Des Places Residence Hall

Duquesne University
Pittsburgh, PA


DUQUESNE UNIVERSITY

Project Team

Owner: Duquesne University
Architect: WTW Architects
Mechanical/Electrical Engineer: CJL Engineering
Structural Engineer: Barber and Hoffman Inc.
Civil Engineer: Gateway Engineers
Construction Management Agency: Regency Construction Services Inc.

Peter Edwards – Mechanical Option
Advisor - Dustin Eplee

Presentation Outline

- Building Overview
  - Building Information
  - Building Location and Site
- Thesis Overview
- Existing Mechanical System
- Mechanical System Redesign Objectives
- Analysis I – Dedicated Outdoor Air System
- Analysis II – Solar Thermal System
- Analysis III – Building Envelope Redesign
  - Daylighting Breadth
- Conclusion

Building Information

Basic Information

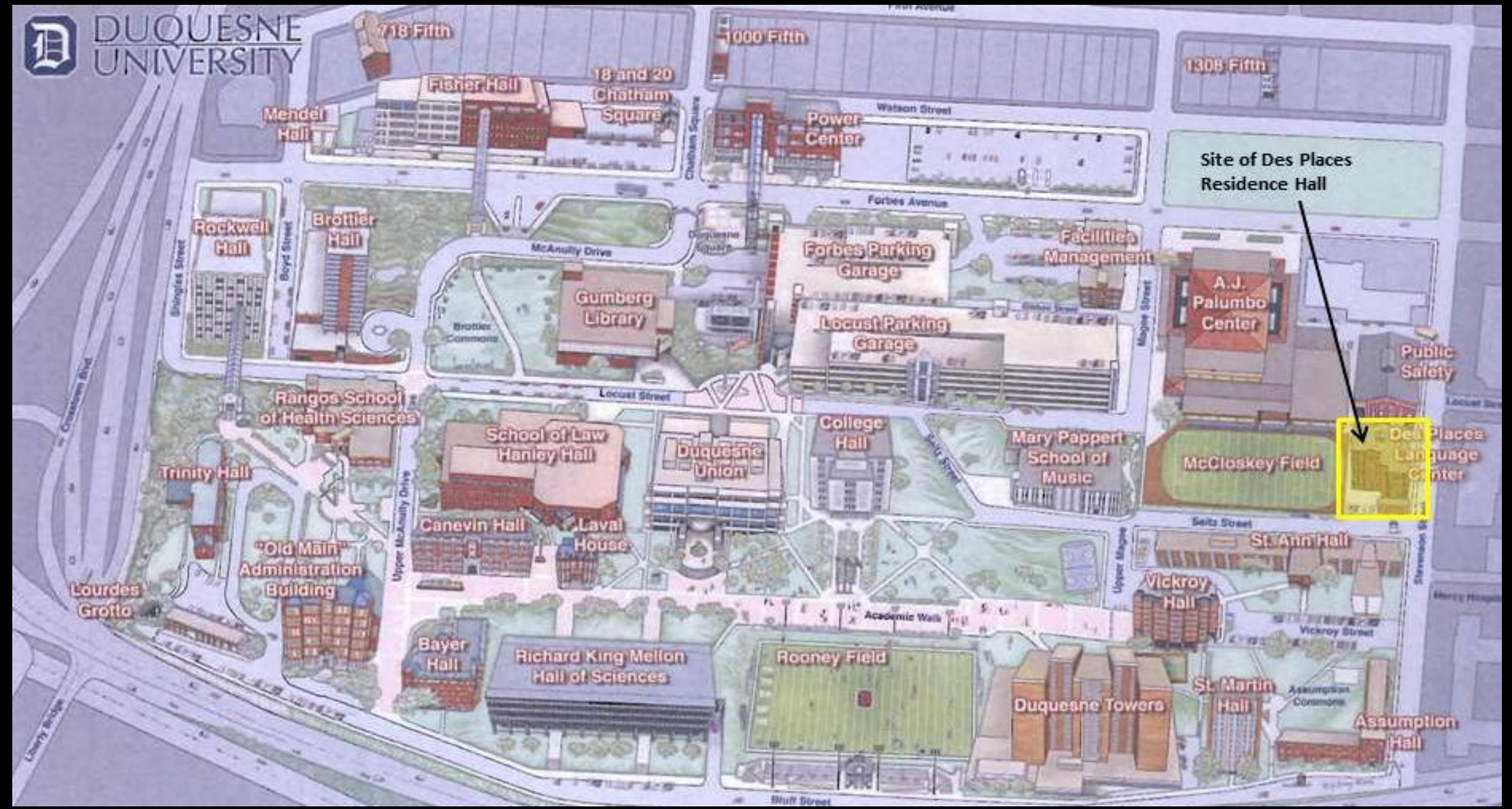
Size:	131, 438 ft^2
Stories Above Grade:	11
Estimated Project Cost:	$27,535,000
Dates of Construction:	March 1, 2010 – August 7, 2012
Project Delivery Method:	Design-Bid-Build
Occupancy Type:	Student Dormitory
LEED:	Minimum of LEED Certification

Presentation Outline

Building Location and Site

Location

- Pittsburgh, Pennsylvania
- Surrounded by an urban environment



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Peter Edwards – Mechanical Option

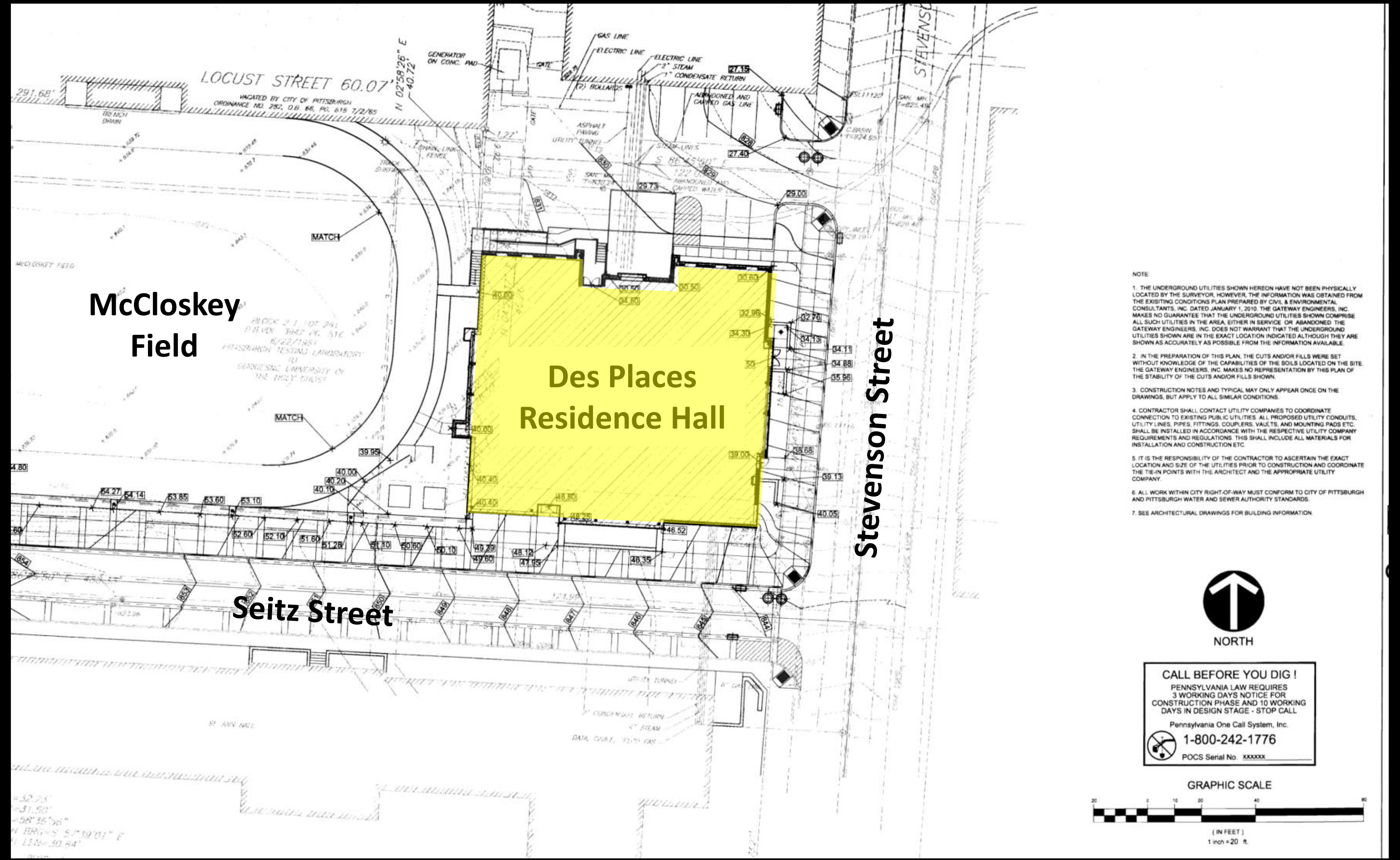
Building Location and Site

Location

- Pittsburgh, Pennsylvania
- Surrounded by an urban environment

Site

- Square building footprint
- Building is oriented so that it faces almost exactly true north
- Surrounded by Seitz Street to the south and Stevenson Street to the east



Presentation Outline

Thesis Overview

Proposal

- Replace fan coil units in existing dedicated outdoor air system with radiant ceilings and baseboard radiators

- Install a solar thermal system to preheat the domestic hot water in Des Places

- Redesign the building envelope of Des Places to allow more natural daylight into the perimeter bedrooms and living rooms

Thesis Overview

Proposal

- Replace fan coil units in existing dedicated outdoor air system with radiant ceilings and baseboard radiators
- Install a solar thermal system to preheat domestic hot water
- Redesign the building envelope by doubling the size of every bedroom and living room window

Results

- **Redesigned Dedicated Outdoor Air System**
  - $7,370 increase in yearly operational costs
  - Cost $186,500 less than original system
  - New system will increase the comfort of occupants
- **Solar Thermal System**
  - Saves the central steam plant approximately 2,350 therms/year
  - Payback period under 11 years with government incentives
- **Building Envelope Redesign**
  - Larger windows allow significantly more natural light into the rooms throughout the year
  - Daylighting analysis showed that some of the rooms already had an adequate amount of daylight
  - Cost $203,312 more than the original building envelope
  - $2,137 increase in yearly operational costs

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Existing Mechanical System

Key Facts

- Total estimated cost = $2,827,770
- System complies with ASHRAE Standards 62.1 and 90.1
- Steam supply comes from central steam plant on campus
- Chilled water supply comes from central chiller plant on campus
- Electricity is supplied by Duquesne Light

Utility Rates

Utility Costs	
Energy Type	Cost
Electricity	0.087 ($/KWh)
Natural Gas	1.282 ($/therm)

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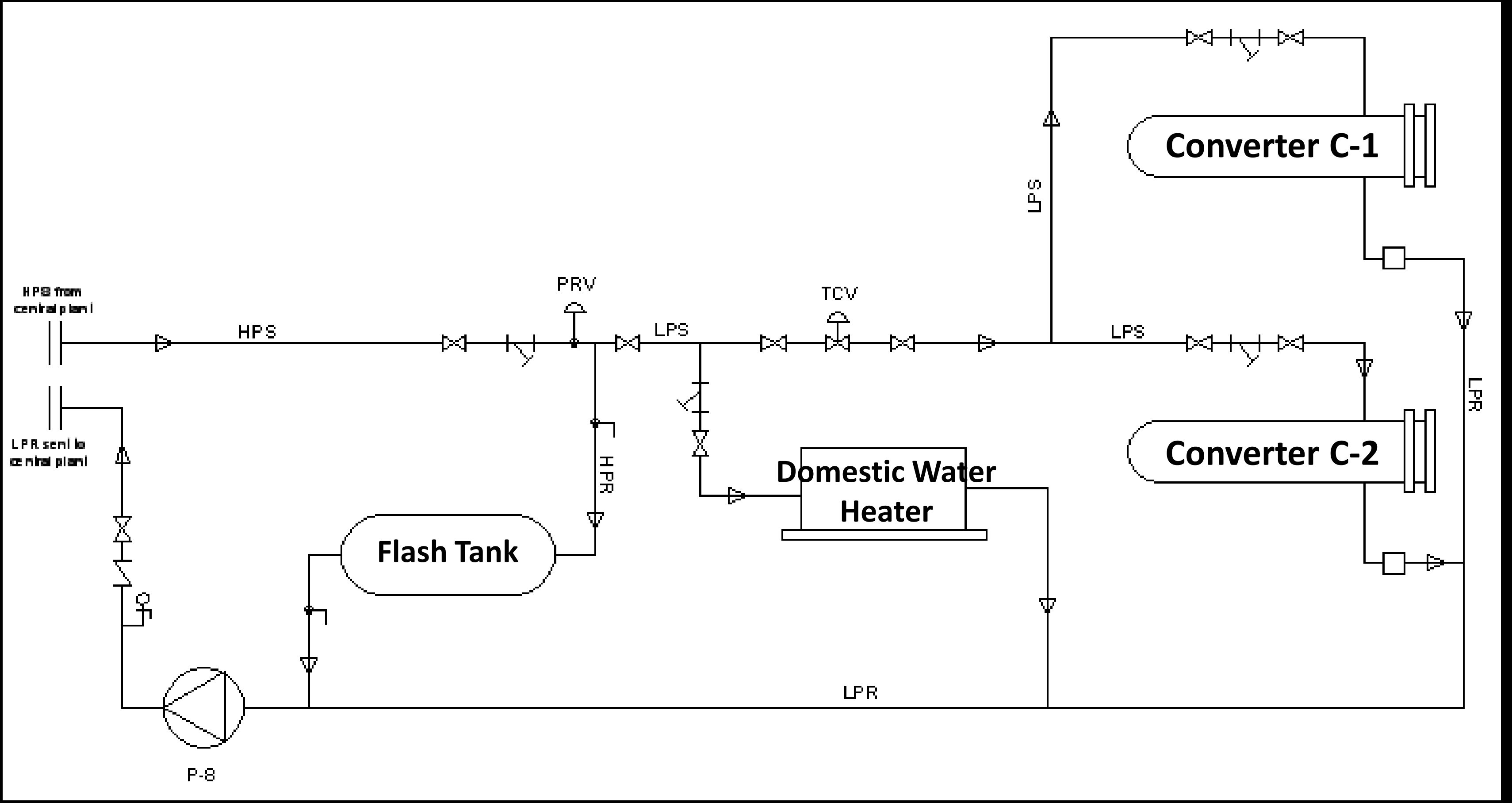
Existing Mechanical System

