

DesignBuilder scripting tools: Unlock almost unlimited flexibility to customise simulation behaviour



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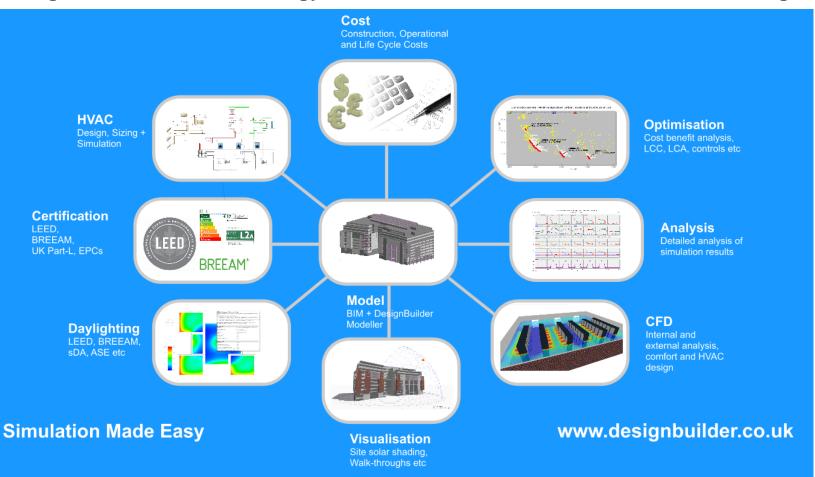


"Hacking Simulation" presentation content

- Introduce DesignBuilder's scripting tools...what they are and how they can help.
- Simple example to illustrate how DesignBuilder's scripting tools work in practise.
- Case studies showing how scripting has been used to customise simulated behaviour to meet non-standard or unusual client needs.

"Simulation Made Easy"...early, compliance or detailed modelling!

Engineers, Architects, Energy Assessors, Academic Research and Teaching





4 ways to "hack" DesignBuilder EnergyPlus simulations

"Regular" Modellers:

- Modify (open source) EnergyPlus input data file (IDF)
- EMS Create/edit scripts in the DesignBuilder EMS editor

Experts:

- FMU Create co-simulation applications in the DesignBuilder FMU/FMI editor
- Modify EnergyPlus open source code





DesignBuilder EMS overview

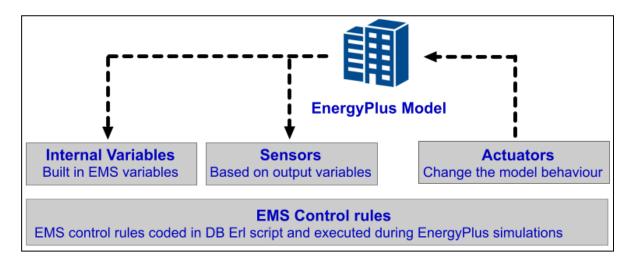
- 1. Customise...add functionality not available in EnergyPlus
- 2. Overwrite standard controls with bespoke project logic
- 3. Dynamically adjusts behaviour during the simulation
- 4. Provides almost limitless range of additional functionality
- 5. EMS scripts pre-compiled...no noticeable impact on simulation times
- 6. Load existing library EMS programs or create (and share) own scripts
- 7. Relatively easily to learn and practical for use on commercial modelling projects...not just academic





DesignBuilder EMS: works like a BMS

- **1. Sensors:** check variable value (zone air temperature, CO2 level etc.)
- 2. Actuators: overrides model settings based on sensor input to change the model behaviour at each time-step in the simulation.
- **3. Results:** Custom output variables can be written to results file.
- 4. **Program:** manages and initiates what is called and at what frequency





Some example DesignBuilder scripting applications

Flexibility to influence EnergyPlus simulation behaviour at each timestep using the EMS...almost limitless applications:

- Programmatic scheduling (over-ride fixed/static schedules)
- Bespoke control of HVAC systems
- Connecting different HVAC systems
- Advanced façade and natvent controls
- Outputs not normally provided in DesignBuilder or EnergyPlus
- Research...novel applications not provided by mainstream tools



DesignBuilder EMS extensions...beyond EnergyPlus

DesignBuilder includes important extensions to the standard EnergyPlus EMS system to **simplify and speed up script generation**:

