HVAC

Thermal Comfort

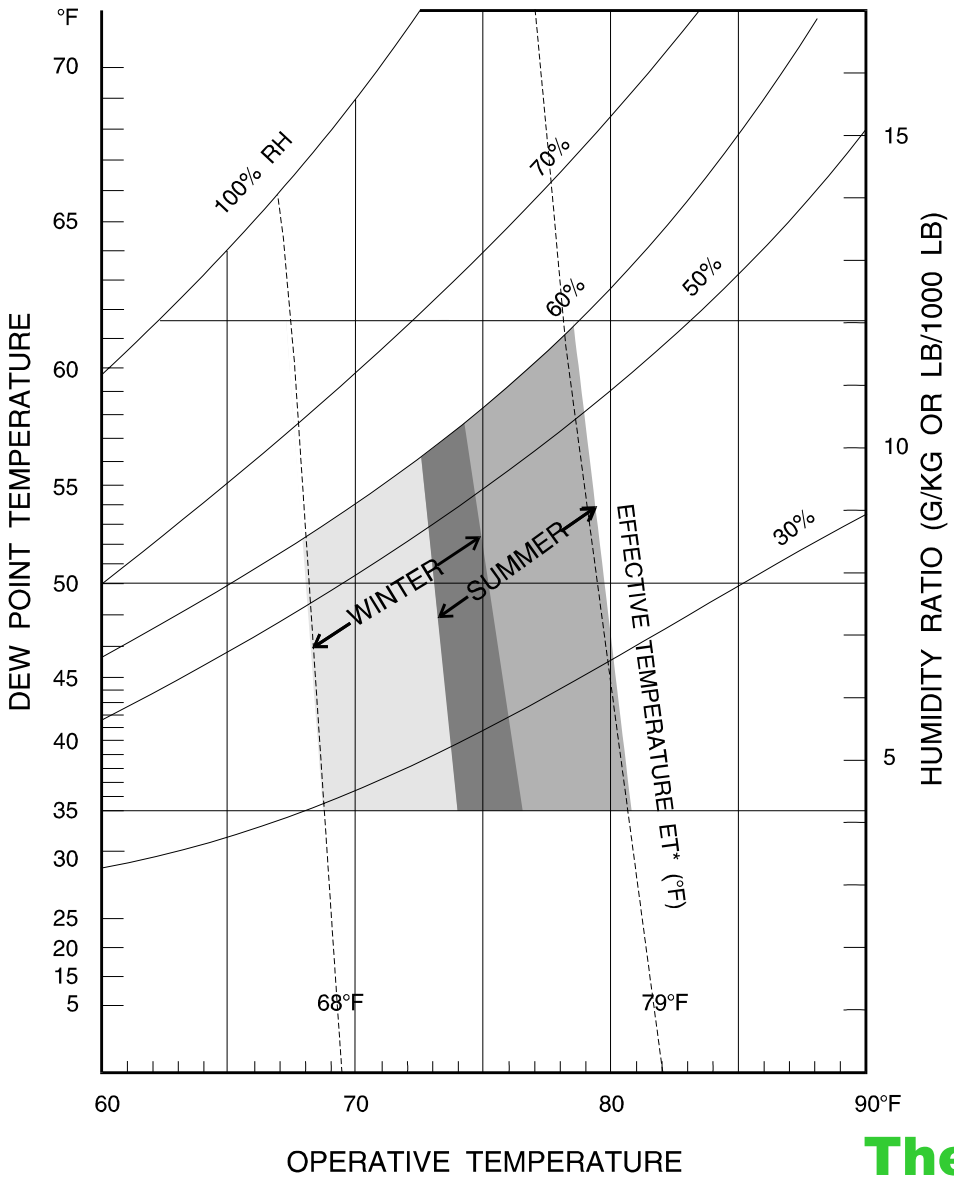
ASHRAE Thermal Sensation Scale

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
-3	-2	-1	0	+1	+2	+3

Thermal Comfort

- Environmental factors.
  - Air temperature.
  - Humidity.
  - Air velocity.
  - Mean radiant temperature (MRT).
- Non-environmental factors.
  - Clothing.
  - Gender.
  - Age.
  - Metabolic activity.

ASHRAE Standard 55

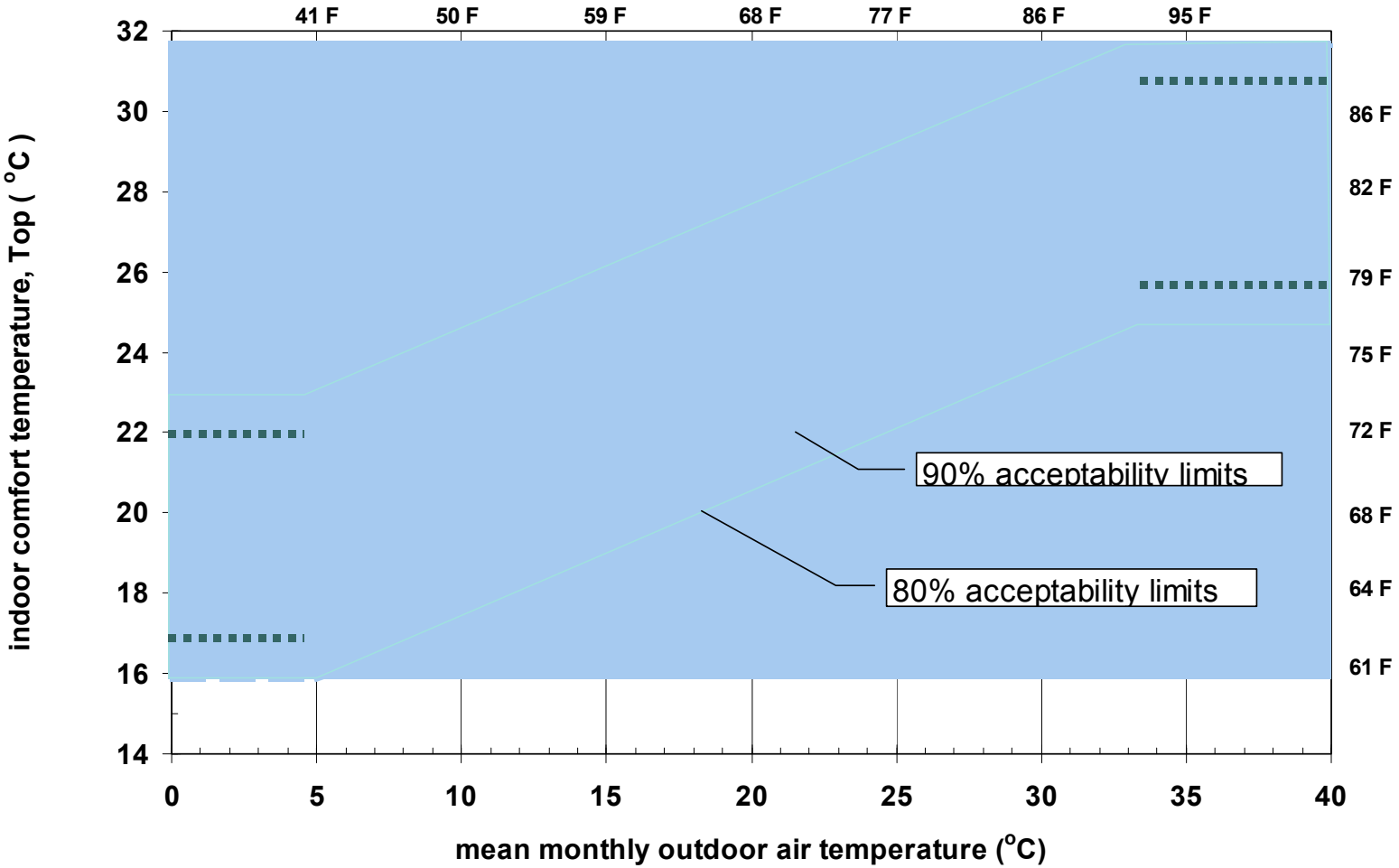


Effect of Air Movement on Occupants

Air Velocity	Probable Impact
Up to 50 ft/m	Unnoticed.
50 to 100 ft/m	Pleasant.
100 to 200 ft/m	Generally pleasant, but causes a constant awareness of air movement.
200 to 300 ft/m	From slightly drafty to annoyingly drafty.
Above 300 ft/m	Requires corrective measures if work and health are to be kept in high efficiency.

Source: Victor Olgyay, Design with Climate, Princeton University Press, 1963.

