Coppin State University Physical Education Complex - Technical Report 2

Building and Plant Energy Analysis Report

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Location: Baltimore, MD

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Executive Summary

The purpose of this report is to complete a building load energy analysis on the Coppin State University Physical Education Complex, as well as to analyze the annual energy consumption, operating costs and emissions of the building. Carrier's Hourly Analysis Program (HAP) version 4.50 was used to perform the energy load analysis and the energy consumption based on the design documents provided by the architects and engineers.

The modeled design loads were compared to the design loads performed by the mechanical engineer. Most of the results for the design load model were relatively close to those modeled by the mechanical engineer. The main reason for these discrepancies was due to the fact that a block load analysis was used for the model while the engineer used a space by space method.

Annual energy consumption, operating costs and emissions for the complex were also calculated using the same model as the design load. The costs and emissions of natural gas and electricity were the only factors considered in this part of the analysis. Overall the Complex's annual energy consumption was reasonably close to the national average of buildings with the same square feet.

Mechanical System Summary

The Complex is served by a total of fourteen air handling units (AHUs) all utilizing variable air volume (VAV) terminal units. For large spaces, such as the arena and auxiliary gym, a single zone VAV system was used. The remaining units were zoned off per floors and architectural zones. There are also two energy recovery units that serve the locker rooms located throughout the complex.

A future central utility plant located on the first level houses two 500 ton chillers, three dual fuel 250HP boilers and space for future expansion. The cooling tower is located close to the central utility plant, on the roof of the complex. The boilers are operated with natural gas or oil while the remaining equipment utilizes electricity.

System Design Load Estimation

Carrier's Hourly Analysis Program (HAP) version 4.50 was used to determine the design load energy consumption of the Coppin State University Physical Education Complex in Baltimore, MD. Information from the architectural and mechanical design documents were used to build and determine heating and cooling loads. The mechanical engineer performed an energy model utilizing an older version of HAP, version 3.2. The model created for this report was compared to the design engineer's model in the sections below.

Block Load Assumptions

A block load analysis was performed for this assignment to help reduce the model calculation time and allowing the model file size to be more manageable. The results are still accurate within reason with the assumptions listed below being considered.

Exterior Walls

The wall construction was simplified to either a typical concrete masonry unit (CMU) wall with face brick or a CMU wall with a metal finish. The actual building has multiple varieties of face brick walls, but these two versions were used for simplification.

Occupancy and Ventilation

All ventilation rates were taken from the design schedules provided by the mechanical engineer. Design occupancies were already calculated in Technical Report 1, which were taken from the architectural drawings. Most of the spaces had an occupancy activity level of typical office work which has a sensible load of 245 BTU/hr/person and a latent load of 205 BTU/hr/person. In other spaces where people are performing physical activities, such as the dance studio and auxiliary gym, an occupancy activity of athletics was used with a sensible load of 710 BTU/hr/person and a latent load of 1090 BTU/hr/person. The occupancy schedules used in the model are summarized in Appendix A.

Infiltration

The Complex was designed to maintain a total building pressurization; this is typically between 3% and 5%, in order to prevent unconditioned air from entering the building. Infiltration was not considered in this model due to the design constraint specified above by the mechanical engineer.

Lighting and Equipment Loads

The electrical loads in the Complex varied so much from space to space that the actual lighting loads given by the electrical engineer were used. Equipment found in each space was input using the actual watts given by the mechanical engineer. Using the actual data in this model will help provide a more accurate result.

Weather Data

Indoor and outdoor air conditions for heating and cooling in Baltimore, MD were used for this analysis. The values summarized in Appendix B were referenced by HAP from the 2001 ASHRAE Handbook.

Results

Tables 1 and 2 below summarize the results of the energy model and compare the results to the engineer's design. The block load energy model resulted in different values than those designed for each air handling unit and energy recovery unit. Templates of typical spaces and components used can be found in Appendix C. The differences in these values could be consequences of the safety factors applied by the mechanical engineer or the details put into each space. The main reason for these differences is most likely due to the fact that a block load analysis was used in the model while the mechanical engineer used a space by space method for the design.

Table 1 –Modeled vs. Designed Energy Analysis

		AHU-1	AHU-2	AHU-3	AHU-4	AHU-5/6	AHU-7	AHU-8
Cooling (MBH)	Designed	621	397	650	637	6540	509	1029
	Modeled	281.4	267.8	411.8	362.1	3084.2	245.1	481.9
Supply Air (cfm)	Designed	12250	9000	13750	14750	80000	11500	19600
	Modeled	5023	8453	12411	11426	72892	7316	16290
Ventilation Air (cfm)	Designed	4000	1975	3800	3400	62000	2800	7500
	Modeled	2062	1362	1694	1190	10800	762	1399
Heating (MBH)	Designed	529	389	594	637	1728	497	847
	Modeled	127.5	91.3	142	161.5	899.7	122.1	182.7

Table 2 - Modeled vs. Designed Energy Analysis (continued)

		AHU-9/10	AHU-11	AHU-12	AHU-13	AHU-14	ERU-1	ERU-2
Cooling (MBH)	Designed	958	1404	539	596	-	733	1091
	Modeled	779.9	8601.1	418.8	430.6	-	267	488.8
Supply Air (cfm)	Designed	23000	28000	13000	13950	4800	9820	14100
	Modeled	19057	22157	10162	8453	4773	9765	14022
Ventilation Air (cfm)	Designed	4600	9150	2600	2500	480	9820	1410
	Modeled	4295	5140	2168	2329	136	401	1190
Heating (MBH)	Designed	497	1210	562	603	207	283	404
	Modeled	386.9	352.2	201.8	185.9	140.4	71.5	162.4

Energy Consumption and Operating Costs

Annual energy consumption and operating costs were modeled using the same model as the heating and cooling loads. The chiller plant was modeled using a primary/secondary distribution system with the secondary being variable speed. The chillers are centrifugal while to cooling tower was modeled after the details given by the mechanical engineer. The boiler plant was modeled simply as natural gas instead of the actual dual-fuel installed.

Assumptions

The electrical and natural gas rates for the local Baltimore area were used for the energy consumptions and operating costs shown in Table 3 below. These values were taken from the US Energy Information Administration (EIA).