- Access attribute data (setpoints, schedules etc.) direct from model data lists
- Quickly add actuators, sensors and internal variables
- Loops simplify scripts and make them portable
- Colour syntax highlighting

Script	Help
Script	Info Data
General	EMS Program
Name Change Heating and Cooling Setpoints Daily	Use the editor on the left to enter EMS and/or standard IDF script by typing, pasting from an external source or b
Description Change the setpoints based on the day of the week.	using the inbuilt tools to add new EMS programs,
Category EMS	 sensors, actuators and variables.
Script	You can add any extra IDF script you need to include here including normal non-EMS IDF.
🗆 Enable program	If the 'Enable script' checkbox is checked, the script will
Change the setpoint temperature of cooling and heating based on th	be processed to expand any loops and other
day of the week	DesignBuilder EMS extensions and the expanded script added to the standard EnergyPlus IDF input data before
	running the simulation.
<foralloccupiedzones></foralloccupiedzones>	Position the cursor in the editor where code is to be
EnergyManagementSystem:Actuator,	inserted and use one of the tools to add the code.
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<loopzoneidfname> COOLING SP SCH,</loopzoneidfname>	Add Output
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Schedule Value;	Add Program
EnergyManagementSystem:Actuator,	Add Sensor
Schedule_Value_ <loopzonevariablename>_HEATING_SETPOINT_SCHEDULE,</loopzonevariablename>	Add Actuator
<pre><loopzoneidfname> HEATING SETPOINT SCHEDULE,</loopzoneidfname></pre>	Add Internal variable
Schedule:Compact,	
Schedule Value;	Add EMS variable
<loopnextzone></loopnextzone>	Add DB variable
EnergyManagementSystem:ProgramCallingManager.	Other tools
My Setpoint Schedule Calculator Example,	Refrech EMS Sensor Actuator & Variable lists
BeginTimestepBeforePredictor.	Refresh EMS Sensor, Actuator & Variable lists
MyComputedCoolingSetpointProg,	Align comments to cursor
MyComputedHeatingSetpointProg;	Maximise editor
EnergyManagementSystem:Program,	EMS code libraries
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DesignBuilder's example script library