Adaptive Comfort Model



Thermal Loads in Schools

Heat Gains (independent of outside temperature)

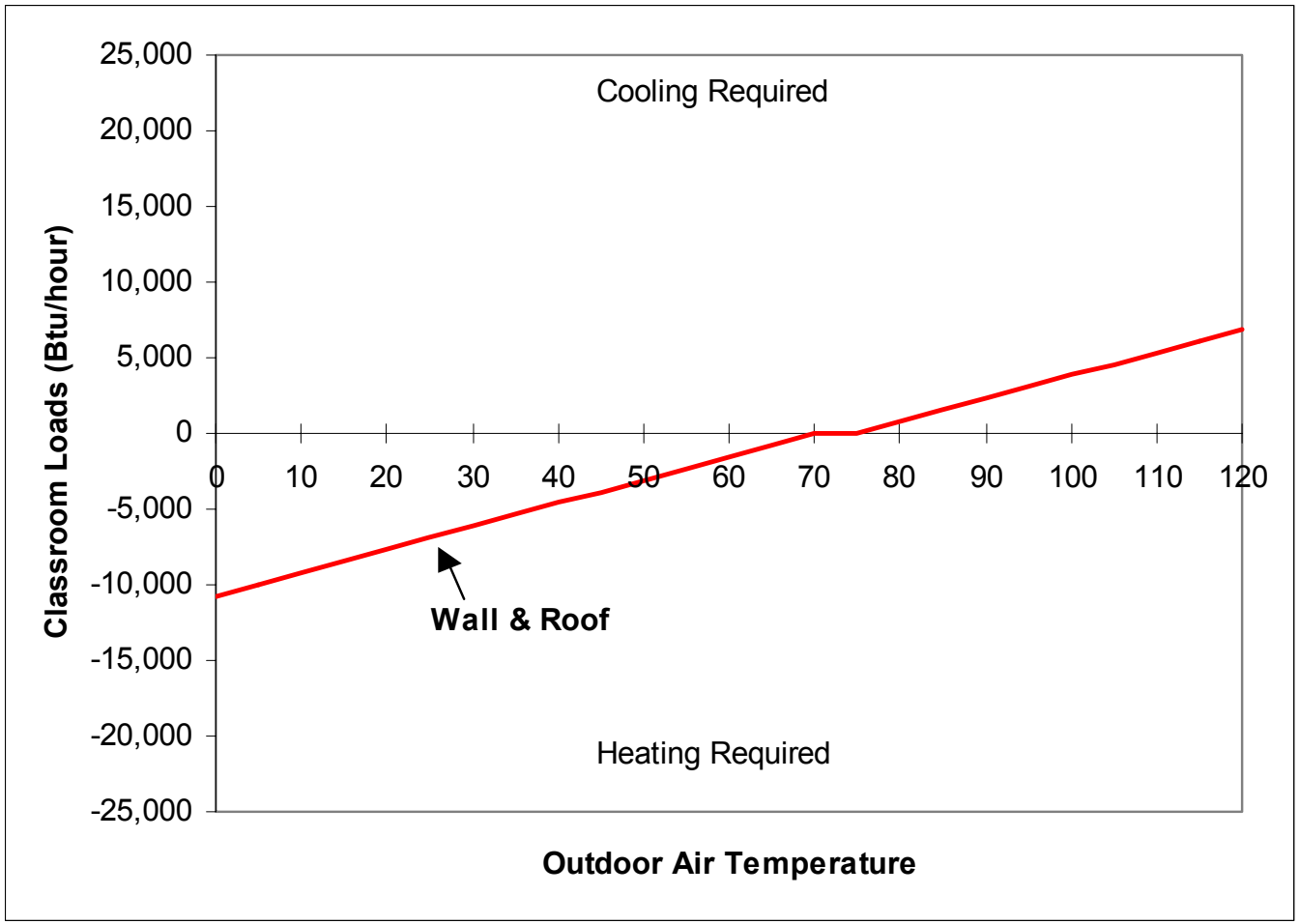
People	24-30 kids	5,000 Btu/h
Lights	1 watt per square foot	3,300 Btu/h
Plugs	About 150 watts per computer	1,500 Btu/h
Solar	Fairly small with correct orientation and shading	up to 3,000 Btu/h
Total		12,800 Btu/h

Heat Losses/Gains

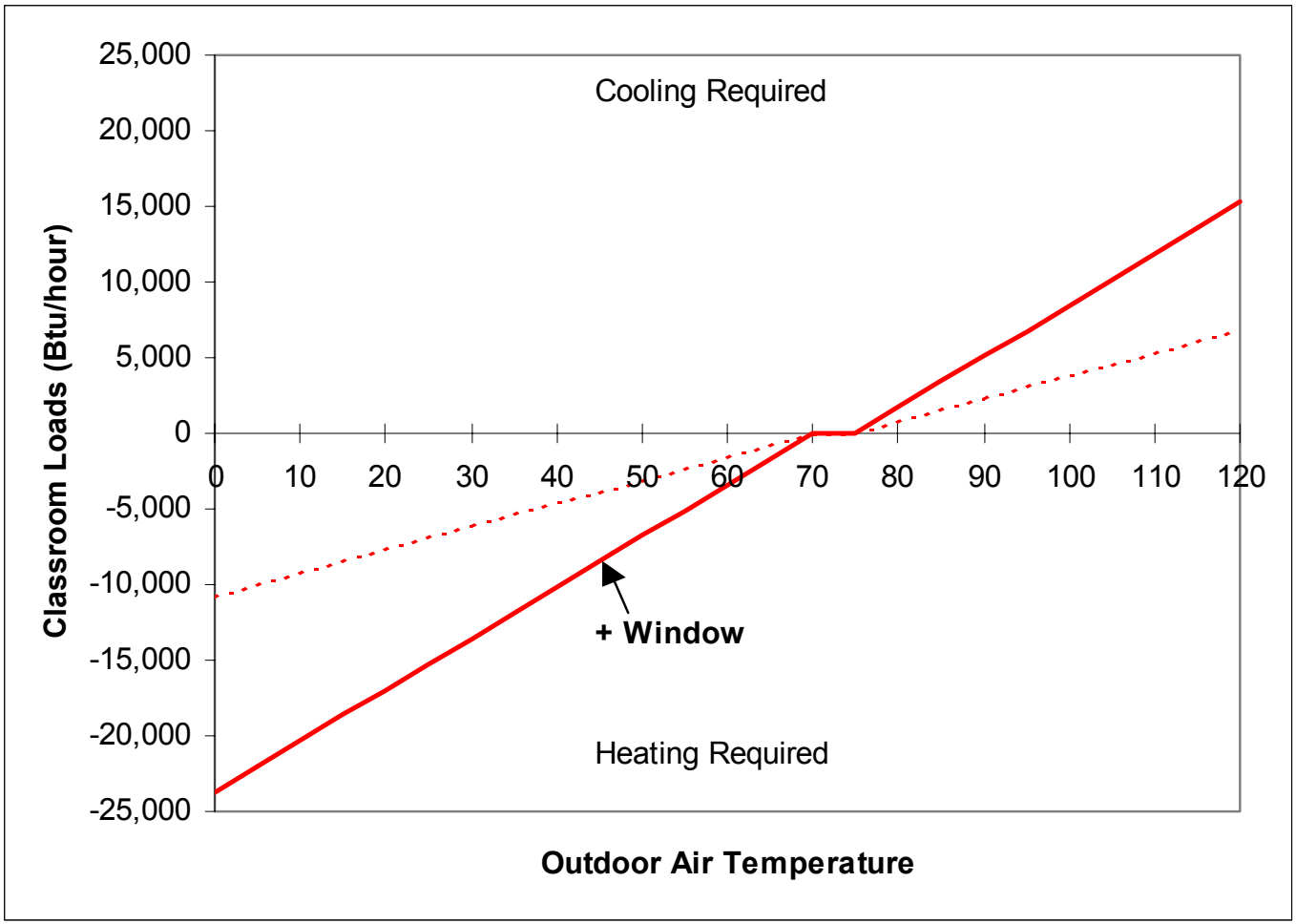
(dependent on outside air temperature)

- Window conduction.
- Walls, roofs and floors.
- Infiltration.
- Outside air ventilation.