Steam

- High pressure steam comes from central plant at a pressure of 50 lbs and a velocity of 6,000 fpm
- HPS passes through a pressure reducing valve
- Low pressure steam is used for the domestic water heater
- Remaining LPS is converted to hot water



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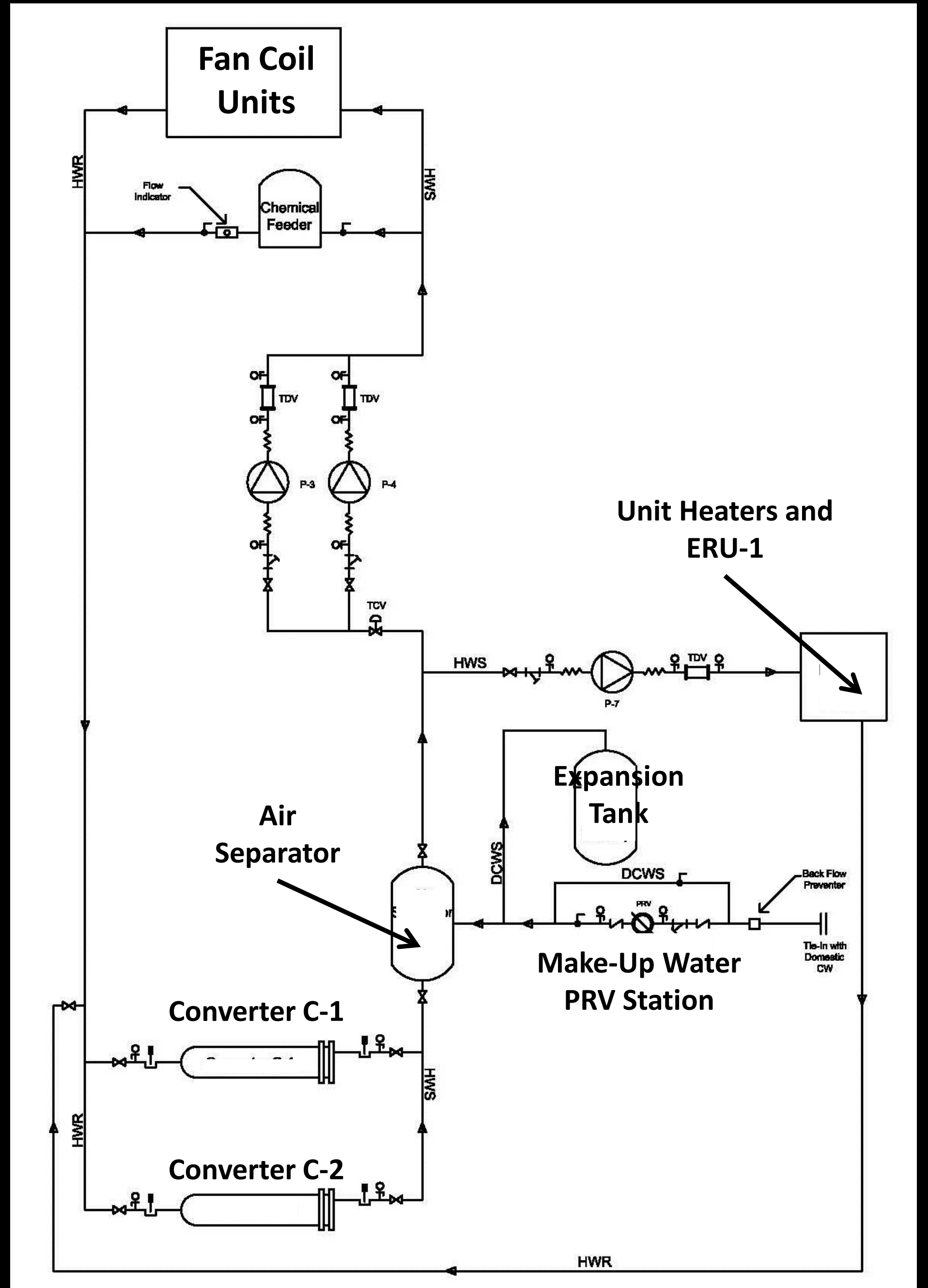
Existing Mechanical System

Steam

- High pressure steam comes from central plant at a pressure of 50 lbs and a velocity of 6,000 fpm
- HPS passes through a pressure reducing valve first
- Low pressure steam is used for the domestic water heater
- Remaining steam is converted to hot water

Hot Water

- Hot water supply starts at the two steam to hot water converters
- 140 °F supply temperature
- Hot water supply feeds coils in unit heaters, fan coil units and ERU-1



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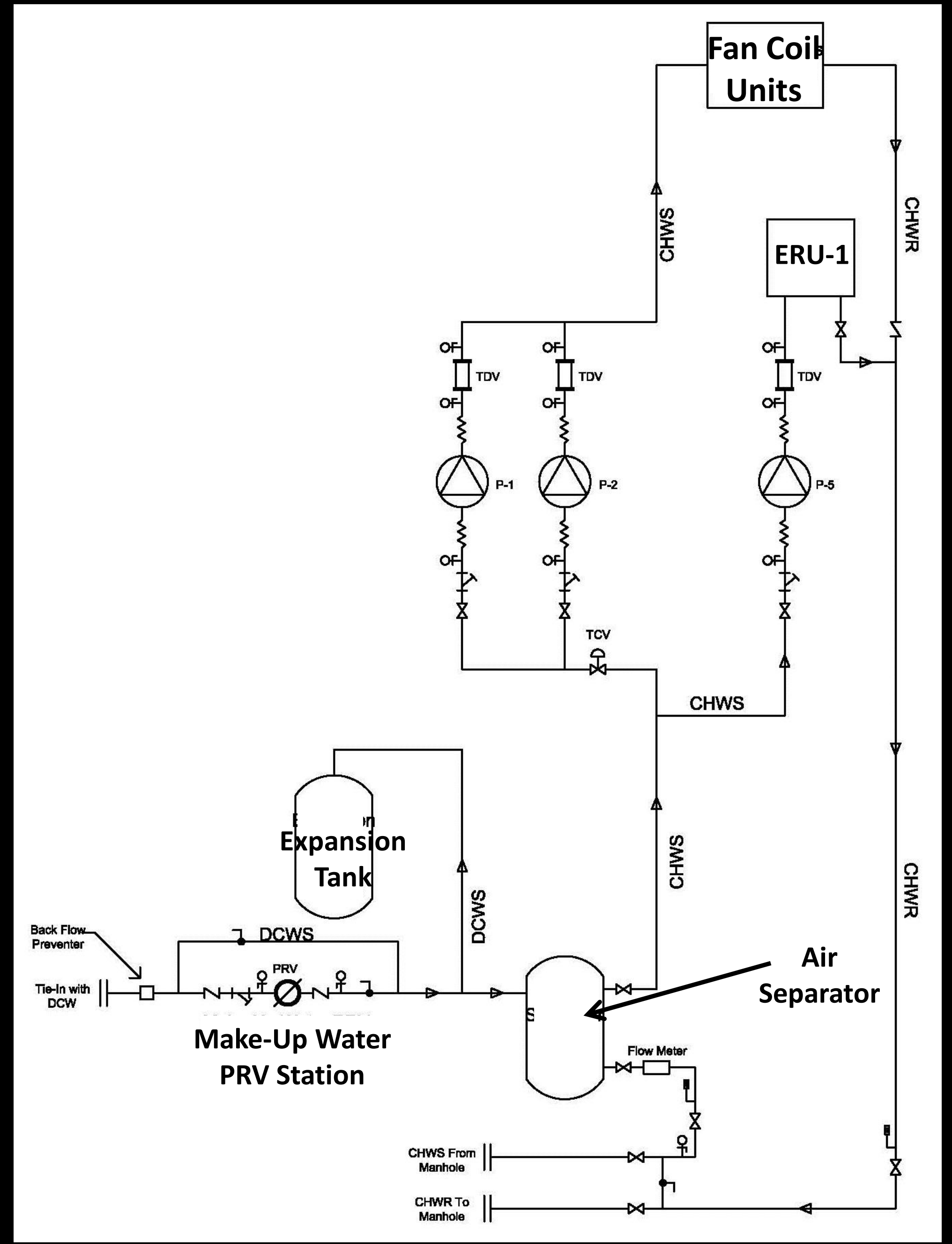
Peter Edwards – Mechanical Option

Existing Mechanical System

Chilled Water

- Chilled water supply comes directly from central chiller plant
- 45 °F supply temperature
- Chilled water supply feeds coils in fan coil units and ERU-1



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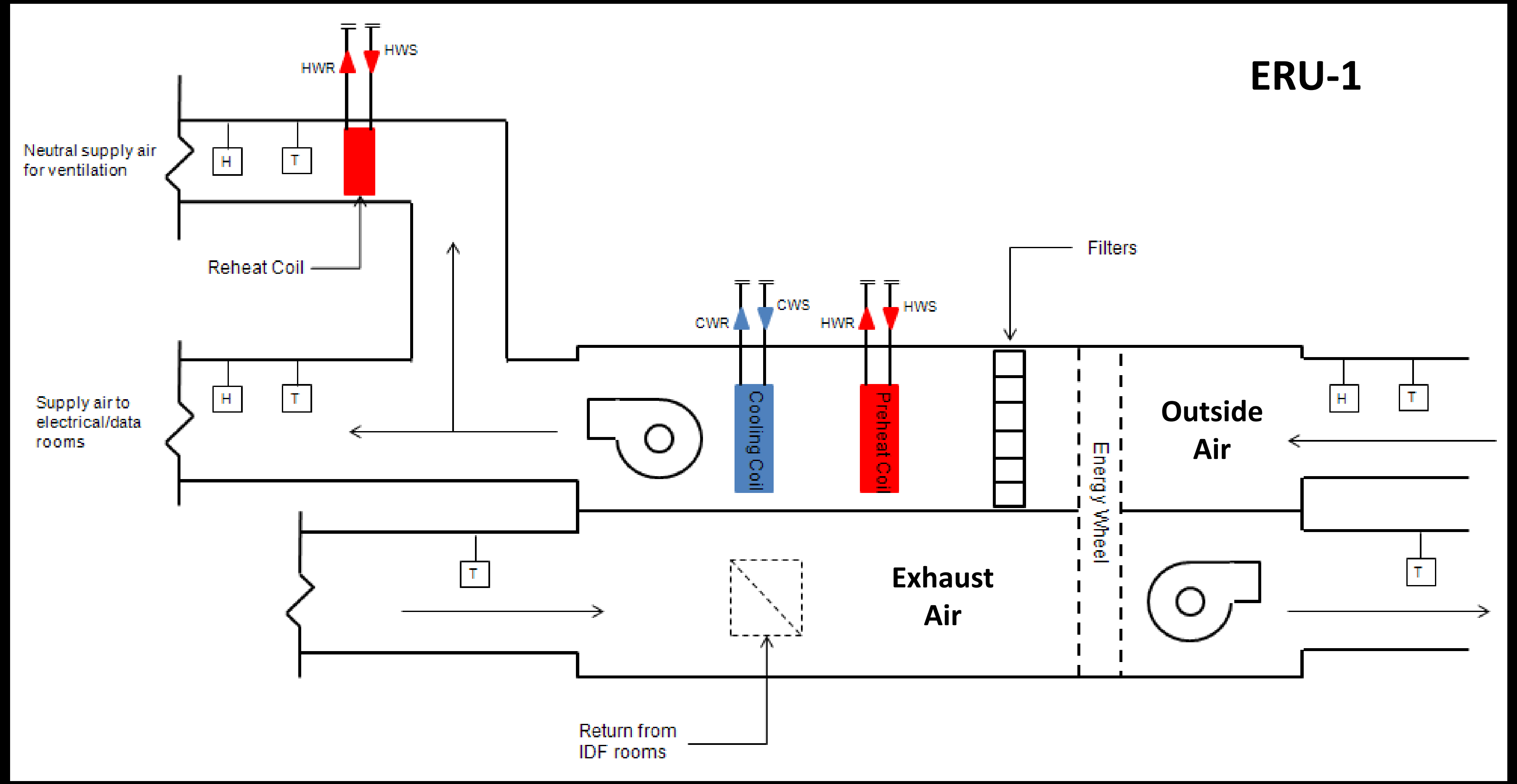
Dedicated Outdoor Air System

- Energy recovery unit uses 100% outdoor air
- Outdoor air is delivered to every room at a constant flow rate



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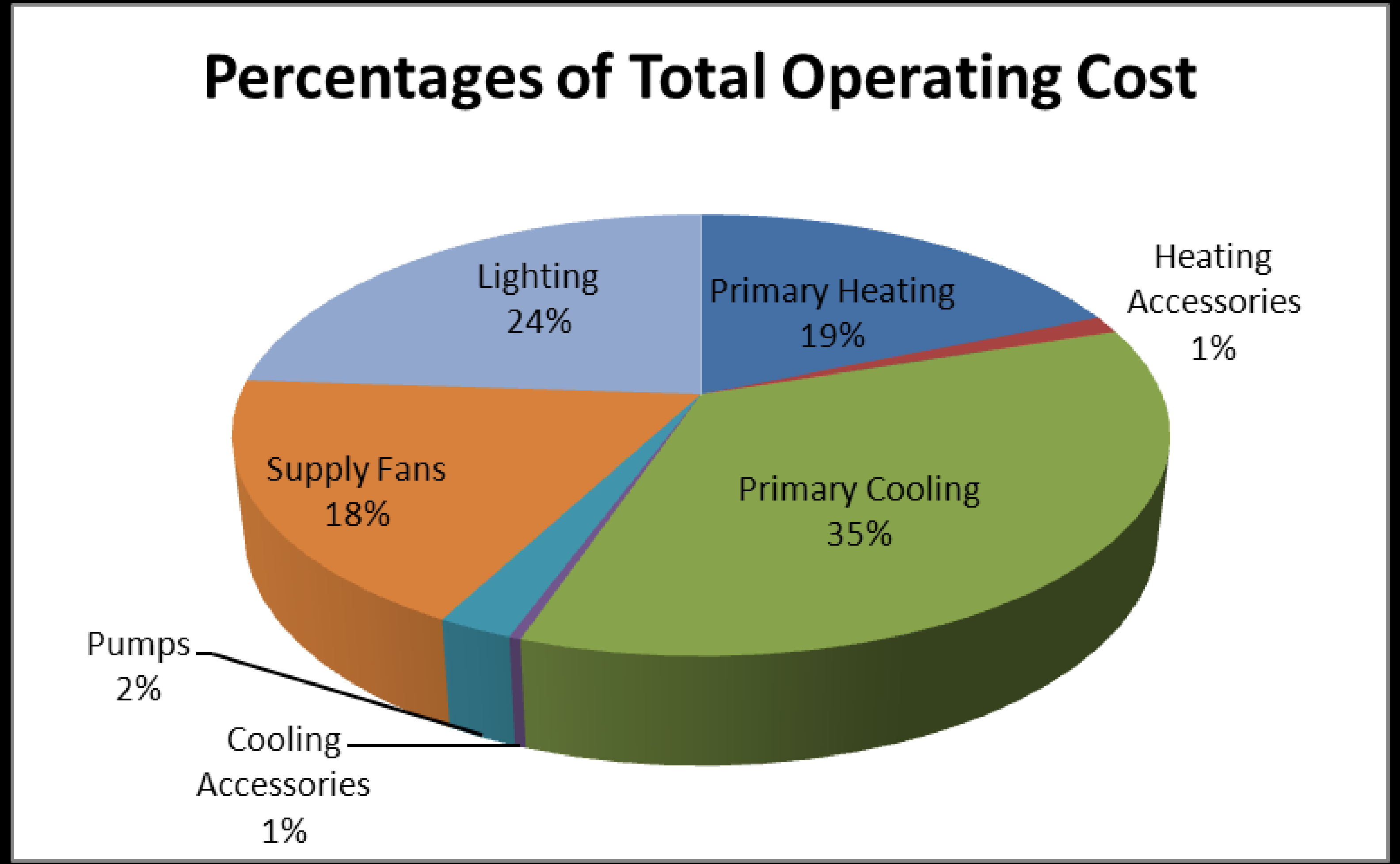
Existing Mechanical System

