DesignBuilder Software

Simulation and CFD

3-Day Training Course

Preparation

- Uninstall any previously installed versions of DesignBuilder.
- **Install DesignBuilder v.1.9.5** from USB drive supplied
- **Run** DesignBuilder
- Open **Licence** dialog (Help > Licence)
- Click on **Activate from file** button
- Select the **.lif file** supplied on the USB drive
- **6 Months free** use of **Visualisation**, **EnergyPlus** and **CFD**.
- *The .lif file will expire end February so make sure to activate DesignBuilder on the computer you will be using before then.*

DesignBuilder Introduction

- Best Interface to EnergyPlus simulation engine!
- First released 2005
- CFD calculations in beta test
- European certification calculations
- UK Developers - DesignBuilder Software
- OTEC are the exclusive reseller in Brazil
- Course uses v.1.9 beta – mostly stable but unfinished beta for v.2.
- 6 month free licences will be upgraded to v.2 when available (end March)

Course Contents – Day 1

- Understanding modelling in DesignBuilder
- Drawing tools
- Importing 2-D floor plans
- Model options
- Setting adjacency
- Model data overview
- Templates

Course Contents – Day 2

- Heating Design, Cooling Design, Simulation
- Timing - Schedules, Profiles, Holidays
- Glazing and Solar Shading
- Daylighting calculations
- Comparing results
- Natural ventilation and Mixed mode
- HVAC (Simple and Compact)

Course Contents – Day 3

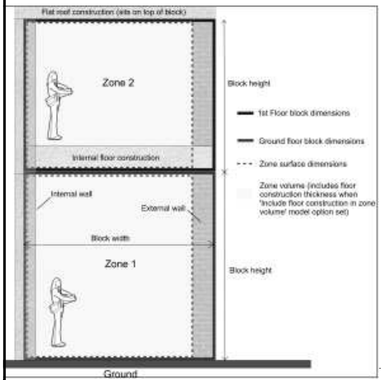
Optional Day 3

- CFD internal and external analysis
- Advanced DesignBuilder topics (depending on time and requests)

Typical Simulation Process

1. Load DXF floor plan (or PDF, bitmap etc) if available
2. Create building geometry by adding blocks
3. Partition blocks into zones using zoning rules
4. Set model options as required based on design stage etc
5. Set as much building default data as possible
6. Set data for individual blocks, zones, surfaces etc
7. Run test simulations for winter and summer weeks looking at hourly results in all zones to check for correct operation
8. Run annual simulations *without hourly results* (typically select monthly and temperature distribution results)

Defining Block Dimensions



- Blocks drawn using **external dimensions**
- Block height is the **floor-floor height**
- **Zones have internal dimensions** calculated from blocks using block wall thickness
- **Block wall thickness** used for creating zones from blocks – otherwise **it has no thermal effect**
- Partition thickness not used in calcs

Drawing Aids

- **Point Snaps** – End-point, Mid-point, Edge, DXF, Snap to lower perimeter, Increment (change direction)
- **Direction Snaps** – snap direction of line to major axes or normal/parallel to another line
- **Protractor** – for precise angles, set increment
- **Drawing Guides** – pick up x and y positions of key points of other objects

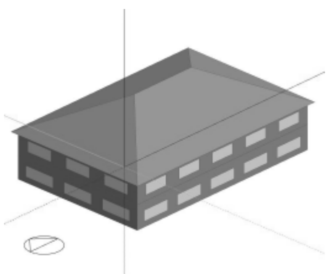
Exercise 1

Create simple rectangular building:

External dimensions:	30 x 20m
Wall thickness:	0.35m
Block height ground	3.5
Block height 1st floor	3.0

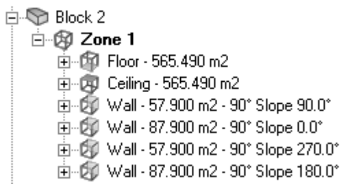
Pitched roof (non gable) slope 25 degrees with 0.5 m overhang and wall thickness 0.1m

Exercise 1 - Continued



Exercise 1 - Continued

- Check wall thickness set correctly
- Internal zone floor dimensions should be 19.3 x 29.3m
- Internal area = 565.49m^2 - check in Navigator (below)



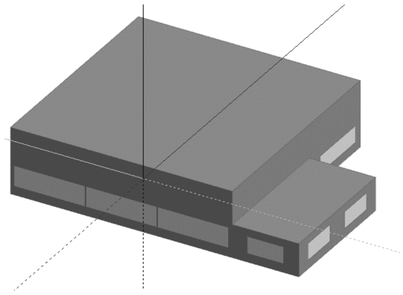
Exercise 2

Using the Drag face tool

1. Draw a block 20m x 20m and 6m high
2. Starting at the south west corner add a block that is 3m high and extends 12m along the south wall of the original block and stands out from that block by 6m
3. Now use the Drag face tool to pull the smaller block out to a distance of 10m

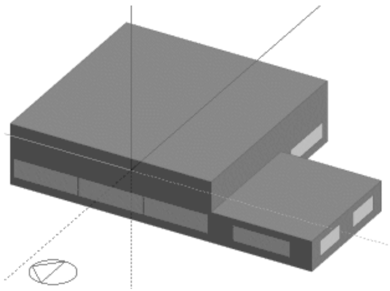
Exercise 2 - Continued

Before face is dragged



Exercise 2 - Continued

After face has been dragged



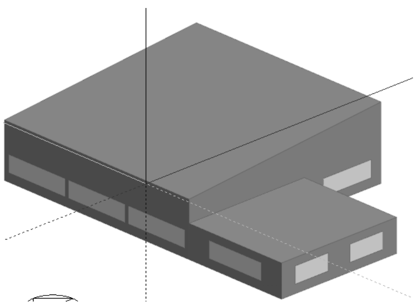
Exercise 3

Using cutting and protractor tools to create a mono pitch roof

1. Continuing from Exercise 2, use the drag face tool to increase the height of the larger block by 2m
2. Turn on the protractor and set the increment to 5º
3. Use the Cut Block tool to cut the block across the south face at 5 degrees starting at a height of 5m from the south west corner
4. Delete smaller cut block to leave a mono-pitched sloping roof

Exercise 3

After block has been cut to create mono-pitch sloping roof



Exercise 4

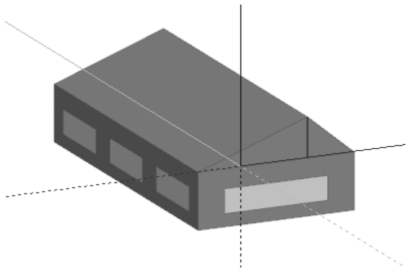
Using a horizontally extruded block to create a roof

1. Draw a simple block 10m x 20m and 3.5m high
2. Add a gable end roof with the geometry shown below
3. Ridge is 2.5m above eaves and 7m from left hand corner
4. Suggest use construction line (in blue) to locate ridge position

