2009

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Thesis Technical Assignment 2

Manoa Elementary School

[BUILDING AND PLANT ENERGY ANALYSIS REPORT]

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Executive Summary

The purpose of this report is to perform a building load energy analysis on Manoa Elementary School and also to analyze the building annual energy consumption, operating costs and emissions. Trane Trace 700 was used to perform both the energy load analysis and energy consumption based on the information provided in the design documents.

The modeled design loads were comparable to the actual system design for the most part. Inconsistencies in cooling loads are mainly due to the use of ASHRAE Standard 62.1 to determine zone populations for most spaces, the use of simplified schedules and the assumption of miscellaneous loads in the spaces. A more detailed summary along with all assumptions, schedules, inputs and alterations is included.

The building energy analysis seems to produce a reliable estimation of building energy consumption and cost, however further analysis of space heating appears to be necessary. Manoa Elementary School utilizes both electricity and natural gas to energize their building. Their total energy consumption as modeled was found to be 34,434 MBH for a total energy cost per year of $87,337 or $1.23 per square foot. This cost can be reduced by improving the building space heating system which has the highest energy consumption and cost.

Mechanical System Overview

Manoa Elementary School is designed to utilize three variable volume air handling units that serve the classroom spaces and two constant volume air handlers that serve the multipurpose and kitchen areas. The classroom units are equipped with energy recovery ventilators and supply outdoor ventilation air to the classroom and learning spaces. The constant volume systems that serve both the multipurpose and kitchen areas are designed to control occupant comfort and safety in the supplied zones. Schematics showing the zones covered by each air handling unit can be seen in Figures 1 and 2 below.

Figure 1: Wing A AHU Distribution Schematic

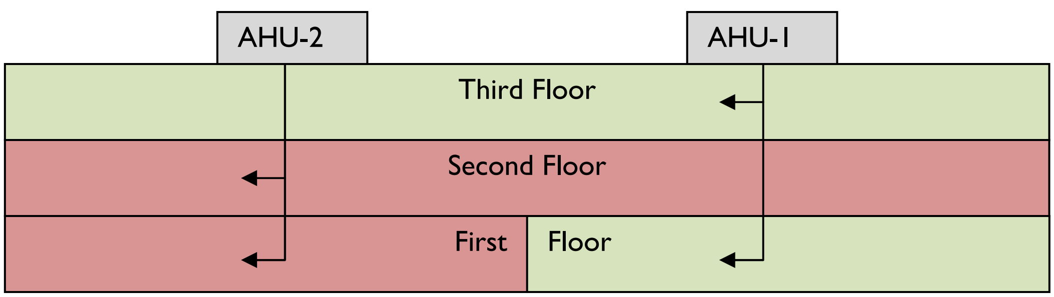
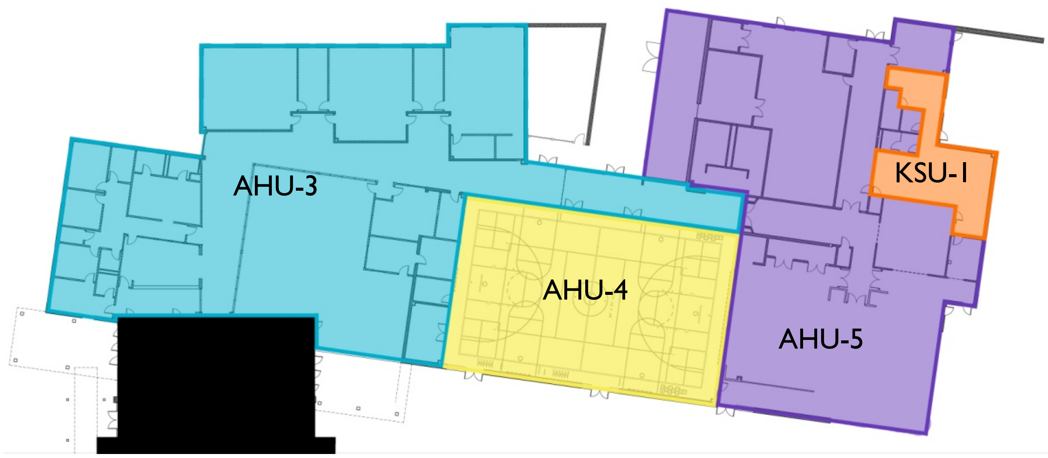


Figure 2: Wing B AHU Distribution



Design Cooling Load

Assumptions

Trane Trace 700 was used to model Manoa Elementary School in order to calculate the design cooling and heating loads. All required input parameters were obtained from the architectural and engineering design documents. The major input assumptions are detailed below.

Outdoor Ventilation Rates

Ventilation rates were specified by the design engineer in the mechanical equipment schedules in the mechanical design documents. These values, which are the same as those used in Technical Report 1 are summarized in Appendix A for reference.

Lights and Equipment Loads

Because Manoa Elementary School is a relatively small building, it was possible to use the designed lighting power densities in the model instead of that prescribed in ASHRAE 90.1. These numbers, which can be seen in Appendix B, were entered into Trace on a watts-per-square-foot basis. Heat gain due to lighting was scheduled based on space type. All spaces except the following were modeled based on the classroom schedule summarized below in Table 1. Table 2 summarizes the schedule used for the multipurpose room and Table 3 summarizes the schedule for spaces served by AHU-5. This utilization schedule is defined in Table 1 below.

Table 1: Lighting Schedule- Elementary School Classroom

School Year- Weekday			Summer			Weekend		
Times		%	Times		%	Times		%
12am	6am	0	12am	7am	0	12am	12pm	10
6am	7am	10	7am	8am	10			
7am	8am	50	8am	3pm	30			
8am	11am	100	3pm	5pm	10			
11am	12pm	80	5pm	12am	0			
12pm	1pm	20						
1pm	3pm	100						
3pm	5pm	30						
5pm	12am	0						

Table 2: Lighting Schedule- Elementary Gym

School Year- Weekday			Summer			Weekend		
Times		%	Times		%	Times		%
12am	7am	0	12am	7am	0	12am	12pm	0
7am	8am	50	7am	3pm	10			
8am	7pm	100	3pm	12am	0			
7pm	12am	0						

Table 3: Lighting Schedule- Elementary Kitchen

School Year- Weekday			Summer			Weekend		
Times		%	Times		%	Times		%
12am	7am	0	12am	7am	0	12am	12pm	0
7am	3pm	100	7am	1pm	10			
3pm	5pm	50	1pm	12am	0			
7pm	12am	0						

Electrical equipment loads were input based on recommendations by the design engineer. Manoa Elementary School is a high-tech school and utilizes a significant amount of computer equipment. Table 4 below outlines the entered values for specific space-types of the building on a watts-per-square-foot basis. These loads were assigned to the elementary school schedule for miscellaneous loads to determine the heat gain to the space. This utilization schedule is outlined in Table 5 below.

Table 4: Entered Miscellaneous Electrical Loads for Space Type

Miscellaneous Equipment Loads								
	Classroom	Corridor	Office	Vestibule	Storage	Restrooms	Library	Multipurpose
W/sf	0.5	0.25	0.5	0.25	0	0	0.5	0.22

Table 5: Miscellaneous Electrical Load Utilization Schedule

School Year- Weekday		
Times		%
12am	6am	0
6am	7am	10
7am	8am	50
8am	11am	100
11am	12pm	80
12pm	1pm	20
1pm	3pm	100
3pm	5pm	30
5pm	12am	0

Summer		
Times		%
12am	7am	0
7am	8am	10
8am	3pm	30
3pm	5pm	10
5pm	12am	0

Weekend		
Times		%
12am	12pm	10

Occupancy

The number of occupants per space was determined in Technical Report 1 based on the architectural design documents and the ASHRAE 62.1 analysis performed. The occupancy load for all classroom and office spaces is based on moderate activity levels which produce a sensible load of 250 BTU/hour and a latent load of 200 BTU/hour. The multipurpose room is modeled for a high level activity which provides a sensible and latent load of 275 BTU/hour each. The occupancy schedules for classrooms, the multipurpose room and kitchen spaces are summarized in Tables 6, 7 and 8 respectively.

