PSUAE

Technical Report: Two

Building and Plant Energy Analysis

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2010

Mechanical Option-IP

Table of Contents

Executive Summary

In today's building design industry the capability of creating energy models is becoming a must. Energy models allow a designer to predict more accurately the cost of operation, efficiency and the carbon footprint of the building. If done at early stages of a design the energy model can serve as a tool throughout the entire design. The designer can test the feasibility of different systems and better understand the impact of using these systems on both an economic basis and an environmental basis. The designers of The Sunshine Elementary School developed an energy model through eQuest, which satisfied the LEED's energy requirements and thus received the maximum amount of points by LEED due to the buildings reduction of energy use, a predicted 47%.

In an attempt to better understand the eQuest model and building system utilized a TRACE 700 model was developed for this report. The results were then compared to the eQuest model. Although the eQuest model was seemingly far more advanced the results were similar in many regards. The cooling load was calculated to be 15% more than the original model while the heating load was calculated to be 9% less than the original model.

For this analysis the results of the TRACE 700 energy model are used to analyze the cost of operation, efficiency and the carbon footprint of the building. All of the analysis is an estimate and should be taken as so. The actual energy usage and building performance cannot truly be known until the construction is complete and an energy audit is taken of the building. Energy costs for the analysis are also subject to change.

Mechanical System Overview

The Sunshine Elementary School uses a highly energy efficient system which was determined by an energy model, produced by the Mechanical Designer, to reduce the energy consumption by 47%, compared to a baseline model. The system utilizes ten ground source heat pumps located throughout the design to share both the heating and cooling loads of the building. In addition there are also nine air-to-air energy recovery units in place in nine of the HP zones. These units help reduce the humidity and save valuable energy that would otherwise be exhausted to the outside air. The other keys to success in the design are in the demand ventilation control by

the use of CO2 detection ensure ventilation is met by demand and over ventilation will not occur and also lighting control sensors allowing for a reduction of internal load.

The heat pumps placed throughout the building handle varying loads depending on the size and part of the building they are serving. The smallest load is handled by HP-1, which handles 200-250 cfm of air while the largest is HP-8 which handles 2000-21000 cfm of air.

The Air-to-Air energy recovery units are also placed within these zones and serve a varying amount of air to the spaces. ERU-8 is the smallest supplying 1400 cfm, while ERU-2 is the largest supplying 5730 cfm.

Design Load Estimation

Assumptions

Trane TRACE 700 was used to calculate the design heating and cooling loads for The Sunshine Elementary School. This energy modeling software performs a yearly, 8760 hour analysis for the energy consumption, design loads and performance. A room by room analysis was calculated by assigning each of the 98 rooms to a generalized 10 room templates. The 98 rooms were then placed in a zone through a logical manner which attempted to separate the different solar heat gain areas throughout the building. The information used to construct the model was taken from both a preexisting REVIT model which was imported into TRACE 700, and the preexisting eQuest model was referenced throughout the process.

Infiltration

The infiltration for The Sunshine Elementary School was assumed to be 0.0 air changes an hour. This is because the construction was assumed to above average and allow for a positively pressurized building. This assumption was made within the previous model as well.

Design Air Conditions

The building is located near Harrisburg, PA so the design conditions for Harrisburg, PA were used in building the model. The outdoor design conditions were preset within the TRACE 700 weather data as can be seen below in Table 1.

TRACE 700 Design Conditions for Harrisburg, PA		
Summer		Winter
DB (°F)	MCWB (°F)	DB (°F)
91	74	11

Table 1: TRACE 700 Weather Data

The indoor design conditions were obtained from the schedules provided by the designer.

Scheduled Indoor Designed Conditions				
	Cooling		Heating	
	EAT		EAT	EWT
	DB (°F)	WB (°F)	DB (°F)	(°F)
HP-1	76	80	70	45
HP-2	76	80	70	45
HP-3	76	80	70	45
HP-4	76	80	70	45
HP-5	76	80	70	45
HP-6	76	80	70	45
HP-7	76	80	70	45
HP-8	76	80	70	45
HP-9	76	80	70	45
HP-10	76	80	70	45

Energy Wheel				
	Summer		Winter	
	EAT	LAT	EAT	LAT
	DB/WB (°F)	DB/WB (°F)	DB (°F)	DB (°F)
ERU-1	90/74	79	10	59
ERU-2	90/74	79	10	59
EERU-3	90/74	79	10	59
ERU-4	90/74	80	10	59
ERU-5	90/74	79	10	59
ERU-6	90/74	79	10	59
ERU-7	90/74	80	10	59
ERU-8	90/74	80	10	59
ERU-9	90/74	79	10	59

Table 2: Scheduled Indoor Design Temperatures

Loads and Schedules

The internal loads of the spaces were determined by the functions of the space. In TRACE 700 templates were used to generalize these spaces into 10 types; Classrooms, Office, Corridors/Vestibules, Gym, Storage, Conference, Cafeteria, Kitchen, Restrooms and Electrical/Mechanical rooms. Table 3 shows the internal loads assigned to these templates based on occupancy and space type. The lighting loads used were calculated in several similar spaces and then averaged for the templates. The miscellaneous loads were assumed to be 0.5 W/SF for all spaces. Sensible and Latent loads used were given by TRACE 700 software for the space type as well as the SF/Person.

Internal Loads Based on Occupancy and Space					
	Classroom	Office	Corr/Vest	Gym	Storage
	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent
Lighting (W/SF)	1.192	1.3	1.7	0.13	0
Misc (W/SF)	0.5	0.5	0.5	0.5	0
People (BTU/Hr)	250/200	250/200	250/200	250/200	0/0
People (SF/Person)	75	143	75	75	0
	Conference	Cafeteria	Kitchen	Elec/Mech	Restrooms
	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent	Sensible/Latent
Lighting (W/SF)	1.1	1.4	0.303	0	1.61
Misc (W/SF)	0.5	0.5	0.5	15	0.5
People (BTU/Hr)	250/200	275/275	250/200	0/0	250/200
People (SF/Person)	20	10	75	0	20

Table 3: Internal Loads for Templates

The schedules used for the building were the preset schedules supplied by the TRACE software and can be seen below in Tables 4 and 5. These assumptions follow well with the functions of a school wherein the majority of the building is only fully occupied during the hours of 8am-5pm. Due to light sensors these times correspond for the lighting schedules as well.

Occupancy Schedule	
Time	People (%)
Midnight-7am	0
7am-8am	30
8am-5pm	100
5pm-6pm	30
6pm-7pm	1
7pm-Midnight	0

Table 5: Occupancy Schedule

Lighting Schedule	
Time	Lights (%)
Midnight-6am	0
6am-7am	10
7am-8am	50
8am-5pm	100
5pm-6pm	50
6pm-7pm	10
7pm-Midnight	0

Table 4: Lighting Schedule

Design vs. Computed Loads

The design utilized eQuest to calculate to loads on the building and on the 10 different heat pumps. Using TRACE 700, I analyzed the space by creating my own zones in a logical manner. I created 10 systems in TRACE 700 that I feel are close to the systems chosen in eQuest. Heat Pumps with energy recovery units were utilized in the model closely resembling the design. After creating the systems I assigned each of the 98 rooms to a system creating zones that each HP will serve. The results can be seen below in Table 6.