Exercise 4 - Continued

Roof created using extruded block

Note construction line in blue



Model Options

Click spanner icon to open model options 

In data tab use sliders to set up level of detail required in model

Review settings on other tabs – these can be changed later

Exercise 5

Using Outline blocks to create complex geometry

1. Create 2-storey building 10m x 20m with pitched roof
2. Add dormer window **outline block** in middle of sloping 30º slope roof – align vertical face with wall below
3. Vertical walls height 1.5m and sloping roof 1.5m long at 45º
4. Cut outline block using roof as cutting plane (cutting method = **Select plane**)
5. Convert dormer outline block to building block using **wall thickness 0.1m**
6. Add a window 1m x 1m
7. Cut a hole in the sloping roof - merge the dormer zone with the main roofspace zone (use '**Merge zones connected by holes**' Model option)
8. **Visualise** - look inside, explore visualisation options

Exercise 5 - Continued

Using outline blocks

Using Component Blocks

Three types

1. **Standard** – used for shading, reflection and visualisation
2. **Ground** – for setting ground adjacency
3. **Adiabatic** – for setting adiabatic adjacency e.g. party wall to adjoining conditioned space

Exercise 6

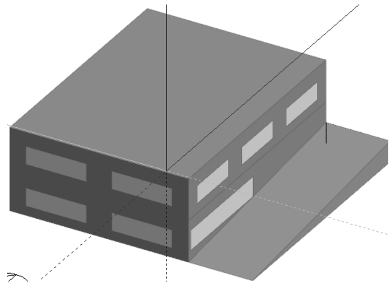
Using ground component blocks to set ground adjacency

1. Create a two storey building with flat roof 15m x 15m with default block heights
2. The ground rises along the south wall from floor level at the west corner to 1.75m at the east corner
3. Use a ground component block to set the adjacency for the south wall.

Tip use construction line to provide snap point for ground block at south east corner

Exercise 6 - Continued

Setting ground adjacency using component block



- Note how the ground component block has modified the layout of the default façade
- Go down to the surface level and check that the surface next to the ground component block has been split into 2 adjacencies

Exercise 7

*Using **adiabatic** component blocks to represent other spaces at similar conditions*

1. Rotate model from Exercise 6 to show North face
2. Add 4m high adiabatic block to middle of North facade

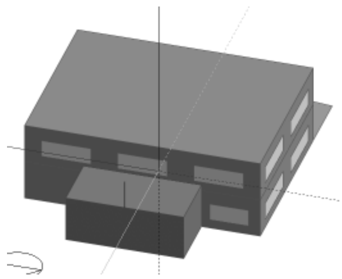
Tip use construction line and outline block

*Using **standard** component blocks for shading and reflections*

1. Add standard block in front of west face
2. Visualise and turn on shading

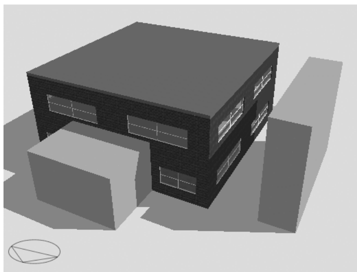
Exercise 7 - Continued

Using **adiabatic** component block



Exercise 7 - Continued

Using **standard** component block for shading and reflection



Activity areas (zones)

Building is divided into zone according to activities

Each activity has following data associated with it

- Occupancy density and hours including holidays
- Metabolic rates
- Demand for DHW
- Environmental control – set points etc
- Gains from all sources

Zoning Process

1. Divide building into separate physical areas by drawing in partitions.
2. If any part of area has different HVAC or lighting create separate area bounded by those services
3. Where there is no physical partition use virtual partitions
4. Define the activity of each resultant area
5. Combine contiguous areas with same activity, HVAC and lighting using hanging partitions to define thermal mass
6. Areas of the building having same activity, HVAC and lighting but different solar gains or conduction losses need a separate zone (e.g. core and perimeter)
7. Allocate any overlap to one of the neighbouring zones
8. Show typical 4 x perimeter zones + 1 core zone example

Exercise 8

Zoning the building

1. Create a building 10m x 20m external dimensions
2. Add 2m wide corridor down middle parallel with the longer wall
3. Insert partitions to create 5 equal cellular offices along west wall - assume all have same HVAC system

Tip: You should have created just 3 zones

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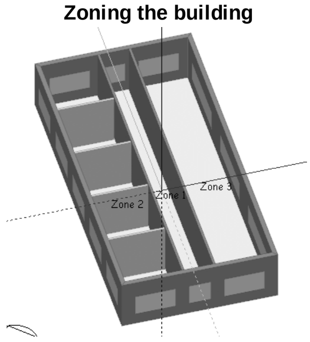
Exercise 8 - Continued

Zoning the building



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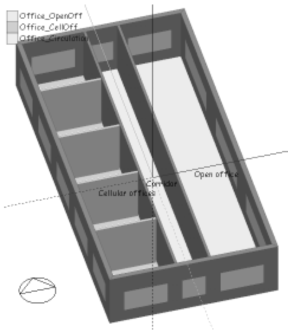
Exercise 8 - Continued

Assigning activities & naming zones



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Zone Types

1. **Standard** – occupied, not necessarily heated or cooled.
2. **Semi-exterior unconditioned** - unoccupied zone in the building which is neither heated or cooled. Examples are roofspaces, sunspaces, car parks etc.
3. **Cavity** - the zone is a cavity such as the glazed cavity within a double facade or a Trombe wall.
4. **Plenum** – for HVAC supply or return air - unoccupied and has no heating, cooling, or mechanical ventilation. Air flows through to meet the needs of zones it serves

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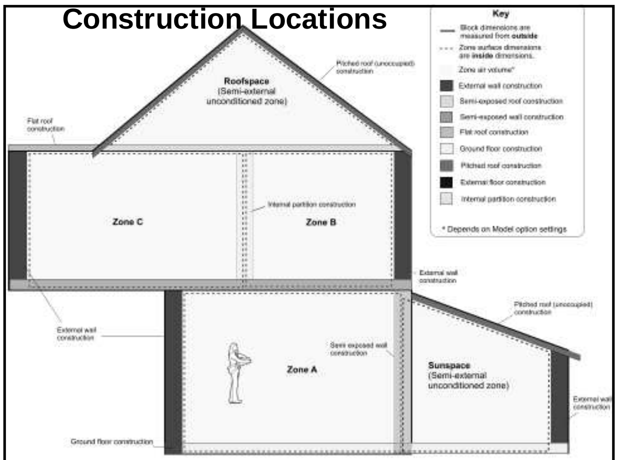
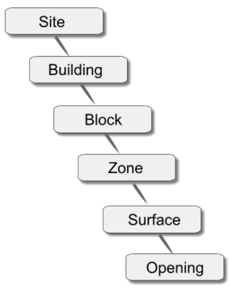
Construction Locations



Model Data Hierarchy

DesignBuilder models are organised in a hierarchy:



- Defaults are inherited from the level above in the hierarchy
- Hard set data (shown in red) overrides defaults
- Hard set data can be cleared using 'Clear data'

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Exercise 10 - Continued

Editing default constructions

- Draw simple building 10 x 15 m
- Add second floor and unheated pitched roof
- Modify construction wall for second floor to:

1. Outer leaf metal cladding steel 2 mm thick (look under metals)
2. Insulation polyurethane board diffusion tight, 0.1m thick
3. Inner leaf concrete 1800kg/m³ concrete block, medium density inner leaf 0.1m thick

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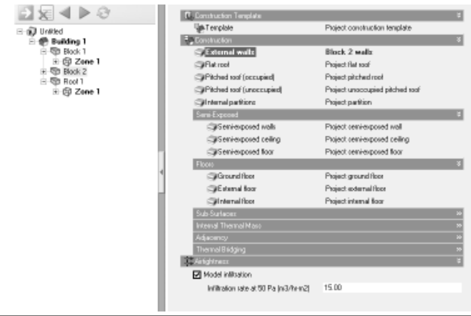
Exercise 10 - Continued

Editing default constructions - *note external wall data hard set at block 2 level is in red*



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Adjacent Condition

The default for adjacency is **Auto** where the adjacency of the surface is determined automatically by DesignBuilder based on its position. Adjacency can also be set using **component blocks** or **manually** at surface level to:

- **Not adjacent to ground** - even if below ground plane
- **Adjacent to ground** - adjacent to ground even if it   is above the ground plane or it is an internal surface
- **Adiabatic** - the surface is adiabatic for modelling other zones at similar conditions to this one.

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Roof in Roof

- Treat as standard activity area
- Draw partitions between conditioned and unconditioned spaces and set zone type as appropriate

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Exercise 11

Occupied roof space – room in roof

1. Draw a 20 x 30 two storey building with a 45 degree pitched roof
2. Using construction lines position partitions 2m for each edge of the sort dimension as illustrated in next slide
3. Name the zones as ‘Room in the roof’ and ‘Roof void’
4. Go to building level and cut the roof block at a height of 3m to create a ceiling.
5. Select room on roof zone and set zone type to standard and set activity to hotel bedroom.

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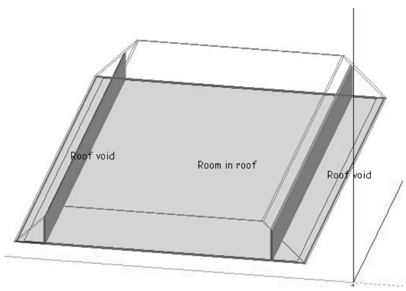
Exercise 11 - Continued

Occupied roof space – room in roof



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Unheated Roofspaces

Set zone type as:

Semi exterior unconditioned

OR

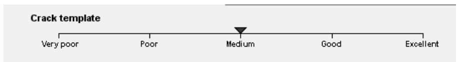
Use 'pitched roof' option leaving "roofspace occupied" box unchecked when drawing the pitched roof block

Infiltration

Infiltration rate is set in construction tab under 'Airtightness'

There are two ways of defining air tightness depending on the Natural ventilation model option:

- **Scheduled** – set as air changed per hour and is **constant**
- **Calculated** - the Airtightness is defined by a position on a five point scale corresponding to the 5 crack templates



In both cases infiltration can be switched off at building, block or zone level.

Openings

'Opening' refers to any opening in the main building fabric. There are five types:

- Windows
- Sub-surfaces (i.e. opaque elements within the surface that have different properties from the main construction.) e.g. lintels and lightweight panels
- Holes
- Doors
- Vents

- CFD boundaries are special type of opening covered later in the course

Exercise 12

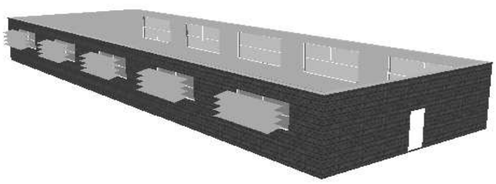
Defining openings

1. Draw simple 10 x 30m building with long dimension running North to South
2. Change default glazing to 4-20-4 low coated air filed
3. Using default facades to create building with:
   - 20% glazing in West wall with window height of 1.3m and sill height of 1.5m. Apply local shading with 1m overhang louvre
   - 40% glazing in East wall with window height of 2m and sill height of 1m. Apply window shading using venetian blinds - light, internal, always on.
   - South wall has no glazing but has a door

Exercise 12 - Continued

Defining openings

Appearance of building at block level



Lighting

- Default data is loaded from the reference template
- Click and use browse to load alternative template, including specific lamp types
- Use slider to adjust default lighting thermal output
- Gain to the zone calculated from the luminaire type
- Lighting schedule inherited from activity
- Select luminaire type
- If task or display lighting specify gain and schedule
- Task and display lighting is never affected by lighting control and by activity target illumination levels

Lighting Controls

Where electric light can be controlled according to the availability of daylight turn on lighting controls

Control types: **Linear**
Linear/off
Stepped

- Lighting sensors: By default one main sensor controls
- 100% of zone area – can vary this
- Sensor located at 0.8m above floor by default – change working plane height in Model options dialog
- Can also introduce second sensor – more on day 2

Exercise 9

Specify lighting
See Training Manual for details

- Create building 10 x 30m with 4 zones (any layout)
- Set activity at building level to **Office_OpenOff**
- Set activity for Zone 3 as **Office_Reception**
- Set activity for Zone 4 as **Office_Store**
- At building level set lighting template as:
- T8 Fluorescent, triphosphor, high frequency control gear

Continued…

Exercise 9

Specify lighting continued

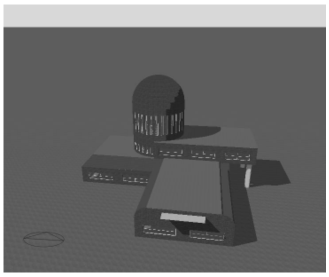
- Set lighting energy as 16 W/m^2
- Note schedule **Office_OpenOff_ Light** set from activity
- Set luminaire type as **Surface mount**
- Turn on lighting control - set control type to **Linear**
- Set % area cover by lighting area to 40%
- Now follow instruction in Manual for Zones 3 and 4
- Lighting data inherits from building level in Zone 1 and 2

Exercise 13

Create building with more complex geometry

Use as many drawing tools as possible

Example:



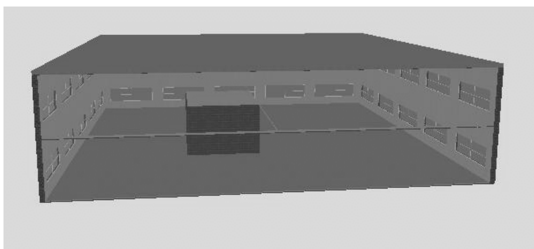
Exercise 14

Free standing office in Warehouse

1. Draw the ground block to height of office – draw partitions for office in middle of warehouse
2. Draw the 1st floor block representing the high-level warehouse space.
3. Draw holes (two will be required) so as to cut away all the floor of the 1st floor block except that around the top of the office.
4. Go to Model options > Advanced tab and select 'Merge zones connected by holes'.
5. From Navigation tree in first floor block select element corresponding to the ceiling of the office. Under the Construction tab > Adjacency Header tick 'Exclude this surface area from the total zone floor area'

