Penn State AE
Senior Thesis Presentation

Altoona Area Junior High School • Altoona, PA

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Introduction

- Presentation Outline
  - Thesis Goals
  - Building Information
  - Existing Mechanical Systems Summary
  - Ground Source Heat Pump Redesign Depth
  - Daylighting Breadth
  - Summary
  - Conclusions
  - Questions

Goals

- Reduce HVAC systems' energy consumption in the AAJHS athletic facility
- Reduce lighting system energy consumption in AAJHS gymnasiums
- Reduce energy costs for AAJHS
- Present a ground source heat pump system as a feasible, responsible design *alternative*
- Present gymnasium daylighting system as a feasible, energy-saving design *enhancement*

Building Information

Building Information

- Owner – Altoona Area School District
- Architects – L. Robert Kimball & Associates
- Replaces two older existing schools
- 292,000 square feet
- $48 Million
- Scheduled to open Fall 2008
- Will accommodate 1,800 students
- Grades 7-9

Building Information

- Two separate building sections

Building Information

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  - **Academic Building (239,434 sq. ft.)**
    - Classrooms
    - Offices
    - Auditorium
    - Library

Building Information

- Two separate building sections
  - **Athletic Building (52,632 sq. ft.)**
    - Gymnasiums
    - Locker Rooms
    - Athletics

    (Primary thesis focus area)

Existing Mechanical Systems

Existing Mechanical Systems

- **Two-pipe Hydronic Changeover System**
  - Serves academic building
  - Central boiler/chiller
    - Two 225-ton chillers
    - Two 3,322-MBH boilers
  - Three-way mixing valve
  - Heating/cooling modes
    - Change-over valves
    - Chilled water @ 45°F
    - Hot water @ 180°F
  - Supplies unit ventilators and building AHUs

Existing Mechanical Systems

- **DX/Natural Gas Air Handling Units**
  - Serve athletic building
  - Constant Air Volume (CAV)
  - Single-zone
  - Refrigerant cooling
  - Natural gas heating
  - Interior mounted units
  - Traditional duct system
  - Seven units considered for replacement

Existing Mechanical Systems

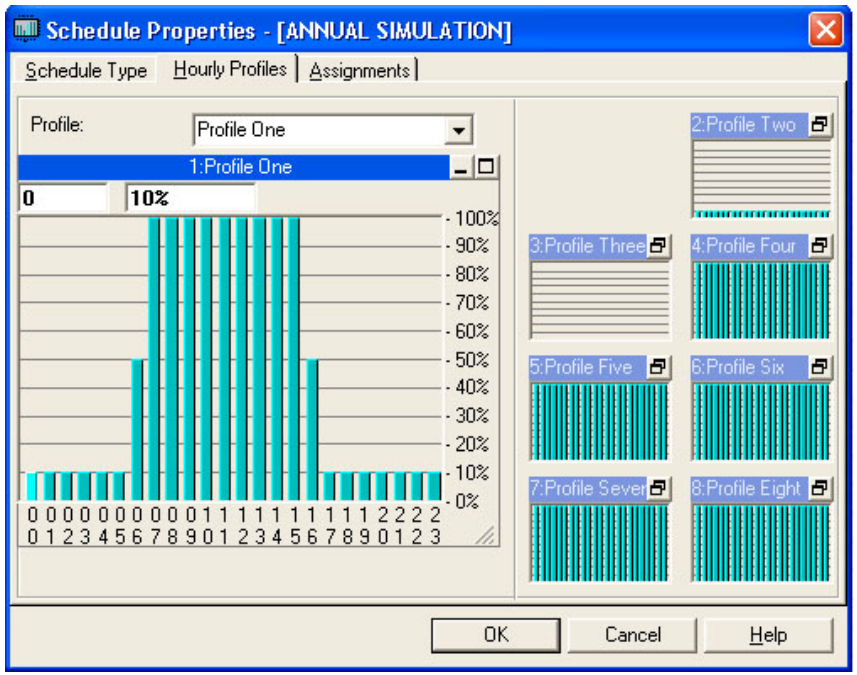
Athletic Building Equipment Schedule								
Mark	Total CFM	Min. O.A. CFM	Cooling (DX)			Heating (Gas)		
			MBH	EAT	LAT	MBH	EAT	LAT
AHU A-1	7400	3875	306.3	82.3	55	560	35.3	100
AHU A-2	7400	3875	306.3	82.3	55	560	35.3	100
AHU A-3	3200	1440	122.6	81.1	55	200	40.5	100
AHU A-4	3200	1440	122.6	81.1	55	200	40.5	100
AHU A-5	13150	1500	378.5	76.6	55	560	63.8	100
AHU A-6	2250	1475	102.7	84.2	55	200	27	100
AHU A-7	3650	1040	122	79	55	200	51.5	100