Table 6: Occupancy Schedule- Classrooms

School Year- Weekday		
Times		%
12am	7am	0
7am	8am	50
8am	11am	100
11am	12pm	80
12pm	1pm	20
1pm	3pm	100
3pm	5pm	30
5pm	12am	0

Summer		
Times		%
12am	7am	0
7am	8am	10
8am	3pm	30
3pm	5pm	10
5pm	12am	0

Weekend		
Times		%
12am	12pm	10

Table 7: Occupancy Schedule- Multipurpose Room

School Year- Weekday		
Times		%
12am	7am	0
7am	8am	50
8am	3pm	100
3pm	5pm	50
5pm	7pm	20
7pm	12am	0

Summer		
Times		%
12am	7am	0
7am	3pm	10
3pm	12am	0

Weekend		
Times		%
12am	12pm	0

Table 8: Occupancy Schedule- Kitchen

School Year- Weekday		
Times		%
12am	7am	0
7am	11am	20
11am	1pm	80
1pm	3pm	20
3pm	12am	0

Summer		
Times		%
12am	7am	0
7am	1pm	10
1pm	12am	0

Weekend		
Times		%
12am	12pm	0

ASHRAE Design Indoor and Outdoor Air Conditions

Outdoor air conditions are specified in the ASHRAE Handbook of Fundamentals and are based on location. Manoa Elementary is located in a suburb of Philadelphia Pennsylvania therefore weather information for Philadelphia as noted in Table 9 was used in the model. Indoor design temperatures came from the design engineer's specifications and are also included in the table below.

Table 9: Design Indoor and Outdoor Air Conditions

Design Temperatures	
ASHRAE 0.4% Cooling Dry Bulb	92.7 ˚F
ASHRAE 0.4% Cooling Wet Bulb	75.6 ˚F
ASHRAE 99.6% Heating Dry Bulb	11.6 ˚F
Indoor Cooling Dry Bulb	75 ˚F
Indoor Heating Dry Bulb	70 ˚F

Infiltration

Manoa Elementary in a newly constructed building and it was assumed to be tightly constructed for this analysis. This assumption defines the infiltration rate as 0.3 air changes per hour.

Additional Assumptions

For the purpose of modeling, all wall and roof construction types were based off the architectural design documents. The amount of glazing was entered in based on take-off areas from the design documents. Appendix B summarizes these and other assumptions made for each typical space.

Results

Table 10 summarizes the results of the energy model detailed above and compares the results to the engineer's design.

Table 10: Modeled Results versus Designed System

Modeled vs Designed		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5
Cooling sf/ton	Modeled	373.70	426.83	330.40	63.43	129.80
	Designed	336.31	272.86	228.49	171.62	170.73
Cooling Load tons	Modeled	64.40	51.10	38.20	85.20	51.50
	Designed	71.58	81.50	55.17	31.50	39.17
Supply Air cfm/sf	Modeled	0.67	0.61	0.44	2.33	1.39
	Designed	0.73	0.92	1.07	1.48	2.18
Ventilation Air cfm/sf	Modeled	0.33	0.33	0.23	2.33	0.93
	Designed	0.29	0.36	0.42	0.55	0.75

Great effort was put into modeling as accurately as possible, however several discrepancies exist between the design system and the model. The major discrepancies seen in the table above occur in AHU-4 and AHU-5. Further analysis of the model inputs revealed that the space occupancies calculated using ASHRAE Standard 62.1 were drastically larger than the amount that would ever be in the space at any given time. For instance, Standard 62.1 calculated 629 people to be the zone population of the multipurpose room which is almost the total school population. In the event of a school assembly, the partition between the multipurpose room and the cafeteria is retracted meaning the air handling equipment will never service the entire population. Also, this occupant load is modeled using the schedule outline in Table 7 which is unreasonable for such a large population. An additional analysis was run using more reasonable zone populations to determine the magnitude of error caused by population alone. The results are summarized below:

Table 11: Alternate Analysis

Zone Population Adjustments		62.1	Adjustment
AHU-4	Multipurpose Room	629	150
AHU-5	Serving	57	10
	Kitchen	82	20
	Dishwash	15	2

Modeled vs Designed		AHU-4	AHU-5
Cooling sf/ton	Modeled	194.86	172.75
	Designed	171.62	170.73
Cooling Load tons	Modeled	27.70	38.70
	Designed	31.50	39.17
Supply Air cfm/sf	Modeled	0.95	0.79
	Designed	1.48	2.18
Ventilation Air cfm/sf	Modeled	0.55	0.56
	Designed	0.55	0.75

It can be seen that these population values result in less error between the designed and modeled systems; therefore this result has been used for the remaining analysis detailed in this report. Additional sources for error in the systems can be caused by the generic schedules used instead of the actual room schedules. For example, it is very unlikely that both music classrooms will be used at once or for the entire day as dictated by the schedule detailed in Table 6 which would cause the modeled cooling load to be higher than the design. Other sources of error are the use of ASHRAE 62.1 values for zone population to be used instead of actual information about the number of people in each space, which as seen above can cause a large margin of error in system design as well as the assumption of values for the miscellaneous loads which could be significantly larger than what was modeled.

Energy Consumption and Operating Costs

Assumptions

Trane Trace 700 was used to estimate the annual energy consumption and operating costs of Manoa Elementary School. Assumptions from the above analysis are valid here along with others described below.

Equipment Efficiencies: Equipment was modeled using the efficiencies and EER's specified in the design documents. A summary of these are included in Technical Report 1 and Appendix C.

Supply and Return Fans: Supply and return fan types modeled were based off the specifications in the design documents and their energy use is modeled using the designed motor horsepower listed on the mechanical equipment schedule. Fan motor mechanical efficiency was assumed to be 75% since no specific information was given.

Domestic Hot Water: Domestic hot water loads for Manoa Elementary School are covered by the two boilers. The utilization schedule used for this parameter was defined in Trace and summarized in Table 12 below.

Table 12: Domestic Hot Water Load Schedule

School Year- Weekday		
Times		%
12am	7am	0
7am	8am	50
8am	11am	100
11am	12pm	80
12pm	1pm	20
1pm	3pm	100
3pm	5pm	30
5pm	12am	0

Summer		
Times		%
12am	7am	0
7am	8am	10
8am	3pm	30
3pm	5pm	10
5pm	12am	0

Weekend		
Times		%
12am	12pm	0

Utilities

Manoa Elementary School utilizes electricity and gas to power the building. Building designers specify duel fuel gas and fuel oil boilers to be used with gas as the primary source. However this configuration was unable to be modeled using Trace, therefore gas boilers were modeled instead. Specific information including rates is further described below.

Electricity

Manoa Elementary School purchases its electricity from PECO Electric Company, which is a subsidiary of the Excelon Company. Rate Schedule 22 was selected for analysis because it is applicable to churches and schools. This rate structure has no time dependence and the charges are as follows:

Customer Charge: $0 per month
Demand Charge: $6.21 per kilowatt per month
Energy Charge: $0.07 per kilowatt hour per month for the first 300 kilowatt hours
$0.06 per kilowatt hour per month for 301 to 1200 kilowatt hours
$0.05 per kilowatt hour per month for the remaining kilowatt hours

Gas

PECO services the natural gas to the building at the rates defined by the schedule for General Service Commercial and Industrial. This rate schedule is not dependant on time and the charges are as listed below:

Fixed Distribution Charge: $25.00 per month
Variable Distribution Charge: $3.7785 per Mcf for the first 200 Mcf
$2.6387 per Mcf for the remaining usage

Energy Analysis

Design Engineer Energy Analysis: Manoa Elementary School was not designed to be a LEED Certified project, therefore an energy analysis done by the project engineer was not necessary or in the project budget.