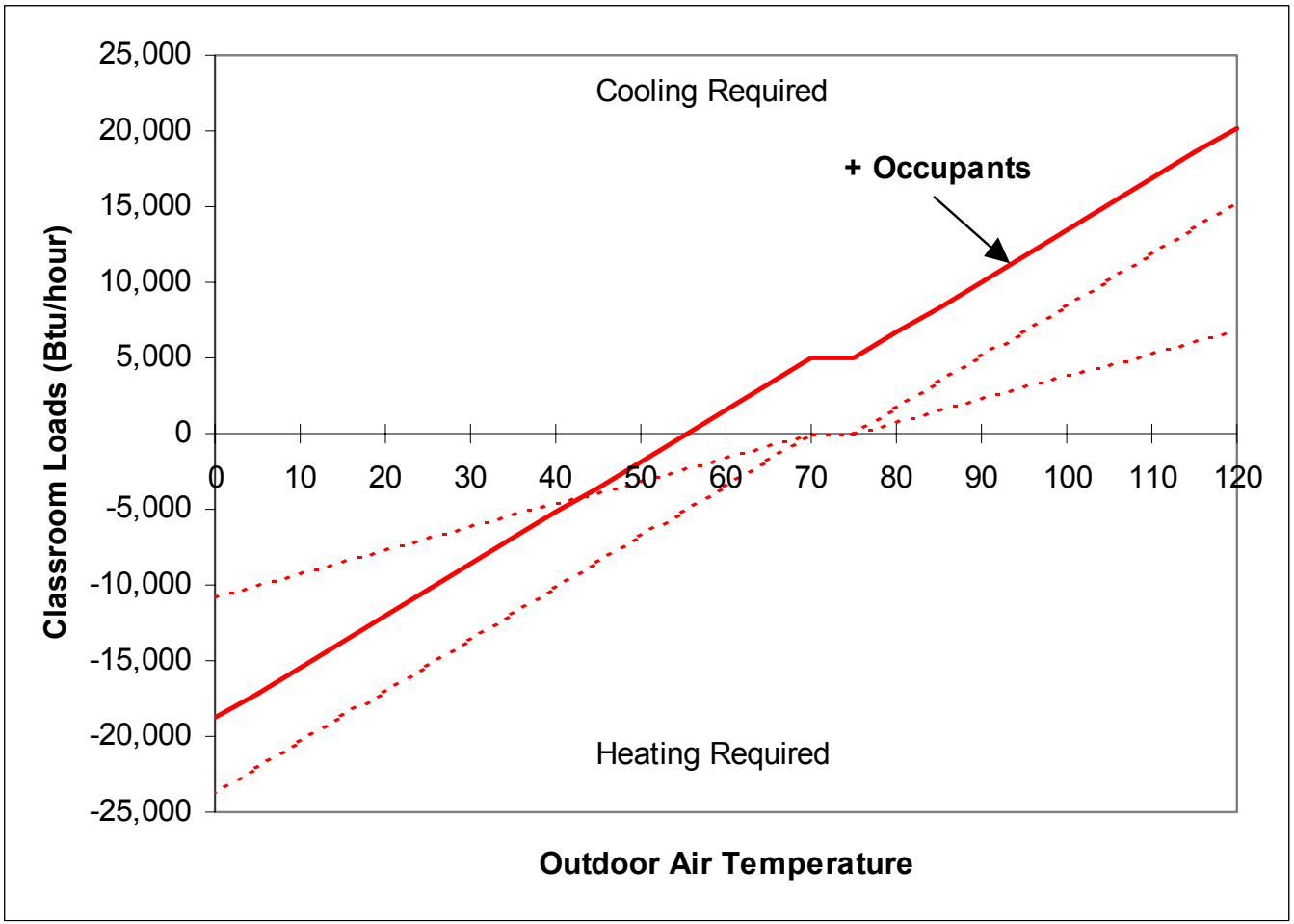
Balance Point Temperature



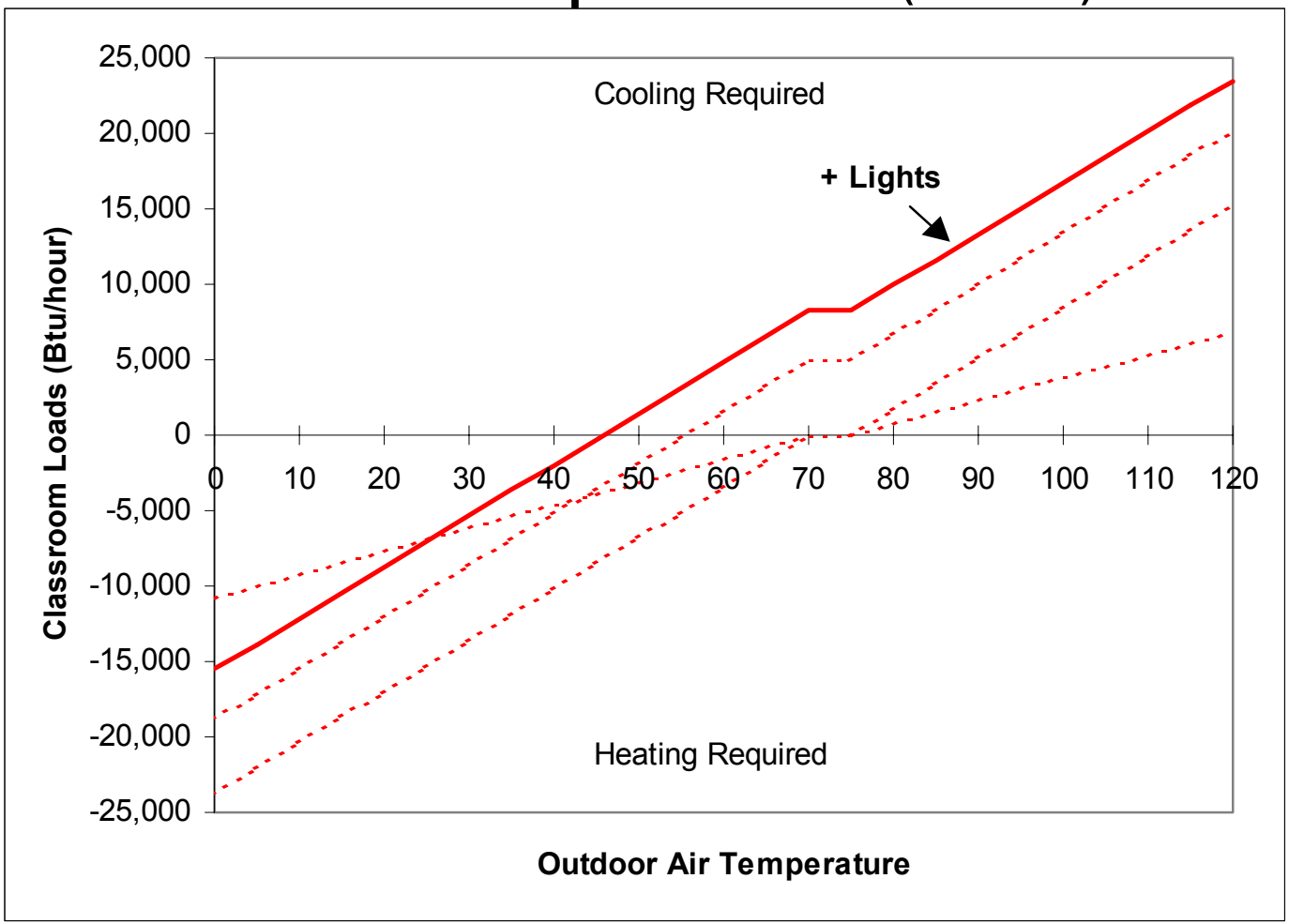
Balance Point Temperature (cont'd)



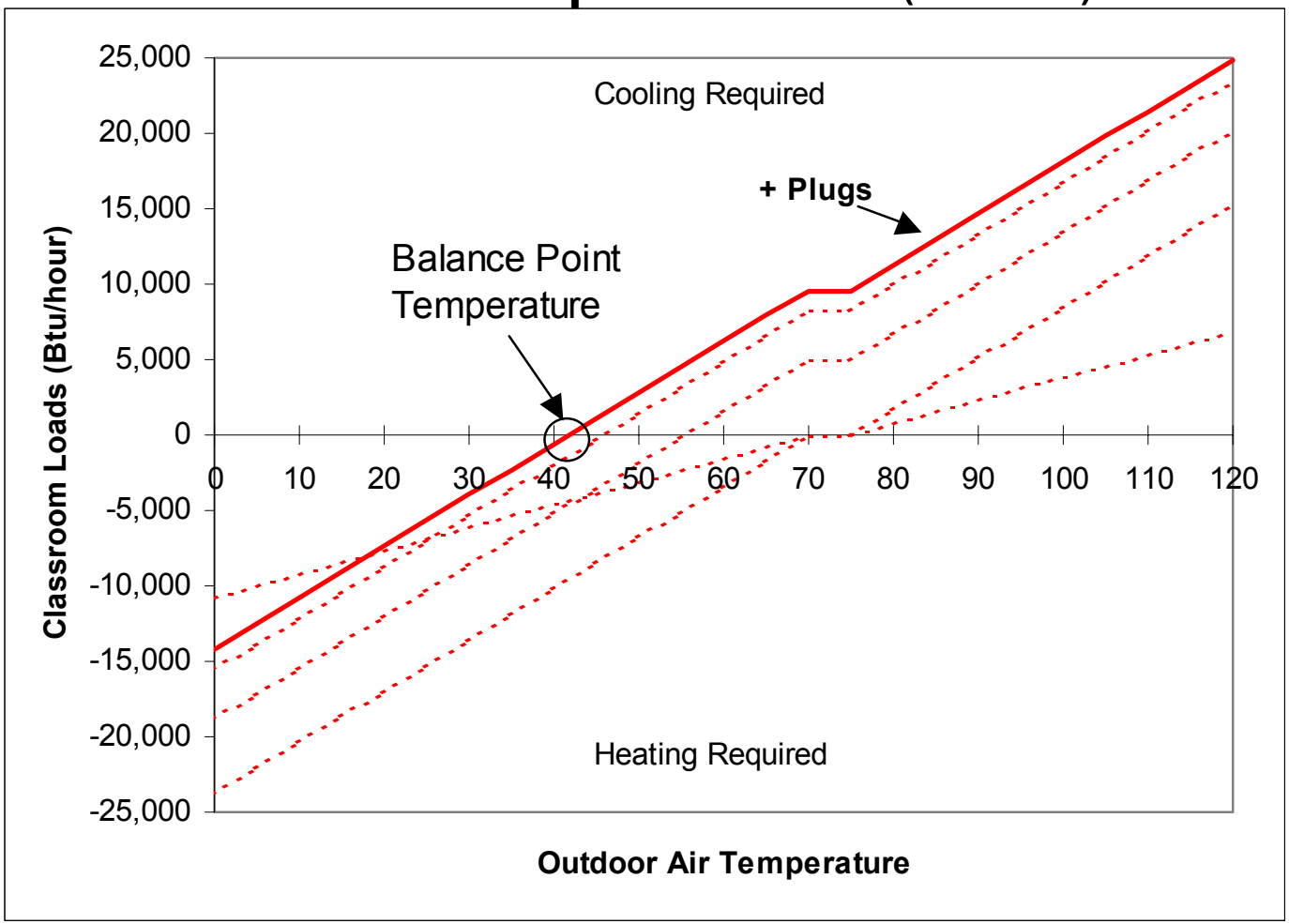
Balance Point Temperature (cont'd)