- Scope reduced to consider replacement of single-zone CAV air handling units in the athletic building
- System modeled for basis of comparison
- Design aides (HAP)
  - Assumptions
  - Requirements

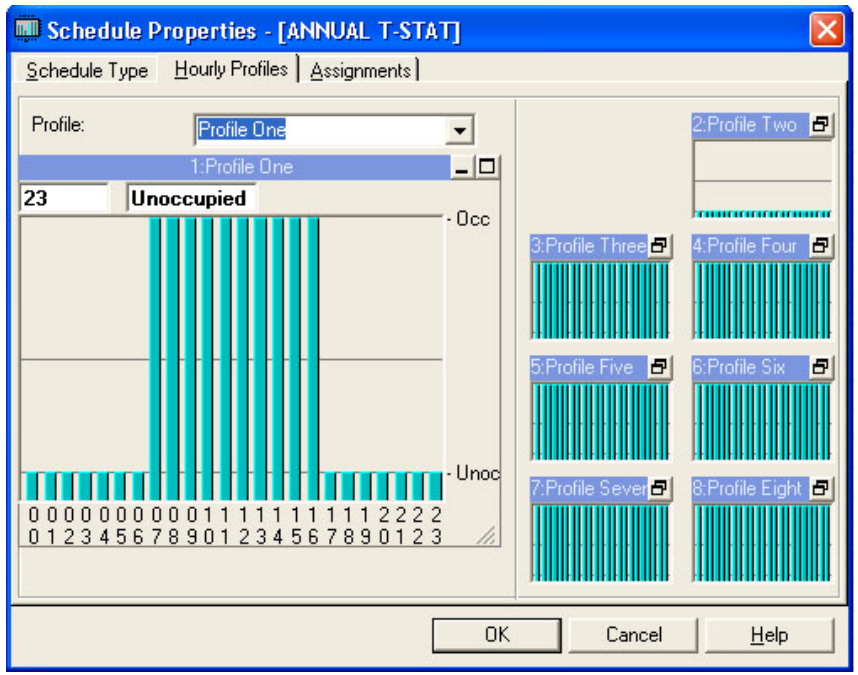
Modeling the Existing System

- **Design Tools**
  - Carrier's Hourly Analysis Program
- **Assumptions**
  - No loading June-August (building unoccupied)
  - Reduced loading on weekends and holidays
  - Each AHU modeled as its own system
  - Include lights (depth study)
- **Requirements**
  - Local utility rates
    - Dominion Peoples (natural gas)
    - PENELEC (electricity)
  - Separate occupancy and thermostat schedules

Modeling the Existing System

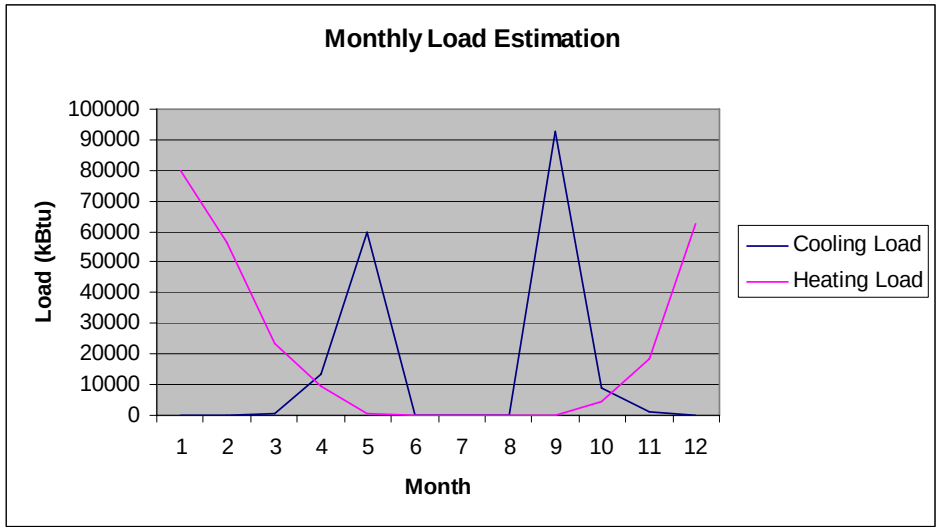


Typical daily occupancy schedule



Typical daily thermostat schedule

Modeling the Existing System



Estimated Annual Energy Consumption	
HVAC Components	
Electric	60,490 kWh
Natural Gas	3,190 Therms
Non-HVAC Components	
Electric	88,310 kWh
Totals	
Electric	**148,800 kWh**
Natural Gas	**3,190 Therms**

