Thermal Displacement Ventilation

Heritage K-12

Design Charrette

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John Arent
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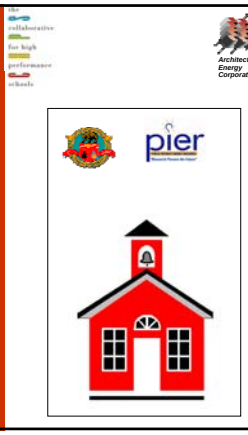

TDV is a part of a high performance classroom

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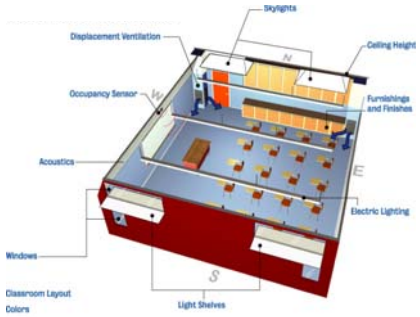
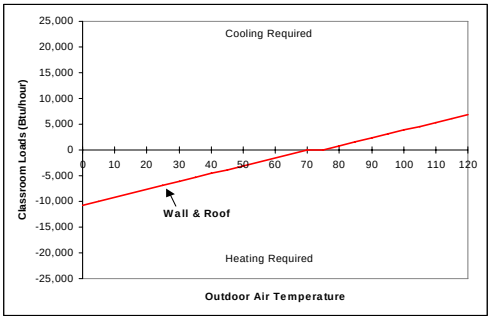


Balance Point Temperature

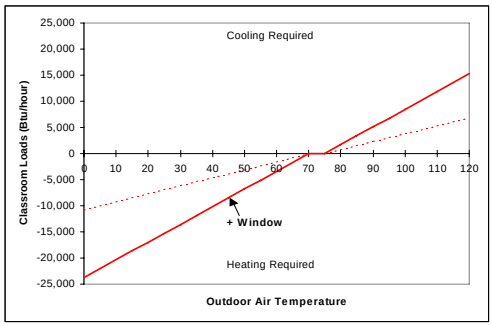
3



Thermal Loads in School

Balance Point Temperature (cont'd)

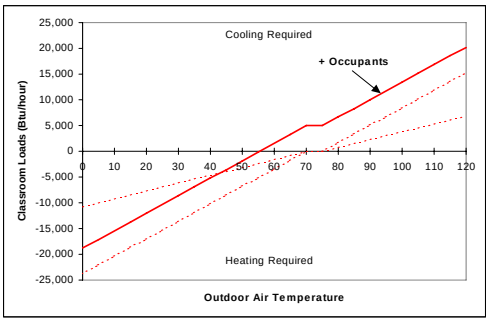
4



Thermal Loads in School

Balance Point Temperature (cont'd)

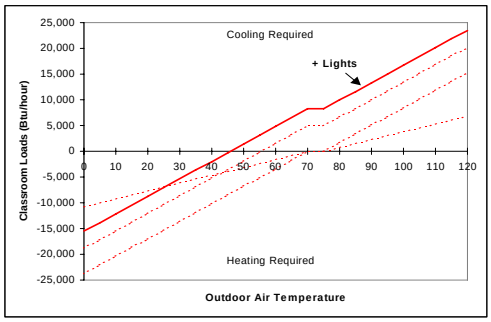
5



Thermal Loads in School

Balance Point Temperature (cont'd)

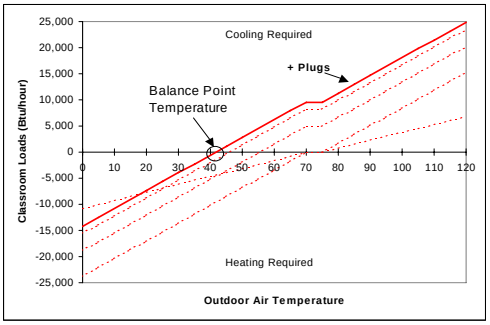
6



Thermal Loads in School

Balance Point Temperature (cont'd)

7

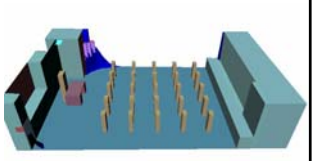


Thermal Loads in School

Design Details

8

- Deliver between 500 and 1000 cfm of 65 ºF air to each conventional classroom (more for computer labs or spaces with higher internal loads).
- Provide primary temperature control by varying the volume of air (provide less air if the space is overcooled and more if it is under cooled).
- Provide secondary temperature control by reducing or increasing the svupply air temperature.

