Technical Report 2

Building and Plant Energy Analysis

Steelstacks Preforming Arts Center

Bethlehem, Pa

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Executive Summary

The purpose of this document is to report and discuss results from a whole building block load energy analysis describing predicted energy use for the Steelstacks Performing Arts Center in Bethlehem, Pa. Along with energy use, the predicted energy cost and total building pollutant outputs were calculated. The results were compared to the available information provided by the professional engineers, as well as comparable baseline for a building of this size and use. This process was possible using Trane Trace 700 building load software package.

The results of this energy analysis seem to be within reason for the Steelstacks building. All values that could be compared to the professional engineers' numbers were within an acceptable range. Some of the inconsistencies had appropriate reasoning for being differences and are explained in the later in this report.

Also in this report is the annual energy cost for running the building. These values were estimated using reasonable values for electric and gas cost and applying them to the consumption per month and per year. These values were than analyzed for errors and discussed.

Following the energy cost analysis, an emissions analysis was done to the building. This was done by using the National Renewable Energy Library values for emissions in the northeast for electricity and gas. This estimates how many pounds of harmful pollutants the Steelstacks building puts into the environment on a yearly basis.

Mechanical System Overview

The Steelstacks building utilizes a fairly simple conditioning system. It consists of six rooftop units (RTUs) that serve almost the entire building. Each of these systems serves a very specific area; this is done so that the building can be controlled according to what type of event is going on. There is also one Air Handling Units (AHU) that serves exclusively the Blast Furnace Room. The Blast Furnace Room is the one of the highlight areas of this building; it is a multipurpose room that can host events from concerts to banquets.

	Supply Air(CFM)	Supply Fan Power(HP)	Exhaust Fan Power (HP)	Enthalpy Wheel Power (HP)	Cooling Coil Cap (MBH)	Gas Fired Cap (MBH)
RTU-1	6800	5	-	-	191.1	199
RTU-2	1650	1	-	1.18	39.9	52.5
RTU-3	3020	2	-	3.62	79.3	126.7
RTU-4	23485	25	-	7.24	457.4	117.5
RTU-5	17500	20	10	10.86	443.3	790
RTU-6	3000	1.5	0.5	-	113.4	126.7
AHU-1	5300	7.5	0	-	291.2	378.8

RTU-1- This unit serves the kitchen area on the third floor and the areas relating to this area such as storage areas.

RTU-2- This unit serves exclusively the Small Cinema on the first floor

RTU-3- This unit serves the Large Cinema on the first floor

RTU-4- This unit serves the Creative Commons area, this area has portions of it that are two stories high. The Creative Commons is an area for people to gather, it boast views of the blast furnaces as well as sitting areas and places to relax

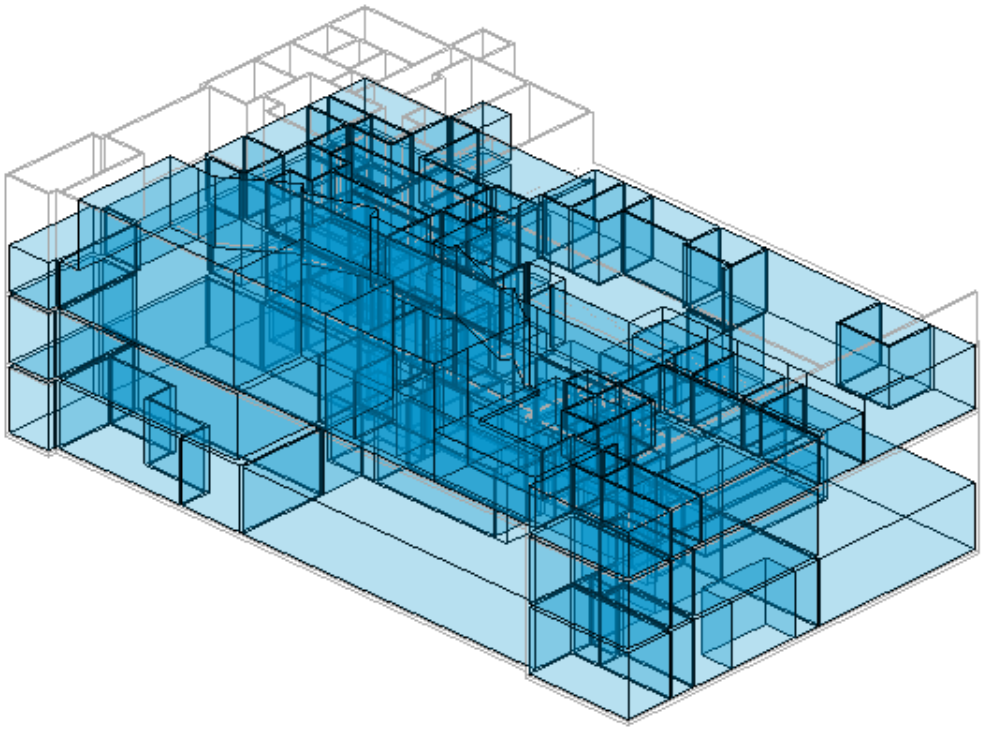
RTU-5- This unit serves the Musikfest Café that is on the third floor and is two floors high. It also serves the mezzanine level that overlooks the Café. This area will hold concerts and musical events, with the VIP area located on the Mezzanine as well as bar. This area also overlooks the blast furnaces to the north.

RTU-6- This unit is the most diverse unit, it serves most of the remaining space in the building that require conditioned air. Areas include offices, retail areas, corridors, green room, and some storage areas.

AHU-1- This unit is used to condition the Blast Furnace room.