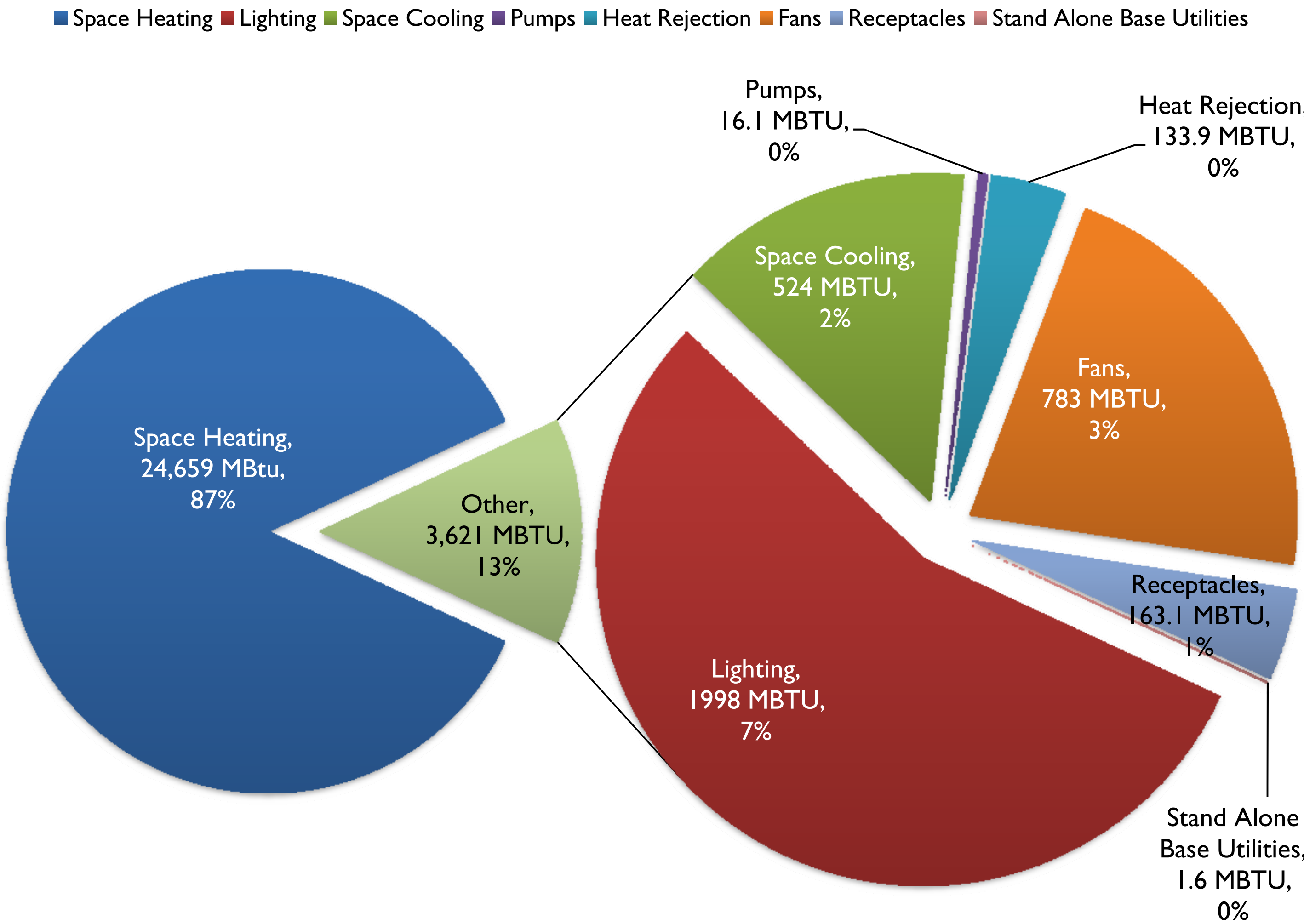
Total Energy Consumption: As modeled, Manoa Elementary School consumes a total of 1,055,152 kWh and 446 kW from the power company and 224,819 therms of gas per year. Further breakdown of energy consumption for major equipment is summarized below in Table 13.

Table 13: Total Energy Consumption

Total Energy Consumption			
Equipment	Utility	Unit	Total
Lights	Electric	kWh	582,614
	Peak	kW	67
Miscellaneous	Electric	kWh	39,874
	Peak	kW	27
AHU-1 Fans	Electric	Kwh	55,666
	Peak	kW	38
AHU-2 Fans	Electric	Kwh	72,813
	Peak	kW	40
AHU-3 Fans	Electric	Kwh	24,310
	Peak	kW	16
AHU-4 Fans	Electric	Kwh	17,686
	Peak	kW	7
AHU-5	Electric	Kwh	59,181
	Peak	kW	9
Chiller	Electric	Kwh	197,592
	Peak	kW	241
Boilers	Gas	therms	224,670
	Peak	therms/hour	642

In order to analyze the impact each piece of equipment has on the total building energy use it is necessary to convert the values above to the same unit system before comparison. As shown in Figure 3 below, space heating consumes by far the largest amount of energy for the building.

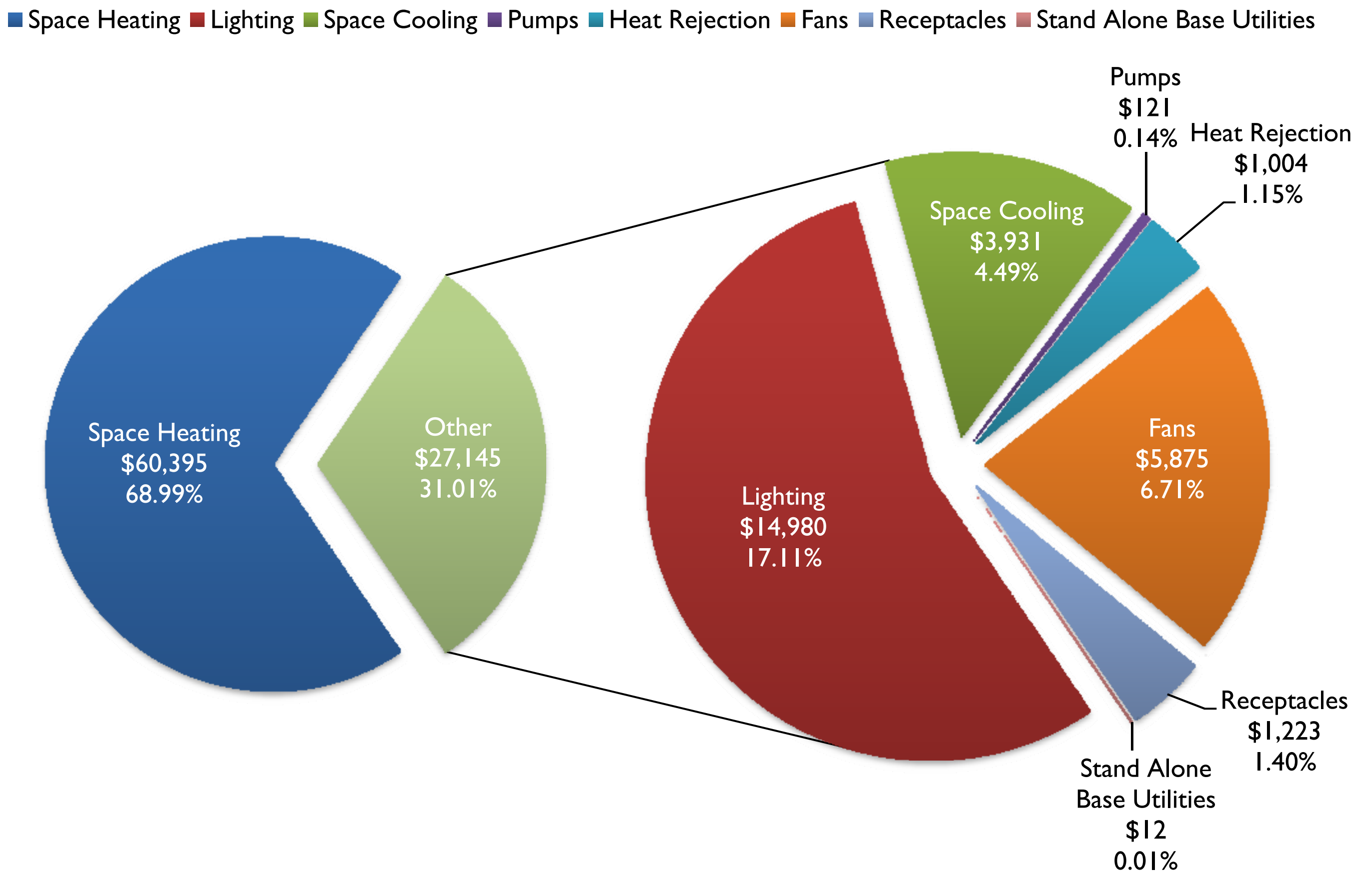
Figure 3: Annual Energy Consumption by Category