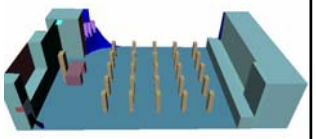


Courtesy Julianne Laue, PE
Dunham Associates,

Design Details

9

- Provide at least two diffusers in each classroom or a continuous diffusser under the casework on one wall (preferred). Deliver air at a low velocity, less than 75 ft/min.
- Locate the return air diffuser anywhere at the ceiling.
- Locate the thermostat 42 in. above the floor and at least 5 ft from the diffusers.

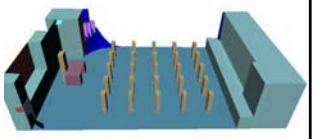


Courtesy Julianne Laue, PE
Dunham Associates,

Design Details

10

- In the Los Angeles climate, heating will only be needed prior to occupancy for morning warm-up or recovery from the school being closed for an extended period of time.
- Provide at least 500 cfm of outside air when the space is occupied.
- Initiate outside air ventilation at least an hour prior to occupancy.



Courtesy Julianne Laue, PE
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Benefits

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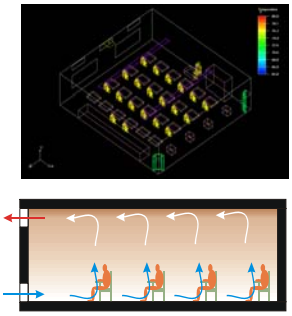
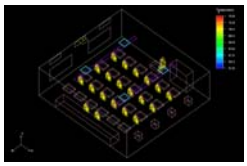
- Healthier environment; germs are not spread as easily
- Better thermal comfort
- Better air quality
- Improved acoustics
- Energy efficiency
- Compatible with operable windows and natural ventilation



Conventional Overhead System

12

- Constant volume, variable temperature
- 1,800 to 2,000 cfm of total supply air per classroom
- Supply temperature about 55 ºF, but with packaged systems, this varies widely
- About 500 cfm of outside air (the rest recirculated)
- Ventilation effectiveness of 1.0
- Air delivered at 600 to 800 ft/min (noisy)



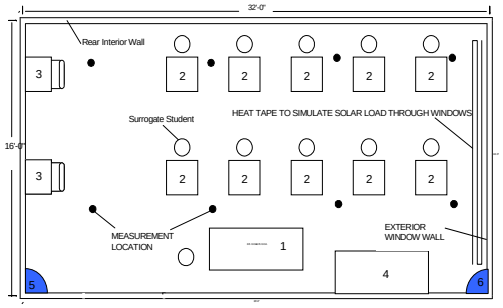
CFD Analysis: Objectives

13

- How many diffusers are needed? What are the delivery points?
- Where should the return be located?
- What supply air temperature can be used? What is the required airflow?
- What is the largest load for which TDV can be effective?
- Are drafts at floor level a problem?
- When is down draft from the window a problem in the winter? When is perimeter heat needed?
- How do operable windows affect performance?

Mockup Test Lab Layout

14

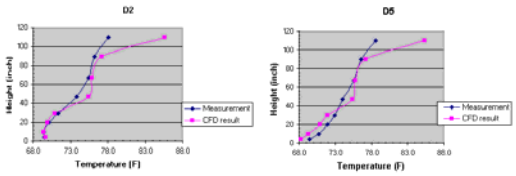


Photos of Test Facility

15

CFD Validation: Temperature Distribution

16



Vertical Temperature distribution near diffuser

CFD Validation: Air Velocity Prediction

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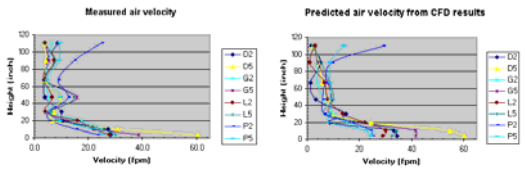