Design Load Estimation

For this section of the report Trace 700 Version 6.2 was used to simulate building block load conditions for the Steelstacks building. Trace was chosen over the other software packages due to the ease of use as well as the familiarity with the program. Information was taken from the design drawing to complete the Trace model. The first step of the design process when using trace was to put the building into Revit and do a building model, this model could then be exported into Trace very easily. The exported model has all the room characteristics attached to it such as floor area, volume, exterior walls, as well as window dimensions.



Load Sources and Modeling Information

The main loads on this building are occupant loads. The large amount of people that this building can entertain at one time has the greatest impact on the load fluctuations. The ventilation, infiltration, lighting, electrical equipment, mechanical equipment, as well solar gain area all contributors to the building load. The solar gain is especially relevant in all the rooms with an exterior north side, because the whole north wall of the building is a large curtain wall. Some example templates made in the Trace software can be found in Appendix A.

Design Occupancy and Ventilation

The ventilation rates taken for this analysis were taken from the Construction Drawing provided by the mechanical Engineer. All unspecified occupancy was taken from the ASHRAE recommended occupancy for this analysis. The restaurant ventilation schedule was used for all ventilation rates because of the similarity in peak and usage times.

Start time	End time	%
Midnight	1 a.m.	100
1 a.m.	8 a.m.	0
8 a.m.	Midnight	100

Infiltration

The Steelstacks was assumed to have a relatively tight construction. From this the infiltration rate can be assumed to be 0.3 air changes per hour.

Electrical Loads

The lights and electrical loads were to be assumed on W/ft^2 basis. Therefore the lighting load was estimated using the values from the table below. Values were obtained from ASHRAE Standards.

Room Type	W/ft2
Preforming Arts	2.6
Office	1.1
Retail	1.7
Dining/Cafeteria	1.4
Cinema	1.2
Corridor	0.5
Lobby	3.3
Storage	0.8

Weather Data

The indoor and outdoor conditions for this building were used for the load analysis of this building. The outdoor conditions were found using the ASHRAE handbook using 0.4% Cooling Design and the 99.6% heating design. These values are found in the table below.

ASHRAE Values	Summer Design Cooling- 0.4%	Winter Design Heating- 99.6%
OA Dry Bulb (F)	90.7	6.6
Oa Wet Bulb(F)	73.4	-
IA Temperature	75	70
Clearness Number	1	1
Ground Reflectance	0.2	0.2

Solar Gain

Solar gain is very important to include for this building because of the large amount of windows on the north side of the building. The widows have a U-value of 0.29 and a SHGC (solar heat gain coefficient) of 0.440. Below are elevations of each side of the building. It is shown that the north side will have high solar heat gain, the east and west will have a considerable heat gain and the south side will have minimal heat gain. (Based on wall construction)

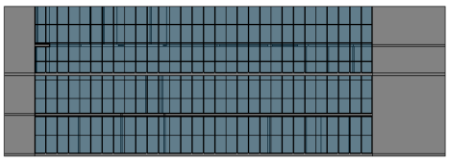


Figure 1- North elevation

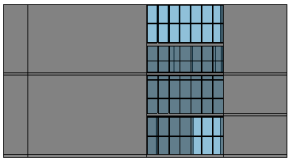


Figure 2-East Elevation

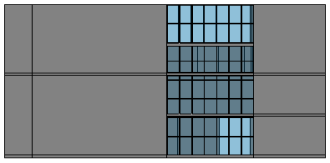


Figure 3- West Elevation

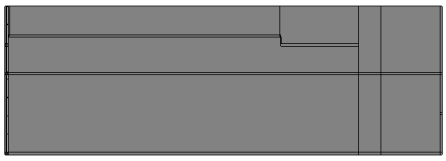


Figure 4- South Elevation

Results

All of the previous considerations were factored into the Trace software and a simulation of the building loads was calculated. A chart below shows what exactly calculated. Numerous calculations did not match or were not close to the designed values. The percent difference was hung around the 30% value, this could be due to a number of variables that will be discussed in the 'Possible Error' section part of this report. Overall, the building load is in a reasonable range for this type of building.

	Heating Load (MBH)		Cooling Load (tons)		Supply Air cfm/sf	
	Modeled	Designed	Modeled	Designed	Modeled	Designed
RTU-1	230.5	199	22.9	17.8	3858	6800
RTU-2	47	52.5	11.4	4.9	1582	1650
RTU-3	97.6	126.7	12.6	9.71	1927	3050
RTU-4	1108	117.5	84.9	55	13111	23485
RTU-5	404	790	78.3	51.47	16564	17500
RTU-6	31	126.7	1.7	11.9	423	3000
AHU-1	199	378.8	35.2	24.25	9862	5300
Total	2117.1	1791.2	247	175.03	47327	60785
Percent Difference	15.4		29.1		28.4	

Possible Error

Although a lot of effort was put into this model to assure accuracy there is few areas in which the error could be caused from. The leading cause of this error is can be attributed to the occupancy load. For most of the larger areas such as the Musikcafe, Creative Commons, and Blast Furnace room (RTU-4, RTU-5,AHU-1), I used the ASHRAE standards to obtain a value for the maximum occupancy. This value to my belief was greatly overestimated which made the cooling value much higher and the heating value lower. The ASHRAE standards are based on a square foot basis, these previously stated rooms have very large square footage (4000-8000 ft^2), and so this would rapidly increase the number of people in these rooms. If I were have to the anticipated occupancy of these rooms, my values would be much different. I did a simple adjustment to the occupancy which made my cooling load go down considerably; I reduced the amount of people by roughly half. This estimation was justified by the idea that these rooms have multiple areas in them and that the same group of people will be going from one area to the other (bar area to concert area), and they will not occupy all space at all times. The adjusted Cooling load is in the table below.

