McCarran International Airport
Terminal 3
Las Vegas, NV

Evaluation of Underfloor Air Distribution and Displacement Ventilation Systems

The Pennsylvania State University
AE Senior Thesis Presentation, Spring 2008

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Mechanical Option

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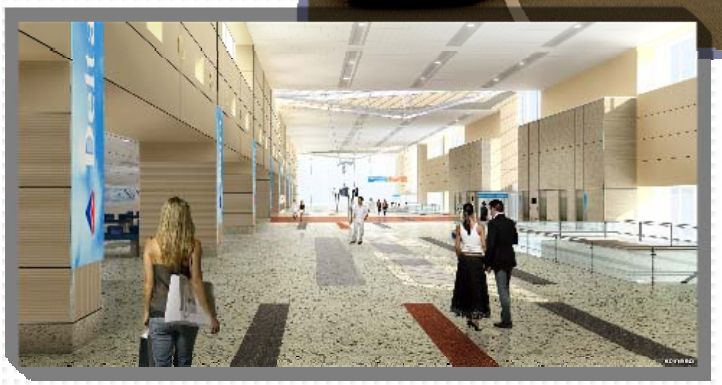


Outline

- Building Background and Existing Mechanical Conditions
- Mechanical Redesign
- Access Floor Design Breadth
- Acoustical Breadth
- Conclusions

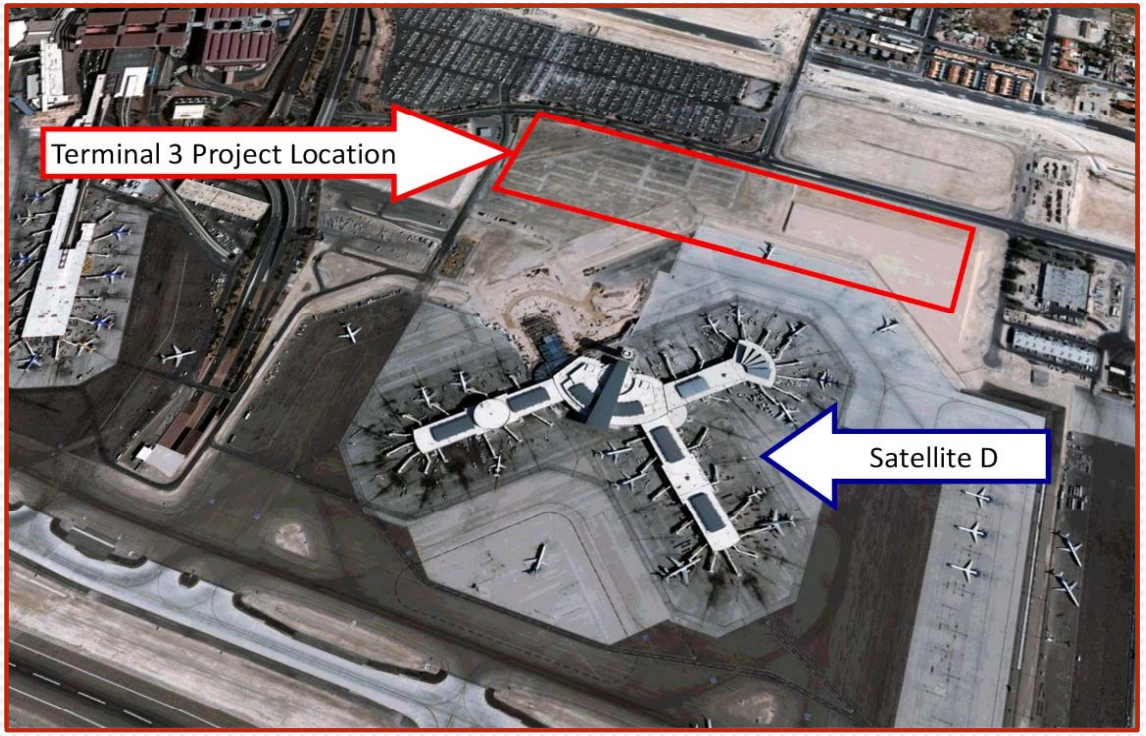
Terminal 3 Background

Location
- Las Vegas, NV

Owner
- Clark County Department of Aviation

Size
- 1.8 Million SF

Construction
- April 2007 – Mid 2012



Existing Mechanical Conditions

Waterside

- (5) 2,200 ton centrifugal chillers
  - Variable primary flow
- (6) 21,000 MBH water tube boilers

