Building Simulation Performance:

Validation and Parametric Analysis of EnergyPlus: Air Flow Network Model Using CONTAM

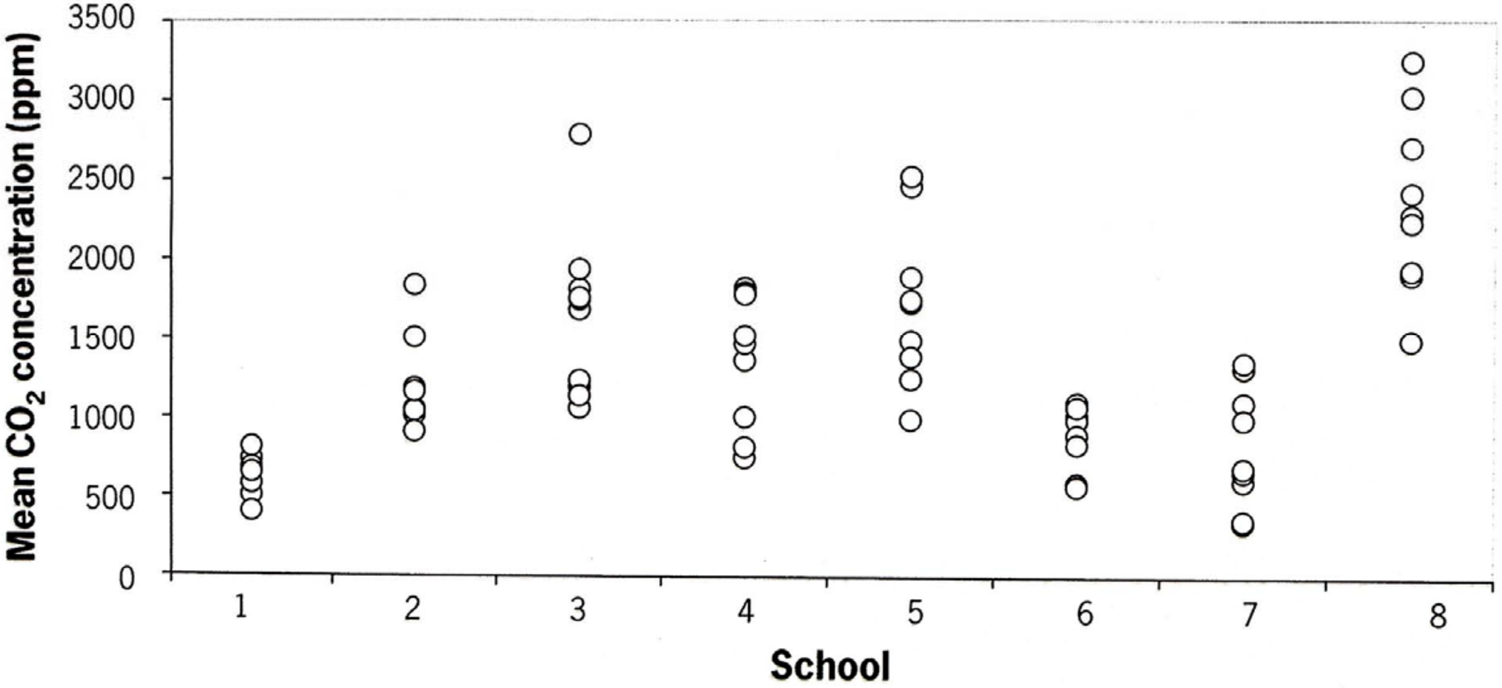
by Spencer Dutton

Internal Air Quality In Schools

- Studies have shown a link between IAQ and student performance.
- A large proportion of schools are naturally ventilated.
- There exists a IAQ - thermal comfort-energy efficiency dilemma.

The Issue

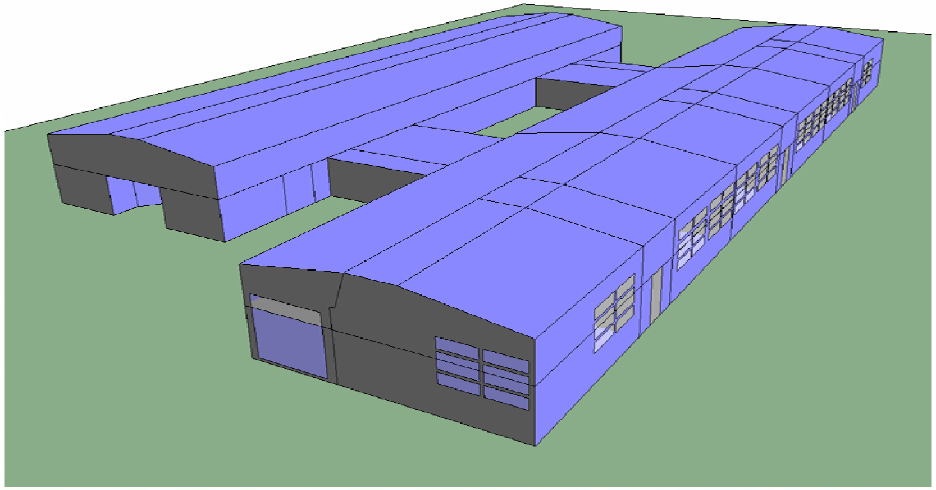
- A study by Building Research Establishment suggests many UK schools are not meeting air quality requirements.



- Guideline - 1000 ppm

School post occupancy study

- Monitoring weather
- Internal environment
- Carbon dioxide level
- Window opening behavior



Classroom monitoring

- Class room carbon dioxide concentration.
- Window opening.
- Wind speed and direction, outside temperature.
- Classroom humidity, temperature.

