | 44 | 28 | 12 | 31.8 | 16.5 | 8.0 | 5.1 | 2.2 |
| West | 360 | 208 | 85 | 29 | 38 | 40.5 | 23.4 | 9.6 | 3.3 | 4.3 |
| Mountain | 190 | 132 | 35 | 6 | 17 | 58.4 | 40.5 | 10.8 | 2.0 | 5.1 |
| Pacific | 170 | 76 | 50 | 23 | 21 | 30.1 | 13.5 | 8.9 | 4.0 | 3.8 |

Released: September, 2008

## Table E4A. Electricity Consumption (Btu) Intensities by End Use for All Buildings, 2003

| | Electricity Energy Intensity (thousand Btu/square foot) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Space Heating | Cooling | Ventilation | Water Heating | Lighting | Cooking | Refrigeration | Office Equipment | Computers | Other |
| **All Buildings** | 50.7 | 2.4 | 6.9 | 6.2 | 1.3 | 19.1 | 0.3 | 5.4 | 1.0 | 2.2 | 6.0 |
| **Building Floorspace (Square Feet)** | | | | | | | | | | | |
| 1,001 to 5,000 | 60.6 | 2.9 | 6.8 | 2.8 | 1.7 | 14.8 | 1.1 | 21.2 | 1.2 | 1.8 | 6.0 |
| 5,001 to 10,000 | 44.0 | 2.6 | 5.7 | 2.8 | 1.1 | 14.3 | 0.7 | 8.6 | 0.9 | 1.4 | 5.8 |
| 10,001 to 25,000 | 38.8 | 2.1 | 4.4 | 4.1 | 1.1 | 14.7 | 0.2 | 4.5 | 0.8 | 1.6 | 5.1 |
| 25,001 to 50,000 | 43.7 | 2.0 | 6.8 | 6.1 | 1.3 | 15.4 | 0.2 | 4.0 | 0.8 | 1.9 | 5.3 |
| 50,001 to 100,000 | 50.9 | 2.7 | 7.5 | 7.6 | 1.4 | 19.6 | 0.3 | 3.4 | 0.7 | 2.0 | 5.8 |
| 100,001 to 200,000 | 57.7 | 2.3 | 8.0 | 8.9 | 1.1 | 23.0 | 0.1 | 2.9 | 1.3 | 3.2 | 6.7 |
| 200,001 to 500,000 | 51.8 | 1.5 | 7.4 | 7.5 | 0.8 | 23.0 | 0.2 | 1.3 | 1.1 | 2.7 | 6.2 |
| Over 500,000 | 65.4 | 3.0 | 9.0 | 8.8 | 1.5 | 28.7 | 0.3 | 2.4 | 1.2 | 3.2 | 7.3 |
| **Principal Building Activity** | | | | | | | | | | | |
| Education | 37.6 | 1.5 | 7.5 | 8.4 | 1.1 | 11.5 | 0.2 | 1.6 | 0.4 | 3.3 | 2.1 |