Table 3 - Energy Rates

	Local Rates
Electricity Cost ($/kWh)	0.12
Natural Gas Cost ($/Therm)	1.138

Equipment efficiencies were determined by those listed by the manufacturer. The efficiencies were assumed to be constant, not a part load curve for simplification of the model. Supply and exhaust fans were modeled based on the horsepower listed in the design documents.

Results

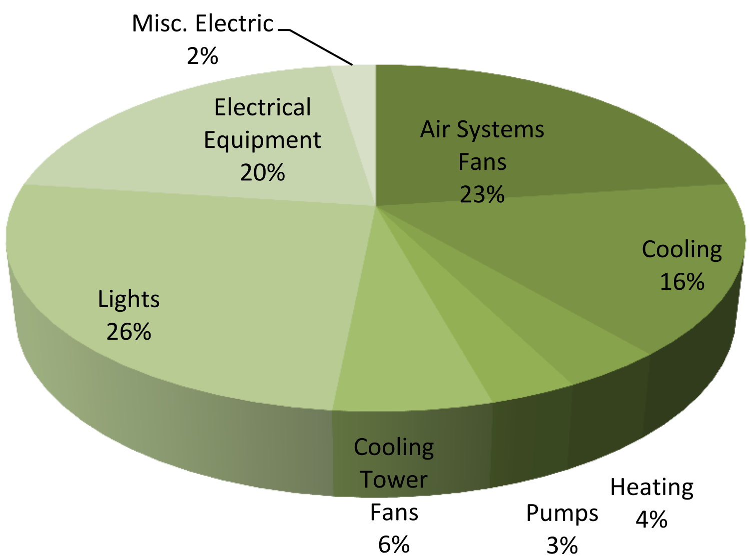
Table 4 below shows the annual energy consumption used by the complex broken down by component type. Referencing Figure 1, the largest consumer of energy in the building is the cooling tower fans. This large percentage is due to the large flow rate of the condenser at 1,015 GPM. The cooling tower for the complex is a very large tower and was sized with expansion in mind. The lights, electrical equipment, and air system fans consume the next largest amount of energy.

This annual energy consumption was compared to the Commercial Buildings Energy Consumption Survey (CBECS) 2003. In Table E2A (Major Fuel Consumption Intensities by End Use for all Buildings) of CBECS a building with the same ranger of square footage as the complex consumed an average of 100,200 BTU/SF. When comparing this value to the complex at approximately 92,000 BTU/SF the numbers produced by the model appear accurate.

Table 4 - Annual Energy Consumption

	Energy (kWh)
Air Systems Fans	1,434,527
Cooling	1,010,456
Heating	751,846
Pumps	201,676
Cooling Tower Fans	3,653,707
Lights	1,621,230
Electrical Equipment	1,289,010
Misc. Electric	150,600
Grand Total	**10,113,052**

Figure 1 - Annual Energy Consumption Percentages



In Table 5 and Figure 2 the annual cost is illustrated and Figure 3 breaks down the cost in detail showing a month by month cost. The month by month analysis illustrates accurate results. The electrical costs are much greater in the summer during the peak cooling season while the natural gas cost increases during the winter during the peak heating season. The electrical consumption is consistently larger than the natural gas due to the high miscellaneous equipment operating throughout the complex.

Table 5 - Annual Energy Costs

	Cost per year ($)	Cost per SF ($/SF)
Air Systems Fans	182,762	0.873
Cooling	127,354	0.609
Heating	30,009	0.143
Pumps	25,681	0.123
Cooling Tower Fans	46,526	0.222
Lights	204,333	0.977
Electrical Equipment	164,142	0.785
Misc. Electric	18,981	0.091
Grand Total	**799,699**	**3.822**

Figure 2 - Annual Energy Cost Percentages

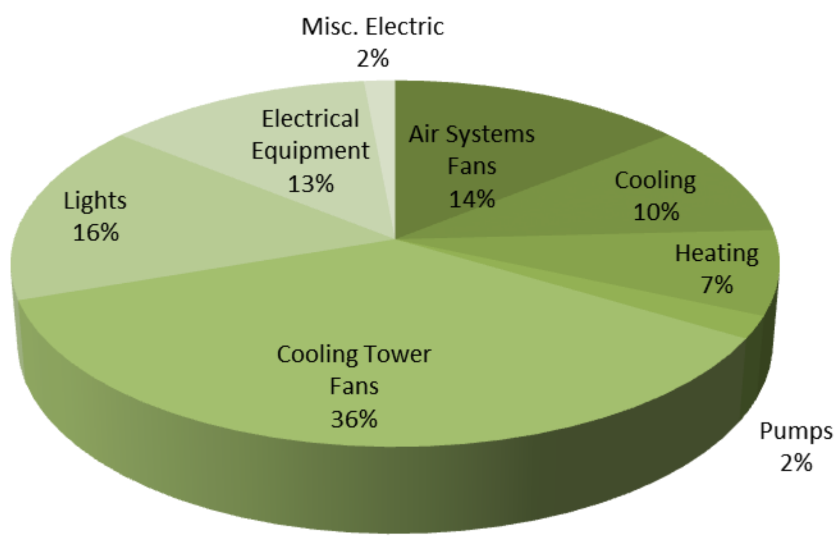
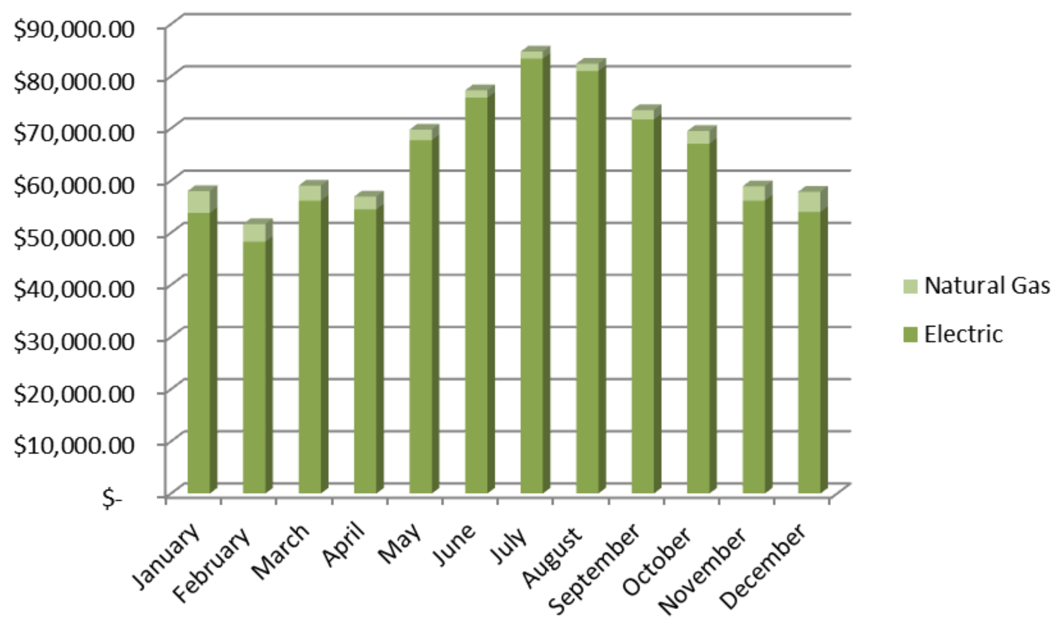