Annual Energy Cost

- **Primary Heating** - $17,914/year
- **Primary Cooling** – $33,725/year

- **Total - $95,663/year**



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Mechanical System Redesign Objectives

Dedicated Outdoor Air System with Radiant Ceilings

- Reduce yearly energy consumption of building
- Reduce the cost of the dedicated outdoor air system
- Improve comfort of occupants

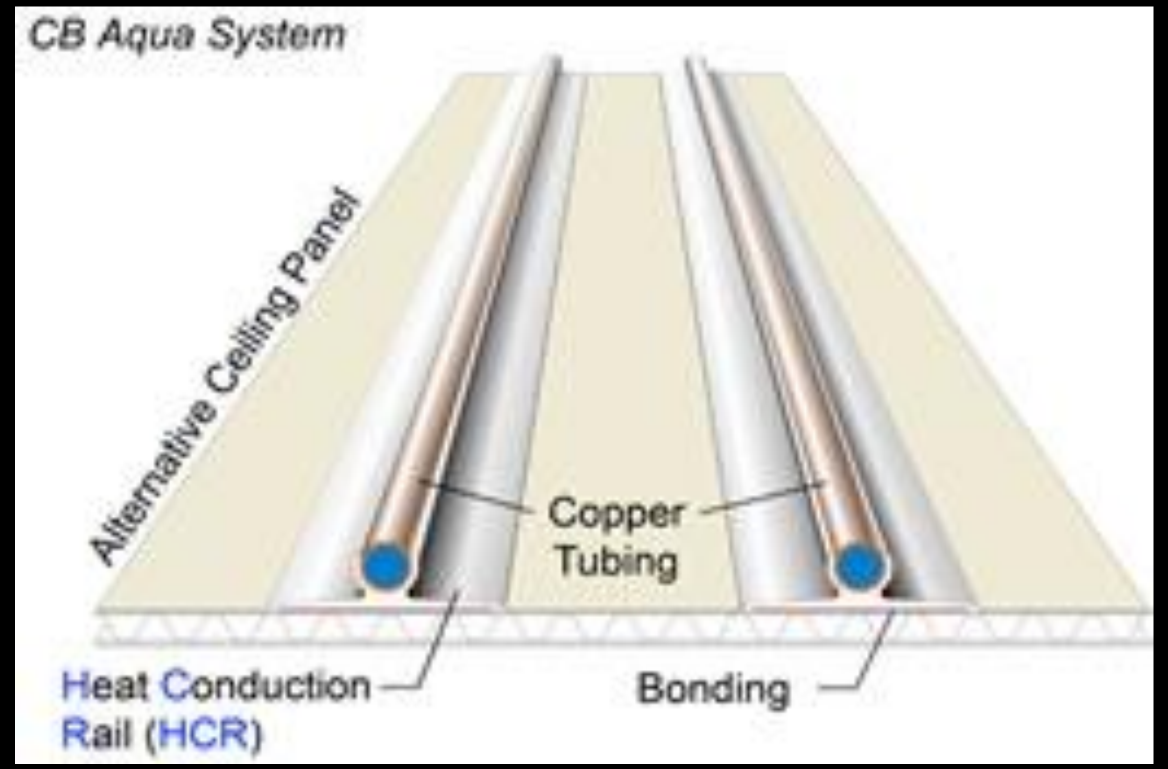


Diagram of a radiant ceiling produced by Barcol-Air

Presentation Outline

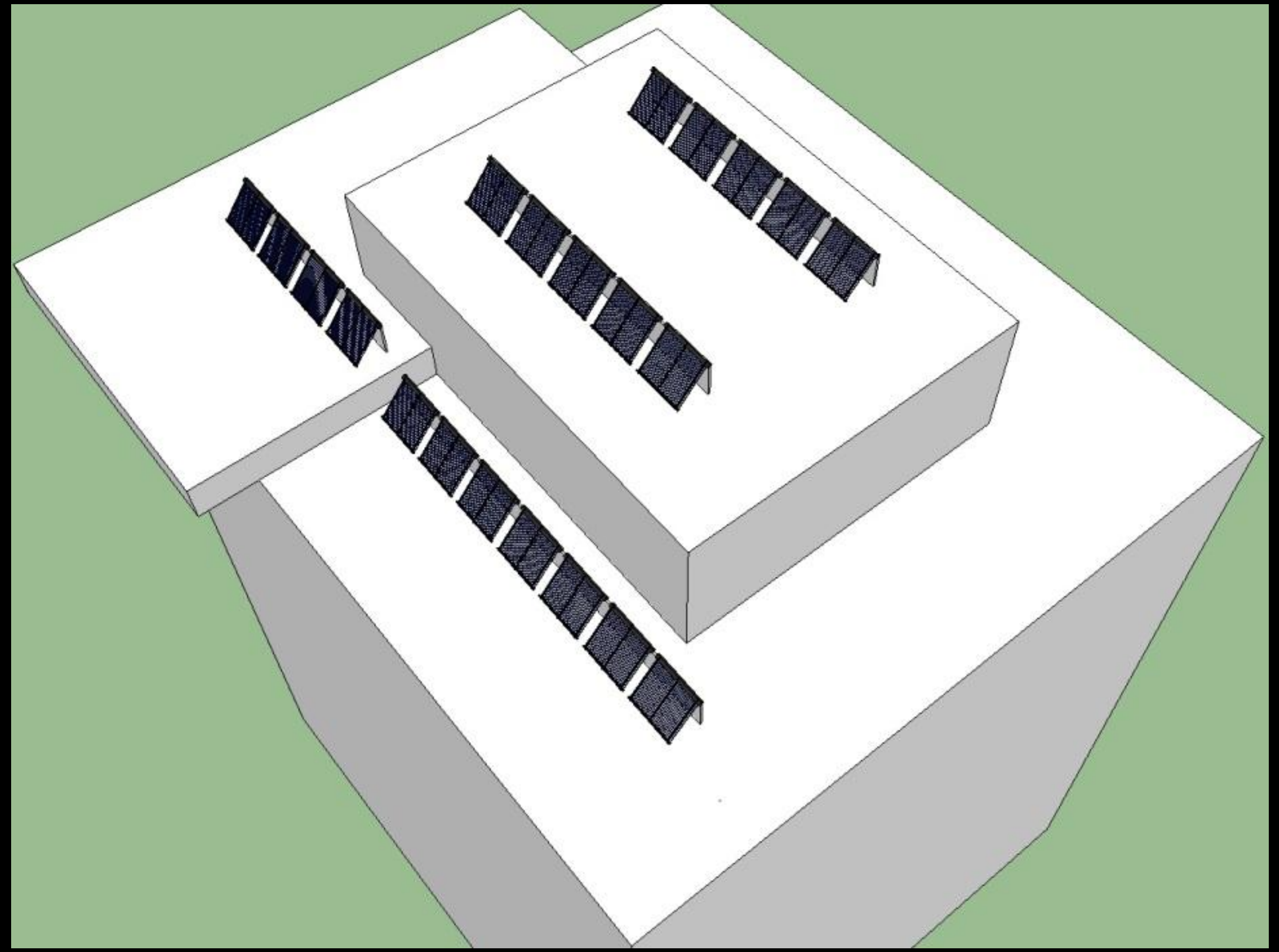
Mechanical System Redesign Objectives

Dedicated Outdoor Air System with Radiant Ceilings

- Reduce yearly energy consumption
- Reduce the cost of the dedicated outdoor air system
- Improve comfort of occupants

Solar Thermal System

- Add renewable energy source to Des Places
- Reduce energy consumption of steam domestic water heater
- Produce a reasonable payback period



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Mechanical System Redesign Objectives

Dedicated Outdoor Air System with Radiant Ceilings

- Reduce yearly energy consumption
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- Improve comfort of occupants

Solar Thermal System

- Add renewable energy source to Des Places
- Reduce energy consumption of steam domestic water heater
- Produce a reasonable payback period

Building Envelope Redesign

- Increase natural daylight in bedrooms and living rooms
- Eliminate the need for artificial light in perimeter rooms during the day

Presentation Outline

Analysis I - Dedicated Outdoor Air System

Design Overview

- Replace all fan coil units with radiant ceilings and baseboard radiators
- Energy recovery unit remains the same
- Thermostat and dew point sensor in each room
- Reduce fan energy consumption
- Eliminate fan noise in rooms

Chosen Manufacturers

- CB Aqua radiant ceilings produced by Barcol-Air
- Baseboard radiators produced by Slantfin

Barcol-Air radiant ceiling panel

Slantfin baseboard radiator

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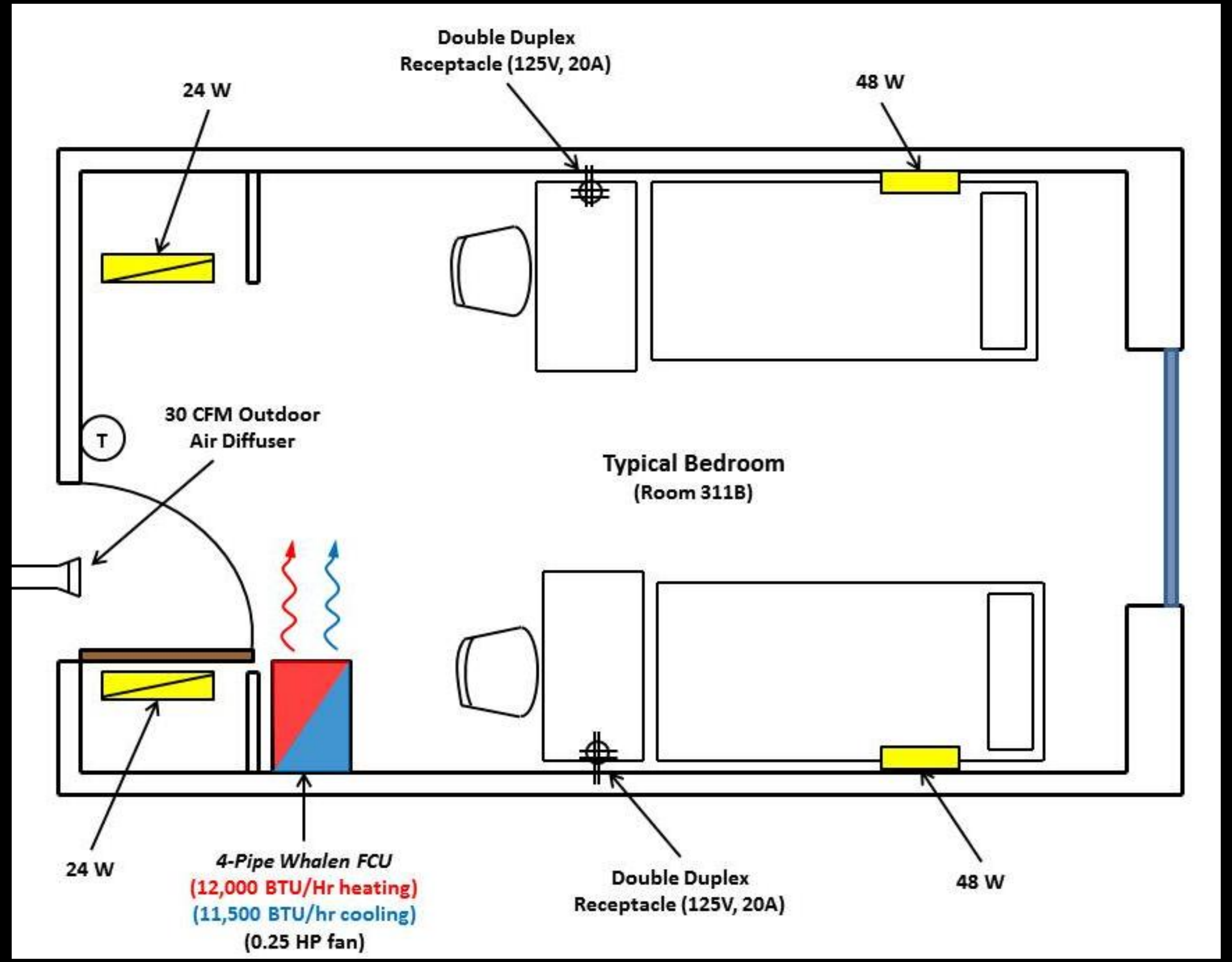
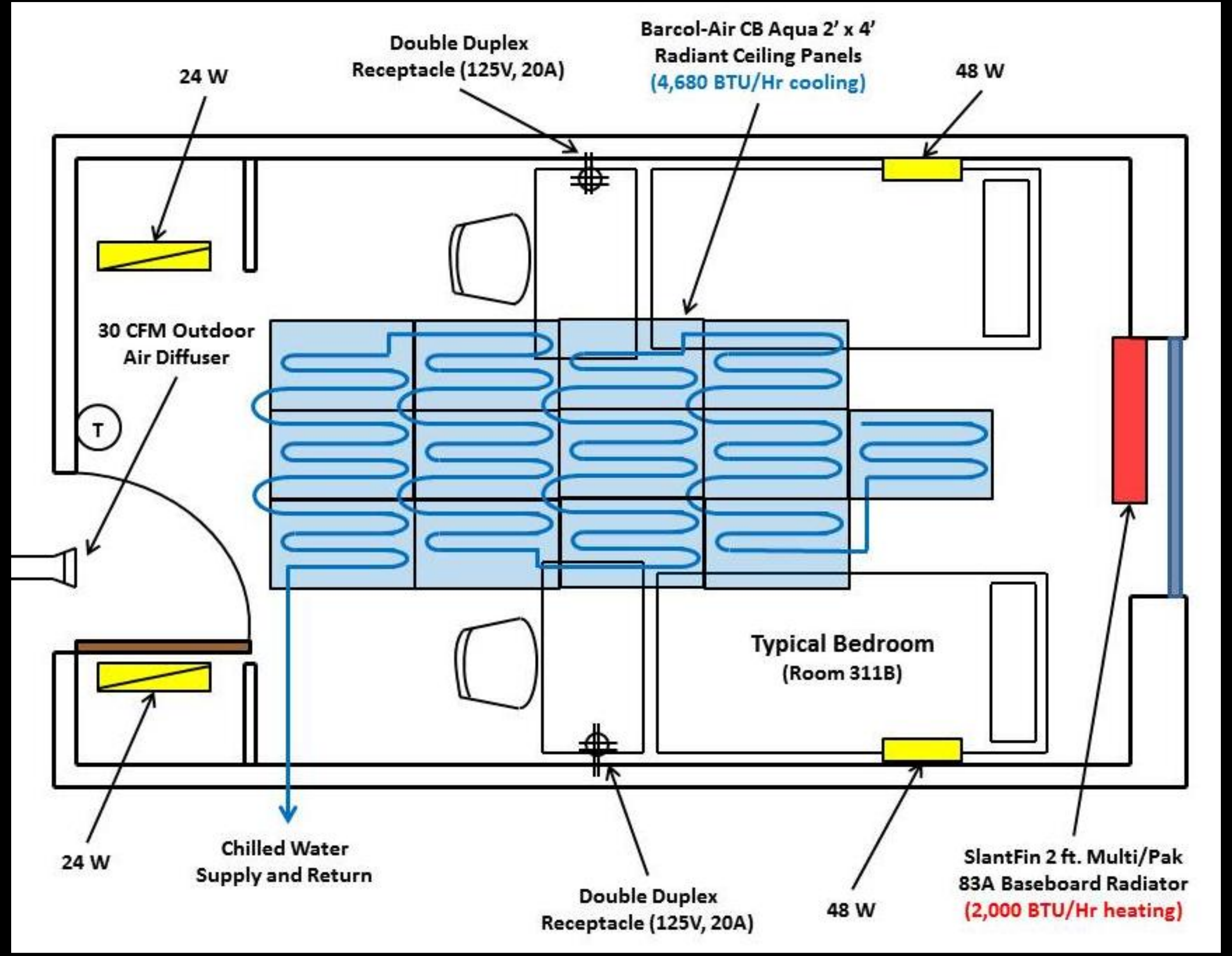
Peter Edwards – Mechanical Option