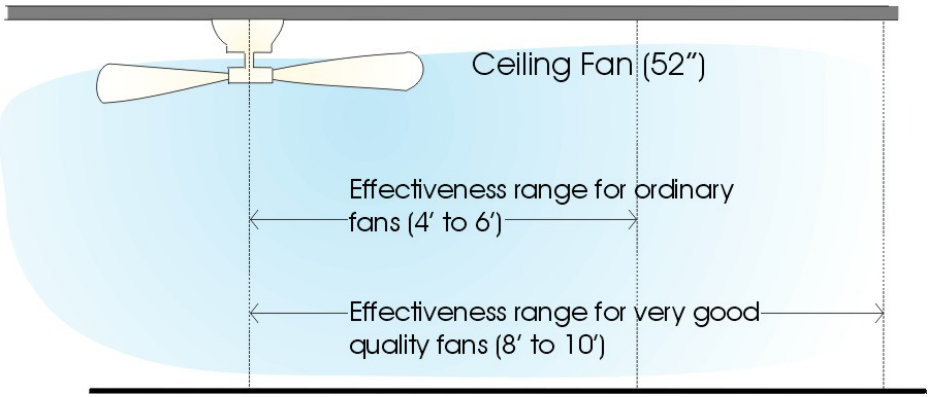
Balance Point Temperature (cont'd)

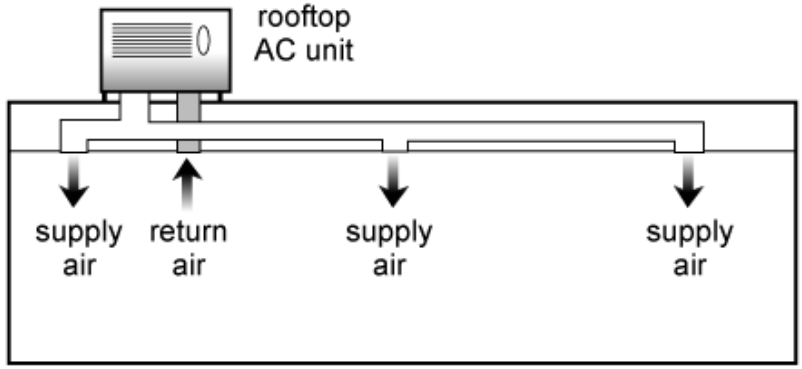


Balance Point Temperature (cont'd)



Ventilation: Natural and Mechanical



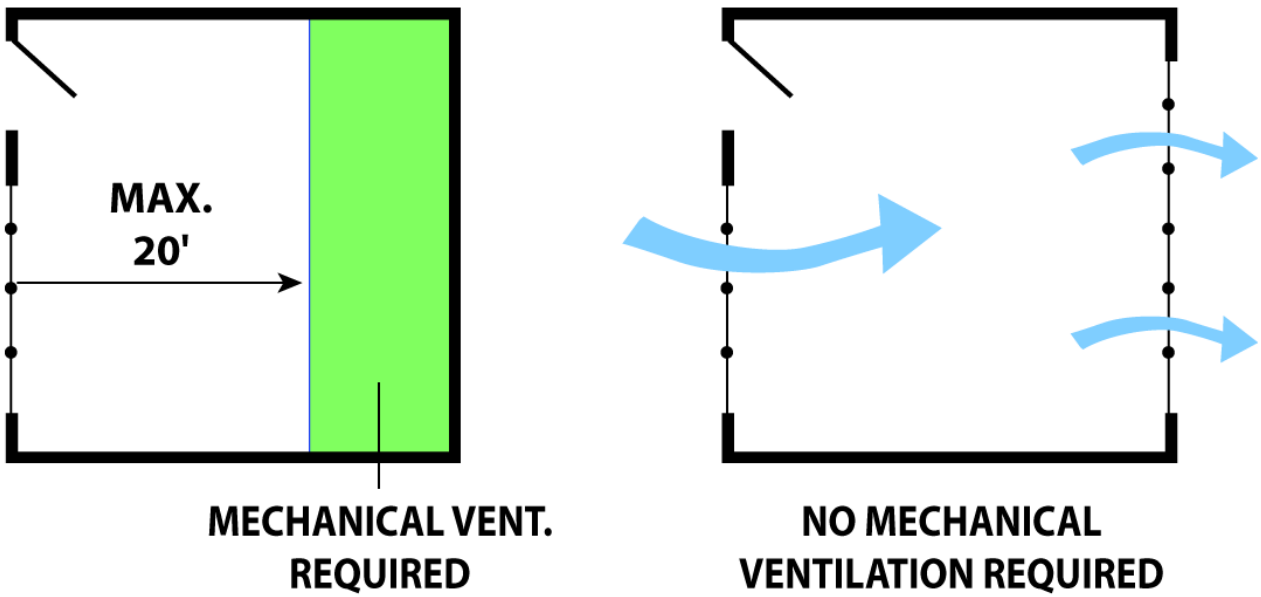


Ventilation Requirements

- Ventilation is needed to remove carbon dioxide, odors, and pollutants.
- ASHRAE Standard 62 is the national consensus standard.

Using Natural Ventilation

- For a typical 960 ft² (30 ft x 32 ft) classroom,
  - At least 48 ft² opening area.
  - Openings on two sides of the room.

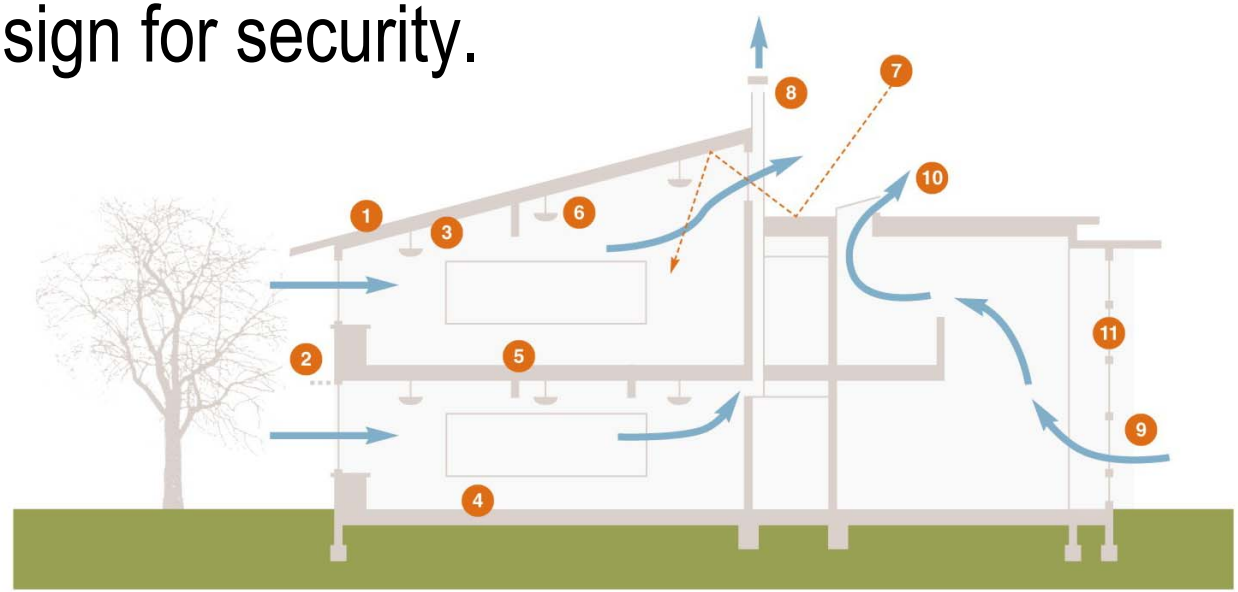


Using Mechanical Ventilation

- 15 cfm per person minimum.
  - Typical classroom calculation.
  - 15 cfm/person X 30 people = 450 cfm.

Natural Ventilation

- Energy efficient ventilation potential.
- Traditional in certain climate areas.
- Still appropriate strategy in many climates.
- Design for security.