	Heating Load (MBH)		Coolin Load (tons)	
	Modeled	Designed	Modeled	Designed
RTU-1	314	199	22.9	17.8
RTU-2	79	52.5	11.4	4.9
RTU-3	131	126.7	12.6	9.71
RTU-4	875	117.5	53.1	55
RTU-5	355	790	51.7	51.47
RTU-6	32	126.7	1.7	11.9
AHU-1	157	378.8	23.4	24.25
Total	1943	1791.2	176.8	175.03
Percent Difference	7.8		1.0	

These values are now much closer the designed loads now, I believe that all of these values could get even closer to the designed value if I were to have more information about the building usage and occupancy.

Energy Consumption and Operating Costs

The energy bills are not available for this building because the building will not be complete till March. The rates that I found were average values from what I could find for rates in the Bethlehem area. I also compared these numbers to national average to make sure that they were reasonable rates. Unfortunately the energy model performed by the design engineers was not available to me at this point.

Electricity

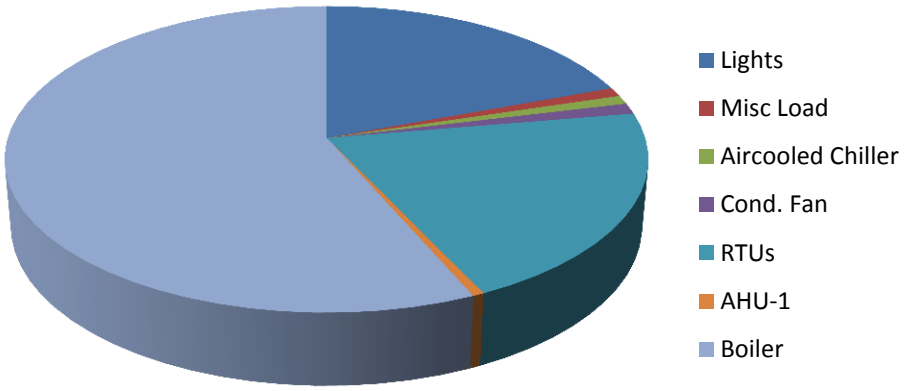
Electric demand charge	$6.25
Electric Consumption charge	$0.14/kWh

Gas

Consumption charge	S1.25/therm

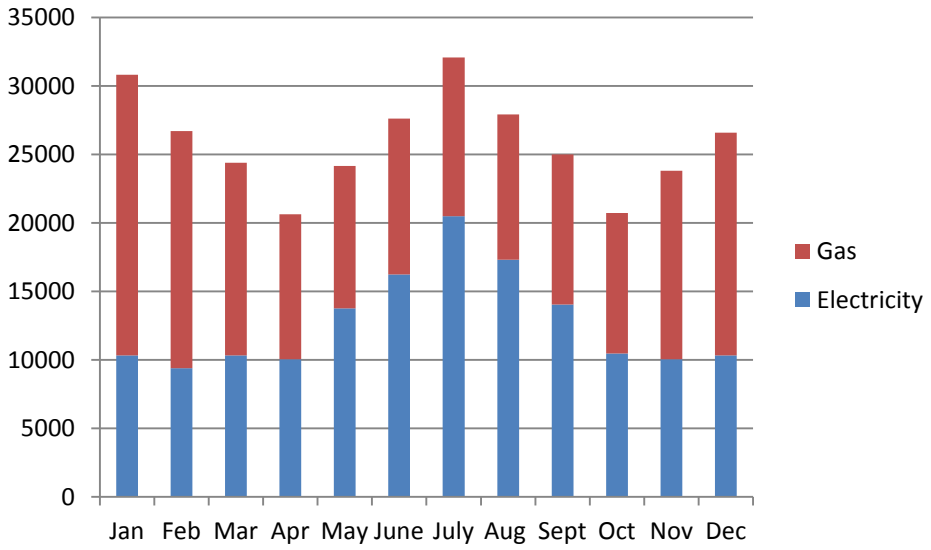
All of the equipment efficiencies and sizes were taken from the design drawing and the energy consumptions were calculated and reported below.

Equipment	Utility	Unit	Total
Lights	Electric	kWh	373086
	Peak	kW	42.6
Misc. Loads	Electric	kWh	17955
	Peak	kW	2.1
Air-cooled Chiller	Electric	kWh	17805
	Peak	kW	156.9
Cond. Fan	Electric	kWh	21806
	Peak	kW	17.1
RTU-1	Electric	kWh	32766
	Peak	kW	3.7
RTU-2	Electric	kWh	6553
	Peak	kW	0.8
RTU-3	Electric	kWh	13107
	Peak	kW	1.5
RTU-4	Electric	kWh	163831
	Peak	kW	18.7
RTU-5	Electric	kWh	131065
	Peak	kW	15
RTU-6	Electric	kWh	49149
	Peak	kW	5.6
AHU-1	Electric	kWh	9830
	Peak	kW	1.1
Boiler	Gas	therms	3698
	Peak	therms/Hr	2.8