Modeling the Existing System

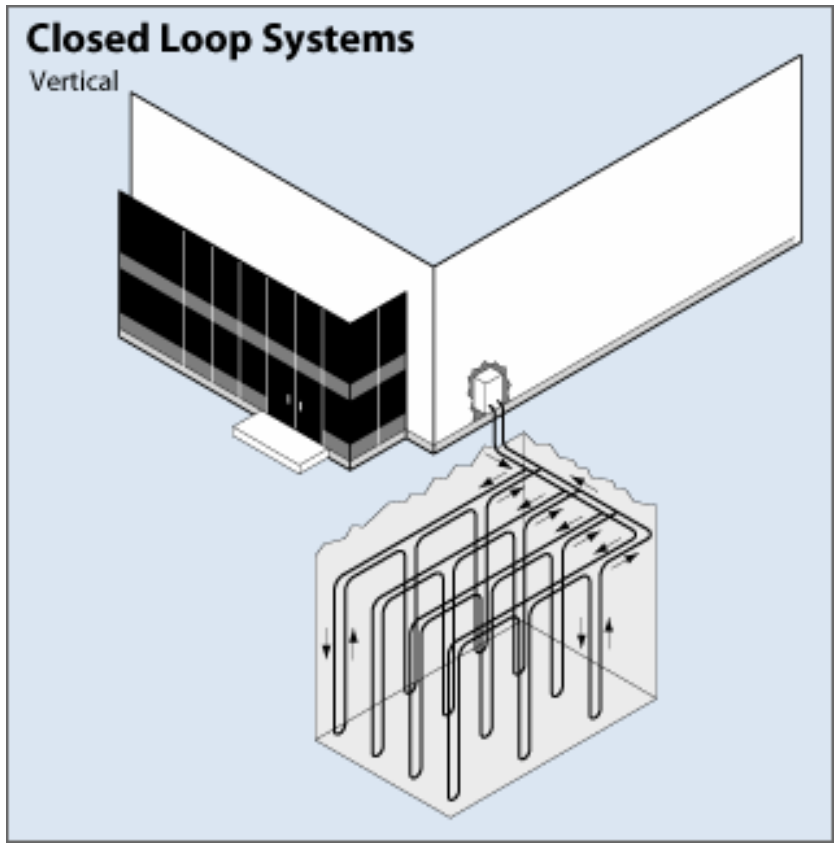
Estimated Annual Energy Costs	
HVAC Components	
Cooling	$7,420
Heating	$12,970
Subtotal	**$20,390**
Non-HVAC Components	
Lights	$11,620
Subtotal	**$11,620**
Totals	
Grand Total	**$32,010**

- **In Summary,**
  - Systems consume:
    - 148,800 kWh electricity
    - 3,190 Therms natural gas
  - Annual Operation:
    - $32,010/year (does not include maintenance costs)

Ground Source Heat Pump Redesign Project

Ground Source Heat Pump Redesign Project
Introduction

- Ground Source Heat Pump (GSHP) system
  - Closed-loop system
  - Vertical bore holes
  - Components
- Advantages
  - Thermal comfort
  - Quiet
  - Humidity control
  - Low maintenance
- Disadvantages
  - High first cost
  - Installation



Ground Source Heat Pump Redesign Project
Initial Considerations

Loop Field Site Selection

- Parking lots considered – why?
- Adjacent school building (RJHS) to be demolished
  - Offers 112,600 sq. ft. of unoccupied land
  - Will be replaced by new soccer field
  - Unique construction phasing challenges (not considered)

Ground Source Heat Pump Redesign Project
Initial Considerations

- Loading
  - Use simulation values
  - Keep same zone configuration
  - Consider increased load from daylighting

