APRIL 15, 2009

the regional learning alliance
At Cranberry Woods.

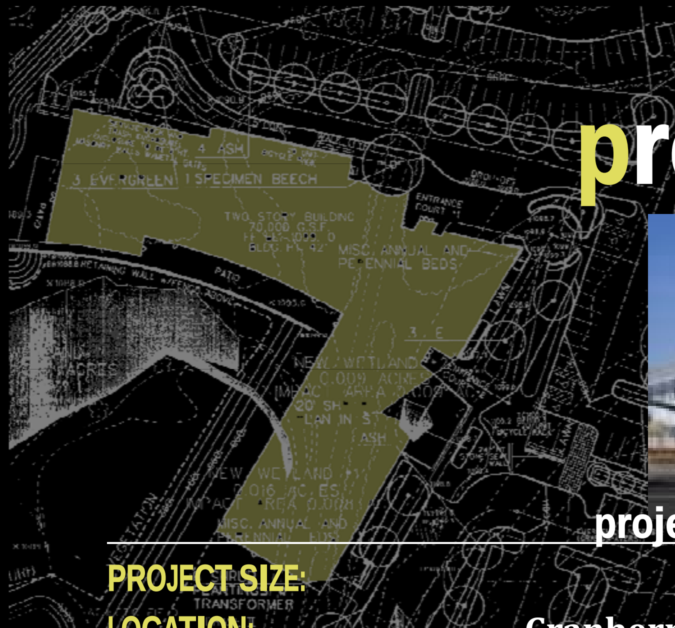
CAITLIN HANZEL

MECHANICAL OPTION

THE PENNSYLVANIA STATE UNIVERSITY

THE DEPARTMENT OF ARCHITECTURAL ENGINEERING

ADVISOR: DR. WILLIAM BAHNFLETH, P.E.



project information

project information:

PROJECT SIZE:	76,000 SF
LOCATION:	Cranberry Township, PA
COST:	$14,290,677
STORIES:	(1) below (2) above grade
CONSTRUCTION TIME:	10/15/04-08/24/05
DELIVERY METHOD :	Design-Bid-Build

project team:

OWNER:	Regional Learning Alliance
ARCHITECT:	Renaissance 3 Architects
M E P :	Tower Engineering
STRUCTURAL:	Barber Hoffman, Inc.
G C:	Landau Building Company

LEED SILVER

INTRODUCTION

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existing mechanical system

air side:

AHU-1:

- AAON RL-075 Variable Volume air handling unit
- ***100% outdoor air*** to the building's fan-coils
- Controlled by direct digital controller & CO2 sensors.

AHU-2:

- AAON (size 18), constant volume air handling unit
- Dedicated to the conditioning and ventilation of the lobby/atrium air.

FCU'S:

- Horizontal Blower Coil Air Handler's (BCHC)

TERMINAL BOXES:

- Regulates amount of outdoor air based on occupancy sensors.

existing mechanical system

water side:

Chilled Water:

- 75-ton, LL-075 air-cooled chiller with evaporative condenser and scroll compressor
- Driven by (2) VFD pumps, (180 & 165 gpm)
- EWT: 52 F, LWT: 42 F, Delta T= 10F

Hot Water:

- **(2) high-efficiency gas-fired boilers.**
- **Designed for net output of 1402 MBH.**
- **EWT: 100F, LWT: 120 F, Delta T=20F**

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redesign concerns

- Implement a system with better *acoustics .*
  (reduce noise level from current terminal equipment)
- Reduce the *operating costs* of the facility.
- Increase *energy efficiency*
- Enhance *thermal comfort and IAQ* in office and classroom spaces.

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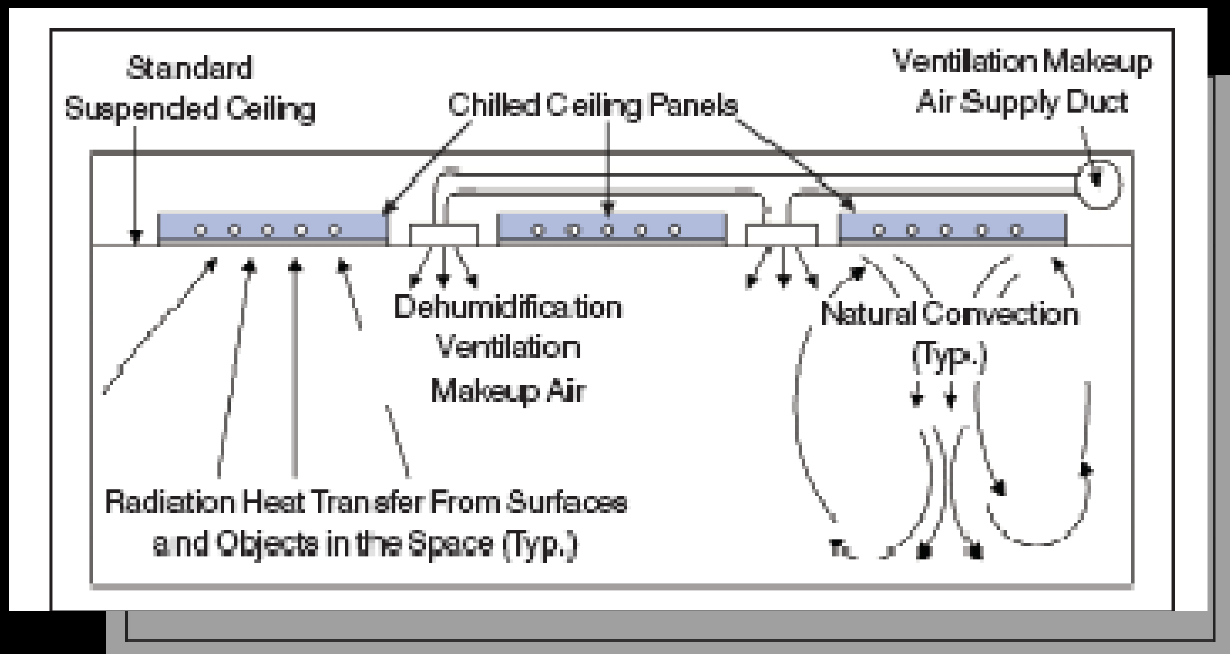
redesign proposal



► Replace fan-coil units with *Radiant Ceiling Panels* and high induction diffusers

► Redesign the DOAS for a *supply air temperature of 45 F* vs. 55F

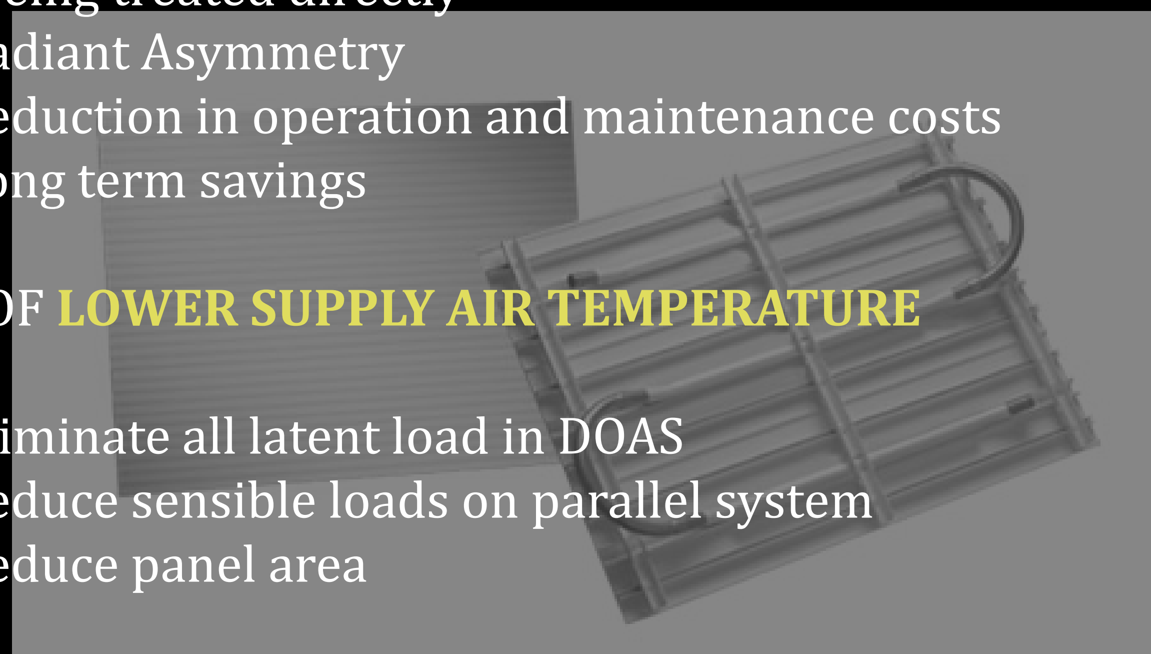
redesign proposal

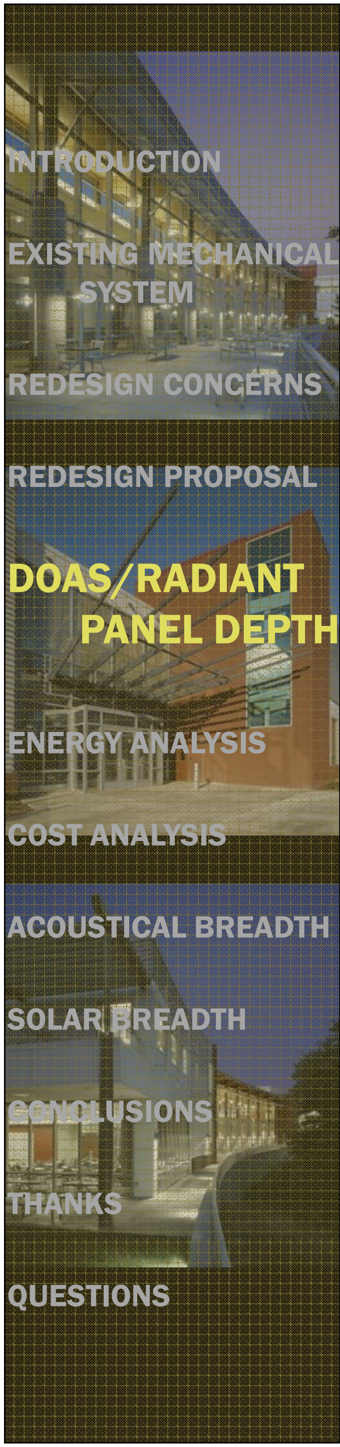
▶ BENEFITS OF **RADIANT CEILING PANELS**

