Outside Air Control – the most cost-effective energy efficiency measure of all

Rob Bishop
Energy Solutions Ltd.

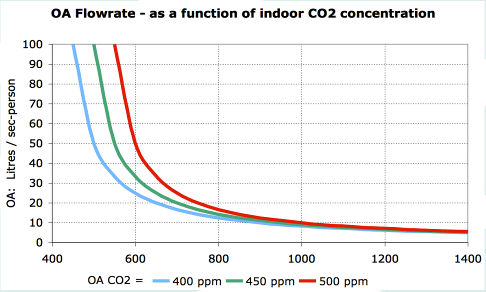
Summary

- Problem: most mechanically ventilated buildings supply too much OA (outside air).
- This causes higher heating and cooling loads.
- Remedying this using CO_2 sensing offers very large potential energy savings.
- Estimated value: $70 million/year (in NZ)
  $30 billion/year (world-wide)
- Emissions red'n: 300 kT CO_{2e}/yr (0.4% of NZ total)
  100 MT CO_{2e}/yr world-wide

Why supply fresh air?

- To maintain indoor air quality.
- To allow pressurisation of building interior to avoid infiltration, especially at ground level.
  (This includes replacing exhaust air.)
- To give "free cooling" via "economiser cycle".

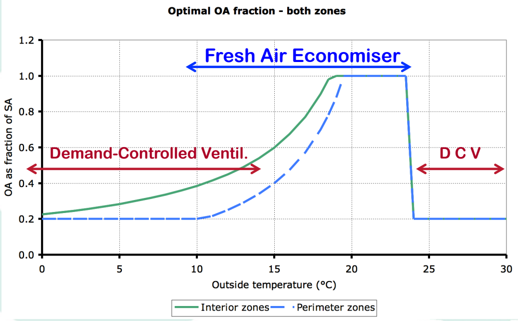
Ventilation Rates from CO_2 levels

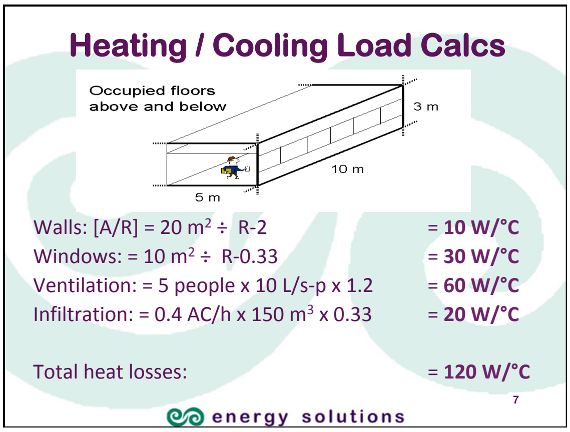


Definitions

- *ECONOMIZER* – A system of fans, dampers and controls to reduce cooling loads, by increasing OA in certain temperature ranges.
- *DEMAND CONTROLLED VENTILATION* – A system of fans, dampers and controls to reduce heating and cooling loads, by reducing OA.

OA Control Strategies vs. T





Heading / Cooling Load Calcs

Walls: [A/R] = 20 m^2 ÷ R-2	**= 10 W/°C**
Windows: = 10 m^2 ÷ R-0.33	**= 30 W/°C**
Ventilation: = 5 people x 10 L/s-p x 1.2	**= 60 W/°C**
Infiltration: = 0.4 AC/h x 150 m^3 x 0.33	**= 20 W/°C**
Total heat losses:	**= 120 W/°C**

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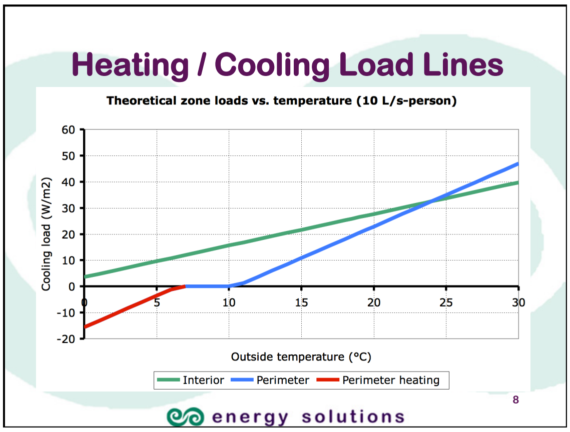

Heating / Cooling Load Lines

Theoretical zone loads vs. temperature (10 L/s-person)

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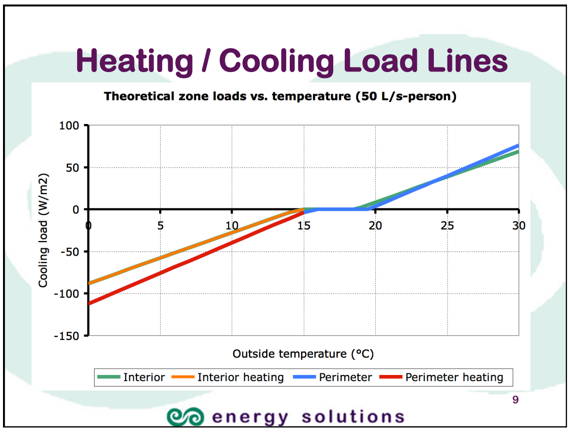

Heating / Cooling Load Lines

Theoretical zone loads vs. temperature (50 L/s-person)