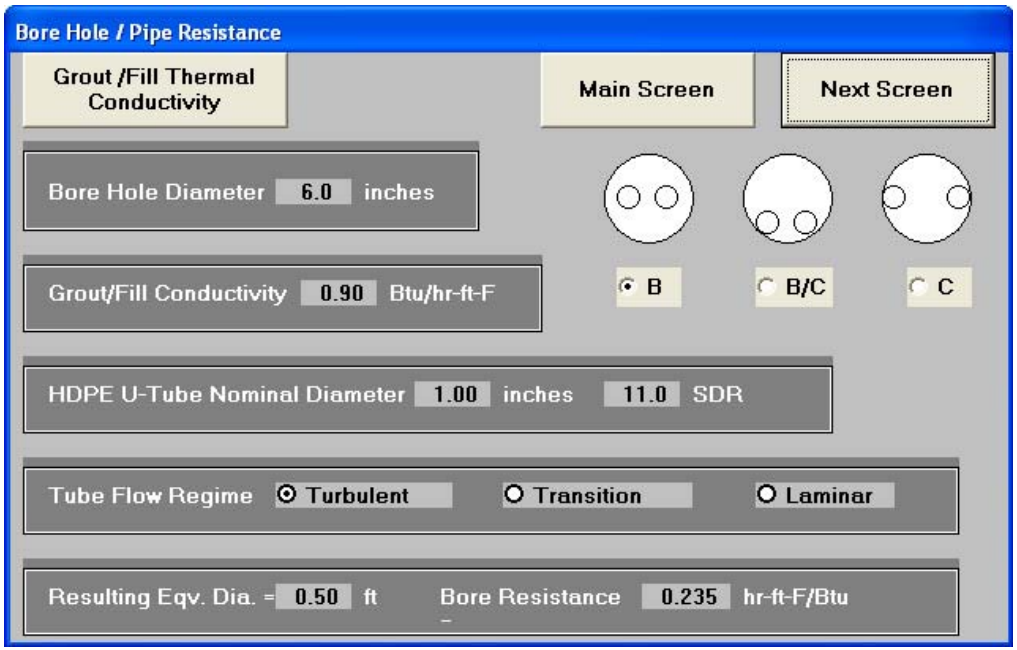
Athletic Building Design Loads				
Zone	**Space**	**Area**	**Cooling**	**Heating**
1	Gym #1	11,200 ft^2	340.3 MBH	394.8 MBH
2	Gym #1	11,200 ft^2	340.3 MBH	394.8 MBH
3	Gym #2	7,420 ft^2	164.5 MBH	155.1 MBH
4	Gym #2	7,420 ft^2	164.5 MBH	155.1 MBH
5	Concourse	4,280 ft^2	249.6 MBH	144.3 MBH
6	Locker Rooms	3,550 ft^2	37.1 MBH	23.1 MBH
7	Fitness Rooms	7,250 ft^2	153.7 MBH	120.9 MBH

Ground Source Heat Pump Redesign Project
Initial Considerations

- **Design Tools**
  - GCHPCalc (for design)
  - RETScreen International (for simulation)
- **Assumptions**
  - Same occupancy schedule
  - Soil conductivity = 1.20 Btu/hr-ft-°F
    - Program default
    - Field measurement is best – cost estimated in simulation
  - New system utilizes existing ductwork and mechanical rooms
    - In reality, new configuration needed (not designed)
    - No cost difference considered
  - Buying multiple heat pumps of same size = money savings
    - Used as design parameter
    - Figures based off of Trane high-efficiency WSHPs

Ground Source Heat Pump Redesign Project
Initial Considerations

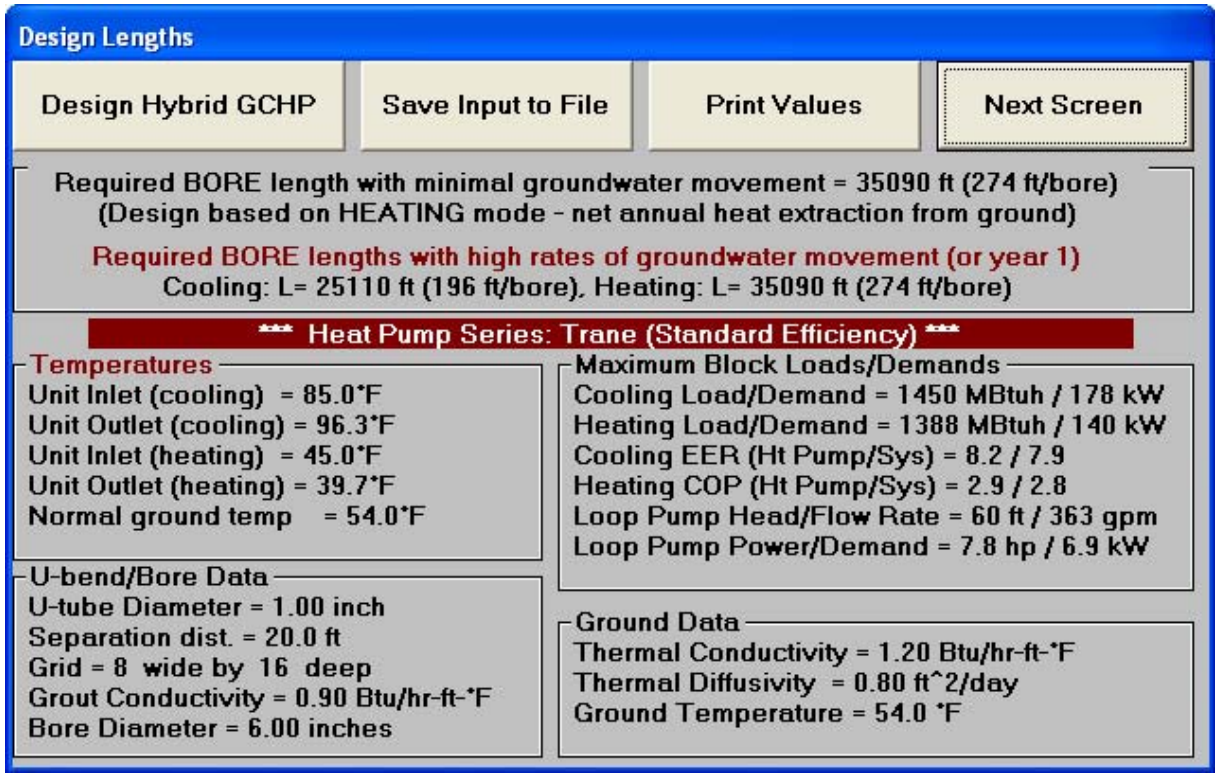
- **Selected Parameters**
  - Inlet loop water cooling @ 85°F
  - Inlet loop water heating @ 45°F
  - 3 GPM/ton water loop flow
  - Undisturbed ground temp. = 54°F (from USGS)