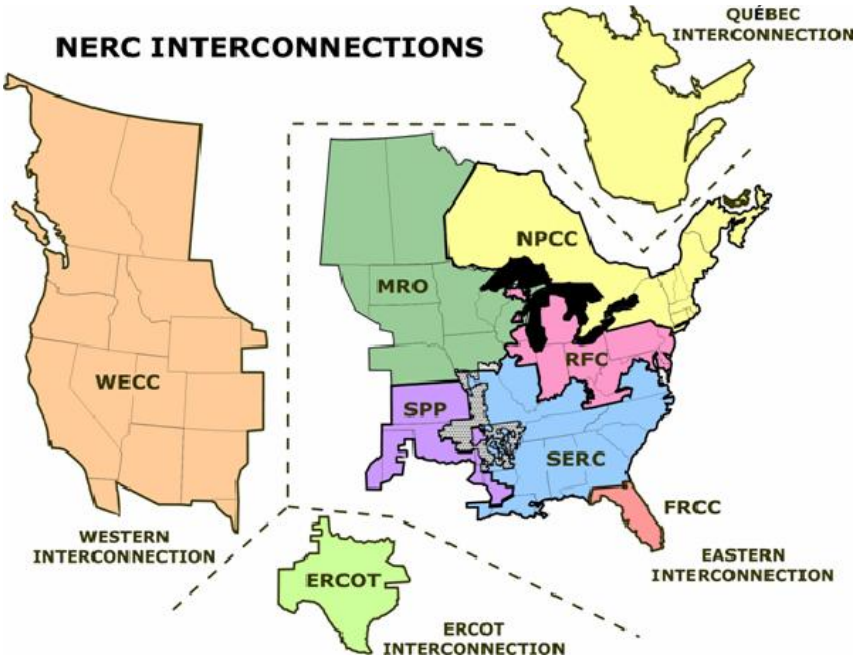
This pie chart above was done by converting all of the values to the same units. From this comparison it is very apparent that the boiler and the fans for each of the units are the main areas for energy consumption.

From this model the total energy cost was calculated. The total energy cost per year was $310,327, and $4.63/ft^2 which seems to be on the high side, the energy rates could be a little off, but I am not immediately sure for this error. Below is a graph of the cost for both electricity and gas for each month during the year.



System Emission Rates

Emission rates of CO_2, NO_x, SO_x, and particulates were calculated using the total energy consumption of the building. The energy consumption was multiplied with the energy emission factors found by the National Renewable Energy Laboratory. The NREL has Pennsylvania in the RFC Eastern Grid Interconnections as seen in the figure below.



The charts below show the total pollutants from the Steelstacks building. The values from NREL have are determined by the energy source that is producing the electricity as well other imposing factors that affect the total pollutants into the air.

	Total Electricity Usage	Electricity Emission Factors	Total Pollution
	kWh	lb pollutant/ kwh	lbm
CO_2	1002388	1.64	1643916.32
NO_x		3.00E-03	3007.16
SO_x		8.57E-03	8590.47
PM 10		9.26E-05	92.82

	Total Electricity Usage	Electricity Emission Factors	Total Pollution
	ft^3	lb pollutant/1000 ft^3	lbm
CO_2	359029	1.22E+02	43801.55
NO_x		1.11E-01	39.85
SO_x		6.32E-04	0.23
PM 10		8.40E-03	3.02

References

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

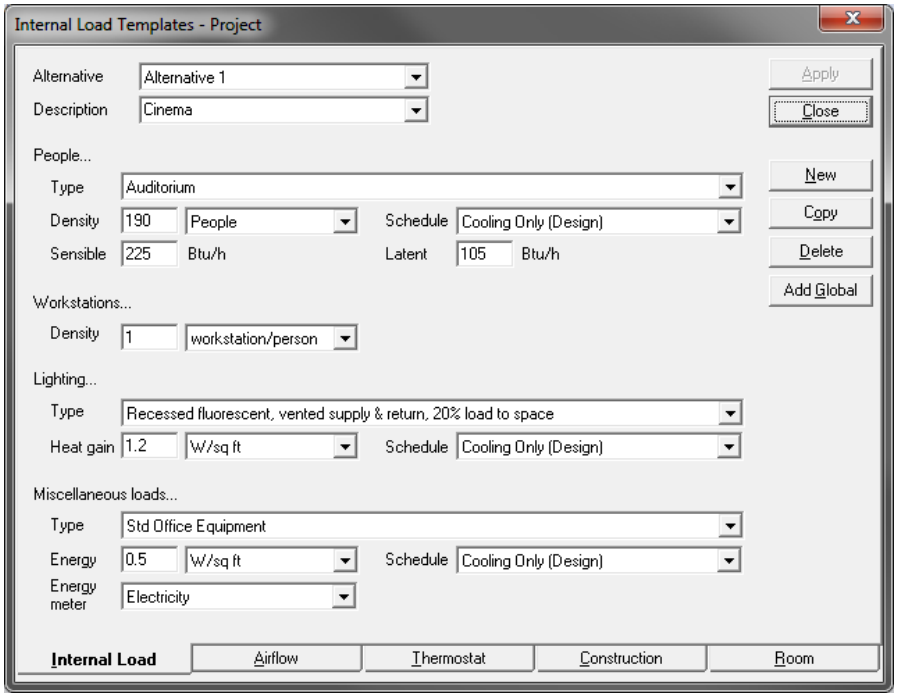
ASHRAE (2005). Handbook – Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