Total Energy Cost: The total annual energy cost of Manoa Elementary School is $87,337 or approximately $1.23 per square foot which is comparable to the value listed is ASHRAE Handbook of Applications. Table 4 in Chapter 35 of this handbook gives a reference value of $1.09 for the 50th percentile. The data used by the authors of the handbook are from 2003 and are obviously outdated.

The cost of natural gas per therm is significantly less than that of electricity and therefore it is useful to look at the contribution of each piece of equipment to the total energy cost of the building. The results in Figure 4 show that the cost for space heating is still much greater than the rest, but, the fraction of energy cost is smaller than the fraction of energy consumed.

Figure 4: Annual Energy Cost by Category



A month by month analysis is also useful when looking for areas of energy savings. Figure 5 shows the monthly combined usage of natural gas and electricity. From this figure it is obvious that during the summer months electric consumption increases because air conditioning is needed and consumption of natural gas consumption increases during the winter months when heating is needed. Figure 6 shows each utilities contribution to the monthly utility bills. The same relationship for heating and cooling described above is also seen here. The figures clearly show that space heating controls both energy consumption and monthly utility costs and therefore energy saving measures should be focused here. A more efficient heating system design and further analysis of the model is necessary to determine what energy saving measures would be most effective.

Figure 5: Monthly Combined Natural Gas and Electric Consumption

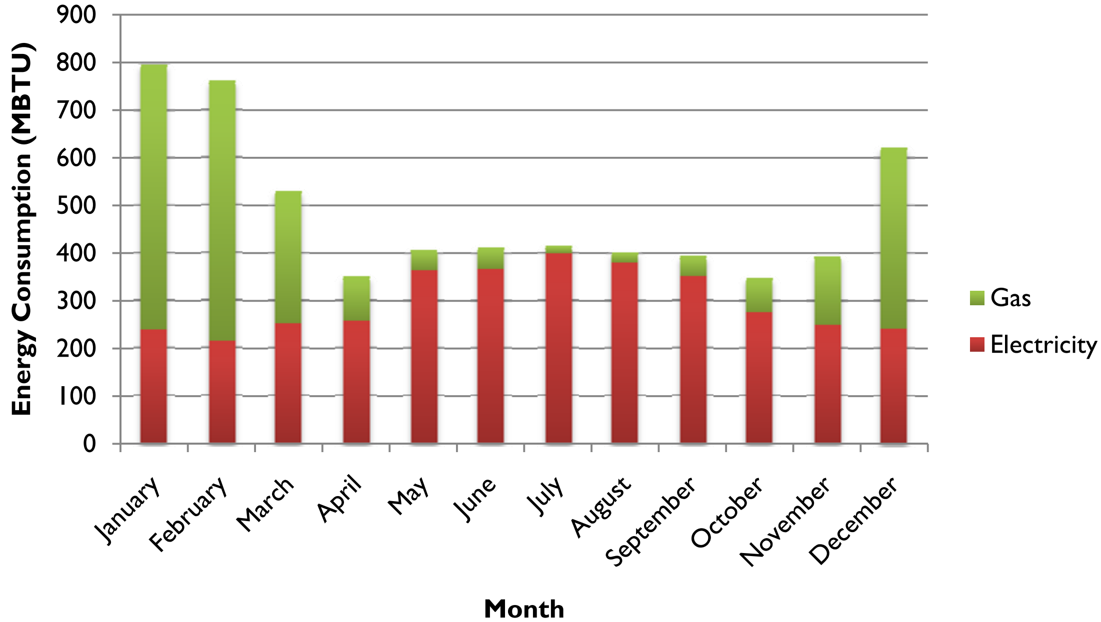
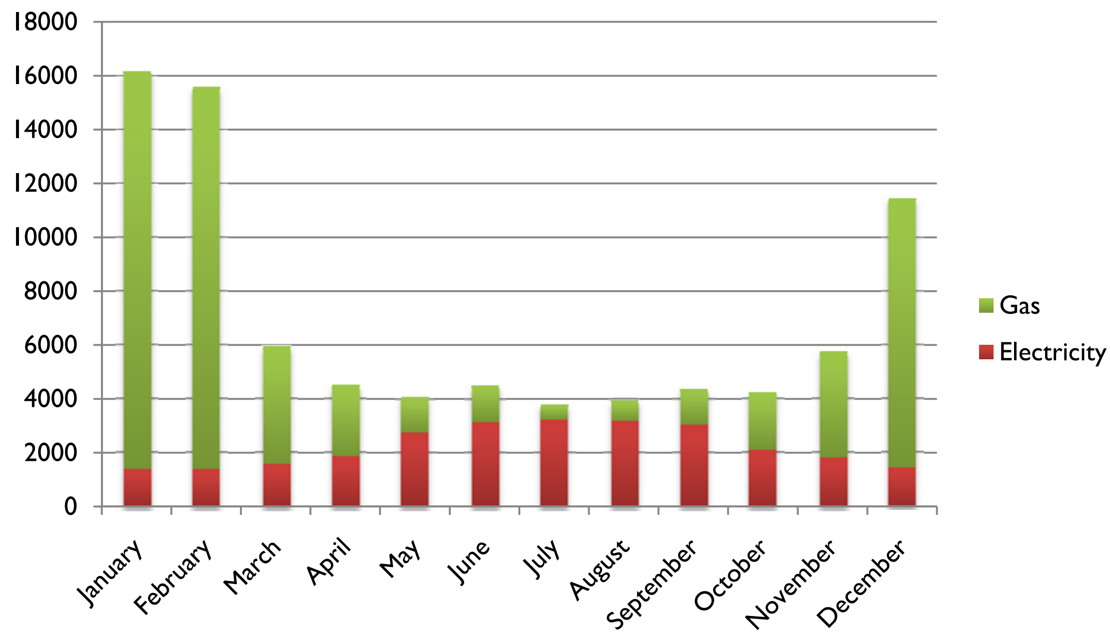