1. Ability to alter acoustical performance
2. Enhanced comfort levels due to radiant loads being treated directly
3. Radiant Asymmetry
4. Reduction in operation and maintenance costs
5. Long term savings

▶ BENEFITS OF **LOWER SUPPLY AIR TEMPERATURE**

1. Eliminate all latent load in DOAS
2. Reduce sensible loads on parallel system
3. Reduce panel area





doas/radiant panel depth

▶ **Step 1:** Determine outdoor air conditions (**WB/MCDB:74.9/85.0 F)**

▶ **Step 2:** Determine target space conditions

ENTITY	VALUES
Radiant Panel Surface	62 F
Room Set Thermostat	79 F
Corresponding Room Dew Point	58.6 F
Humidity Ratio	73.8 gr/lb=10.54 g/kg
Room Relative Humidity	50%

▶ **Step 3:** Determine: a.) required ventilation rates (**20,221 CFM of OA**)
b.) design cooling loads (TRACE)

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doas/radiant panel depth

▶ **Step 4:** Determine supply air conditions (**45F**)

EQN 1: $Wsa = Wsp - Q_L/(0.68\ Vsa)$

Wsa- SA humidity ratio (gr/lb)
Wsp=target space humidity ratio (gr/lb)
QL =space latent load (Btu/hr)
Vsa= space SA flow rate (cfm)

▶ **Step 5:** Determine sensible cooling loads required by the panels

EQN 2: $Qsa = 1.08\ Vsa\ (Tsp - Tsa)$

Qsa= SA cooling capacity (Btu/h)
Vsa= SA flow rate in each space (OA cfm)
Tsp= Space dry-bulb temperature (79 F)
Tsa= SA dry-bulb temperature (45 F)

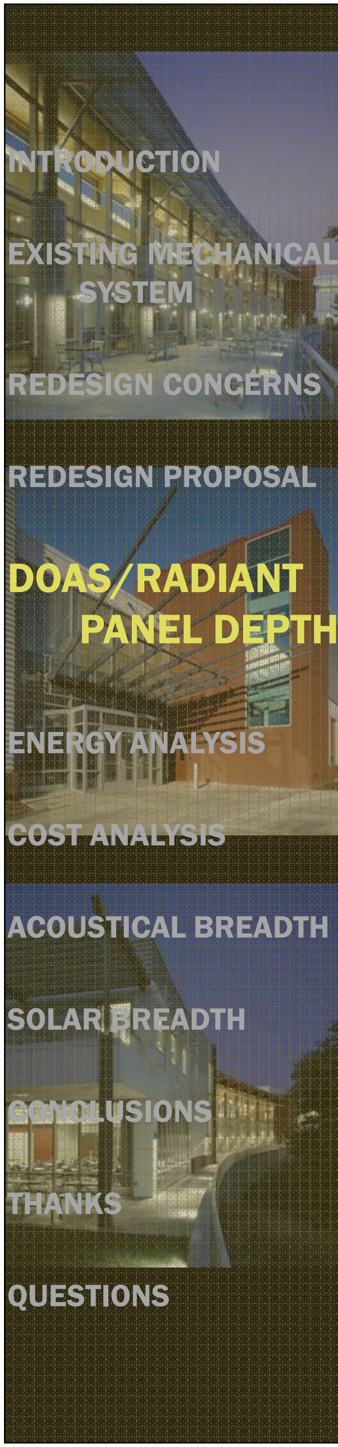
doas/radiant panel depth

- **Step 6:** Determine design panel cooling capacity (**30-52 Btuh/sf**)
- **Step 7:** Determine required panel area

EQN 3: Ap=Qsp/Qp

Ap= Radiant panel area required (ft2)
Qsp=Space sensible cooling load required from panel (Btu/h)
Qp= Cooling capacity of panel (Btu/hft2)

- **Step 8:** Determine heating (4-pipe) adjustments



doas/radiant panel depth

► RESULTS:

Total Panel Area	**7436 sf (30%)**
Average Area of Ceiling (per room) Dedicated to Radiant Panels (%)	**38%**
Number of Rooms Not Requiring Panels	**13**
Number of RoomsNot Able To Meet Area Requirements	**2**
Number of Interior Rooms (theoretically) Not Needing Heating	**11**

► Rooms not requiring panels were typically large discussion/lecture classrooms or conference space

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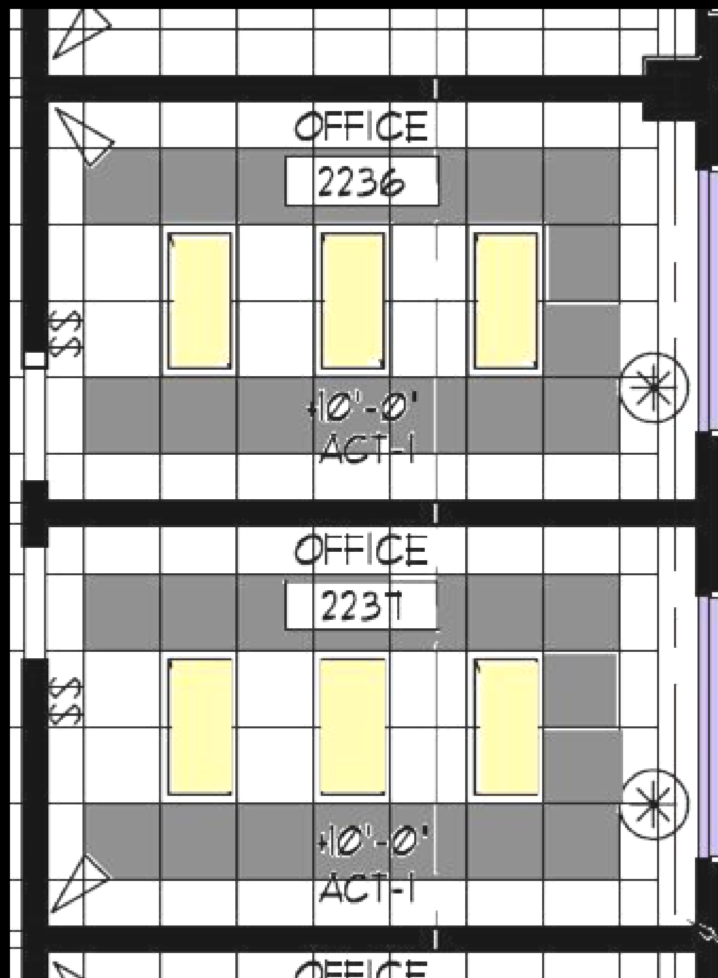
doas/radiant panel depth

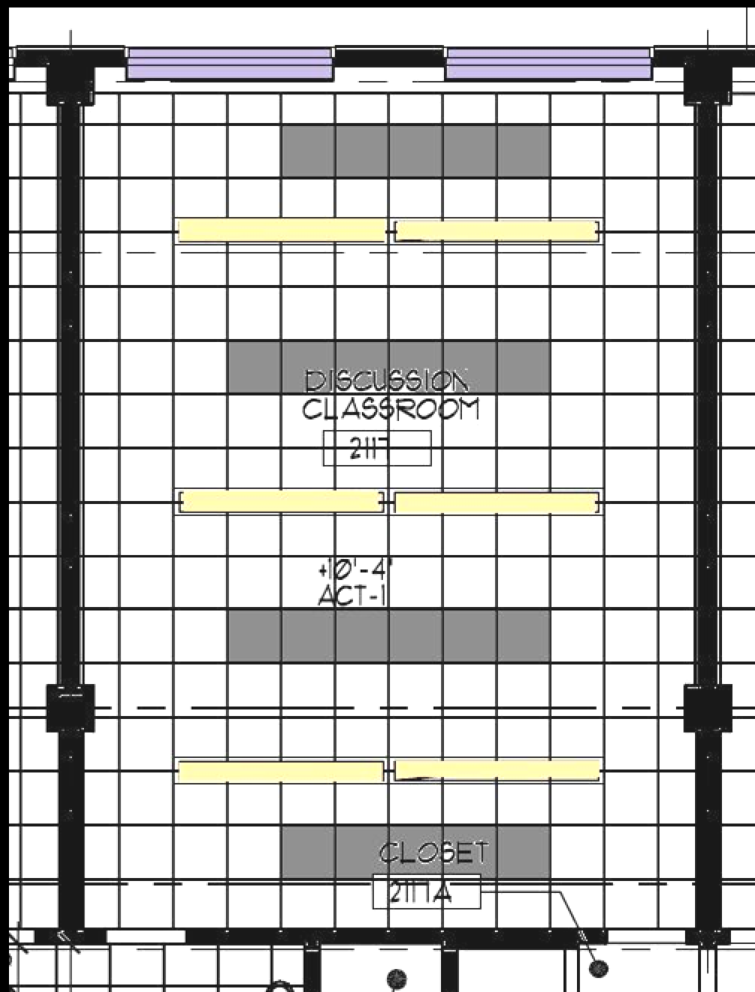


Typical Tenant Office:

- 178 square feet
- 64 SF of radiant paneling required (16, 2x2 tiles)

- 36% Radiant Panels
- 27% Lighting Fixtures
- 37% ACT

doas/radiant panel depth



Typical Lecture Classroom:

- 707 square feet
- 88 SF of radiant paneling required (22, 2x2 tiles)

- 15% Radiant Panels
- 7% Lighting Fixtures
- 78% ACT

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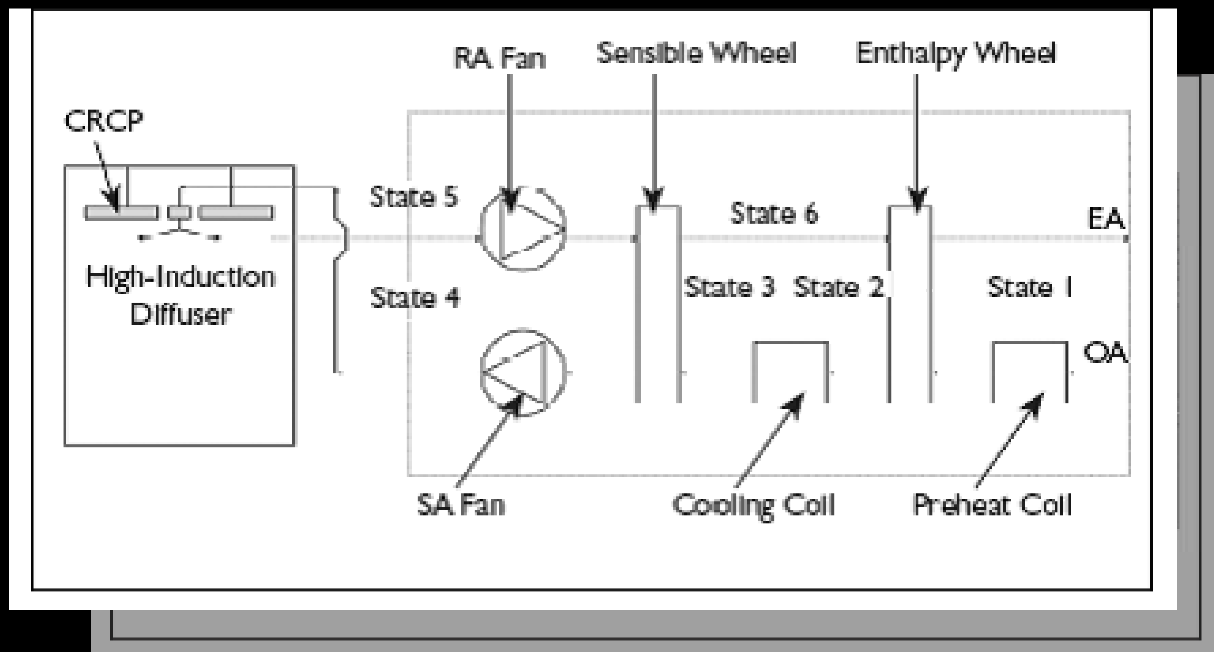
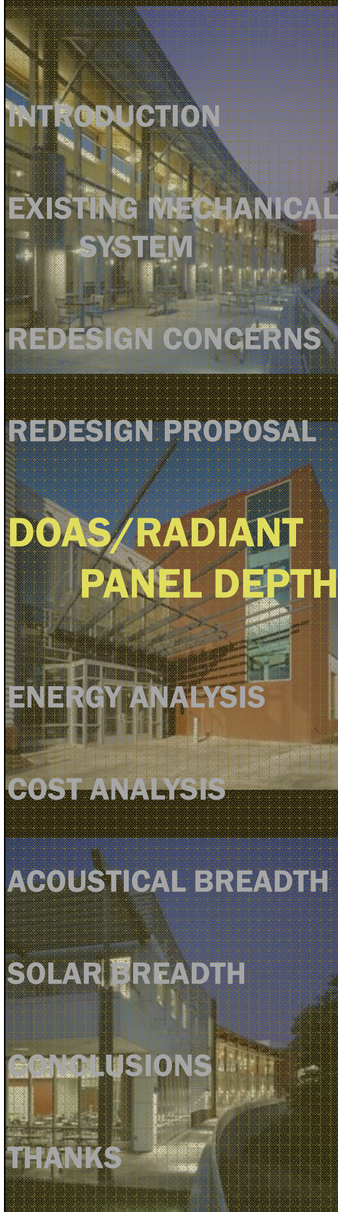
doas/radiant panel depth



State 1: *Outdoor Air*-- 74.9 WB/85.0 DB
State 2: *Preconditioned Air*-- 79.5F, 31.8 Btu/lb
State 3 & 4: *Supply Air*-- 45F DB, 17.5 Btu/lb
State 5 & 6: *Return Air*-- 79F DB, 50% RH



doas/radiant panel depth

EQN 4: Qcc = 0.06 p Vsa,tot (h2-h3)

Qcc= cooling coil load (kBtu/hr)
p= average supply air density (lb/ft3)
Vsa,tot= total air supply quantity (cfm)
h2 and h3= SA enthalpy at states 2 and 3 (Btu/lb)

SUPPLY AIR TEMP (F)	COOLING COIL LOAD (kBTU/HR)	COOLING COIL LOAD (tons)
55	1,146	96
45	1,255	105
DIFFERENCE:	109	9

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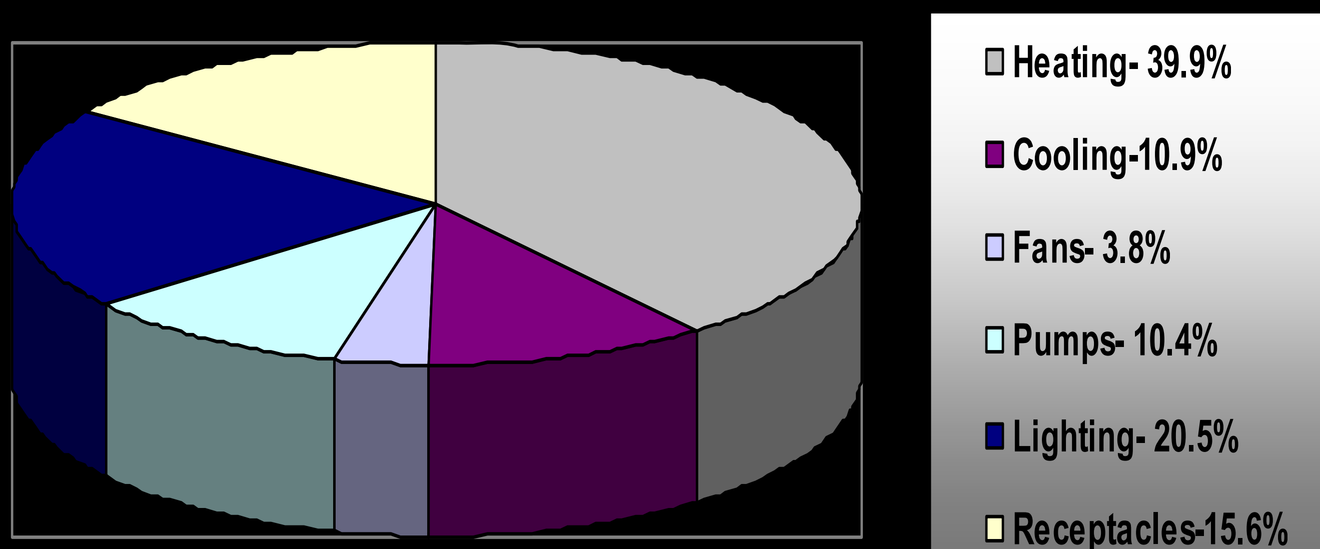
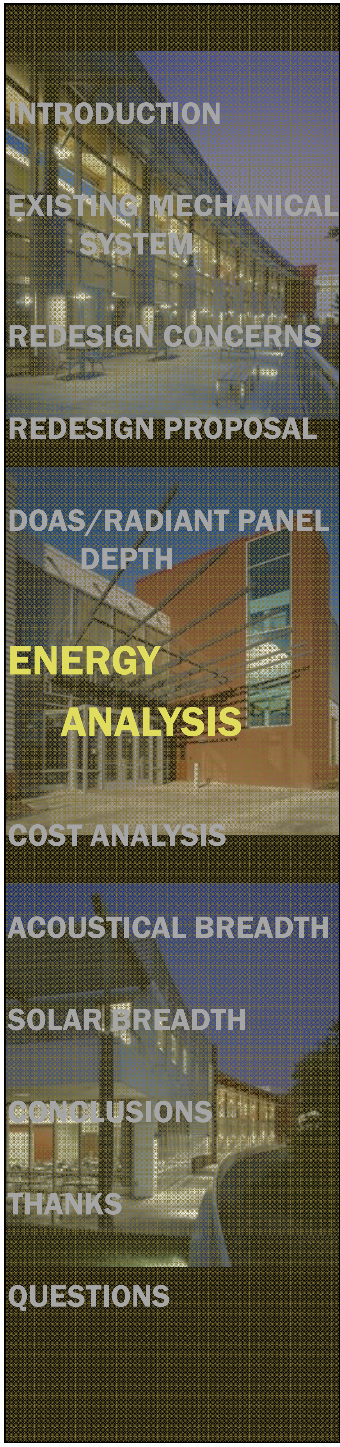
energy analysis

energy consumption by building component :

