Saving Energy with Natural Ventilation Strategies

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Topics

- Motivations
- Feasibility
- Driving forces
- Strategies
  - Cross ventilation
  - Single-sided ventilation
  - Stack ventilation
- Design methods
- Energy impact estimation
- Integrated design issues
- Examples

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Motivations

- Energy
  - An important step towards net zero
- Comfort and personal control
- IAQ
  - Reduced sick building syndrome
- Connection to outdoors
- Passive survivability
- Collaborative for High Performance Schools (CHPS)
  - Credits for naturally ventilated classrooms
- Productivity?
- Others?

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Roles of Natural Ventilation

- Air quality
  - Ventilation
- Comfort
  - Cooling people via air movement
  - Cool space via air exchange
  - Cool structure via nighttime ventilation

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When is Natural Ventilation Feasible?

- Appropriate climate
  - Temperature meets occupant comfort requirements
- Acceptable outdoor air quality
  - Dust
  - Odors
- Acceptable outdoor noise levels
- Design meets building code requirements
  - Ventilation
  - Smoke management

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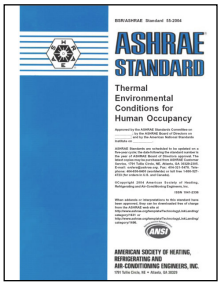
Feasibility – Comfort Requirements



- ASHRAE Standard 55-2004 defines comfort "envelope"
- Can stretch the envelope in a few cases:
  - Adaptive comfort model for spaces where occupants have control over natural ventilation
  - Increase in upper temperature limit with some air movement
    - If occupants can control the air movement, e.g. operable window or local fans
- Might be able to provide comfort without mechanical cooling in some fairly warm climates

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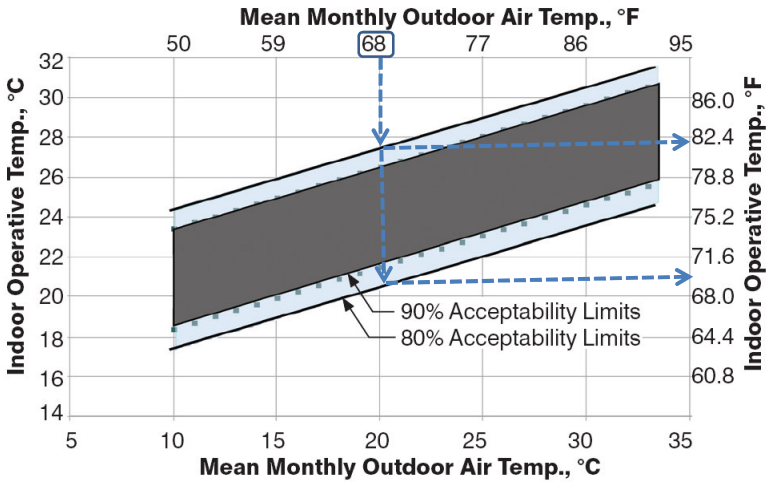
ASHRAE Standard 55-2004
Adaptive Comfort Model for Nat Vent Spaces



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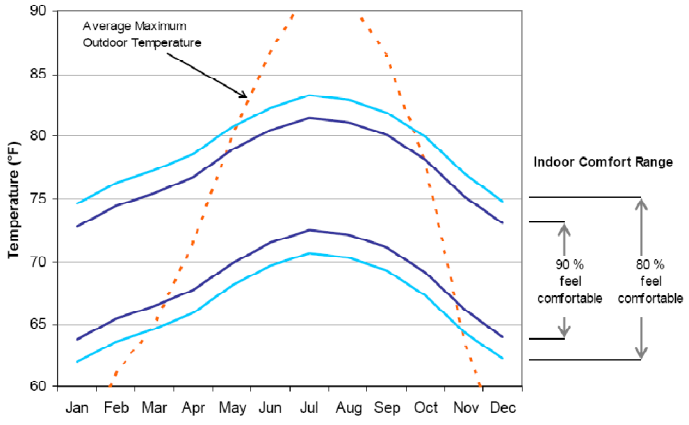
ASHRAE Standard 55-2004
Adaptive Comfort – Sacramento Example



Source: Collaborative for High Performance Schools, *Best Practices Manual, Volume 2*, www.chps.net

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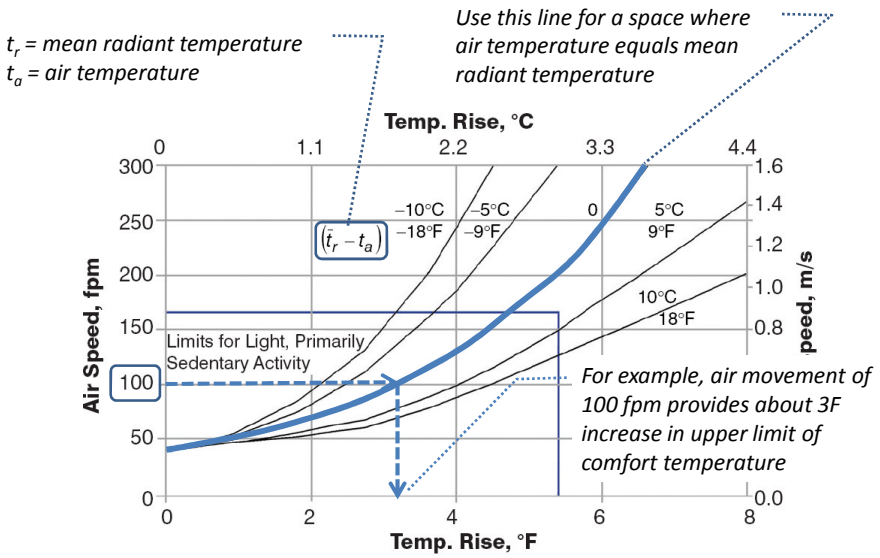
ASHRAE Standard 55-2004
Temperature Adjustment for Air Movement