Trace	Cooling (BTU/h) Net Peak	Heating (Btu/h) Coil Peak Tot Sens
HP1	170822	157168
HP2	185526	137875
HP3	305395	154479
HP4	348488	199290
HP5	317647	216880
HP6	477053	325661
HP7	370650	273413
HP8	416438	284860
HP9	223251	157365
HP10	233085	150062
Totals	**3048355**	**2057053**
eQuest	2599199	2258724
% Diff	15%	-9%

Table 6: Trace Peak Loads

A direct comparison for each individual heat pump cannot be evaluated due to the differences in zones. However, the Peak cooling and Peak heating loads can be summed and compared to the sum of the designed modeled. The eQuest model results in a 15% lower peak cooing load while the Peak heating load in TRACE 700 was calculated to 9% lower than in eQuest. Thus the final result is within 5% as can be seen in Table 7 below.

Overall % Difference	
	Btu/Hr
eQuest	4857923
Trace 700	5105408
% difference	5%

Table 7: Overall Percent Difference

In General the Trane TRACE 700 model and the eQuest design model were very close in final results. With the cooling loads of eQuest being lower while the heating loads of TRACE 700 were lower a balance was created on an annual energy consumption basis.

Annual Energy Consumption and Operating Costs

Assumptions

The utility rates used for the analysis were based upon rates supplied by the designer. These rates are negotiated by the power company and the owner Sunshine Elementary School and a flat rate was created. The designer used a previous bill secured from owner of school in order to complete the energy cost analysis. The assumption has been made that the rates will stay the same for the new building. In the Appendix a copy of this bill is present with all billing information removed for privacy.

Energy Costs

The monthly energy cost analysis estimates can be seen below in Tables 8 and 9.

On Peak Monthly Electricity Energy Consumption Cost Analysis							
	Electricity		Price	Demand	Monthly Cost ($)		
Month	Consumption (kWh)	Demand (kW)	($/kWh)	($/kW)	Consumption	Demand	Total Monthly Cost
Jan	230546	648	0.0764	6.96	17614	4510	22124
Feb	194132	498.9	0.0764	6.96	14832	3472	18304
Mar	199377	521.2	0.0764	6.96	15232	3628	18860
Apr	185677	509.2	0.0764	6.96	14186	3544	17730
May	186920	557.7	0.0764	6.96	14281	3882	18162
June	226293	591.6	0.0764	6.96	17289	4118	21406
July	257974	435.4	0.0764	6.96	19709	3030	22740
Aug	252781	635.9	0.0764	6.96	19312	4426	23738
Sep	189787	638.8	0.0764	6.96	14500	4446	18946
Oct	177297	433.9	0.0764	6.96	13545	3020	16565
Nov	181376	472.4	0.0764	6.96	13857	3288	17145
Dev	212934	527.6	0.0764	6.96	16268	3672	19940
Total	2495094	638.8			190625	45035	235661

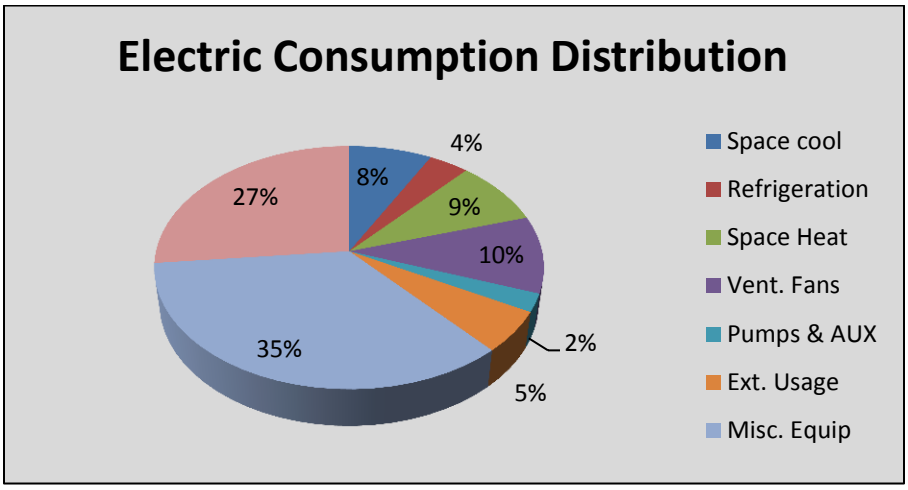
Table 8: Electricity Energy Cost Analysis

On Peak Monthly Natural Gas Consumption Cost Analysis			
Month	Consumption (Therms)	Price per Therm ($)	Cost ($)
Jan	804	1.1787	948
Feb	745	1.1801	879
Mar	725	1.1807	856
Apr	516	1.1891	614
May	473	1.1917	564
June	320	1.2068	386
July	311	1.2083	376
Aug	312	1.2083	377
Sep	372	1.2003	447
Oct	527	1.1885	626
Nov	567	1.1864	673
Dev	739	1.1803	872