Air Velocity Prediction: velocity is generally <40 fpm

CFD Parametric Runs

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Case	Variation	Total Load (kBtu/h)
Baseline	None	15.39
12 ft Ceiling	High Ceiling, same loads	15.54
9 ft Ceiling	Low Ceiling, same loads	15.32
Poor Insulation	Roof Ins of R-11, no wall insulation	22.34
Three Exterior Walls	3 exterior walls, same fenestration	16.75
East Orientation	Exterior wall faces east	21.12
High solar heat gain	Unshaded single-glazing	25.72
Computer Laboratory	Computer at every desk	22.29
High Lighting Power	LPD of 2.0 W/ft^2	17.45
High Occupancy	30 students	17.30
Heating Simulation	Variable winter design conditions	

Results: CFD Simulation Runs

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		Average Temperature of 6 Room Locations			
Case	CFM	4 in	39.4 in	60 in	90 in
Baseline	1100	71.0	73.5	74.7	76.5
12 ft Ceiling	1100	70.5	72.8	73.9	75.2
9 ft Ceiling	1100	71.0	73.7	74.9	77.7
Poor Insulation	1600	70.2	72.1	73.7	76.2
3 Exterior Walls	1200	70.5	72.7	74.1	76.2
East Orientation	1510	70.7	72.3	74.1	76.7
High Window Area	1840	71.1	73.0	74.6	76.7
Computer Lab	1590	71.1	73.4	75.2	77.0
High Lighting Power	1250	70.4	72.6	73.9	75.8
High Occupancy	1250	71.1	73.5	74.7	76.2

Figure 3 – Locations in Room for Stratification Graphs

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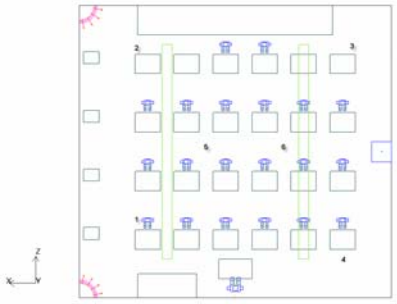
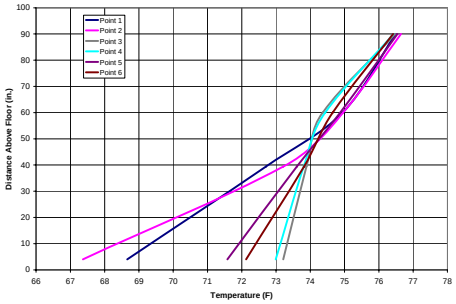


Figure 4 – Basecase, Temperature Stratification

21



Temperature

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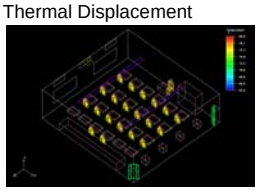
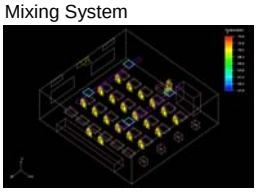
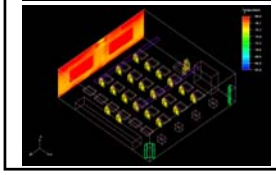
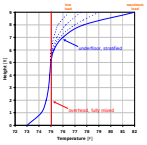
Thermal Displacement

Mixing System







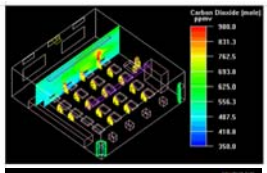


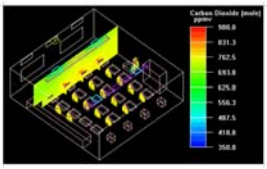
Carbon Dioxide Concentrations

23

Thermal Displacement

Mixing System



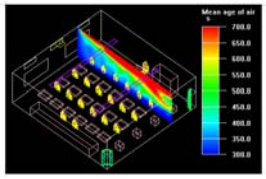


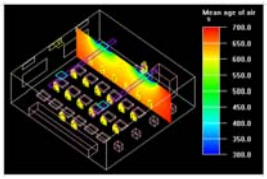
Mean Age of Air

24

Thermal Displacement

Mixing System

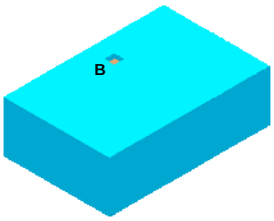




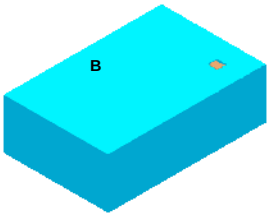
Germ Concentrations

25

Thermal Displacement



Mixing System



The occupant in cubical A has a cold and just sneezed

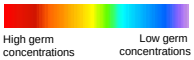


Figure 5 – Basecase, Vertical Temperature Slices

26

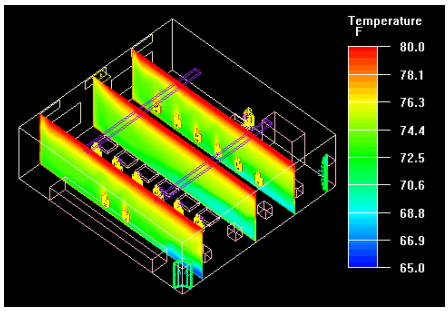


Figure 9 – Basecase, Horizontal PMV Slice at 4 in.