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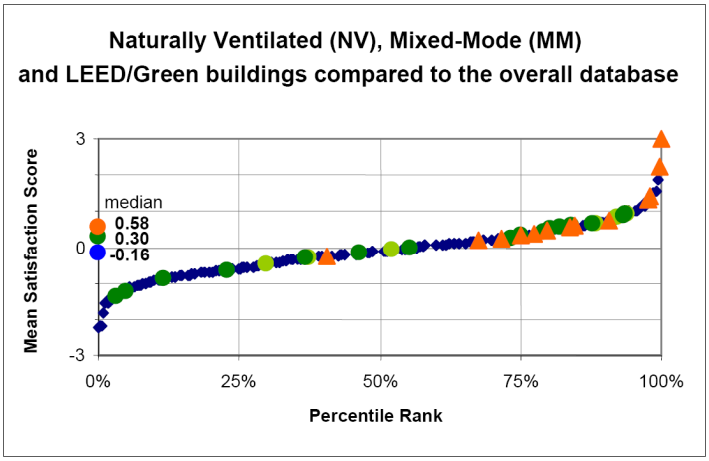
Thermal Comfort
Effect of Air Movement on Occupants

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

Occupant Survey Results
Thermal Satisfaction



Source: Gail Brager, Center for the Built Environment, UC Berkeley

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Feasibility - Climate

- Do outdoor air conditions fall within comfort envelope?
- If not all the time, then how many hours would comfort not be satisfied?
- Are typical wind speed and direction conducive to natural ventilation?

Some Climate Visualization Tools

- Climate Consultant 3.0
  - Takes EnergyPlus weather files as input
    - Available on the Internet
    - *.EPW file name
  - Provides visual representations of climate data
    - Air temperature and humidity
    - Solar radiation
    - Wind speed and direction
  - Free at www2.aud.ucla.edu/energy-design-tools
- Ecotect WeatherTool
  - More flexible, polished interface
  - www.squ1.com
  - Recently acquired by Autodesk
  - $2,499 packaged with Ecotect

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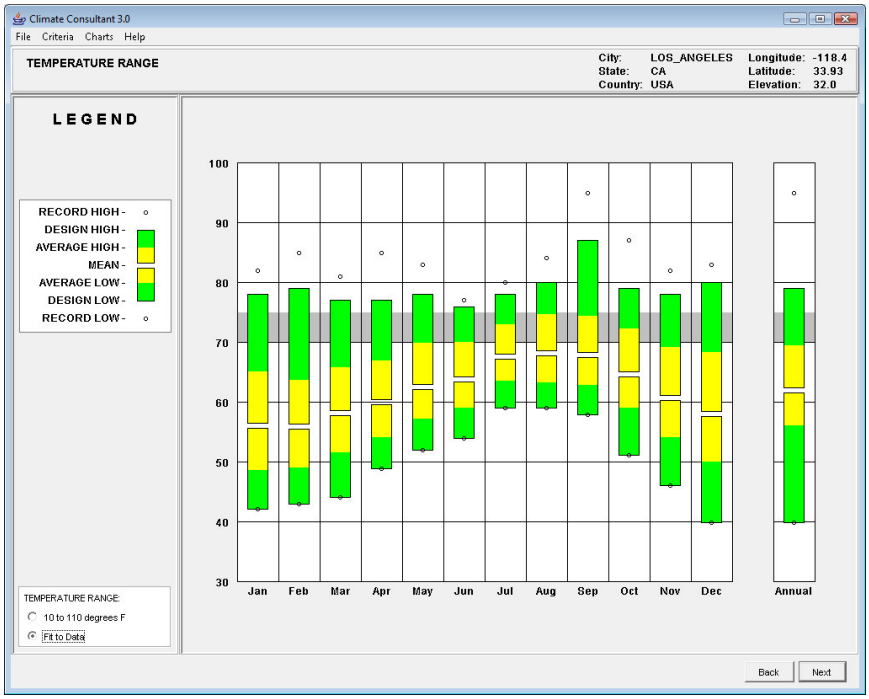