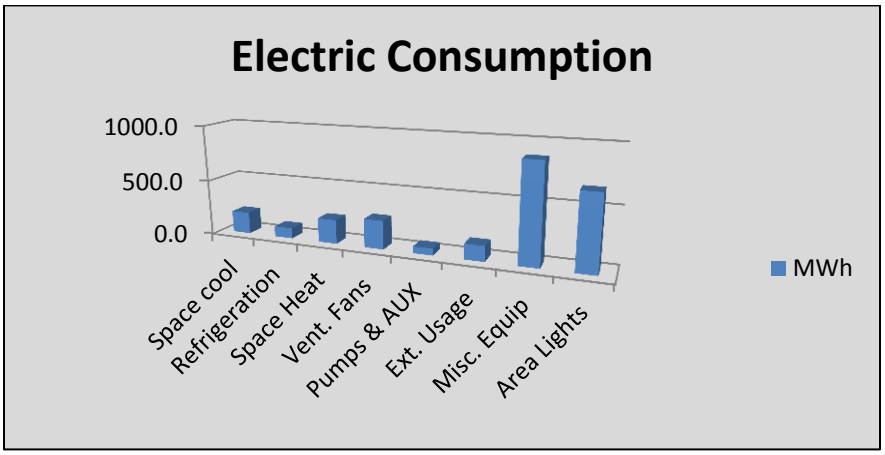
Table 9: Natural Gas Cost Analysis

Annual Energy Consumption

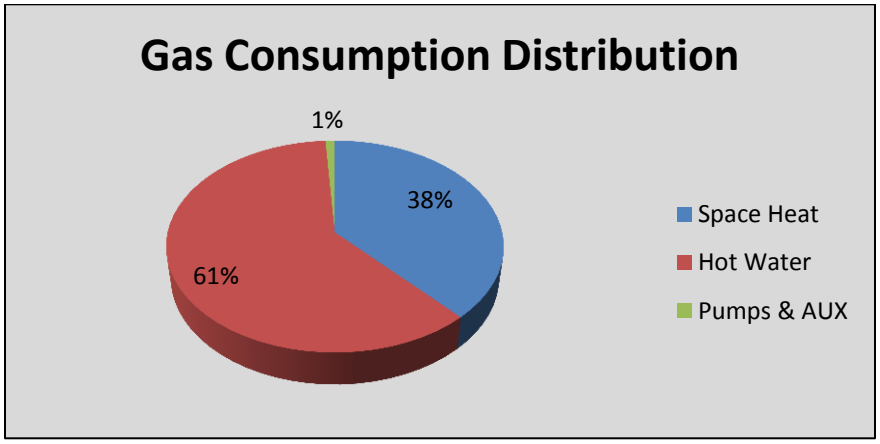
The distribution of electricity was also analyzed. The largest consumer of electricity is the miscellaneous equipment using 35% followed closely behind by the area lighting using 27%, while pumps and auxiliary equipment only used 2% of the energy. Graph 1 on the following page shows the distribution of electricity thorough out the system. Cooling and Heating are only using a total of 17% of the energy for the entire building. This is possible due to the highly efficient ground source heat pumps and the air to air energy recovery units placed in each zone. The yearly amounts of electricity used by the system can be seen in Graph 2, indicating the amounts of electricity consumed by each of the systems different components. The usage of Natural gas was analyzed in the same way as the electric. Graphs 4 and 5 show the estimated breakdown of the distribution of the natural gas used by The Sunshine Elementary School. Also the amount used by each component is shown. It can been seen from the graphs that the Natural Gas is primarily being used for hot water using 389.5 MBtu's annually. Some of the space heating also uses natural gas using 244.4 MBtu's annually.



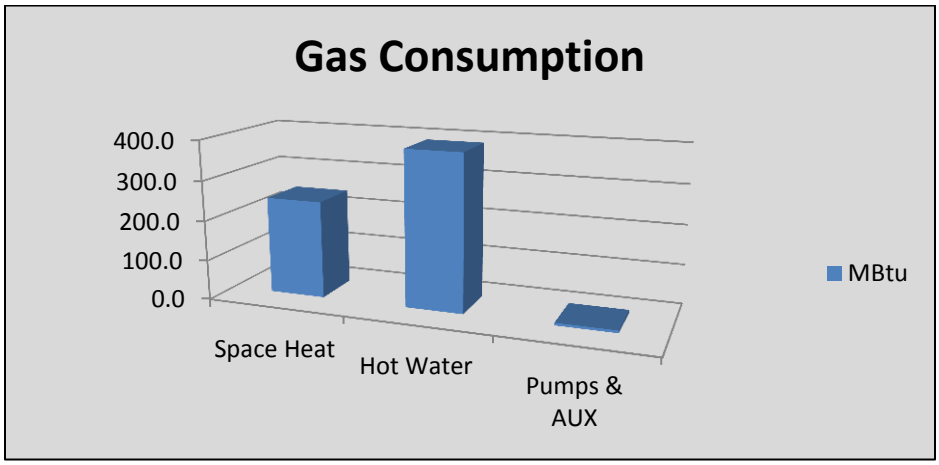
Graph 1: Electric Consumption Distribution



Graph 2: Electric Consumption



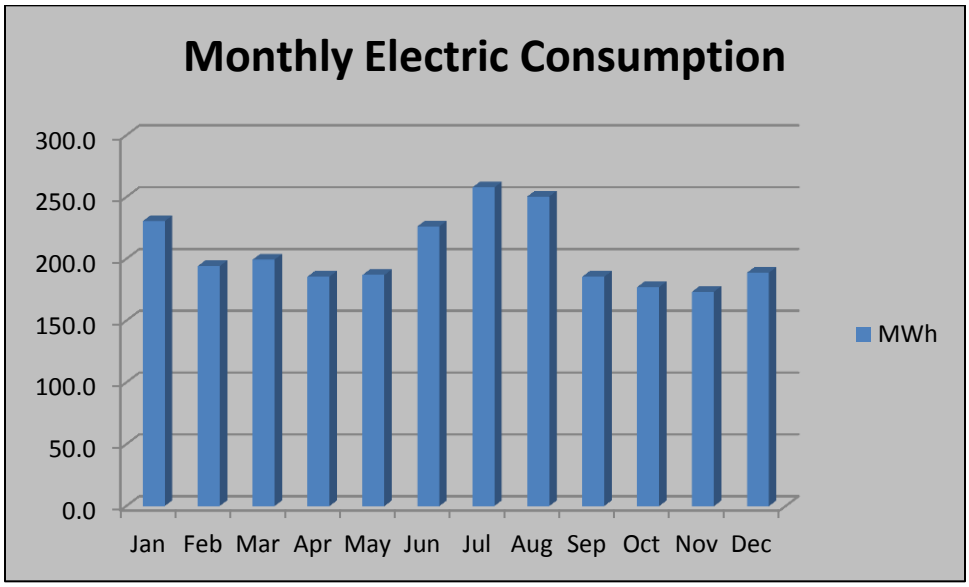
Graph 3: Gas Consumption Distribution



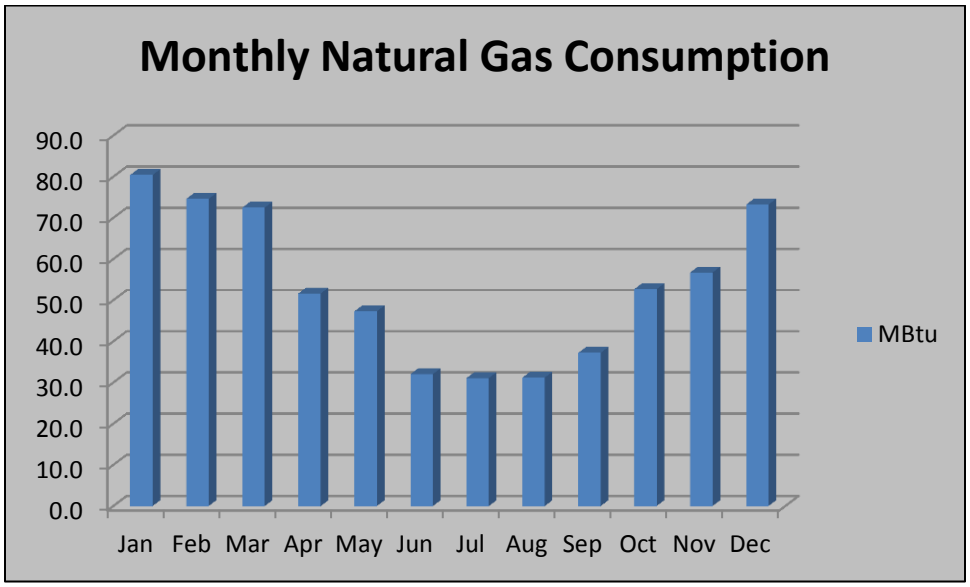
Graph 4: Gas Consumption

Monthly Energy Consumption

A monthly energy consumption analysis was also performed. This reveals that the peak of electricity consumption is in the month of July while the lowest consumption is in November. This can be seen below in Graph 5. Interestingly the natural gas usage is lowest in the summer months. This is due to the lack of need for space heating during these months, which is a major user of the resource. The peak usage for natural gas in January as is expected due to the extreme cold weather and high need for space heating. This can be seen in Graph 6.



Graph 5: Monthly Electric Consumption



Graph 6: Monthly Natural Gas Consumption

Annual Carbon Footprint

The annual Carbon footprint or emission for The Sunshine Elementary School has also been estimated. The emission profiles were based upon data from the Source Energy and Emission Factors for Energy Use in Buildings that has been provided. The amount of yearly kWh were total and then multiplied by the lb per kWh given in the data.