Select the Script

🕀 🗁 CS-Script

🖶 🦰 EMS

E Python-Script

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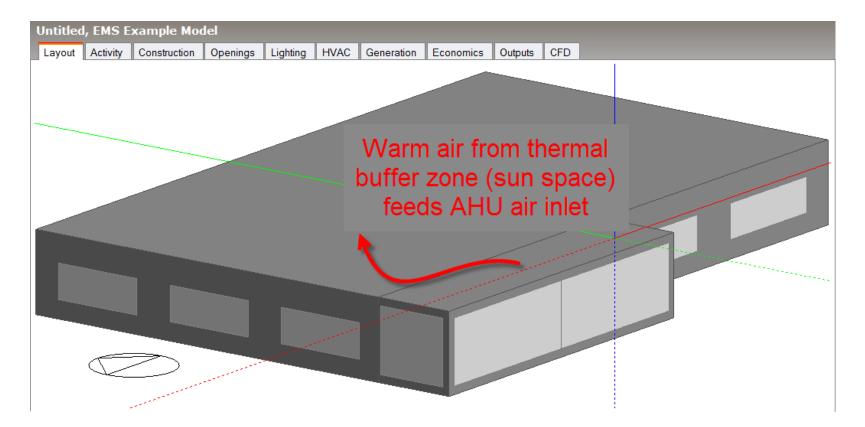
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Edit Script - Multiple State Electrochromic Glass with Sensor Groups Script Help Script Info 📲 BaseScript - This base script must be compiled once. It i EMS Program 👰 EpNet IDF find and replace - EpNet find and replace thei Use the editor on the left to enter EMS and/or Multiple State Electrochromic Glass with Sensor Groups Name standard IDF script by typing, pasting from an 😤 Load heating setpoints from template to model - Load he Description Simulate multiple state electrochromatic glass, with each window belonging to a sensor group. external source or by using the inbuilt tools to add new EMS programs, sensors, actuators and 📲 MultiScript - This will call all public methods from the impo EMS Category variables. 📲 SampleScript1 - All public methods in the DBScript class You can add any extra IDF script you need to SampleScript2 - All public methods in the DBScript class Enable program include here including normal non-EMS IDF. 😤 SampleScript3 - EpNet find and replace thermal absorpt If the 'Enable script' checkbox is checked, the script !-Multiple state electrochromatic windows with sensor groups will be processed to expand any loops and other SampleScript4 - Write report called CSVReport.csv to de <ForAllElectrochromicSensorWindows> DesignBuilder EMS extensions and the expanded 📲 SampleScript5 - Load heating setpoints from an activity t !-<LoopSensorWindowIDFName> Sensor script is added to the standard EnergyPlus IDF input data before running the simulation. EnergyManagementSystem:Sensor, Simple example model report - Write report called CSVF Position the cursor in the editor where code is to be <LoopSensorWindowVariableName> Reference Sensor. inserted and use one of the tools to add the code <LoopWindowIDFName>. 😤 Building Average Zone Air Temperature - Calculate build Insert EMS/IDF code Surface Outside Face Incident Solar Radiation Rate per Area; 📲 Change Heating and Cooling Setpoints Daily - Change th Add Output Separate CIBSE TM52 Reports - Generate CIBSE TM52 Reports <If LoopWindowAttribute InternalBlindControlMultipleStateElectrochromic = 2 Sadd Program Then> Add Sensor EnergyManagementSystem:Sensor, Sector CIBSE TM59 Ventilation temperature control enhanceme <LoopWindowVariableName> Heating Load. 📲 CO2 control (On/Off) - Control external windows in nat ver Add Actuator <LoopWindowZoneIDFName>. 📲 CO2 control (Proportional) - Vary external window openin X Add Internal variable Zone Air System Sensible Heating Rate; 📲 L5 HR Bypass IdealLoads - Bypass heat recovery when <endif> K Add EMS variable 📲 L5 HR Bypass ZoneVentilation - Bypass heat recovery v Add DB variable 😤 Multiple State Electrochromic Glass with Individual Sensi <If LoopWindowAttribute InternalBlindControlMultipleStateElectrochromic = 3</pre> Then> Multiple State Electrochromic Glass with Sensor Groups Other tools EnergyManagementSystem:Sensor, 😤 Optimum start heating control (domestic) - Override heati 2 Refresh EMS Sensor, Actuator & Variable lists <LoopWindowVariableName> Cooling Load, 👰 Optimum start heating control (non-domestic) - Override I <LoopWindowZoneIDFName>. Align comments to cursor Set external heat transfer coefficient - Set the heat transfer Zone Air System Sensible Cooling Rate; Maximise editor <endif> 😤 Python-Script Example - Test the Python-Script interface EMS code libraries <If LoopWindowAttribute InternalBlindControlMultipleStateElectrochromic = 4</pre> Then> DesignBuilder UK EMS library EnergyManagementSystem:Sensor. Locked Library data Help Cancel OK



Simple AHU pre-heat example

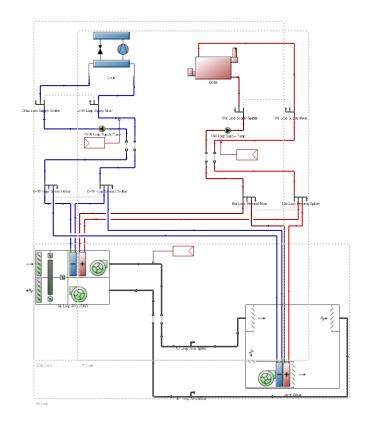
Pre-heat or pre-cool AHU inlet air from sun space, earth tube etc