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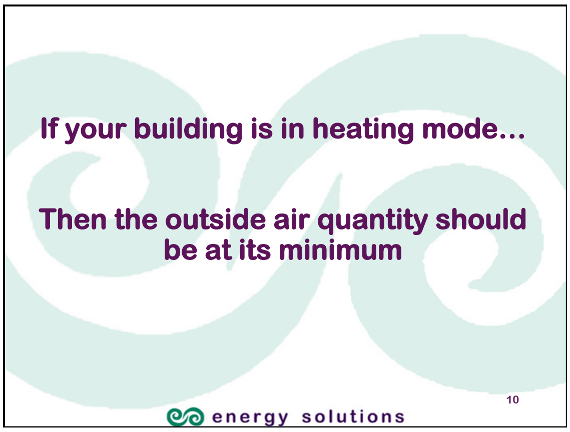

If your building is in heating mode…

Then the outside air quantity should be at its minimum

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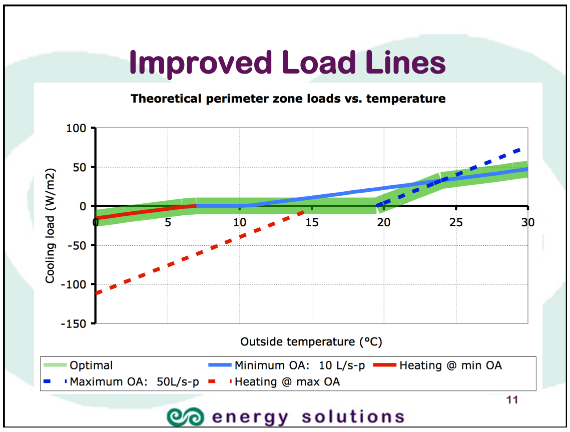

Improved Load Lines

Theoretical perimeter zone loads vs. temperature

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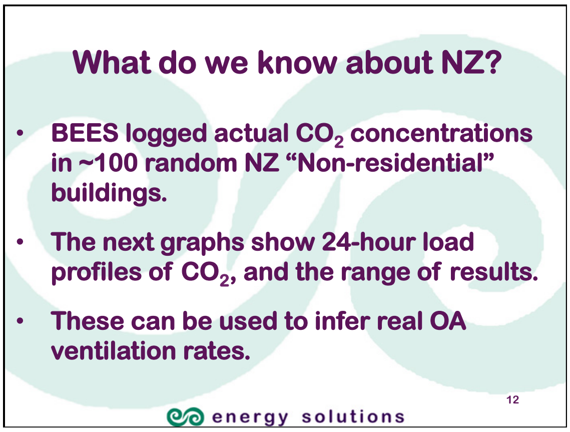

What do we know about NZ?

- **BEES logged actual CO$_2$ concentrations in ~100 random NZ “Non-residential” buildings.**
- **The next graphs show 24-hour load profiles of CO$_2$, and the range of results.**
- **These can be used to infer real OA ventilation rates.**

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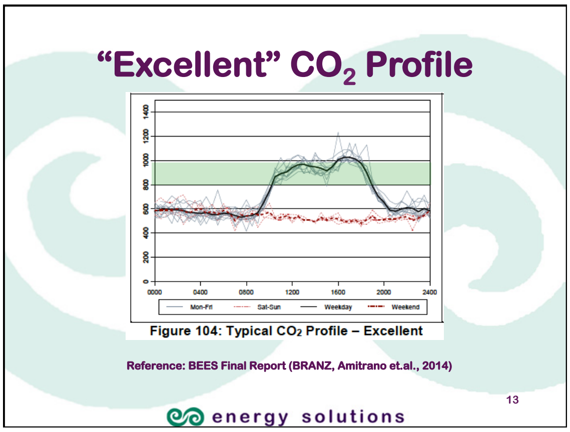

“Excellent” CO_2 Profile

Figure 104: Typical CO₂ Profile – Excellent

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

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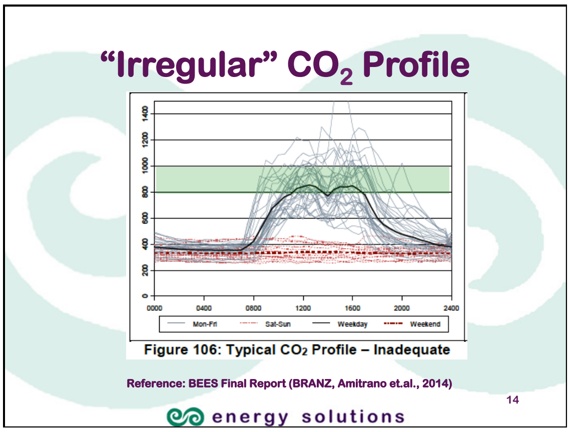

“Irregular” CO_2 Profile

Figure 106: Typical CO₂ Profile – Inadequate

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

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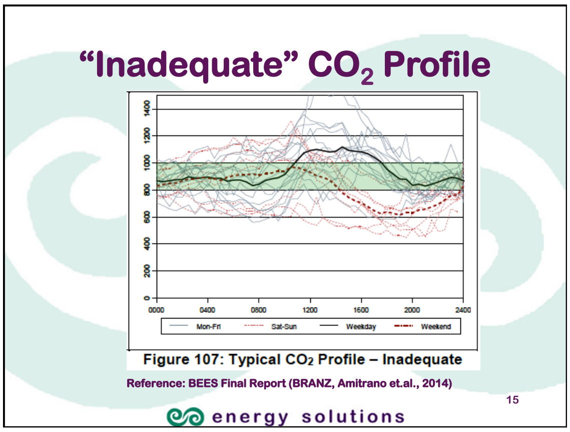