Analysis 1 - Dedicated Outdoor Air System





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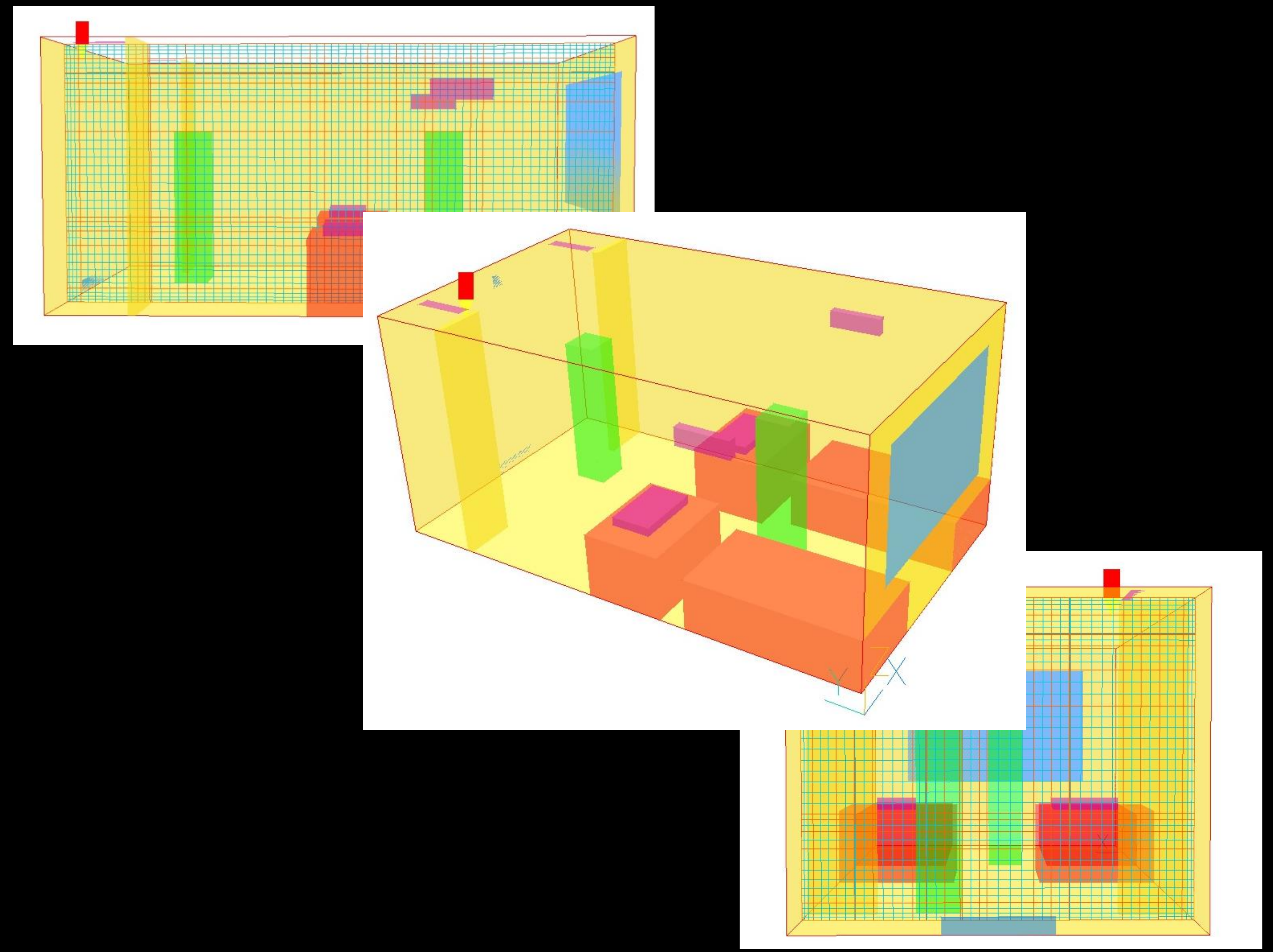
Analysis I - Dedicated Outdoor Air System

Computational Fluid Dynamics Analysis

- Accurate models of a typical bedroom with a fan coil unit and a radiant ceiling were created in Phoenics
- Cooling performance of each system was analyzed and compared

Results

- Radiant ceiling produced a more uniform temperature distribution throughout the space
- Radiant ceiling produced a lower average temperature in the space by 1 °F



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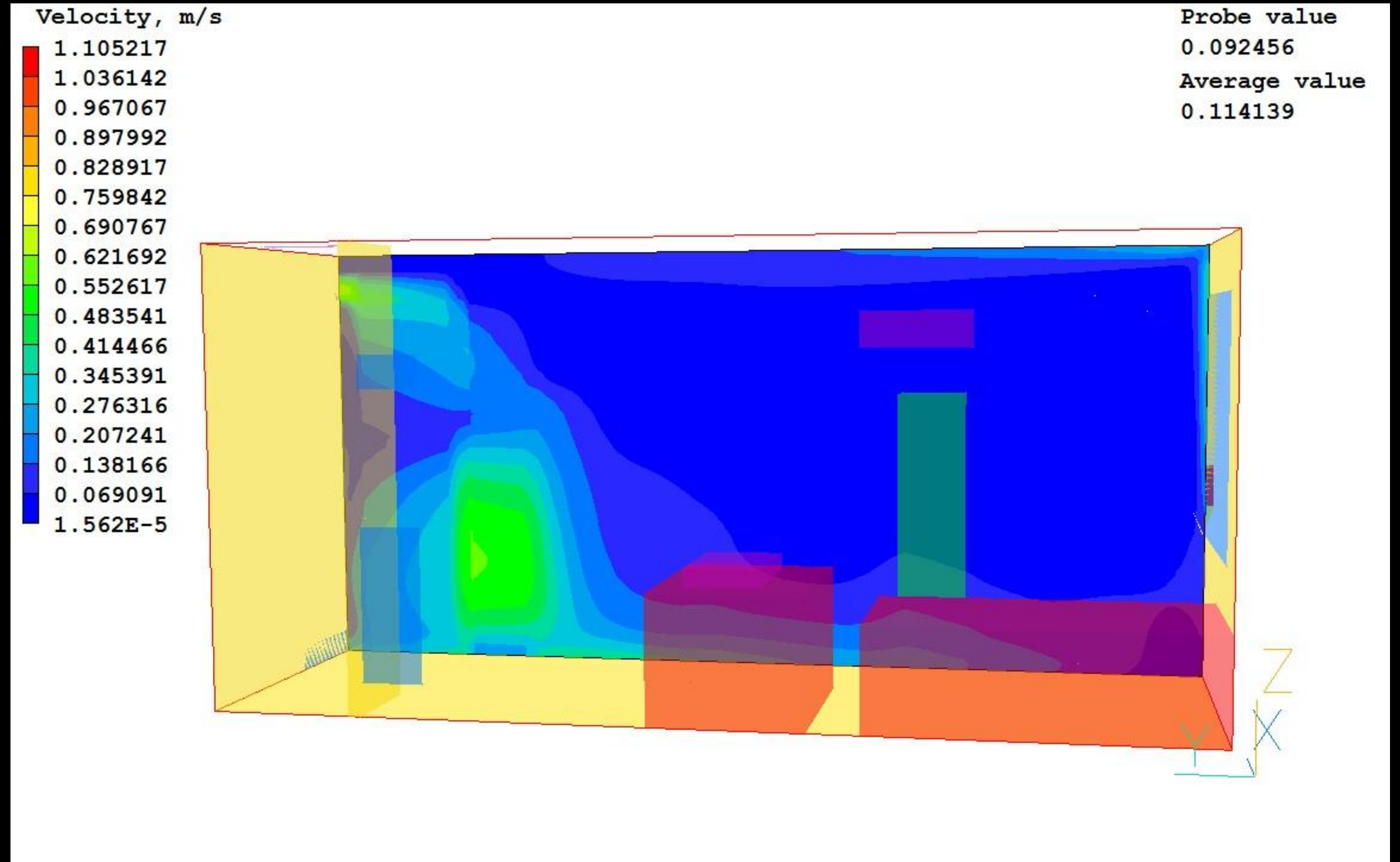
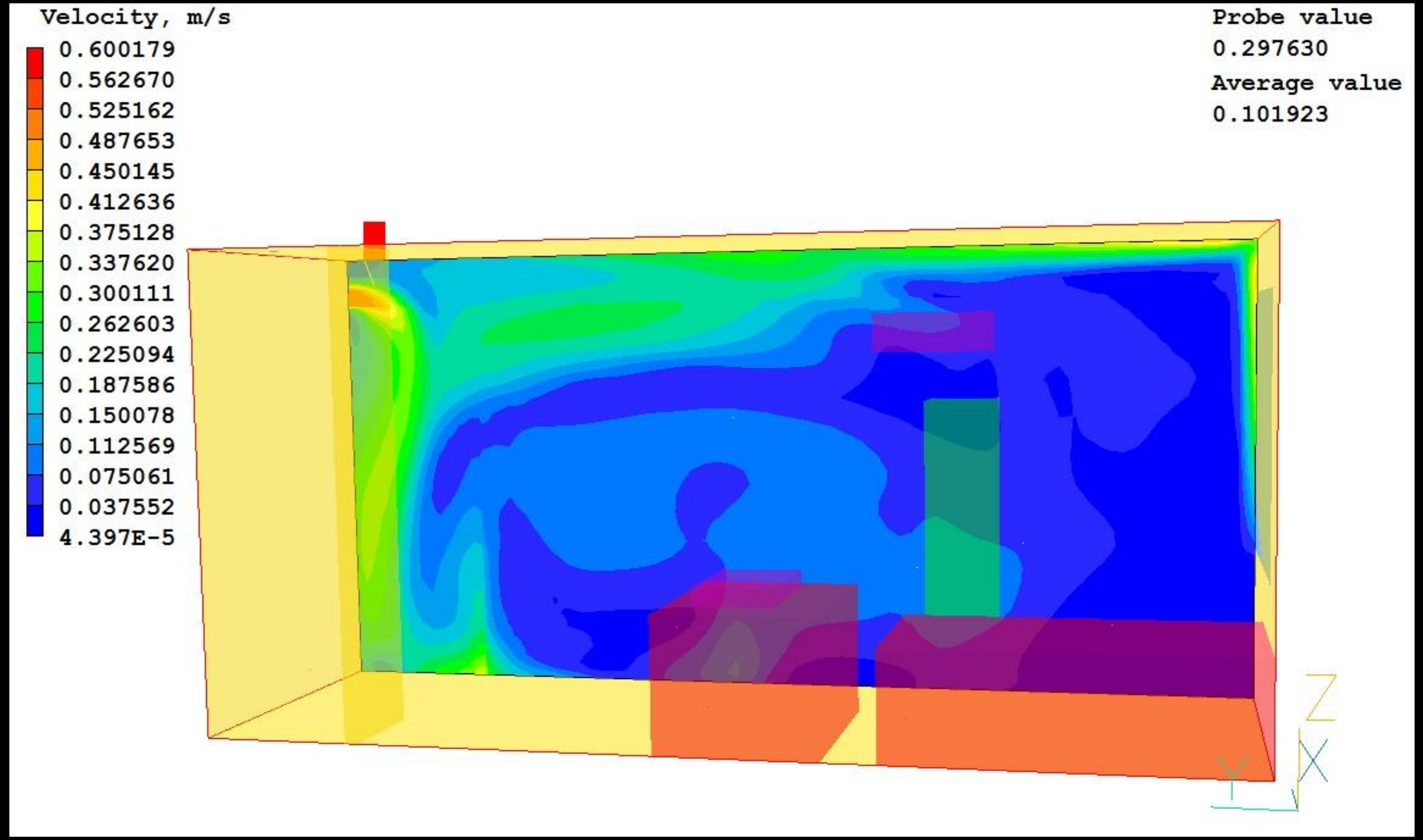
Analysis I - Dedicated Outdoor Air System