Ground Source Heat Pump Redesign Project
Loop Field Configuration

- 8x16 bore grid arrangement (128 total)
  - 8 bores/parallel loop
  - 20ft. separation distance between bores
- Vault placement/building entry
- Vertical depth determined by GCHPcalc program

Ground Source Heat Pump Redesign Project
Required Bore Length



- Total bore length = 35,090 ft (274 ft/bore)

Ground Source Heat Pump Redesign Project
Equipment Selection

- **Program Outputs**
  - Based on Trane high-efficiency GEV commercial series water-source heat pumps (WSHPs)
  - Zones 1 and 2
    - Six 12.5-ton units
  - Zones 3 and 4
    - Two 12.5-ton units
  - Zone 5
    - Two 12.5-ton units
  - Zone 6
    - One 6-ton unit
  - Zone 7
    - One 12.5-ton unit

Ground Source Heat Pump Redesign Project
Cost and Energy Usage

- **RETScreen International**
  - GSHP modeling software
  - Estimated cooling and heating
- **Local climate data used**
- **No natural gas figure**
  - System is all electric
- **No lights**
  - Will be considered later in the presentation
- **153,000 kWh total**
  - Basis for system comparison

Total Estimated Energy Consumption	
Cooling	87,000 kWh
Heating	66,000 kWh
Total	153,000 kWh

Ground Source Heat Pump Redesign Project
Cost and Energy Usage

Total Estimated Initial Costs		
Feasibility Study	$	2,500
Development	$	1,935
Engineering	$	1,625
Equipment	$	114,986
System Balance	$	11,080
Miscellaneous	$	20,946
Total	$	153,072

Total Estimated Annual Costs		
Operation and Maintenance	$	5,606
Fuel and Electricity	$	10,457
Total	$	16,063

- Initial costs estimated at $153,072
- Annual costs estimated at $16,063/year
- Values used for comparison