“Inadequate” CO_2 Profile

Figure 107: Typical CO₂ Profile – Inadequate

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

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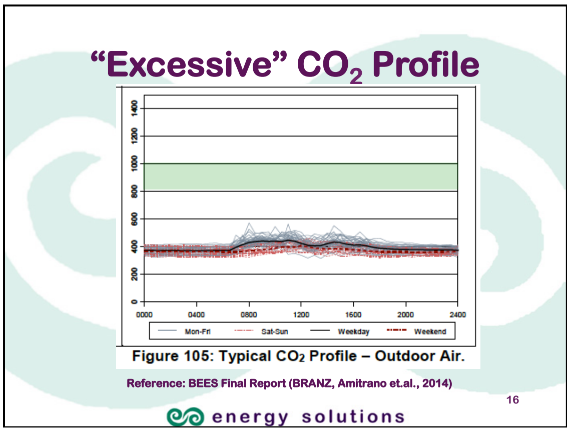

“Excessive” CO_2 Profile

Figure 105: Typical CO₂ Profile – Outdoor Air.

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

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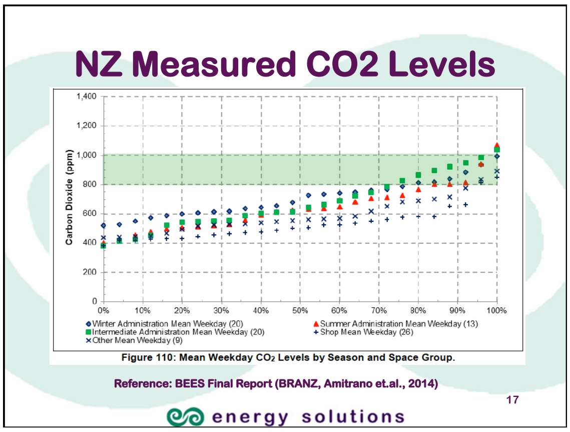

NZ Measured CO2 Levels

Figure 110: Mean Weekday CO₂ Levels by Season and Space Group.

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

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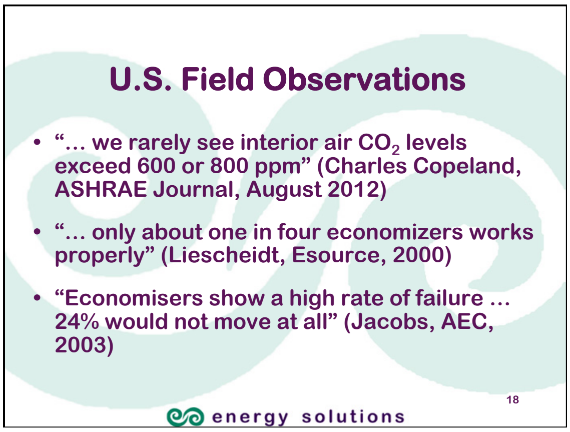

U.S. Field Observations

- “… we rarely see interior air CO_2 levels exceed 600 or 800 ppm” (Charles Copeland, ASHRAE Journal, August 2012)
- “… only about one in four economizers works properly” (Liescheidt, Esource, 2000)
- “Economisers show a high rate of failure … 24% would not move at all” (Jacobs, AEC, 2003)

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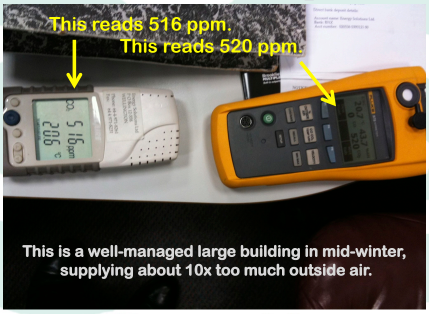
NZ Observed CO_2 levels



This reads 516 ppm.

This reads 520 ppm.

This is a well-managed large building in mid-winter, supplying about 10x too much outside air.

NZ Standard 4303:1990

- Ventilation for Adequate Indoor Air Quality
- Based on ASHRAE 62.1-1989.
- **Ventilation Rate Procedure**: 10 L/sec-person.
- **IAQ Procedure**: Indoor CO_2 concentration under 1100 ppm, or 700 ppm above outdoors, indicates good air quality.

ASHRAE Standard 62.1

- Through 2004, Standard only considered ventilation per person. Typically 7 – 10 L/s per person.
- Post 2004 Standards reduces air per person, but adds a term per floor area – effectively the same, but dependent on people density.
- Standard 62.1:2013 typically requires 2.5 L/s-person plus 0.3 L/s – square metre

Cooling load calculations

SA (L/s) = Load (W) / ΔT_{air} x 1.21 W/(L/s)-°C

So, SA quantities for different situations

(@ 15 W/m^2 electrical loads):

Room type	m^2/person	L/s-person	L/s-m^2
Office	10 m^2	19 L/s-p	1.9 L/s-m^2
Office	20 m^2	31 L/s-p	1.5 L/s-m^2
Stores	100 m^2	130 L/s-p	1.3 L/s-m^2
Meeting rm.	2 m^2	9 L/s-p	4.3 L/s-m^2

Required OA Quantities

Compare the minimum OA quantities

(NZS 4303:1990 vs. ASHRAE 62.1:2013)

	OA L/s-person	RA CO_2
Room type	(NZS / ASHRAE)	(NZS / ASHRAE)
Office (10 m^2/p)	10 / 5.5	950 / 1360
Office (20 m^2/p)	10 / 8.5	950 / 1040
Stores (100 m^2/p)	10 / 32.5	950 / 600
Meeting (2 m^2/p)	10 / 3.1	950 / 2100

The “Meeting room” problem

Densely and irregularly occupied spaces can have difficult-to-meet ventilation requirements.