Simple AHU example...HVAC system

Zone FCUs served by AHU with CHW and HW coils...but no AHU pre-heat





Simple AHU pre-heat example...script

Script links pre-heat zone air to AHU inlet to over-ride standard HVAC setup

dit EMS Program = Generic =	
EMS Program Data	Help
EMSCode	Info Centa
General	EMS Program
Name AHU Preheat	Use the editor on the left to enter EMS code by typing, pasting from an externa source or by using the inbuilt tools to add new programs, sensors, actuators
Description	and variables.
Category Generic	The EMS code will be added to the EnergyPlus IDF input file without
EMS program	modification. You can therefore also include any other non-EMS related IDF data here.
Enable program	Position the cursor in the editor where code is to be inserted and use one of the
Based on AirConditionsFromZone2AHU.txt by German Campos (https://github.com/DesignBuilderES/DB EMS)	tools to add the code.
Pased on ArronautionsPromitonezano.txt by German Campos (https://github.com/besignouilderts/bb_ths)	Insert EMS code
! This EMS program uses a buffer zone air conditions (Dry-bulb and Wetbulb) as AHU Outdoor air inlet air conditions.	
I You can use it, for example, to simulate situations where outdoor air is taken from a zone such as a double-facade, trombe-wall, sun-space.	Add Output
The code introduces outdoor air to the buffer zone to preserve thermal balance through infiltration.	Add Program
! Change AIR LOOP AHU OUTDOOR AIR INLET to the corresponding node name for your system. If your air loop is called "DOAS" then	Add Sensor
! the outdoor inlet node is called "DOAS AHU OUTDOOR AIR INLET". Likewise change Buffer:Zone for the buffer zone name (e.g. Block1:Zone1).	
	# \$& Add Actuator
EnergyManagementSystem:Actuator,	X Add Internal variable
DBTempAHUINIet,	Other tools
AIR LOOP AHU OUTDOOR AIR INLET,	Other tools
Outdoor Air System Node, Drybulb Temperature:	Refresh EMS Sensor, Actuator & Variable lists
brybuib temperature;	Align comments to cursor
EnergyManagementSystem:Actuator.	
WBTempAHUInlet,	Maximise editor
AIR LOOP AHU OUTDOOR AIR INLET,	EMS code libraries
Outdoor Air System Node,	
Wetbulb Temperature;	DesignBuilder UK EMS library
	DesignBuilder Spain EMS library
Output:Variable, *, Zone Infiltration Mass Flow Rate, Timestep;	
EnergyManagementSystem:Sensor.	Suggest an alternate translation for the currently selected item.
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system_node_ngss_ride_rate, Air Loop AHU Outdoor Air Inlet.	
Air Loop and Voltador Air Inter, System Node Mass Flow Rate;	
System Hode Hass from Hatery	
EnergyManagementSystem:Sensor,	
BufferZoneMAT,	
Buffer:Zone,	
Zone Mean Air Temperature;	
EnergyManagementSystem:Sensor.	
tnergyNanagementSystem:Sensor, BufferZoneHR.	
Buffer.Zonenk, Buffer.Zone.	
Zone Mean Air Humidity Ratio;	
EnergyManagementSystem:Sensor,	
Outdoor_Air_Density,	
Environment.	*
Model data	Help Cancel OK



Simple AHU pre-heat example...results

Results show that the AHU air inlet temperature matches buffer zone (not OAT)

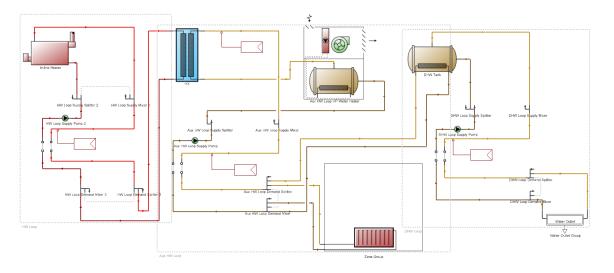
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Zone Mean Air Temperature	BUFFER-ZONE	c	
Zone Infiltration Mass Flow Rate	BUFFER-ZONE	kg/s	20/01/2002 00:00 - 26/01/2002 23:50, Timestep Frequency
Zone Air CO2 Concentration	BUFFER-ZONE	ppm	Zone Mean Air Temperature, OFFICES:EAST - eplusout
Zone Cooling Setpoint Not Met Time	BUFFER:ZONE	hr	Zone Mean Air Temperature, BUFFER:ZONE - eplusout
Zone Cooling Setpoint Not Met While Occupied Time	BUFFER:ZONE	hr	Zone Mean Air Temperature, OFFICES:WEST - eplusout
Zone Mean Radiant Temperature	BUFFER:ZONE	C	Site Outdoor Air Drybulb Temperature - eplusout
Zone Air System Sensible Heating Rate	BUFFER:ZONE	W	System Node Temperature, AIR LOOP AHU OUTDOOR AIR INLET - eplusout
Zone Air System Sensible Cooling Rate	BUFFER-ZONE	W	
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System Node Temperature	BOILER WATER OUTLET NODE	C	
System Node Mass Flow Rate	BOILER WATER INLET NODE	kg/s	
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Boiler Gas Rate	BOILER	w	20-
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Hybrid ASHP - EMS case study

(Project with Delta-ee and Dr Dave Kane)

Range of LT/HT/Hybrid ASHP systems modelled for different dwelling types.