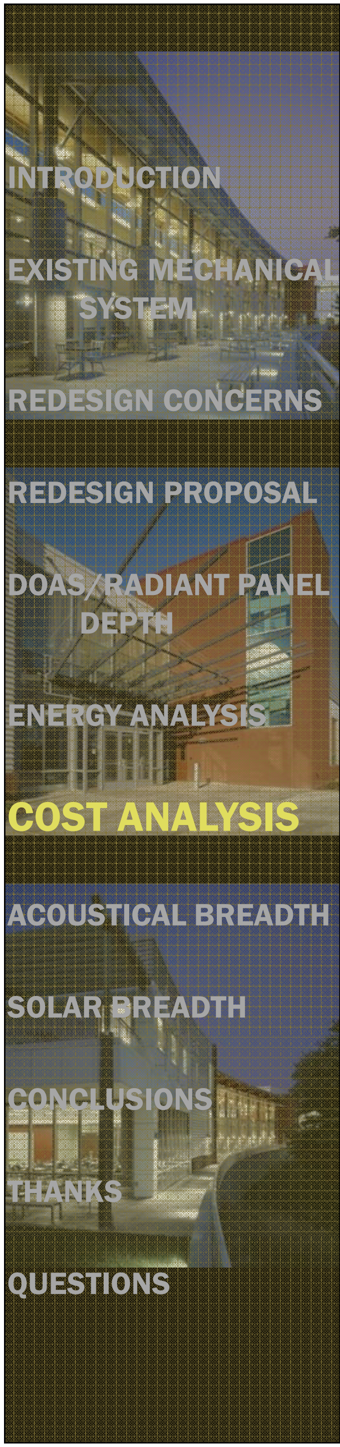




energy analysis

energy consumption & operating cost comparison:

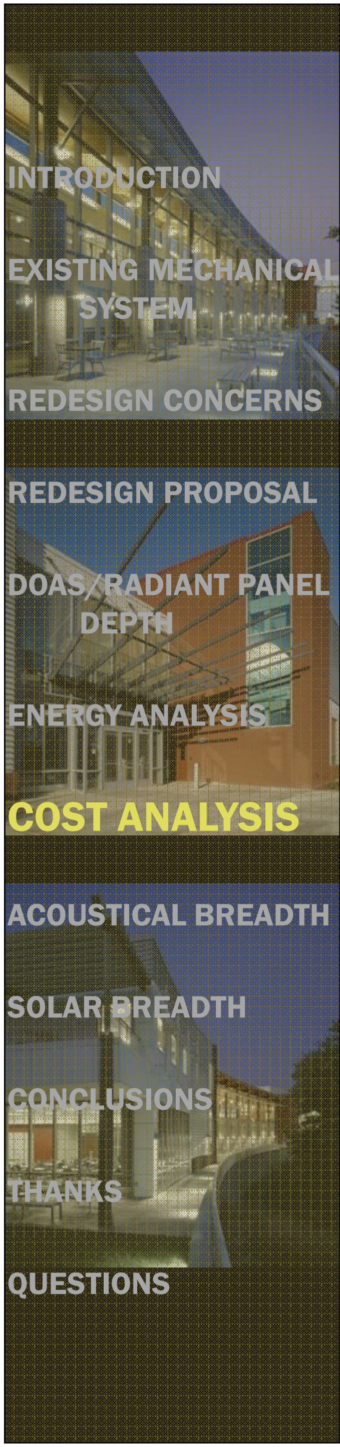
SOURCE	ORIGINAL FAN COIL DESIGN	TOWER	RADIANT CEILING PANEL DESIGN	
	Total Energy (kwH/yr)	% of Total Energy	Total Energy (kwH/yr)	% of Total Energy
Heating	571,237	40.5	498,297	39.9
Cooling	198,875	14.1	136,126	10.9
Fans	211,569	15	47,457	3.8
Pumps	45,840	3.25	129,882	10.4
Lighting	271,091	19.22	256,017	20.5
Receptacles	114,247	8.1	194,823	15.6
TOTAL ENERGY CONSUMPTION (kwH):	1,410,460	100	1,248,864	100
TOTAL COST PER YEAR:	$115,687.00		$102,842.00	



initial cost analysis

existing system initial cost :

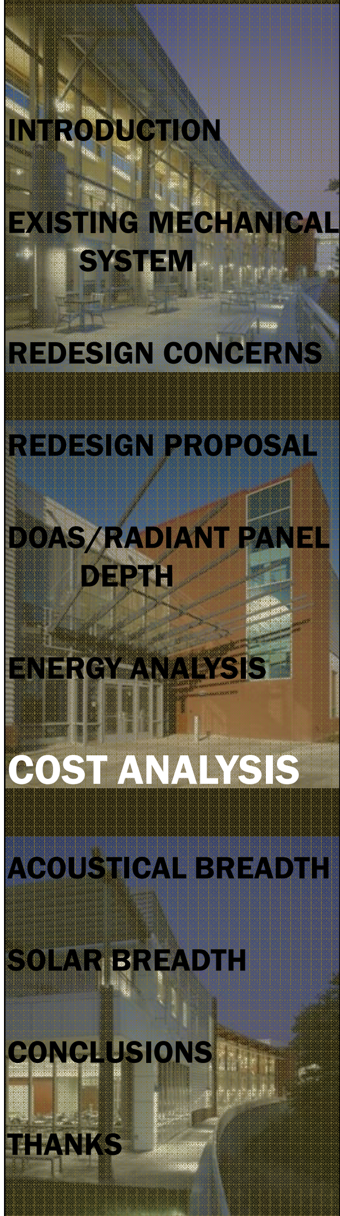
MECHANICAL SYSTEM COMPONENT	QUANTITY	COST PER QUANTITY ($)	TOTAL COST ($)
Trane Fan Coil Units			
BCHC012	1	1470	1470
BCHC018	3	1635	4905
BCHC024	19	1885	35815
BCHC036	14	2145	30030
BCHC054	5	2495	12475
BCHC072	1	2760	2760
BCHC090	5	3195	15975
E.H. Price Terminal Box Units	49	average $500	24500
AAON LL-075 Chiller	1	65000	65000
Lochinvar Boiler	2	6250	12500
AHU-1			
AAON Outdoor Air Handler RL-075	1	50000	50000
AHU-2			
AAON M2 18 Indoor Air Handler	1	18000	18000
E.H. Price Diffusers	303	Varies	28508
TOTALS:			**301938**



initial cost analysis

proposed system initial cost :

MECHANICAL SYSTEM COMPONENT	QUANTITY	COST PER QUANTITY ($)	TOTAL COST ($)
Fan Coil Units			
BCHC024	1	1885	1885
BCHC090	2	3195	6390
Radiant Panels (4-pipe)	7426 sf	$19/sf + heating adjustments	138985
E.H. Price Terminal Box Units	12	average $500	6000
AAON LL-075 Chiller	1	65000	65000
Lochinvar Boiler	2	6250	12500
AHU-1			
AAON Outdoor Air Handler RL-100	1	67000	67000
AHU-2			
AAON M2 18 Indoor Air Handler	1	18000	18000
High Induction Diffusers	303	100	30300
TOTALS:			**346060**



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initial cost analysis

proposed system initial cost :

- ► Estimated increase in chiller size: $1,000/ton

- ► Additional $25,000 increase

EQN 5: Q=1.08(CFM)(Tew-Tsupp)

Q= Required Cooling Load(BTU/hr))
CFM=20,221 CFm of OA
QL =space latent load (Btu/hr)
Vsa= space SA flow rate (cfm)

- ► Proposed design initial cost now estimated at $371,060, which is $69,122 more than the existing system

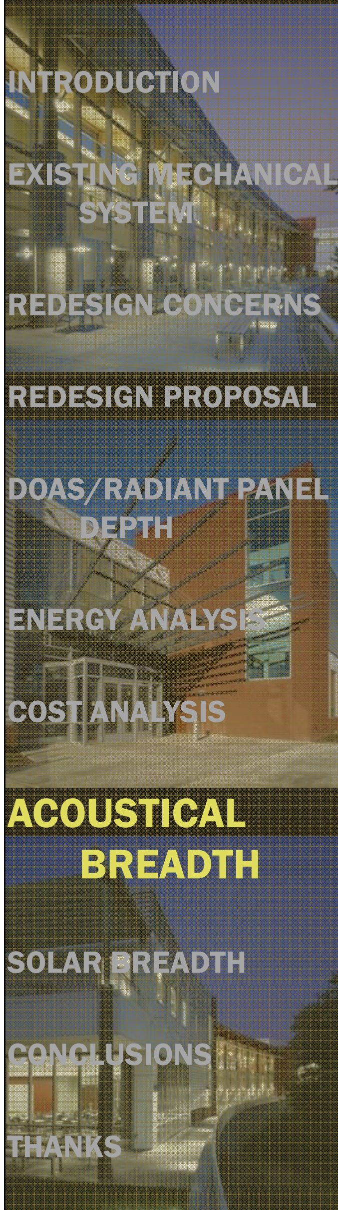
estimated payback period

$12,800 savings per year

$44,122 initial cost increase

$0.58 / square foot increase

[[potential payback of 4.5 YEARS]]