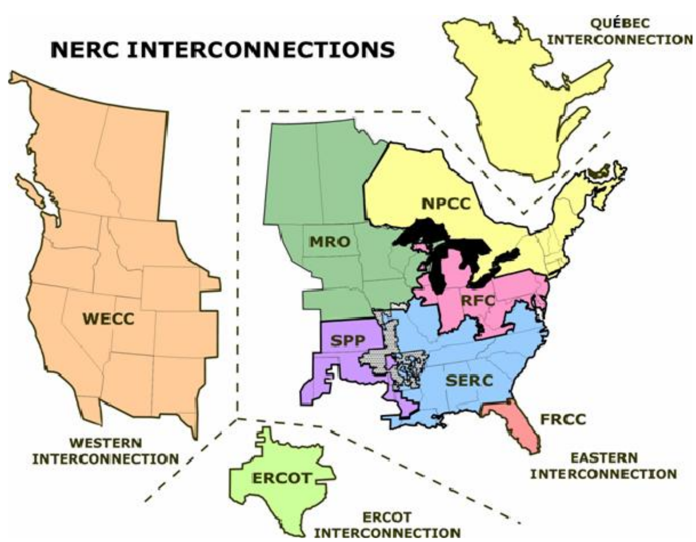
Figure 3 - Monthly Energy Costs



Building Emission Rates

The emission rates for pollutants such as CO_2, NO_x, and SO_x were calculated based on the total energy consumption of the complex. The total amount of electricity and natural gas amounts from the HAP model previously discussed were used. Maryland is located in the Eastern Region according to the National Renewable Energy Laboratory (NREL), shown in pink below, in Figure 4.

Figure 4- Monthly Energy Costs



The total source pollution emissions that are generated by the Complex are illustrated in Tables 6 and 7. The amount of pollutant per amount of energy source was taken from Tables 3 and 6 of the NREL Energy and Emissions Report. As seen in the tables, most of the pollutants come from electricity. This is due to the drastic efficiency difference of natural gas and electricity. The natural gas is burnt and used in the boilers which are 80% efficient versus the electricity which has an efficiency of approximately 30% from the original utility provided.

Table 6 - Annual Emission Rates

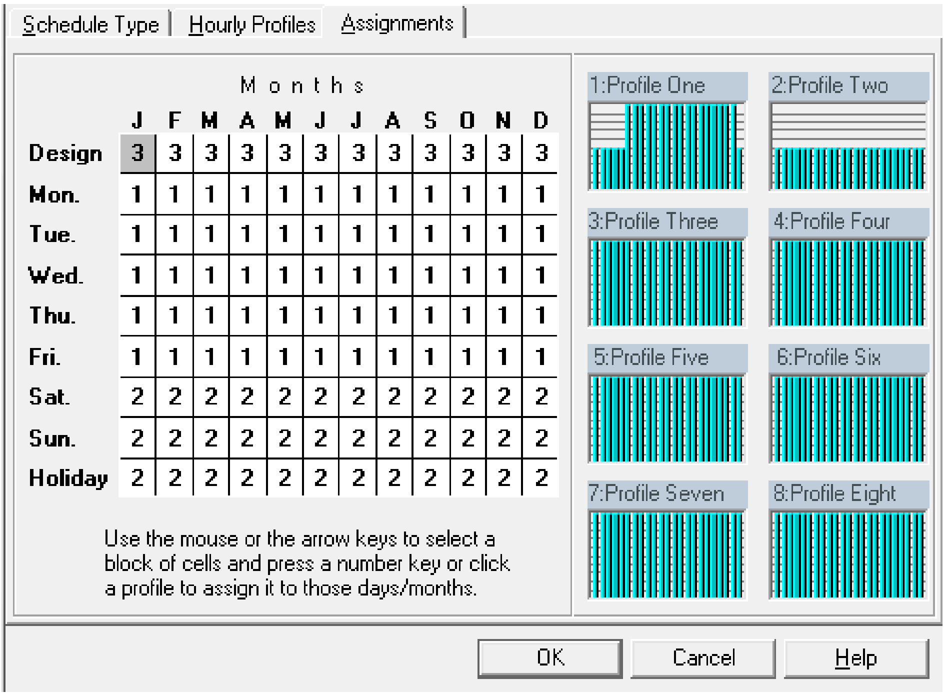
Pollutants	lb of Pollutant per kWh of electricity	kWh of electricity per year	Amount of Pollutant per year (lb)
CO2	1.64	24,511,204	40,198,375
Nox	0.003	24,511,204	73,534
Sox	0.00857	24,511,204	210,061

Table 7 - Annual Emission Rates (continued)

Pollutants	lb of Pollutant per 1000 cubic feet of Natural gas	Natural Gas per year (1000 cubic feet)	Amount of Pollutant per year (lb)
CO2	11.6	30,486	353,638
Nox	0.0164	30,486	500
Sox	1.22	30,486	37,193

Appendix A – Energy Model Schedules

Air Handling Units Schedule (Most Spaces)



Hourly Profiles:

1:Profile One

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50

2:Profile Two

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50

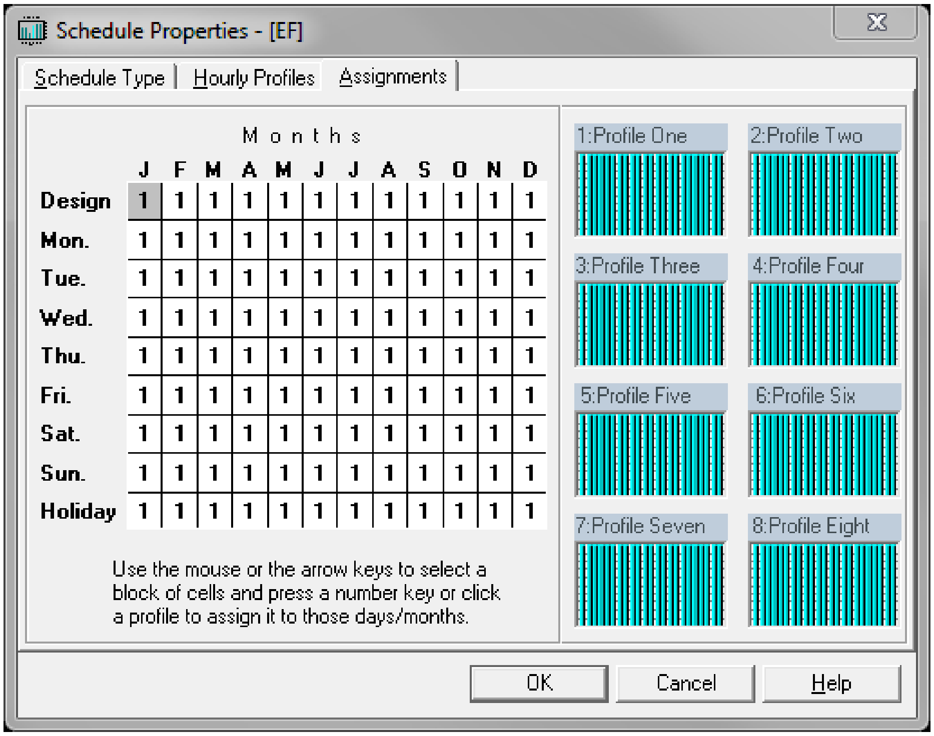
3:Profile Three

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Assignments:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design	3	3	3	3	3	3	3	3	3	3	3	3
Monday	1	1	1	1	1	1	1	1	1	1	1	1
Tuesday	1	1	1	1	1	1	1	1	1	1	1	1
Wednesday	1	1	1	1	1	1	1	1	1	1	1	1
Thursday	1	1	1	1	1	1	1	1	1	1	1	1
Friday	1	1	1	1	1	1	1	1	1	1	1	1
Saturday	2	2	2	2	2	2	2	2	2	2	2	2
Sunday	2	2	2	2	2	2	2	2	2	2	2	2
Holiday	2	2	2	2	2	2	2	2	2	2	2	2

24/7 Equipment Schedule



1:Profile One

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

2:Profile Two

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

3:Profile Three

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

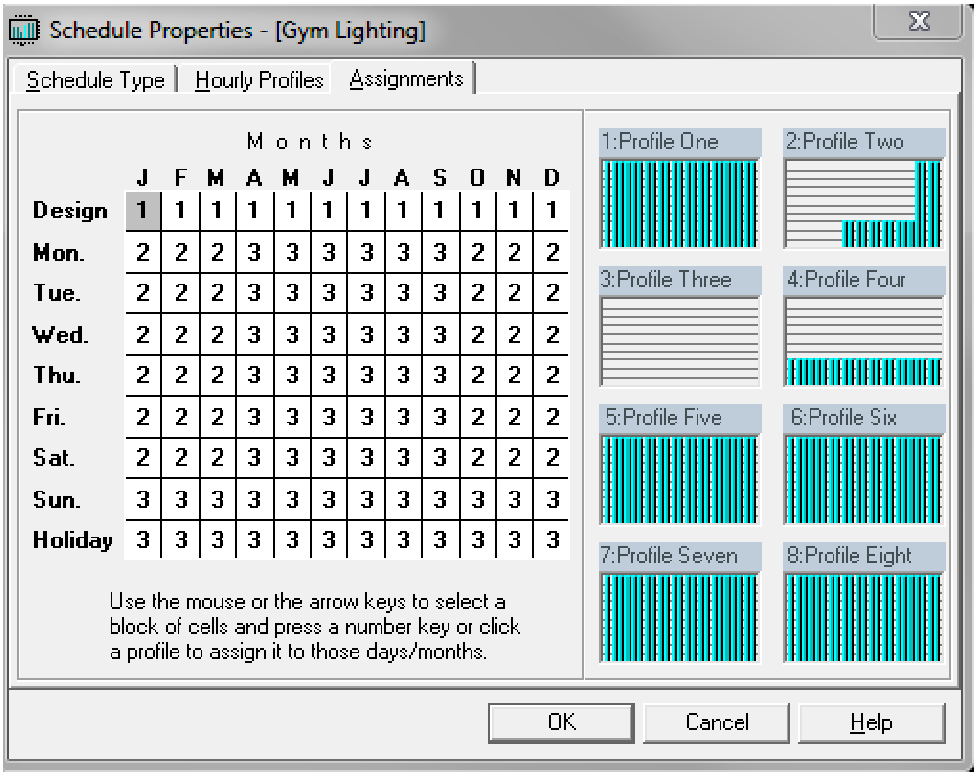
4:Profile Four

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Assignments:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design	1	1	1	1	1	1	1	1	1	1	1	1
Monday	2	2	2	2	2	2	2	2	2	2	2	2
Tuesday	2	2	2	2	2	2	2	2	2	2	2	2
Wednesday	2	2	2	2	2	2	2	2	2	2	2	2
Thursday	2	2	2	2	2	2	2	2	2	2	2	2
Friday	2	2	2	2	2	2	2	2	2	2	2	2
Saturday	3	3	3	3	3	3	3	3	3	3	3	3
Sunday	4	4	4	4	4	4	4	4	4	4	4	4
Holiday	4	4	4	4	4	4	4	4	4	4	4	4

Gym Schedule



Hourly Profiles:

1:Profile One

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

2:Profile Two

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	0	0	0	0	0	0	0	0	30	30	30	30	30	30	30	30	30	30	30	100	100	100	100	30

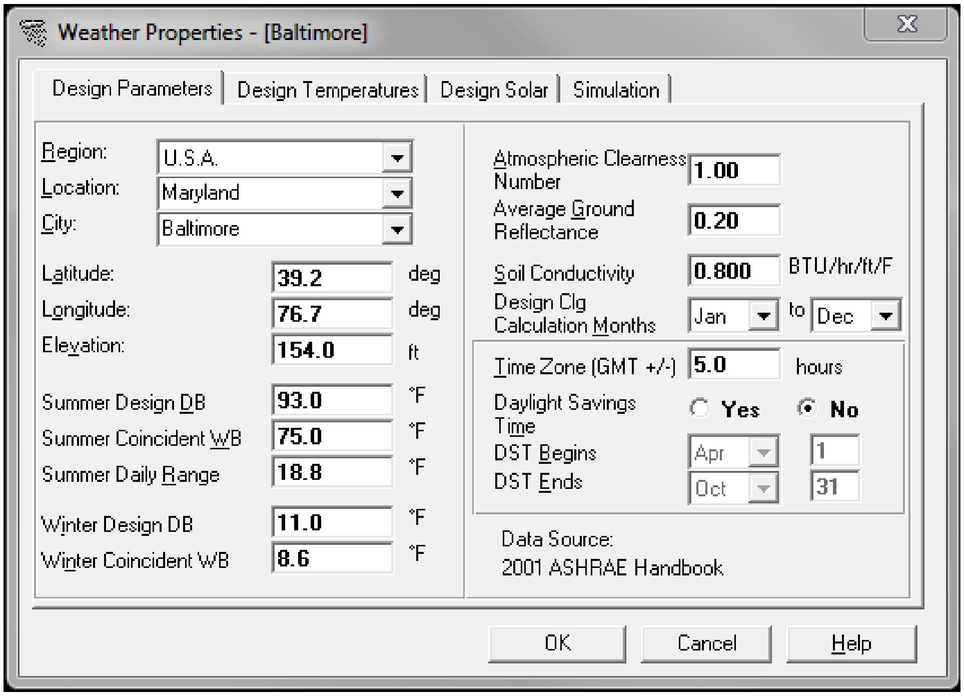
3:Profile Three

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Assignments:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design	1	1	1	1	1	1	1	1	1	1	1	1
Monday	2	2	2	3	3	3	3	3	3	2	2	2
Tuesday	2	2	2	3	3	3	3	3	3	2	2	2
Wednesday	2	2	2	3	3	3	3	3	3	2	2	2
Thursday	2	2	2	3	3	3	3	3	3	2	2	2
Friday	2	2	2	3	3	3	3	3	3	2	2	2
Saturday	2	2	2	3	3	3	3	3	3	2	2	2
Sunday	3	3	3	3	3	3	3	3	3	3	3	3
Holiday	3	3	3	3	3	3	3	3	3	3	3	3

Appendix B – Weather Data



Design Day Maximum Solar Heat Gains

(The MSHG values are expressed in BTU/(hr-ft²))

Month	N	NNE	NE	ENE	E	ESE	SE	SSE	S
January	19.9	19.9	19.9	83.1	153.9	210.8	240.9	250.7	253.7
February	24.3	24.3	47.8	131.8	190.2	234.0	248.2	244.2	239.0
March	29.1	29.1	102.3	166.2	219.3	238.4	236.0	215.6	202.9
April	33.8	67.9	142.1	194.8	219.4	224.8	200.1	167.9	149.0
May	37.1	103.1	163.5	206.7	219.0	206.8	170.1	128.8	107.0
June	46.7	113.7	171.1	208.4	214.5	197.7	156.5	112.2	90.7
July	38.1	99.0	163.2	202.4	212.3	202.8	167.1	125.8	104.7
August	35.5	66.2	138.6	186.6	213.6	216.8	193.9	162.4	144.4
September	30.1	30.1	96.7	156.2	206.1	229.2	225.8	208.3	195.5
October	25.1	25.1	53.4	118.9	186.2	223.8	241.4	237.6	231.1
November	20.2	20.2	20.2	84.1	150.2	205.2	237.5	249.4	248.6
December	17.9	17.9	17.9	65.8	135.4	196.6	231.7	248.4	252.0
Month	**SSW**	**SW**	**WSW**	**W**	**WNW**	**NW**	**NNW**	**HOR**	**Mult**
January	253.6	243.0	205.2	156.3	81.7	19.9	19.9	137.1	1.00
February	243.9	248.3	235.2	191.0	128.3	54.4	24.3	183.6	1.00
March	213.9	232.4	240.5	214.0	171.2	100.0	29.1	225.2	1.00
April	166.9	199.0	224.0	221.6	195.6	139.7	72.0	252.4	1.00
May	128.1	171.1	206.0	220.1	206.4	161.8	104.3	265.0	1.00
June	110.8	158.3	195.4	216.7	207.0	168.6	116.0	267.7	1.00
July	124.3	167.8	199.8	216.3	201.6	159.1	104.4	262.8	1.00
August	160.9	192.3	215.9	213.9	188.9	135.6	71.3	248.2	1.00
September	208.4	226.0	228.9	206.5	155.1	96.7	30.1	216.2	1.00
October	237.5	240.9	223.1	185.1	125.2	46.8	25.1	179.5	1.00
November	248.3	234.2	207.1	147.2	84.6	20.2	20.2	135.4	1.00
December	250.0	230.6	196.4	130.6	67.7	17.9	17.9	116.0	1.00

Mult. = User-defined solar multiplier factor.