Natural Ventilation Potential

Boston, MA
September - June
7 am - 3 pm, weekdays

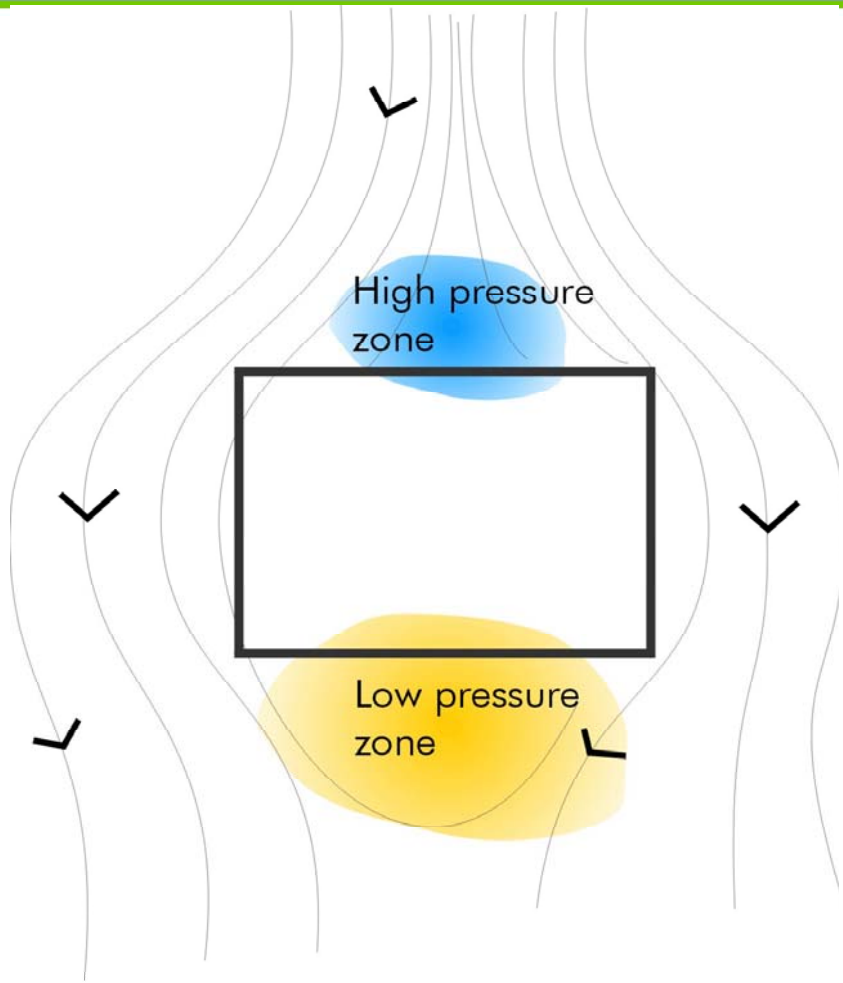
Dry Bulb Temp	15%-20%	20%-25%	25%-30%	30%-35%	35%-40%	40%-45%	45%-50%	50%-55%	55%-60%	60%-65%	65%-70%	70%-75%	75%-80%	80%-85%	85%-90%	90%-95%	95%-100%	>100%	Total
88-92					4	2	1												7
83-87				2	2	7	6	7	4										28
78-82		1	1	12	7	5	3	7	13	5	1								55
73-77		1	3	4	4	3	10	9	14	6	12	8	5	1					80
68-72			1	4	6	14	12	10	8	11	6	8	15	7	15	2	1		120
63-67				3	10	10	15	17	14	6	11	21	13	6	8	8		1	143
58-62			1	6	12	6	15	8	13	10	6	10	12	15	21	10	1	1	147
53-57	1	2	8	13	7	13	12	11	8	11	5	4	1	10	13	24			143
48-52		2	2	7	11	11	14	11	11	13	10	12	1	5	29	26	3	2	170
43-47		3	12	10	11	19	19	22	18	14	2	10	28	4	16	23	3	5	219
38-42			2	13	12	14	11	20	12	4	10	1	12	18		7		4	140
33-37			8	16	20	19	15	18	15	10	10	18		26		20	3	5	203
28-32		1	3	16	16	17	33	4	28		23		14		6		3	1	165
23-27	2	1	5	3	14	7	11	11	4	11		3	6					2	80
18-22			5	5	13	11		7	9										50
13-17			3	4		6	3	4		2									22
<13				1	1	4	3	2	1										12
Total	3	11	54	119	150	168	183	168	172	103	96	95	107	92	108	120	14	21	1784

Relative Humidity

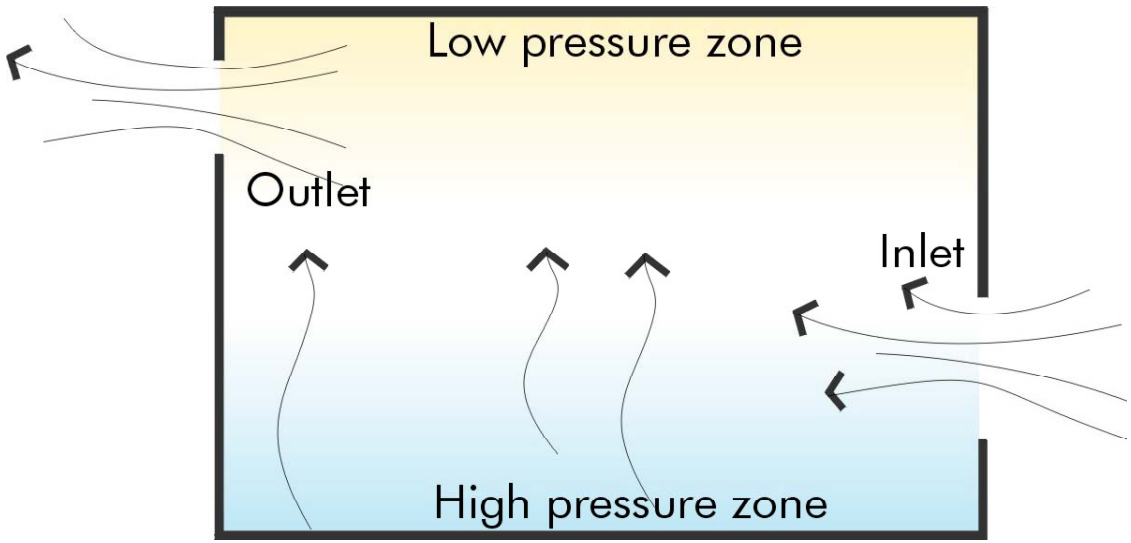
ASHRAE 55 Comfort Zone — **Total Hours** 76

Cross Ventilation

- Provide equal area of operable openings on the windward and leeward side.
- Ensure that the windward side is well shaded to provide cool air intake.
- Locate the openings on the windward side at the occupied level.



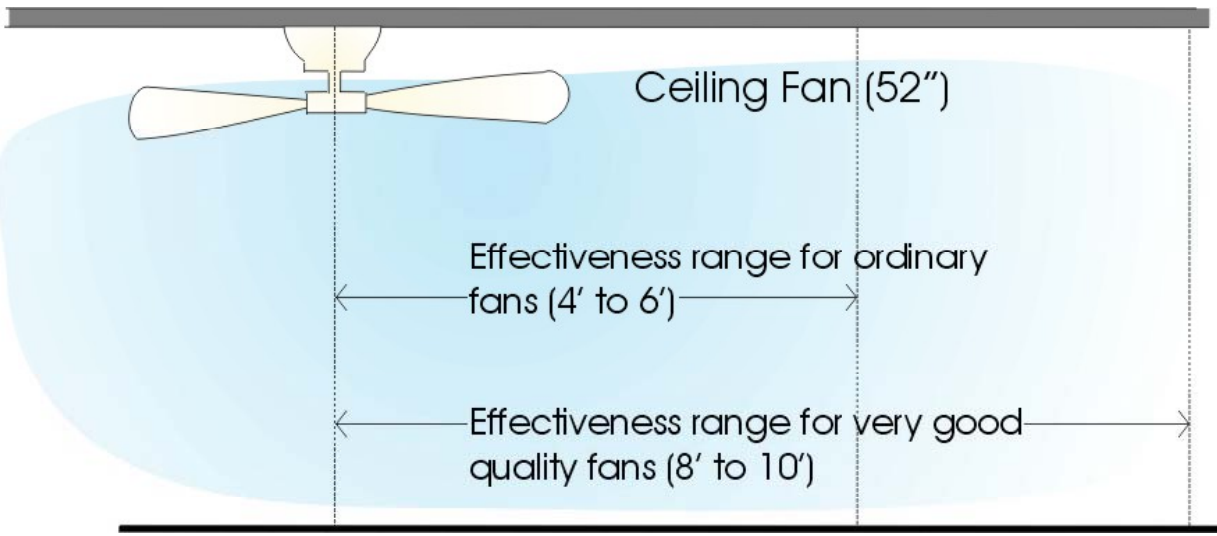
Stack Ventilation



- Use inlets and outlets of equal area and maximize the vertical distance between these two sets of apertures. Place inlets close to the floor or at the occupied level. Locate the outlets closer to the ceiling on the opposite wall.