27

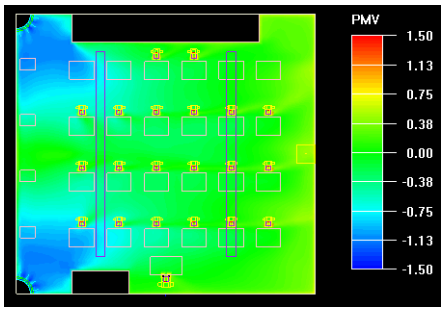
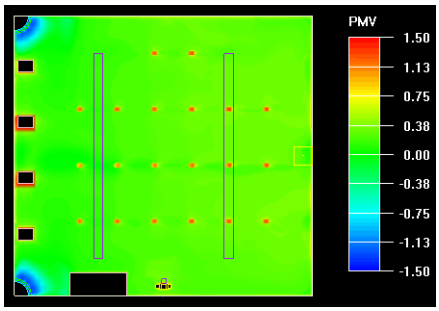


Figure 10 – Basecase, Horizontal PMV Slice at 39.4 in.

28



Basecase, Vertical CO_2 Slice

29

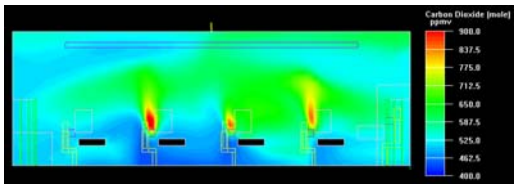
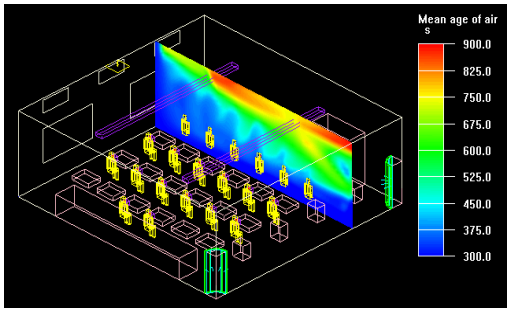


Figure 13 – Basecase, Mean Age of Air

30



Survey Key Findings

31

- Preference is packaged systems due to ease of design and maintenance
- Perceived higher initial cost with TDV and increased risk due to lack of experience
- Some concerns with using 100% outside air in hotter climates
- Some equated TDV with underfloor distribution systems
- Would be more readily considered if financial incentives were available
- Need for documented case studies to demonstrate that it works in California schools
- Need to focus on TDV system designs that are easy to maintain

Objectives: Demonstration Classrooms

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- Demonstrate the viability of TDV in two demonstration classrooms, one in northern California and one in southern California
- Install instrumentation to monitor air temperature and quality during typical classroom operations, and compare this to temperature and air quality in comparable conventional classrooms.
- Interview teachers and students on their experience with the system.
- Objective is to demonstrate that thermal comfort and IEQ can be maintained with a displacement ventilation system supplying 65F supply air near the floor through low velocity displacement diffusers

Coyote Ridge – "Packaged" Solution

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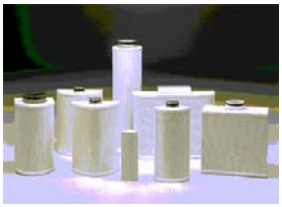
- A packaged heat pump is converted to a reversible chiller with a refrigerant-water heat exchanger and reversing valve
- System provides chilled water in cooling and warm water in heating mode
- Water storage tank provides capacity in the system to maintain a stable CHW/HW temperature, and in turn, SAT
- Control valve modulates water flow to air handler to maintain required SAT
- Trane Air Handler is custom modified to adapt to existing Carrier roof curb
- Control is linked to school's Alerton EMS

Displacement Diffusers

34



Diffusers can be recessed into the wall, surface mounted, mounted in the corner of the classroom, or under casework.