Airside

- (88) air handling units
  - 15,000 -55,000 CFM

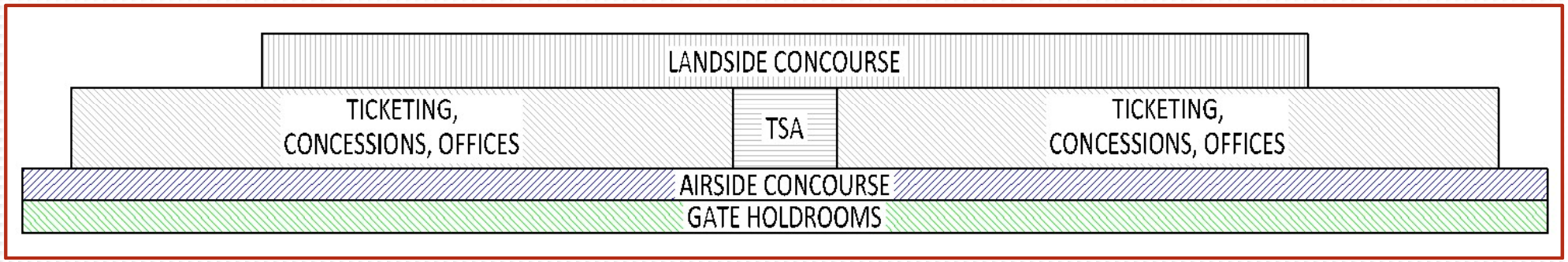
Outline

- Building Background and Existing Mechanical Conditions
- Mechanical Redesign
  - Introduction
  - Goals and applications
  - Revised load calculations
  - Ventilation modifications
  - New SA quantities and temperatures
  - System equipment
  - Initial cost impacts
  - Annual energy consumption and cost
- Access Floor Design Breadth
- Acoustical Breadth
- Conclusions