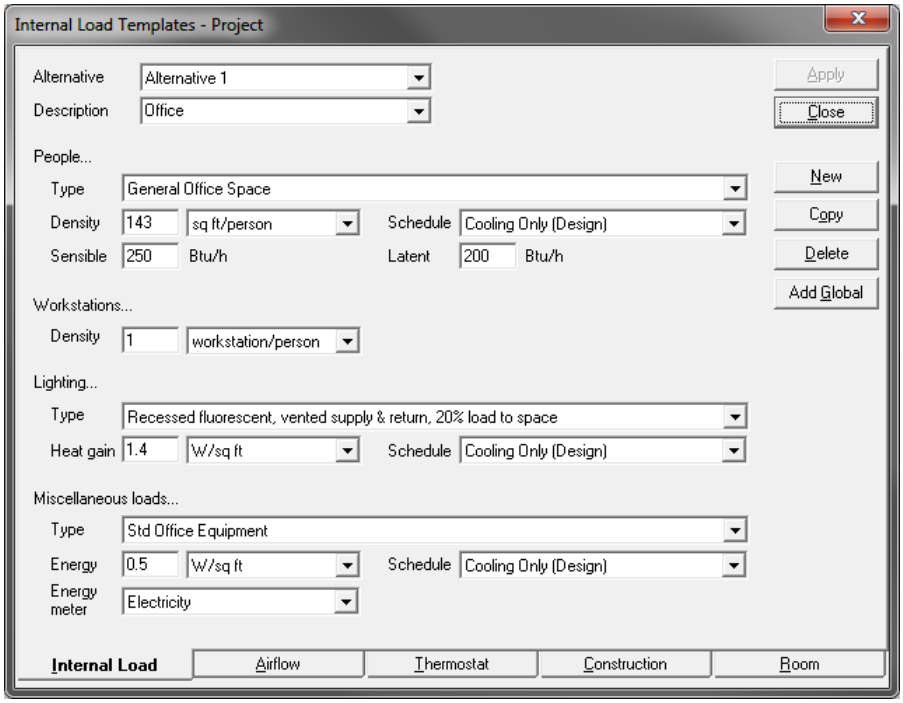
Deru. M., Torcellini. P. (2007). Source Energy and Emission Factors for Energy Use in Buildings. National Renewable Energy Laboratory.

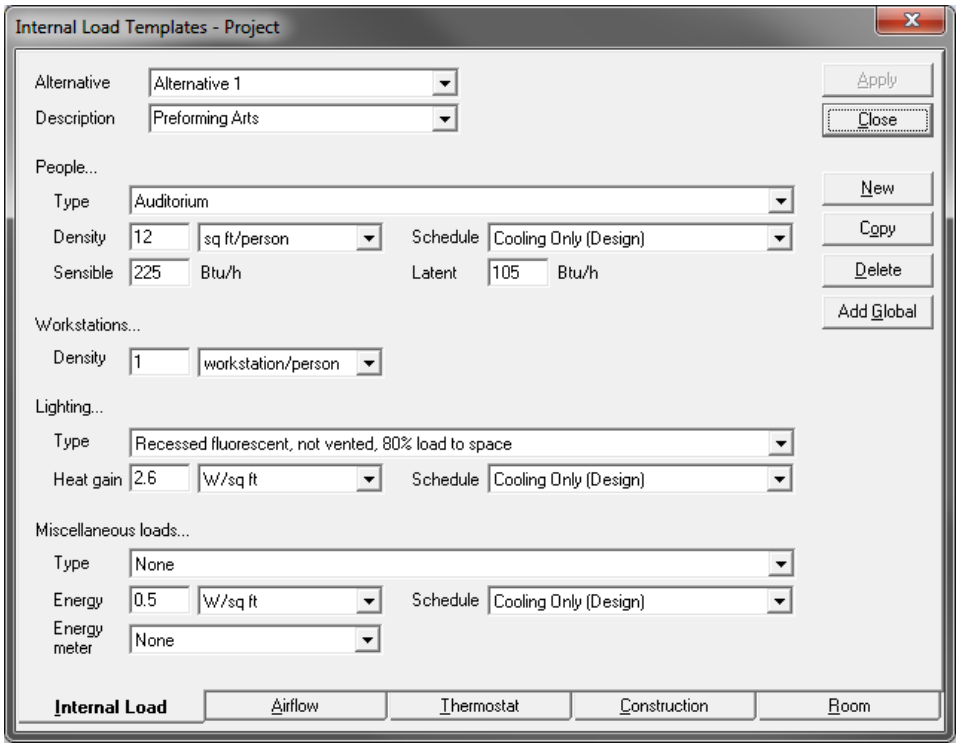
Spillman Farmer Architects. 2009. Architectural Construction Documents. Spillman Framer Architects, Bethlehem,PA. 2008,

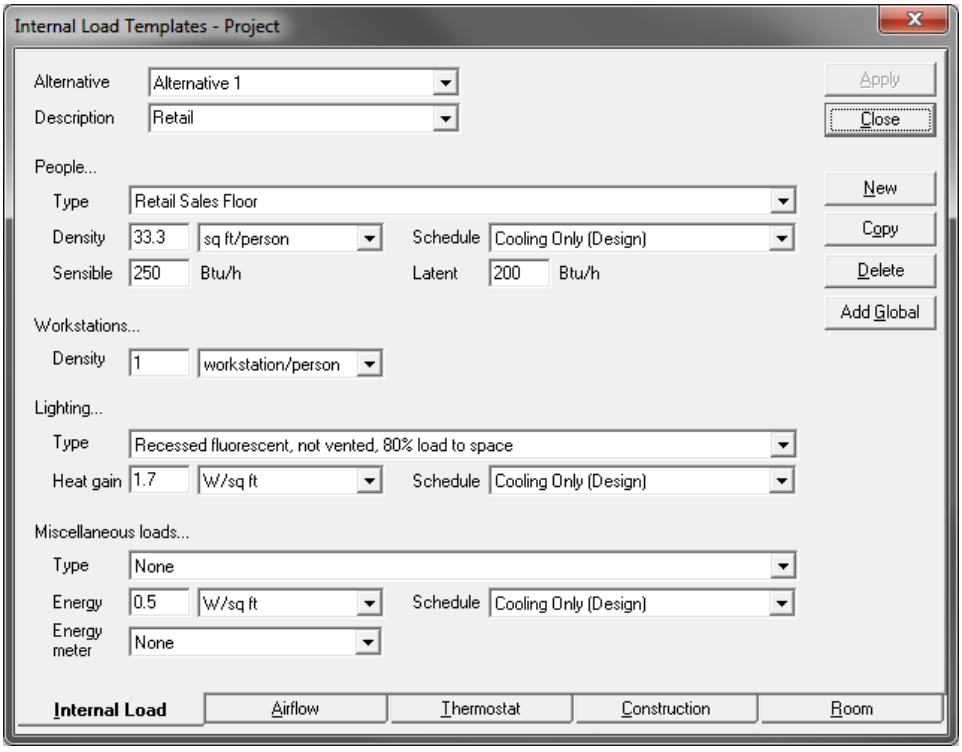
Brinjac Engineering. 2009. MEP Construciton Documents. Brinjac Engineering, Harrisburg, PA. 2009.

