# Army Reserve Center
# Newport, Rhode Island

## Technical Report Two:
## Building and Plant Energy Analysis Report

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## Executive Summary

The purpose of this report is to estimate the design loads, to determine the annual energy consumption, and to determine the operating costs of the Army Reserve Center. To model the Army Reserve Center, a block load estimate was performed using Trace 700. The information for the model was taken from the design documents. Assumptions were made when information was not provided or the information was unable to be applied because a block load estimate was used as opposed to the space-by-space method.

According to the model created in Trace 700, the Army Reserve Center consumes 1915 MMBtu/year of energy compared to the 1137 MMBtu/year that was determined by the designed engineer. Another alternative by the design engineer found there to be 1760 MMBtu/year, however, this was not used in the design. The total cost to operate the Army Reserve Center was found to be $48,700 per year which translates to $0.83/square foot.

There were several discrepancies between the design documents and the modeled energy usage of the building. The main difference was the energy for lighting in the model compared to the design. The design called for 281 MMBtu/year which is less than three times what the model predicted at 863 MMBtu/year. Both of the schedules are the same so it is not due to a schedule difference. However, it could be because natural lighting is considered in the design, but an average of 0.71 $W/ft^2$ was used in the model regardless of the number or size of windows in the space.

Another reason for the differences was that block load was used as opposed to the space-by-space method. Many of the smaller rooms in the building were treated as part of the block. For example, several smaller rooms were either not ventilated or placed on ductless split systems. These rooms did not receive air from any of the main three air handling units. However, they were part of the block and were thus placed on one of the air handling units in the analysis.

## Mechanical Systems Overview

The Army Reserve Center contains three air handling units. All three air handling units are located in mechanical rooms on the second floor. AHU-1 serves the first floor offices, is of the variable air volume type, and provides 3700 CFM of supply air which is 24% outside air. AHU-2 serves the second floor, is also of the variable air volume type, and provides 13,200 CFM of supply air which is 18% outside air. AHU-3 serves the auditorium, is of the constant volume type, and provides 2100 CFM of supply air which is 64% outside air. The rest of the ventilation for several other spaces on the first floor is done using small unit ventilators. Each air handling

unit is manufactured by Trane and contains a supply fan, return fan, cooling coil, heating coil, filter, and enthalpy economizer.

The heating accounts for 198 MMBtu/year which is 10.3% of the total energy used in the Army Reserve Center. This comes mainly from the two boilers present in the building. Both boilers have 959 MBH of heating capacity, are manufactured by AERCO, have enter water temperatures of 100 degrees Fahrenheit and leaving water temperatures of 130 degrees Fahrenheit.

The cooling accounts for 250 MMBtu/year which is 13% of the total energy used in the Army Reserve Center. There are two air-cooled rotary screw packaged water chillers piped in parallel in the building. The chillers have capacities of 40 and 52 tons respectively, are both manufactured by Trane, and both have scroll compressors that use R-410A as the refrigerant.

# Design Load Estimation

To estimate the design load for the Army Reserve Center, a block load estimate was performed using Trane Trace 700. Most of the information was obtained from the design documents. However, several assumptions needed to be made.

## Outdoor / Indoor Design Conditions

The design conditions of Providence, Rhode Island were used for the Army Reserve Center because they were the closet available to Newport, Rhode Island. These are:

Heating: 10.8°F (99.0% Occurrence)
Cooling: 89.7°F DB / 73.2°F WB (0.4% Occurrence)

However, because it was requested by the US Army Corps of Engineers, 0°F was used for heating. Also, because it was requested, indoor cooling design conditions shall be 74°F with 50% relative humidity and indoor heating shall be 72°F for occupied spaces and 55°F for unoccupied spaces.

## Airflow

Airflow was determined by the design engineer using ASHRAE 62.1. The infiltration for the building was assumed to be pressurized tight construction thus allowing 0.3 air changes per hour. In order to provide more detail, several of the spaces used in the Trace model are shown in Appendix A.

## Building Construction

The U values for the walls, roof, and floor of the building were determined from the architectural and structural drawings and other design documents. They are shown in table 1 below. The wall heights, floor to floor heights, and plenum heights are shown in table 2 below.

| | Construction of Building |
|---|---|
| **Roof** | Overall Roof U factor = 0.0330, Fully adhered EPDM membrane roofing system, 1/2" Coverboard insulation, 4" Polyisocyanurate board insulation (R-28 min), 1/2" fiber reinforced gypsum decking, 1-1/2" metal roof deck. The assembly hall roof is flat, and the rest of the building is sloped. |
| **Wall Construction** | Floor 1: Overall Wall U factor = 0.0673. 4" Vaneer face brick, 2" air space, 2" polystyrene insulation, dampproofing barrier, 6" concrete masonry. Floor 2: Overall Wall U factor = 0.0400. 4" Vaneer face brick, 2" air space, 2" Polystyrene insulation, fluid-applied air and vapor barrier, 1/2" glass-mat gypsum sheathing, 6" metal framing with 6" R-19 insulation, 5/6" gypsum wall board (painted), 4" nominal cast stone band. |
| **High Bay Doors** | Overall Door U factor = 1.45 (ASHRAE min) |
| **Swing Doors** | Overall Door U factor = 0.7 (ASHRAE min) |
| **Windows** | U = 0.57 SHGC = 0.49 |
| **Floor** | Slab on Grade heated/unheated: 5" concrete with R-10 surrounding 5 feet from the the perimeter |

Table 1

| | Wall Height | Floor to Floor Height | Plenum Height |
|---|---|---|---|
| **1st Floor** | 14 feet | 14 feet | 4 feet |
| **2nd Floor** | 10 feet | 10 feet | 3 feet |

Table 2

## Block Load Method

The Army Reserve Center was broken up into several blocks for the design load estimation. Each air handling unit had its own block. AHU-1 serves the first floor offices, AHU-2 serves the second floor, and AHU-3 serves the auditorium. The other blocks are the areas served by the unit ventilators. UV-1, UV-2, and UV-3 are treated as one block since they serve several classrooms that are in a row. UV-4, UV-5, and UV-6 each are treated as a separate block because they each serve a group of several spaces. UV-4 and UV-5 are on the exterior while UV-6 is on the interior. A schematic of AHU-1 is located in Appendix B.

## Lighting

The average lighting of the Army Reserve Center is 0.71 Watts / square foot. Since the design load is estimated based on the block load method, this is used for each of the blocks.

## Occupancy

The number of people each space is to be designed for is given in the design documents. Those values are used to determine the occupancy. For the offices, each occupant is assumed to have a personal computer that gives off 150 watts. For the library and the copy center, an appropriate amount of watts for each computer, copier, and printer are assumed.