Total Emission Factors for Delivered Electricity			
Pollutant	lb per kWh	Consumption	Amounts of pollutant
CO_2	1.74E+00	2495094	4341463.56
NO_X	3.00E-03	2495094	7485.28
SO_X	8.57E-03	2495094	21382.96
CH_4	3.59E-03	2495094	8957.39
N_20	3.87E-05	2495094	96.56
CO	8.45E-04	2495094	2108.35
Lead	1.39E-07	2495094	0.35
Mercury	3.36E-08	2495094	0.08
PM10	9.26E-05	2495094	231.05
Solid waste	2.05E-01	2495094	511494.27

Table 10: Estimated Emissions

Summary

The analysis for all parts of this report are simplifies estimates. As stated in the beginning of this report all cost information is subject to change. The Trane TRACE 700 proved to be a good tool for modeling The Sunshine Elementary School, although some of the software could be more complete. Although the design model and TRACE 700 model results ended with a similar total output many of the inputs are different and will have to be evaluated further to understand which energy modeling software is more comprehensive.

The eQuest software allows the user to see a 2-D and 3-D representation of the building, while the TRACE 700 software does not. For this reason it is not possible to conclude that the REVIT model imported into TRACE 700 was complete. For this report it has been assumed to be complete.

References

1. ASHRAE Handbook of Fundamentals 2005
2. Trane TRACE 700
3. eQuest 63.4
4. Reese Engineering Mechanical Drawings
5. Past Thesis Technical Reports, e-studio Archives, 2009-2010

Appendix

Lists of Figures & Graphs

Supplementary Information and Images

Sample bill provided by designer

Basic Charges

Customer Number: 0801106685 0006324849 - General Secondary Medium - ME-GSMF

Distribution			Customer Charge	21.52	
	53,568	KWH	x 0.000570	30.53	
	278.7	KW	x 3.820000	1,064.63	
Total Distribution Charges				1,116.68	**1,116.68**
Consumer Education Charge	53,568	KWH	x 0.000020		**1.07**
Transition	278.7	KW	x 3.140000		**875.12**
Generation	53,568	KWH	x 0.048690		**2,608.23**
Transmission	53,568	KWH	x 0.027810		**1,489.73**
State Tax Surcharge					**-4.87**
Total Charges					**$ 6,085.96**

total - $6.96/kW $0.07709/kWH total

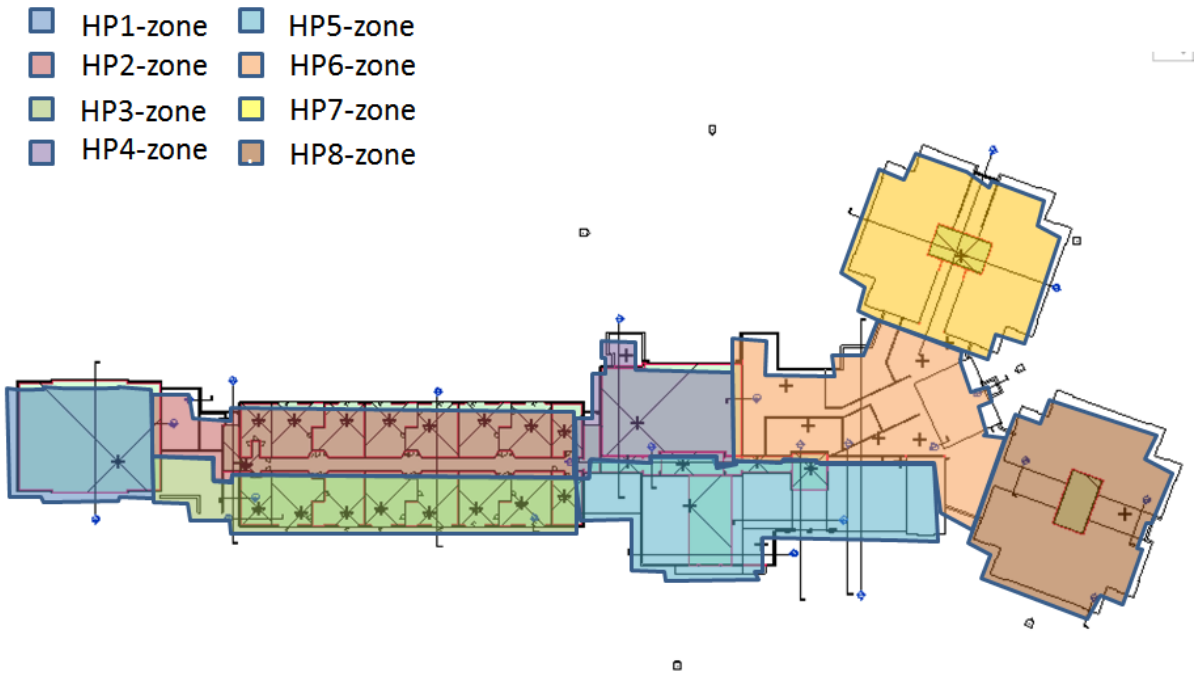
Detail Payment and Adjustment Information

Date	Reference	Amount	
Payments:			
10/15/09		-6,033.94	
Total Payments			**-6,033.94**
Total Payments and Adjustments			**-$6,033.94**

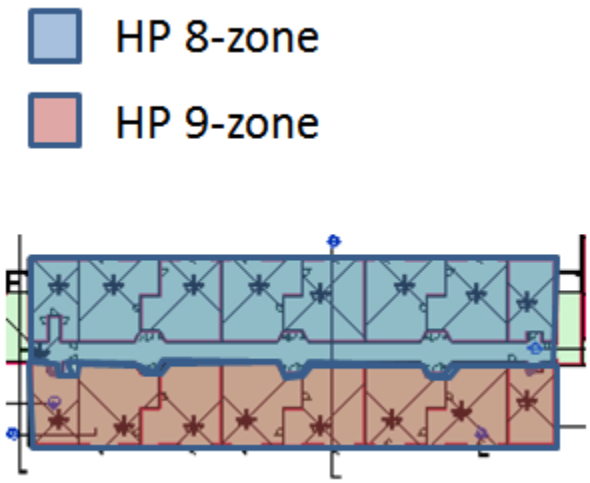
Meter Reading Information

General Secondary Medium	
Meter Number	G23659499
Present KWH Reading (Actual)	6,001
Previous KWH Reading (Actual)	5,908
Difference	93
Multiplier	576
Kilowatt Hours Used	53,568
Metered Load in KW	0.407
Measured Load in KW	234.4
Present KVARH Reading (Actual)	5,330
Previous KVARH Reading (Actual)	5,239
Difference	91
Kilovar Hours Used	52,416
Average Power Factor	71.5%
Billed Load in KW/KVA	278.7