Appendix A


Internal Load Templates - Project
Alternative
Alternative 1
Description
Cinema
Apply
Close
People...
Type
Auditorium
New
Density
190
People
Schedule
Cooling Only (Design)
Copy
Sensible
225
Btu/h
Latent
105
Btu/h
Delete
Add Global
Workstations...
Density
1
workstation/person
Lighting...
Type
Recessed fluorescent, vented supply & return, 20% load to space
Heat gain
1.2
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
Type
Std Office Equipment
Energy
0.5
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
Electricity
Internal Load
Airflow
Thermostat
Construction
Room


Internal Load Templates - Project
Alternative
Alternative 1
Description
Office
Apply
Close
People...
Type
General Office Space
New
Density
143
sq ft/person
Schedule
Cooling Only (Design)
Copy
Sensible
250
Btu/h
Latent
200
Btu/h
Delete
Add Global
Workstations...
Density
1
workstation/person
Lighting...
Type
Recessed fluorescent, vented supply & return, 20% load to space
Heat gain
1.4
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
Type
Std Office Equipment
Energy
0.5
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
Electricity
Internal Load
Airflow
Thermostat
Construction
Room


Internal Load Templates - Project
Alternative
Alternative 1
Description
Preforming Arts
Apply
Close
People...
Type
Auditorium
Density
12
sq ft/person
Schedule
Cooling Only (Design)
Sensible
225
Btu/h
Latent
105
Btu/h
New
Copy
Delete
Add Global
Workstations...
Density
1
workstation/person
Lighting...
Type
Recessed fluorescent, not vented, 80% load to space
Heat gain
2.6
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
Type
None
Energy
0.5
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
None
Internal Load
Airflow
Thermostat
Construction
Room