Sensor Layout

Weather Station

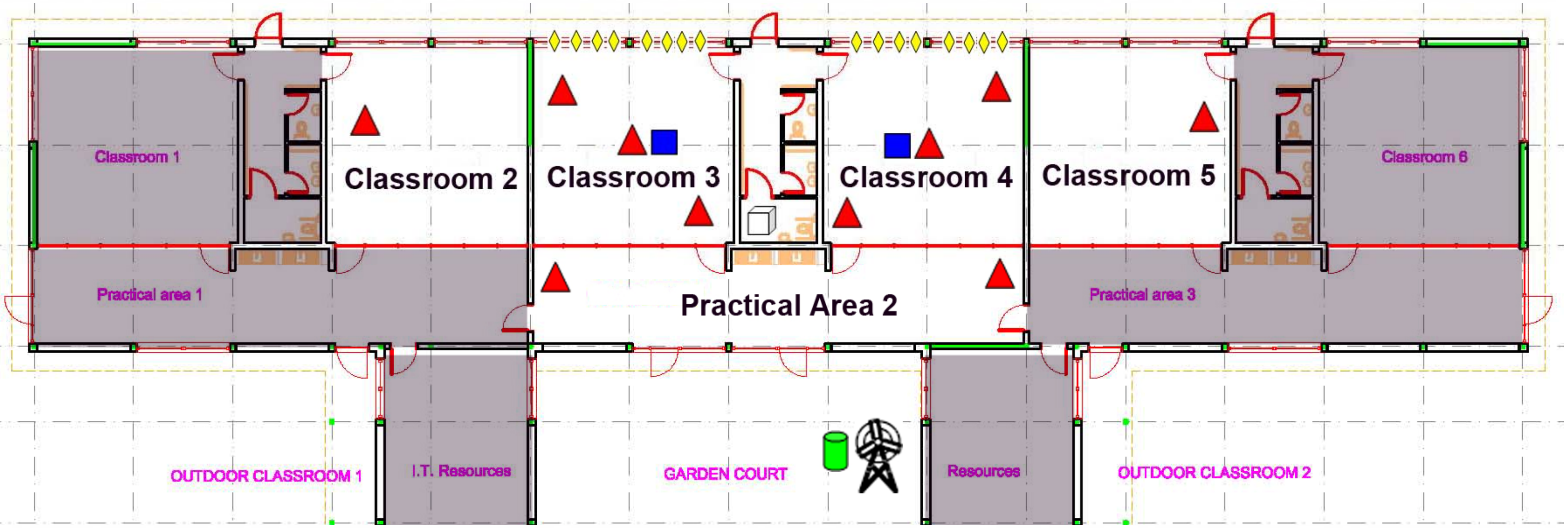
Window sensor

Temperature sensor

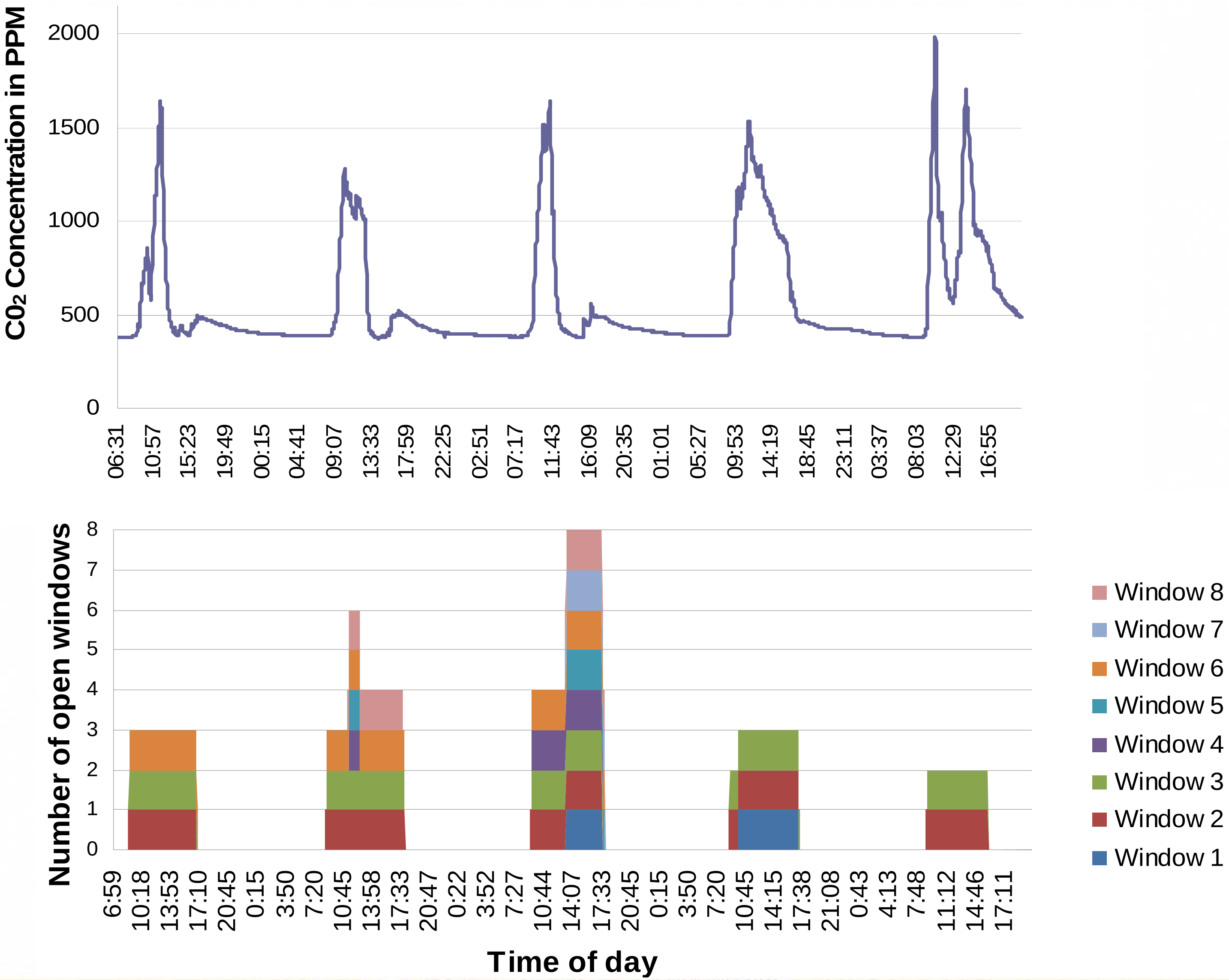
Monitoring station

CO_2 sample inlet

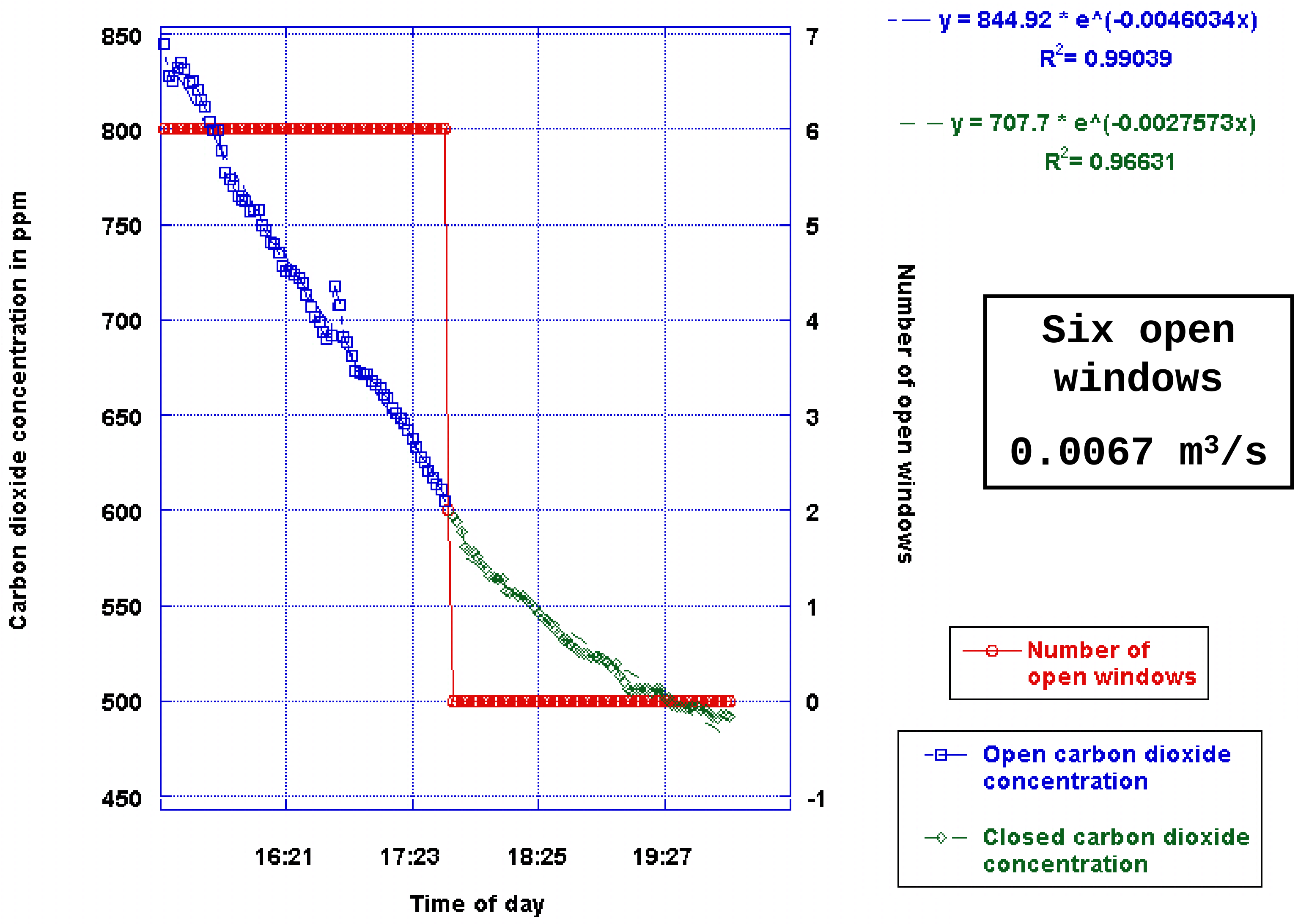
Humidity Sensor



Selected results



Ventilation rate calculation



Ventilation rate calculation

- By rearrangement of CO_2 equation, ventilation rate found using:

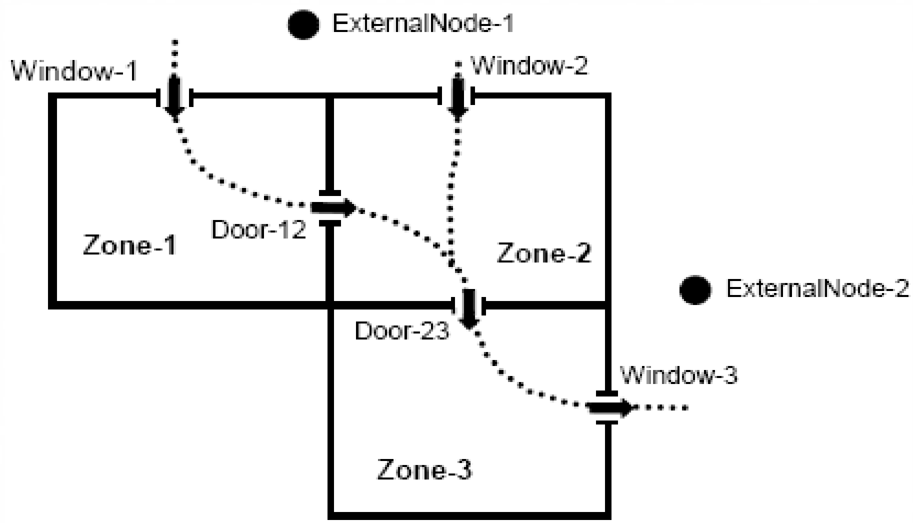
$$Q = -\frac{V}{t}\ln\left(\frac{C_t - C_{ext}}{C_0 - C_{ext}}\right)$$

- Ventilation rates when windows open used to calibrate effective area of windows.
- Rate when all closed used to calibrate crack discharge co-efficient.

Building simulation and ventilation

- Existing building simulation programs have differing approaches to natural ventilation.

EPAFN model allows weather file driven natural ventilation.



EnergyPlus: Air Flow Network

- EnergyPlus: Air Flow Network (EPAFN) required validation.
- Model to model comparison between CONTAM and EPAFN.
- Comparison between modeled and measured data.