Diffuser at Coyote Ridge elementary school in Roseville, California

Coyote Ridge Control Operation

35

- The room temperature is maintained at the setpoint by varying the supply fan speed.
- The minimum SAT setpoint of 65F is used in cooling; the setpoint is raised as needed.
- The SAT setpoint is maintained by modulating a 3-way control valve.
- The compressor operation is controlled from the return water temperature (i.e., on at 65F, off at 59F).
- Compressor operation is locked out for cooling when within 3F of the setpoint; locked out for heating when within 1F of the setpoint.
- A SAT setpoint up to 80F is used in heating.

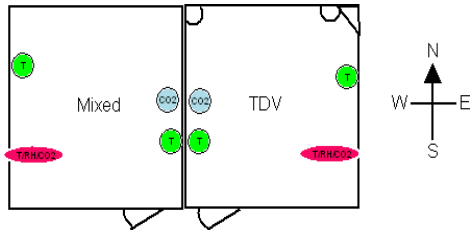
Coyote Ridge Monitoring Points

36

Measurements (for both classrooms)	Location	Qty	Purpose
Temperature	Near Interior Wall, 4 heights at three locations	24	Observe temp stratification, verify thermal comfort
Relative Humidity	In occupied zone, exhaust, outdoors	5	Thermal comfort
Carbon dioxide	In occupied zone, exhaust, outdoors	5	IAQ
HVAC System Power	Electrical Panel – power of heat pump, fans	4	Energy use of TDV system and conventional RTU
Supply Airflow and SAT	Alerton System Controller	2	Determine actual airflow requirements, diagnostics
Door and window status	Two windows, one exterior and one interior door	8	Account for external effects on temperature and CO_2