Velocity Profiles in a Typical Bedroom



Room with Fan Coil Unit
Maximum Velocity = 1.1 m/s



Room with Radiant Ceiling
Maximum Velocity = 0.6 m/s

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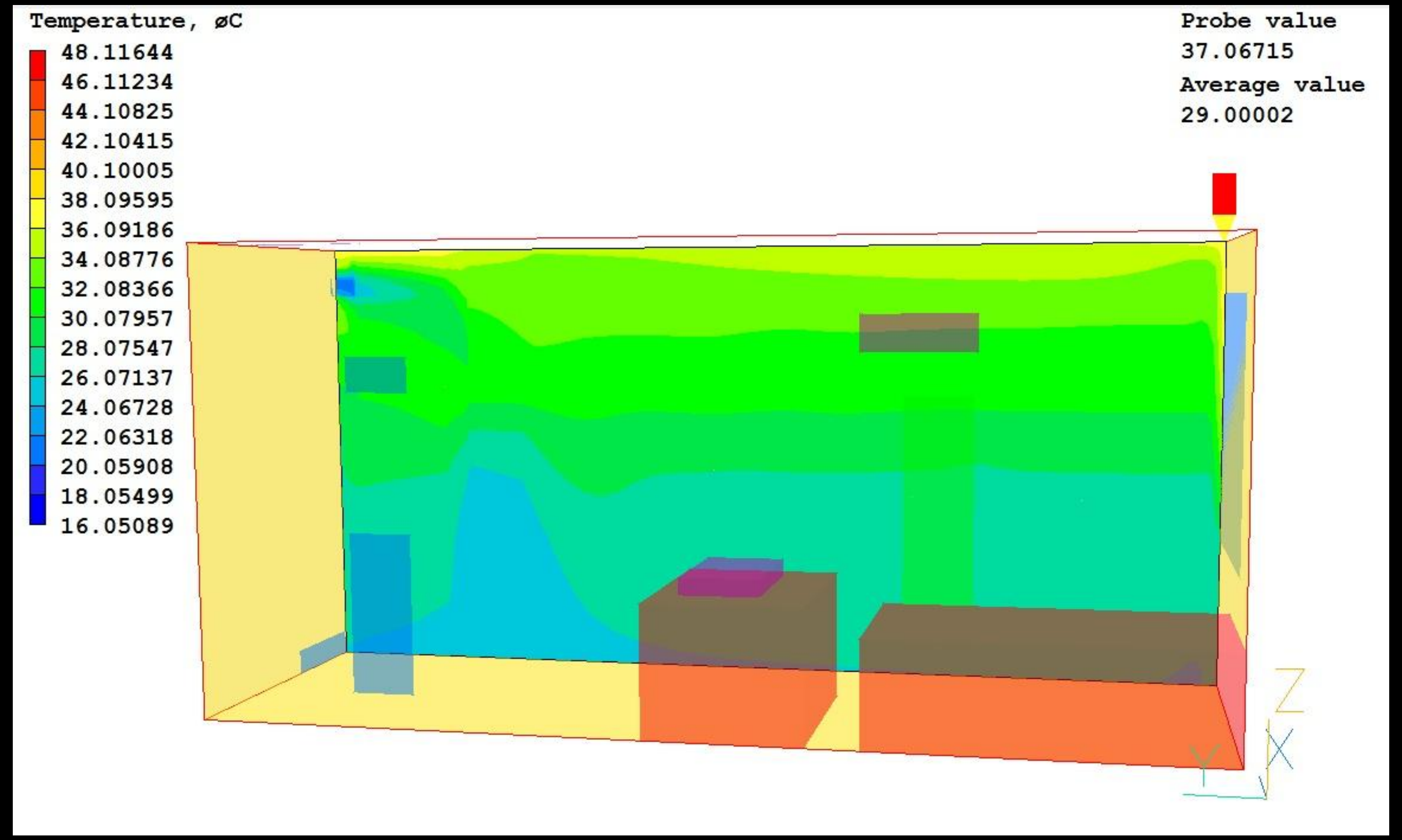
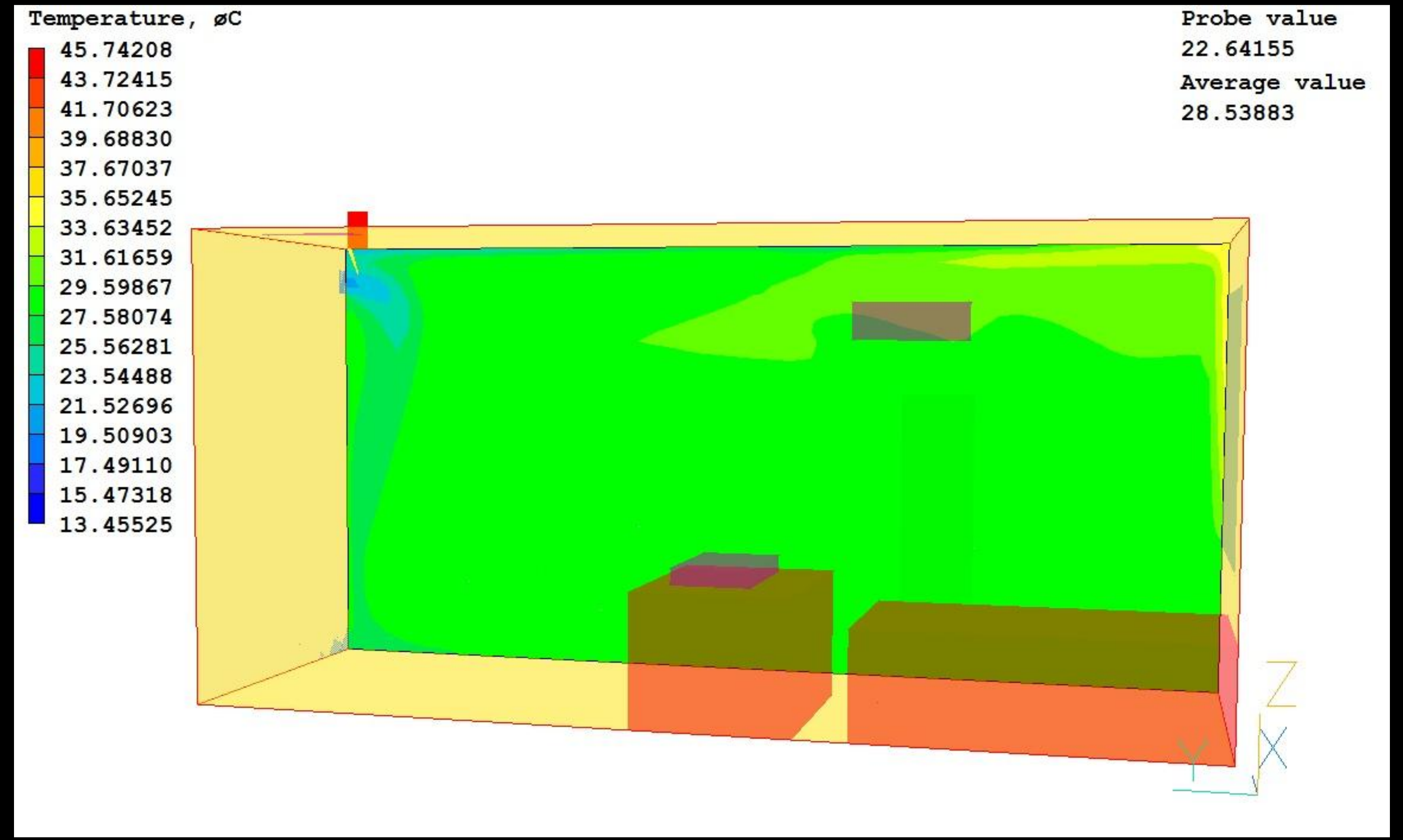
Analysis I - Dedicated Outdoor Air System

Temperature Profiles in a Typical Bedroom



Room with Fan Coil Unit



Room with Radiant Ceiling

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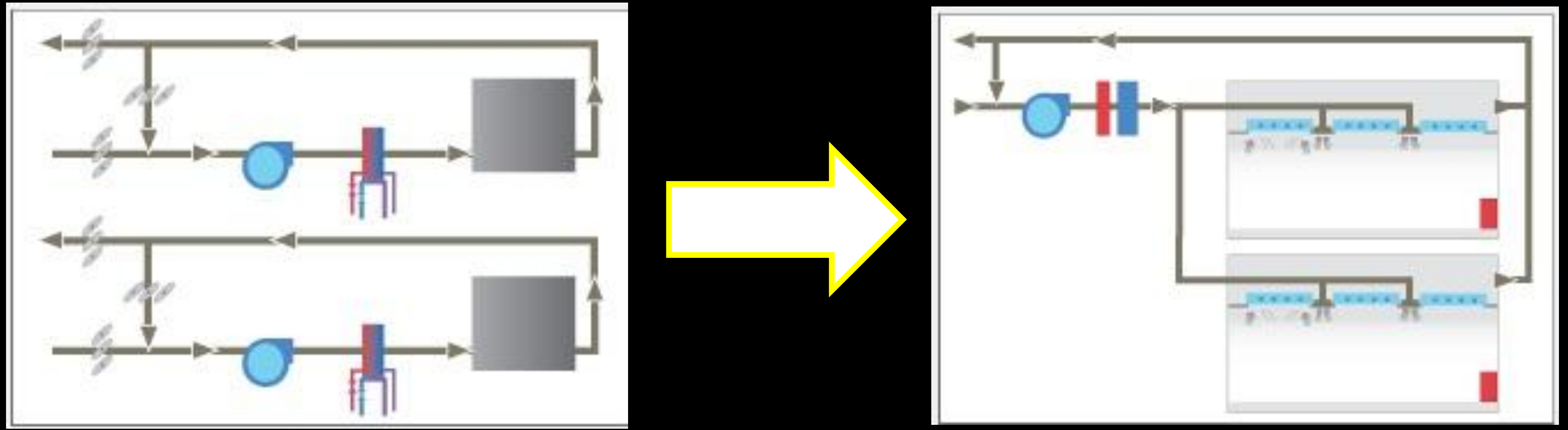
Analysis I - Dedicated Outdoor Air System

Energy Analysis

- In comparison to the original design, DOAS with radiant ceilings and baseboard radiators:
    - Consumes 12,545 kW-hr LESS per year
    - Consumes 6,611 therms MORE per year
    - **Costs $7,370 MORE per year to operate**



Annual Energy Costs		
	Fan Coil Unit Model	Radiant Ceiling Model
Total Annual KW-hr Used	169, 472 kW-hr	156,927 kW-hr
Annual Cost of kW-hr Consumption	$14,744	$13,653
Total Annual therms used	6,624 therms	13,235 therms
Annual Cost of therm Consumption	$8,479	$16,941
Total Annual Energy Cost	**$23,223**	**$30,594**

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Analysis I - Dedicated Outdoor Air System

System Cost Comparison

DOAS with radiant ceilings and baseboard radiators costs $186,528 LESS than DOAS with fan coil units

Fan Coil Unit Dedicated Outdoor Air System Cost				
Component of System	Quantity	Unit	Cost/Unit	Total Cost
Energy Recovery Unit (20,000 cfm)	1	Each	$150,570	$150,570
Supporting ductwork and mechanical equipment	1	Each	$796,676	$796,676
4-Pipe Whalen Fan Coil Unit	257	Each	$3,240	$832,680
			TOTAL:	$1,779,926

Radiant Ceiling Dedicated Outdoor Air System Cost				
Component of System	Quantity	Unit	Cost/Unit	Total Cost
Energy Recovery Unit (20,000 cfm)	1	Each	$150,570	$150,570
Supporting ductwork and mechanical equipment	1	Each	$796,676	$796,676
SlantFin Multi/Pak 83A Baseboard Radiator	689	Linear Foot	$18	$12,402
Barcol-Air CB Aqua 2' x 4' radiant ceilng panel	4482	Each	$86	$385,452
Setup cost of radiant ceiling	1	Each	$650	$650
Barcol-Air nipple connector	1794	Each	$6	$10,764
Barcol-Air flexible hose with quick connector	5379	Each	$18	$96,822
Steel Ceilings Inc. 2' x 4' steel ceiling panel	4482	Each	$31.25	$140,062
			TOTAL:	$1,593,398

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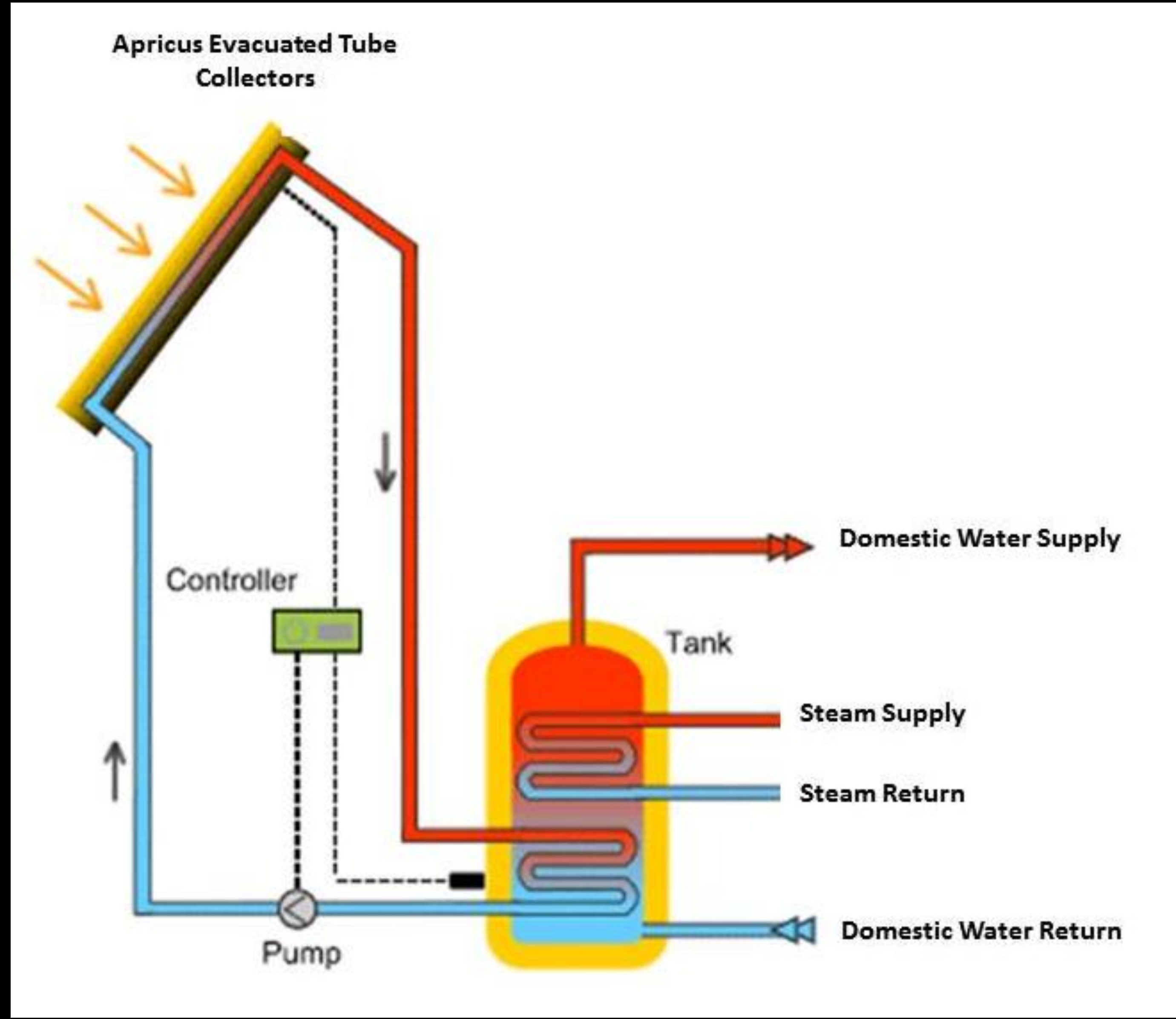
Analysis II - Solar Thermal System