Local wind speed calculation

- CONTAM local wind speed calculation based on ASHRAE 1993 fundamentals.

$$V_H = V_{met} \times A_o \left(\frac{H}{Z_{met}} \right)^{\alpha}$$

H= Wall height
Z_{met}= fixed at 10m

Terrain Type	Coefficient (A_o)	Exponent (a)
Urban	0.35	0.40
Suburban	0.60	0.28
Airport	1.00	0.15

Local wind speed calculation

- EPAFN calculation derived from COMIS implementation which was based on the ASHRAE 1989 fundamentals.

$$V_H = V_{met}\left(\frac{Z_{boundary}}{Z_{met}}\right)^{\alpha_{met}}\left(\frac{Z_{ref}}{Z_{boundary}}\right)^{\alpha}$$

Z_{met} = Station height

Z_{ref} = WCP ref height

For α < 0.32, $Z_{boundry}$= Boundary height = 60

For α > 0.32, $Z_{boundary} = 60+(\alpha\text{-}0.34)\times(10800\times(\alpha\text{-}0.34)+440)$

Terrain	Description	Exponent, a	Layer Thickness, δ (m)
1	Flat, open country	0.14	270
2	Rough, wooded country	0.22	370
3	Towns and cities	0.33	460
4	Ocean	0.10	210
5	*Urban, industrial, forest*	*0.22*	*370*

Model to model comparison

Wind speed calculation standardization requires correction factor:

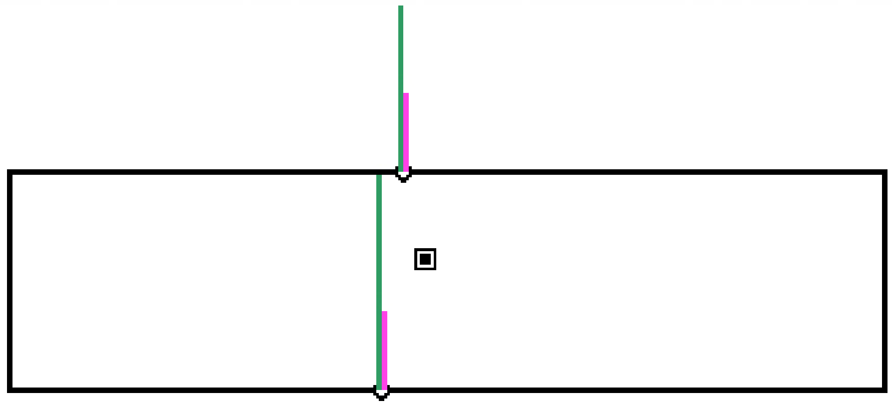
$$V_{Contam} = V_{EnergyPlus}$$

$$A_o\left(\frac{H}{Z_{met}}\right)^{\alpha} = \left(\frac{Z_{boundary}}{Z_{met}}\right)^{\alpha_{met}}\left(\frac{Z_{ref}}{Z_{boundary}}\right)^{\alpha}$$

$$A_o = \left(\frac{Z_{boundary}}{Z_{met}}\right)^{\alpha_{met}}\left(\frac{Z_{ref} \times Z_{met}}{Z_{boundary} \times H}\right)^{\alpha}$$

Test building element verification

Verification tests performed to demonstrate the equivalence of flow elements



Test building built in both EP and CONTAM.