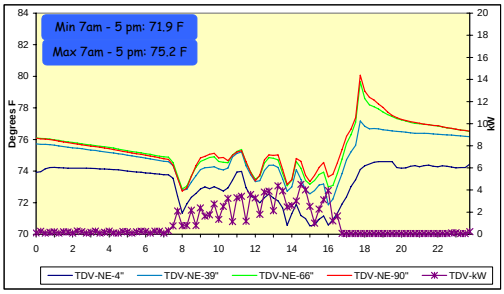
TDV Monitoring Sensor Layout

37



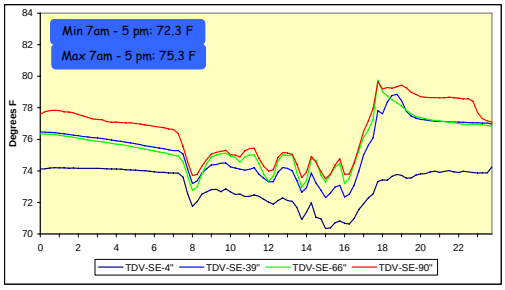
TDV Room Temps, Sept 7, 2004 - NE

38



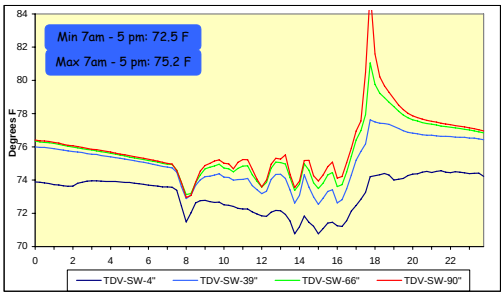
TDV Room Temps, Sept 7, 2004 - SE

39



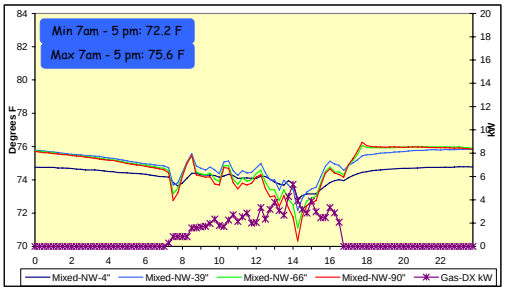
TDV Room Temps, Sept 7, 2004 - SW

40



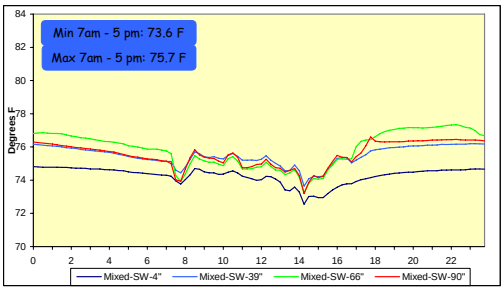
Conventional Room Temps, NW

41



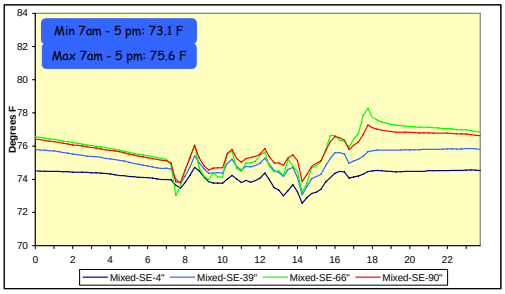
Conventional Room Temps, SW

42



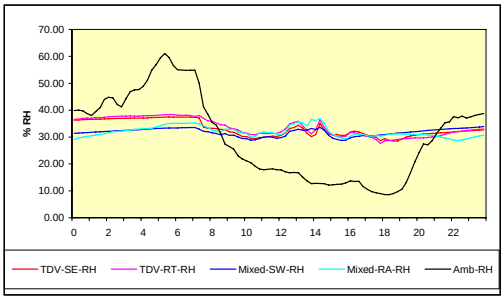
Conventional Room Temps, SE

43



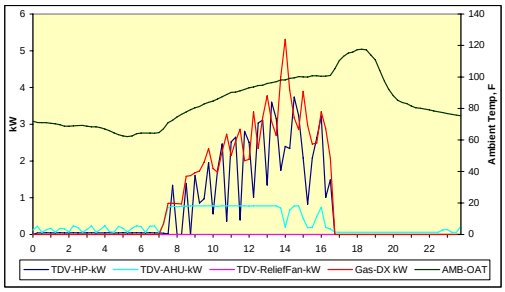
Relative Humidity, Sept 7, 2004

44



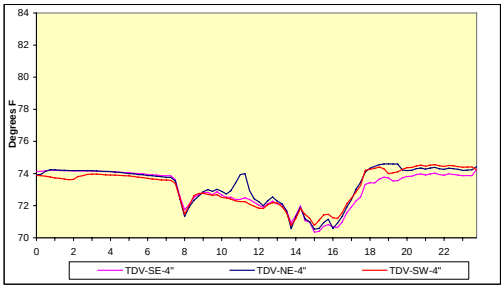
HVAC Consumption, Sept 7, 2004

45



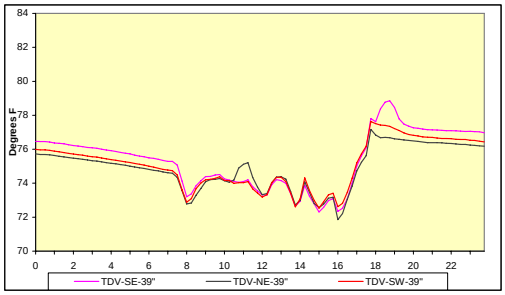
TDV Room Temp Comparison at 4" (9/7)

46



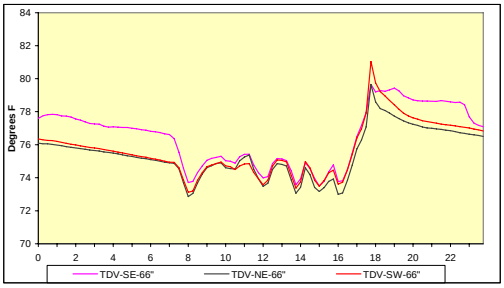
TDV Room Temp Comparison at 39" (9/7)

47



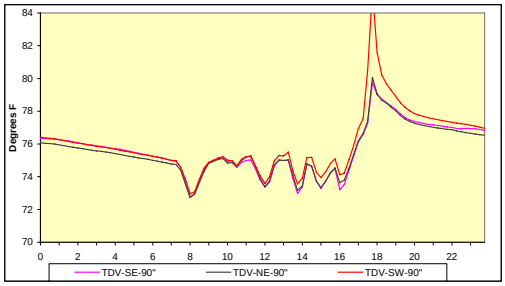
TDV Room Temp Comparison at 66" (9/7)