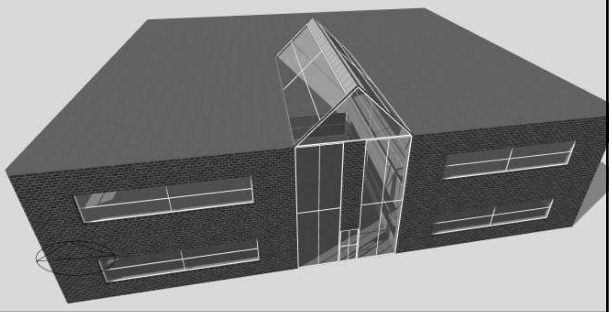
Exercise 14 - Continued

Free standing office in warehouse



Exercise 15 - Atrium Example

See Training manual



Templates

- Quick way to load commonly used data sets
- Create your own templates or use templates provided
- Each Model data tab has it's own template - Construction, Glazing, Façade, Activity, Lighting and HVAC data
- Templates useful when working with portfolios of buildings with common features
- Load templates to individual objects or target a list of building, blocks, zones, surfaces or openings using **Load data from template** dialog (esp. useful for entering an activity, such as toilet, distributed throughout a building)
- Section 8 of Training Manual has more details

Calculations

3 Main calculations:

- **Heating design** – steady-state UA(Ti – To)
- **Cooling design** – periodic, thermal mass
- **Simulation** – energy, comfort, real weather data weather

These thermal calculations all use **EnergyPlus**

EnergyPlus

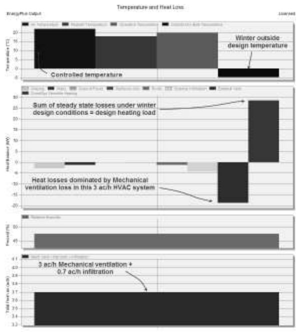
- Advanced DSM engine calculates energy flow + resource consumption including:
- Heating, cooling, lighting, ventilation, water
- US DOE, Dru Crawley, 10 years
- Best of BLAST and DOE-2…Plus:
- Time steps < 1hr,
- Modular HVAC integrated with Zone,
- Multizone air flow for Natural ventilation, Thermal Comfort, Photovoltaics, Water

Heating Design Calculations

- Equivalent to CIBSE & ASHRAE methods
- Steady state calculation
- Uses outside winter design temperature
- Wind, no solar, no gains, interzone, float
- Inside design temperatures for activity

Heating Design Output

- Detailed breakdown of heat flows and comfort for each zone on **Analysis** tab



Heating Design Output

Summary building heating design loads

Untitled, House , Entrance block, Entrance

Steady State | Summary

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Heating Capacity(kW)
House (Total design heat loss = 28.160 (kWh)			
Entrance block (Total design heat loss = 6.840 (kWh)			
Entrance	**18.34**	**4.56**	**6.84**
Roof 1 (Total design heat loss = 0.000 (kWh)			
Zone 1	7.05	0.00	0.00
Roof 2 (Total design heat loss = 1.740 (kWh)			
Zone 1	10.07	1.16	1.74
Ground floor (Total design heat loss = 19.580 (kWh)			
Toilet	18.35	0.88	1.32
Kitchen	18.73	1.52	2.28
Bedroom	18.16	3.93	5.90
Sitting room	20.07	5.38	8.07
Cupboard	18.45	0.67	1.00
Bathroom	18.79	0.67	1.01

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Cooling Design Calculations

- Equivalent to CIBSE Heat Gain
- Periodic calculation
- Outside summer design temperature
- Inside design temperatures for activity
- Solar, daylight, shading, gains, mass, vent, interzone heat
- July/Jan
- Half-hourly

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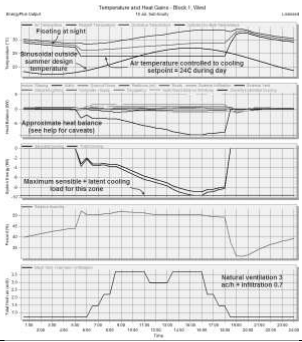
Cooling Design Output

- Detailed breakdown for each zone on **Analysis** tab



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Cooling Design Output

Summary design loads for each zone

Analysis | Parametric | Summary

Zone	Design Capacity (kW)	Design Flow Rate (m3/s)	Total Cooling Load (kW)	Sensible (kW)	Latent (kW)	Air Temperature (°C)	Humidity (%)	Time of Max Cooling	Max Op Temp in Day (°C)	Floor Area (m2)	Volume (m3)	Flow/Floor Area (l/s-m2)
Building 1 Total Design Cooling Requirement = 12.590 (kW)												
Block 1 Total Design Cooling Requirement = 12.590 (kW)												
East	0.00	0.00	0.00	0.00	0.00	-	-	-	39.1	113.0	395.4	0.00
West	**12.59**	**0.80**	9.68	8.91	0.77	24.0	50.3	16:00	33.2	69.8	244.3	11.50

Cooled zone requires cooling equipment of size 12.59 kW

Uncooled zone

Reality check

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Parametric Cooling Design

- Allows automated parametric variations in model to be simulated and results displayed.

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Simulation

- Detailed **energy** & **comfort** performance
- Hourly weather data
- Dynamic - 2-10 timesteps / hour
- Solar, daylight, shading, gains, mass, vent, interzone heat
- HVAC simultaneous with zones
- Warmup

More versatile, options.

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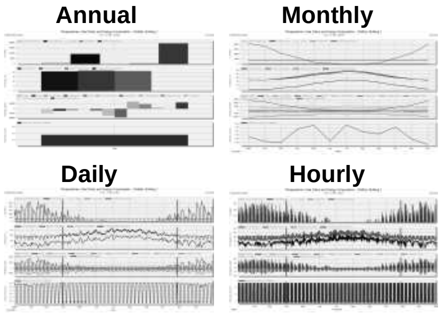
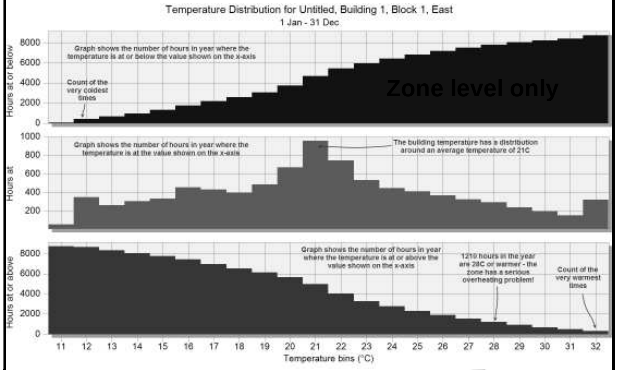
Simulation Output

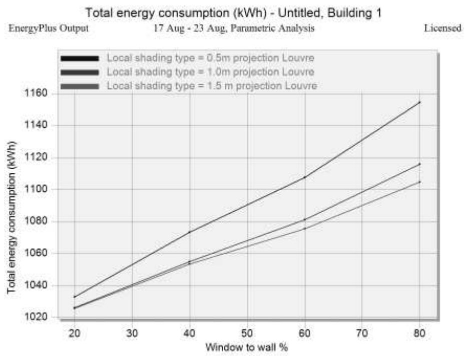
Example 20x10 2-Zone



Simulation Output - Distribution



Simulation Output - Parametric



Timing

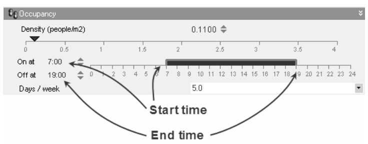
Ways to set the time-varying elements.