| Food Sales | 168.5 | 5.1 | 9.9 | 6.0 | Q | 37.2 | 1.9 | 96.1 | 1.6 | 1.5 | 8.1 |
| Food Service | 130.9 | 6.3 | 17.0 | 14.8 | 6.3 | 25.4 | 8.1 | 42.1 | 1.0 | 1.0 | 8.9 |
| Health Care | 78.3 | 1.9 | 10.6 | 13.3 | 0.8 | 33.1 | 0.2 | 2.6 | 1.2 | 3.2 | 11.3 |
| Inpatient | 93.7 | 1.6 | 13.0 | 20.0 | 1.1 | 40.1 | 0.4 | 2.0 | 1.1 | 3.6 | 10.9 |
| Outpatient | 55.0 | 2.3 | 7.0 | 3.3 | 0.3 | 22.6 | 0.1 | 3.5 | 1.3 | 2.6 | 12.0 |
| Lodging | 46.1 | 2.8 | 4.7 | 2.7 | 2.3 | 24.3 | 0.4 | 2.3 | Q | 1.2 | 4.7 |
| Mercantile | 65.5 | 5.2 | 9.7 | 6.0 | 3.4 | 27.5 | 0.2 | 4.4 | 0.7 | 1.0 | 7.4 |
| Retail (Other Than Mall) | 48.8 | 1.5 | 5.9 | 3.7 | 0.4 | 25.7 | 0.1 | 5.0 | 0.6 | 0.9 | 5.1 |
| Enclosed and Strip Malls | 76.0 | 7.5 | 12.2 | 7.5 | 5.2 | 28.6 | 0.3 | 4.0 | 0.8 | 1.1 | 8.8 |
| Office | 58.9 | 2.7 | 8.3 | 5.2 | 0.6 | 23.1 | 0.1 | 2.9 | 2.6 | 6.1 | 7.5 |
| Public Assembly | 42.6 | 1.3 | 8.9 | 15.9 | 0.1 | 7.0 | 0.1 | 2.2 | Q | 0.8 | 5.8 |
| Public Order and Safety | 52.3 | 1.6 | 7.2 | 9.5 | 3.0 | 16.5 | 0.1 | 2.9 | 0.6 | 1.5 | 9.2 |
| Religious Worship | 16.6 | 0.8 | 2.8 | 1.4 | 0.1 | 4.4 | 0.1 | 1.7 | 0.1 | 0.2 | 4.9 |
| Service | 37.5 | 1.4 | 3.8 | 6.1 | 0.1 | 15.8 | Q | 2.2 | 0.3 | 0.8 | 7.0 |
| Warehouse and Storage | 25.9 | 0.5 | 1.4 | 2.2 | 0.2 | 14.0 | Q | 3.8 | 0.2 | 0.5 | 3.2 |
| Other | 76.8 | 1.4 | 9.3 | 6.1 | 0.3 | 34.3 | Q | 6.0 | Q | 2.9 | 12.6 |
| Vacant | 8.3 | 0.5 | 0.8 | 0.5 | Q | 2.4 | Q | 0.2 | Q | 0.1 | 3.7 |
| **Year Constructed** | | | | | | | | | | | |
| Before 1920 | 24.2 | 0.5 | 1.7 | 2.9 | Q | 9.2 | 0.3 | 4.5 | 0.6 | 0.9 | 3.2 |
| 1920 to 1945 | 32.1 | 0.7 | 2.5 | 4.5 | 0.4 | 13.8 | 0.2 | 3.9 | 0.4 | 1.2 | 4.6 |