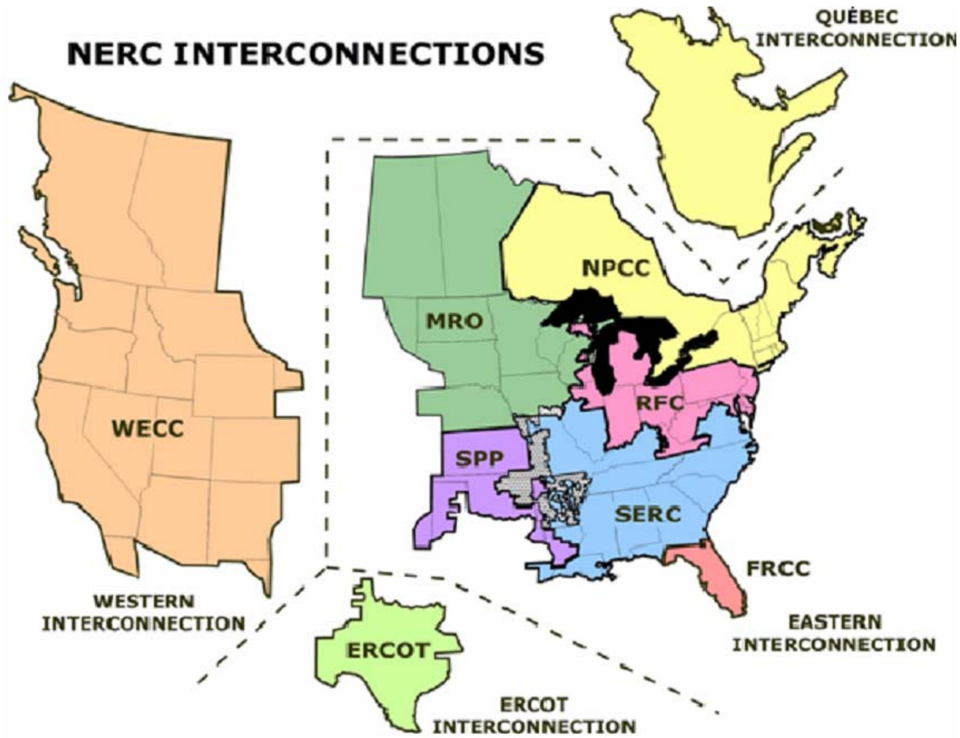
Figure 6: Monthly Combined Natural Gas and Electric Cost



System Emission Rates

Emission rates for CO_2, NO_x, SO_x and particulates were calculated using the total energy consumption described above in conjunction with the energy emission factors found by the National Renewable Energy Laboratory. According to NREL, Pennsylvania is a part of the RFC Eastern Grid Interconnection as seen in Figure 7 below.

Figure 7: North American Electrical Grid Interconnections



The source emission factors are determined based on the percentages of fuels used in creating the electricity. For the Eastern Interconnection, bituminous coal, nuclear, sub-bituminous coal and natural gas are the main fuels used to generate electricity. Total source pollution emissions generated by the use of electricity and natural gas by Manoa Elementary School are shown in Table 14 and Table 15.

Table 14: Electric Pollution Emissions

	Total Electricity Usage	Electricity Emission Factors	Total Pollution
	[kWh]	[lb pollutant/kWh]	[lbs]
CO2	1,053,170	1.64E+00	1,727,198.80
NOx		3.00E-03	3,159.51
SOx		8.57E-03	9,025.67
PM 10		9.26E-05	97.52

Table 15: Natural Gas Pollution Emissions

	Total Gas Usage	Natural Gas Emission Factors	Total Pollution
	[Mcf]	[lb pollutant/Mcf]	[lbs]
CO2	224,670	1.16E+01	2,606,172.00
NOx		1.64E-02	3,684.59
SOx		1.22E+00	274,097.40
PM 10		8.17E-04	183.56

References

ASHRAE. 2007, ASHRAE, Handbook of HVAC Applications. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA

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

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Trane Company. 2007. Trane Trace 700 Help File. American Standard Inc.

Appendix A: Outdoor Ventilation Rates

AHU-1

Room Number	Room Name	Vpz
101	SE-1 Classroom	600
102	SEM-2 Classroom	500
103	SEM Classroom	600
104	SEM-3 Classroom	500
105	SE-6 Classroom	1200
106	Kindergarten Classroom 1	1200
111	Corridor	200
124	Faculty Work Room	350
126	**Vestibule**	**615**
301	SE-4 Classroom	1000
302	Fifth Grade Classroom 2	1000
304	Storage	100
305	Fifth Grade Classroom 1	1200
306	Girls Restroom	100
307/318	Corridor	400
308	Boys Restroom	100
309	Fifth Grade Classroom 3	1200
310	Fifth Grade Classroom 1	1000
313	Fourth Grade Classroom 3	1200
314	Fourth Grade Classroom 4	1000
315	Reading Seminar	600
316	SE Classroom	1200
317	Speech & Language Seminar	600
322	Faculty Meeting	140
323	Faculty Planning	140
324	Fourth Grade Classroom 2	1000
325	Fourth Grade Classroom 1	1200
326	Storage	250
327	SE-5 Classroom	1200

AHU-2

Room Number	Room Name	Vpz
107	First Grade Classroom 1	1200
109	First Grade Classroom 2	1200
112	Kindergarten Classroom 2	1200
113	Conference	100
115	Storage	100
117	First Grade Classroom 3	1200
118	Kindergarten Classroom 3	1200
119	First Grade Classroom 4	1200
120	Faculty Work Room	120
121	Corridor	400
201	SE-3 Classroom	1500
202	Second Grade Classroom 2	1000
204	Storage	100
205	Second Grade Classroom 1	1200
206	Girls Restroom	100
207 & 228	Corridor	500
208	Boys Restroom	100
210	**Second Grage Classroom 4**	**1000**
213	Third Grade Classroom 3	1200
214	Third Grade Classroom 4	1000
215	SEM Classroom	600
216	Seminar Learning Support	600
217	Gifted Seminar	600
218	Seminar Learning Support	600
222	Faculty Meeting	140
223	Faculty Planning	140
224	Third Grade Classroom 3	1000
225	Third Grade Classroom 1	1200
226	Storage	250
227	SE-2 Classroom	1200

AHU-3

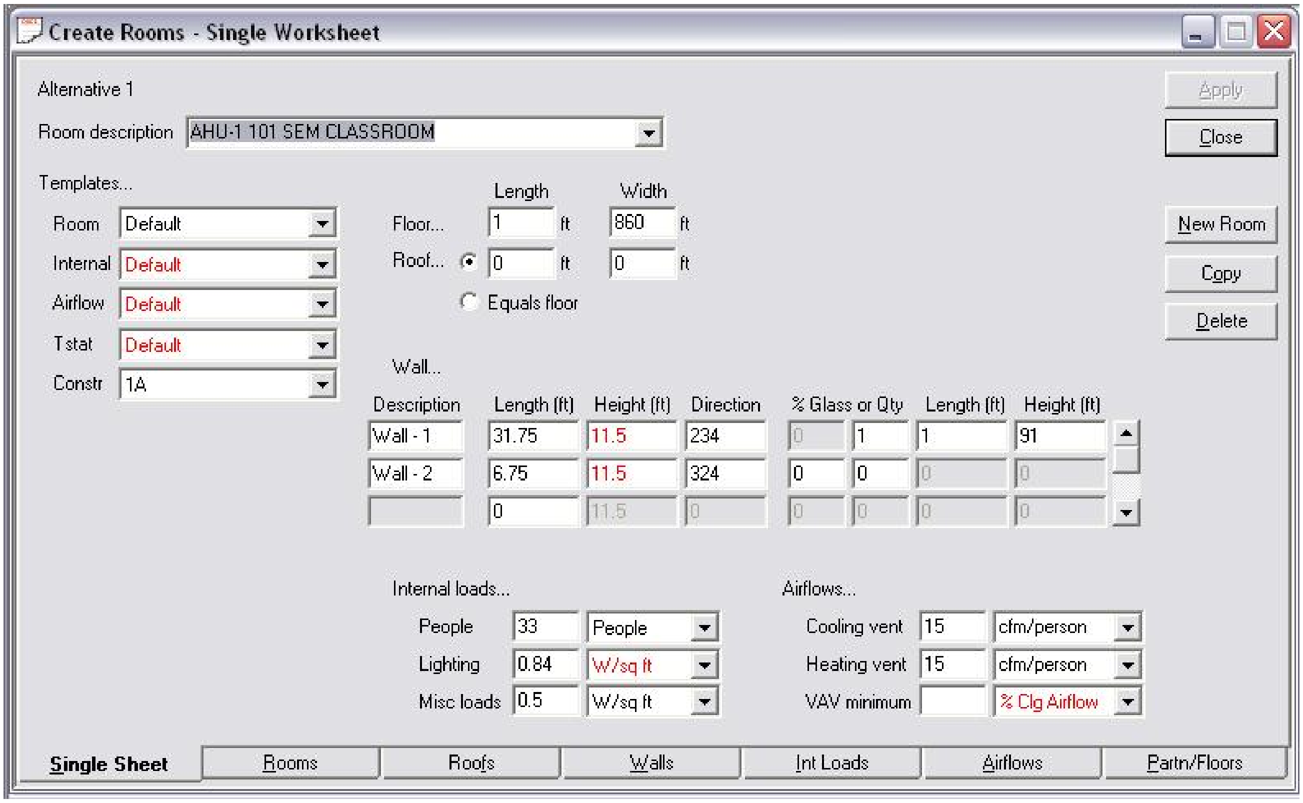
Room Number	Room Name	Vpz
129	Administration	200
130	Reception	580
131	Hallway	100
132	Nurse	275
132.2	Exam Room	125
133	Hallway	100
134	Conference	175
135	Conference	425
136	Guidence	250
139	1st	200
140	Principal	500
141	Corridor	200
142	Library	2895
142.1	Storage	75
143	Office	150
144	IT Work Room	225
145	Music Room	1400
145.1	Storage	100
146	Faculty Dining	600
147	Music Room	1200
147.1	Storage	100
149	**Art Room**	**1200**
149.1	Art Storage	75
150	Corridor	1075
151	Corridor	1275
152.1	Gym Office	100