Timing options:

- **Typical workday** – fast, easy
- **Schedules** – more flexibility (*default*)

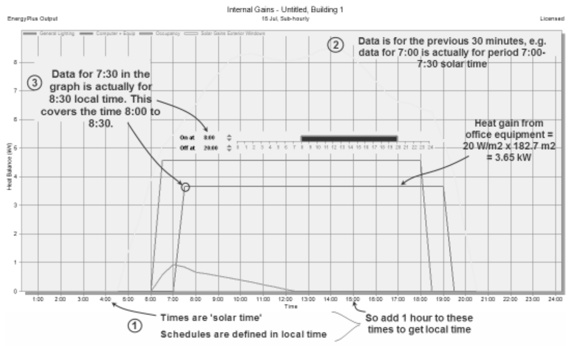
Timing - Typical workday

- Fast, convenient
- Less flexible



- Exercise 20x10 Default, 8-20, Equip, Cooling design

Timing - Typical Workday



Timing - Schedules

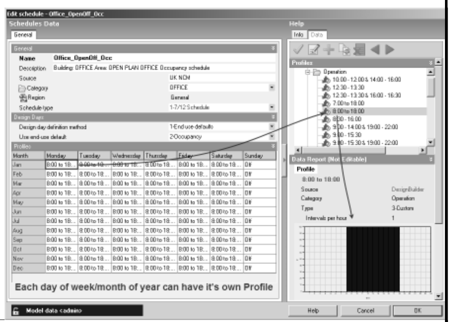
- Schedule **components** – export
- More **flexible** than Typical workday

Schedule options:

- **7/12** Schedules - graphical
- **Compact** Schedules - text

7/12 Schedules

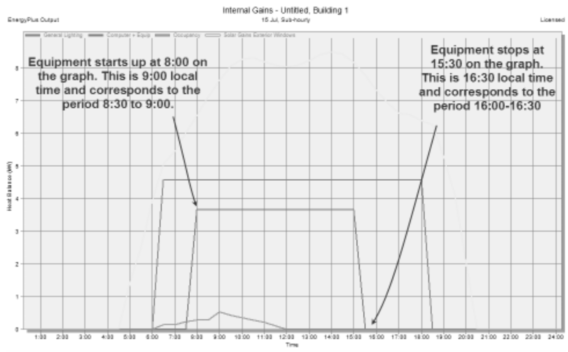
- 7 x 12 Grid of Daily Profiles
- 7 days / week,
- 12 months / year



7/12 Schedules - Exercise

- **Schedules** Timing Model option
- New **Office equipment** schedule
- Select all cells
- Edit selected cells
- Select **8:30 – 16:00** profile
- Switch off at weekends
- Select it

7/12 Schedules Example Output



Compact Schedules – Example 1

```
SCHEDULE:COMPACT,                 Error Checking but No GUI
Office_CellOff_Light,
Fraction,                         < Type
Through: 31 Dec,                  < Season
For: Weekdays SummerDesignDay WinterDesignDay, < Weekdays
Until: 07:00, 0,                  < Daily Profile
Until: 19:00, 1,
Until: 24:00, 0,
For: Weekends,                    < Weekends
Until: 24:00, 0,
For: Holidays AllOtherDays,       < Holidays
Until: 24:00, 0;
```


Compact Schedules – Example 2

```
SCHEDULE:COMPACT,            Temperature Setpoint Schedule
Bedroom_Cool,                Values 0, 0.5 and 1 only
Temperature,                 Error Checking but No GUI
Through: 31 Dec,
For: Weekdays SummerDesignDay WinterDesignDay,
Until: 05:00, 0.5,
Until: 09:00, 1,
Until: 17:00, 0.5,
Until: 24:00, 1,
For: Weekends,
Until: 05:00, 0.5,
Until: 24:00, 1,
For: Holidays AllOtherDays,
Until: 24:00, 0;
```

Glazing and Solar Shading

2 ways to define glazing layout:

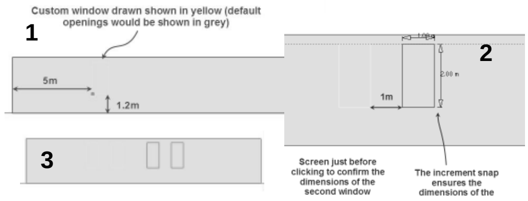
- Default facades
- Draw openings

You can also copy, move and delete openings at the building level

DesignBuilder Software

Glazing Exercise

- Atrium Example Base
- Delete all windows (Window to wall % = 0 or **No glazing** façade**)**
- West surface of Ground floor > Zone 1, Normal, define windows



Copy windows to other facades at building level

DesignBuilder Software

Solar Shading

- Window shading (blinds, shades)
- Local shading (louvres, overhangs)
- Solar control glazing
- Component blocks
- Assembly blocks (new)
- Building self-shading

DesignBuilder Software

Window Shading Design Study

Exercise:

- Atrium Example Base
- Cooling design calculation reference case, display Internal gains, Lock Y-axis, Report topic - **make sure to label the results**!
- Window shading on, Blind with high reflectivity slats, control type 4-Solar, rerun calculation, Report topic
- Window shading off, Local shading on, Louvre 1.0m projection + 1m overhangs and sidefins, rerun calculation, Report topic
- As above but model reflections, rerun calculation, Report topic
- Window shading off, Local shading off, component block in front of South window, solar transmission (play with this), model reflections
- If you have time try more options (e.g. solar control glass)

Questions:

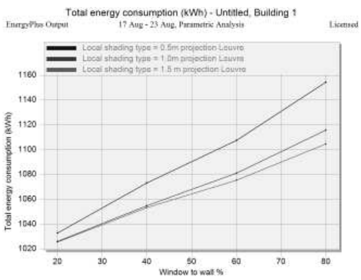
1. Which option reduces solar gains and max temperatures most?
2. Can you see a difference due to **model reflections** option?