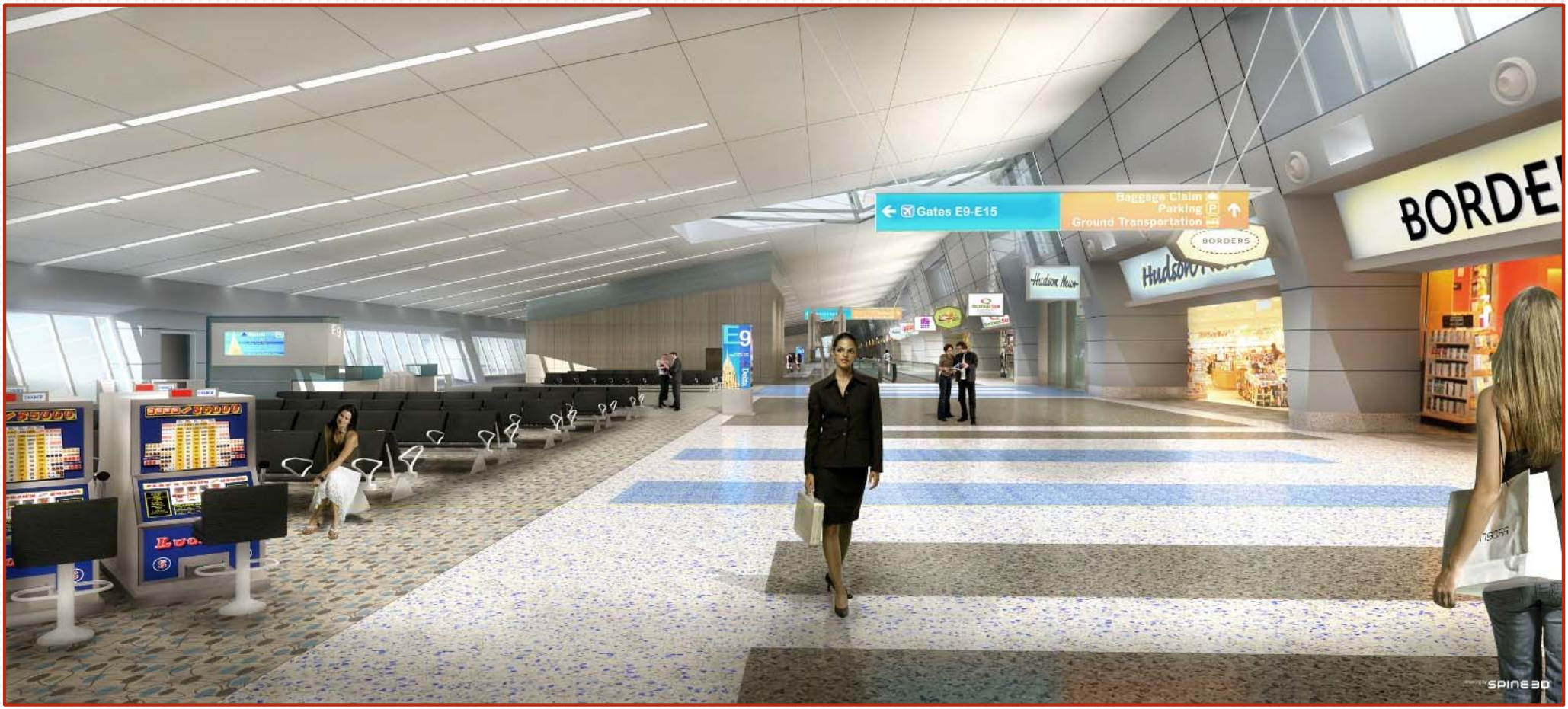
Mechanical Redesign Introduction

Focus on level 2 airside

- 14 gate holdrooms and adjacent concourse
- Area ≈ 170,250 SF
- Ceiling slopes from 12’-6” above finished floor to 30’-6”



Level 2 Key Plan



Interior Rendering of Redesigned Area (Courtesy PGAL, LLC)

Mechanical Redesign Introduction

Existing system is a traditional overhead mixing type

- VAV system served by 11 air handling units
- Linear ceiling diffusers in holdrooms
- Sidewall jet nozzle diffusers in airside concourse

Redesign Goals

Create a comfortable indoor environment

- Thermal comfort
- Indoor air quality

Minimize energy consumption

- Reduce annual operating costs

System Applications

Potential Benefits of UFAD and DV Systems

- Better ventilation effectiveness
- Reduced SA quantities
- Increased economizer operation

UFAD reserved for holdrooms

- Conceal floor diffusers

DV used in airside concourse

- Low sidewall diffusers

Revised Load Calculations

Must separate occupied and unoccupied zone loads:

- Occupied zone extends 6-8 feet above the floor
  - Loads must be conditioned through SA to the space
- Unoccupied zone is above the occupied zone
  - Stratification eliminates need for SA to this zone
- Coil must still handle both load types

There are many different opinions on the percentage of load transferred to each zone.

Revised Load Calculations

The UFAD load factors used for the redesign are based on various ASHRAE publications.

Component of Load	Occupied Zone Load Factors According to Various Research		Occupied Zone Load Factor Used for Design
	Minimum	Maximum	
Occupants	0.65	0.75	0.75
Lights (Fluorescent)	0.60	0.70	0.67
Equipment	0.67	0.70	0.67
Envelope Conduction	0.70	0.82	0.77
Envelope Solar	0.70	1.00	1.00

Revised Load Calculations

The DV load factors used for the redesign are based on the ASHRAE Design Guide.

Component of Load	Occupied Zone Load Factors According to Various Research		Occupied Zone Load Factor Used for Design
	Minimum	Maximum	
Occupants	0.295	0.670	0.295
Lights (Fluorescent)	0.132	0.500	0.132
Equipment	0.295	0.500	0.295
Envelope Conduction	0.185	0.820	0.185
Envelope Solar	0.185	1.000	0.185

Revised Load Calculations

Combined results indicate ≈50% reduction in load for the occupied zone.

System Type	Traditional Load [BTU/HR]	Redesigned Load [BTU/HR]	Difference [BTU/HR]
Underfloor Air Distribution	3,305,705	2,579,315	726,390
Displacement Ventilation	3,689,920	877,487	2,812,433
Total	**6,995,625**	**3,456,802**	**3,538,823**

Ventilation Modifications

Minimum outdoor air flow rates calculated in accordance with ASHRAE Standard 62.1-2007.