Required OA per person can be more than total SA.

Boosting (SA) ventilation to crowded meeting rooms can cause over-cooling if OA need is met.

Solution: either supply dedicated OA duct, or install reheat coils in meeting rooms to prevent over-cooling, and ensure sufficient SA is available.

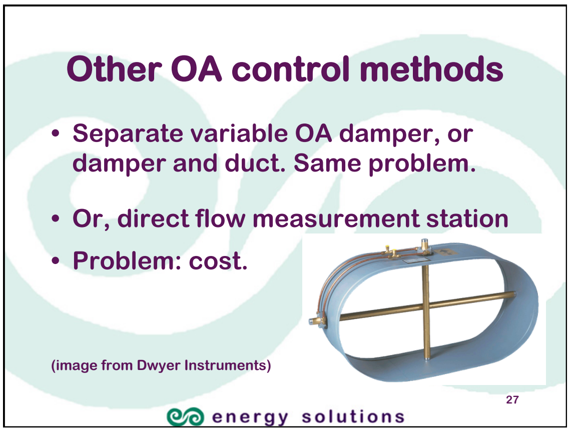
Otherwise, cooling and vent loads won’t be met.

Recommendation re. Standards

- Supply enough OA to comply with BOTH new ASHRAE and Aus/NZ ventilation standards.
- In NZ, this will only require more ventilation in lightly occupied spaces – storerooms, etc.
- *(But the problem is: most buildings supply much too much OA)*

Typical control of OA

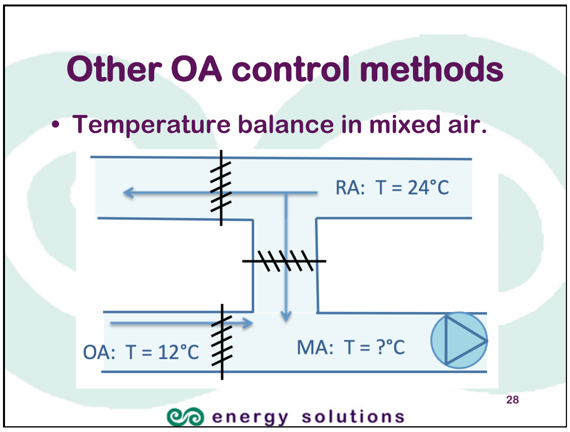
- Simplest method: If using OA economiser, set minimum position on actuator of moveable OA damper.
- How is it set? Commissioned?
- Is this really "controlling" OA?



Other OA control methods

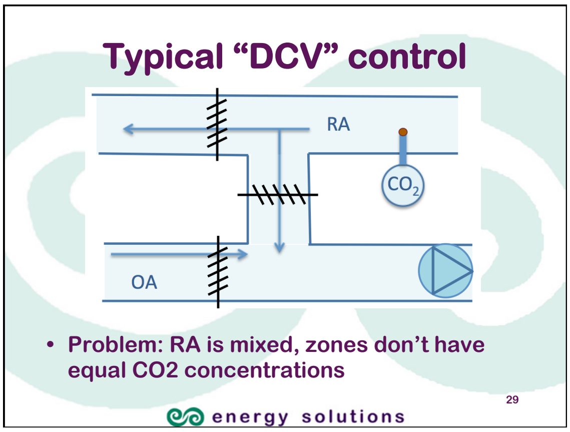
- Separate variable OA damper, or damper and duct. Same problem.
- Or, direct flow measurement station
- Problem: cost.

(image from Dwyer Instruments)



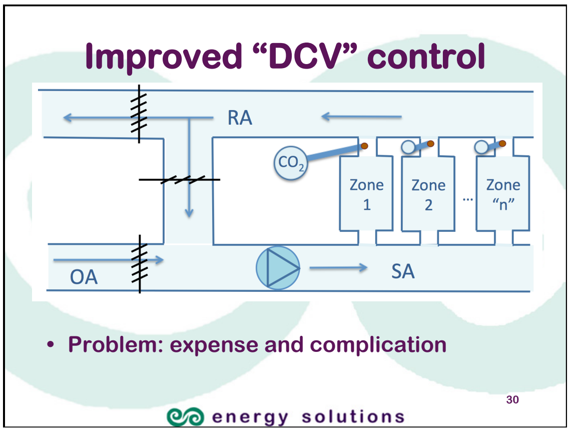
Other OA control methods

- Temperature balance in mixed air.