Design Overview

- Antifreeze loop with internal heat exchanger in existing domestic hot water tank
- Solar hot water heat exchanger will preheat domestic water in series with existing steam heat exchanger



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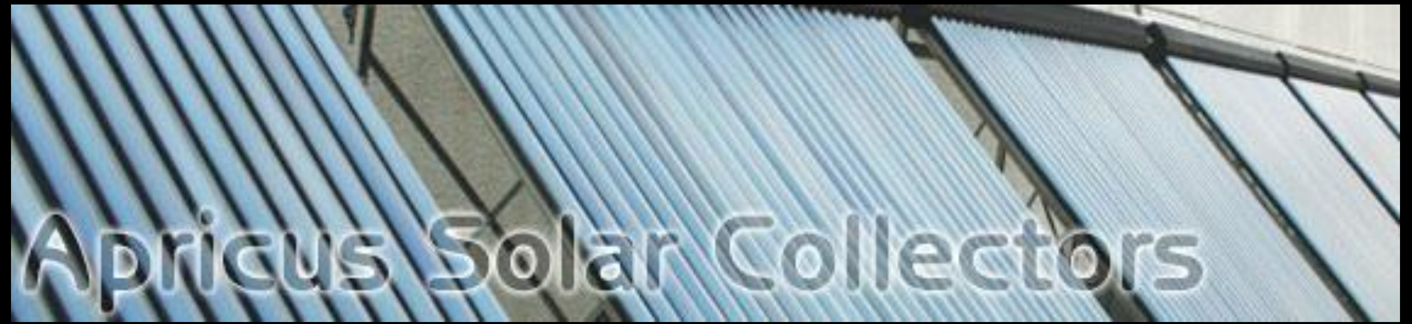
Analysis II - Solar Thermal System

Design Overview

- Antifreeze loop with internal heat exchanger in existing domestic hot water tank
- Solar hot water heat exchanger will preheat domestic water in series with existing steam heat exchanger

Chosen Manufacturers

- Apricus would supply the solar collectors
  - Evacuated tube collectors
- Sunmaxx Solar would supply the piping, pump station, accessories and controls



SunMaxx Solar™ Hot Water Solutions | An Investment with Real Returns

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Peter Edwards – Mechanical Option

Analysis II - Solar Thermal System

Solar Collector Array

- Apricus evacuated tube collectors
    - Better performance in cloudy and cold weather
    - 10 year warranty
- 21 AP-30 collectors in array
- All collectors are at least 10 ft. from the edge of the roof in accordance with OSHA regulations
- Array faces south
- All collectors positioned at 45° from horizontal

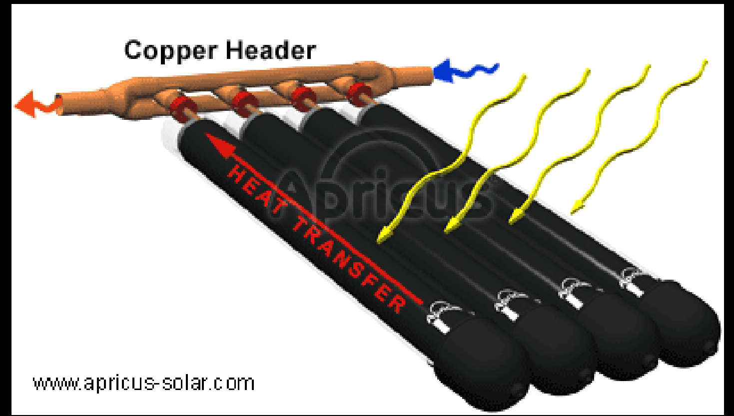
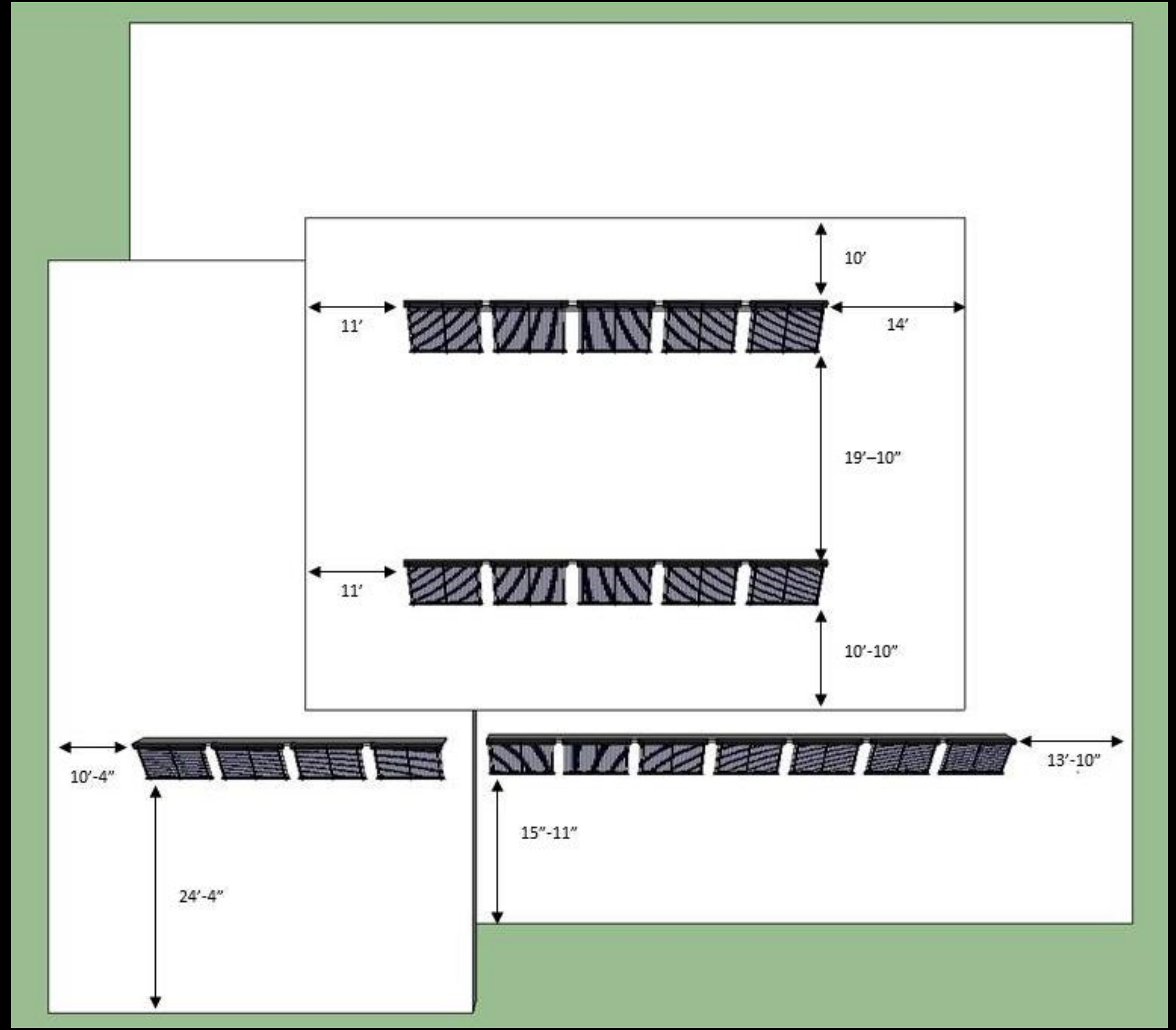


Diagram of an Apricus evacuated tube solar collector



Analysis II - Solar Thermal System

Energy Output

- Solar thermal system produces 1,551 therms per year
- Net efficiency of central steam plant and distribution network is 66%
- Therefore system saves the central steam plant **2,350 therms** per year

Energy Output For Solar Thermal Array	
Insolation Level	3.53 kWh/m²/day
Absorber Area/Collector	2.4 m^2
Number of Collectors	21
Total Absorber Area	50.4 m^2
Average Energy Output Per Day	4.25 therms
Average Energy Output Per Month	127.5 therms
Energy Output Per Year	1551 therms
Equivalent Steam Energy Output per Year	**2350 therms**

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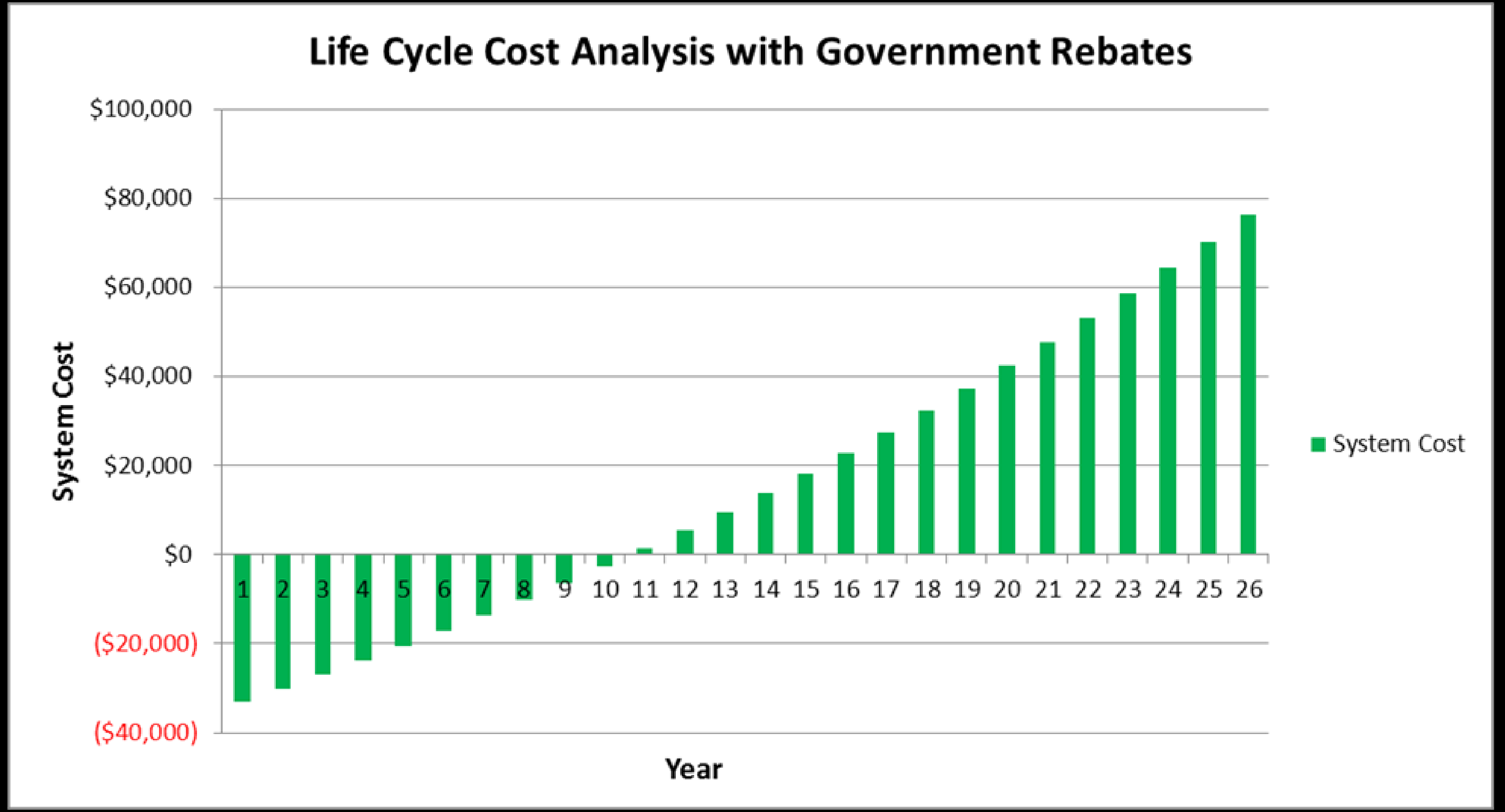
Analysis II - Solar Thermal System

Energy Output

- Solar thermal system produces 1551 therms per year
- Net efficiency of central steam plant and distribution network is 66%
- Therefore system saves the central steam plant **2350 therms** per year

Life Cycle Cost Analysis

- Total cost of system = $94,500
- Applicable Government Financial Incentives
  - Business Energy Investment Tax Credit: 30% of total system cost
  - PA Sunshine Solar Rebate Program: 35% of total system cost
- Payback period between 10 and 11 years with government incentives



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Daylighting Breadth

Daylighting Analysis

- A typical east facing bedroom and west facing bedroom was analyzed
- Models of both rooms were created and analyzed using AGI
- According to IESNA Lighting Handbook there should be at least 30 footcandles of light in each room
- The area of most concern in both rooms is the two desks