Internal Load Templates - Project
Alternative
Alternative 1
Description
Retail
Apply
Close
People...
Type
Retail Sales Floor
Density
33.3
sq ft/person
Schedule
Cooling Only (Design)
Sensible
250
Btu/h
Latent
200
Btu/h
New
Copy
Delete
Add Global
Workstations...
Density
1
workstation/person
Lighting...
Type
Recessed fluorescent, not vented, 80% load to space
Heat gain
1.7
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
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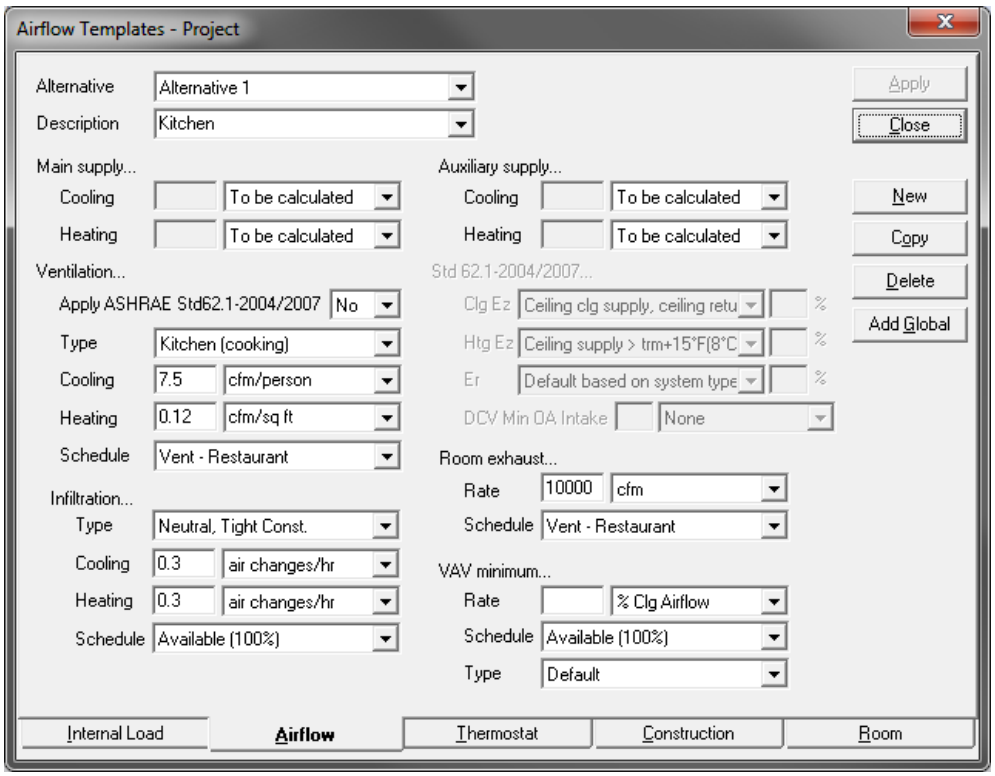
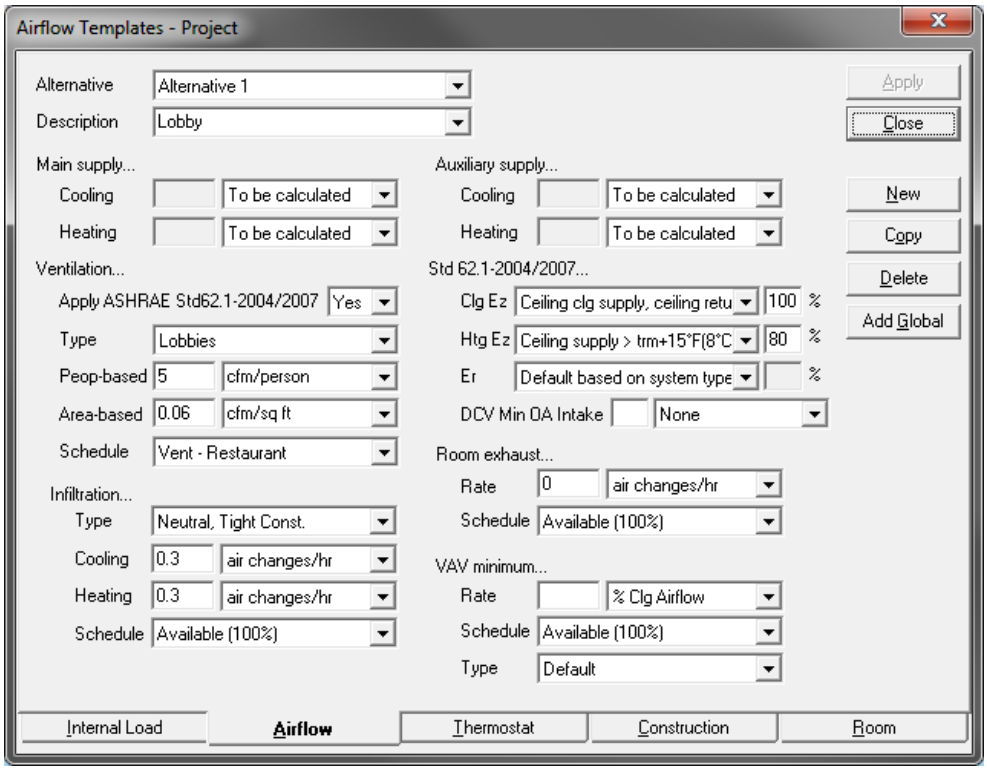
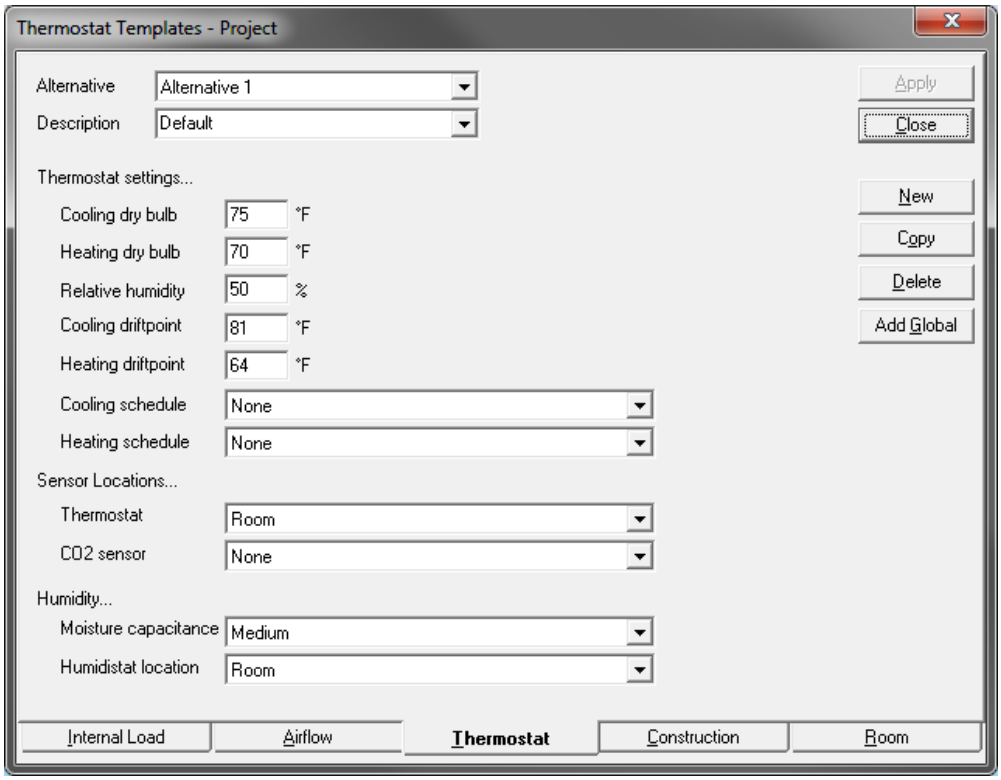
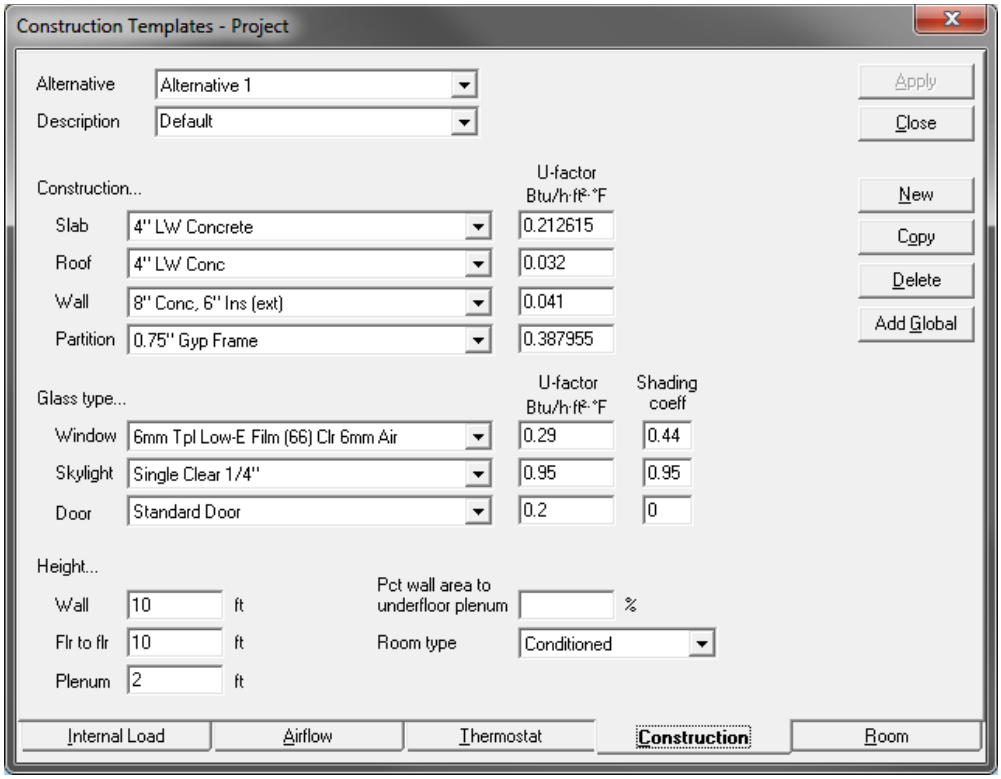
None
Energy
0.5
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
None
Internal Load
Airflow
Thermostat
Construction
Room