Appendix C – HAP Templates

Typical Wall Template

Wall Properties - [Wall 1]

Wall Assembly Name: Wall 1

Outside Surface Color: Dark

Absorptivity: 0.900

Layers: Inside to Outside	Thickness in	Density lb/ft³	Specific Ht. BTU/lb/F	R-Value hr-ft²-F/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
Gypsum board	0.625	50.0	0.26	0.56000	2.6
8-in HW concrete block	8.000	61.0	0.20	1.11111	40.7
R-7 board insulation	2.000	2.0	0.22	9.47000	0.3
Air space	0.000	0.0	0.00	0.91000	0.0
Face brick	4.000	125.0	0.22	0.33333	41.7
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	14.625			13.40	85.3

Overall U-Value: 0.075 BTU/hr/ft²/F

OK | Cancel | Help

Metal Wall Template

Wall Properties - [Wall Metal]

Wall Assembly Name: Wall Metal

Outside Surface Color: Dark

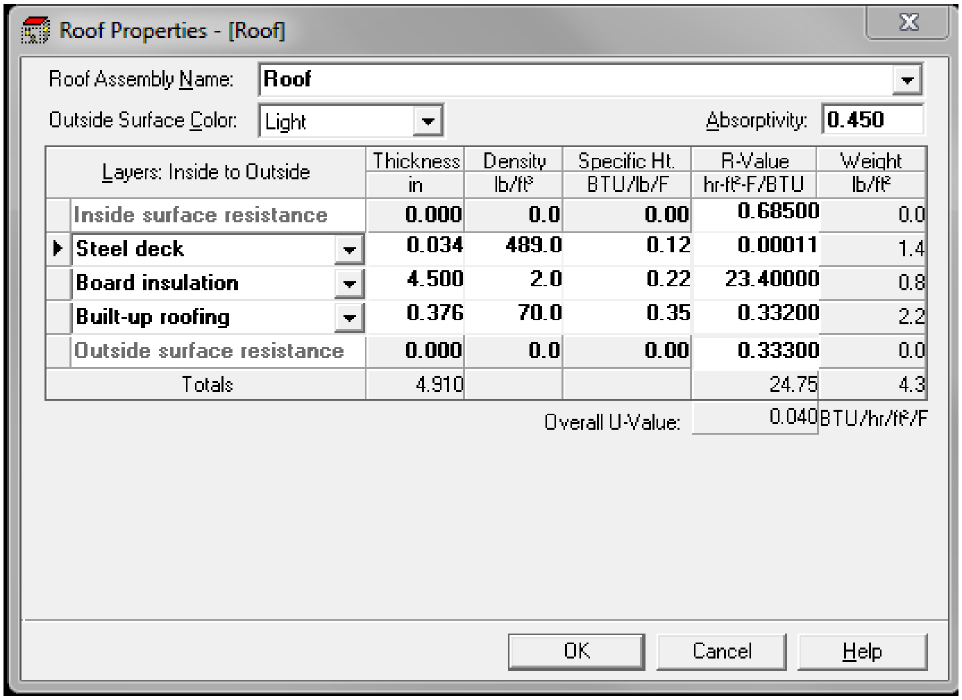
Absorptivity: 0.900

Layers: Inside to Outside	Thickness in	Density lb/ft³	Specific Ht. BTU/lb/F	R-Value hr-ft²-F/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
8-in HW concrete block	8.000	61.0	0.20	1.11111	40.7
R-7 board insulation	1.000	2.0	0.22	14.46000	0.2
Air space	0.000	0.0	0.00	0.91000	0.0
22 gage steel deck	0.034	489.0	0.12	0.00011	1.4
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	9.034			17.50	42.2

Overall U-Value: 0.057 BTU/hr/ft²/F

OK | Cancel | Help

Roof Template



Roof Properties - [Roof]

Roof Assembly Name: Roof

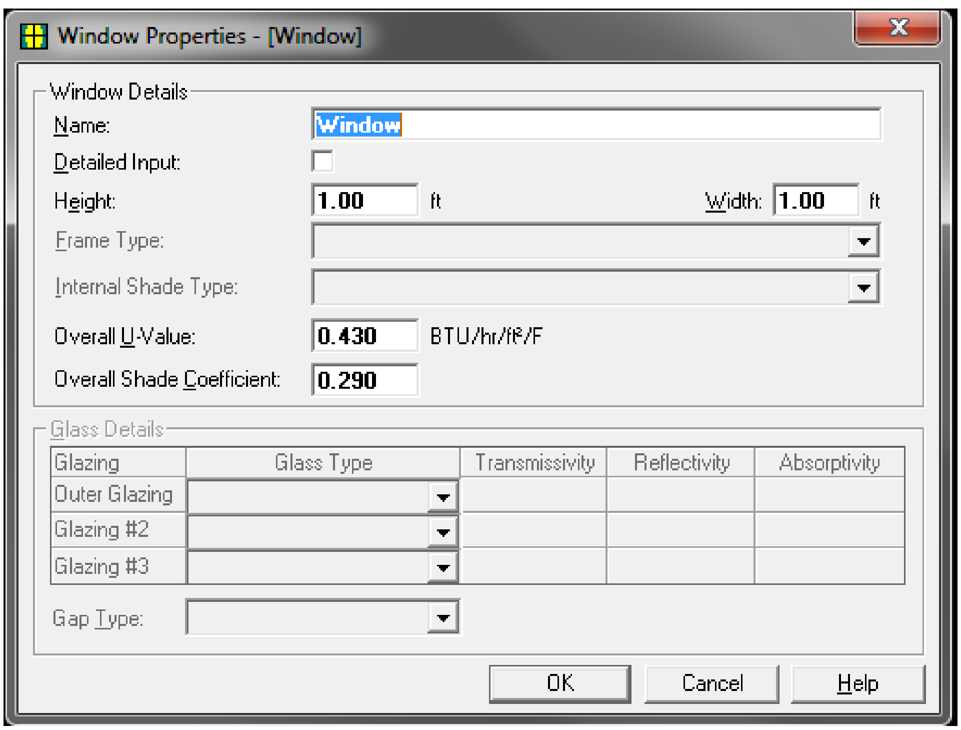
Outside Surface Color: Light   Absorptivity: 0.450

Layers: Inside to Outside	Thickness in	Density lb/ft³	Specific Ht. BTU/lb/F	R-Value hr-ft²-F/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
Steel deck	0.034	489.0	0.12	0.00011	1.4
Board insulation	4.500	2.0	0.22	23.40000	0.8
Built-up roofing	0.376	70.0	0.35	0.33200	2.2
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	4.910			24.75	4.3

Overall U-Value: 0.040 BTU/hr/ft²/F

OK Cancel Help

Window Template



Window Properties - [Window]

Window Details

Name: Window

Detailed Input:

Height: 1.00 ft   Width: 1.00 ft

Frame Type:

Internal Shade Type:

Overall U-Value: 0.430 BTU/hr/ft²/F

Overall Shade Coefficient: 0.290

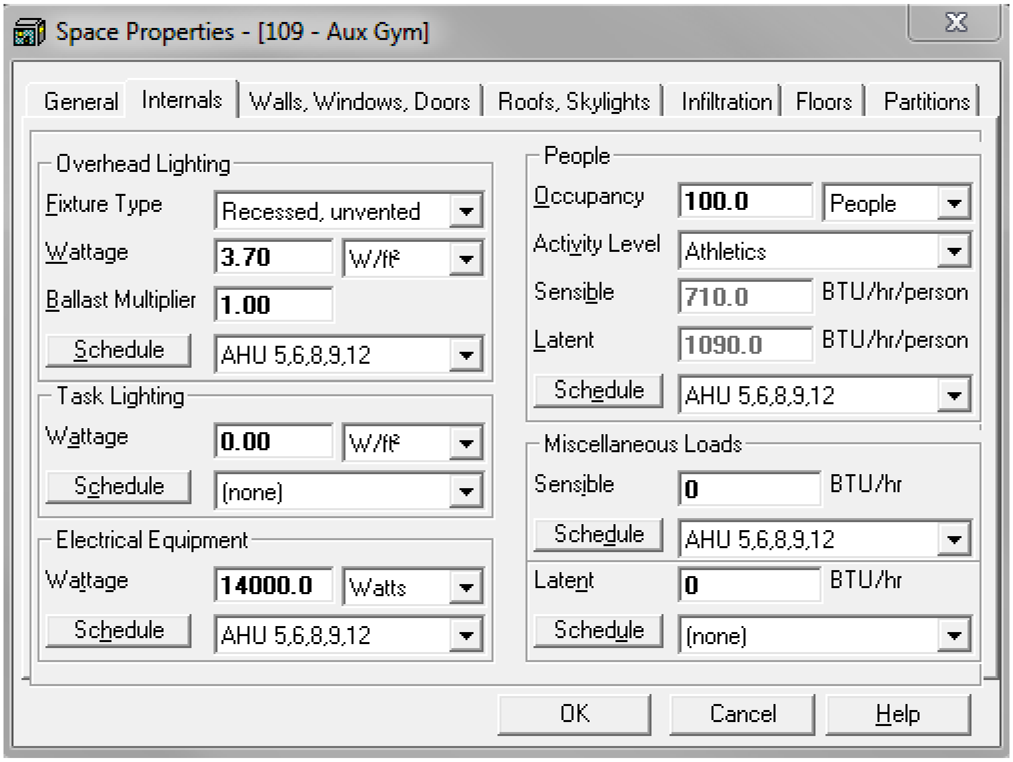
Glass Details

Glazing	Glass Type	Transmissivity	Reflectivity	Absorptivity
Outer Glazing				
Glazing #2				
Glazing #3				

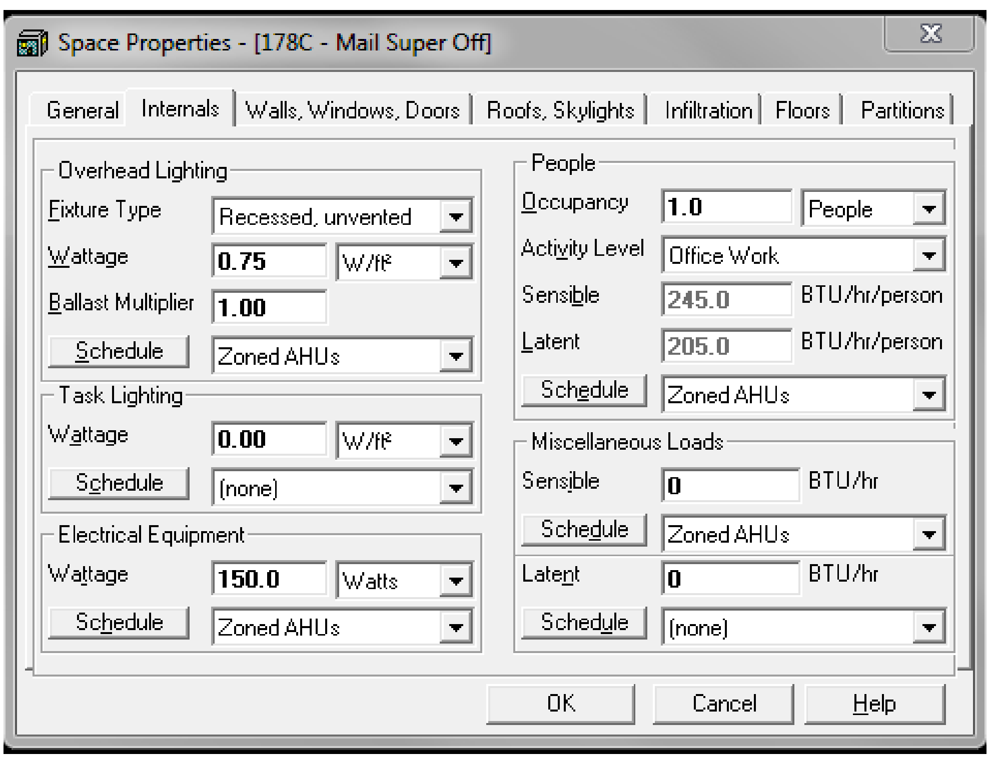
Gap Type:

OK Cancel Help

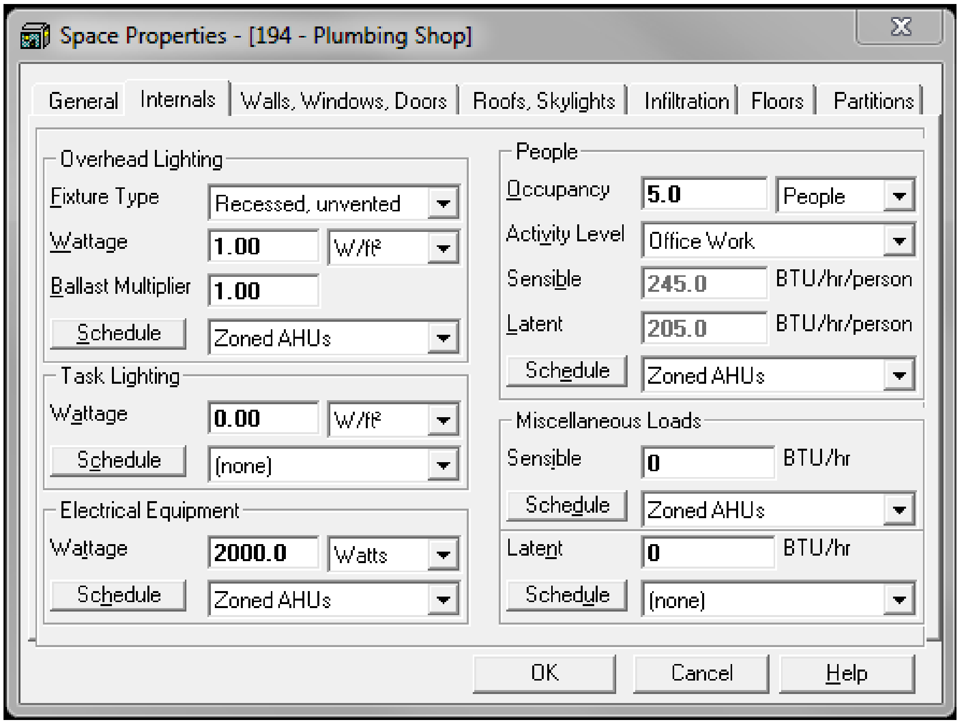
Auxiliary Gym Template



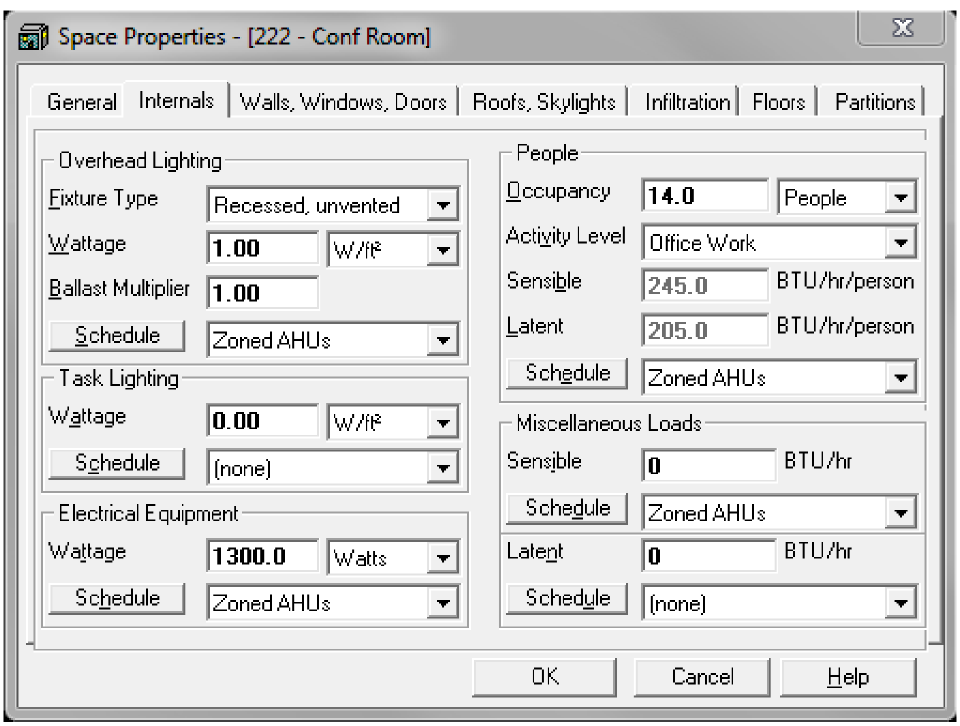
Typical Office Template



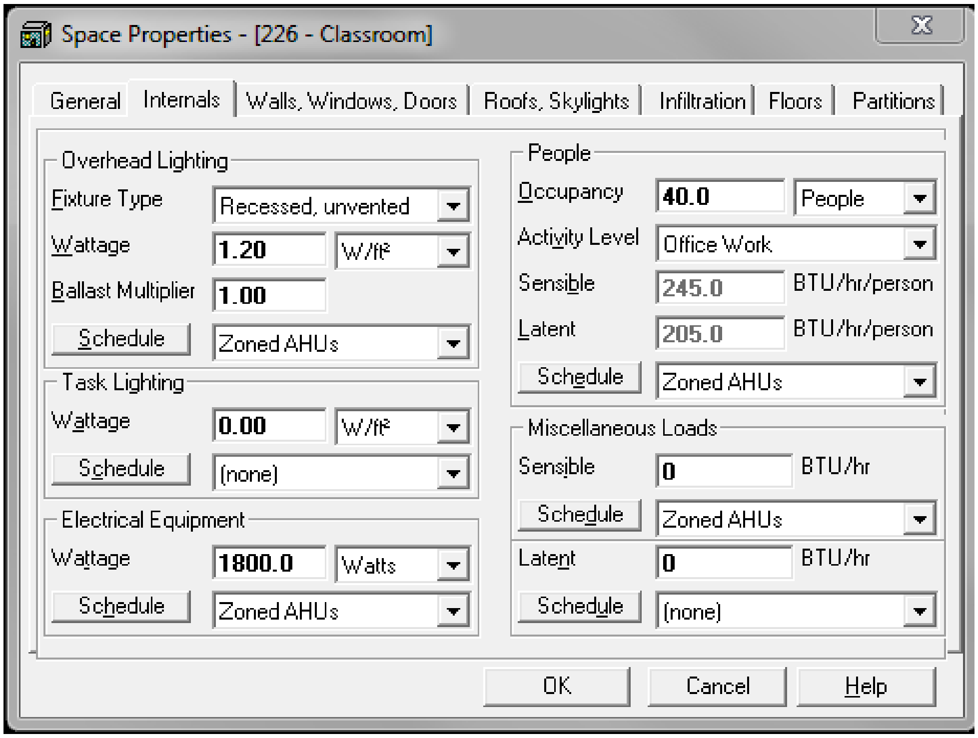
Typical Facilities Maintenance Space Schedule



Typical Conference Room Schedule



Typical Classroom Schedule



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