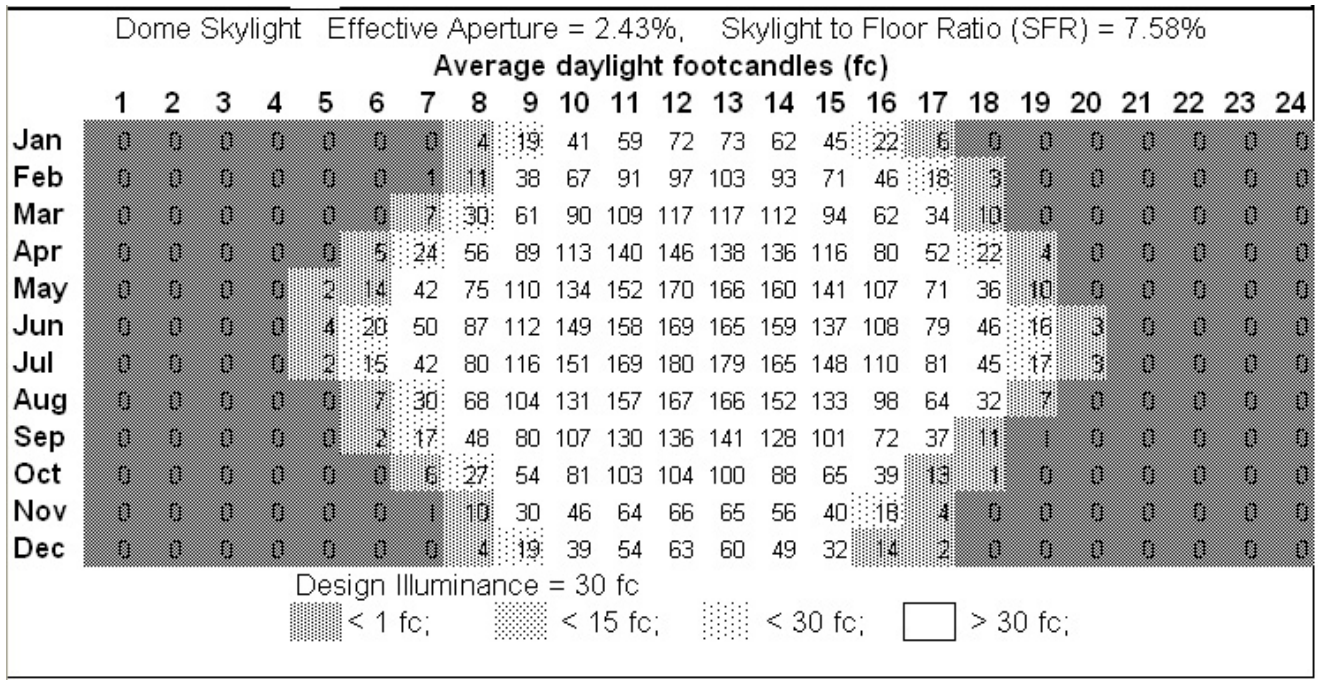
Gymnasium Daylighting System

Gymnasium Daylighting System

- Used to *enhance* existing lighting system in gymnasiums
  - Assumes existing system is adequate
- Reduce energy consumption and cost
- SolaTube luminaires considered
  - Too expensive
- SkyCalc software used to design/simulate skylight system
    - Weather data – Albany, NY
    - Room inputs – size, height, surface properties
    - Lighting inputs
      - 30fc lighting set point
      - 0ft. Task height
- AGI software used to visualize spaces

Gymnasium Daylighting System

- **Gymnasium #1 (22,400 sq. ft.)**
  - Thirty 6x8-ft. skylights selected
  - Polycarbonate, triple-glazed



Dome Skylight Effective Aperture = 2.43%, Skylight to Floor Ratio (SFR) = 7.58%

Average daylight footcandles (fc)

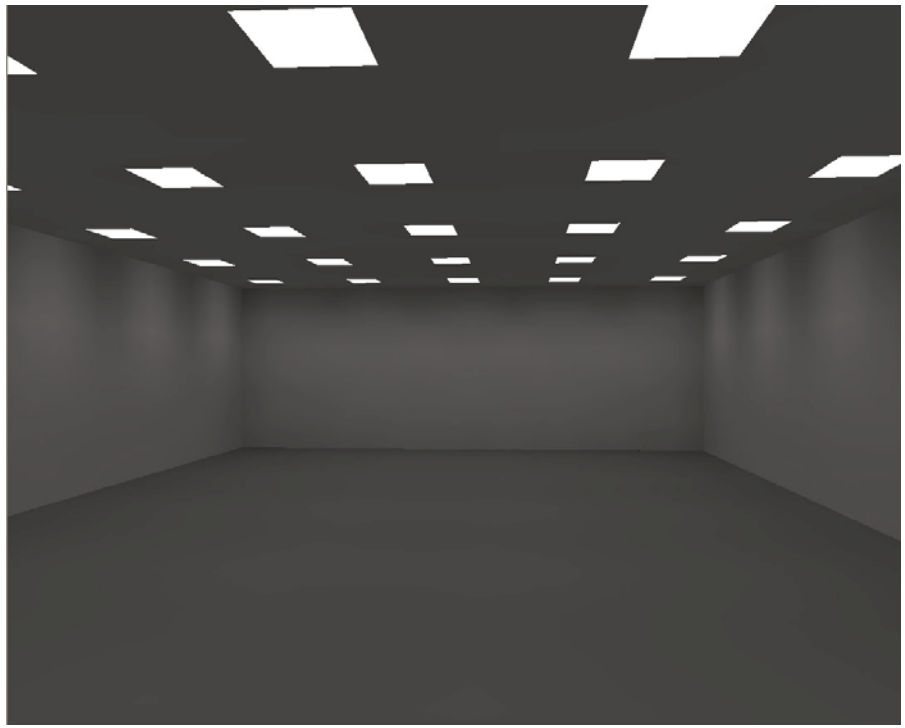
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	4	19	41	59	72	73	62	45	22	6	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	1	11	38	67	91	97	103	93	71	46	18	3	0	0	0	0	0	0
Mar	0	0	0	0	0	0	7	30	61	90	109	117	117	112	94	62	34	10	0	0	0	0	0	0
Apr	0	0	0	0	0	5	24	56	89	113	140	146	138	136	116	80	52	22	4	0	0	0	0	0
May	0	0	0	0	2	14	42	75	110	134	152	170	166	160	141	107	71	36	10	0	0	0	0	0
Jun	0	0	0	0	4	20	50	87	112	149	158	169	165	159	137	108	79	46	16	3	0	0	0	0
Jul	0	0	0	0	2	15	42	80	116	151	169	180	179	165	148	110	81	45	17	3	0	0	0	0
Aug	0	0	0	0	0	7	30	68	104	131	157	167	166	152	133	98	64	32	7	0	0	0	0	0
Sep	0	0	0	0	0	2	17	48	80	107	130	136	141	128	101	72	37	11	1	0	0	0	0	0
Oct	0	0	0	0	0	0	6	27	54	81	103	104	100	88	65	39	13	1	0	0	0	0	0	0
Nov	0	0	0	0	0	0	1	10	30	46	64	66	65	56	40	18	4	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	4	19	39	54	63	60	49	32	14	2	0	0	0	0	0	0	0