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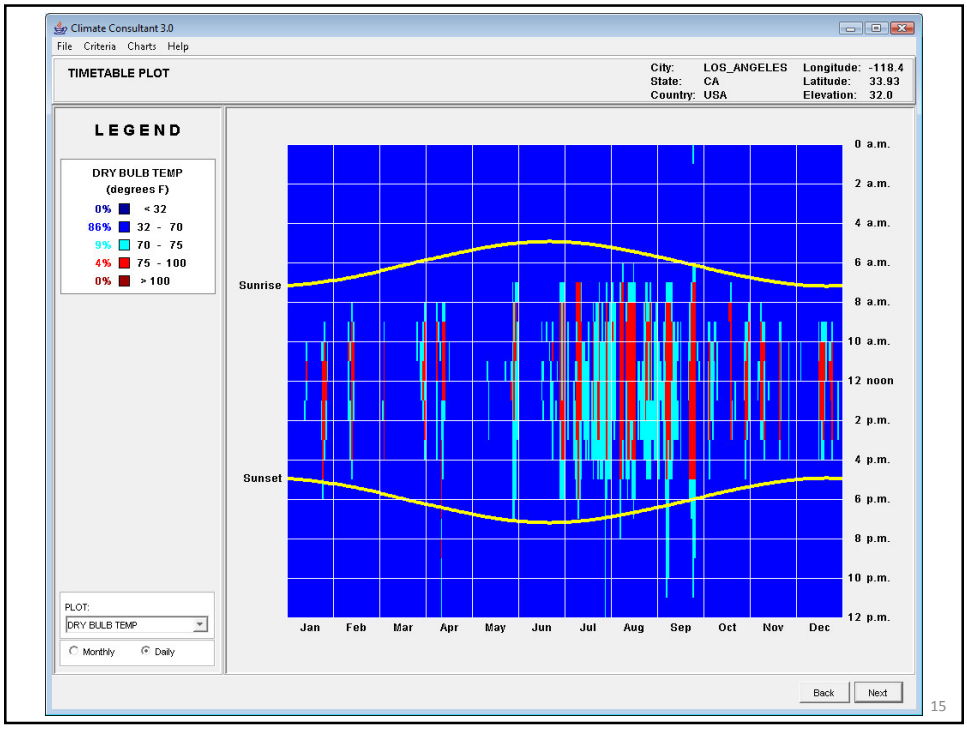
Climate Consultant 3.0
File Criteria Charts Help
TIMETABLE PLOT
City: LOS_ANGELES
State: CA
Country: USA
Longitude: -118.4
Latitude: 33.93
Elevation: 32.0
LEGEND
DRY BULB TEMP (degrees F)
0% < 32
86% 32 - 70
9% 70 - 75
4% 75 - 100
0% > 100
Sunrise
Sunset
0 a.m.
2 a.m.
4 a.m.
6 a.m.
8 a.m.
10 a.m.
12 noon
2 p.m.
4 p.m.
6 p.m.
8 p.m.
10 p.m.
12 p.m.
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
PLOT:
DRY BULB TEMP
Monthly Daily
Back Next
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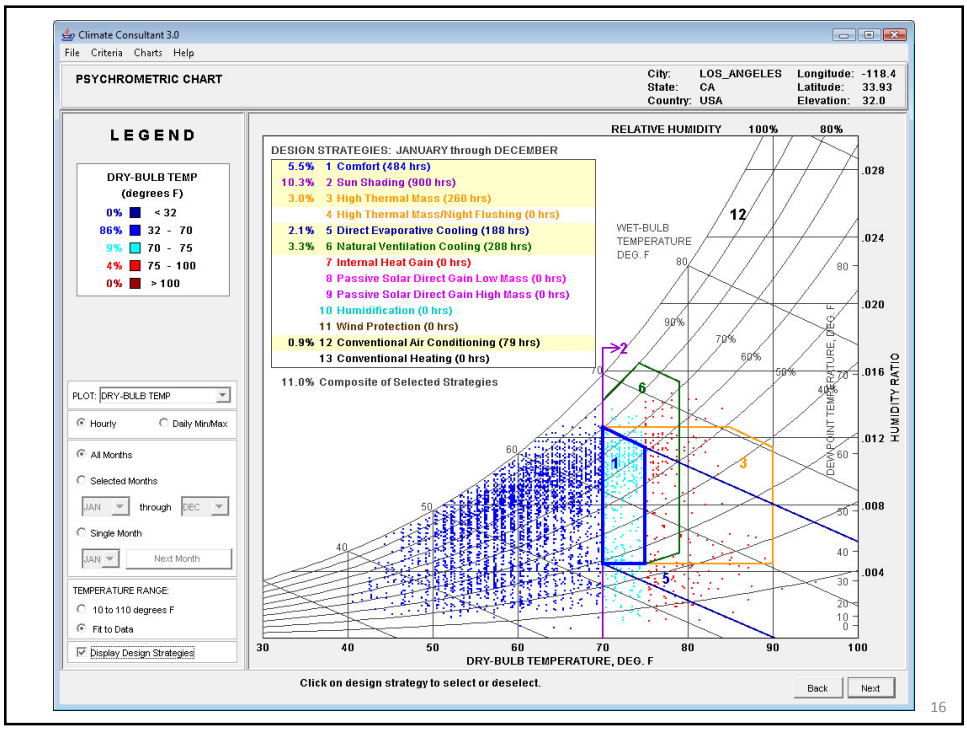
Climate Consultant 3.0
File Criteria Charts Help
PSYCHROMETRIC CHART
City: LOS_ANGELES
State: CA
Country: USA
Longitude: -118.4
Latitude: 33.93
Elevation: 32.0
LEGEND
DRY-BULB TEMP (degrees F)
0% < 32
86% 32 - 70
9% 70 - 75
4% 75 - 100
0% > 100
RELATIVE HUMIDITY 100% 80%
DESIGN STRATEGIES: JANUARY through DECEMBER
5.5% 1 Comfort (484 hrs)
10.3% 2 Sun Shading (900 hrs)
3.0% 3 High Thermal Mass (260 hrs)
4 High Thermal Mass/Night Flushing (0 hrs)
2.1% 5 Direct Evaporative Cooling (188 hrs)
3.3% 6 Natural Ventilation Cooling (288 hrs)
7 Internal Heat Gain (0 hrs)
8 Passive Solar Direct Gain Low Mass (0 hrs)
9 Passive Solar Direct Gain High Mass (0 hrs)
10 Humidification (0 hrs)
11 Wind Protection (0 hrs)
0.9% 12 Conventional Air Conditioning (79 hrs)
13 Conventional Heating (0 hrs)
11.0% Composite of Selected Strategies
WET-BULB TEMPERATURE DEG. F
DEW-POINT TEMPERATURE, DEG. F
HUMIDITY RATIO
DRY-BULB TEMPERATURE, DEG. F
PLOT: DRY-BULB TEMP
Hourly Daily Min/Max
All Months
Selected Months
JAN through DEC
Single Month
JAN Next Month
TEMPERATURE RANGE:
10 to 110 degrees F
Fit to Data
Display Design Strategies
Click on design strategy to select or deselect.
Back Next
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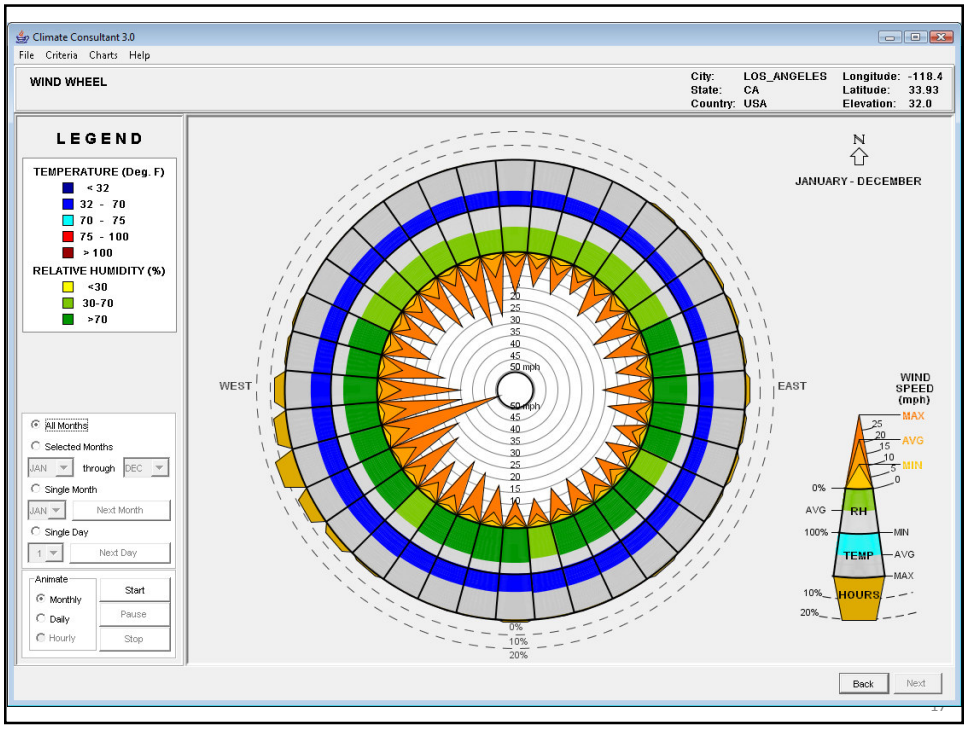