- Specific manufacturers systems modelled in detail using EMS to provide:
 - Weather compensation controls for HW supply temperature
 - Tailored optimum start for both morning and evening heating periods
 - Custom control over electric boost availability to maximise efficiency



Hybrid ASHP – Example part of EMS script

- Weather compensation script to replace simple ASHP supply temperature schedule, accounting for DHW operation.
- Script minimises the HP supply temperature unless the DHW system is operating or outdoor temperature drops.
- This part of the EMS script is a good example of using SET, IF and ELSE statements to dynamically control equipment based on other variables

! override "ASHP outlet setpoint temperature" schedule with weather compensation EnergyManagementSystem:Program, SetASHPSuppyTempSp, SET Tos = Site_Outdoor_Air_Drybulb_Temperature, ! outside temp for max setpoint **SET** TosMin = 0, ! max setpoint SET TspTosMin = 55, ! outside temp for min setpoint SET TosMax = 15, ! min setpoint SET TspTosMax = 40, ! set setpoint based on outside air temperature and DHW operation IF (DHWTankSourceSideHeatTransferRate > 10), ! use high temperature output when DHW is operating SET Tsp = TspTosMin, ELSEIF (Tos <= TosMin),</pre> ! very code outside, use highest supply temperature SET Tsp = TspTosMin, ELSEIF (Tos >= TosMax), ! warm outside, use lowest supply temperature SET Tsp = TspTosMax, ELSE, ! interpolate SET m = (TspTosMax - TspTosMin) / (TosMax - TosMin), SET C = (TspTosMin + TspTosMax - m * (TosMin + TosMax)) / 2, SET Tsp = m * Tos + C, ENDIF. ! actuate the supply setpoint temperature SET ASHPSuppyTempSp = Tsp;



UCL IEDE Case Study: 'Total Performance'

Project to investigate 'total performance': finding ways to minimise energy demand and carbon emissions whilst safeguarding occupant health, wellbeing and productivity



Acknowledgements:

UCL IEDE:

Nishesh Jain, Esfand Burman, Sam Stamp, Clive Shrubsole, Dejan Mumovic, Michael Davies

DesignBuilder: Andy Tindale

More information: <u>www.ucl.ac.uk/bartlett/environmental-design/research/total-performance-low-carbon</u>



UCL IEDE case study building

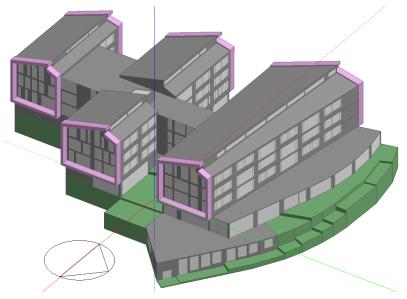
Public sector natvent open-plan office building in Keynsham





Stage 1: Calibrating the energy model

'Performance gap'; measured **energy** results worse than predicted using the designer's typical schedules, weather data etc: **+107% gas and +46% electric**



DesignBuilder model

Criteria	Designed (kWh/m²)	Actual (kWh/m²)	Diff (%)
Total Energy (Gas + Elec)	14 + 57	29 + 68	+37%
Heating & Hot Water (Gas+Elec)	13.9+5.0	28.85+0	+53%
Cooling energy (Elec)	0.17	0	NA
Pumps + Mech Vent (Elec)	1.73	9.97	+478%
Int. Lighting (Elec)	5.00	11.13	+123%
Ext. Lighting (Elec)	1.11	0	NA
Small Power (Elec)	16.49	28.89	+75%
Catering (Elec)	0.85	1.60	+89%
Server Elec (Elec)	26.42	15.19	-42%
Lifts (Elec)	0.28	0.72	+159%
PV Generation (Elec)	31.22	30.43	-3%
Net Energy (Gas + Elec)	14 + 26	29 + 38	+67%