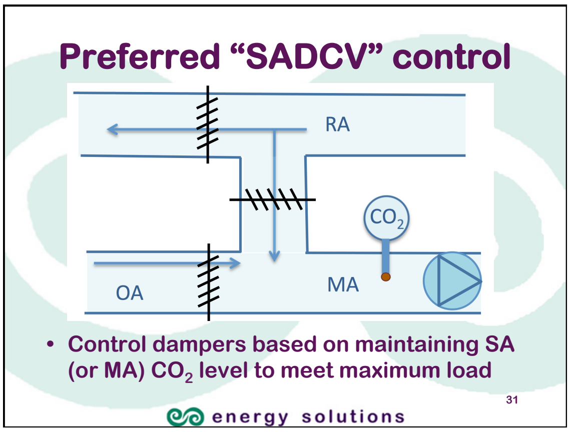
Typical "DCV" control

- Problem: RA is mixed, zones don't have equal CO2 concentrations



Improved "DCV" control

- Problem: expense and complication



Preferred "SADCV" control

- Control dampers based on maintaining SA (or MA) CO$_2$ level to meet maximum load

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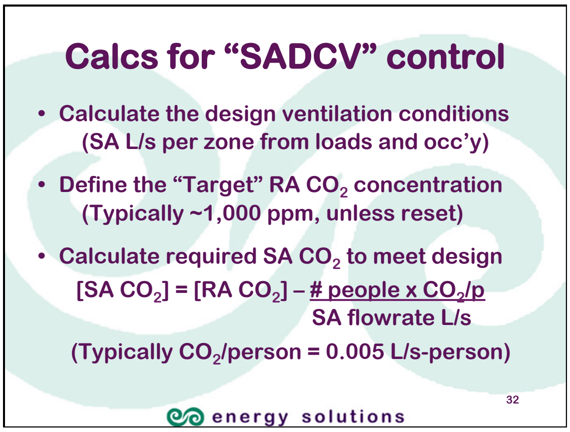

Calcs for "SADCV" control

- Calculate the design ventilation conditions (SA L/s per zone from loads and occ'y)
- Define the "Target" RA CO$_2$ concentration (Typically ~1,000 ppm, unless reset)
- Calculate required SA CO$_2$ to meet design

$$[\text{SA CO}_2] = [\text{RA CO}_2] - \frac{\text{\# people x CO}_2\text{/p}}{\text{SA flowrate L/s}}$$

(Typically CO$_2$/person = 0.005 L/s-person)

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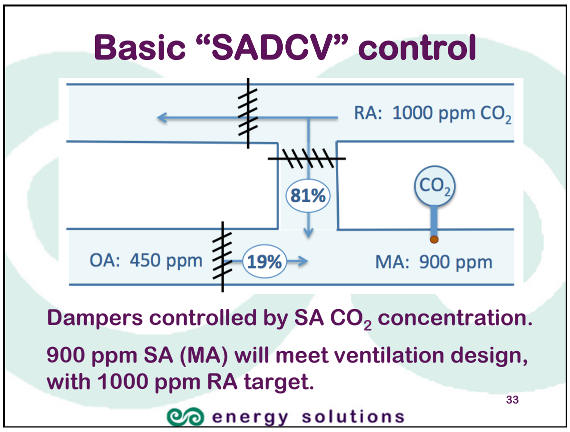

Basic "SADCV" control

Dampers controlled by SA CO$_2$ concentration.

900 ppm SA (MA) will meet ventilation design, with 1000 ppm RA target.

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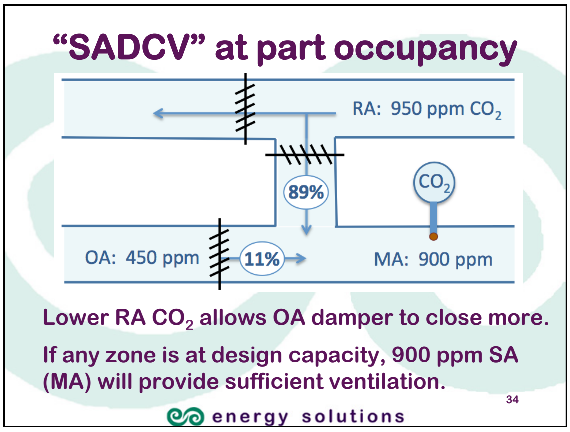

"SADCV" at part occupancy

Lower RA CO$_2$ allows OA damper to close more.

If any zone is at design capacity, 900 ppm SA (MA) will provide sufficient ventilation.

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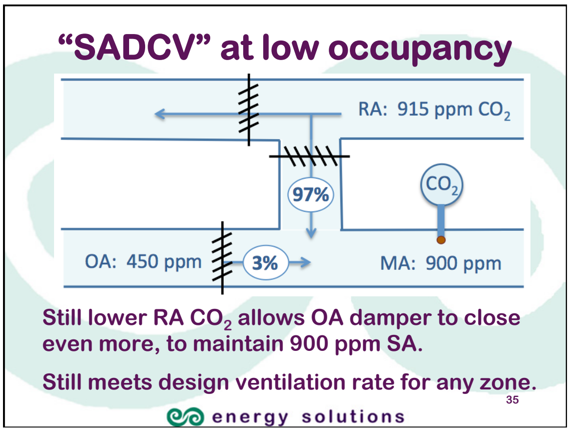

"SADCV" at low occupancy

Still lower RA CO$_2$ allows OA damper to close even more, to maintain 900 ppm SA.

Still meets design ventilation rate for any zone.