- Breathing zone outdoor air flow rate (V_{BZ}) remains unchanged
- Zone air distribution effectiveness (E_Z) varies
  - E_Z = 1.0 for existing systems
  - E_Z = 1.2 for redesigned systems
- Consequently, zone outdoor air flow (V_{OZ}) varies

$$\dot{V}_{OZ} = \frac{\dot{V}_{BZ}}{E_Z}$$

Ventilation Modifications

Increased ventilation effectiveness and re-zoning allows for 40% reduction in zone outdoor air flows at louver.

System Type	V_{ot}, Outdoor Air Intake Flow Required [CFM]
Exisitng Overhead Systems	129,760
Redesigned UFAD and DV Systems	77,083
Difference	**52,677**

SA Quantities and Temperatures (UFAD)

Higher UFAD SA temperatures are required to maintain thermal comfort in the space.

- Minimum advisable SA temperature is 64 °F
- Air temperature increases 4-7 °F directly above floor outlets
- ASHRAE Standard 55
  - Maximum 5 °F gradient between ankle and head

Calculations assume SA temperature of 65 °F for UFAD systems

SA Quantities and Temperatures (UFAD)

Supply air quantities calculated using occupied zone loads only:

$$\dot{V}_{\text{Cool, UFAD}}[CFM] = \frac{Q_{Total,OccupiedZone}[BTU/HR]}{(1.08)\times(T_{Setpoint} - T_{SA}[^{\circ}F])}$$

Return air temperatures based on total space load:

$$T_{RA}[^{\circ}F] = T_{SA}[^{\circ}F] + \frac{Q_{Total}[BTU/HR]}{(1.08)\times(\dot{V}_{SA}[CFM])}$$

SA Quantities and Temperatures (DV)

Higher SA temperatures are also required for DV systems, though they must actually be calculated.

- Air supplied slightly above the floor
- Occupants more sensitive to temperature from lower velocities

SA Quantities and Temperatures (DV)

Supply air quantities calculated using occupied zone loads only:

$$\dot{V}_{\text{Cool, UFAD}}\,[CFM] = \frac{Q_{Total,OccupiedZone}\,[BTU\ /\ HR]}{(1.08)\times(\Delta T_{hf}\,[^{\circ}F])}$$

Supply and return air temperatures based on total space load:

$$T_{SA}\,[^{\circ}F] = T_{Setpoint}\,[^{\circ}F] - T_{hf}\,[^{\circ}F] - \frac{A_{[SF]}\times Q_{Total}\,[BTU\ /\ HR]}{(2.33)\times(\dot{V}_{SA}\,[CFM])^2 + (1.08)\times(A_{[SF]})\times(\dot{V}_{SA}\,[CFM])}$$

$$T_{RA}\,[^{\circ}F] = T_{SA}\,[^{\circ}F] + \frac{Q_{Total}\,[BTU\ /\ HR]}{(1.08)\times(\dot{V}_{SA}\,[CFM])}$$

SA Quantities and Temperatures

Higher SA flow rates are required for both system types.

- Lower ΔT for redesigned systems
- Not enough reduction in occupied zone loads

System Type	Existing Supply Air Flow Rate [CFM]	Redesigned Supply Air Flow Rate [CFM]	Difference [CFM]
Underfloor Air Distribution	160,650	253,182	92,532
Displacement Ventilation	130,335	162,497	32,162
Total	**290,985**	**415,679**	**124,694**

Average SA temperatures:

- ≈ 65 °F for both UFAD and DV

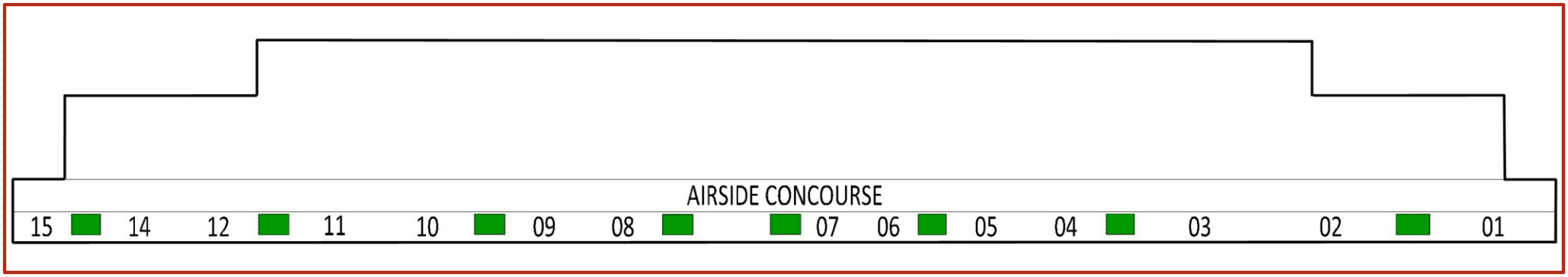
Average RA temperatures:

- ≈ 80 °F for UFAD and ≈85 °F for DV

Air Handling Equipment

Nine additional air handling units are required to provide the increased supply air quantities.