## Modeled Versus Designed

Shown in table 3 below are the actual cooling square foot/ton, the heating BTUH/square foot, the total supply air CFM/square foot, and the supply air CFM/square foot. Although the design documents include several Trane Trace 700 files, they do not include the system checksums so the actual numbers cannot be obtained from the Trace file. However, the numbers can be determined from the mechanical schedules.

| MODELED VERSUS DESIGNED | | | | | |
|---|---|---|---|---|---|
| | | COOLING FT2 / TON | HEATING BTUH/FT2 | TOTAL SA CFM/FT2 | VENT SUPPLY CFM/FT2 |
| AHU-1 | MODELED | 653 | 11.45 | 0.42 | 0.125 |
| | DESIGNED | 544 | 7.32 | 0.45 | 0.11 |
| | % DIFF | 20.04 | 56.42 | 6.67 | 13.64 |
| AHU-2 | MODELED | 620 | 11.52 | 0.5 | 0.098 |
| | DESIGNED | 561 | 5.81 | 0.53 | 0.096 |
| | % DIFF | 10.52 | 98.28 | 5.66 | 2.08 |
| AHU-3 | MODELED | 287 | 27.82 | 0.86 | 0.37 |
| | DESIGNED | 235 | 43 | 0.72 | 0.464 |
| | % DIFF | 22.13 | 35.30 | 19.44 | 20.26 |
| UV-1, UV-2, UV-3 | MODELED | 383 | 24.95 | 0.76 | 0.334 |
| | DESIGNED | 408 | 30.6 | 0.52 | 0.157 |
| | % DIFF | 6.13 | 18.46 | 46.15 | 112.74 |
| UV-4 | MODELED | 330 | 23.51 | 1.54 | 0.1 |
| | DESIGNED | 506 | 26.5 | 0.81 | 0.127 |
| | % DIFF | 34.78 | 11.28 | 90.12 | 21.26 |
| UV-5 | MODELED | 301 | 24.2 | 1.54 | 0.1 |
| | DESIGNED | 359 | 28.3 | 0.87 | 0.127 |
| | % DIFF | 16.16 | 14.49 | 77.01 | 21.26 |
| UV-6 | MODELED | 1320 | 8.35 | 0.19 | 0.083 |
| | DESIGNED | 801.00 | 14.60 | 0.56 | 0.12 |
| | % DIFF | 64.79 | 42.81 | 66.07 | 29.06 |

Table 3

As shown table 3, most of the systems appear to be accurately modeled since the percent differences are rarely above 30%. However, there are several discrepancies. This occurs partially because the rooms were designed using the space by space method while the model created used the block method. The block method placed several smaller spaces on the air handling units when they really were not conditioned. The other reason for the differences could be that, especially for the unit ventilators, there are only so many standard sizes. The unit ventilators thus had to be oversized in order to meet the required capacities. The schedules, which had these oversized unit ventilators, were used in determining the heating, cooling, and ventilation CFM/ square foot since the Trace 700 files documenting the required capacities of the spaces which contained the unit ventilators were not given. This error was not noticeable on the larger air handling units because they are big enough that even if they are oversized, it is by a much smaller percentage.

# Annual Energy Consumption and Operating Costs

## Energy Usage

| | Electric Consumption (kWh) | Gas Consumption (kBTU) | % of Total Building Energy | Total Building Energy (mmBtu/yr) |
|---|---|---|---|---|
| **Heating** | | | | |
| Primary Heating | | 153,112 | 8.00% | 153 |
| Other Htg. Accessories | 13,065 | | 2.30% | 44.6 |
| **Cooling** | | | | |
| Cooling Compessor | 62,509 | | 11.10% | 213.3 |
| Tower/Cond Fans | 9,625 | | 1.70% | 32.9 |
| Other Clg Accessories | 876 | | 0.20% | 3 |
| **Auxiliary** | | | | |
| Pumps | 59,755 | | 10.70% | 203.9 |
| **Lighting** | 252,839 | | 45.10% | 862.9 |
| **Receptacles** | 117,384 | | 20.90% | 400.6 |
| **Total** | **516053** | **153112** | **100%** | **1,914.40** |

Table 4 (above)

As shown in table 4 above, the majority of the energy consumption of the Army Reserve Center is due to lighting and receptacles which make up 45.1% and 20.9% of the energy respectively. The cooling and heating loads are both relatively small percentages of the total energy used. This is due to the tight construction of the building, each of the components of the building having small U values, and the building minimizing glass (less than 10%).

Figures 1 and 2 below show the monthly usage of natural gas and electricity, respectively. As one may predict, natural gas usage is negligible (if at all) in the summer because there is hardly any heating from the boilers. However, it increases in the winter month and is a maximum at 422 therms in January.

Electricity usage is at a maximum in July at 51,618 kilowatt hours because many of the air conditioning applications need a lot of electricity to meet their capacities. It is higher also in June and August, but really is about the same for the rest of the year. One thing to consider for the re-design of the building would be to attempt to maximize day lighting. This would help because the most of the energy is due to lighting which makes up 45% of the total energy usage of the building.

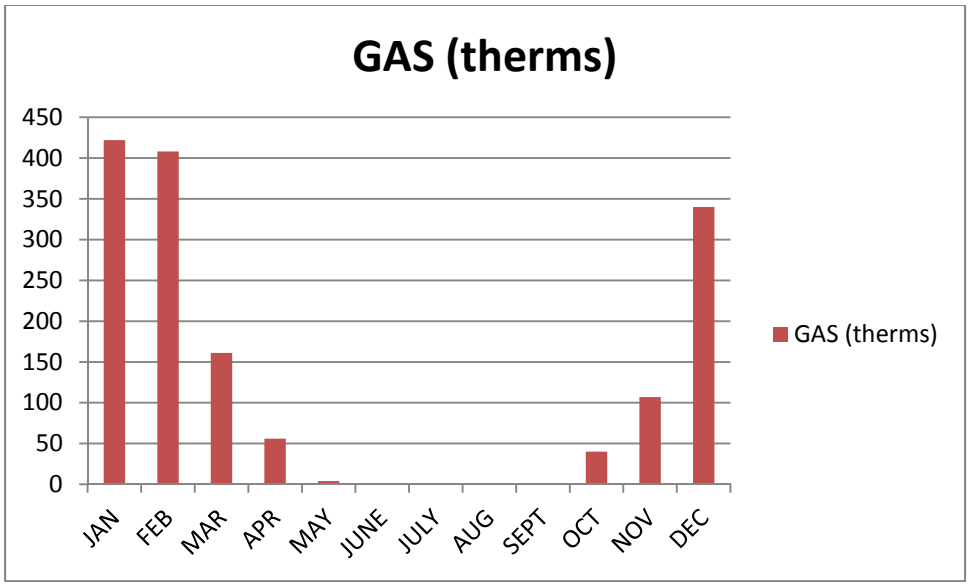



Figure 1 (above)