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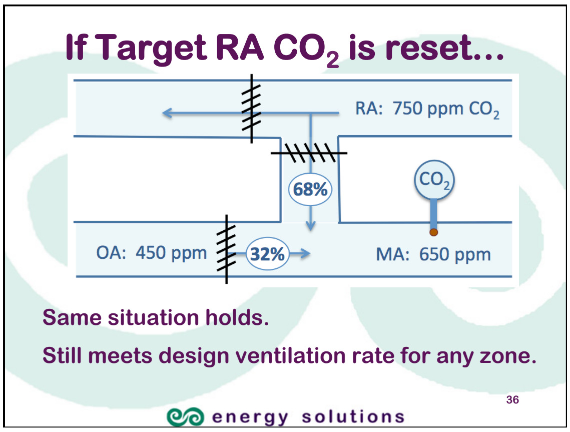

If Target RA CO$_2$ is reset…

Same situation holds.

Still meets design ventilation rate for any zone.

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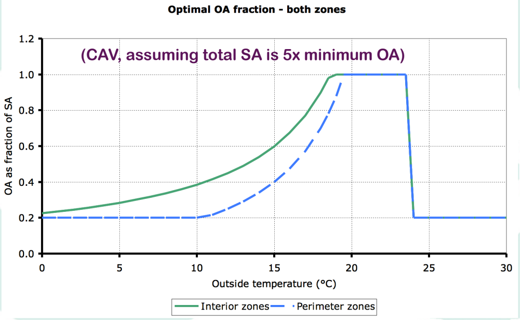
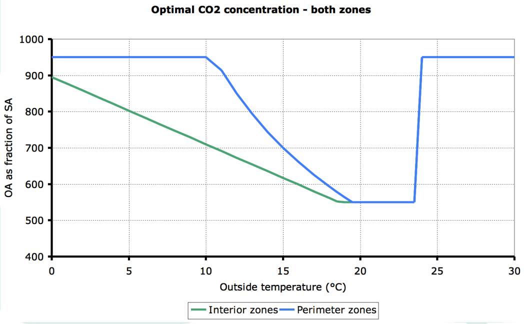
Optimisation of OA

- Manage delivery of OA to building (by resetting target SA CO_2), to minimise heating and cooling loads.
- Effective economiser, between 15 - 22°C.
- Effective DCV, below 15°, above 22°C.
- Significant (up to 90+%) heating and cooling energy savings.
- Potential of avoiding cost and space of boilers in mild climates -> capital cost savings

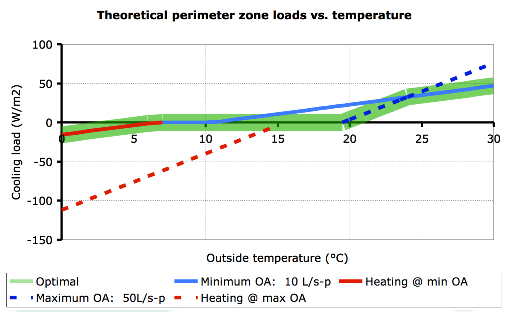
Optimal Outside Air Supplied



Optimal RA CO_2 concentrations



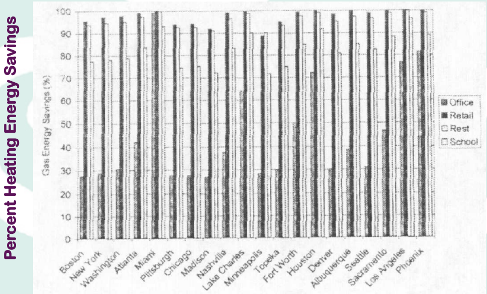
Optimised OA minimises loads



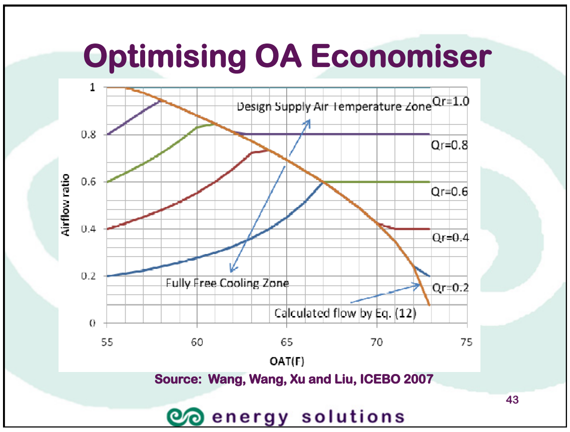
International research – three separate streams

- Effects of DCV, assuming that buildings were already achieving 1000 ppm.
- Measurements of indoor CO2, indicating that buildings generally have very low CO2.
- Warnings about the effects of reducing ventilation too much.