Feasibility – Code Requirements

- Air quality/ventilation requirements
  - No mechanical ventilation required
    - ASHRAE Standard 62-2007, www.ashrae.org
      - Spaces within 25 feet of openings
      - Opening size at least 4% of floor area
    - California Title 24-2005, www.energy.ca.gov/title24
      - All spaces within 20 ft of operable opening
      - Opening size at least 5% of floor area
- Smoke management
  - Natural ventilation paths can contribute to spread of smoke
  - May need automatic control of nat vent openings

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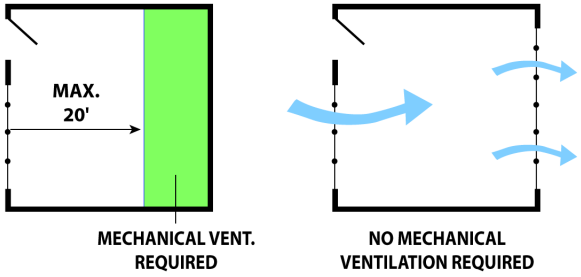
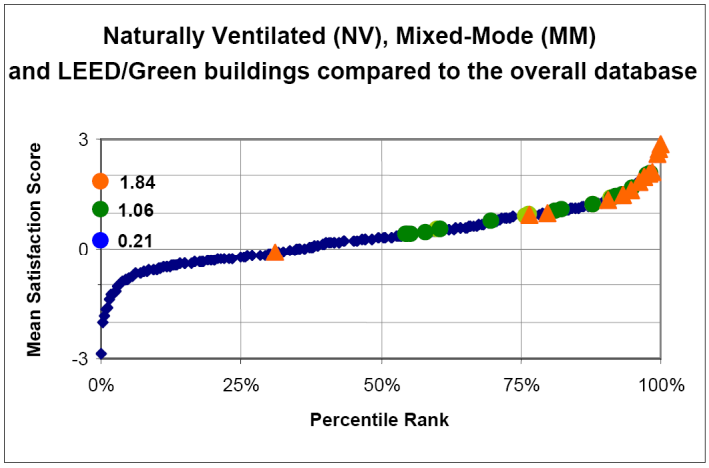
Ventilation - Title 24 and Natural Ventilation

- Title 24 compliance using natural ventilation permitted if:
  - All spaces within 20 ft of operable opening.
  - Total opening area > 5% of floor area.
- For a typical 960 ft² (30 ft x 32 ft) classroom,
  - At least 48 ft² opening area.
  - Openings on two sides of the room.



Source: www.chps.net 19

Occupant Survey Results
Air Quality Satisfaction



Source: Gail Brager, Center for the Built Environment, UC Berkeley 20

Feasibility – Noise

- Noisy outdoor environment may limit use of natural ventilation openings
  - Some sound-attenuating openings are available
- Potential problems
  - Traffic noise
  - Outdoor conversations
  - School playgrounds
- However, it is likely that indoor noise (phones, conversations) are more distracting than typical outdoor noise

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Natural Ventilation Driving Forces

- Air moves through an opening (e.g. window) when there is a pressure difference across the opening
  - Greater pressure difference = higher airflow
  - Larger opening area = higher airflow
- Natural ventilation pressure differences driven by two mechanisms
  - Air density difference (stack effect)
    - Warm air is less dense than cool air (more bouyant)
    - Works when indoor air is warmer than outdoor air
      - Harder to achieve stack airflow in summer
  - Wind
    - Creates varying surface pressures around the building

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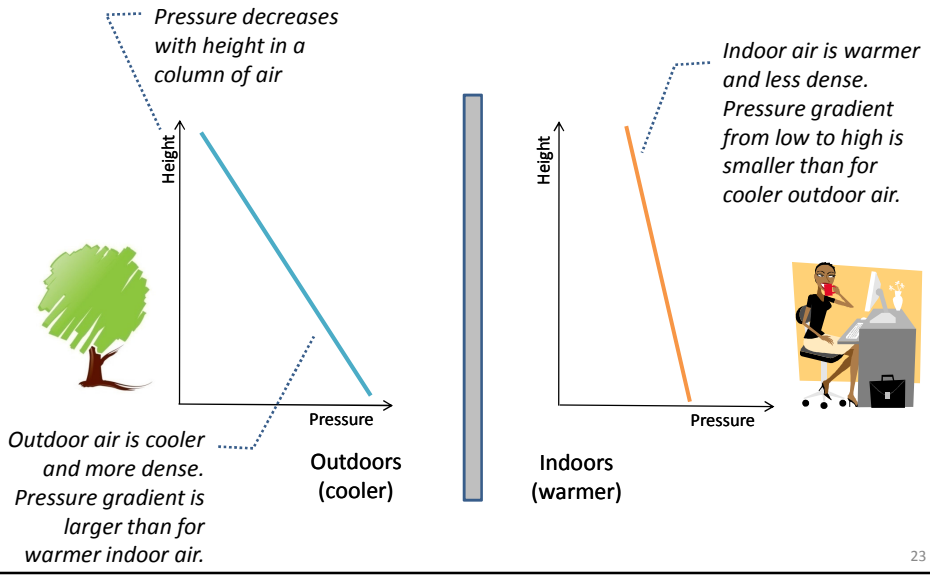
Stack Effect