EMS used in the calibration process

EMS used to calibrate the DesignBuilder model more efficiently by modifying key operational data to match the actual building:

EnergyManagementSystem:Program, KTHElecEnergy.	
! add program code	
If (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Ho	ar >= 7) & (Hour < 8).
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ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) &&	(Hour >= 8) 88 (Hour < 9),
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Occupancy/lighting patterns/schedules

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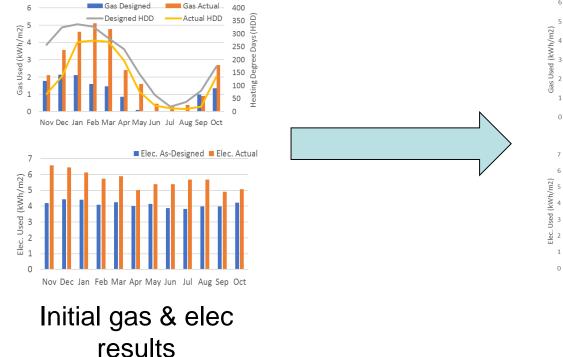
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	pm = 1,									
Endif.										

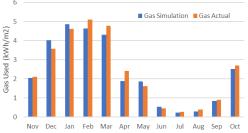
HVAC pump operation



Calibrated model results

Model calibrated to CV(RSME) and NMBE tolerances of <5% error:







Calibrated gas & elec results



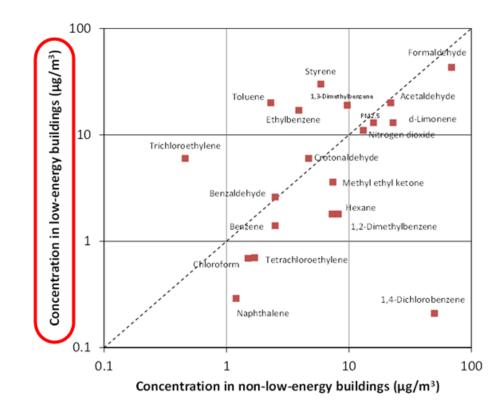
Stage 2: Focus on Health and Wellbeing

The 'tension' between low energy and good IAQ

IEA Annex 68 report:

Finds higher pollutant concentrations in lowenergy buildings

Recommends that key pollutants such as PM2.5 should be measured and kept within limitsnot just CO2!

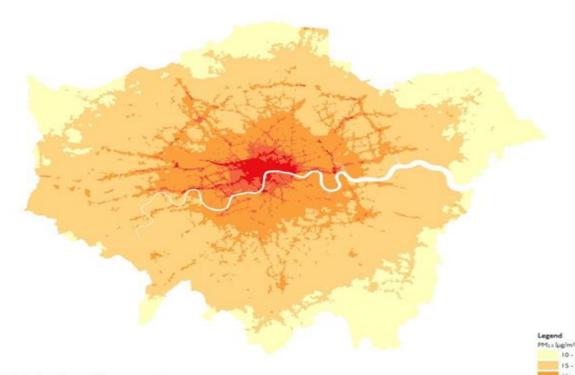




Health and Wellbeing: PM2.5 concentrations

London PM2.5 values exceed WHO guidelines and sometimes EU limits

- EU legal limit (annual mean): 25 µg/m³
- WHO guideline limit (annual mean): 10 µg/m³
- Estimated that difference between EU and WHO limits doubles risk of early death

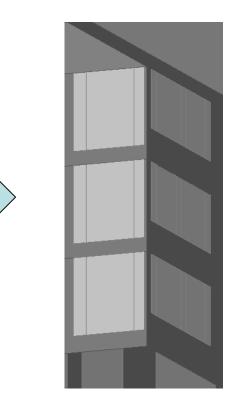




With IAQ in mind: natvent strategy

Vents controlled on CO2 by BMS...CO2 good IAQ proxy but perhaps not in isolation?