DesignBuilder Software

Parametric Study

Investigate effect of local shading device projection

******* Check Building => Surface inheritance *******



Shows diminishing returns from extra projection

Good for:

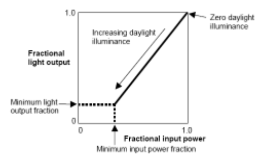
- •Design curves
- •Teaching aid
- •Communication
- •Optimisation

DesignBuilder Software

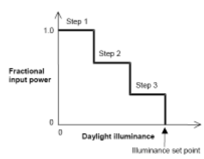
Daylighting

- Controls electric lights based on daylight availability

Linear



Stepped

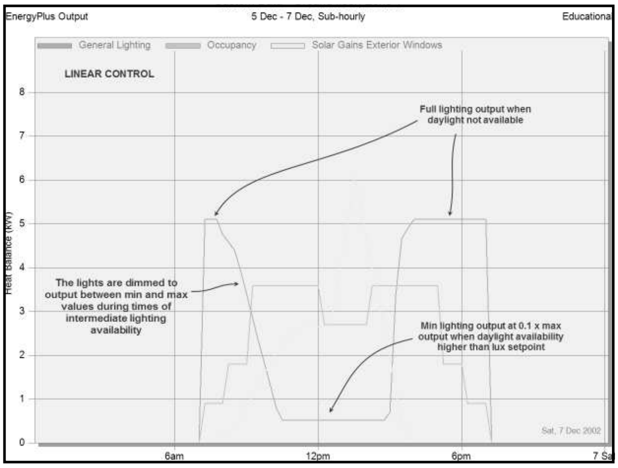


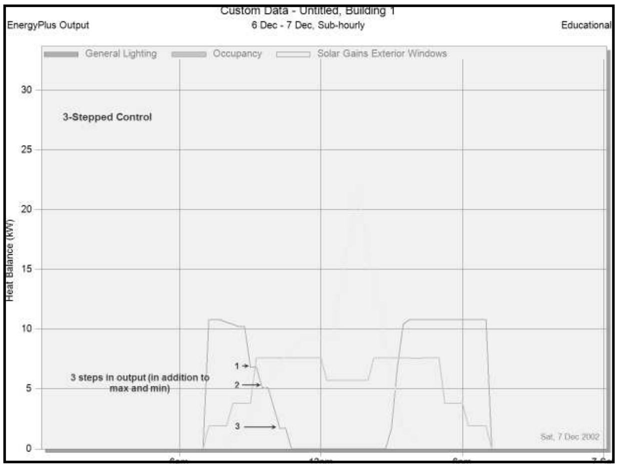
DesignBuilder Software

Daylighting Exercise

- Lighting control on, **Linear**
- Sensor position – move it
- Model options > Advanced tab > Lighting
- Simulation 6 Dec, Sub-hourly, 6 timesteps
- Results East zone
- Repeat with **2-Linear/Off**
- Repeat with **3-Stepped**

DesignBuilder Software





Comparing Results

2 methods:

- **Report topics**
- **Different buildings**
- Compare daylighting results using both
- Use **Lock Y-axis**
- New design comparison tools in v.2.

DesignBuilder Software

Natural Ventilation

Includes consideration of:

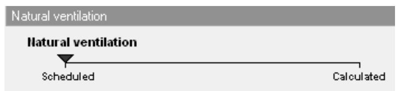
- Windows, vents, holes and cracks
- Size, shape, position and orientation
- Wind-speed and outside temperatures
- Internal temperature in each zone
- Control for comfort

DesignBuilder Software

2 Modes

DesignBuilder offers 2 Nat vent modes:

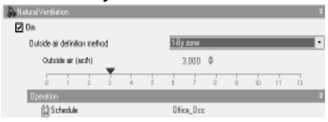
- **Scheduled**
- **Calculated**

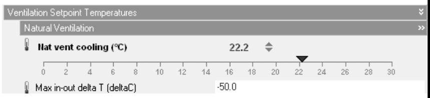


DesignBuilder Software

Scheduled Nat Vent

- Exterior airflow + schedule set directly
- Infiltration constant.
- Interior airflow by 'mixing'
- Cooling setpoints
- Avoidance of heating





DesignBuilder Software

Scheduled Nat Vent Exercise 1

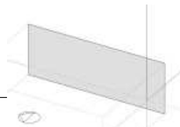
- 'Hot water radiator heating, nat vent' HVAC template
- Table of data in Manual
- Avoid simultaneous heating and venting: Heating setpoint < Cooling setpoint
- 5 ac/h Natural ventilation
- Also switch off night cooling and check effect on max daytime temperatures

DesignBuilder Software

Scheduled Nat Vent Exercise 2

Same as first but with Internal Airflow

- Draw a large hole in partition
- Model options > Advanced > Natural Ventilation > Airflow through internal openings on
- Check change in results



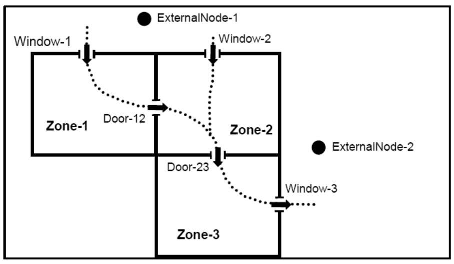
DesignBuilder

Calculated Natural Ventilation

- You define openings, controls and weather and EnergyPlus **calculates** airflow
- Bulk airflow movement, average zone temperatures
- Nodes connected by air flow elements
- Wind Pressure Coefficient (Cp) values need to be defined – Input/Auto
- More data needed, simulations slower

DesignBuilder Software

Airflow Network Model

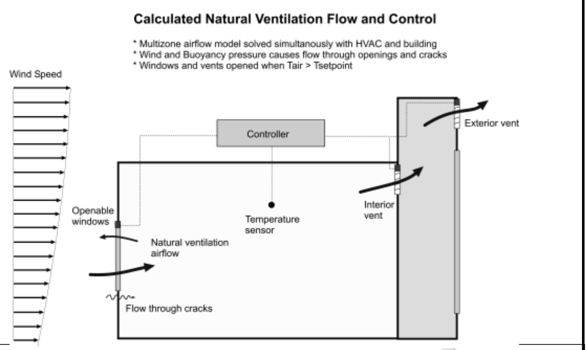


***Plan view* of a simple airflow network showing a possible airflow pattern**

•Developed by NIST (Walton 1989)
•Coupled to E+

DesignBuilder Software

DesignBuilder Implementation



DesignBuilder Software

Calculated Nat Vent Exercise 1

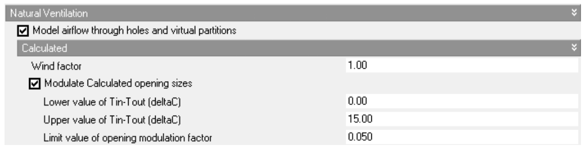
- Continue from Scheduled example
- Model options > Natural ventilation > Calculated
- Windows open by 5%
- Modulate off – no concern about cold o/s air
- Infiltration medium (show crack)
- Simulate Summer typical, Hourly
- Results – Nat vent control 21℃, high ac/h - cross vent + stack vent, low night infiltration

Calculated Nat Vent Exercise 2

As previous but with variations:

1. Modulation
2. Wind factor set to 0

Check effect of above on fresh air delivery



HVAC

Heating, Cooling, Ventilation for comfort

HVAC Model options:

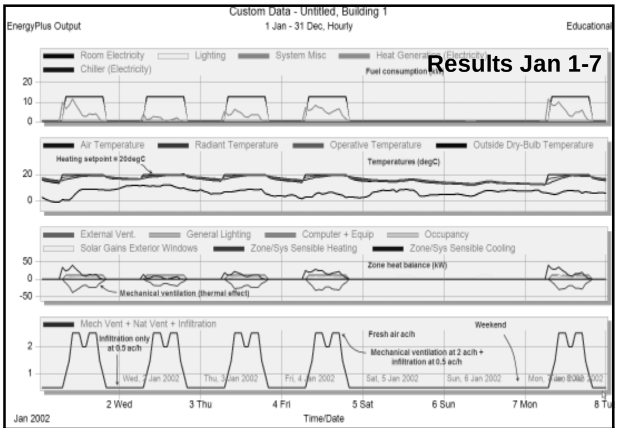
- **Simple** – loads x CoP
- **Compact** – parametric data