Airflow Templates - Project
Alternative
Alternative 1
Description
Kitchen
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
Kitchen (cooking)
Cooling
7.5
cfm/person
Heating
0.12
cfm/sq ft
Schedule
Vent - Restaurant
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
10000
cfm
Schedule
Vent - Restaurant
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


Airflow Templates - Project
Alternative
Alternative 1
Description
Lobby
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
Yes
Type
Lobbies
Peop-based
5
cfm/person
Area-based
0.06
cfm/sq ft
Schedule
Vent - Restaurant
Std 62.1-2004/2007...
Clg Ez
Ceiling clg supply, ceiling retu
100
%
Htg Ez
Ceiling supply > trm+15°F(8°C
80
%
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
°F
Heating dry bulb
70
°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
None
Humidity...
Moisture capacitance
Medium
Humidistat location
Room
Internal Load
Airflow
Thermostat
Construction
Room


Construction Templates - Project
Alternative
Alternative 1
Description
Default
Apply
Close
Construction...
U-factor Btu/h·ft²·°F
Slab
4" LW Concrete
0.212615
Roof
4" LW Conc
0.032
Wall
8" Conc, 6" Ins (ext)
0.041
Partition
0.75" Gyp Frame
0.387955
New
Copy
Delete
Add Global
Glass type...
U-factor Btu/h·ft²·°F
Shading coeff
Window
6mm Tpl Low-E Film (66) Clr 6mm Air
0.29
0.44
Skylight
Single Clear 1/4"
0.95
0.95
Door
Standard Door
0.2
0
Height...
Wall
10
ft
Flr to flr
10
ft
Plenum
2
ft
Pct wall area to underfloor plenum
%
Room type
Conditioned
Internal Load
Airflow
Thermostat
Construction
Room

Appendix B

Table 3 Total Emission Factors for Delivered Electricity
(lb of pollutant per kWh of electricity)

Pollutant (lb)	National	Eastern	Western	ERCOT	Alaska	Hawaii
CO_{2e}	1.67E+00	1.74E+00	1.31E+00	1.84E+00	1.71E+00	1.91E+00
CO_2	1.57E+00	1.64E+00	1.22E+00	1.71E+00	1.55E+00	1.83E+00
CH_4	3.71E-03	3.59E-03	3.51E-03	5.30E-03	6.28E-03	2.96E-03
N_2O	3.73E-05	3.87E-05	2.97E-05	4.02E-05	3.05E-05	2.00E-05
NO_X	2.76E-03	3.00E-03	1.95E-03	2.20E-03	1.95E-03	4.32E-03
SO_X	8.36E-03	8.57E-03	6.82E-03	9.70E-03	1.12E-02	8.36E-03
CO	8.05E-04	8.54E-04	5.46E-04	9.07E-04	2.05E-03	7.43E-03
TNMOC	7.13E-05	7.26E-05	6.45E-05	7.44E-05	8.40E-05	1.15E-04
Lead	1.31E-07	1.39E-07	8.95E-08	1.42E-07	6.30E-08	1.32E-07
Mercury	3.05E-08	3.36E-08	1.86E-08	2.79E-08	3.80E-08	1.72E-07
PM10	9.16E-05	9.26E-05	6.99E-05	1.30E-04	1.09E-04	1.79E-04
Solid Waste	1.90E-01	2.05E-01	1.39E-01	1.66E-01	7.89E-02	7.44E-02

Table 8 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

* from the U.S. LCI data module: Bituminous Coal Combustion in an Industrial Boiler (NREL 2005)
** from the U.S. LCI data module: Lignite Coal Combustion in an Industrial Boiler (NREL 2005)
*** Gas volume at 60°F and 14.70 psia.
† no data available