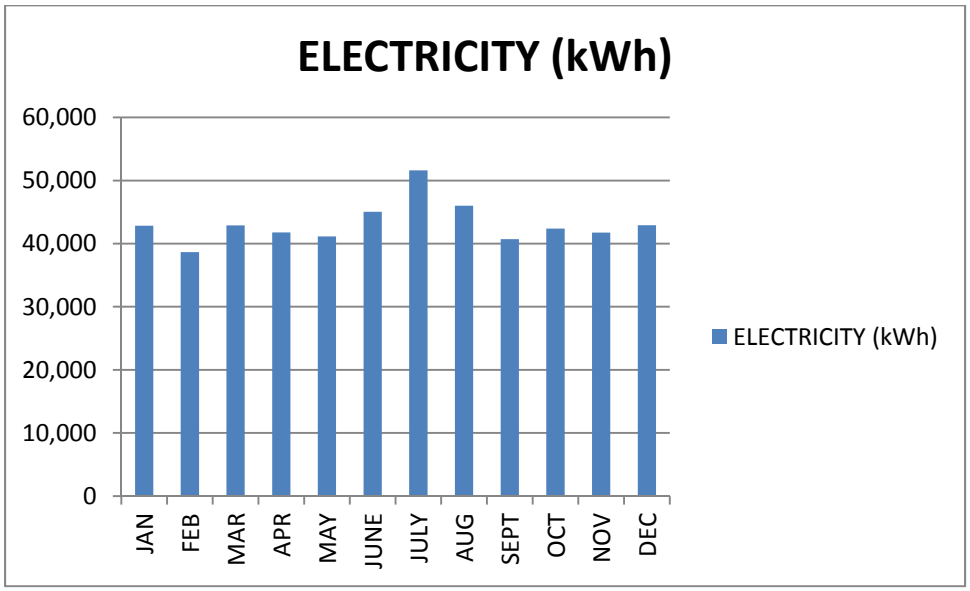



Figure 2 (above)

## Schedules

The Army Reserve Center is composed of mostly office spaces. An office-based schedule, shown below in table 5, is thus used.

| Start | End | Percentage |
|---|---|---|
| Midnight | 6 a.m. | 0 |
| 6 a.m. | 7 a.m. | 10 |
| 7 a.m. | 8 a.m. | 30 |
| 8 a.m. | 11 a.m. | 100 |
| 11 a.m. | 1 p.m. | 80 |
| 1 p.m. | 5 p.m. | 100 |
| 5 p.m. | 6 p.m. | 10 |
| 6 p.m. | Midnight | 0 |

Table 5

## Fuel Costs

According to the specifications, the cost for electricity is $93.15/MWH or $0.09315/Kwh. The cost of natural gas is approximately $4.00/MMBtu. As shown in table 6 below, the total cost to operate the building per year is $48,682.78. Since the area of the building is approximately 59,000 square feet, the cost per square foot be operate the Army Reserve Center is $0.83 / square foot.

| Total Cost of Energy | | | | |
|---|---|---|---|---|
| | **Electric Cost** | **Gas Cost** | **% of Total Building Cost** | **Total Building Cost** |
| **Heating** | | | | |
| Primary Heating | | $612.45 | 8.00% | $612.45 |
| Other Htg. Accessories | $1,217.00 | | 2.30% | $1,217.00 |
| **Cooling** | | | | |
| Cooling Compessor | $5,822.71 | | 11.10% | $5,822.71 |
| Tower/Cond Fans | $896.57 | | 1.70% | $896.57 |
| Other Clg Accessories | $81.60 | | 0.20% | $81.60 |
| **Auxiliary** | | | | |
| Pumps | $5,566.18 | | 10.70% | $5,566.18 |
| **Lighting** | $23,551.95 | | 45.10% | $23,551.95 |
| **Receptacles** | $10,934.32 | | 20.90% | $10,934.32 |
| **Total** | **$48,070.34** | **$612.45** | **100%** | **$48,682.78** |

Table 6

## Equipment Performance Characteristics

Shown below in table 7 are the horsepower for each fan and the supply CFM that the fan creates. These are used to determine the total energy consumption of each fan.

| Tag | Supply CFM | HP |
|---|---|---|
| **AHU-1 Supply Fan** | 3700 | 7.50 |
| **AHU-2 Supply Fan** | 13200 | 20.00 |
| **AHU-3 Supply Fan** | 2100 | 3.00 |
| **AHU-1 Return Fan** | 3700 | 3.00 |
| **AHU-2 Return Fan** | 13200 | 10.00 |
| **UV-1** | 625 | 0.50 |
| **UV-2** | 440 | 0.50 |
| **UV-3** | 440 | 0.50 |
| **UV-4** | 606 | 0.50 |
| **UV-5** | 650 | 0.50 |
| **UV-6** | 975 | 0.50 |

Table 7

## Compare to Actual Energy Analysis

Shown below in table 8 below are two alternatives for the building energy consumption created by the design engineer. The Army Reserve Center was designed based on Alt-1 Training Center Proposed. Although both the design engineer and the model created used Trane Trace 700 for the energy model, alternative 1 was very different than the total energy calculated. The calculated model, closer to alternative 2, used 1,914 * 10^6 BTU/yr, which is a 68% difference from alternative 1, but only an 8% difference from alternative 2. The lighting load of the model is 863 mmBTU/yr; about three times greater than alternative 1 and twice as large as alternative 2.

Part of this is because the design only takes into account conditioned spaces, while the model created is based on the block load method and thus takes the lighting load of several unconditioned spaces. Another reason for the discrepancies in lighting loads could have arisen if the design engineer took into account natural lighting and thus assumed that the lights would be off or dimmed during much of the day. The model does not take that into account because it assumes 0.71 Watts / square foot for each of the blocks.

The actual utility bills are not yet available as the Army Reserve Center is currently under construction thus no comparison of predicted and actual utility costs can be performed.