| 1946 to 1959 | 35.0 | 1.5 | 4.0 | 5.1 | 0.8 | 13.3 | 0.3 | 3.8 | 0.6 | 1.6 | 4.2 |
| 1960 to 1969 | 41.8 | 1.6 | 5.4 | 6.2 | 0.9 | 14.8 | 0.1 | 4.8 | 0.8 | 2.2 | 5.0 |
| 1970 to 1979 | 57.1 | 3.3 | 7.4 | 7.1 | 1.5 | 22.0 | 0.3 | 5.3 | 1.1 | 2.4 | 6.7 |
| 1980 to 1989 | 64.2 | 3.4 | 9.6 | 6.7 | 2.0 | 24.2 | 0.4 | 6.0 | 1.4 | 3.2 | 7.4 |
| 1990 to 1999 | 60.1 | 2.7 | 9.0 | 7.3 | 1.6 | 21.4 | 0.5 | 6.7 | 1.3 | 2.7 | 6.8 |
| 2000 to 2003 | 57.6 | 2.9 | 8.9 | 6.2 | 1.2 | 22.5 | 0.5 | 6.7 | 0.7 | 1.6 | 6.3 |
| **Census Region and Division** | | | | | | | | | | | |
| Northeast | 42.2 | 2.4 | 3.1 | 5.5 | 0.9 | 17.2 | 0.2 | 4.5 | 0.9 | 2.3 | 5.3 |
| New England | 41.1 | 2.9 | 2.4 | 4.5 | 1.3 | 16.1 | 0.3 | 6.1 | 0.7 | 2.0 | 4.9 |
| Middle Atlantic | 42.6 | 2.2 | 3.4 | 5.8 | 0.7 | 17.5 | 0.1 | 4.0 | 1.0 | 2.4 | 5.4 |
| Midwest | 45.1 | 3.0 | 3.2 | 6.2 | 0.9 | 17.7 | 0.3 | 5.2 | 0.9 | 2.0 | 5.8 |
| East North Central | 47.0 | 2.7 | 3.1 | 6.8 | 0.8 | 18.9 | 0.3 | 5.1 | 1.0 | 2.2 | 6.1 |
| West North Central | 40.8 | 3.6 | 3.4 | 4.8 | 0.9 | 15.0 | 0.2 | 5.4 | 0.7 | 1.6 | 5.1 |
| South | 59.3 | 2.0 | 11.5 | 6.9 | 1.8 | 20.9 | 0.5 | 6.4 | 0.8 | 2.2 | 6.3 |
| South Atlantic | 62.5 | 2.2 | 11.1 | 7.2 | 2.1 | 22.5 | 0.6 | 6.9 | 0.9 | 2.7 | 6.4 |
| East South Central | 55.2 | 2.4 | 7.5 | 6.9 | 1.5 | 20.4 | Q | 7.1 | 0.6 | 1.6 | 6.8 |
| West South Central | 55.7 | 1.3 | 13.7 | 6.3 | 1.5 | 18.5 | 0.4 | 5.5 | 0.7 | 1.7 | 6.0 |
| West | 50.3 | 2.3 | 6.5 | 5.7 | 1.1 | 19.5 | 0.3 | 4.7 | 1.6 | 2.4 | 6.2 |
| Mountain | 55.7 | 3.1 | 7.3 | 6.5 | 1.1 | 22.6 | 0.2 | 4.8 | Q | 2.2 | 6.4 |
| Pacific | 47.7 | 2.0 | 6.1 | 5.4 | 1.1 | 18.0 | 0.3 | 4.6 | 1.7 | 2.5 | 6.0 |