Design Illuminance = 30 fc

< 1 fc; < 15 fc; < 30 fc; > 30 fc;

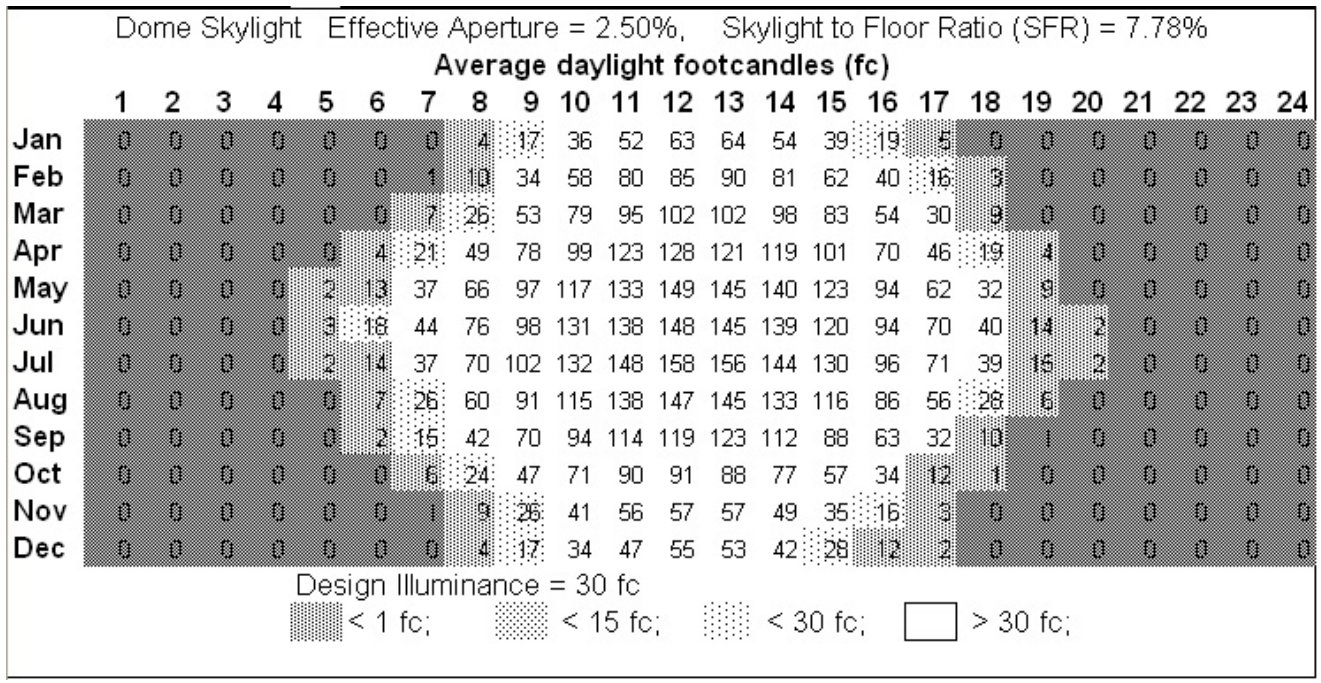
Gymnasium Daylighting System

- **Gymnasium #1 (22,400 sq. ft.)**
  - AGI visualization
  - Worst-case scenario (winter solstice)