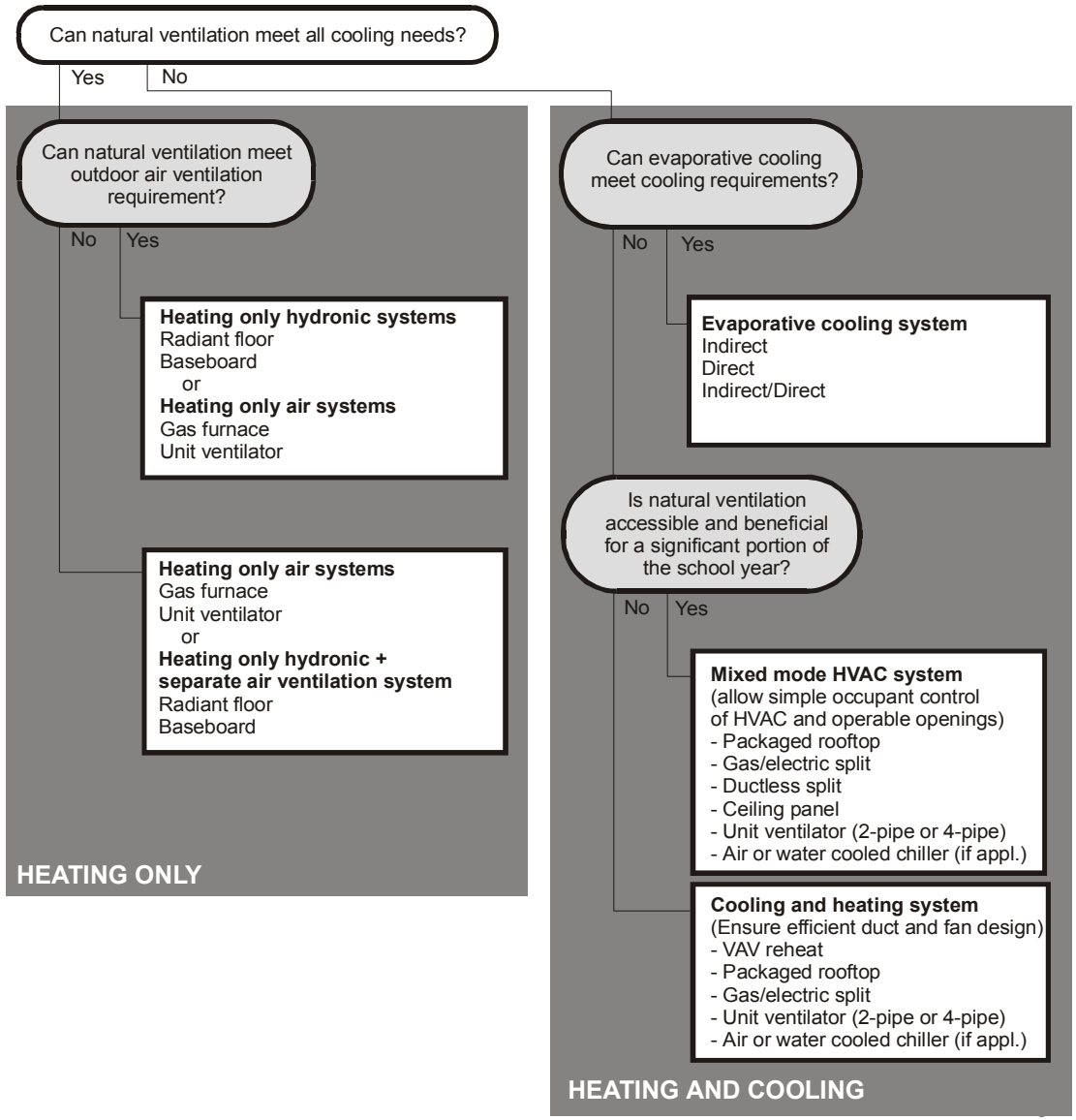
Ceiling Fans

- Use ceiling fans in classrooms to provide enhanced thermal comfort for occupants through higher air velocity. Use the ceiling fans instead of air conditioners in mild coastal climates. In more extreme climates, use ceiling fans as a supplement to cooling systems.



HVAC System Design and Selection

HVAC Decision Tree



Other Selection Considerations

- Noise and vibration.
- Indoor air quality ventilation performance.
- Thermal comfort performance.
- Operating costs and energy efficiency.
- Maintenance costs and needs.
- Space requirements (in the classroom, on the roof or in mechanical rooms).
- Durability and longevity.
- The ability to provide individual control for classrooms and other spaces.
- The type of refrigerant used and its ozone-depleting potential.

Equipment Sizing

- Bigger is not always better! Avoid oversizing for:
  - AC/heat pump compressors.
  - Furnaces.
  - Boilers.
  - Chillers.
- Sometimes bigger is better!
  - Ducts.
  - Fans (if they have speed control).
  - Cooling towers.
  - Pipes.

Integrated Desvign

- Eliminate cooling with careful envelope design.
- Eliminate ducts with natural ventilation.
- Underfloor air distribution.
- Reduce heating by attention to MRT.
- Central plant to allow thermal energy storage.
- Use motion sensors for HVAC control.

Temperate and Mixed Climate

Best Applicability	Mid-Range Applicability	Worst Applicability
-Cross Ventilation -Stack Ventilation -Ceiling Fans -Unit Ventilator System -Radiant Slab System -Baseboard Heating System -Gas-fired Radient Heating System -Geothermal Heat Pumps -Water Loop Heat Pumps -Economizers	-Displacement Ventilation System -Hydronic Ceiling Panel System -Ductless Split System -VAV Reheat System -Dedicated Outside Air Systems -Hydronic Distribution -Chilled Water Plants	-Gas/Electric Split Systems -Packaged Rooftop System -Evaporative Cooling System -Evaporatively Precooled Condenser

Cool and Dry Climate

Best Applicability	Mid-Range Applicability	Worst
-Cross Ventilation	-Ceiling Fans	
-Stack Ventilation	-Gas/Electric Split Systems	
-Displacement Ventilation System	-Packaged Rooftop System	
-Hydronic Ceiling Panel System	-VAV Reheat System	
-Unit Ventilator System	-Hydronic Distribution	
-Ductless Split System	-Chilled Water Plants	
-Evaporative Cooling System	-Evaporatively Precooled Condenser	
-Radiant Slab System		
-Baseboard Heating System		
-Dedicated Outside Air Systems		
-Gas-fired Radient Heating System		
-Geothermal Heat Pumps		
-Water Loop Heat Pumps		
-Economizers		

Hot and Dry Climate

Best Applicability	Mid-Range Applicability	Worst Applicability
-Gas/Electric Split Systems -Packaged Rooftop System -Evaporative Cooling System -VAV Reheat System -Evaporatively Precooled Condenser -Hydronic Distribution -Economizers -Chilled Water Plants	-Stack Ventilation -Ceiling Fans -Displacement Ventilation System -Hydronic Ceiling Panel System -Unit Ventilator System -Ductless Split System -Gas-fired Radient Heating System -Geothermal Heat Pumps -Packaged Rooftop System -VAV Reheat System	-Cross Ventilation -Radiant Slab System -Baseboard Heating System -Water Loop Heat Pumps -Dedicated Outside Air Systems

Cold and Humid Climate

Best Applicability	Mid-Range Applicability	Worst Applicability
-Cross Ventilation -Stack Ventilation -Ceiling Fans -Unit Ventilator System -Ductless Split System -Radiant Slab System -Baseboard Heating System -Gas-fired Radient Heating System -Geothermal Heat Pumps -Water Loop Heat Pumps -Dedicated Outside Air Systems -Economizers	-Displacement Ventilation System -Hydronic Ceiling Panel System -Evaporative Cooling System -Hydronic Distribution -Chilled Water Plants	-Gas/Electric Split Systems -Packaged Rooftop System -VAV Reheat System -Evaporatively Precooled Condenser

Cool and Humid Climate

Best Applicability	Mid-Range Applicability	Worst Applicability
-Cross Ventilation -Stack Ventilation -Ceiling Fans -Displacement Ventilation System -Hydronic Ceiling Panel System -Radiant Slab System -Baseboard Heating System -Gas-fired Radient Heating System -Water Loop Heat Pumps -Geothermal Heat Pumps -Economizers	-Gas/Electric Split Systems -Packaged Rooftop System -Unit Ventilator System -Ductless Split System -Evaporative Cooling System -Evaporatively Precooled Condenser -Dedicated Outside Air Systems -Hydronic Distribution -Chilled Water Plants	-VAV Reheat System