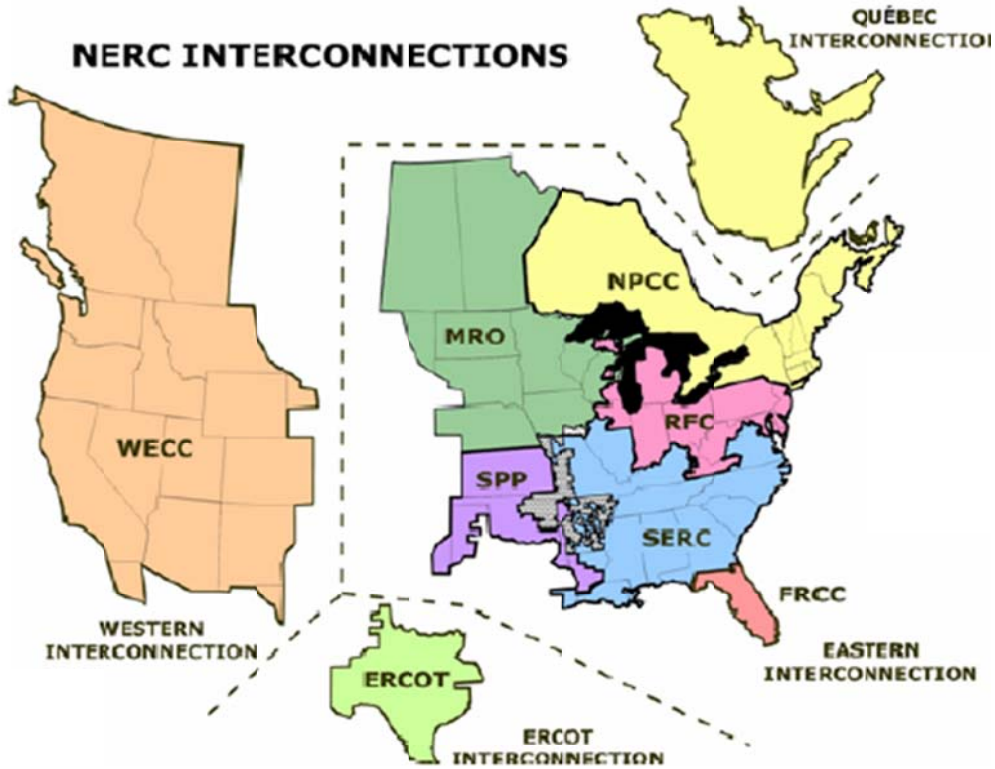
Note: The percentage displayed for the "Proposed/ Base %" column of the base case is actually the percentage of the total energy consumption.

* Denotes the base alternative for the ECB study.

| | | * Alt-2 | | | Alt-1 Training Center Proposed | | |
|---|---|---|---|---|---|---|---|
| | | Energy 10^6 Btu/yr | Proposed / Base % | Peak kBtuh | Energy 10^6 Btu/yr | Proposed / Base % | Peak kBtuh |
| Lighting - Conditioned | Electricity | 405.2 | 23 | 166 | 280.7 | 69 | 109 |
| Space Heating | Electricity | 1.4 | 0 | 2 | 37.0 | 2,738 | 10 |
| | Gas | 454.4 | 26 | 712 | 203.1 | 45 | 510 |
| Space Cooling | Electricity | 155.0 | 9 | 310 | 97.9 | 63 | 220 |
| Pumps | Electricity | 0.0 | 0 | 0 | 1.9 | 0 | 4 |
| Heat Rejection | Electricity | 64.4 | 4 | 33 | 14.6 | 23 | 27 |
| Fans - Conditioned | Electricity | 99.9 | 6 | 84 | 67.6 | 68 | 108 |
| Receptacles - Conditioned | Electricity | 219.5 | 12 | 98 | 219.5 | 100 | 98 |
| Stand-alone Base Utilities | Electricity | 299.0 | 17 | 63 | 163.6 | 55 | 34 |
| | Gas | 60.4 | 3 | 7 | 50.8 | 84 | 6 |
| **Total Building Consumption** | | **1,759.2** | | | **1,136.6** | | |

Table 8

## Emissions




North American electrical grid interconnections, including the 10 NERC regional reliability councils (NERC 2007)

Figure 3 (above)

As shown in figure 3 above, Rhode Island and thus the Army Reserve Center are part of the Eastern Interconnection.

As shown in table 9 below, the Eastern Interconnection uses primarily coal (53.9%), nuclear (23.0%), and natural gas (12.7%) for electricity generation. Also shown in tables 10 and 11 below are the total pounds of toxic substances that are emitted because of the Army Reserve Center's use of electricity and natural gas. The building creates 846,327 and 1,300 pounds of carbon dioxide due to electricity and natural gas respectively.

**Percent Electricity Generation by Energy Type for 2004**

| Energy Type | National % | Eastern % | Western % | ERCOT % | Alaska % | Hawaii % |
|---|---|---|---|---|---|---|
| Bituminous Coal | 27.8 | 34.3 | 13.1 | 0.0 | 0.0 | 1.0 |
| Subbitumious Coal | 19.8 | 19.6 | 19.8 | 21.4 | 9.9 | 13.1 |
| Lignite Coal | 2.3 | 1.4 | 0.0 | 14.8 | 0.0 | 0.0 |
| Natural Gas | 18.3 | 12.7 | 27.4 | 49.4 | 55.5 | 1.5 |
| Petroleum Fuels | 2.8 | 3.6 | 0.5 | 0.5 | 11.5 | 77.4 |
| Other Fossil Fuel | 0.2 | 0.2 | 0.3 | 0.2 | 0.0 | 0.2 |
| Nuclear | 19.9 | 23.0 | 9.9 | 12.4 | 0.0 | 0.0 |
| Hydro | 6.8 | 3.4 | 24.6 | 0.3 | 23.0 | 0.8 |
| Renewable Fuels | 1.5 | 1.7 | 1.3 | 0.2 | 0.1 | 4.2 |
| Geothermal | 0.4 | 0.0 | 2.1 | 0.0 | 0.0 | 1.9 |
| Wind | 0.4 | 0.1 | 1.0 | 0.9 | 0.0 | 0.1 |
| Solar (PV) | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| **Fossil Fuel Total** | 71.2 | 71.8 | 60.9 | 86.2 | 76.9 | 93.1 |
| **Renewable (non hydro)** | 2.2 | 1.8 | 4.6 | 1.1 | 0.1 | 6.1 |

Table 9 (above)

| | TOTAL ELECTRICAL USAGE (kWh) | TOAL EMISSION FRACTION (LB / kWh) | TOTAL POLLUTION (LB) |
|---|---|---|---|
| **$CO_2$** | 516,053 | 1.64 | 846,327 |
| **NOx** | | 3.00 * 10^-3 | 1,548 |
| **SOx** | | 8.57 * 10^-3 | 4,423 |
| **PM** | | 9.26 * 10^-5 | 4,779 |