Simple HVAC

- Energy consumption = Loads x constant seasonal system CoP
- Fans and Pumps modelled using empirical data from UK NCM
- For 'Early' design this may be ideal

Simple HVAC Exercise

- HVAC tab load **Packaged direct expansion** HVAC template
- Mechanical ventilation: **By zone**, **2 ac/h**, schedule **Office_OpenOff_Occ**
- Auxiliary energy from UK NCM
- **Heating & cooling setpoints** on Activity tab **20ºC** and **26ºC**

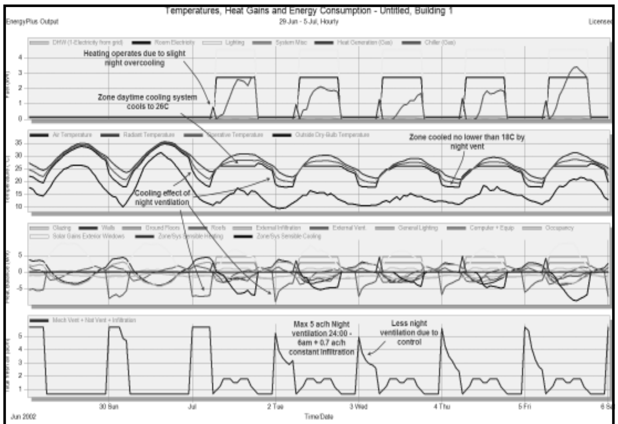


Radiant Heating Exercise

- Simple HVAC
- **Underfloor heating system, nat vent** HVAC template
- Note Heating type is **2-Radiative/convective**
- Radiant distribution 2-Floor
- Natural ventilation > Outside air definition method to **2-Min fresh air (Per person)**.
- Activity tab > Nat vent cooling setpoint 10ºC
- Simulate Winter design week

Night Cooling - Mech Ventilation

- Simple HVAC thermostatic night cooling
- Check Mech vent, Heating & Cooling on
- Create new schedule - copy **Summer cooling workdays (Northern Hemisphere)** See manual for changes
- Select it as Mech vent operation schedule
- Mech vent > Outside air flow rate **5 ac/h**
- Nat vent on, **Min fresh air per person** to provide fresh air for occupants during the day. Default **Office_OpenOff_Occ** schedule
- Activity tab > Environmental Control:
  a. Cooling setpoint = 26°C.
  b. Natural ventilation cooling setpoint = 18°C.
  c. Mechanical ventilation setpoint = 18°C. (prevents overcooling).
  d. Mechanical ventilation Max in-out delta T = 2K. Avoids warm air
- Simulation: Hourly data, Summer typical week



Compact HVAC

- More detailed model of some common HVAC system types
- Simple parametric input data loaded from templates.
- No networks of ducts and pipes
- Auto sizing of components

EnergyPlus Compact HVAC System types

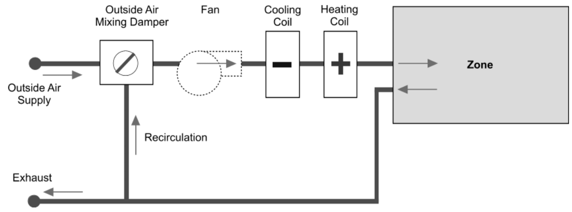
- **Fan coil units**
- **Unitary Single Zone** (constant volume packaged DX and split systems)
- **Unitary Multizone** – multizone DX systems with a single AHU
- **CAV**- Constant Air Volume systems with central AHU.
- **VAV** - Variable Air Volume systems with central AHU.

Zone-based Systems

- **Unitary single zone**
- **Fan coil units**

- Separate data for each zone (no AHU)
- Defined at the zone level
- Like Simple HVAC

Fan Coil Units



•4-pipe FCU - hot + chilled water

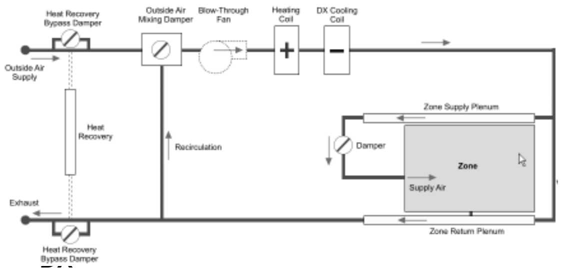
•Outside air optional (mech vent checkbox)

•Data entry like Simple HVAC

Fan Coil Unit Example

- Based on Atrium Example
- Compact HVAC, Scheduled nat vent
- Winter typical week, hourly results
- Note constant fresh air delivery
- Store results for comparison

Unitary Single Zone



•Rooftop and split

•Options for free fresh air and heat recovery

Unitary Single Zone Example

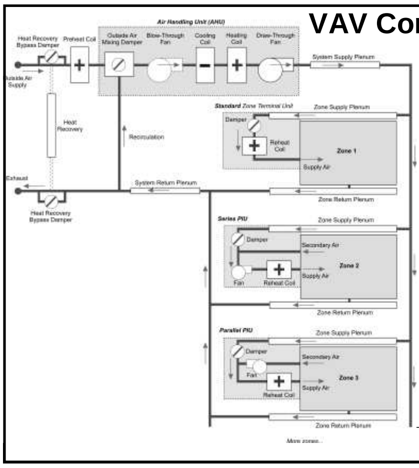
- ‘Packaged direct expansion’ HVAC template, re-run **Winter design week**, store results, compare with FCU
- Run **Summer typical week**, store results
- Add free cooling (Economiser **Return air temperature** option) re-run summer typical week, store and compare results
- How much free cooling is provided?

AHU-based Systems

- **Unitary multizone**
- **VAV**
- **CAV**

- 1 AHU max, data defined at building level
- The AHU Data for zone terminal units, fresh air requirement, heating/cooling requirement and setpoints etc is set at the zone level
- More data required to define VAV and CAV

VAV Compact HVAC



•Variable Air Volume with fixed AHU outlet temperature

•zone supply airflow varied to control cooling

•Reheat may be needed

•When heating, zone damper closes to min and reheat operates

•Outside air can be Fixed, Proportional, Full fresh air

•Zone terminal unit options are: Standard + 2 powered induction unit options

VAV Cooling

- Air from AHU at constant temperature
- Volume of air adjusted at zone terminal unit by opening/closing damper
- Max AHU air volume autosized
- If min fresh air would overcool then reheat

DesignBuilder Software

VAV Heating

- Zone damper closes to minimum
- Reheat coil operates to maintain comfort
- AHU heating possible but care needed to avoid simultaneous heating & cooling
- Zone damper options for heating:
  - 1-Normal, constant volume, min fresh air
  - 2-Reverse, as 1-Normal but damper can open to meet high heating loads