- Separate units to serve various system types
  - 7 for UFAD, 8 for DV, 5 for overhead mixing
- Additional space found above egress stairs

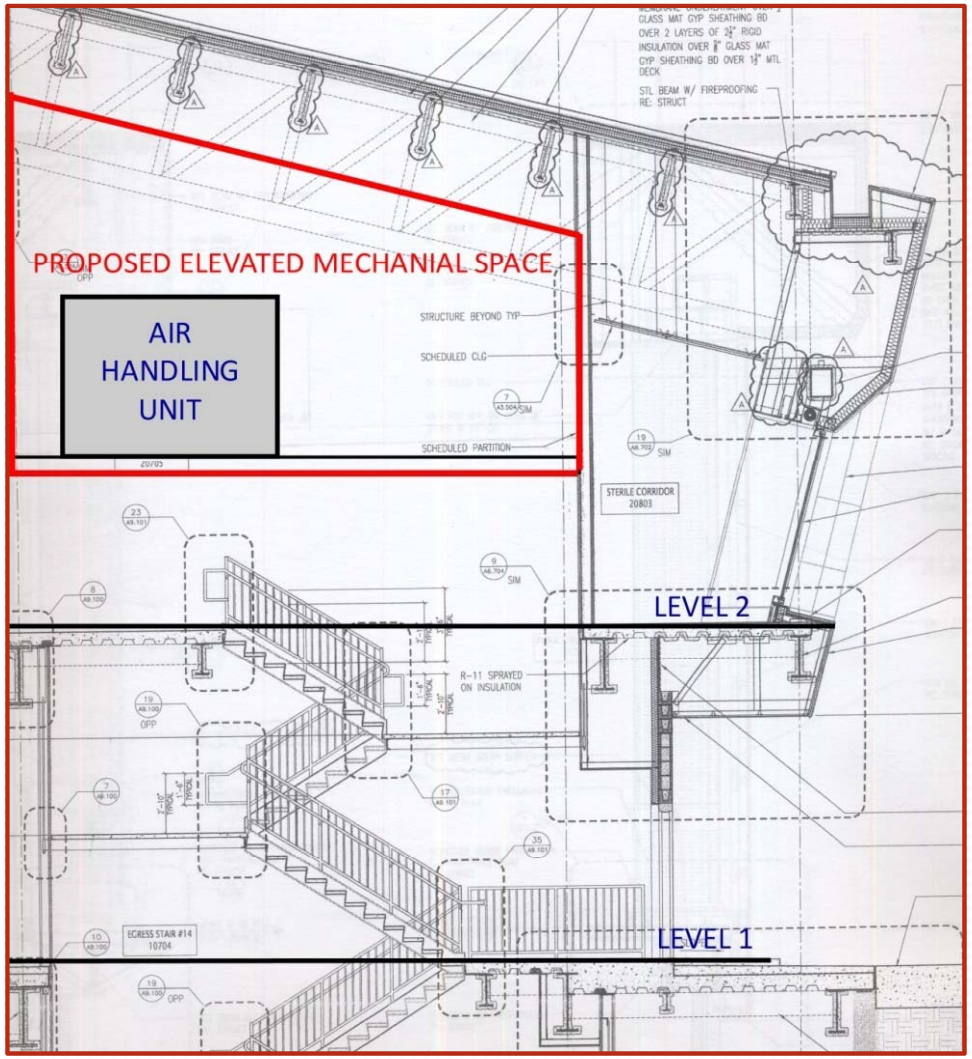


Location of Egress Stairs

Air Handling Equipment

Elevated mechanical space within egress stair towers

- 45’-6” x 29’-0”
- 8 units serving airside concourse
- Up to 25,000 CFM each
- Louvers located at low roof to maintain architecture



Section Through Egress Stairs

UFAD Equipment

Perimeter diffusers

- Linear floor grilles provide cooling or heating
- Used in Sterile Circulation and along south wall of holdrooms