48



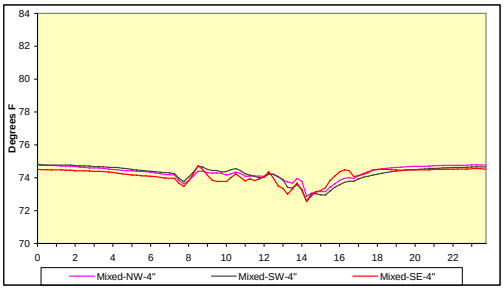
TDV Room Temp Comparison at 90" (9/7)

49



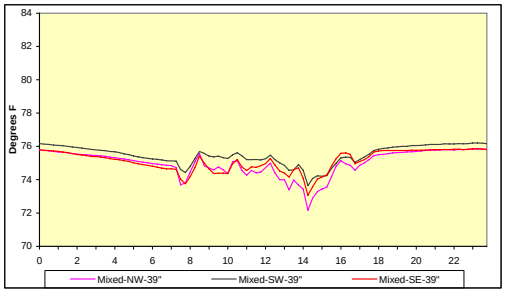
Conventional Room Temp Comparison at 4" (9/7)

50



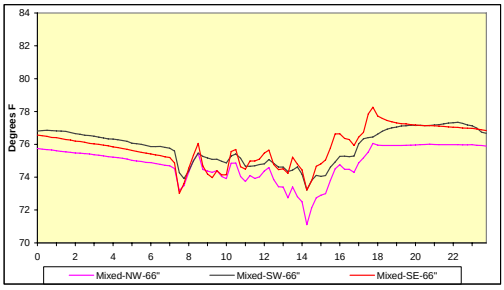
Conventional Room Temp Comparison at 39" (9/7)

51



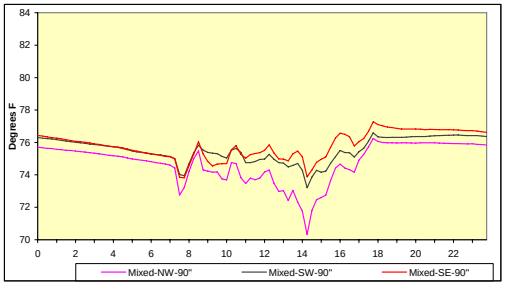
Conventional Room Temp Comparison at 66" (9/7)

52



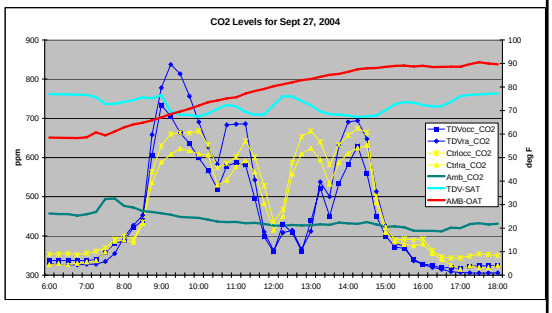
Conventional Room Temp Comparison at 90" (9/7)

53



Carbon Dioxide Comparison (9/27)

54



Conclusions: Coyote Ridge

55

- **Supply air flow of 1100 cfm and minimum SAT of 65F does provide sufficient cooling at design conditions**
- **Survey results are very positive for TDV on comfort, perceived air quality and acoustics**
- **Temperature stratification is established in the classroom, although not as large as that predicted by empirical models**
- **Floor temps are maintained at comfortable levels (72F) with current implementation**
- **Demonstrates good ventilation effectiveness**
- **Provides adequate comfort in the heating season, with higher air velocity**
- **Even with 100% outside air, the TDV system uses the same energy as the conventional unit with return air**

Load Calculations with TDV

56

Calculation procedure:

1. **Itemize the cooling loads and estimate the fraction of the cooling loads convected to the occupied space.**
2. **Specify: space setpoint, supply air temperature or comfort condition (ΔT_{hl}).**
3. **Determine supply airflow from energy balance on the occupied space.**
4. **Calculate return air temperature.**
5. **Specify required ventilation airflow, and estimate required system cooling capacity.**

Displacement Load Calculations (ASHRAE)

57

	Conventional System (Space Load)	Displacement System (Occupied Zone Load)
Cooling load (lights)	**3,300 Btu/h**	**x 0.132 = 436 Btu/h**
Cooling load (people)	**7,500 Btu/h**	**x 0.295 = 2,213 Btu/h**
Cooling load (equip)	**1,500 Btu/h**	**x 0.295 = 443 Btu/h**
Cooling load (envelope)	**5,000 Btu/h**	**x 0.185 = 925 Btu/h**
Total space cooling load	17,300 Btu/h	4,017 Btu/h
ΔT	**74 – 55 =** 19F	3.6F (Occupied Zone)
Supply Airflow	**852 cfm**	1015 cfm
SAT / RAT	**55F / 74F**	**65.7F/ 81.2F**