# Appendix C | Emission Factor Data

**Total Emission Factors for Delivered Electricity by State (lb of pollutant per kWh of electricity)**

| Pollutant (lb) | RI | SC | SD | TN | TX | UT | VA | VT | WA | WI | WV | WY | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $CO_{2e}$ | 1.18E+00 | 1.00E+00 | 1.45E+00 | 1.46E+00 | 1.99E+00 | 2.62E+00 | 1.40E+00 | 1.88E-02 | 4.11E-01 | 2.03E+00 | 2.41E+00 | 2.67E+00 | |
| $CO_2$ | 1.04E+00 | 9.57E-01 | 1.36E+00 | 1.40E+00 | 1.85E+00 | 2.51E+00 | 1.33E+00 | 1.78E-02 | 3.82E-01 | 1.92E+00 | 2.31E+00 | 2.52E+00 | |
| $CH_4$ | 5.65E-03 | 1.72E-03 | 3.02E-03 | 2.43E-03 | 5.80E-03 | 4.21E-03 | 2.52E-03 | 2.25E-05 | 1.13E-03 | 4.13E-03 | 3.85E-03 | 5.42E-03 | |
| $N_2O$ | 2.04E-05 | 2.12E-05 | 3.91E-05 | 3.28E-05 | 4.37E-05 | 5.53E-05 | 2.81E-05 | 1.70E-06 | 1.05E-05 | 5.32E-05 | 5.08E-05 | 7.30E-05 | |
| $NO_X$ | 7.91E-04 | 1.90E-03 | 2.45E-03 | 2.77E-03 | 2.42E-03 | 5.00E-03 | 2.67E-03 | 1.38E-04 | 6.13E-04 | 3.51E-03 | 4.62E-03 | 4.58E-03 | |
| $SO_X$ | 9.90E-03 | 5.73E-03 | 3.97E-03 | 7.32E-03 | 1.05E-02 | 1.47E-02 | 8.04E-03 | 1.13E-04 | 1.70E-03 | 6.60E-03 | 1.35E-02 | 7.05E-03 | |
| CO | 8.52E-04 | 3.22E-04 | 5.26E-04 | 4.14E-04 | 9.77E-04 | 6.89E-04 | 9.74E-04 | 5.90E-05 | 1.80E-04 | 7.13E-04 | 6.50E-04 | 9.00E-04 | |
| TNMOC | 9.92E-05 | 4.89E-05 | 4.12E-05 | 4.17E-05 | 8.22E-05 | 5.78E-05 | 8.77E-05 | 1.02E-04 | 3.74E-05 | 8.26E-05 | 5.26E-05 | 7.43E-05 | |
| Lead | 6.87E-09 | 7.66E-08 | 1.47E-07 | 1.24E-07 | 1.49E-07 | 2.08E-07 | 1.02E-07 | 6.33E-10 | 3.21E-08 | 1.97E-07 | 1.92E-07 | 2.77E-07 | |
| Mercury | 4.09E-09 | 1.62E-08 | 3.01E-08 | 2.50E-08 | 2.96E-08 | 4.15E-08 | 3.24E-08 | 1.03E-09 | 6.62E-09 | 4.01E-08 | 3.87E-08 | 5.54E-08 | |
| PM10 | 7.02E-05 | 4.61E-05 | 8.12E-05 | 6.75E-05 | 1.37E-04 | 1.14E-04 | 7.25E-05 | 7.67E-06 | 2.46E-05 | 1.11E-04 | 1.05E-04 | 1.49E-04 | |
| Solid Waste | 1.31E-02 | 1.17E-01 | 2.26E-01 | 1.91E-01 | 1.82E-01 | 3.20E-01 | 1.47E-01 | 2.83E-04 | 4.96E-02 | 3.03E-01 | 2.95E-01 | 4.26E-01 | |

**Emission Factors for On-Site Combustion in a Commercial Boiler (lb of pollutant per unit of fuel)**

| Pollutant (lb) | Commercial Boiler | | | | | |
|---|---|---|---|---|---|---|
| | Bituminous Coal * | Lignite Coal ** | Natural Gas | Residual Fuel Oil | Distillate Fuel Oil | LPG |
| | 1000 lb | 1000 lb | 1000 $ft^3$ *** | 1000 gal | 1000 gal | 1000 gal |
| $CO_{2e}$ | 2.74E+03 | 2.30E+03 | 1.23E+02 | 2.56E+04 | 2.28E+04 | 1.35E+04 |
| $CO_2$ | 2.63E+03 | 2.30E+03 | 1.22E+02 | 2.55E+04 | 2.28E+04 | 1.32E+04 |
| $CH_4$ | 1.15E-01 | 2.00E-02 | 2.50E-03 | 2.31E-01 | 2.32E-01 | 2.17E-01 |
| $N_2O$ | 3.68E-01 | ND † | 2.50E-03 | 1.18E-01 | 1.19E-01 | 9.77E-01 |
| $NO_X$ | 5.75E+00 | 5.97E+00 | 1.11E-01 | 6.41E+00 | 2.15E+01 | 1.57E+01 |
| $SO_X$ | 1.66E+00 | 1.29E+01 | 6.32E-04 | 4.00E+01 | 3.41E+01 | 0.00E+00 |
| CO | 2.89E+00 | 4.05E-03 | 9.33E-02 | 5.34E+00 | 5.41E+00 | 2.17E+00 |
| VOC | ND † | ND † | 6.13E-03 | 3.63E-01 | 2.17E-01 | 3.80E-01 |
| Lead | 1.79E-03 | 6.86E-02 | 5.00E-07 | 1.51E-06 | ND † | ND † |
| Mercury | 6.54E-04 | 6.54E-04 | 2.60E-07 | 1.13E-07 | ND † | ND † |
| PM10 | 2.00E+00 | ND † | 8.40E-03 | 4.64E+00 | 1.88E+00 | 4.89E-01 |