Interior diffusers

- Round floor inclined flow diffusers
- Distributor baskets for debris

Underfloor terminal units

- VAV terminal units for all diffusers

Linear Floor Grilles

Round Floor Diffuser and Basket

DV Equipment

Displacement diffusers

- Sidewall rectangular diffusers
- Coverage area 20’-0” x 20’-0”

Traditional terminal units

- VAV terminal units

Duct covers when necessary

- Architectural integration

Displacement Diffuser and Cover

Initial Cost Impacts

Air handling units

- Cost data is obtained from actual design estimate

System Type	Capacity [CFM]		Total Cost
Existing System Air Handling Units	460,000		$2,023,580.00
Redesigned UFAD and DV Air Handling Units	560,000		$2,740,000.00
Total Cost Difference			**$716,420.00**
Total Cost Difference per SF	**170,251**	**SF**	**$4.21**

UFAD and DV equipment

- Cost data is obtained from manufacturer's budget pricing

Initial Cost Impacts

Total initial cost difference

Air handling units	= $716,420.00
UFAD components	= $104,369.36
DV components	= $230,497.22
Total	**≈ $1,051,287.00**

Total existing mechanical system cost ≈ $80.6 million

Reasonable increase given total project cost

Annual Energy and Cost Impacts

Economizer savings

- Higher supply and return air temperatures allow for increased economizer operation
  - Increase of 5 - 10°F in OA temperature range
- Bin analysis allows for estimate of energy savings

Annual Energy and Cost Impacts

Economizer savings

- UFAD systems
  - 2,735,358,255 BTU/yr
  - 39,385.4 BTU/SF-yr
- DV systems
  - 2,998,765,000 BTU/yr
  - 29,650.4 BTU/SF-yr
- Potential for large savings in annual energy consumption

Annual Energy and Cost Impacts

Trane TRACE is used to simulate the existing and redesigned systems taking into account:

- Economizer operation
- Outdoor air flow rates
- Supply air flow rates
- Other factors
  - Zoning
  - Fan static
  - etc.

Annual Energy and Cost Impacts

Annual operating costs

Utility	Annual Cost [$/yr]	Annual Cost per Square Foot [$/(SF*yr)]
Existing System		
Electricity	$627,893	$3.69
Natural Gas	$5,227	$0.03
Existing System Annual Cost	**$633,120**	**$3.72**
Redesigned System		
Electricity	$778,054	$4.57
Natural Gas	$13,707	$0.08
Redesigned System Annual Cost	**$791,761**	**$4.65**
Total Difference Between Systems	**$158,641**	**$0.93**

Annual Energy and Cost Impacts

TRACE actually indicates an increase in energy consumption:

- Increase of $0.93 per SF-yr in area of focus
- Increase of $0.09 per SF-yr for the total building area

Again, reasonable increases given building size

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Access Floor Breadth

Required for implementation of UFAD system

- Plenum height of 1’-0” to 1’-6”
- Maintain carpet finish

Line Number	Item Description	Quantity	Unit	Total Cost
09 69 13.10	**Access Floors**			
0250	Panels, particle board or steel, 1250# load, no covering; Over 6,000 SF	69,451	SF	$316,696.56
0600	For carpet covering, add	69,451	SF	$576,443.30
0910	For snap on strigner system, add	69,451	SF	$139,596.51
1050	Pedestals	17,365	Each	$257,870.25
--	Minus Existing Carpet	69,451	SF	-$296,555.77
			Total	**$994,050.85**
			Adjusted For Location (0.989)	**$983,116.29**
			Total Per Square Foot	**$14.16**

Access Floor Breadth

Cost

- ≈ $1 million

Architectural impacts

- Transition to concourse
- Two slab elevations required
- Jet bridges and baggage handling dictate elevation

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Acoustical Breadth

Existing conditions

- Sound attenuators for supply and return ductwork
- Duct lagging

Ambient noise

- Highly occupied, transient space
- Jet noise from exterior
- Fan noise likely minimal

Acoustical Breadth

Noise criteria (NC)