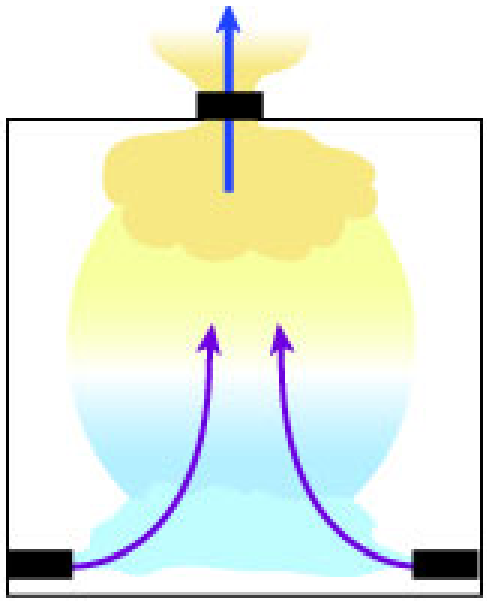
Temperate and Humid Climate

Best Applicability	Mid-Range Applicability	Worst Applicability
-Gas/Electric Split Systems -Packaged Rooftop System -Displacement Ventilation System -VAV Reheat System -Evaporatively Precooled Condenser -Geothermal Heat Pumps -Hydronic Distribution -Chilled Water Plants	-Cross Ventilation -Stack Ventilation -Ceiling Fans -Unit Ventilator System -Ductless Split System -Radiant Slab System -Baseboard Heating System -Gas-fired Radient Heating System -Water Loop Heat Pumps -Dedicated Outside Air Systems -Economizers	-Hydronic Ceiling Panel System -Evaporative Cooling System

Hot and Humid Climate

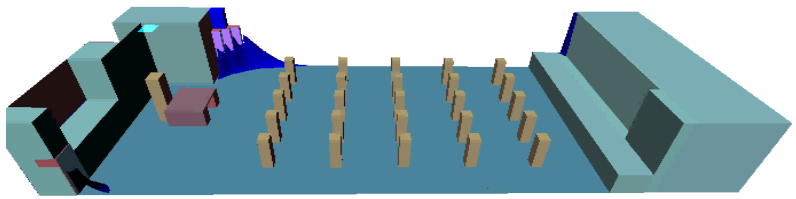
Best Applicability	Mid-Range Applicability	Worst Applicability
-Gas/Electric Split Systems -Packaged Rooftop System -VAV Reheat System -Hydronic Distribution -Chilled Water Plants	-Displacement Ventilation System -Unit Ventilator System -Gas-fired Radient Heating System -Evaporatively Precooled Condenser -Geothermal Heat Pumps -Economizers	-Cross Ventilation -Stack Ventilation -Ceiling Fans -Hydronic Ceiling Panel System -Ductless Split System -Evaporative Cooling System -Radiant Slab System -Baseboard Heating System -Water Loop Heat Pumps -Dedicated Outside Air Systems

Special HVAC Systems: Displacement Ventilation



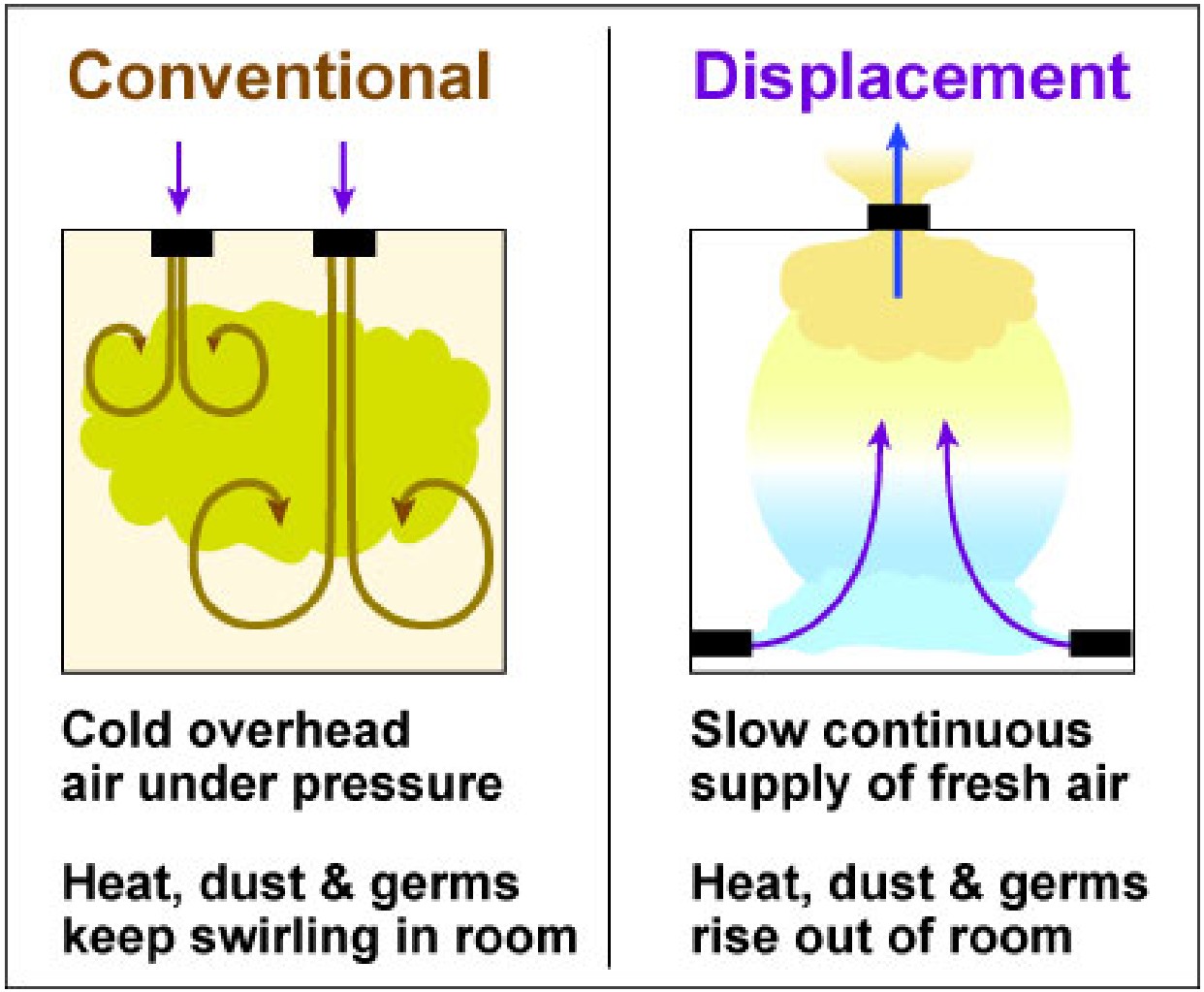
Displacement Ventilation

- Fresh cool air is slowly supplied near the floor.
- Air rises as it warms.
- Air is exhausted near the ceiling.



Courtesy H. L. Turner Group

Conventional vs. Displacement Ventilation



Benefits of Displacement Ventilation

- Healthier environment; germs are not spread as easily.
- 100% fresh air vs. recirculation of return air.
- Improved acoustics.
- Energy efficient system.
- Compatible with operable windows and natural ventilation.

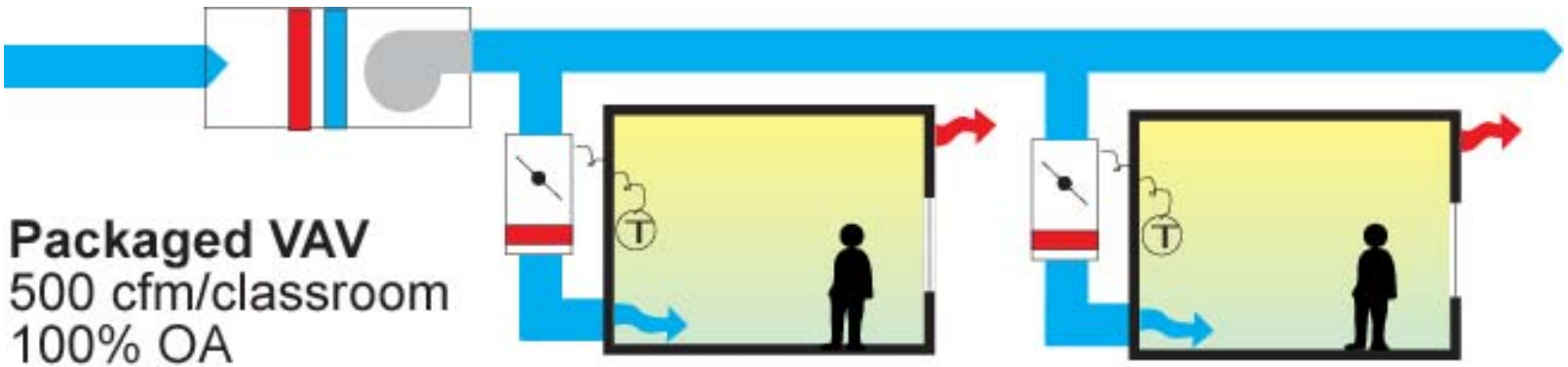
Displacement Ventilation Details

	Conventional System	Displacement System
Ceiling Height	8'+	10'+
Supply air flow	1,000 – 1,500 cfm	400 - 600 cfm
Diffuser air velocity	600 – 800 fpm	<100 fpm
Cooling supply air temperature	52° - 55°	63° – 68°
Outside air flow	400 – 500 cfm (~30%)	400 – 600 cfm (100%)