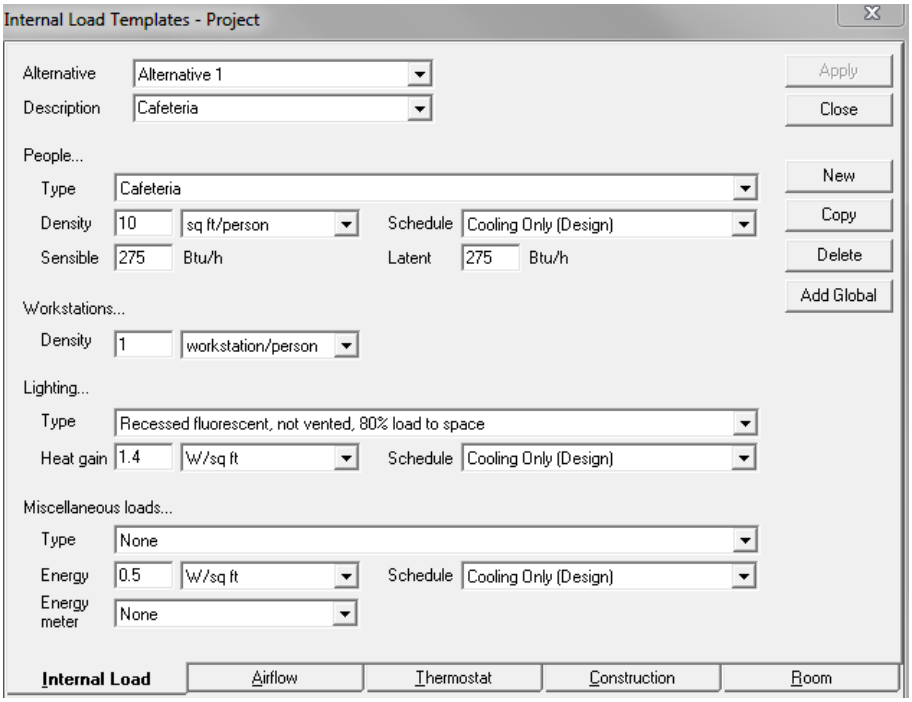
Floor One Heat Pump Zones

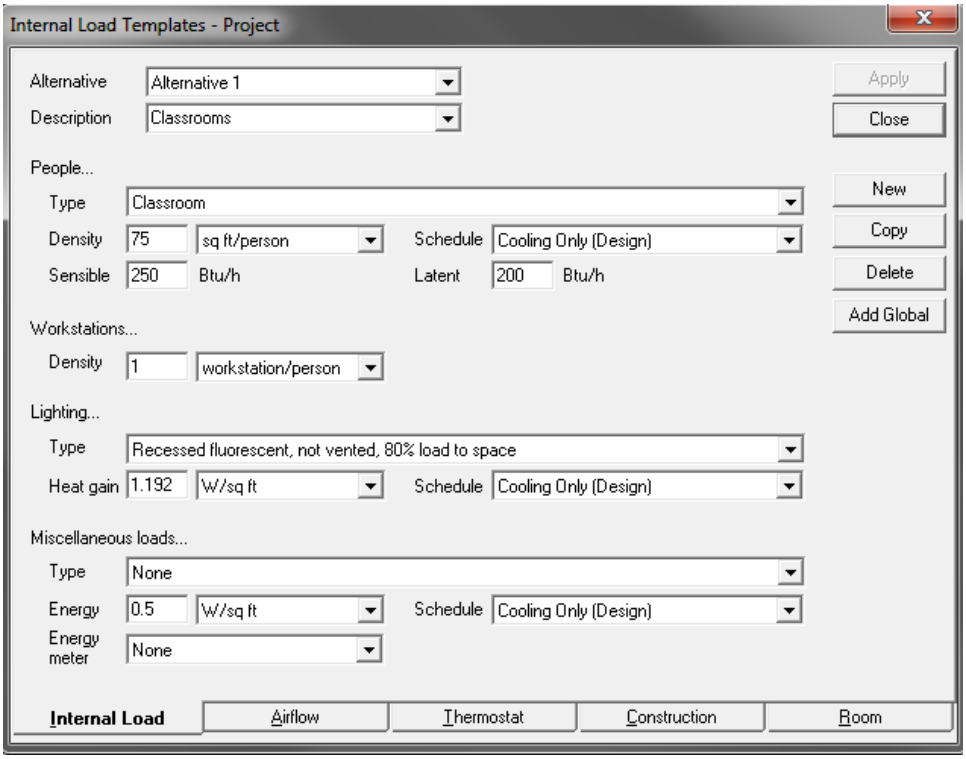


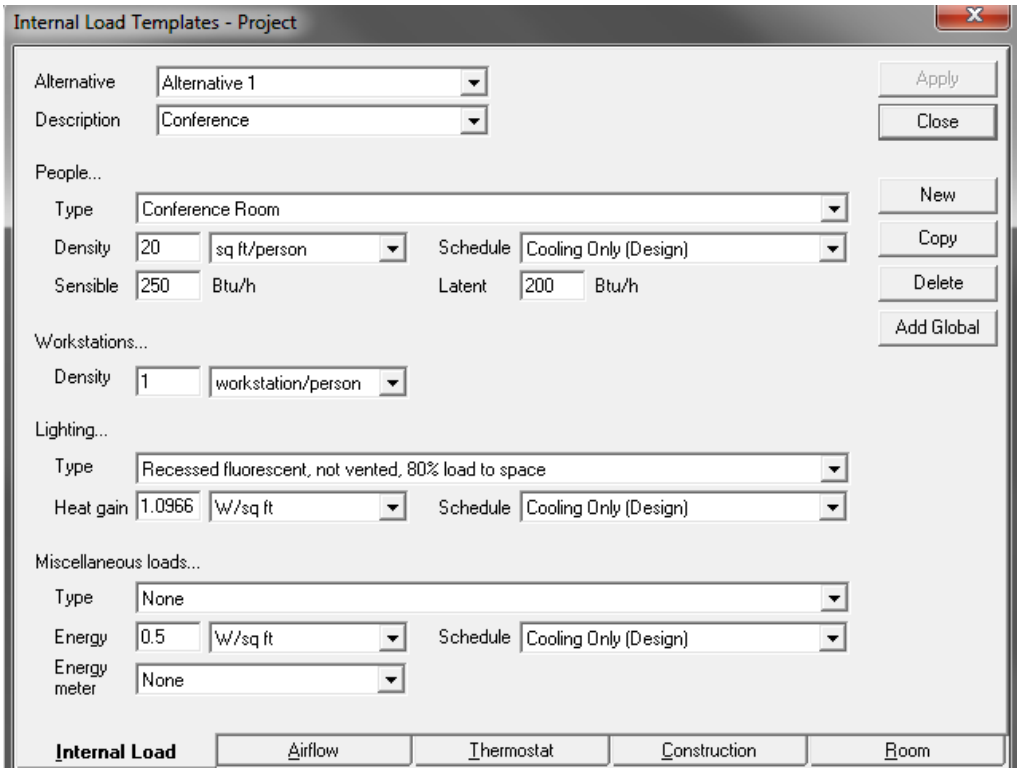
Floor Two Heat Pump Zones

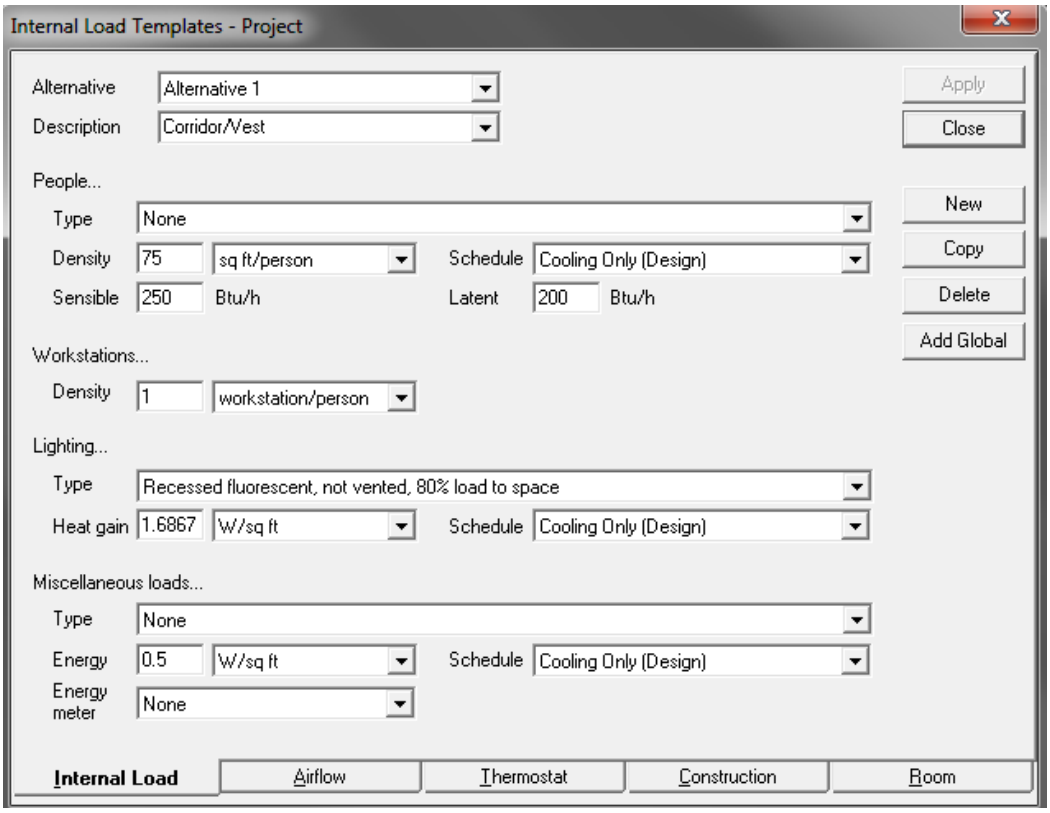


Templates for TRACE 700






Internal Load Templates - Project
Alternative
Alternative 1
Description
Conference
Apply
Close
People...
Type
Conference Room
Density
20
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
1.0966