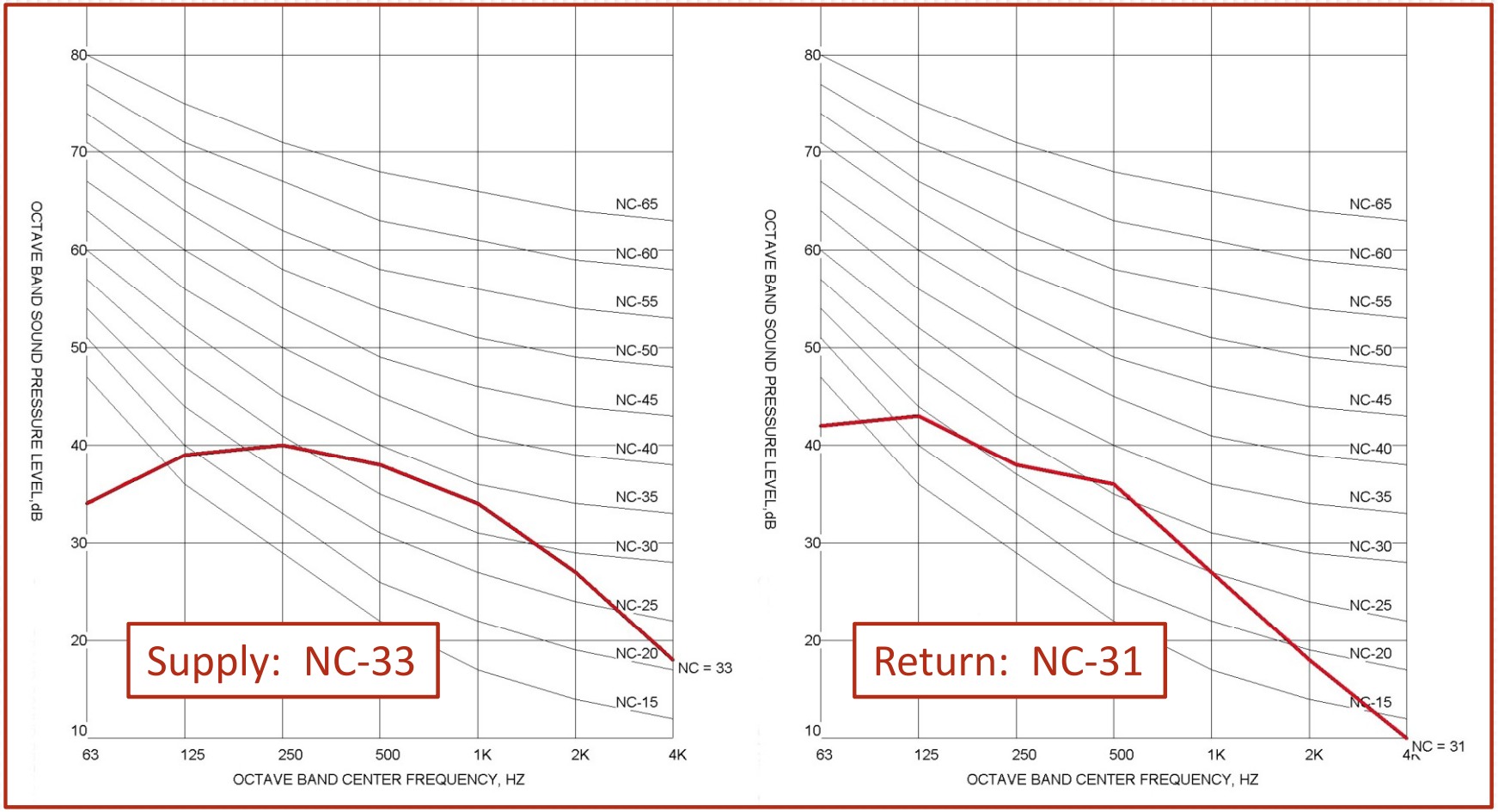
- Large public spaces, circulation
- NC-45

Trane Acoustics Program (TAP)

- Used to model duct layouts
  - Fans, ductwork, fittings, terminal units, diffusers, etc.
- Critical fan only

Acoustical Breadth

Results



NC Graphs for AH-5R Supply and Return Fans

Acoustical Breadth

Results

- Redesign within target NC
- Eliminate existing attenuation
- Savings of at least $50,000 in initial cost

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Final Conclusions

Initial cost

- Mechanical equipment ≈ $1,051,285
- Addition of access floor ≈ $983,115
- Sound attenuation ≈ -$50,000
- **Total increase in cost ≈ $1,984,400**

Annual cost

- Approximately $158,640 per year

Both are significant, though within reason

Final Conclusions

Benefits

- IAQ improved through stratification
- Increased economizer operation
- Sound attenuation unnecessary

Disadvantages

- Larger supply air quantities
- Additional equipment
- Complexities with access floor

Final Conclusions

As designed, UFAD and DV are likely not appropriate for these spaces in Terminal 3.