Table 10

| | TOTAL GAS USAGE (*1000 $FT^3$) | TOAL EMISSION FRACTION (LB / 1000 FT3) | TOTAL POLLUTION (LB) |
|---|---|---|---|
| **$CO_2$** | 112 | 11.6 | 1,300 |
| **NOx** | | 0.0164 | 2 |
| **SOx** | | 1.22 | 137 |
| **PM** | | 0.002237 | 0 |

Table 11

# References

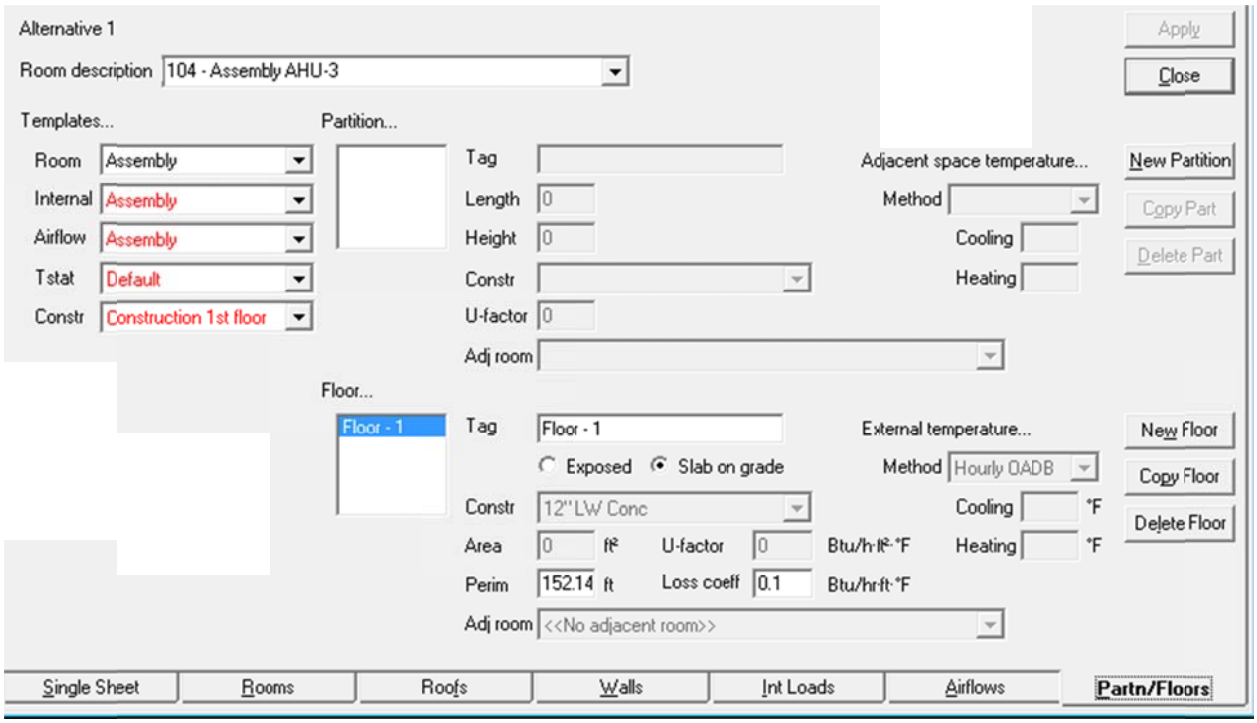
Michel Baker Corporation. Construction Documents & Specifications. 101 Airside Drive, Pittsburgh, PA, 15108.

Previous Senior Thesis Reports 2009-2010.

Trane Trace 700.