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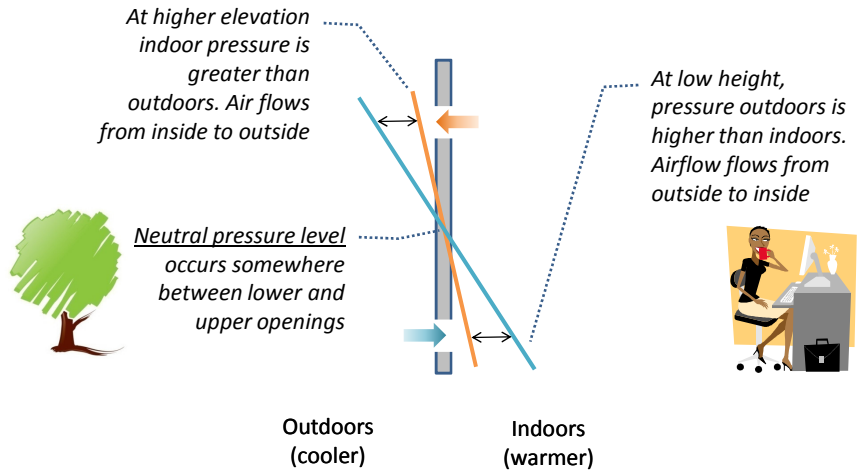
Stack Effect (continued)



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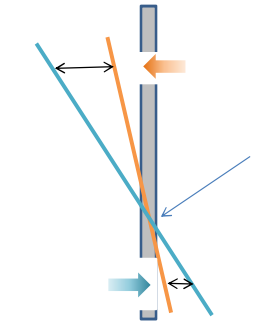
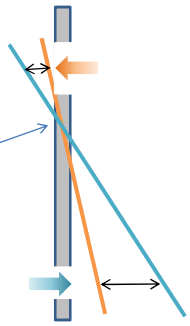
Stack Effect (continued)



Height of neutral pressure level (NPL) depends on relative size of lower and upper openings.
NPL is closer to the larger opening; less pressure needed to move air through a larger opening.



Outdoors (cooler) Indoors (warmer)

Outdoors (cooler) Indoors (warmer)

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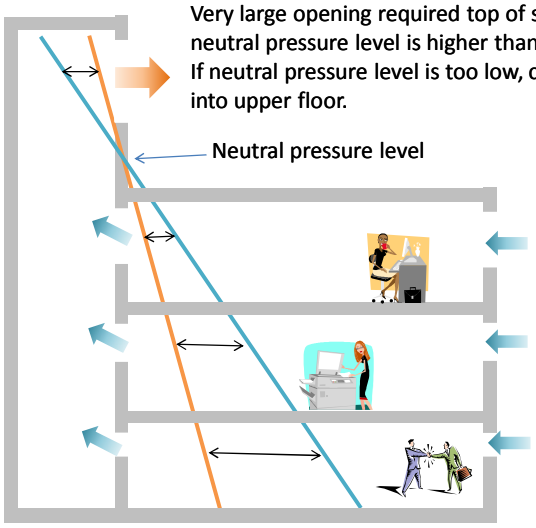
Stack Effect (continued)



Very large opening required top of stack to ensure that neutral pressure level is higher than the upper floor.
If neutral pressure level is too low, can get recirculation into upper floor.

Neutral pressure level

Larger openings required at upper floors to achieve equal airflow, due to smaller pressure difference

Lower floor openings can be smaller

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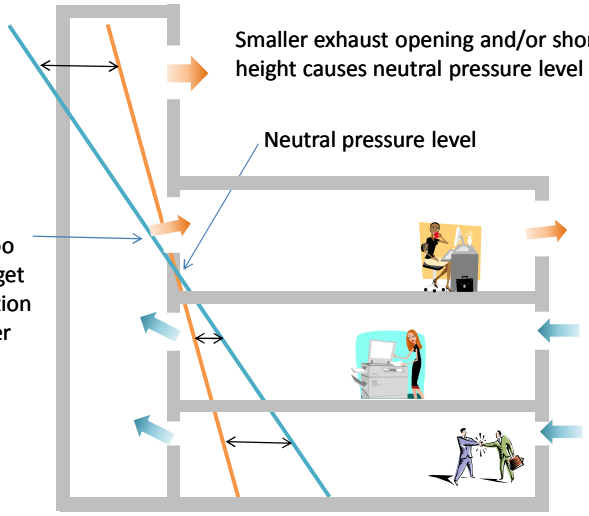
Stack Effect (continued)



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Stack Effect, Approximate Airflow Calculation

T_i, indoor temperature, degrees Rankine (deg F + 459)

T_o, outdoor temperature, degrees Rankine (deg F + 459)

Airflow, cfm

$$q = 60KA\sqrt{\frac{gh(T_i - T_o)}{T_i}}$$

K, discharge coefficient, property of opening, 0.6 typical

h, height of stack from inlet to outlet, ft

Area of opening, ft^2, smaller of inlet or outlet free area

g, gravitational constant, 32.2 ft/s^2

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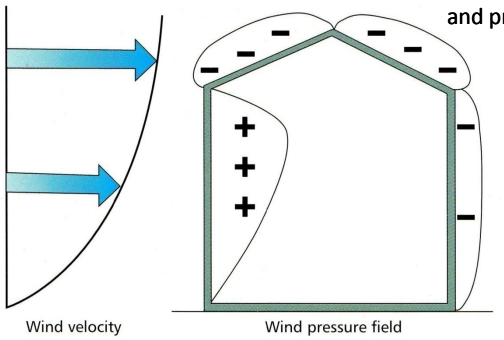
Wind Pressure

Wind flowing around a building creates areas of positive and negative pressure

On the roof and sides, air velocity accelerates and pressure drops

Wind velocity is typically lower near the ground and increases with height above ground



On the leeward (downwind) side, flow separates from the roof and sides creating a low pressure recirculation zone

On the windward (upwind) side, air velocity slows and pressure rises

Source: AM10: 2005, Natural Ventilation in Non-Domestic Buildings, CIBSE

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Wind-Driven Cross Ventilation Approximate Airflow Calculation

Airflow, cfm

$$q = C \cdot A \cdot V$$

V, wind velocity, fpm

C, effectiveness factor (dimensionless) depends on orientation.
0.5 to 0.6 for windows perpendicular to wind.
0.25 to 0.35 for windows diagonal to wind