Improved IAQ control strategy using EMS

EMS used to import external measured pollutant data, sense both internal CO2 and PM2.5 and modify control strategy, then generate custom output reports

<Endif>

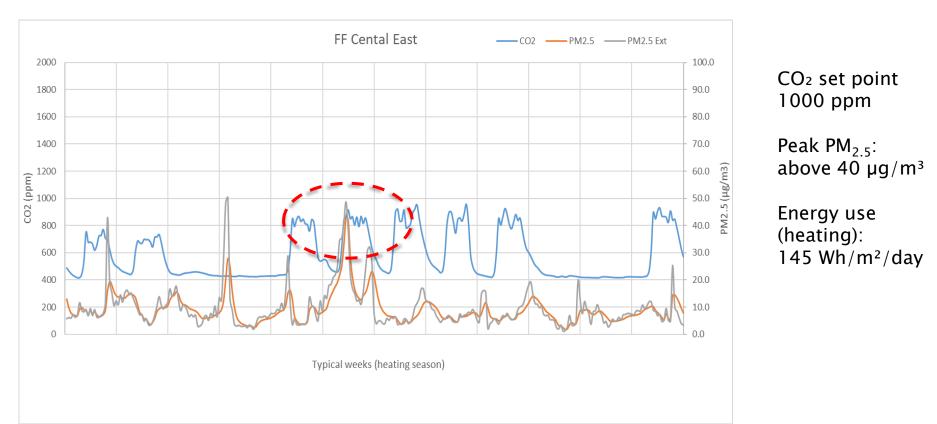
```
EnergyManagementSystem:Program,
C02WindowControl,
<forAllExternalWindows>
! on/off control of window opening factor
If <LoopWindowVariableName>Air_C02_Concentration > 1500,
If Schedule_Value_PM25 < 0.04, |
Set Venting_Opening_Factor_<LoopWindowVariableName> = 1,
Elseif Schedule_Value_PM25 >= 0.04,
Set Venting_Opening_Factor_<LoopWindowVariableName> = 0,
Endif,
Else,
Set Venting_Opening_Factor_<LoopWindowVariableName> = 0,
Endif,
```

```
____Windows>
EnergyManagementSystem:Sensor,
  <LoopWindowVariableName>Air CO2 Concentration.
  <LoopWindowZoneIDFName>,
  Zone Air CO2 Concentration:
EnergyManagementSystem:Actuator,
  Venting Opening Factor <LoopWindowVariableName>,
  <LoopWindowIDFName>.
  AirFlow Network Window/Door Opening,
  Venting Opening Factor;
<LoopNextWindow>
                                      ! extra outputs for viewing in the results viewer
                                      <If BuildingAttribute HourlyOutput = 1 Then>
                                      Output:Variable, *, Zone Air CO2 Concentration, hourly;
                                      Output: Variable, *, Zone Air Generic Air Contaminant Concentration, hourly;
                                      <Endif>
                                      <If BuildingAttribute TimesteplyOutput = 1 Then>
                                      Output:Variable, *, Zone Air CO2 Concentration, timestep;
                                      Output: Variable, *, Zone Air Generic Air Contaminant Concentration, timestep;
```



IAQ control strategy with high CO2 set point

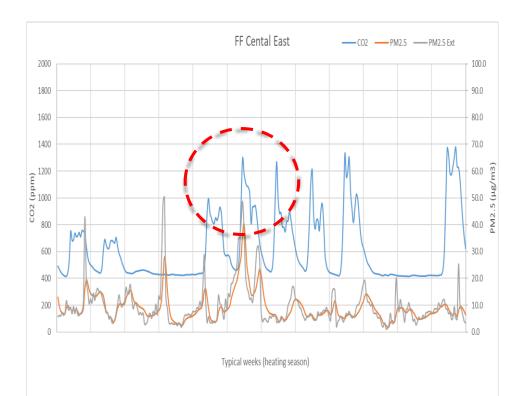
Standard CO2 control: vents open at 1000 PPM: low CO2, high ACH and PM2.5





Holistic IAQ control strategy requires EMS

Revised control strategy: relax CO2 set point, close vents if outdoor PM2.5 high



- CO₂ set point increased to 1500 PPM
- Close vents if outdoor PM2.5 > threshold
- Indoor PM levels maintained below outdoor levels
- Peak PM_{2.5}: now below 40 µg/m³
- Energy use (heating): 105 Wh/m²/day
- 28% reduction in heating energy due to relaxation of CO2 limit



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David Cocking MSc CEng MCIBSE MASHRAE

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