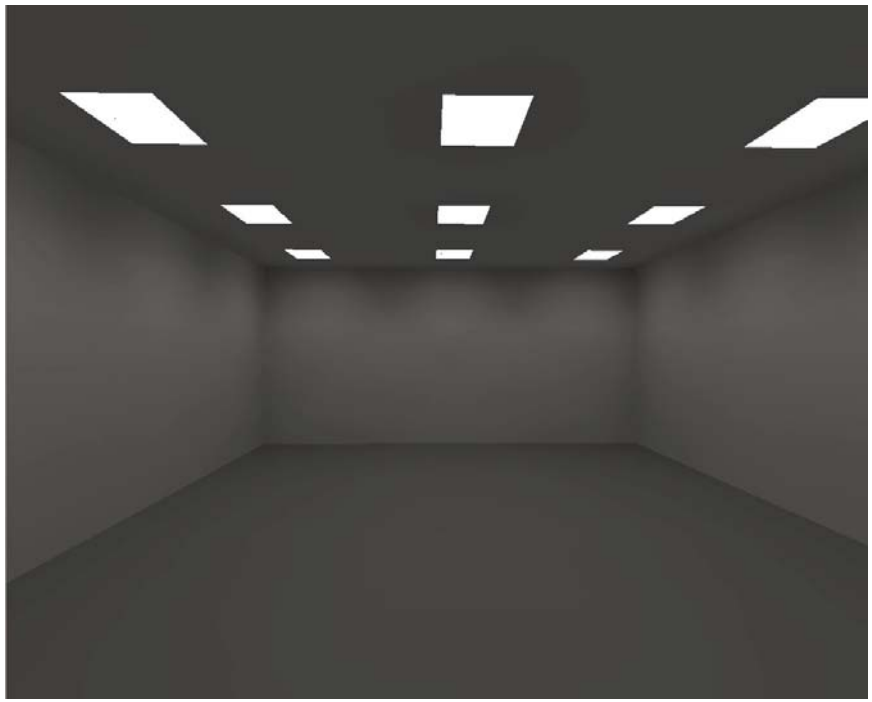
Gymnasium Daylighting System

- **Gymnasium #2 (14,840 sq. ft)**
  - Twelve 6x8-ft. skylights selected
  - Polycarbonate, triple-glazed



Gymnasium Daylighting System

- **Gymnasium #2 (14,840 sq. ft.)**
  - AGI visualization
  - Worst-case scenario (winter solstice)



Gymnasium Daylighting System

- **Results**
  - Increased thermal load (already considered)
  - Estimated energy savings
    - 42,689 kWh
  - Estimated cost savings
    - $3,842/year

Increased Loading due to Daylighting		
Space	**Cooling**	**Heating**
Gym #1	50.4 MBH	77.4 MBH
Gym #2	21.3 MBH	29.1 MBH

Estimated Annual Energy Savings	
Gymnasium #1	
Lights (kWh)	30,911
Gymnasium #2	
Lights (kWh)	11,778
Total (kWh)	42,689

Estimated Annual Cost Savings	
Gymnasium #1	
Lights	$2,782
Gymnasium #2	
Lights	$1,060
Total	$3,842

Project Summary

Project Summary

Estimated Annual Energy Consumption Comparison			
Original		**Redesign**	
Electricity	148,800 kWh	Electricity	198,620 kWh
Natural Gas	3,190 Therms	Natural Gas	0 Therms

Estimated Annual Energy Costs Comparison			
Original		**Redesign**	
Cooling	$7,420	Energy	$10,460
Heating	$12,970		
Lights	$11,620	Lights	$7,780
Total	$32,010	**Total**	$18,240

-50,000 kWh higher electricity consumption - but no natural gas!
-Reduced annual costs by $13,770

Conclusions

Conclusions

- Stated Goals
  - Successfully decreased annual energy consumption in AAJHS athletic facility
  - Reduced gymnasium lighting energy consumption by 42,690 kWh
  - Reduced annual energy costs by $13,770
  - Presented GSHP system as a feasible and responsible design alternative
  - Presented gymnasium daylighting as a feasible and energy-saving design enhancement

Acknowledgements and References

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- My family
- My friends

- GSHP Design
  - www.geokiss.com
- International GSHP Assn.
  - www.igshpa.okstate.edu
- RETScreen International
  - www.retscreen.net
- Trane Commercial Air Sol'ns
  - www.trane.com
- US Dept. of Energy
  - www.energy.gov

Questions?