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

# Appendix A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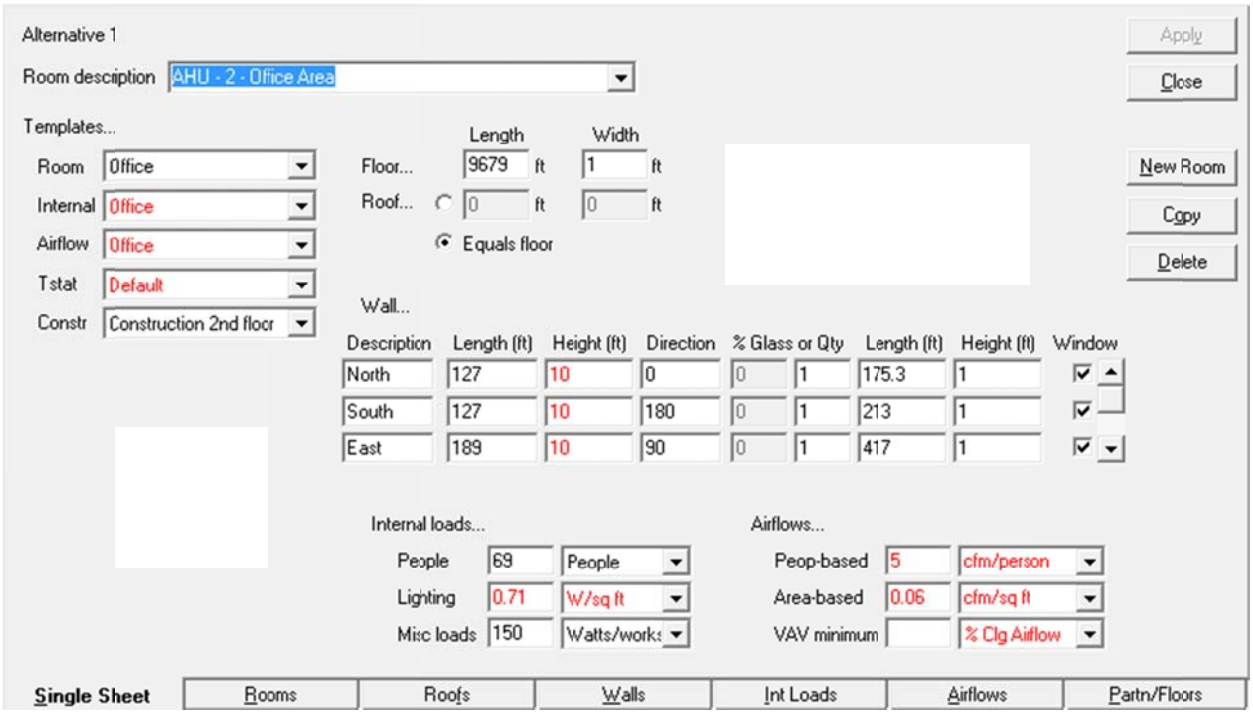
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cfm/person
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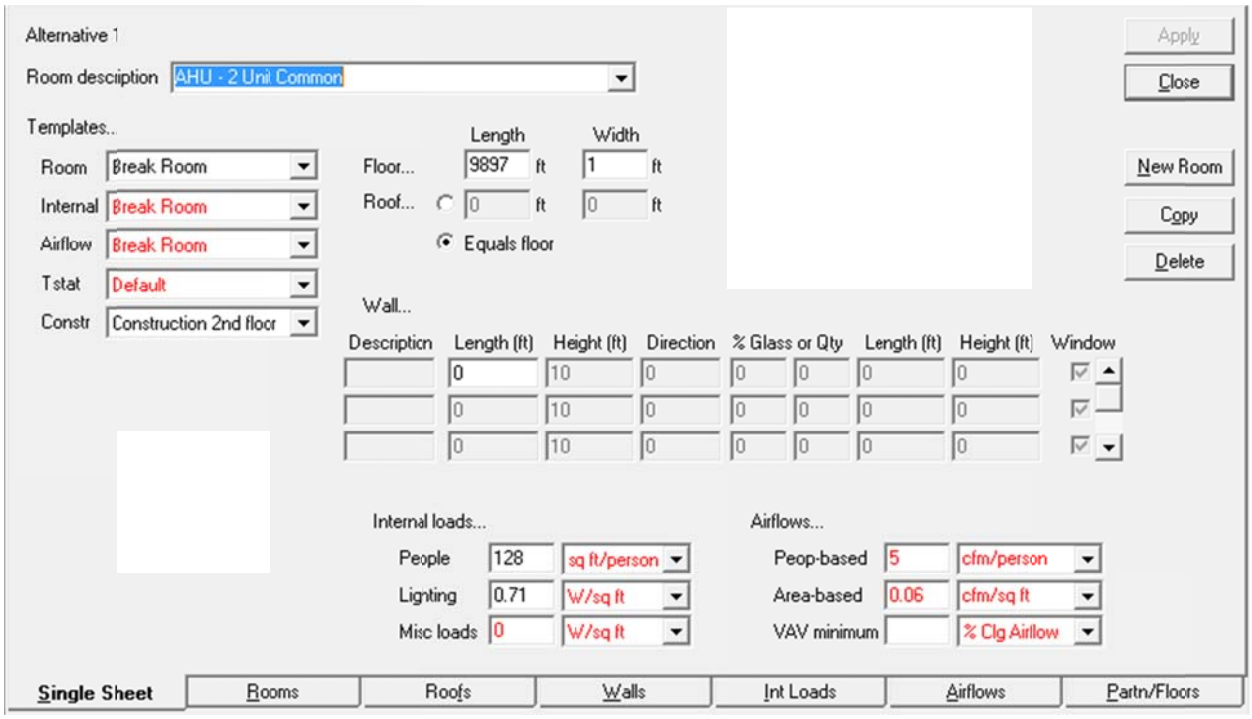
Int Loads
Airflows
Partn/Floors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Length (ft)
Height (ft)