acoustical breadth

1. fan coil unit analysis

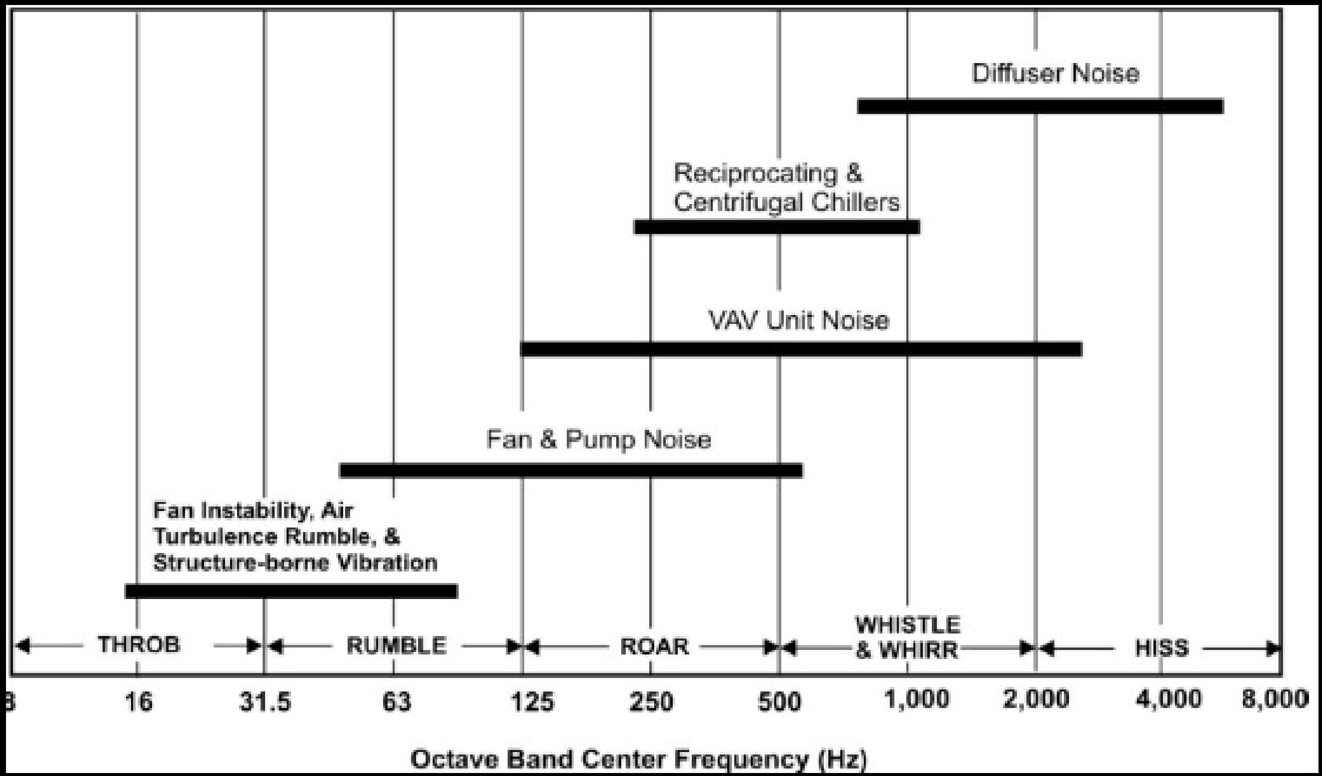
Determine whether or not the tenants were correct in stating that the existing fan coil units are acoustically unacceptable.

2. reverberation time analysis

Analyze the impact the radiant ceiling panels have on the discussion classroom reverberation time.

acoustical breadth

fan coil unit analysis

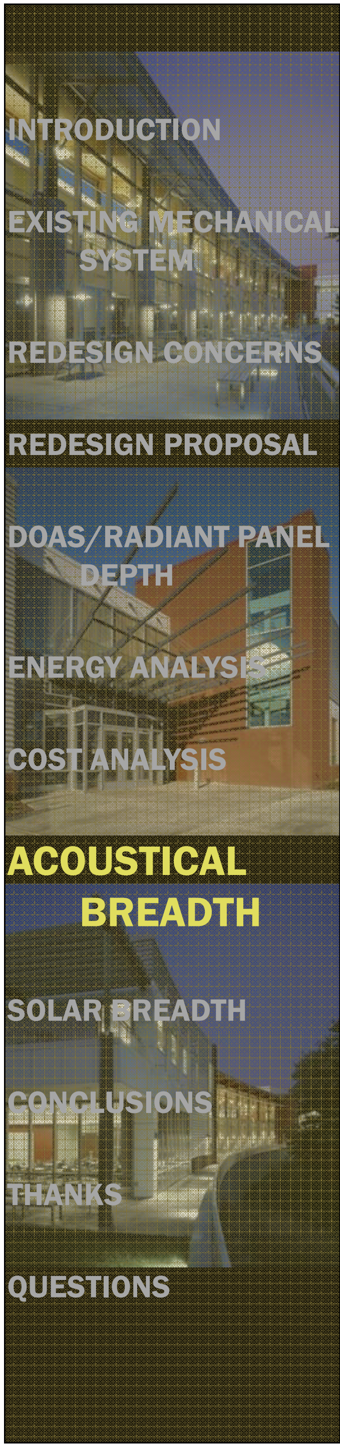


acoustical breadth

fan coil unit analysis

► HVAC equipment noise in lecture halls & offices should be limited to no more than an **NC rating of 30-35** ; equivalent **Leq=35-40 dBA**

► **Fan coil unit in a typical office was examined**

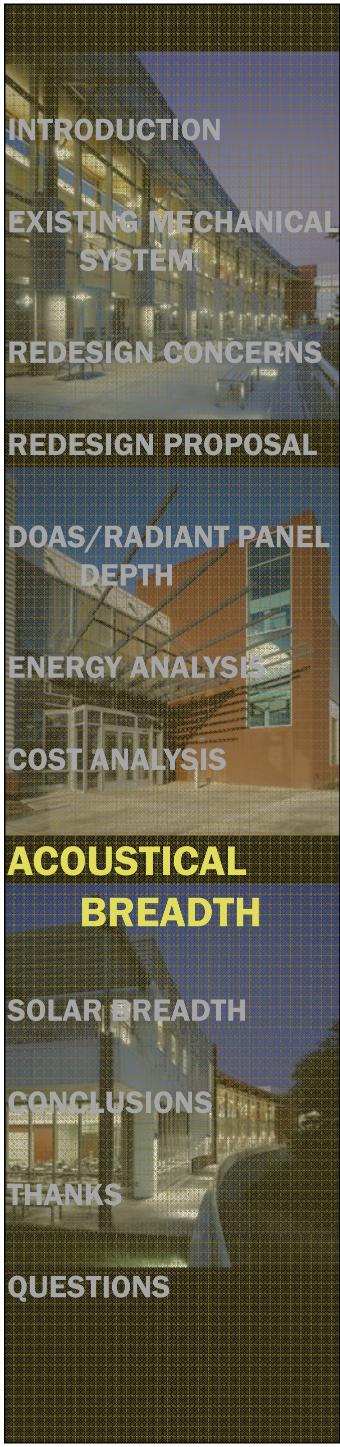


acoustical breadth

fan coil unit analysis

► **Step 1:** Calculate the discharge sound power for the fan coil unit

ROOM	AIRFLOW (cfm)	AIRFLOW (m3/s)	STATIC PRESSURE (in wg)	STATIC PRESSURE (Pa)	FAN HP	CALCULATED Lw (dB)	FAN TYPE CORRECTION FACTOR (dB)	TOTAL Lw OF FCU (dB)
2212-OFFICE	250	0.17987	0.56	139.49	0.5		Forward Curved	
63 Hz						75.44	-2	73.44
125						75.44	-6	69.44
250						75.44	-13	62.44
500						75.44	-18	57.44
1000						75.44	-19	56.44
2000						75.44	-22	53.44
4000						75.44	-25	50.44
8000						75.44	-30	45.44

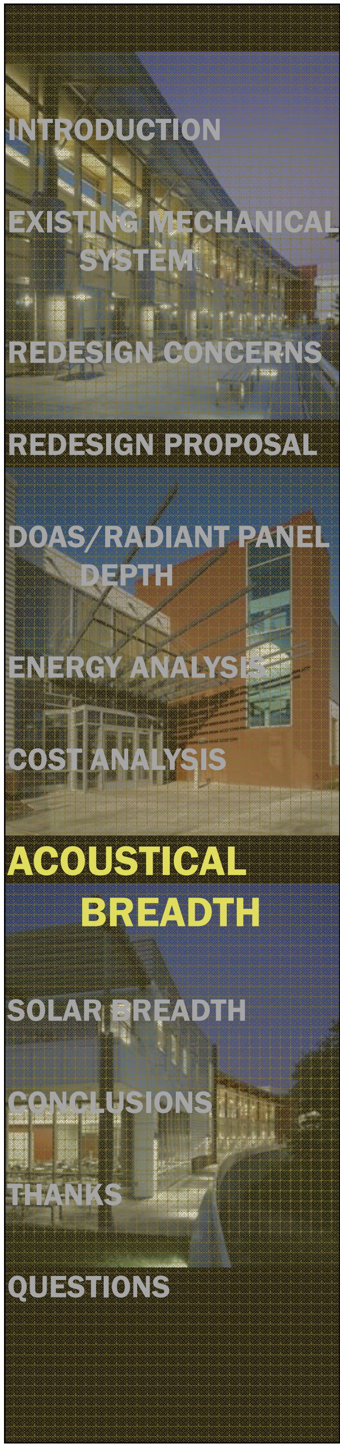


acoustical breadth

fan coil unit analysis

► **Step 2:** Calculate average sound absorption coefficient for the office

ENTITY	SURFACE AREA (sf)	SOUND ABSORPTION COEFFICIENT						
		63 Hz	**125**	**250**	**500**	**1000**	**2000**	**4000**
Walls	440	0.2	0.29	0.1	0.05	0.04	0.07	0.09
Windows	39.7	0.25	0.18	0.06	0.04	0.03	0.02	0.02
Floor (Carpet)	217	0.01	0.02	0.06	0.14	0.37	0.6	0.65
Ceiling (ACT)	217	0.4	0.58	0.59	0.69	0.86	0.84	0.75
Sα		186.90	264.95	187.43	203.70	285.70	344.07	344.19
αavg		**0.21**	**0.29**	**0.21**	**0.22**	**0.31**	**0.38**	**0.38**