System Sizing

58

	Conventional System	Displacement System
Space Design Condition	**74F, 50% RH**	**74F**
Return Air Temperature	**74F**	**81.2F**
Design Dry-bulb / Wet-bulb	**91F / 67F**	**91F / 67F**
Ventilation airflow	**30@ 15 cfm/person = 450 cfm**	**30@ 15 cfm/person = 450 cfm**
Space **Sensible Cooling Load**	**17,300 Btu/h**	**15,300 Btu/h**
Ventilation Load	8,415 Btu/h	3,564 Btu/h
Sensible Capacity	25,715 Btu/h	20,864 Btu/h
Latent Load (Internal + Vent.)	**3,000 Btu/h**	0
Total Required Capacity	26,530 Btu/h	19,570 Btu/h

Load Calculation - Summary

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- **Load calculation must account for contribution to load in occupied zone and higher return temperature**
- **Despite slightly higher airflow, sensible load is reduced slightly**
- **With higher SAT, system latent load is avoided for California climates, but space humidity should be checked**

TDV Design Challenges

60

- **SAT control**
  - Multiple cooling stages
- **Humidity control**
  - Return air bypass
  - Reheat should be avoided
- **Comfort in the heating season**
  - Use high airflow for heating
  - Morning warm-up
  - Special diffusers

New Products for TDV

61

- **Packaged rooftop unit for single classroom**
  - Must have means for SAT control to 3-4F
  - Low temperature lockout on economizer
  - Optional variable air volume control
- **Diffuser Options**
  - Integrate diffuser with casework
  - Variable opening area to increase air velocity in heating mode

Upcoming: Capistrano TDV Demonstration

62

- **New custom 4-ton rooftop unit designed for TDV:**
  - Uses Copeland DigitalScroll compressor for capacity modulation down to 10% of full output
  - Variable speed drive for supply fan for space temperature control
  - Programmable controller for SAT and space temp control, with capability for SAT reset
- **School is a temperate coastal climate (San Juan Capistrano, CA)**
- **Monitoring begins in May and will continue through January 2006**

Questions

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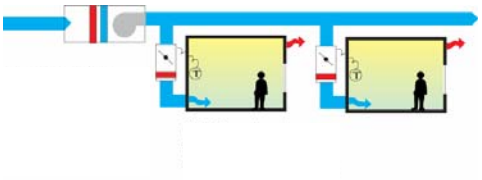
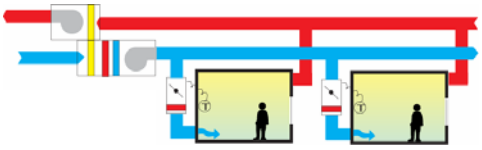
Multiple Classroom VAV System (no return)

64



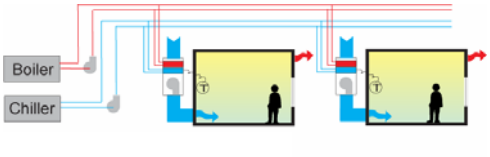
Multiple Classroom VAV System (return)

65



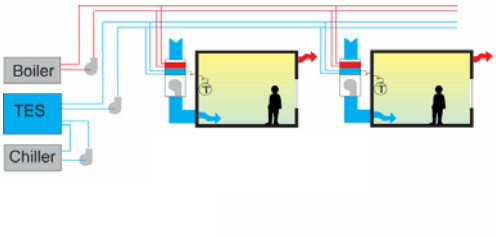
Fan Coil Approach

66



Fan Coil Approach (with thermal storage)

67



Single Classroom Packaged Solution

68

- **Variable speed compressor or other means to modulate cooling (and heating) capacity**
  - Need about 3 to 4 tons under peak conditions
  - Need little or no cooling capacity at moderate temperatures
  - Need ability to modulate between these extremes and deliver a constant 65 ºF supply air temperature
- **Variable speed supply fan**
  - Need between 1,000 and 1,200 cfm at peak conditions
  - Need about 500 cfm at low load conditions
- **Modulating exhaust to maintain positive room pressure (don't want the classroom to "suck")**