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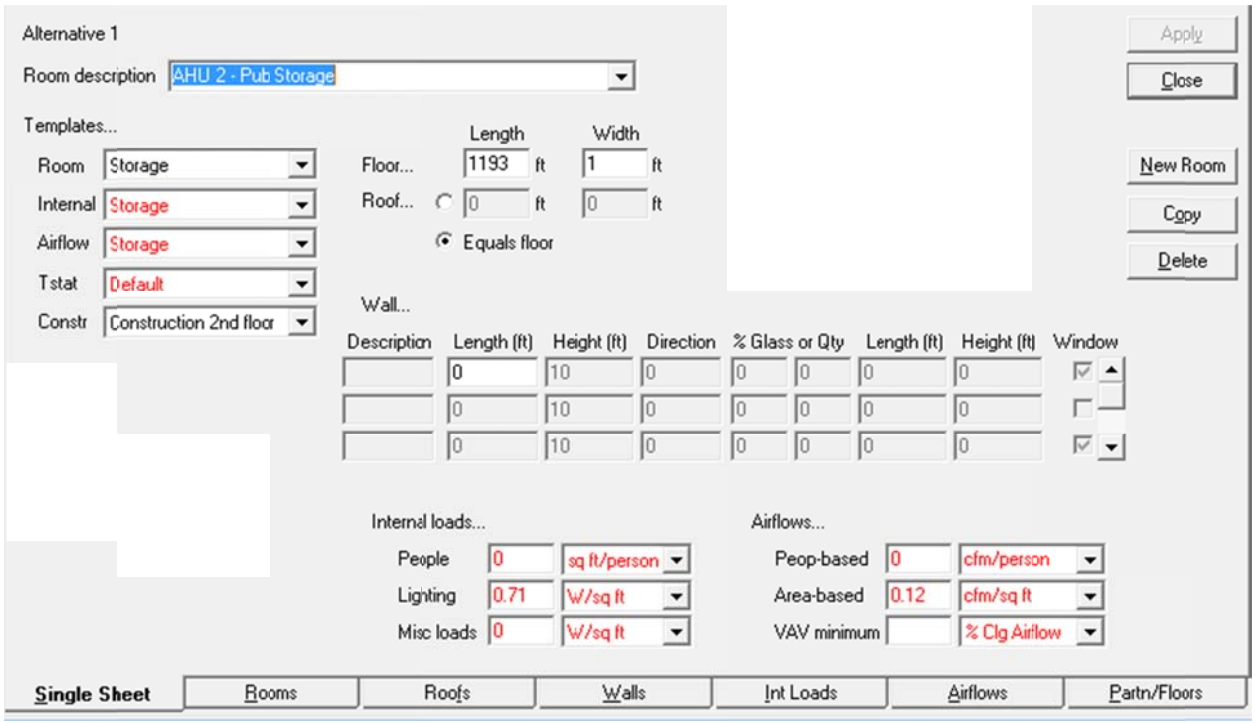
Walls
Int Loads
Airflows
Partn/Floors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W/sq ft
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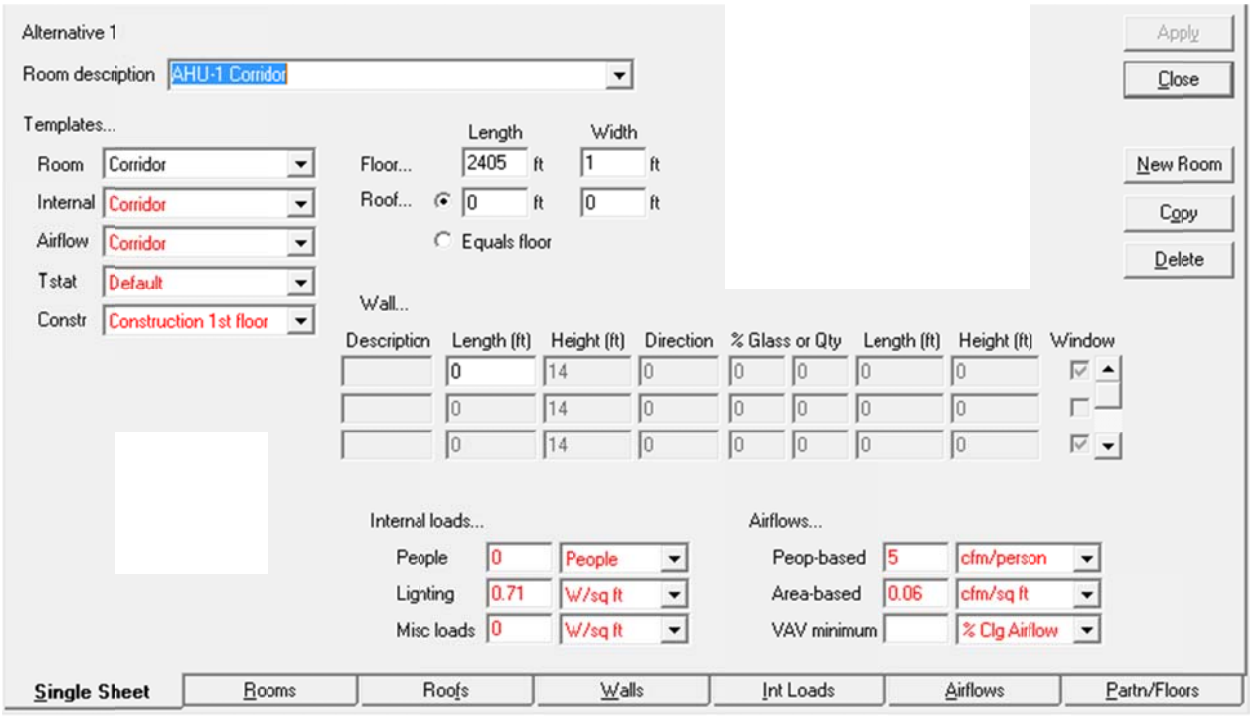
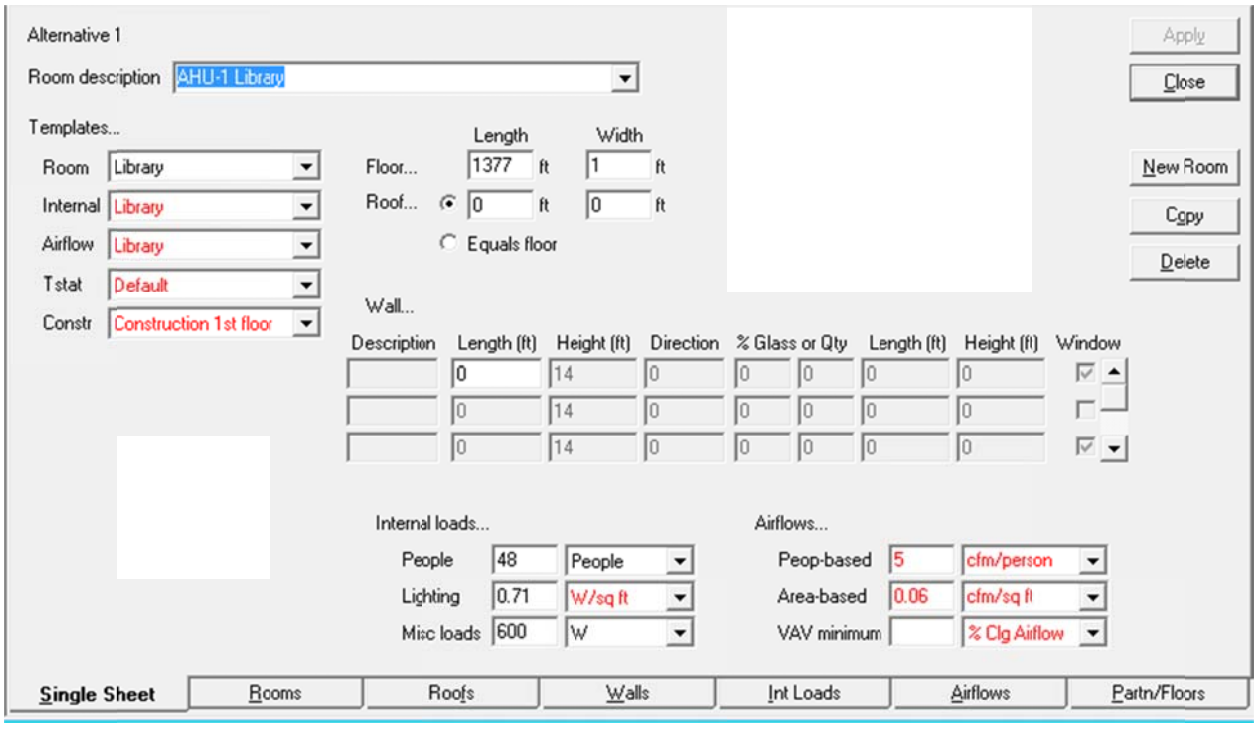
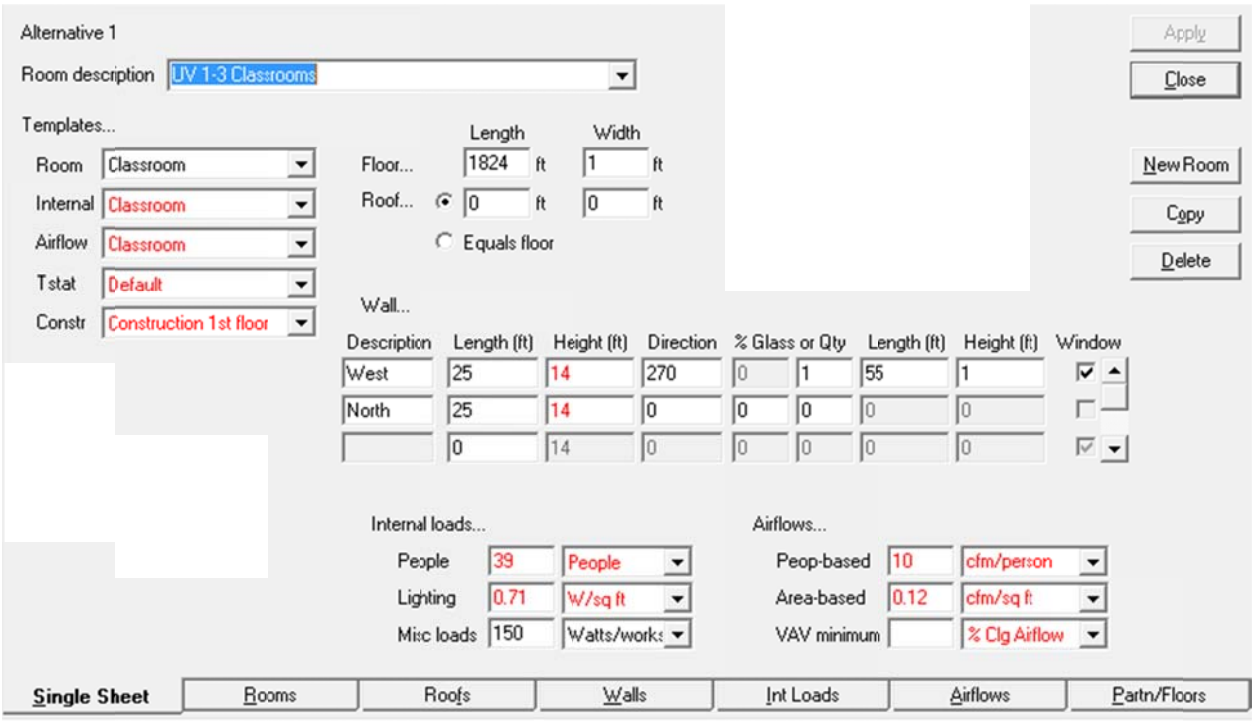
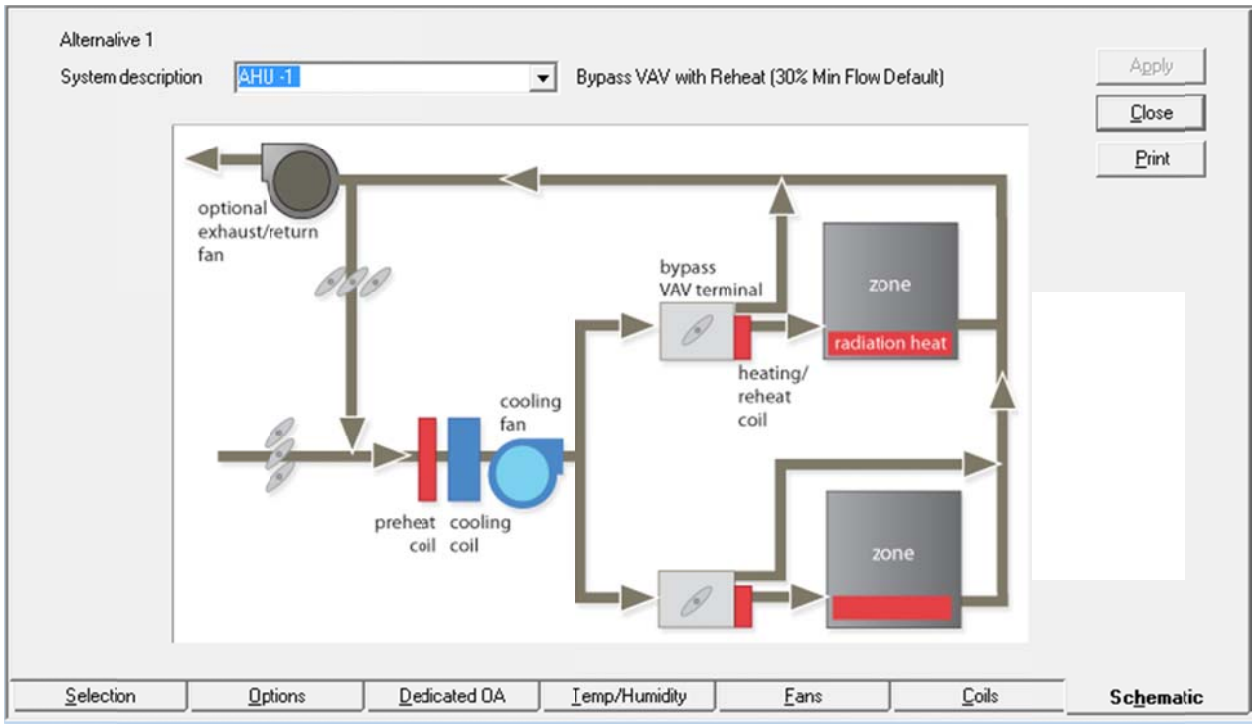
cfm/sq ft
VAV minimum
% Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors