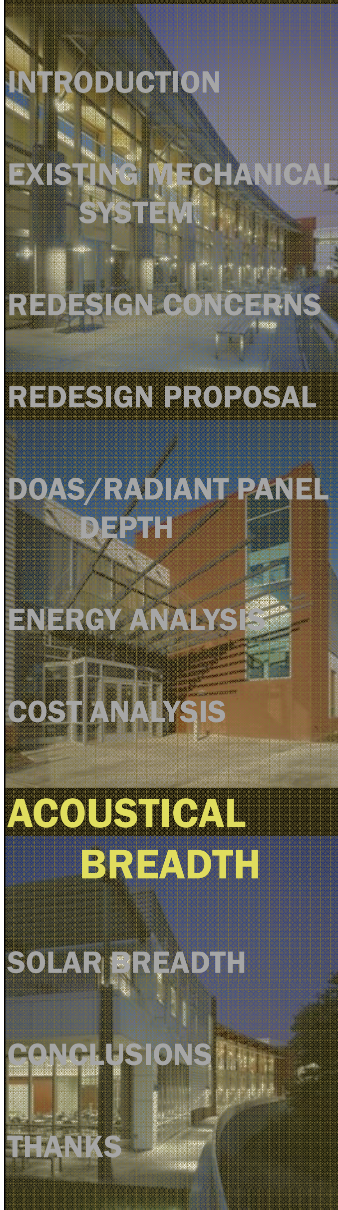


acoustical breadth

fan coil unit analysis

► **Step 3:** Calculate incident sound power on the ceiling common to the office

Frequency Band (Hz)	αavg	Lw, ceiling (dB)
63	0.21	**76.9**
125	0.29	**72.29**
250	0.21	**65.95**
500	0.22	**60.84**
1000	0.31	**59.17**
2000	0.38	**55.83**
4000	0.38	**52.83**



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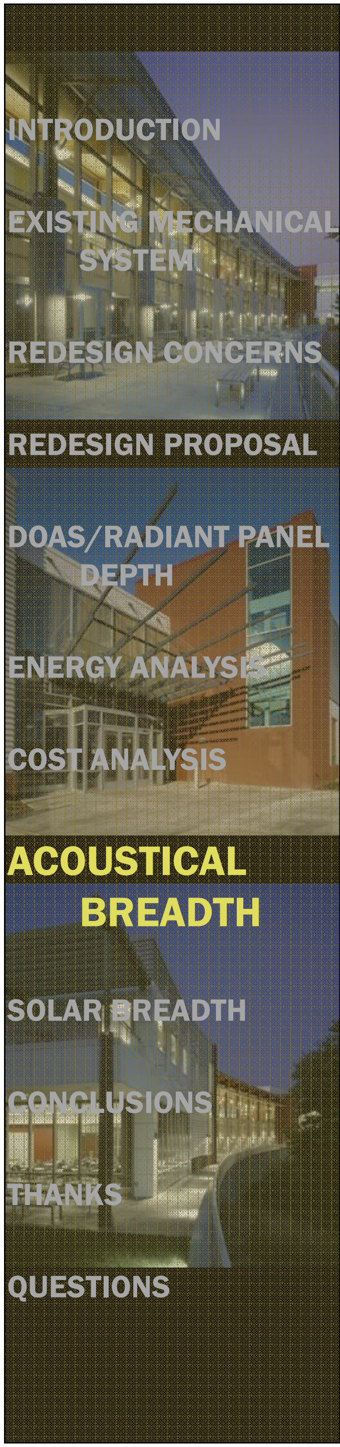
acoustical breadth

fan coil unit analysis

► **Step 4:** Calculate the transmission loss through the acoustical ceiling tile and the final sound power level in the room

Frequency Band (Hz)	TL of ACT (dB)	Correction Factor (T)	TL (dB)	Lw, room (dB)
63	8	0.0001	7.997	68.903
125	9	0.0001	8.996	63.294
250	8	0.0001	7.997	57.953
500	10	0.0001	9.99	50.85
1000	10	0.0001	9.99	49.18
2000	17	0.0001	16.97	38.86
4000	22	0.0001	21.9	30.93



acoustical breadth

fan coil unit analysis

► **Step 5:** Calculate sound pressure level (Lp) and A-Weighted dB values to plot to NC and RC curves

Frequency Band (Hz)	Lp (dB)	A-Weighting	A-Weighted dB Level
63	64.17	-25	39.17
125	57.63	-15	42.63
250	53.22	-8	45.22
500	45.98	-3	42.98
1000	43.3	0	43.3
2000	32.75	1	33.75
4000	25.63	1	26.63

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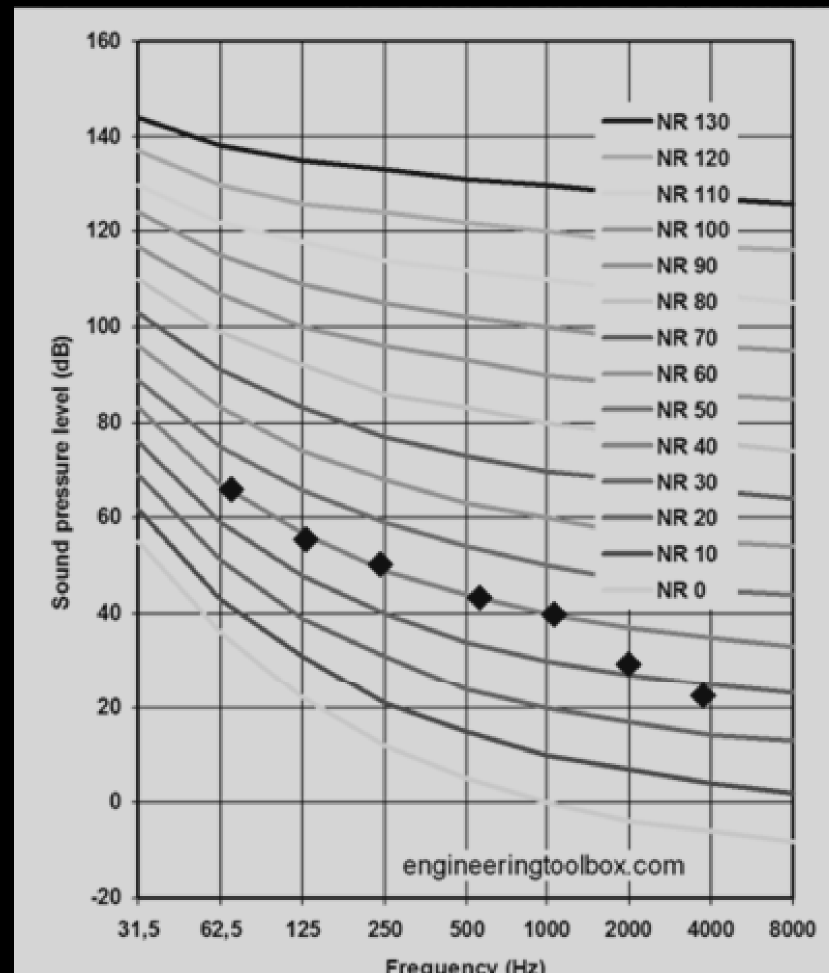
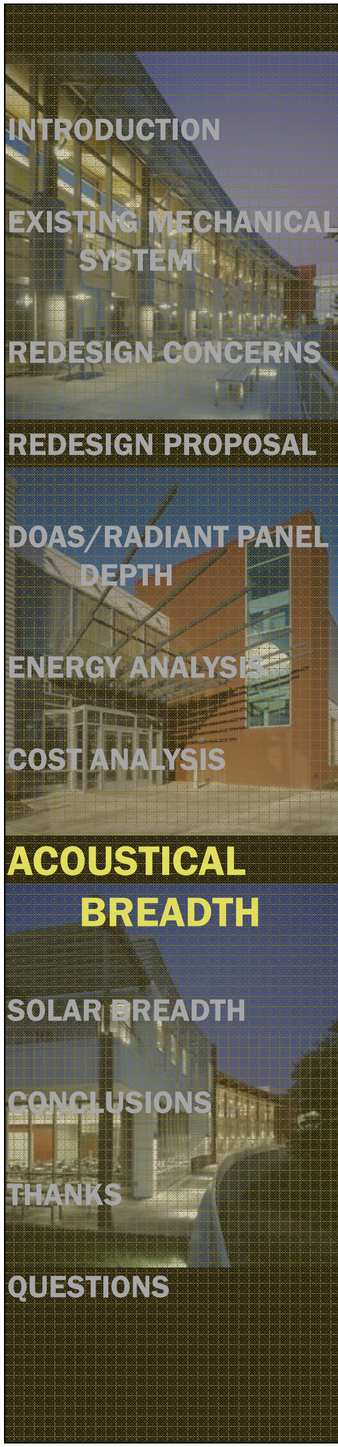
fan coil unit analysis

NC Rating ~ 42

- Exceeds suggested NC ratings of 30-35 by almost 7 decibels
- RC-40 Rating
- Allegations correct in that the acoustics of the FCU's were ***unacceptable***



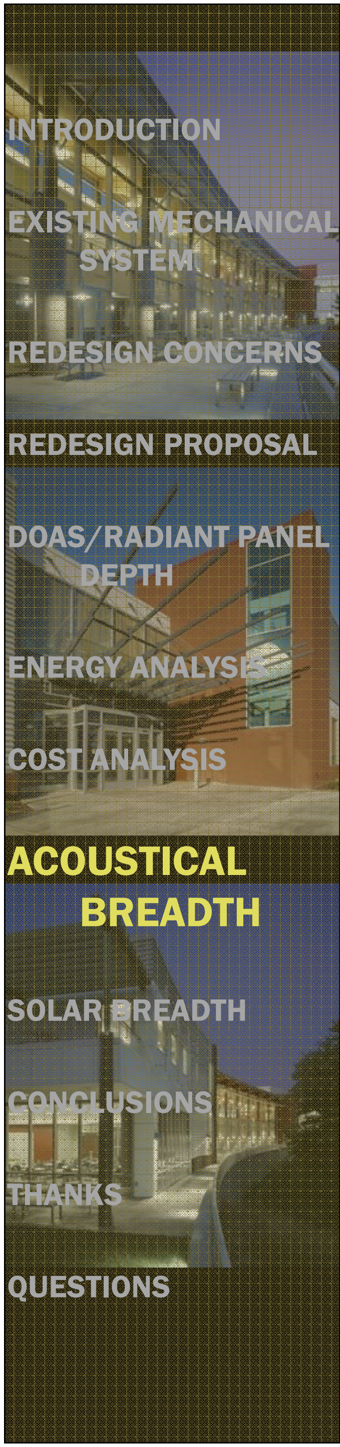


acoustical breadth

reverberation time analysis

►The acceptable reverberation time for lecture & conference space range between **0.7-1.1 seconds** ; classrooms **0.6-0.8 seconds**