Flow Element Models

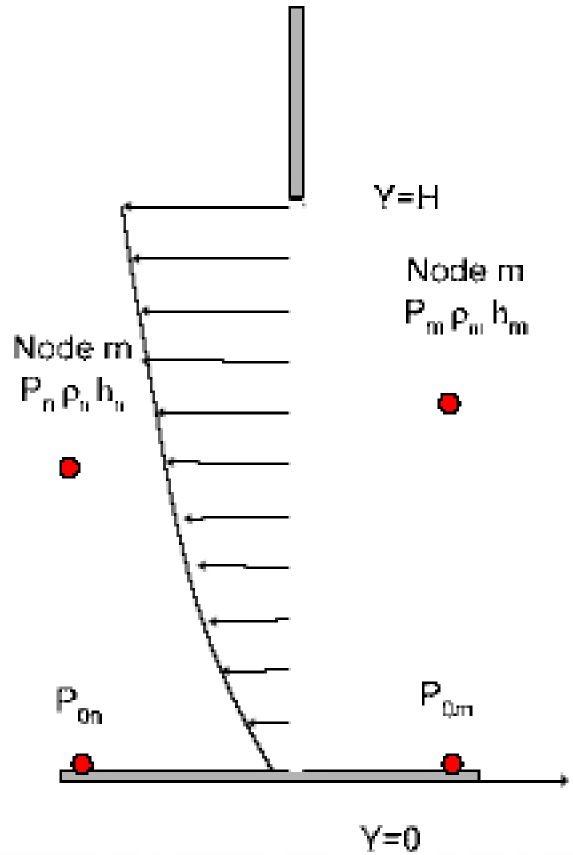
- Crack Model

$$Q = C \times \Delta P^n$$

- Simple Window Model

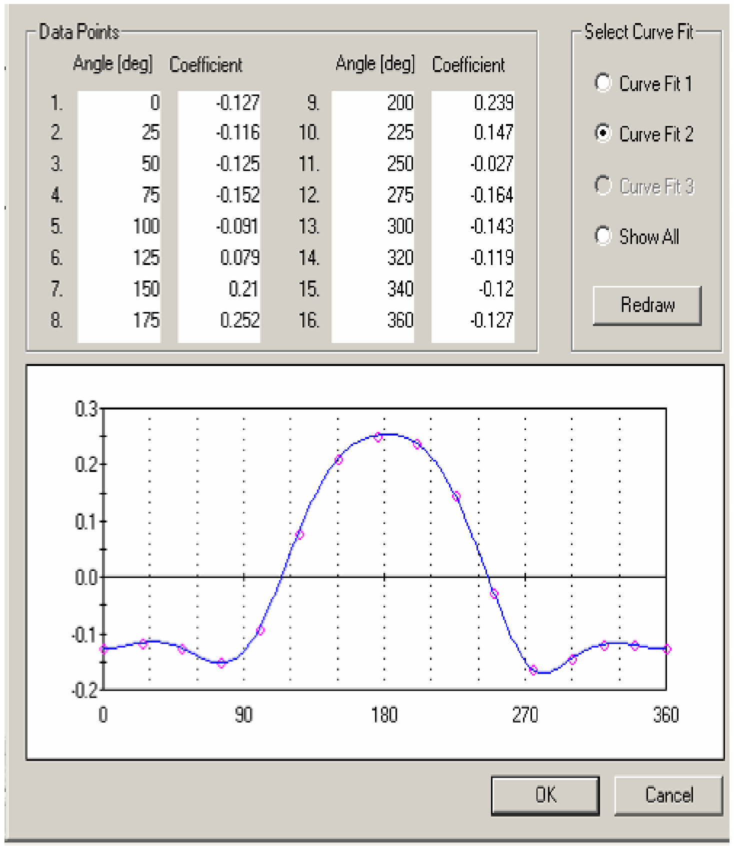
$$Q = C_d \int_0^H v(y) W dy$$

$$V(y) = C_d \sqrt{2 \frac{P_n(y) - P_m(y)}{\rho}}$$



Building wind pressure coefficients

Test building built in both EP and CONTAM

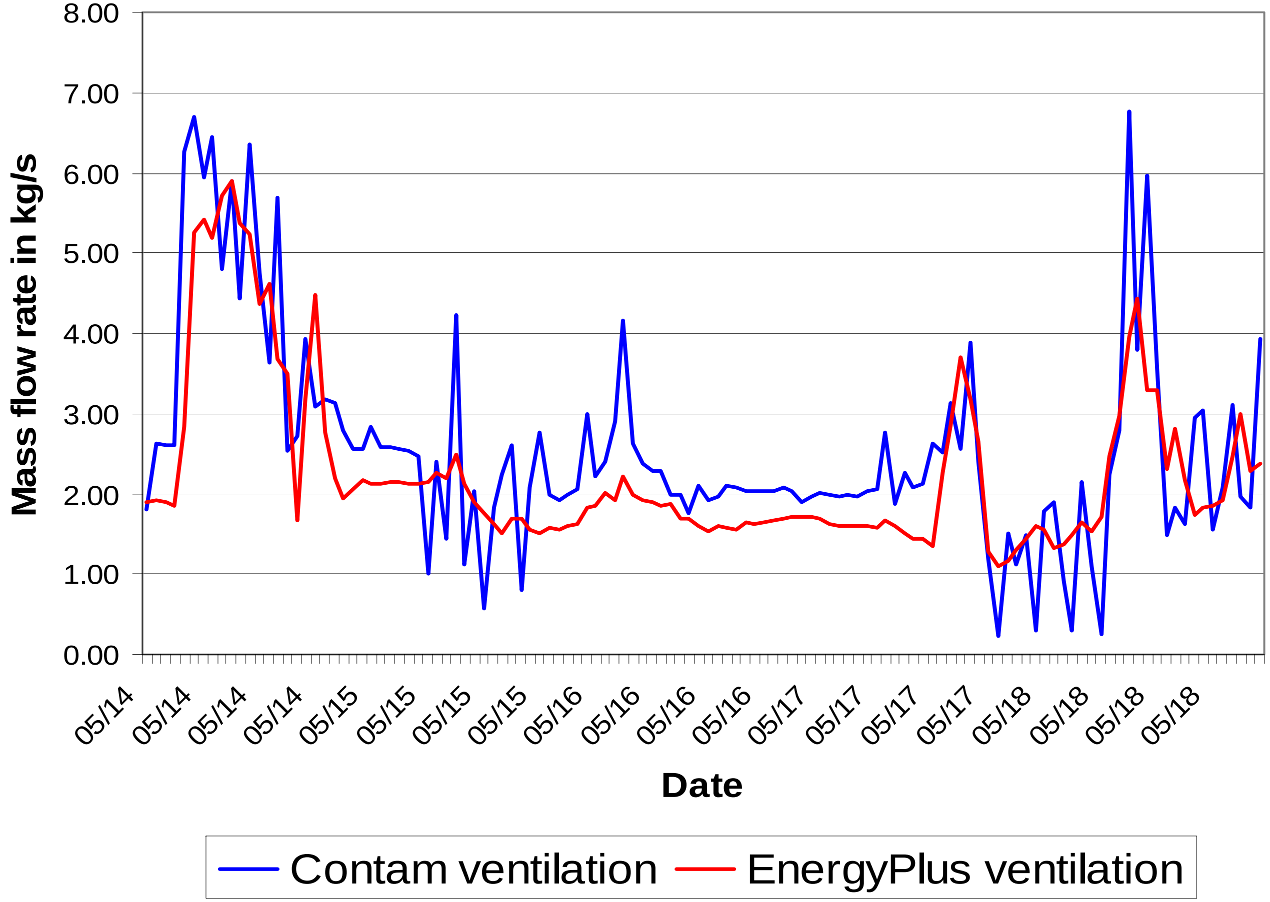


TNO, Dutch building research institute provides a web based interface to software.