A, area of opening, ft^2, smaller of inlet or outlet free area

Source: AM10: 2005, Natural Ventilation in Non-Domestic Buildings, CIBSE

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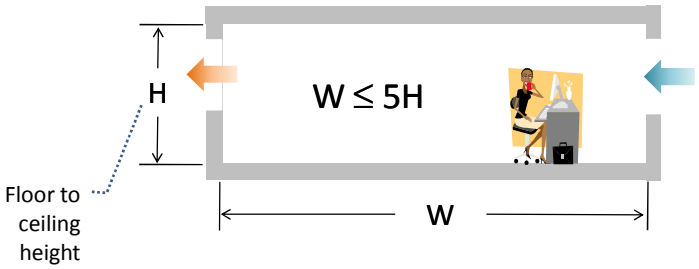
Rule of Thumb for Wind-Driven Cross Ventilation



Source: AM10: 2005, Natural Ventilation in Non-Domestic Buildings, CIBSE

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Single-Sided Natural Ventilation Airflow Due to Stack Effect

K = 0.25 typical

$$q = 60KA\sqrt{\frac{gh(T_i - T_o)}{T_i}}$$

K = 0.6 typical

Source: AM10: 2005, Natural Ventilation in Non-Domestic Buildings, CIBSE

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Single-Sided Natural Ventilation Airflow Due to Wind

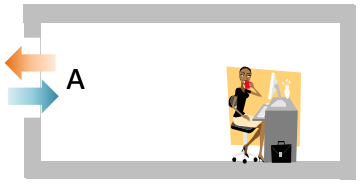
Airflow, cfm

$$q = C \cdot A \cdot V$$

A, area of opening, ft^2

V, wind velocity, fpm

C, effectiveness factor (dimensionless) Typical value 0.01 to 0.05 for single-sided ventilation. Value is much lower than for wind-driven cross ventilation.



Source: AM10: 2005, Natural Ventilation in Non-Domestic Buildings, CIBSE

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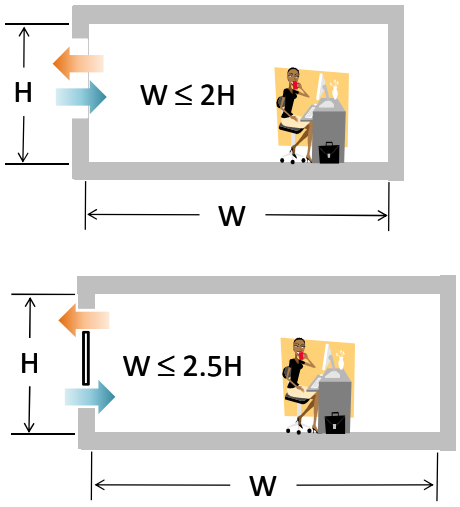
Single-Sided Natural Ventilation Rule of Thumb



Source: AM10: 2005, Natural Ventilation in Non-Domestic Buildings, CIBSE

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Natural Ventilation Design Methods

- Simplified equations
  - Like those just described
  - Or slightly more complicated simplified methods
    - Can account for combined wind and stack effect
  - Good for quick initial sizing calculations and for simple buildings
  - References
    - AM10: 2005, Natural Ventilation in Non-Domestic Buildings, CIBSE, www.carbontrust.uk
    - ASHRAE Handbook Fundamentals
      - Basic cross ventilation and stack ventilation equations

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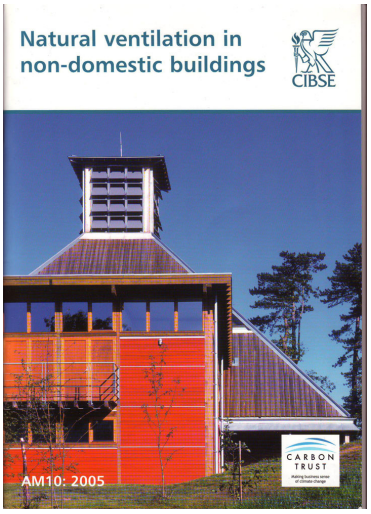
Good Reference Source

- Natural Ventilation in Non-domestic Buildings, CIBSE AM10:2005
  - UK publication
  - Simple calc methods and principles
  - www.cibse.org



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Natural Ventilation Design Methods (continued)

- Airflow network models
  - Set of pressure/temperature nodes (e.g. spaces) connected by openings
  - Multizone modeling software
    - CONTAM
      - http://www.bfrl.nist.gov/IAQanalysis/index.htm
    - COMIS
  - Software with integrated thermal model
    - EnergyPlus; integrated with hourly thermal model
    - Trnsys and CONTAM
    - Tas
      - Developed in the UK
      - www.edsl.net
    - IES-VE
      - Also developed in UK
      - www.iesve.com

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Natural Ventilation Design Methods (continued)

- Computational fluid dynamics (CFD)
  - Predicts airflow throughout the space
  - Appropriate for testing concepts and refining designs
- Physical models in wind tunnel
  - Most often used to predict wind pressure on building surfaces

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Energy Estimation Methods

- DOE2/eQUEST
  - Limited natural ventilation capability
    - (see next slide)
  - Useful to estimate potential energy benefit
- EnergyPlus, Tas, Transys/CONTAM
  - Integrate airflow and thermal simulation
  - Better accuracy
  - Some greater control simulation flexibility

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eQUEST/DOE2 and Natural Ventilation

- Simple natural ventilation model in eQUEST/DOE2
  - Choose one of two airflow methods
    1. You specify air changes per hour when windows are open
    2. Airflow calculated hourly using Sherman-Grimsrud Method
       - Based on opening area, wind speed, inside/outside temperature difference
  - Windows will open when all cooling can be provided by natural ventilation; fan will shut off
    - Otherwise windows will be shut and AC system provides cooling
  - Available for only a limited set of HVAC system types
    - Packaged single zone
    - Residential system type

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Energy Savings Research

Mixed-mode energy savings –simulations

- EnergyPlus simulations, small-med commercial bldg
- Range of savings corresponds to 7 climates
- Min.savings (**9%**): Miami
  Max. savings (**79%**): Los Angeles

	Mixed mode – no fan lockout (*)	Mixed mode – fan lockout (*)
Small office	9-42%	13-79%
Medium-sized office	11-40%	13-42%

(*) Fan lockout when indoor temperature is between the heating and mechanical cooling setpoints (windows are open to varying degrees for ventilation and cooling