►Calculate current reverberation times and the impact the radiant ceiling panels will have on this value

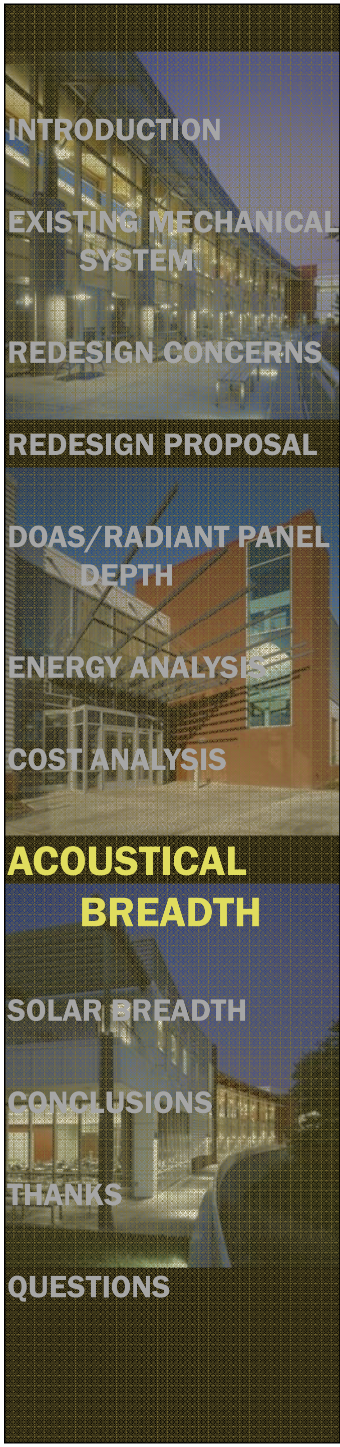


acoustical breadth

reverberation time analysis

► **Step 1:** Calculate the volume of the room
► **Step 2:** Determine room properties and absorption coefficients
► **Step 3:** Determine surface areas of all materials in the room
► **Step 4:** Calculate the total square foot of room absorption in Sabins
► **Step 5:** Calculate the Sabine reverberation time using the following equation:

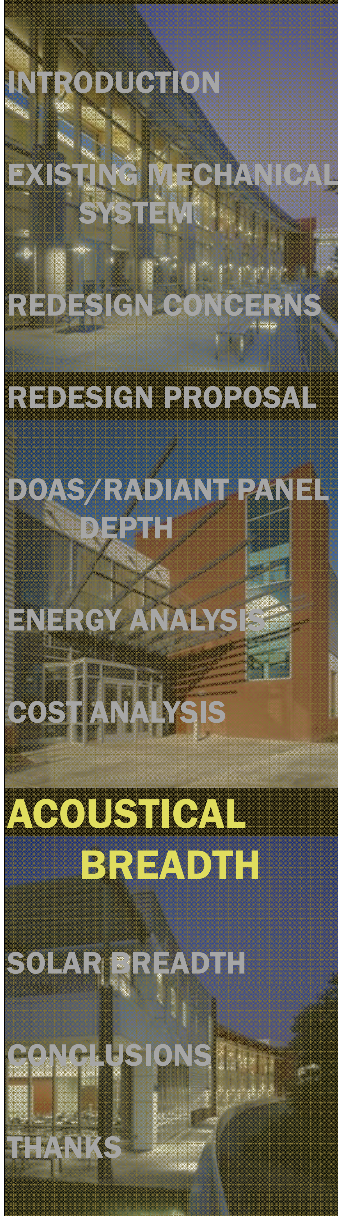
EQN 1: T60 (sec)= 0.05*(Volume/Total Room Absorption)



acoustical breadth

current reverberation time calculations :

CONSTRUCTION MATERIAL	SURFACE AREA (sf)	SOUND ABSORPTION COEFFICIENT					
		125	**250**	**500**	**1000**	**2000**	**4000**
Floor (carpet, heavy on concrete)	746.74	0.02	0.06	0.14	0.37	0.6	0.65
Ceiling (ACT, 3/4" thick in suspension system)	700	0.08	0.29	0.75	0.98	0.93	0.96
Lighting Fixtures (Metal)	46.74	0.05	0.1	0.1	0.1	0.07	0.02
Walls (GWB, 2 layers, 5/8" thick on metal studs w/ batt. Insulation)	830.1	0.28	0.12	0.1	0.07	0.13	0.09
Windows (Glass, heavy, large panes)	88.48	0.18	0.06	0.04	0.03	0.02	0.02
Acoustical Wall Panels (1" thickness)	125.83	0.14	0.27	0.8	1.11	1.14	1.14
Door (solid core wood)	21	0.19	0.14	0.09	0.06	0.06	0.05
Sα		343.23	394.31	823.32	1168.66	1356.70	1379.29
T reverb = 0.05 (V/Sα)		**1.12**	**1.0**	**0.47**	**0.33**	**0.32**	**0.30**



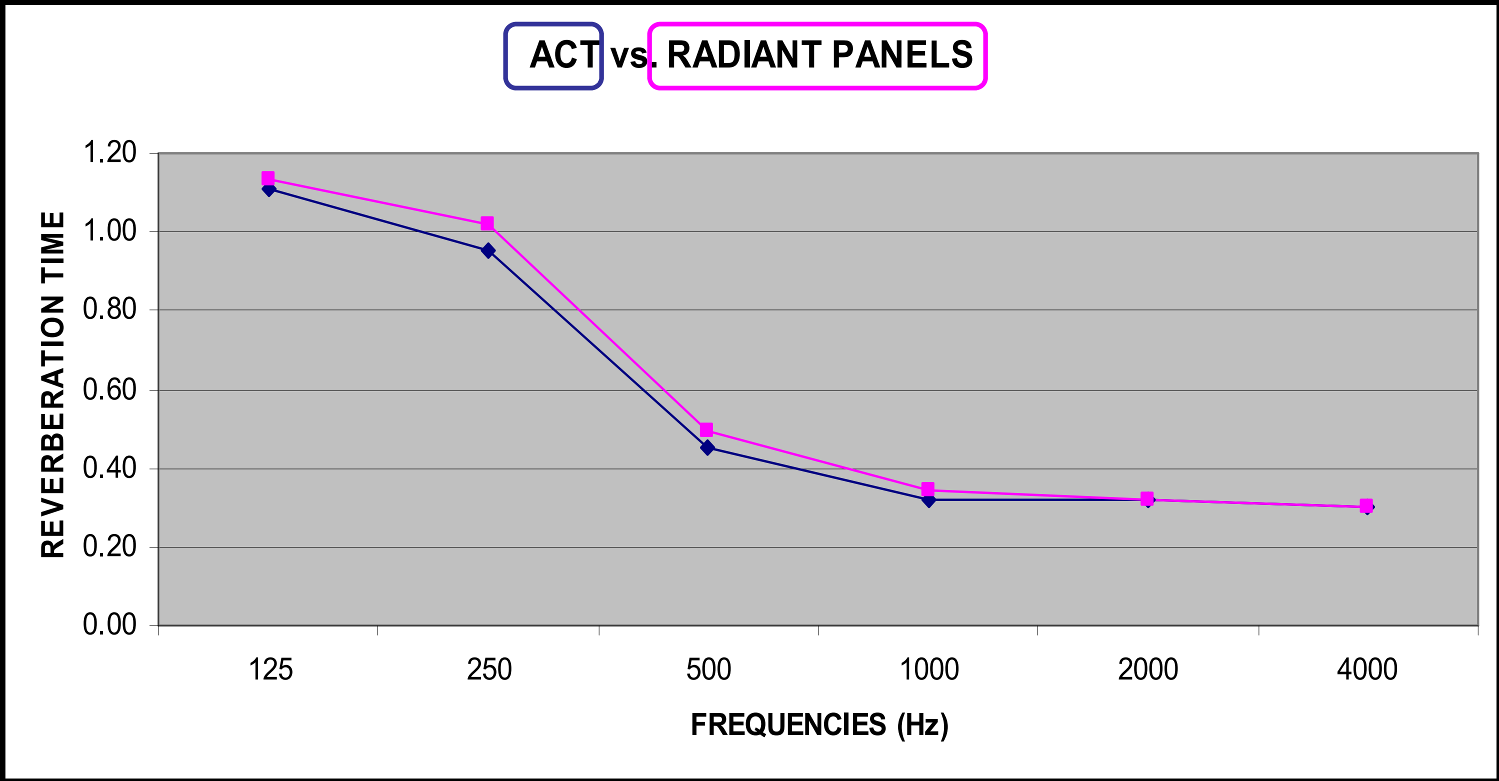
acoustical breadth

proposed reverberation time calculations :