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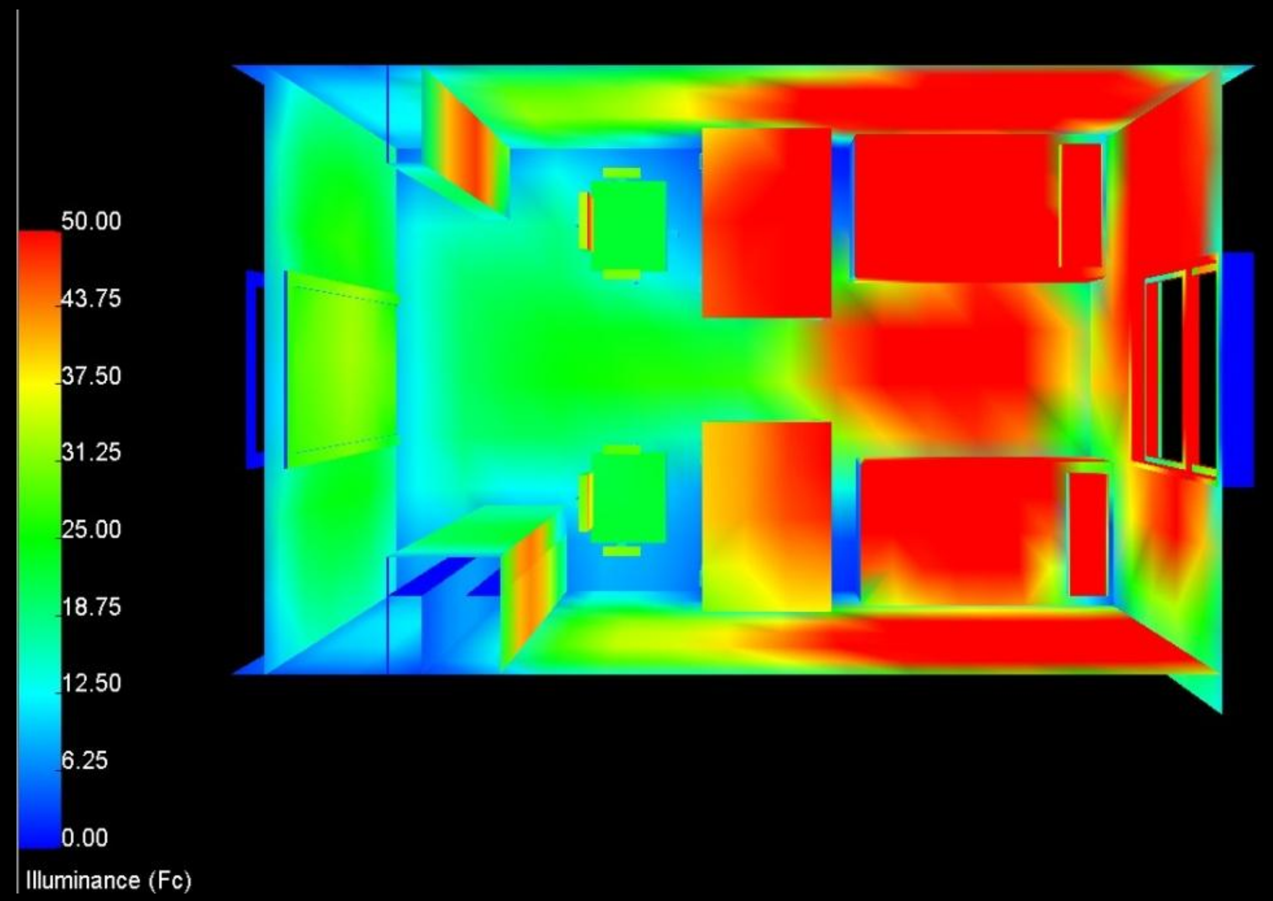
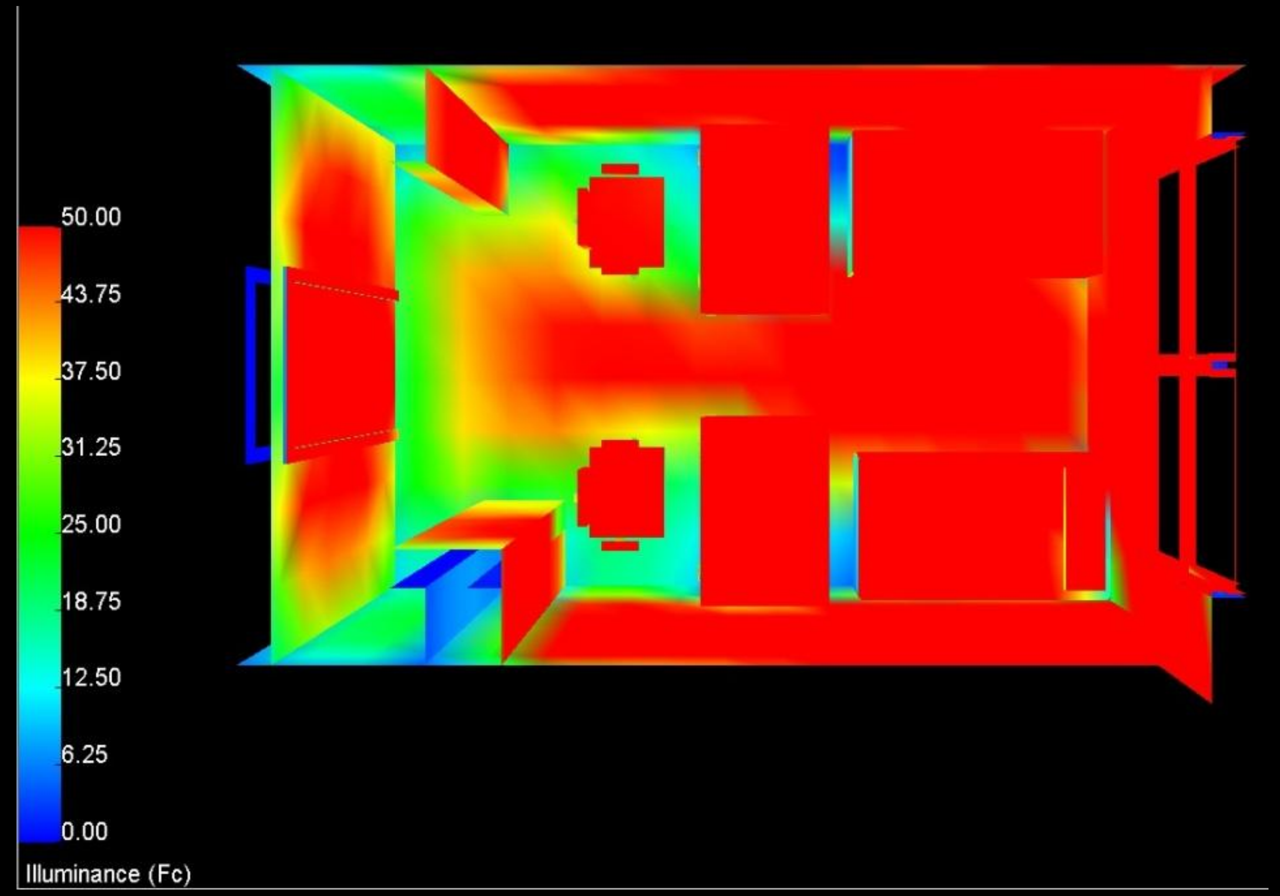
Daylighting Breadth

Illuminance Distribution in a Typical East Facing Bedroom



East facing room with 4 ft. by 5 ft. window at 10 AM on September 23rd



East facing room with 8 ft. by 5 ft. window at 10 AM on September 23rd

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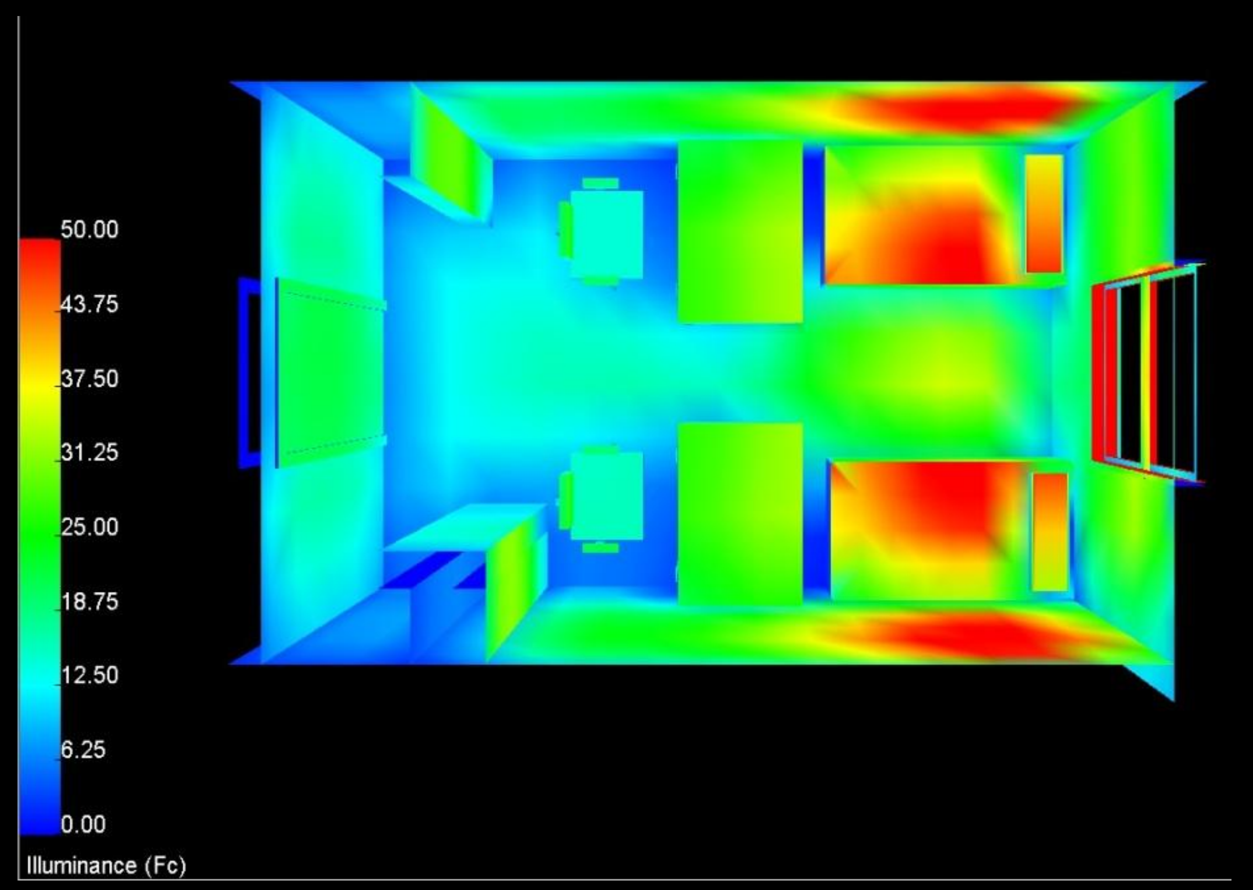
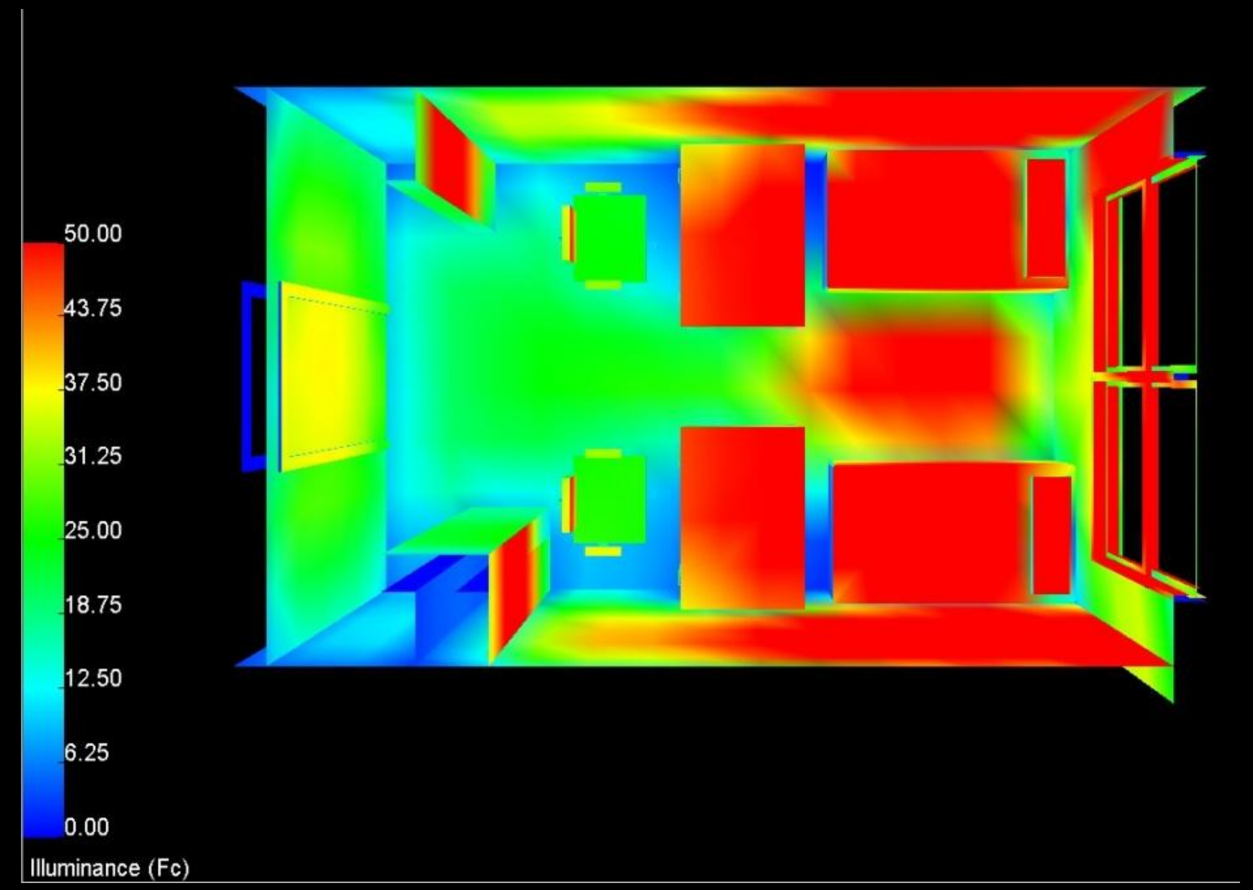
Illuminance Distribution in a Typical West Facing Bedroom



West facing room with 4 ft. by 5 ft. window at 1 PM on September 23rd



West facing room with 8 ft. by 5 ft. window at 1 PM on September 23rd

Presentation Outline

Daylighting Breadth

Results

- Larger windows were more beneficial for the west facing bedroom
- East facing bedroom had an average illuminance value well over 30 footcandles with the smaller window

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Building Envelope Redesign

Cost Analysis

Installation Cost of Building Envelope Redesign						
			Floor 2	Floors 3-11	Floor 12	TOTAL
Item Description	Cost/SF	Cost/Unit	Cost	Cost	Cost	Cost
PPG Solarban 60 window w/ NX-3500 aluminum frame		$1,211	$21,798	$272,475	$23,009	$317,282
Brick wall w/ 6" metal stud back-up	$21.75		($7,830)	($97,875)	($8,265)	($113,970)
TOTAL			$13,968	$174,600	$14,744	**$203,312**