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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Alternative
Alternative 1
Description
Corridor/West
Apply
Close
People...
Type
None
Density
75
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
1.6867
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
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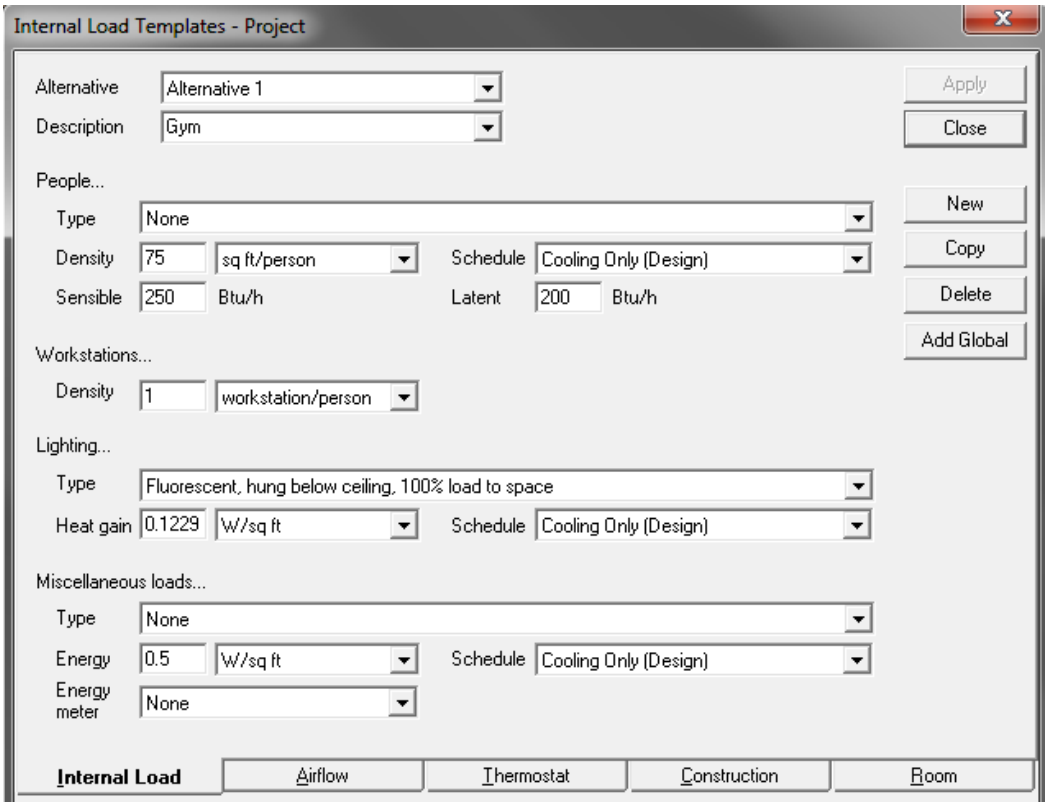
Energy
0.5
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
None
Internal Load
Airflow
Thermostat
Construction
Room