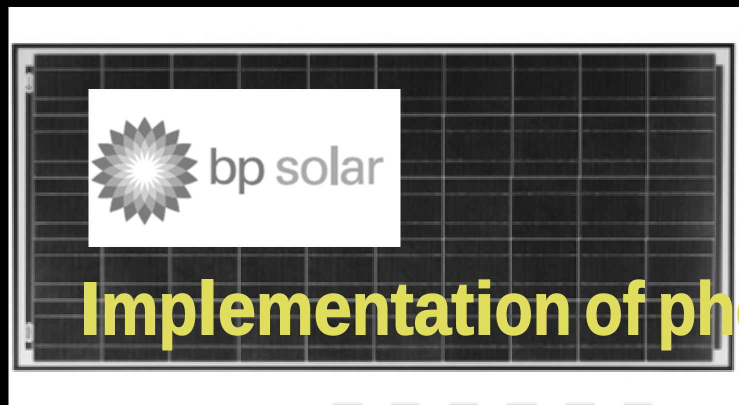
CONSTRUCTION MATERIAL	SURFACE AREA (sf)	SOUND ABSORPTION COEFFICIENT					
		125	250	500	1000	2000	4000
Floor (carpet, heavy on concrete)	746.74	0.02	0.06	0.14	0.37	0.6	0.65
Ceiling (ACT, 3/4" thick in suspension system)	645	0.08	0.29	0.75	0.98	0.93	0.96
Ceiling (Sterling Radiant Ceiling Panels)	88	0.76	0.79	0.79	0.91	0.74	0.53
Lighting Fixtures (Metal)	46.74	0.05	0.1	0.1	0.1	0.07	0.02
Walls (GWB, 2 layers, 5/8" thick on metal studs w/ batt. Insulation)	830.1	0.28	0.12	0.1	0.07	0.13	0.09
Windows (Glass, heavy, large panes)	88.48	0.18	0.06	0.04	0.03	0.02	0.02
Acoustical Wall Panels (1" thickness)	125.83	0.14	0.27	0.8	1.11	1.14	1.14
Door (solid core wood)	21	0.19	0.14	0.09	0.06	0.06	0.05
Sα		338.83	378.36	782.07	1114.76	1305.55	1326.49
T reverb = 0.05 (V/Sα)		**1.14**	**1.0**	**0.49**	**0.35**	**0.32**	**0.30**

acoustical breadth

reverberation time comparison

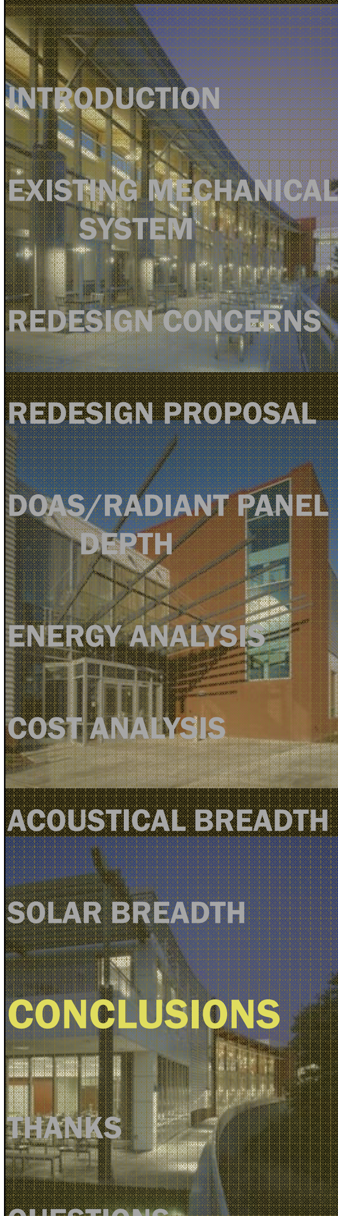


solar breadth



Implementation of photovoltaic panels

- ►Per owner request
- ►Designed to power 3.132 kW of office lighting
- ►(24) panels + (1) inverter for an initial cost of $31,733
- ►Payback period of 60 years
- ►Not including financial incentives



conclusions

►Mechanical Redesign

-Reduced annual operating costs by $12,800 .

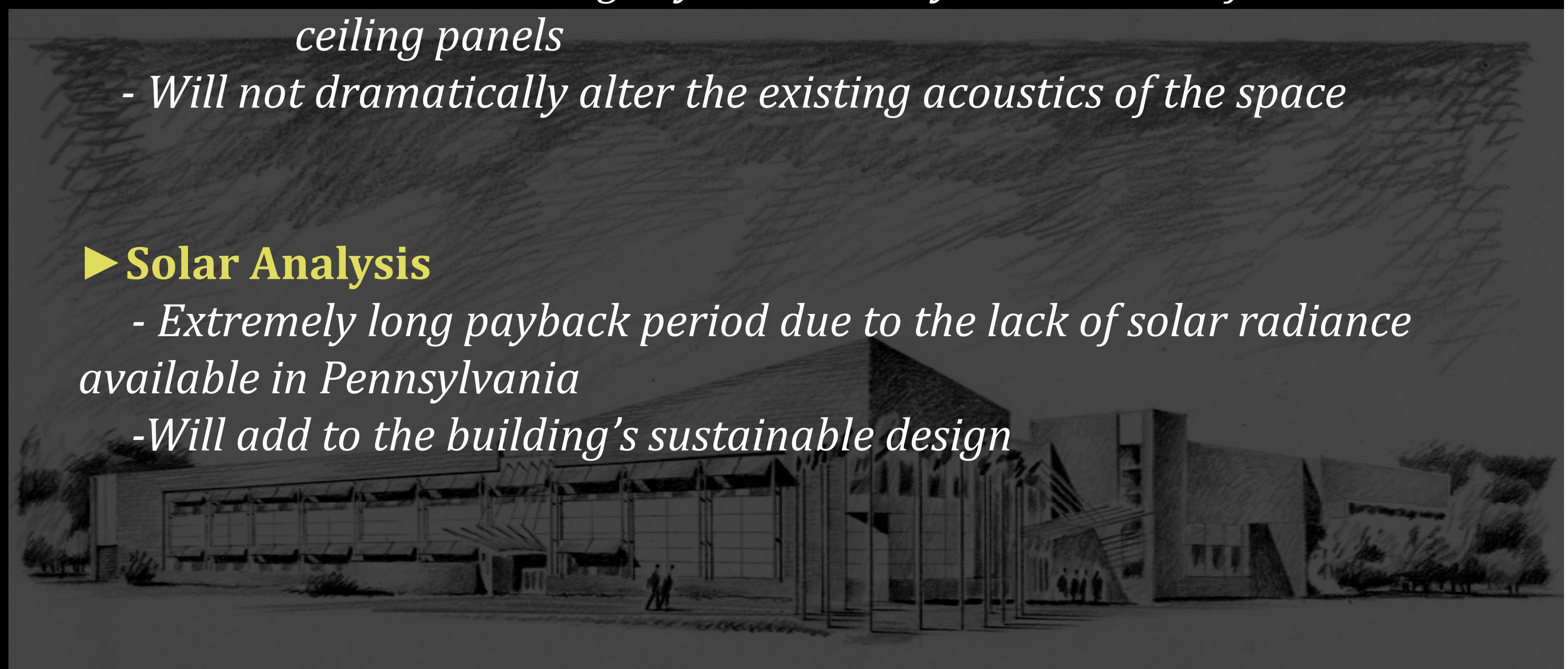
-The $44,122 increase in initial cost has a potential payback of only 4 years

-Enhanced thermal comfort in office & classroom space

►Acoustical Analysis

- Reverberation times slightly increased by installation of radiant ceiling panels

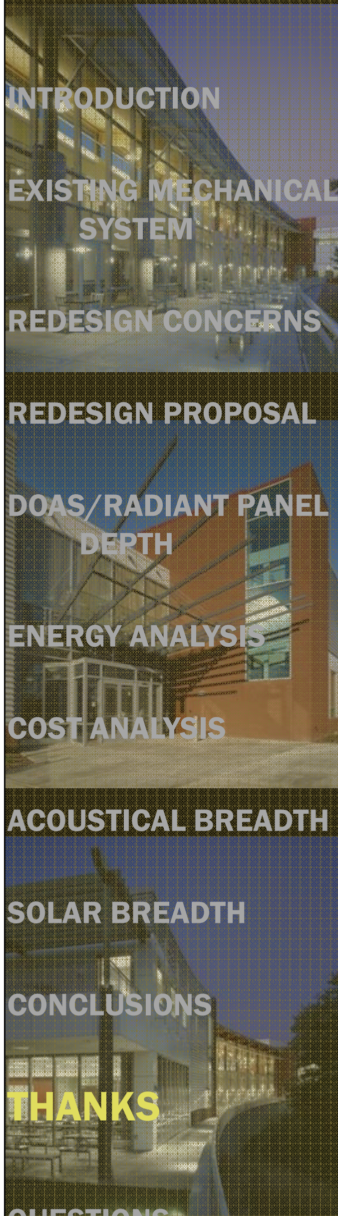
- Will not dramatically alter the existing acoustics of the space



►Solar Analysis

- Extremely long payback period due to the lack of solar radiance available in Pennsylvania

-Will add to the building's sustainable design



Just wanted to say

thanks!

- **Justin Griffith**
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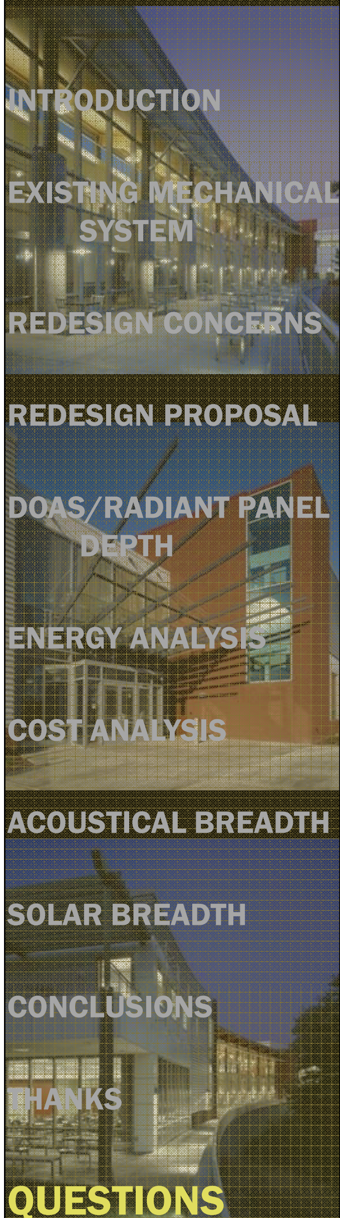
  Mechanical Engineer, Mueller Associates
- **John O'Brien**
  Construction Manager, Landau Building Company
- **Todd Garing**
  Mueller Associates
- **My family & most importantly, the Wonderful AE Class Of '09**



Any

QUESTIONS?