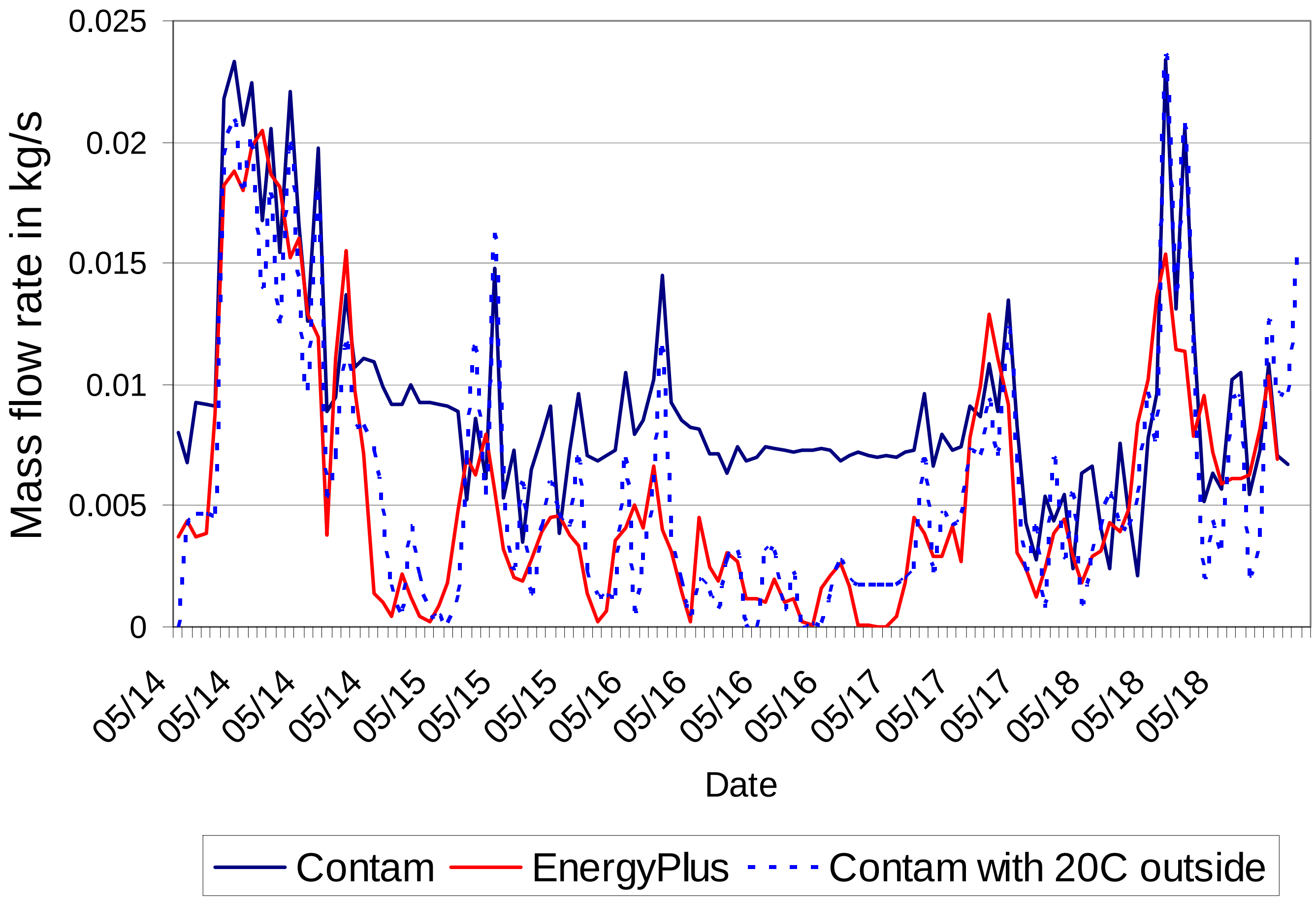
- Provide text based building definition.
- Download WPC.

Simple opening comparison

- Real weather comparison.

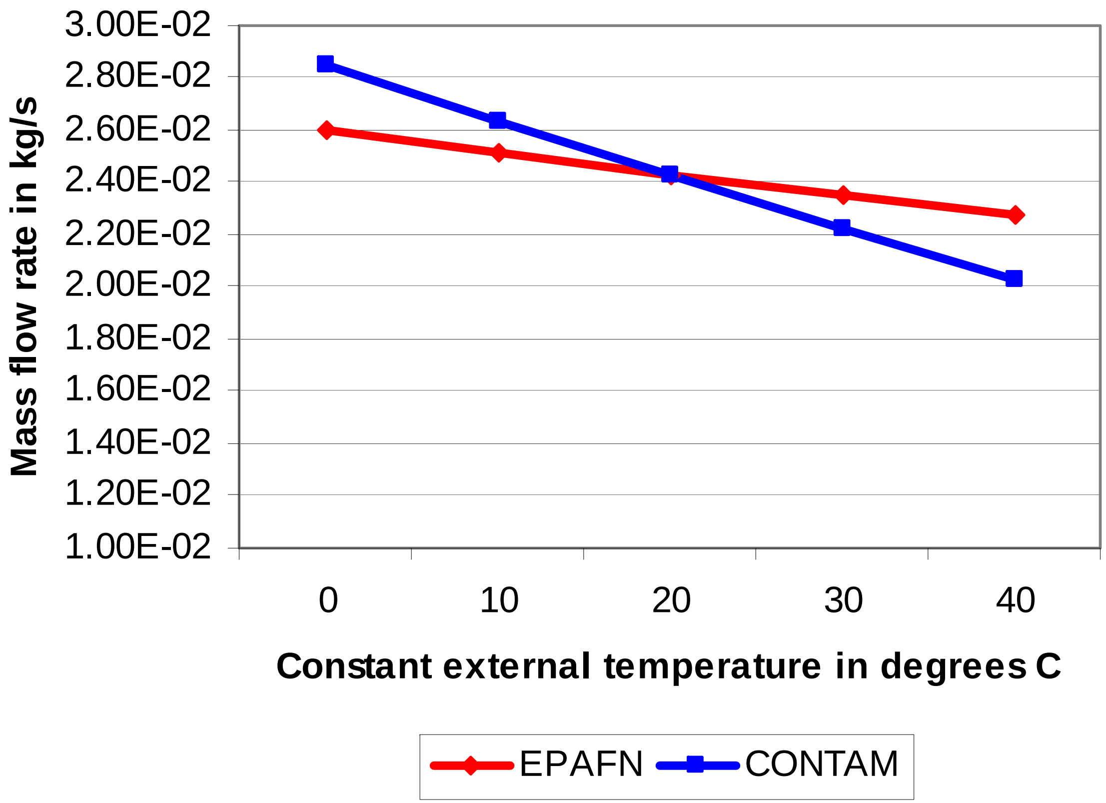


Crack model comparison



Steady state temperature dependence

Variation of external temperature with constant identical weather data.