Haves et al., Assessment of Building Control Systems, LBNL, 2007

Source: Gail Brager, Center for the Built Environment, UC Berkeley

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Natural Ventilation
Integrated Design Strategies

- Cooling load reduction
  - Lighting, solar heat gain, orientation
- Thermal mass and night ventilation
  - Provide secure, rain-proof openings for night ventilation
- Ceiling fans to stretch comfort envelope
- Building zoning and space planning
  - If some uses require conditioning, separate them from nat vent spaces
  - A single building can include a mix of nat vent spaces, mixed mode spaces, and mechanically cooled spaces (e.g. computer room)
- Building form
  - Narrow for cross ventilation
  - Atrium for stack ventilation

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Natural Ventilation Control Strategies

- Manually operated openings, no HVAC integration
- Automatic notification system
  - Red/green lights based on outdoor conditions
- HVAC interlock switches
  - Shut off HVAC when window/door open
- CO_2-based control of mechanical ventilation
  - Fan shuts off when window open, turns on when CO_2 concentration climbs
- BMS
  - As complicated as you want…

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Yang and Yamazaki Environment and Energy (Y2E2) Building Stanford

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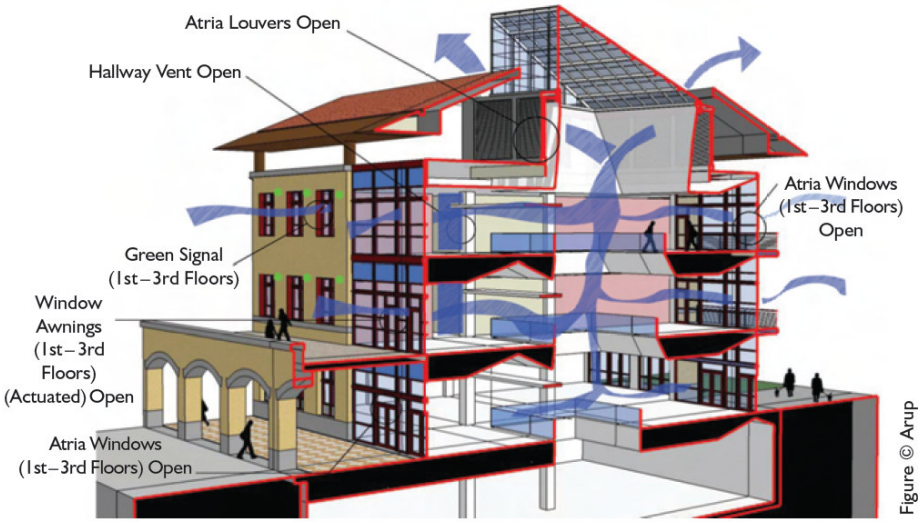
Yang and Yamazaki
Environment and Energy (Y2E2) Building
Stanford



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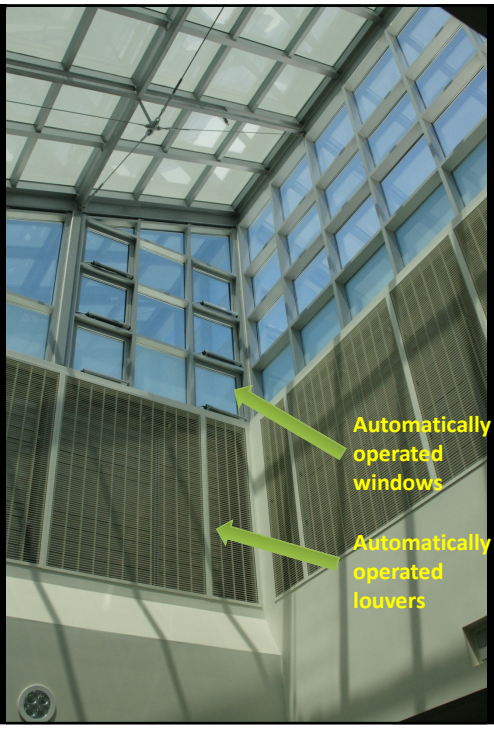

Y2E2 Building, Stanford.
Natural ventilation exhaust damper and louvers at top of atrium.

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Y2E2 Building, Stanford.
Upper and lower operable windows.
Ceiling fan.

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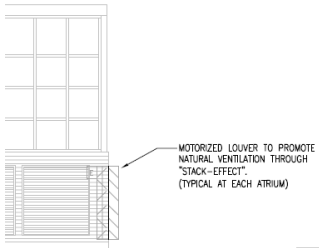

Y2E2 Building, Stanford
Offices on north and east facades are naturally ventilated via manually operable windows.
Ceiling fans are provided to improve comfort in hot weather.
Path for airflow to atrium promotes stack ventilation.
Exposed concrete floor provides thermal mass.

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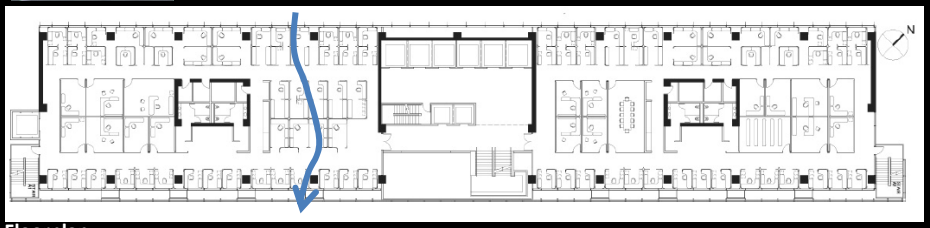
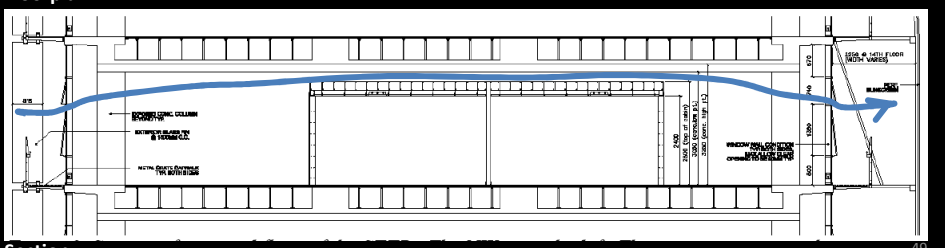
San Francisco Federal Building

Narrow floor plan, about 60 ft wide.
Operable windows on both sides; automatic and manual.
Airspace above enclosed core rooms allows cross ventilation.