Potential Heating Energy Savings

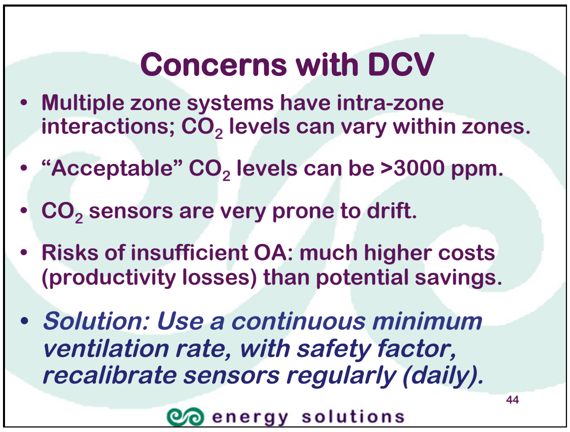


Source: Brandemuhl and Braun, ASHRAE Transactions, 1999



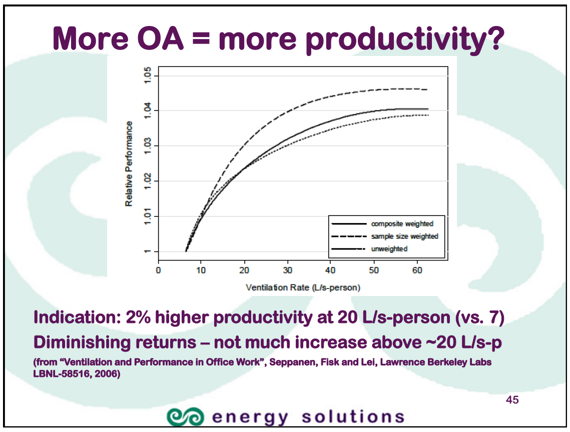
Optimising OA Economiser

Source: Wang, Wang, Xu and Liu, ICEBO 2007



Concerns with DCV

- Multiple zone systems have intra-zone interactions; CO_2 levels can vary within zones.
- “Acceptable” CO_2 levels can be >3000 ppm.
- CO_2 sensors are very prone to drift.
- Risks of insufficient OA: much higher costs (productivity losses) than potential savings.
- *Solution: Use a continuous minimum ventilation rate, with safety factor, recalibrate sensors regularly (daily).*

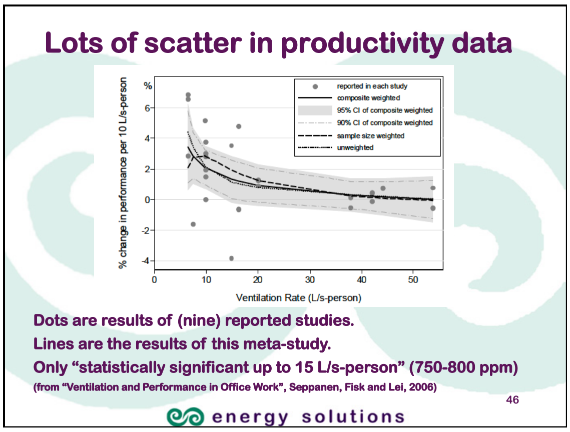


More OA = more productivity?

Indication: 2% higher productivity at 20 L/s-person (vs. 7)

Diminishing returns – not much increase above ~20 L/s-p

(from “Ventilation and Performance in Office Work”, Seppanen, Fisk and Lei, Lawrence Berkeley Labs LBNL-58516, 2006)



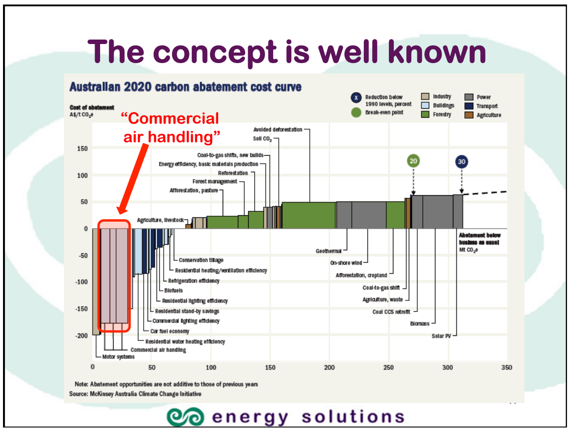
Lots of scatter in productivity data

Dots are results of (nine) reported studies.

Lines are the results of this meta-study.

Only “statistically significant up to 15 L/s-person” (750-800 ppm)

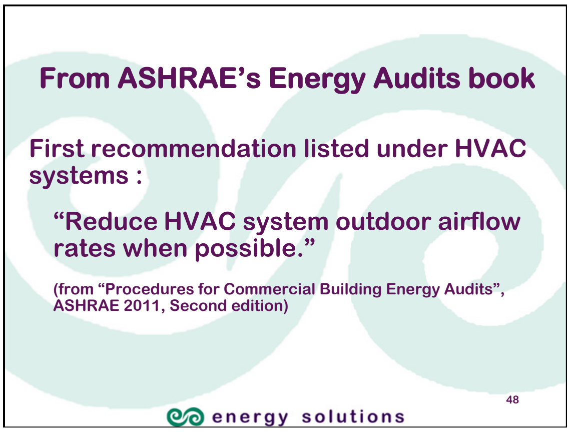
(from “Ventilation and Performance in Office Work”, Seppanen, Fisk and Lei, 2006)



The concept is well known

Note: Abatement opportunities are not additive to those of previous years

Source: McKinsey Australia Climate Change Initiative



From ASHRAE’s Energy Audits book

First recommendation listed under HVAC systems :

> “Reduce HVAC system outdoor airflow rates when possible.”
>
> (from “Procedures for Commercial Building Energy Audits”, ASHRAE 2011, Second edition)

Wulfinghoff provides 60 pages

"Measure 4.2.1 Adjust outside air intake…

Savings potential: May be a large fraction of the cost of heating and cooling energy.

Cost: small, in cases where only adjustments are required.

Payback period: Less than one year."