Test building analysis summary

- Steady state comparisons (thermal equilibrium)
  - Constant weather variables.
  - Crack comparison differed by 0.09%.
  - Simple opening differed by 0.54%.
- Transient comparisons using a weather file:
  - Crack comparison:
    - RMS of 0.55 when using weather file
    - RMS of 0.7 with constant external temperature of 20 degrees.
  - Simple opening RMS of 0.62

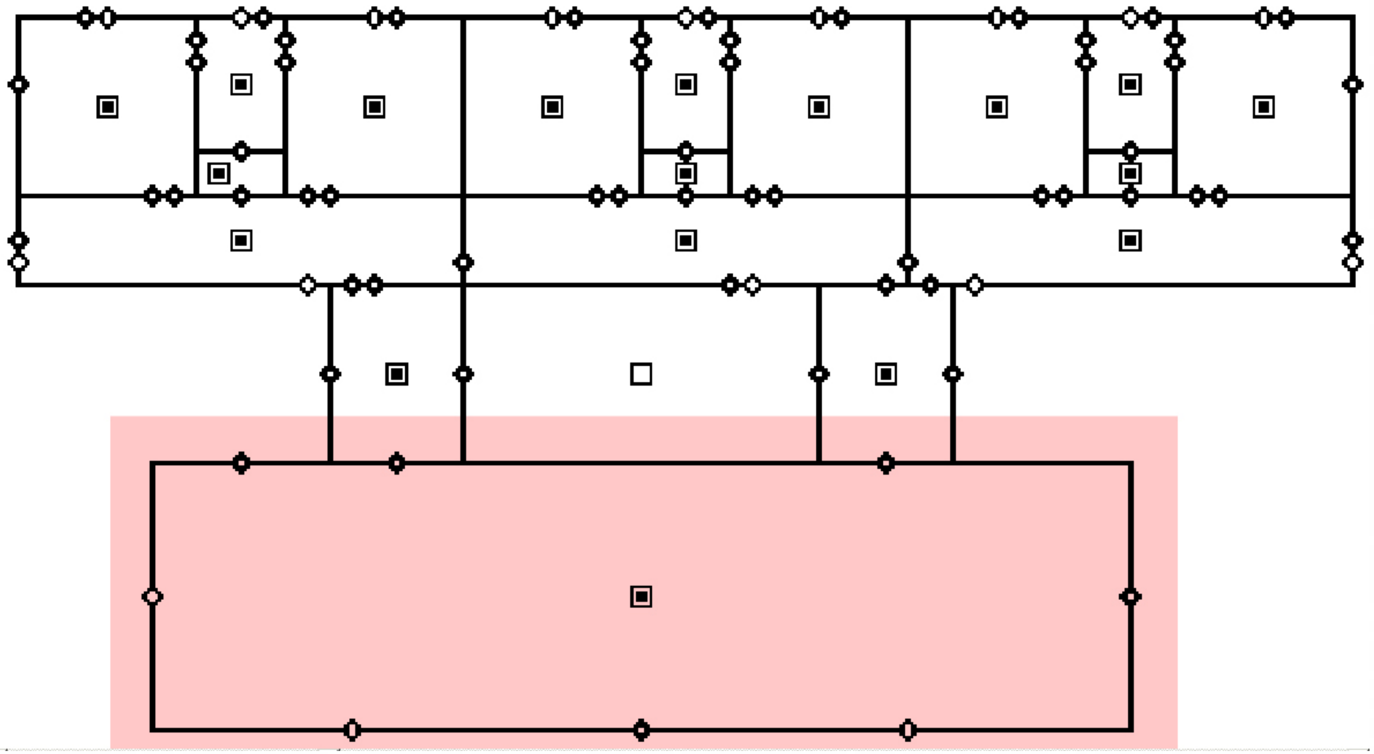
Whole building study

Local weather file creation

- Wind speed and direction averaged using unit vector averaging approach.
- Measured global horizontal irradiation split into diffuse and direct normal using Maxwell's model.
- Two minutely identical weather files used in CONTAM and EnergyPlus.
- Limited interpolation used for some missing data.

Whole building air flow network

Simplified school building built in both EP and CONTAM.



Flow coefficients and assumptions

- Flow coefficients for class room windows derived from measured ventilation rates.
- Class room crack coefficients from closed window infiltration.
- Other coefficients taken from: Input Data for Multizone Airflow and IAQ Analysis (NIST)
- Assumed limited air flow between two halves of building due to fire doors.

Carbon dioxide

- Metabolic CO_2 by child age 8-10 was estimated at 50% of the normal adult sedentary rate of 0.3 liters per minute.
- Recent work by Coley and Beisteiner showed child's CO_2 to be 0.24 liters per minute.
- Future work will use this figure.

Occupation schedule

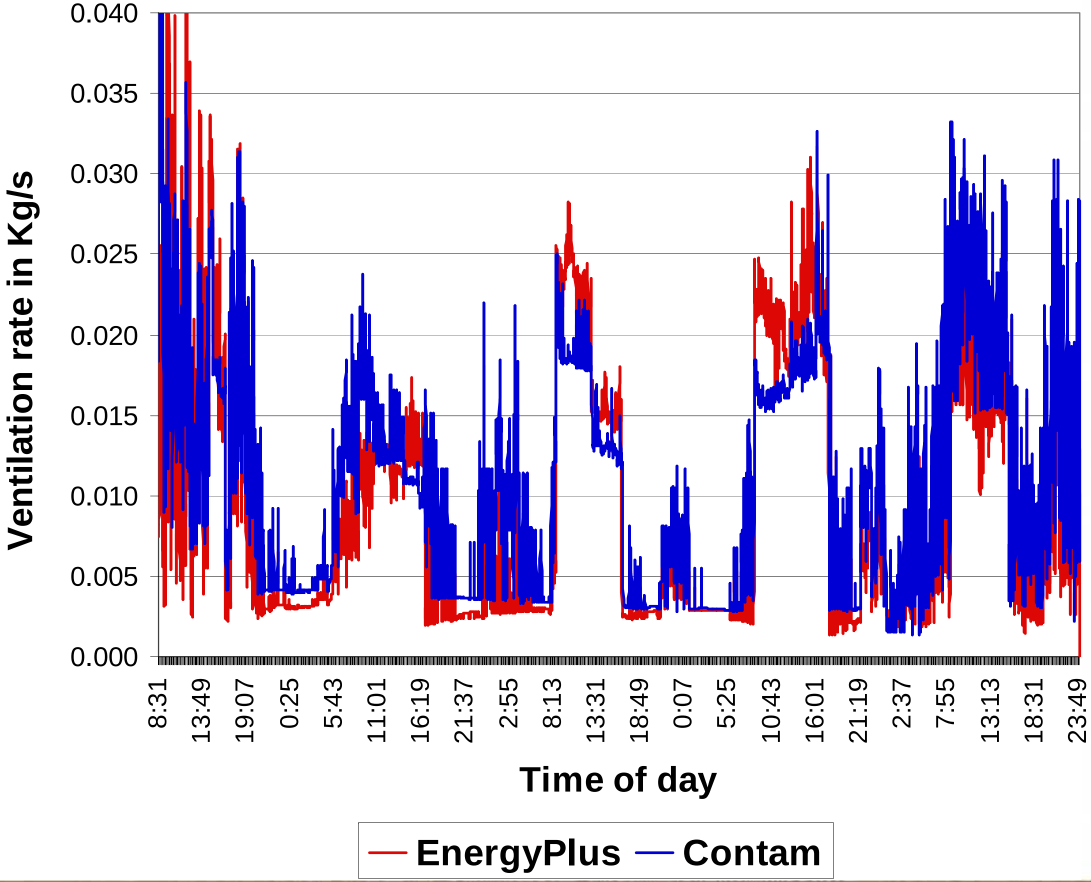
- Calculation of CO_2 concentration used (CIBSE AM 10)