	Conventional System	Displacement System
Cooling load (lights)	3,300 Btu/h	x 0.13 = 430 Btu/h
Cooling load (people)	5,000 Btu/h	x 0.30 = 1,500 Btu/h
Cooling load (equip)	1,500 Btu/h	x 0.30 = 450 Btu/h
Cooling load (shell)	0 – 3,000 Btu/h	x 0.19 = 0 – 570 Btu/h
Total space cooling load	**9,800 – 12,800 Btu/h**	**2,380 – 2,960 Btu/h**
Ventilation air load (varies by climate)	14,000 Btu/h	14,000 Btu/h
Total cooling load	**23,800 – 26,800 Btu/h (2.0 – 2.2 tons)**	**16,380 – 16,960 Btu/h (1.4 tons)**

	Conventional System	Displacement System
AC size	3 tons	2 tons
Cooling demand	3.3 kW	2.2 kW
Fan demand	0.3 kW	0.2 kW
Total demand	3.6 kW	2.4 kW

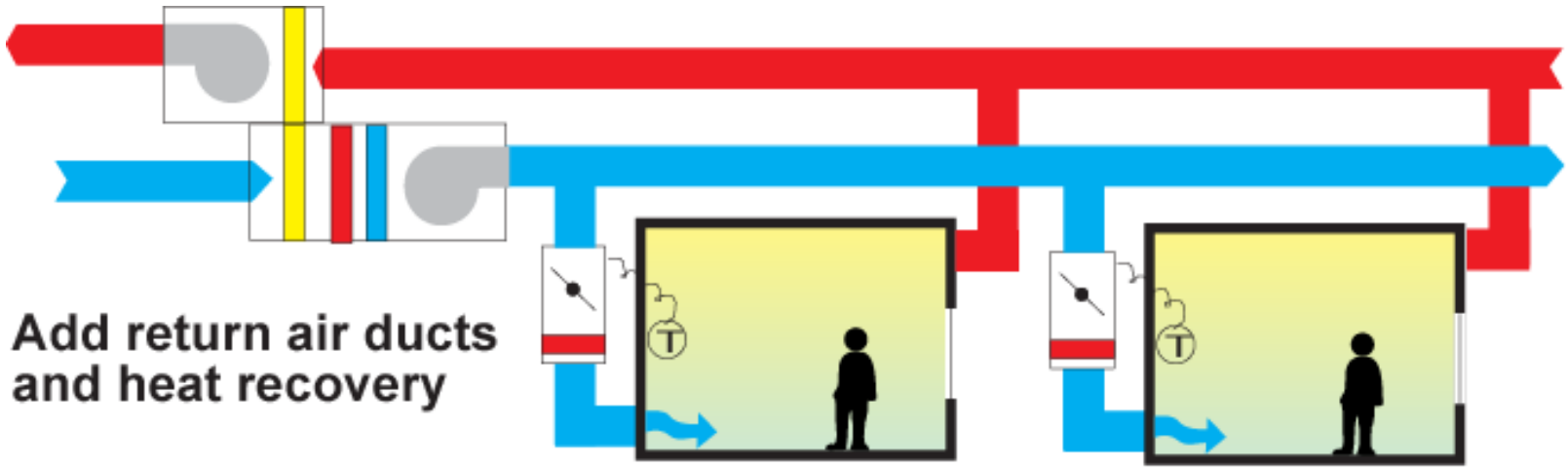
Providing 100 % Outside Air



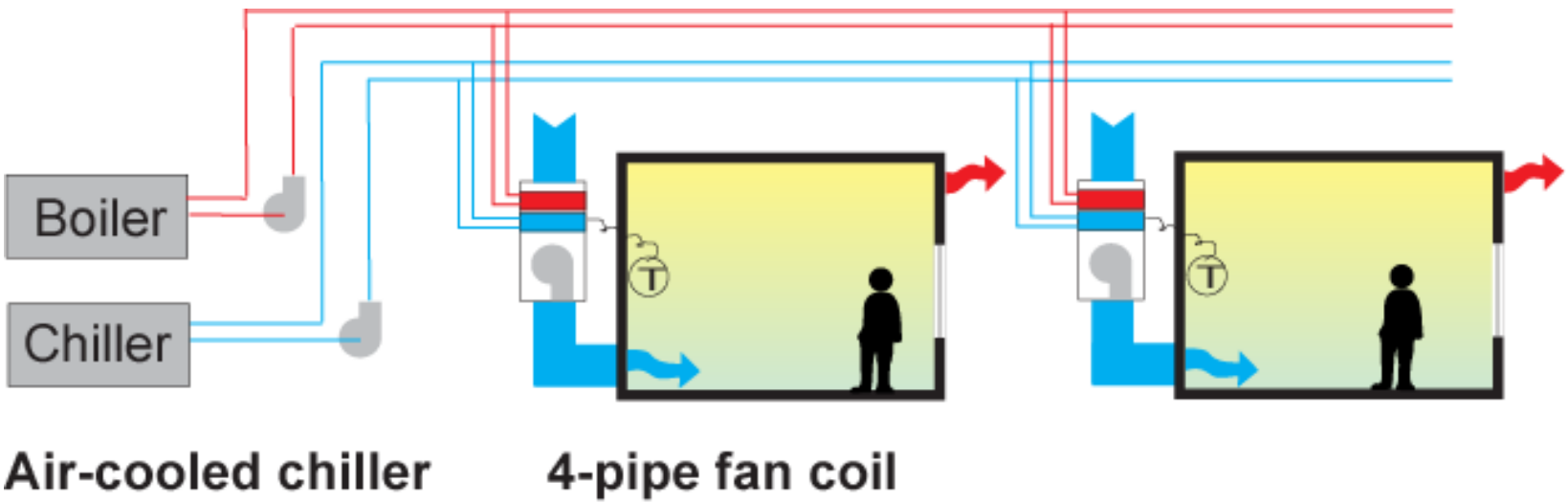
Packaged VAV
500 cfm/classroom
100% OA
DX cooling
1.5 tons/classroom
Gas furnace heat

VAV terminal
with reheat
400/600 cfm min/max

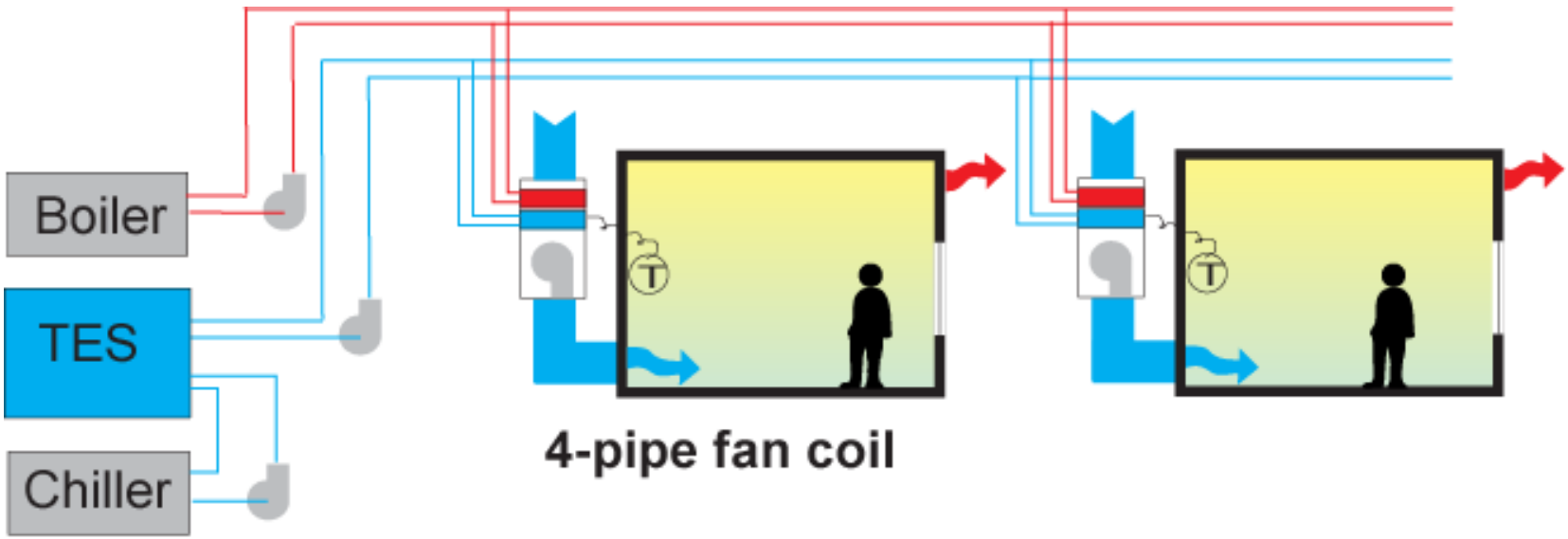
Providing the Neutral Air (cont'd)



Providing the Neutral Air (cont'd)



Providing the Neutral Air (cont'd)



Thermal energy storage
- Chilled water
- Ice

More Information on Displacement Ventilation

- National Best Practices Manual for High Performance Design www.energysmartschools.gov
- Yuan, Xiaoxiong. *Performance Evaluation and Design Guidelines for Displacement Ventilation*. ASHRAE Transactions. 1999. V. 105. Pt. 1. www.ashrae.org.