Internal Load Templates - Project
Alternative
Alternative 1
Description
Gym
Apply
Close
People...
Type
None
Density
75
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
Fluorescent, hung below ceiling, 100% load to space
Heat gain
0.1229
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
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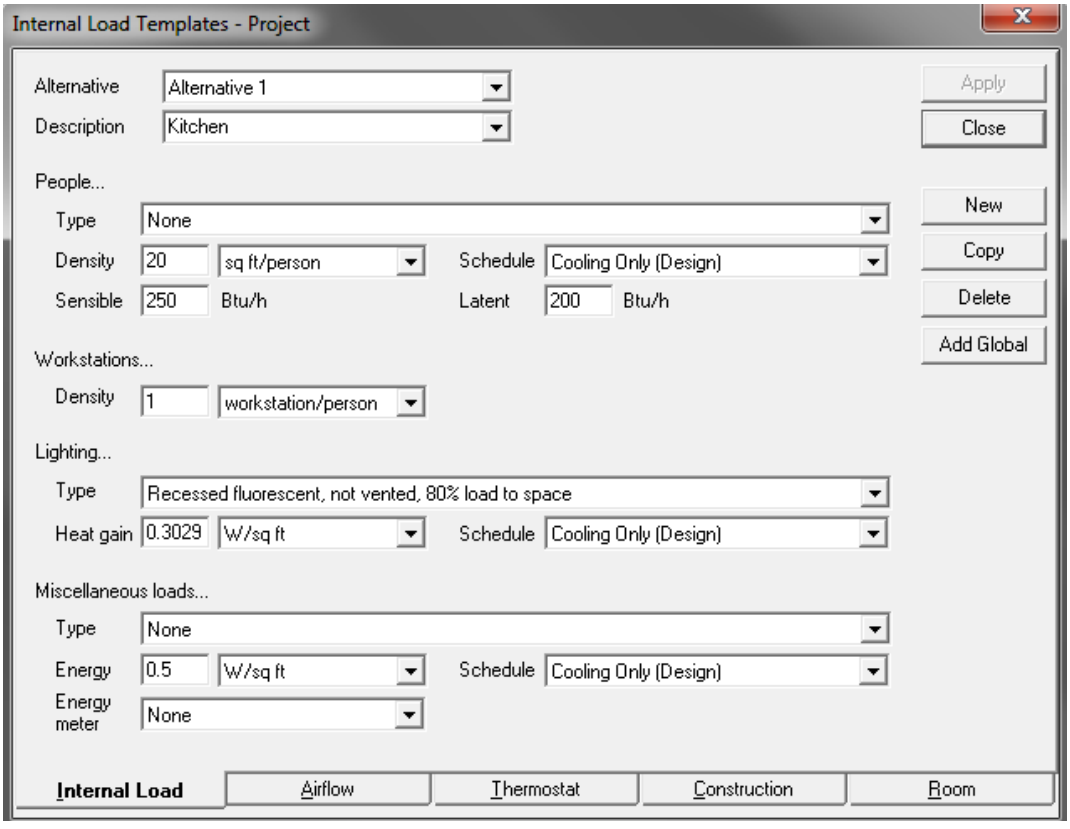
Energy
0.5
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
None
Internal Load
Airflow
Thermostat
Construction
Room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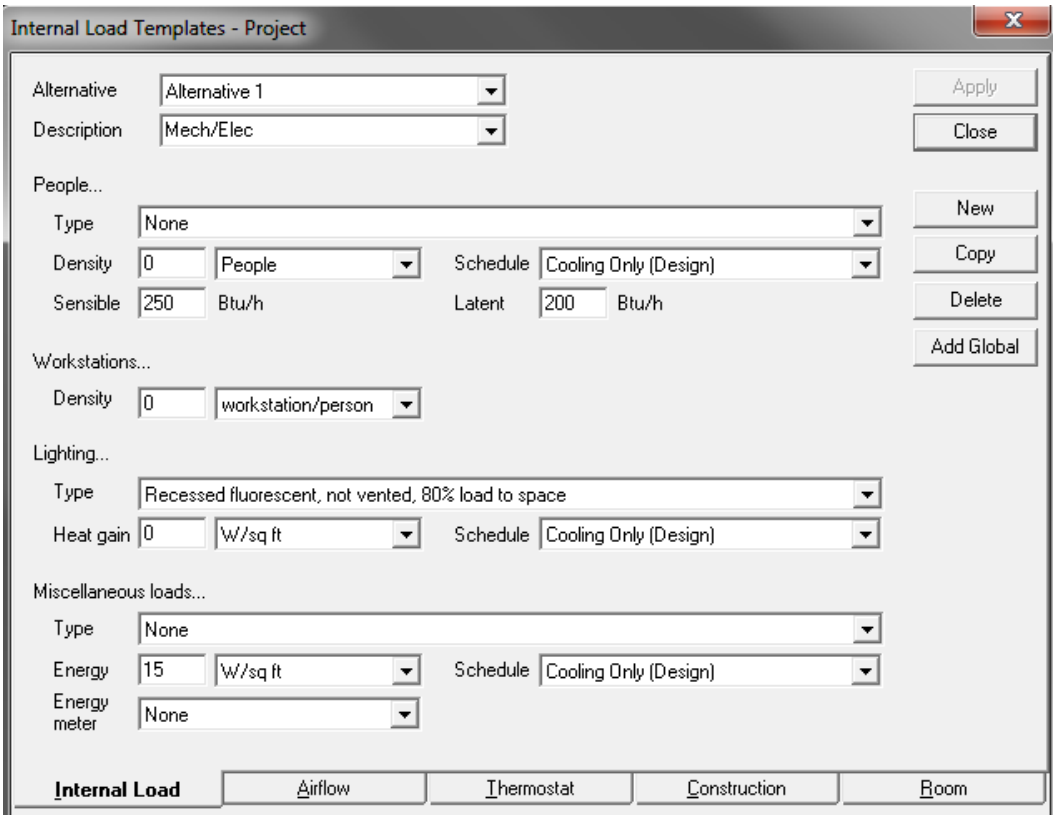
Alternative
Alternative 1
Description
Kitchen
Apply
Close
People...
Type
None
Density
20
sq ft/person
Schedule
Cooling Only (Design)
Sensible
250
Btu/h
Latent
200
Btu/h
New
Copy
Delete
Add Global
Workstations...
Density
1
workstation/person
Lighting...
Type
Recessed fluorescent, not vented, 80% load to space
Heat gain
0.3029
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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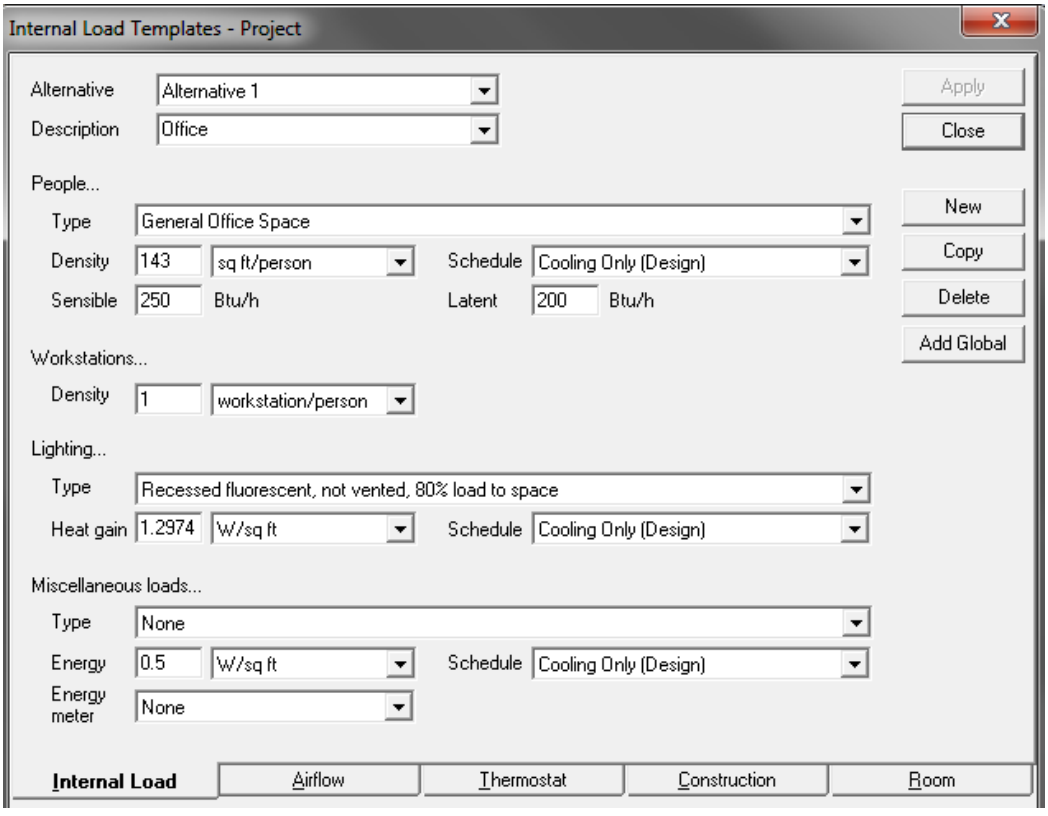
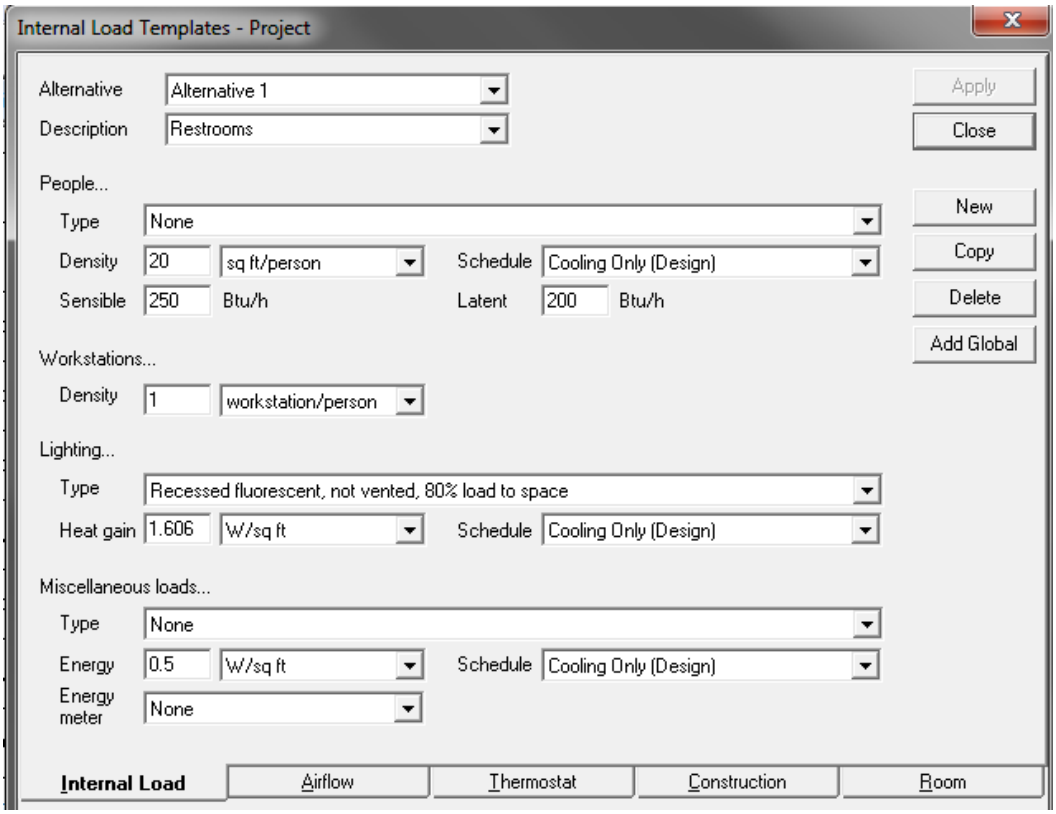
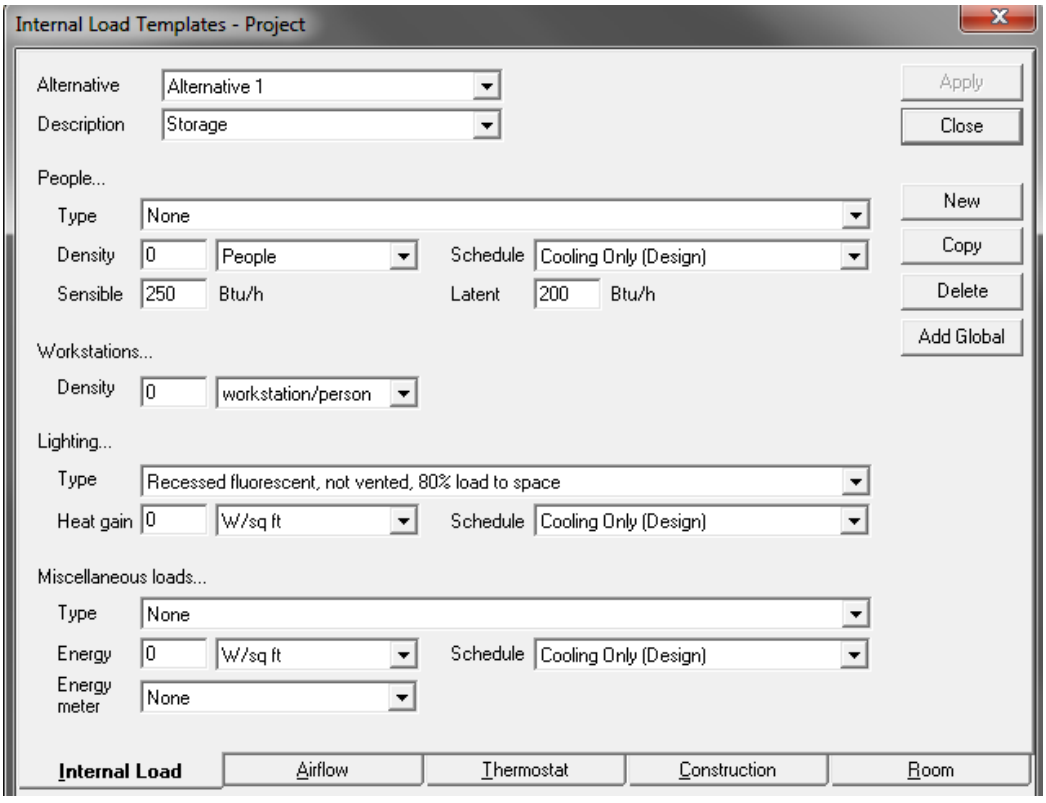
Alternative
Alternative 1
Description
Mech/Elec
Apply
Close
People...
Type
None
Density
0
People
Schedule
Cooling Only (Design)
Sensible
250
Btu/h
Latent
200
Btu/h
New
Copy
Delete
Add Global
Workstations...
Density
0
workstation/person
Lighting...
Type
Recessed fluorescent, not vented, 80% load to space
Heat gain
0
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
Type
None
Energy
15
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
None
Internal Load
Airflow
Thermostat
Construction
Room


Internal Load Templates - Project
Alternative
Alternative 1
Description
Office
Apply
Close
People...
Type
General Office Space
Density
143
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
1.2974
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
Restrooms
Apply
Close
People...
Type
None
Density
20
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
1.606
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
Storage
Apply
Close
People...
Type
None
Density
0
People
Schedule
Cooling Only (Design)
Sensible
250
Btu/h
Latent
200
Btu/h
New
Copy
Delete
Add Global
Workstations...
Density
0
workstation/person
Lighting...
Type
Recessed fluorescent, not vented, 80% load to space
Heat gain
0
W/sq ft
Schedule
Cooling Only (Design)
Miscellaneous loads...
Type
None
Energy
0
W/sq ft
Schedule
Cooling Only (Design)
Energy meter
None
Internal Load
Airflow
Thermostat
Construction
Room