(from “”Wulfinghoff Energy Efficiency Manual, Energy Institute Press 1999, pp. 516-578)

NZ Market - bottom up estimate

- 40% of NZ commercial building floor area is in buildings larger than 3,500 sq.m.
- 500 buildings ~17,000 m^2 (> 9,000 m^2)
  EnPI$_e$ = 223 kWh/m^2 yr
- 1,500 buildings ~ 5,200 m^2 (3,500 – 9,000 m$^{2)}$
  EnPI$_e$ = 201 kWh/m^2 yr
- 3,500 buildings ~ 2,200 m^2 (1,500 – 3,500 m^2)
  EnPI$_e$ = 155 kWh/m^2 yr

Data from BEES Final Report (BRANZ, Amitrano et.al., 2014)

NZ HVAC EnPIs by building size

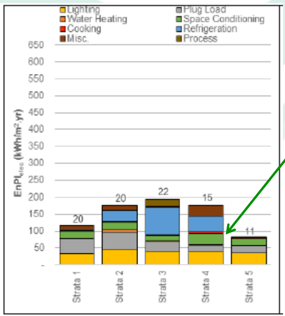


Figure 64: EnPI$_{elec}$ of Premises by Building Size Strata.

Green is HVAC
Avg. ~20 kWh/m^2 yr

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

NZ HVAC EnPIs by building use

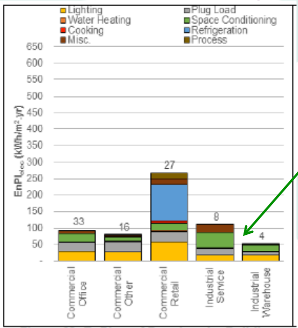


Figure 62: EnPI$_{elec}$ of Premises by Building Use Strata.

Green is HVAC
Avg. ~20 kWh/m^2 yr

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

NZ HVAC System types

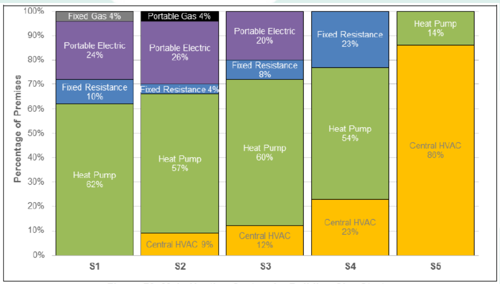
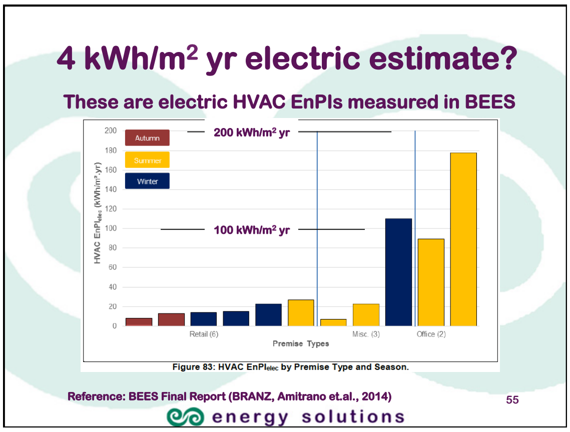


Figure 79: Main Heating System by Building Size Strata.

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

NZ Market - bottom up estimate

- Top 500 buildings > 9,000 m^2. Avg. 17,000 m^2
  EnPI$_e$ = 223 kWh/m^2 yr; EnPI gas ~100 kWh/m^2 yr
- ~20% cooling red’n = 4 kWh/m^2 yr electric; 27 GWh/yr
- ~50% heating red’n = 50 kWh/m^2 yr gas; 300 GWh/yr
- Value = $40k/yr per building = $20M/yr
- CO$_{2e}$ reduction 160 T/yr per building = 80 kT/yr



4 kWh/m² yr electric estimate?

These are electric HVAC EnPIs measured in BEES

Figure 83: HVAC EnPI$_{elec}$ by Premise Type and Season.

Reference: BEES Final Report (BRANZ, Amitrano et.al., 2014)

NZ Market - top down estimate

- Commercial sector electricity = 9,500 GWh/y;
- Com'l gas = 2,000 GWh/y (Energy Data File 2012)
- Electric energy reduction: 50% Buildings x 33% HVAC x 50% cooling x 20% reduction = 160 GWh/yr (4 kWh/m² yr)
- Gas energy reduction: 80% buildings x 90% HVAC x 70% reduction = 1,000 GWh/yr (25 kWh/m² yr)
- Value = \$70 M/yr (@ 15¢/kWh$_e$, 5¢/kWh$_g$)
- CO_{2e} reduction 300 kT/yr (0.4% of NZ total)

World Target Market

- Most major countries have similar energy consumption distributions to New Zealand.
- Australia = NZ potential x 6
  - Potential savings = \$400 M/yr, 2 MT CO_{2e}/yr
- USA = NZ potential x 100
  - Potential savings = \$7 B/yr, 30 MT CO_{2e}/yr
- World = NZ potential x 500
  - Potential savings = \$30 B/yr , 100 MT CO_{2e}/yr

Summary

- CO_2 sensing allows control of OA.
- SA CO_2 is preferred control point.
- Up to 90% heating energy savings, ~20% cooling energy savings result.
- NZ Value: \$20M - \$70M/yr.
- NZ emissions red'n: 80 kT – 300 kT/yr.

Do it right.

- Control OA delivery to spaces by measuring CO_2 concentration in SUPPLY AIR.
- Re-calibrate CO_2 sensors DAILY using full OA, automatically.
- Keep records (trend logs) to prove you haven't compromised comfort.