$$C_t = C_{ext} + \frac{q_{CO_2} \times 10^6}{Q} - (C_{ext} - C_0 + \frac{q_{CO_2} \times 10^6}{Q}) \times e^{-\frac{Q}{V}t}$$

- Occupancy schedule based on registration attendance and class times.
- External CO_2 based on average morning concentration 380 ppm (says 430 in the paper)

Ventilation flow rates comparison

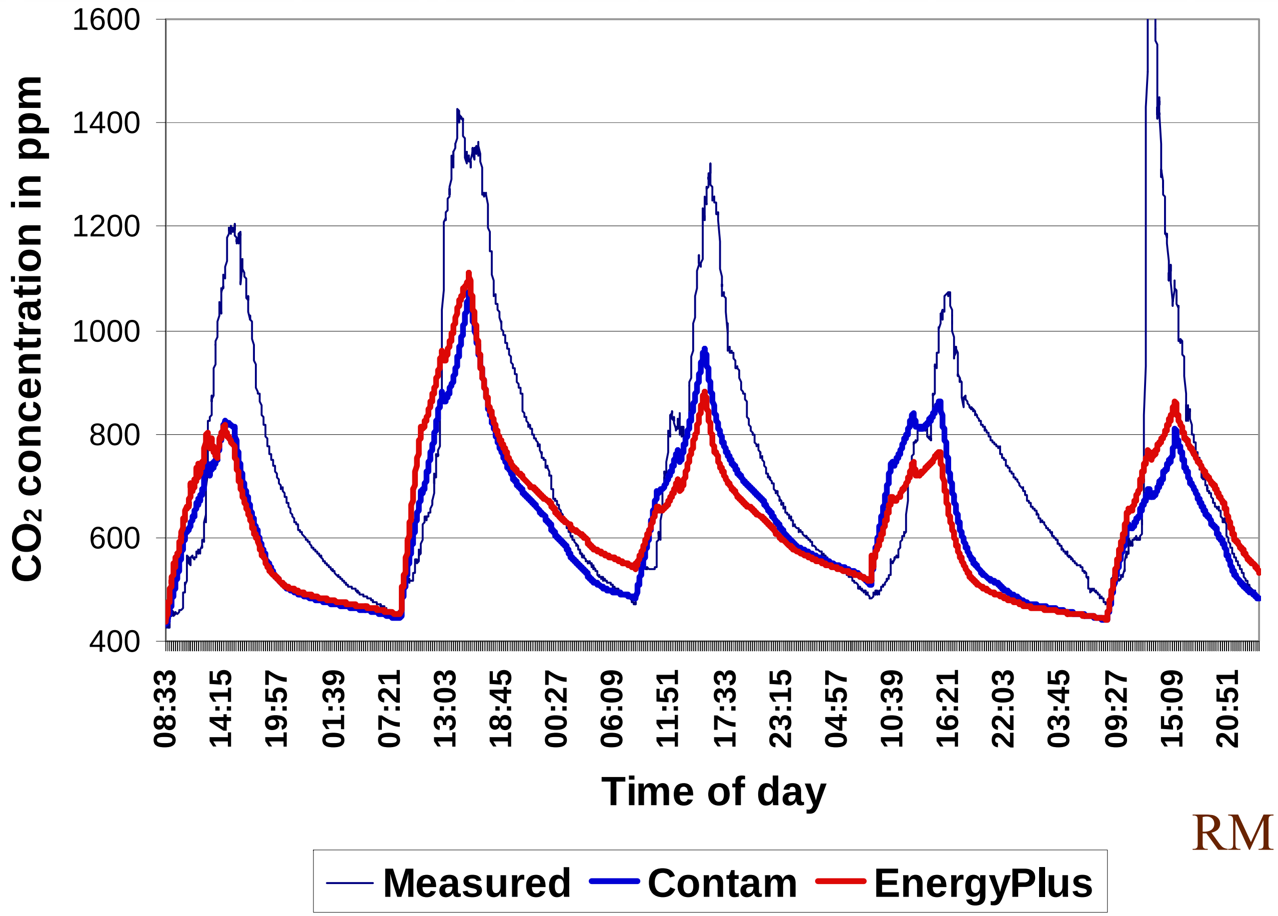
- Total classroom ventilation, using real weather and occupancy schedule.



RMS = 0.75

Carbon dioxide comparison

- Predicted and measured CO_2



RMS = 0.89

Conclusions

- Compared to measured CO_2 , CONTAM and EnergyPlus had RMS of 0.59 and 0.54 respectively.
- More detailed internal flow coefficient information would improve agreement with measured.
- 50% adult metabolic CO_2 appears to underestimate child’s rate, future work will use Coley’s figure.

Conclusions

- Comparing EnergyPlus and CONTAM ventilation predictions gave RMS of 0.75.
- Comparing EnergyPlus and CONTAM CO_2 predictions gave RMS of 0.89.
- Crack models appear to differ in handling buoyancy driven flows due to temperature difference.

Further work

- Correlation analysis of measured input parameters to the measured CO_2 data.
- Comparison of those results with correlation of simulated CO_2 with measured input parameters.