AHU-4		
Room Number	Room Name	Vpz
152	Multipurpose Room	5800

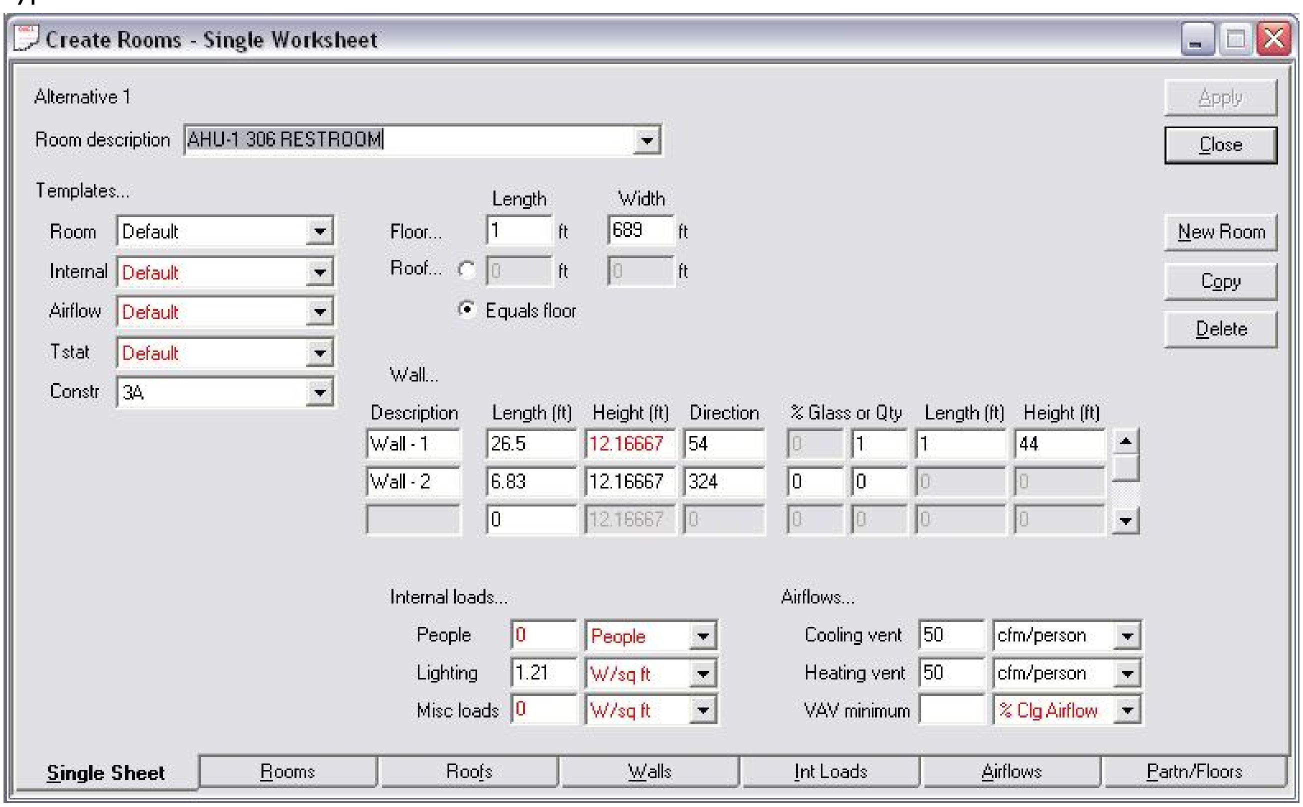
AHU-5		
Room Number	Room Name	Vpz
155	Ramp	150
156	Cafeteria	1880
158	LCI	3420
159	Serving	840
160	Kitchen	1000
161	**Dish Wash**	**100**
163	Office	100
164	Dry Storage	100
166	Locker	100
168	Corridor	300
169	Janitors Office	100

Appendix B: Trace Input Assumptions

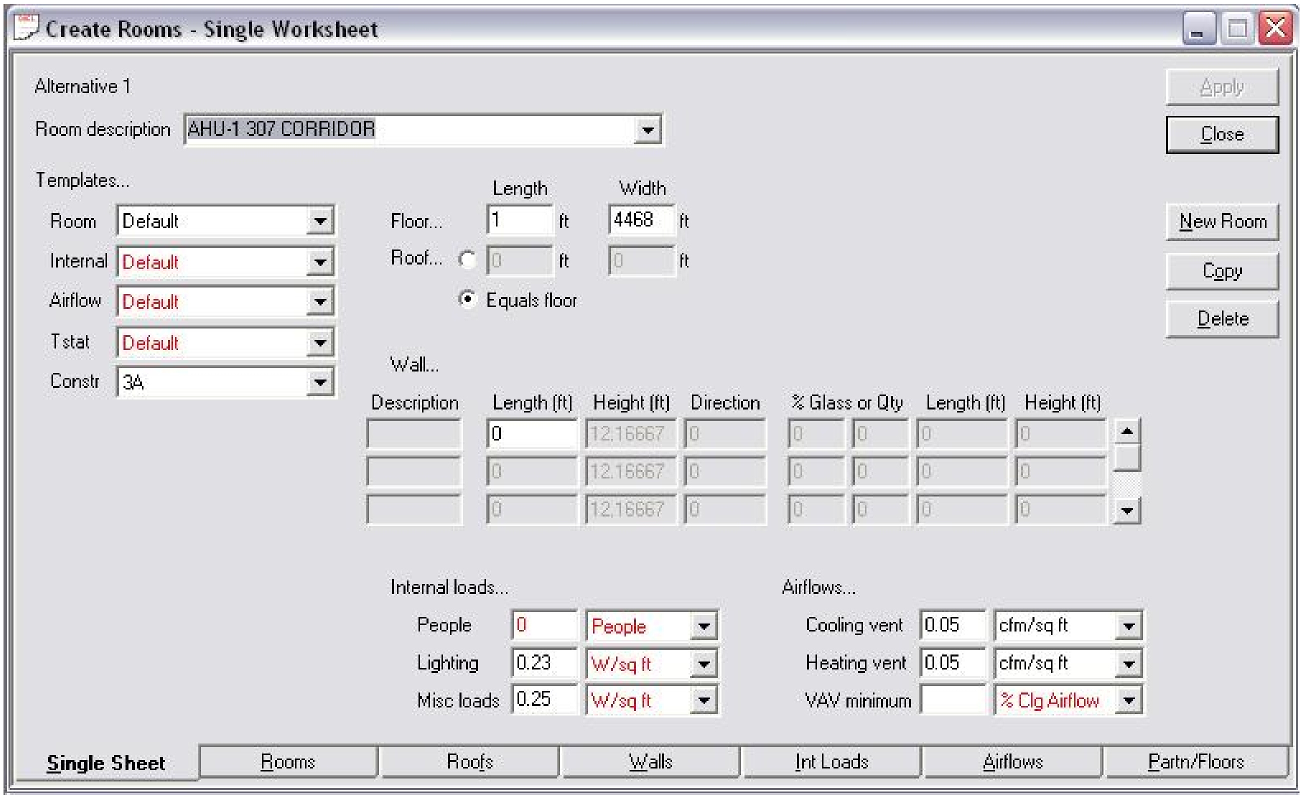
Typical Classroom:



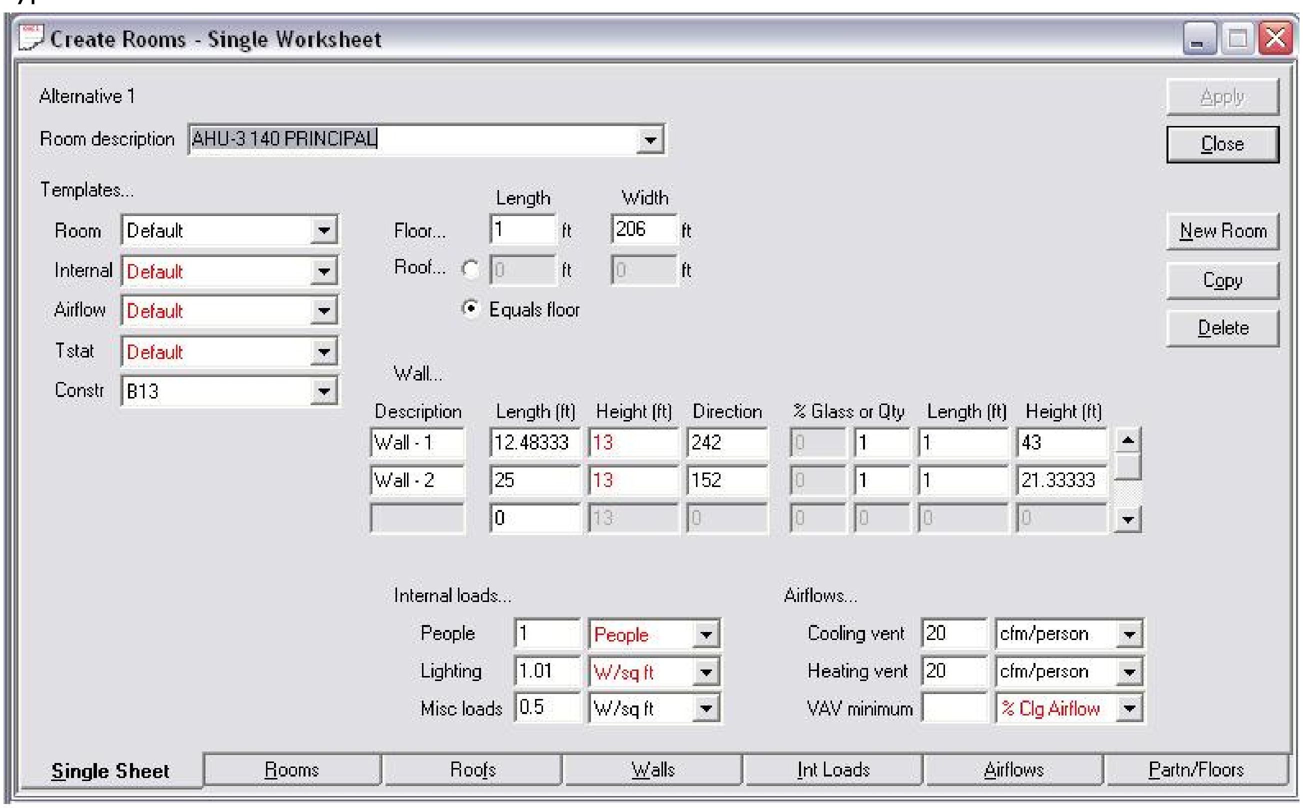
Typical Restroom:



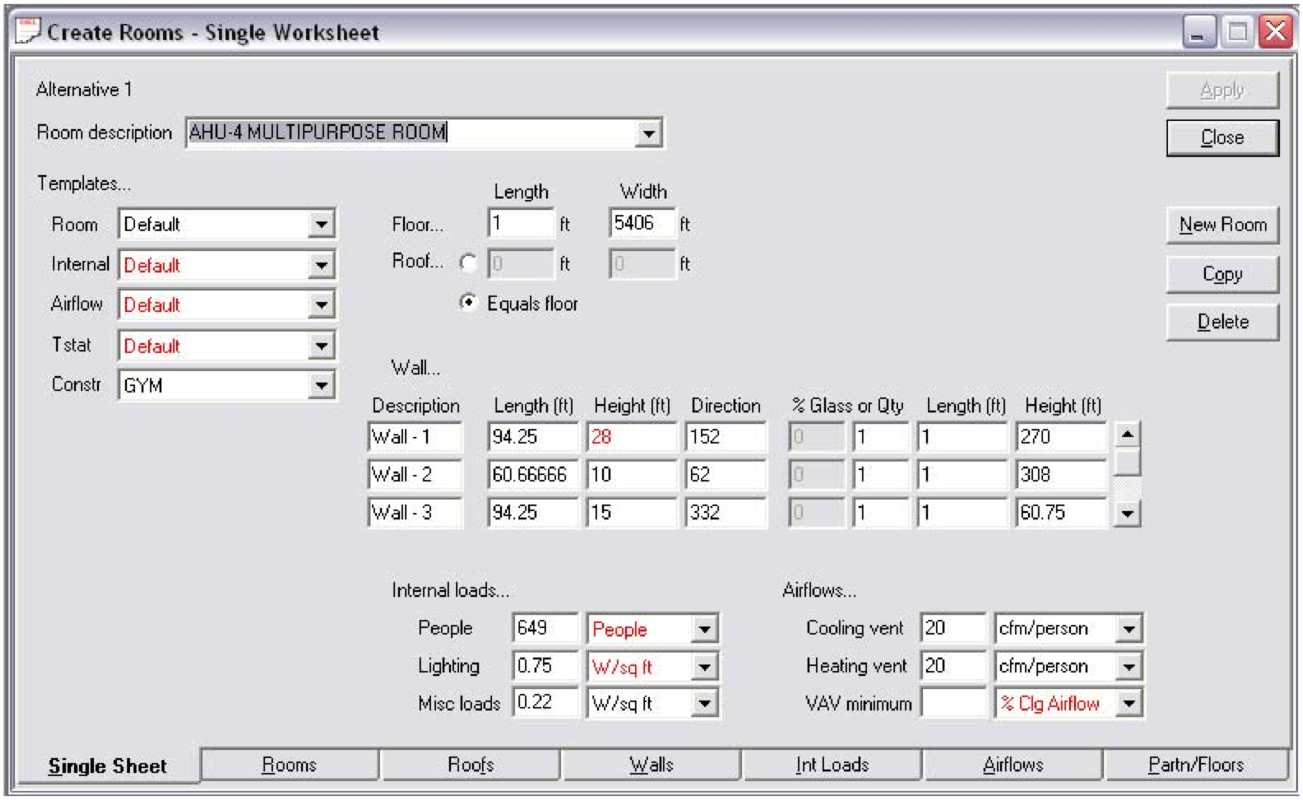
Typical Corridor:



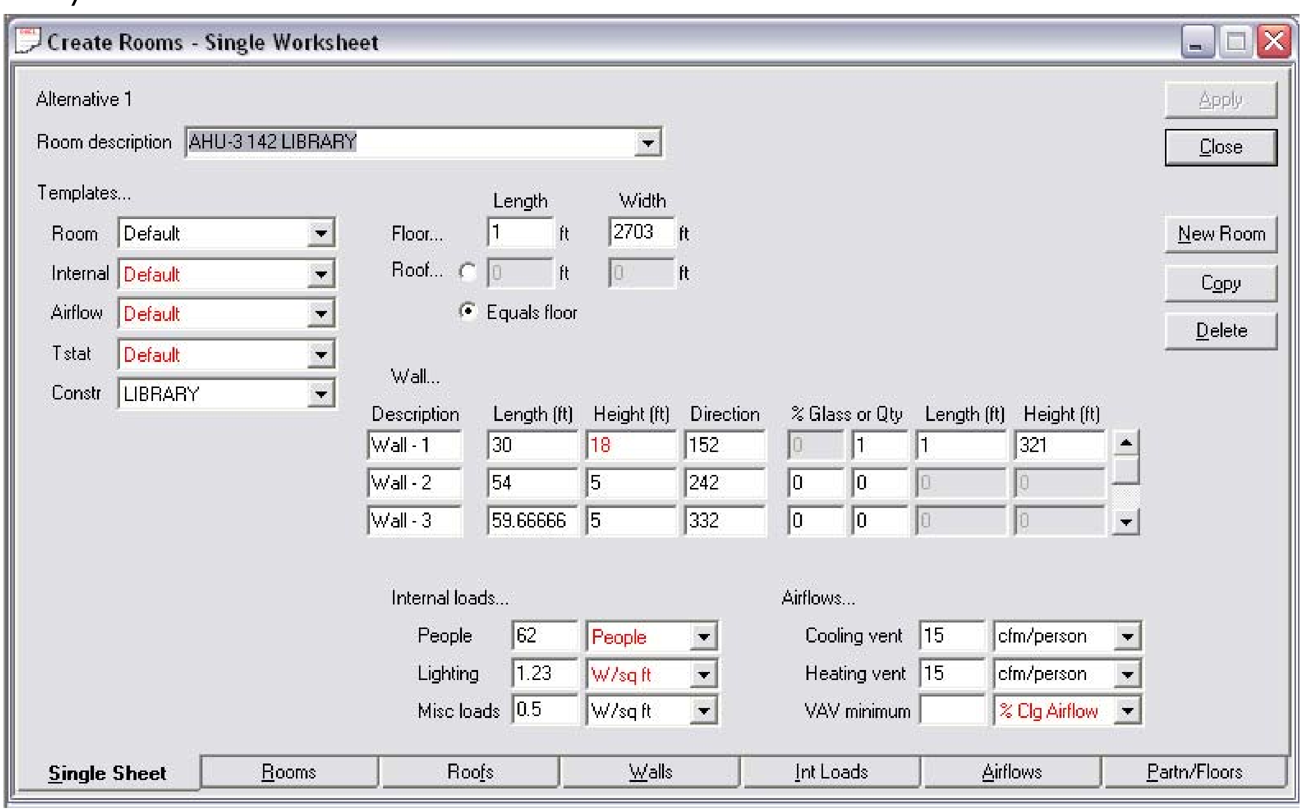
Typical Office:



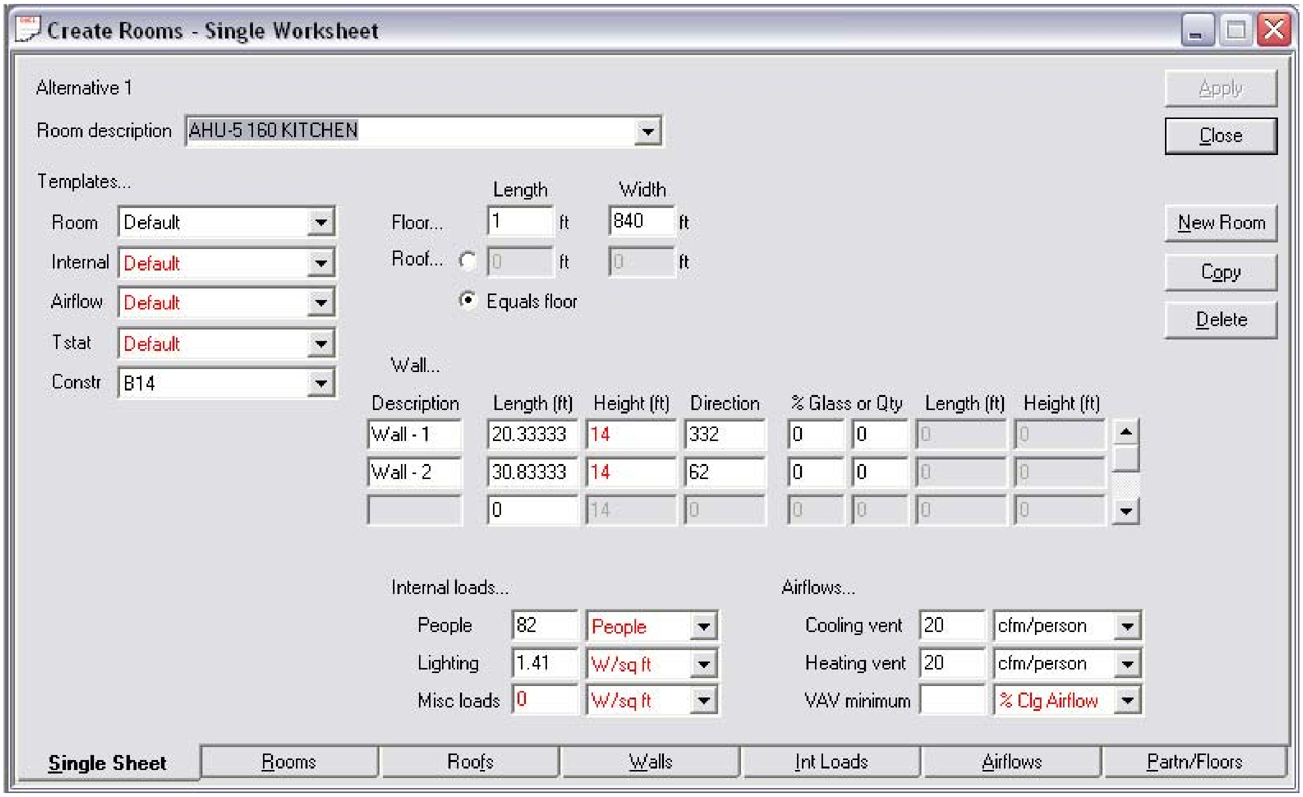
Multipurpose Room:



Library:



Kitchen:


Create Rooms - Single Worksheet
Alternative 1
Room description AHU-5 160 KITCHEN
Apply
Close
Templates...
Room Default
Internal Default
Airflow Default
Tstat Default
Constr B14
Length
Width
Floor... 1 ft 840 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)
Wall - 1 20.33333 14 332 0 0 0 0
Wall - 2 30.83333 14 62 0 0 0 0
0 14 0 0 0 0 0
Internal loads...
People 82 People
Lighting 1.41 W/sq ft
Misc loads 0 W/sq ft
Airflows...
Cooling vent 20 cfm/person
Heating vent 20 cfm/person
VAV minimum % Clg Airflow
Single Sheet
Rooms
Roofs
Walls
Int Loads
Airflows
Partn/Floors