Supply air quantities must be minimized

- Reduced fan energy → Lower annual cost
- Reduced equipment → Lower initial cost

Final Conclusions

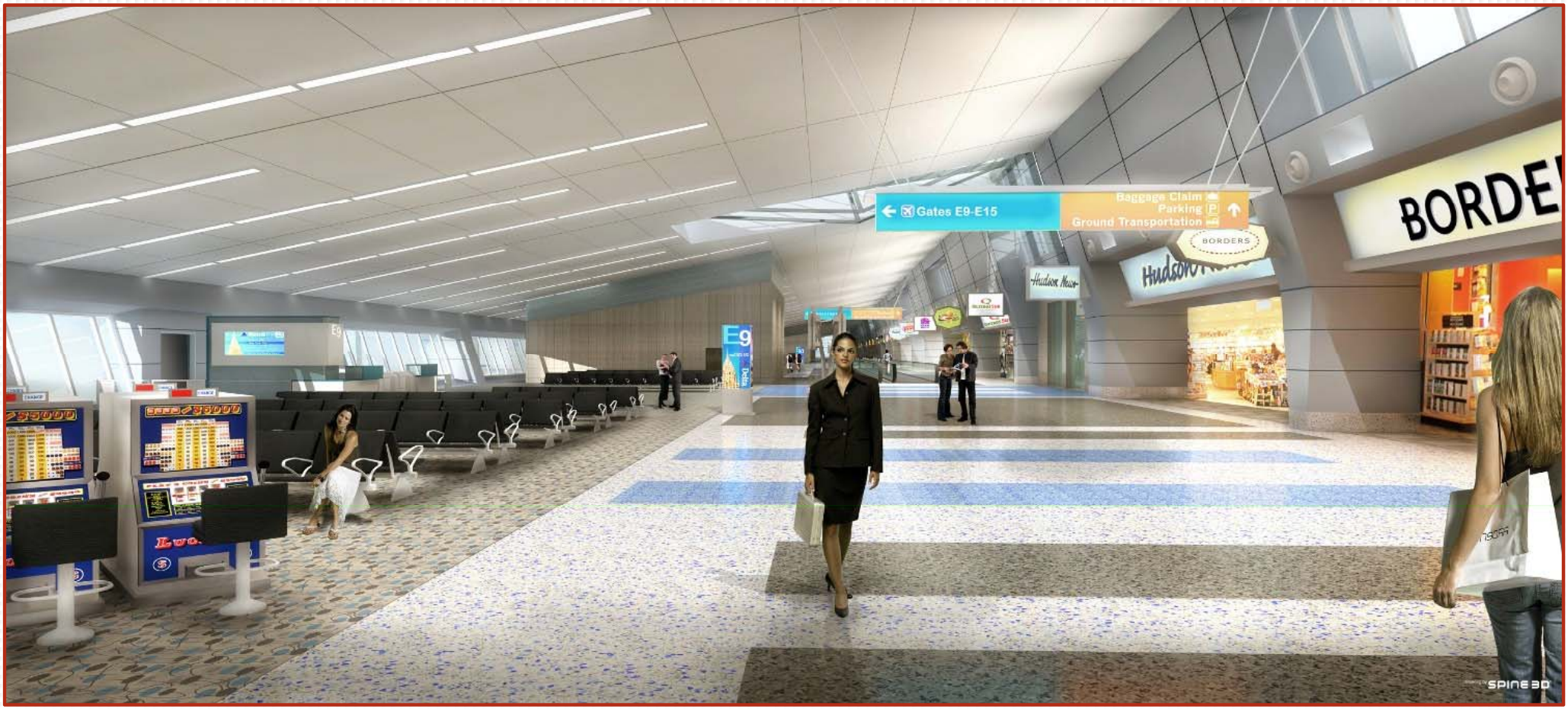
Strategies to reduce SA quantities

- Use sensible cooling panels
- Reduce solar load transmission

Better applications

- Less densely occupied areas
- Interior zones
- Less critical areas

Questions



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