Floorplan



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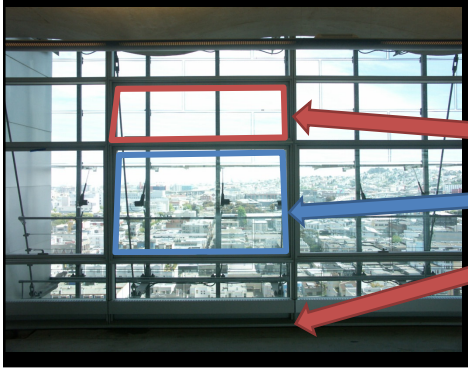

Exposed concrete ceiling for thermal mass.

Upper windows automatically operated.

Lower windows manually operated.

Fin-tube radiator with trickle vent

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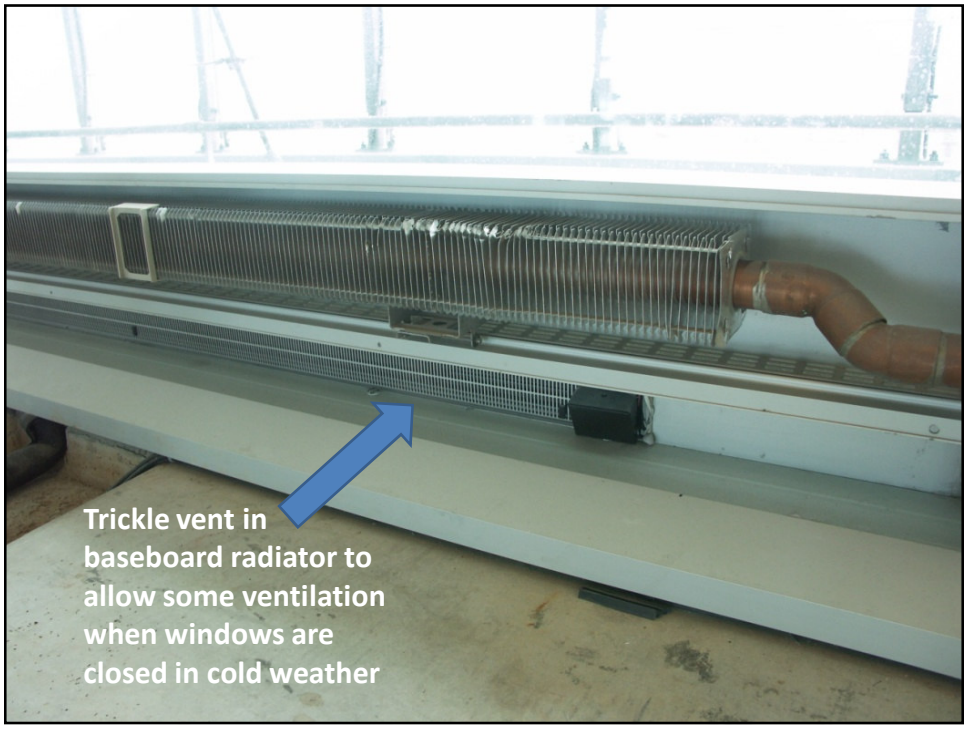
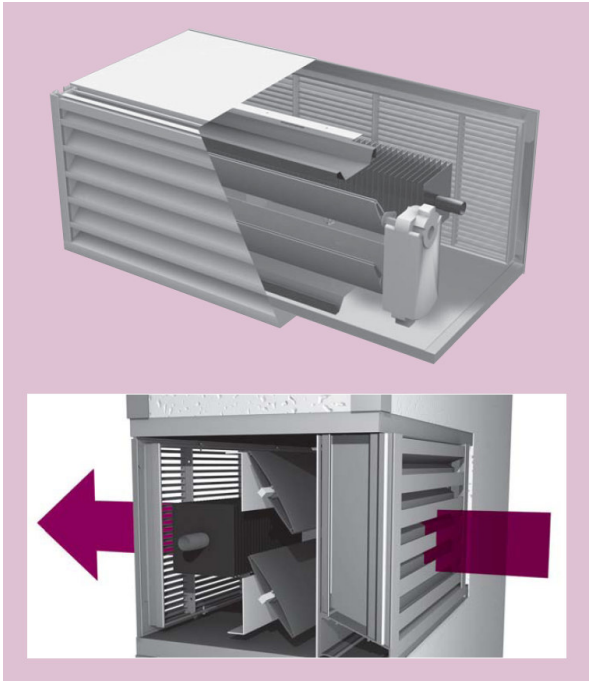


Example trickle vent
Includes motorized damper
&
Fin tube radiator



www.price-hvac.com

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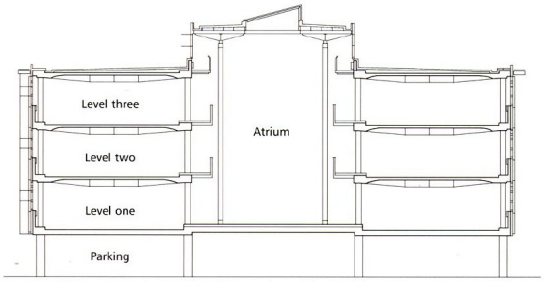
Powergen Headquarters,
Coventry, England
Automatically controlled windows.
Atrium air relief path.
Coffered concrete ceiling for thermal mass.
Nighttime natural ventilation for precooling.



Resources

- Natural Ventilation in Non-domestic Buildings, CIBSE AM10:2005
  - UK publication
  - Simple calc methods and principles
- Whole Building Design Guide
  - www.wbdg.org/design/naturalventilation.php
- GPC237 Natural Ventilation in Non-domestic Buildings - A Guide for Designers, Developers, and owners. DETR.
  - www.carbontrust.co.uk
- ASHRAE Handbook – Fundamentals 2005
  - Basic cross ventilation and stack ventilation equations
- Center for the Built Environment
  - Database of mixed-mode projects, www.cbe.berkeley.edu
- ASHRAE Journal, Sep 2008
  - McConahey, “Mixed Mode Ventilation, Finding the Right Mix”

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Discussion

- Experiences…
- Concerns…
- Ideas…

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