Building envelope cost will increase by **$203,312**

Yearly Energy Cost For Des Places Residence Hall					
	Yearly Gas Consumption (therms)	Gas Cost	Yearly Electricity Consumption (KW-Hr)	Electricity Cost	**Total Cost**
Building with 4 x 5 windows	10,988	$14,099	622,456	$54,153	$68,252
Building with 8 x 5 windows	12,467	$15,983	625,360	$54,406	$70,389
Difference	1,479	$1,884	2,904	$253	**$2,137**

Yearly Energy costs for Des Places will increase by **$2,137**

Presentation Outline

- Building Overview
- Thesis Overview
- Existing Mechanical System
- Mechanical System Redesign Objectives
- Analysis I – Dedicated Outdoor Air System
- Analysis II – Solar Thermal System
- Analysis III – Building Envelope Redesign
    - Daylighting Breadth
- Conclusion
    - Final Recommendations
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    - Questions

Des Places Residence Hall

Peter Edwards – Mechanical Option

Conclusion

Final Recommendations

- **DOAS Redesign – RECOMMENDED**
    - Higher yearly energy costs, but less expensive system
    - Comfort of occupants will be increased
- **Solar Thermal System – RECOMMENDED**
    - Saves central steam plant 2,350 therms per year
    - Payback period under 11 years
- **Building Envelope Redesign – NOT RECOMMENDED**
    - Limited daylighting benefits
    - Significantly higher construction cost and yearly energy cost

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  - Daylighting Breadth
- Conclusion
  - Final Recommendations
  - Acknowledgements
  - Questions

Des Places Residence Hall

Peter Edwards – Mechanical Option

Conclusion

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Presentation Outline

- Building Overview
- Thesis Overview
- Existing Mechanical System
- Mechanical System Redesign Objectives
- Analysis I – Dedicated Outdoor Air System
- Analysis II – Solar Thermal System
- Analysis III – Building Envelope Redesign
    - Daylighting Breadth
- Conclusion
    - Final Recommendations
    - Acknowledgements
    - Questions

Des Places Residence Hall

Peter Edwards – Mechanical Option

Conclusion

Questions

Presentation Outline

- Building Overview
- Thesis Overview
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Conclusion

Inlet Boundary Conditions						
Fan Coil Unit Model						
Diffuser Type	Volume Flow Rate (m^3/s)	Gross Area (A_{gross})	Area Factor (A_o)	Σ (A_o/A_{gross})	Temp (˚C)	Temp (˚F)
Outdoor Air	0.014	0.15 m x 0.15 m	0.0225 m^2	100%	21	70
Fan Coil Unit	0.142	0.2 m x 0.36 m	0.0576 m^2	80%	12.8	55

Properties of Different Phoenics Models								
	Turbulence Model	Differencing Scheme	Iterations	Computation Time	Grid Size (X)	Grid Size (Y)	Grid Size (Z)	Mass Residual
Room with Heat Sources Only	LVEL	Upwind	2000	2 hr, 1 min	66	75	44	2.70%
Room with Fan Coil Unit	KEMODL	Upwind	4000	3 hr, 15 min	48	63	47	0.30%
Room with Radiant Ceiling	LVEL	Upwind	8000	8hr, 10 min	66	75	44	1.26%

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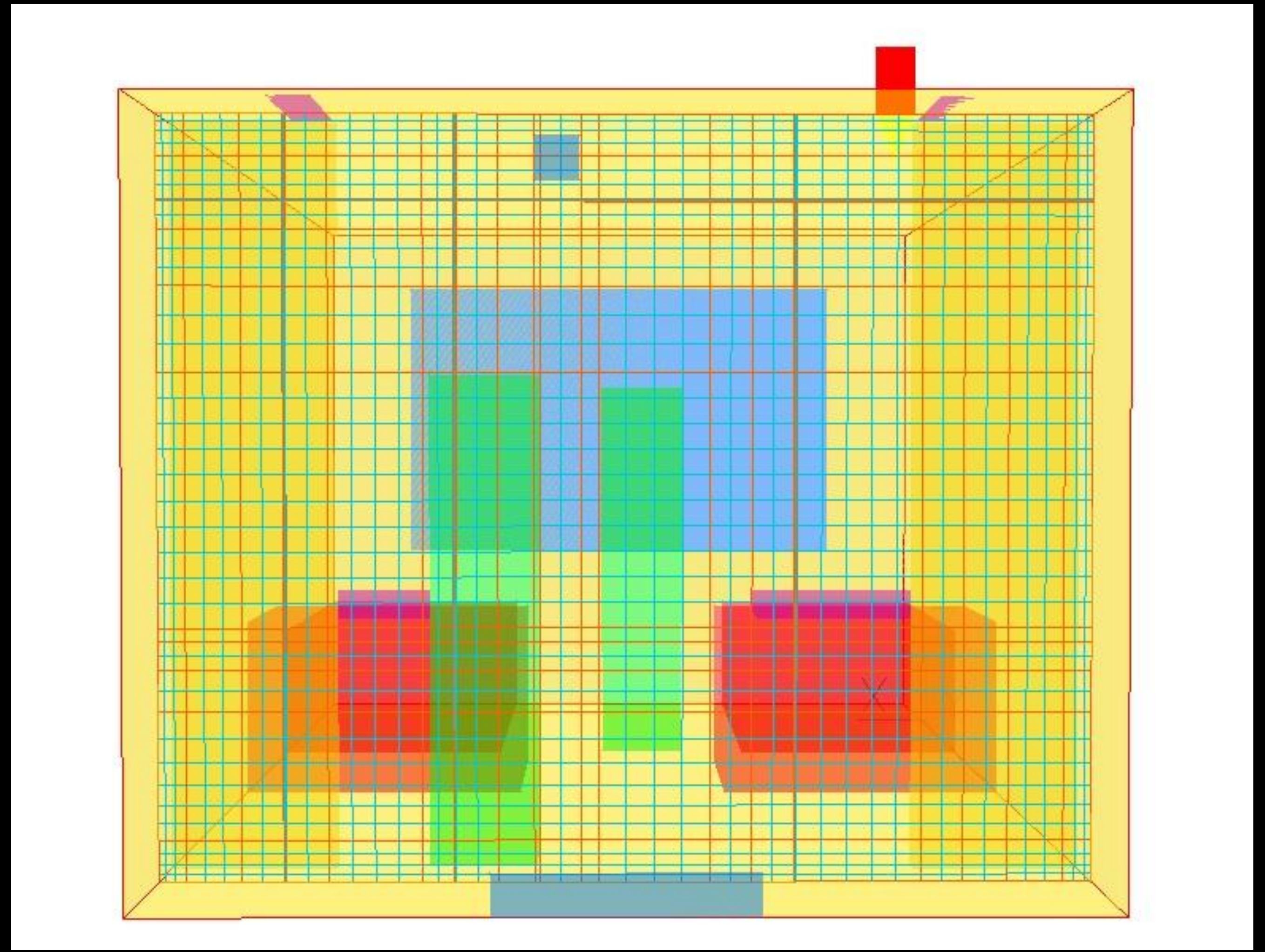
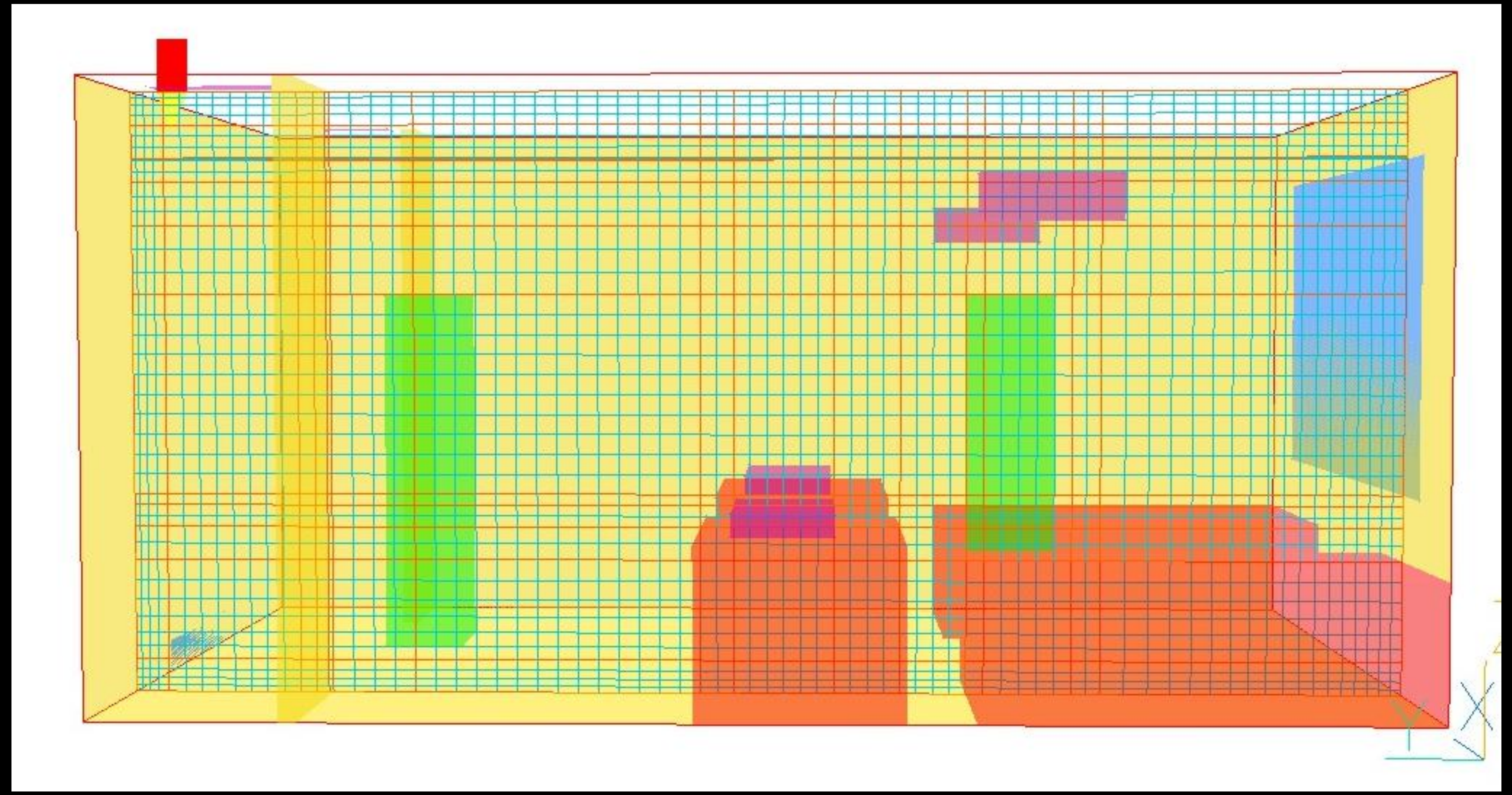
- Conclusion
- Additional Slides

Conclusion





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- Building Overview
- Thesis Overview
- Existing Mechanical System
- Mechanical System Redesign Objectives
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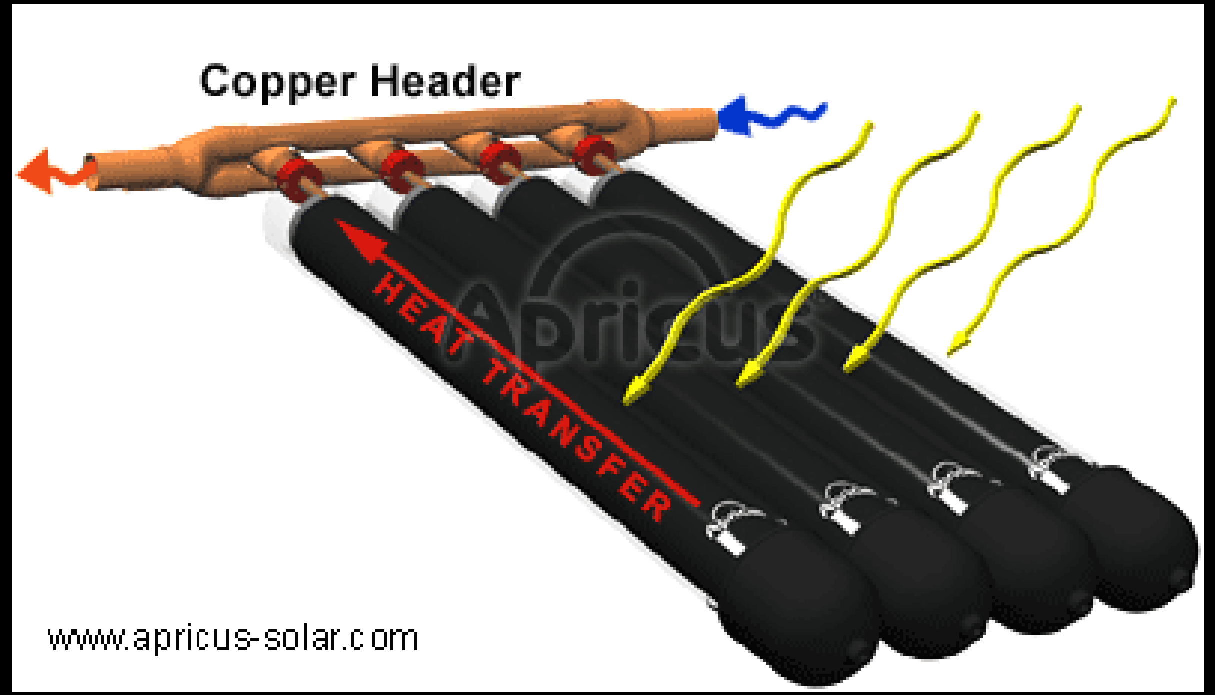
- Additional Slides

Conclusion



Apricus Solar Collector General Specifications	
Manifold Casing Material	Aluminium (grade 3A21)
Frame Material	1.5mm 304 Stainless Steel
Header Pipe Material	99.93% pure Copper & lead free 45% silver brazing
Insulation	Compressed Glass Wool - K = 0.043W/mK
Rubber Seals and Rings	HTV grade silicone rubber
Optimal installation angle	20-70o Vertical, -5o to +5o Horizontal
Maximum Operating Pressure	8bar - 116psi
Optimal flow rate	0.1L/min/tube - 0.026G/min/tube
Performance Data (SPF)	Conversion Factor: ho = 0.717 Loss Coefficients: a1 = 1.52, a2 = 0.0085

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- **Additional Slides**

Des Places Residence Hall

Peter Edwards – Mechanical Option

Conclusion