Alternative 1
Room description
AHU-1 Corridor
Apply
Close
Templates...
Room
Corridor
Internal
Corridor
Airflow
Corridor
Tstat
Default
Constr
Construction 1st floor
Length
Width
Floor...
2405
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
0
People
Lighting
0.71
W/sq ft
Misc loads
0
W/sq ft
Airflows...
Peop-based
5
cfm/person
Area-based
0.06
cfm/sq ft
VAV minimum
% Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors


Alternative 1
Room description
AHU-1 Library
Apply
Close
Templates...
Room
Library
Internal
Library
Airflow
Library
Tstat
Default
Constr
Construction 1st floor
Length
Width
Floor...
1377
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
48
People
Lighting
0.71
W/sq ft
Misc loads
600
W
Airflows...
Peop-based
5
cfm/person
Area-based
0.06
cfm/sq ft
VAV minimum
% Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors


Alternative 1
Room description
UV 1-3 Classrooms
Apply
Close
Templates...
Room
Classroom
Internal
Classroom
Airflow
Classroom
Tstat
Default
Constr
Construction 1st floor
Length
Width
Floor...
1824
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
West
25
14
270
0
1
55
1
North
25
14
0
0
0
0
0
0
14
0
0
0
0
0
Internal loads...
People
39
People
Lighting
0.71
W/sq ft
Misc loads
150
Watts/works
Airflows...
Peop-based
10
cfm/person
Area-based
0.12
cfm/sq ft
VAV minimum
% Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors

# Appendix B


Alternative 1
System description
AHU -1
Bypass VAV with Reheat (30% Min Flow Default)
Apply
Close
Print
optional exhaust/return fan
bypass VAV terminal
zone
radiation heat
heating/ reheat coil
cooling fan
preheat coil
cooling coil
zone
Selection
Options
Dedicated OA
Temp/Humidity
Fans
Coils
Schematic