DesignBuilder Software

VAV Terminal Units

- Usually mounted in ceiling
- During cooling, damper position controls cool air provision
- During heating damper usually closed to min
- Turndown ratio defines minimum supply air
  - 0 = damper can close completely
  - 1 = damper can't close at all – CAV
  - Typical values 0.3-0.5
- Options for series and parallel fan powered units

DesignBuilder Software

Outside Air

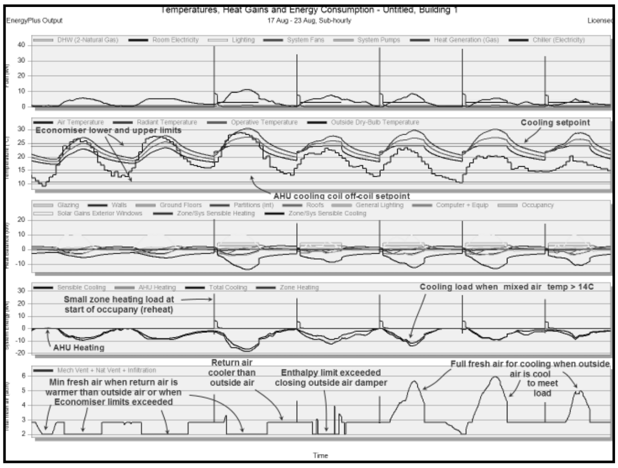
- 1-Recirculation - outside air control can be:
  - 1-Fixed – min fresh air is provided regardless of AHU flow rate
  - 2-Proportional – min fresh air varies in proportion to total system flow - standard
- 2-Full fresh air – no recirculation, supply flow is same as outside air so cooling loads may not be met - requires extra control

DesignBuilder Software

VAV Exercise

- Default 20x10 **2-Zone**
- HVAC template **VAV with terminal reheat**
- Mech vent By-Zone, 2 ac/h
- Mech vent schedule **On**
- Infiltration off
- **Summer design week**, sub-hourly, 10 timesteps / hour

DesignBuilder Software



Mixed-Mode

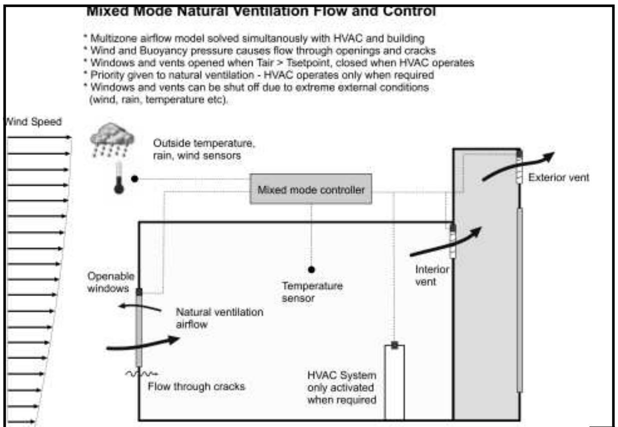
Hybrid nat vent and HVAC cooling system. LBL define 3 types:

1. Concurrent (same space, same time)
2. Changeover (same space, different times)
3. Zoned (different spaces, same time)

- DesignBuilder can do 1 and 3 with no special consideration
- In DesignBuilder mixed mode refers to Changeover mixed mode

Changeover Mixed Mode

- Natural ventilation has priority
- Cooling switched on when cooling setpoint exceeded and then nat vent system closed
- Nat vent can also be shut down due to wind, rain, extreme o/s temperatures or enthalpy
- Requires Calculated Nat vent + Compact HVAC

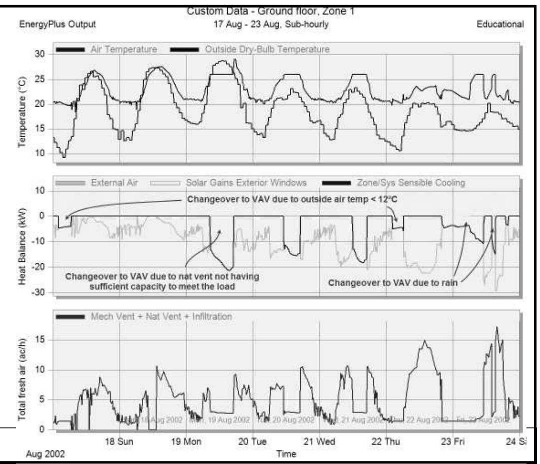


Mixed Mode Exercise

- Compact HVAC, Calculated Nat vent
- Activity **setpoint points**, Heating 20C, Nat vent 22C, Cooling 26C
- HVAC template **VAV with HR outside air reset + mixed mode**
- Mech vent schedule **on**
- Switch off close window and vents when raining
- Ground floor > Zone 1 is **control zone** for whole building
- Infiltration **off**
- Sub-hourly, summer typical week, timesteps 6

Mixed Mode Optimisation

- Close windows and vents when raining
- External window schedule **on** for night cooling



CFD Training Course

What is CFD?

- Computational Fluid Dynamics (CFD) is the term used to describe a family of numerical methods used to calculate the temperature, velocity and other fluid properties throughout a region of space.
- CFD applied to buildings provides the designer with information on probable air velocities, pressures and temperatures occurring in and around building spaces with specified boundary conditions including climate, internal heat gains and HVAC systems.

How does CFD work?

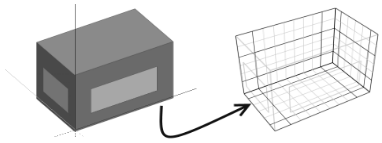
- DesignBuilder CFD is based on a method known as the finite volume (FV) method
- The method involves the solution of a set of partial differential equations (PDEs) describing the transport of momentum, energy and turbulence quantities

$$\underbrace{\frac{\partial}{\partial t}(\rho\phi)}_{\text{Transient}} + \underbrace{\mathrm{div}(\rho u \phi)}_{\text{Convection}} = \underbrace{\mathrm{div}(\Gamma\ \mathrm{grad}\ \phi)}_{\text{Diffusion}} + \underbrace{S}_{\text{Source}}$$

Equation	Variable
Momentum	u, v and w velocities
Energy	temperature
Turbulence KE	turbulence kinetic energy
Turbulence Diss	dissipation rate of turbulence kinetic energy

How does CFD work?

- Partial differential equations are converted into a set of simultaneous algebraic equations
- Building space under analysis is divided into a set of non-overlapping adjoining rectilinear cells (finite volume grid)



- Algebraic equations are set up for each grid cell and the whole set of equations solved using a numerical method

How does CFD work?

What is a partial differential equation?

- A PDE is a type of equation that is used to describe the variation of a dependent variable (such as temperature or velocity) with a number of independent variables (such as time and distance)
- The PDEs are made up of a number of terms incorporating the dependent variable and a multiplier or coefficient
- The PDE coefficients themselves can contain the same dependent variables that they are associated with and consequently the equations cannot be solved using analytical methods

Momentum equation:

$$\frac{\partial}{\partial t}(\rho\, u_i) + \underbrace{\frac{\partial}{\partial x_j}(\rho\, u_j u_i)}_{\text{Convection}} = -\frac{\partial \Pi}{\partial x_i} + \frac{\partial}{\partial x_j}\left\{(\mu + \mu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right\} - g_i$$

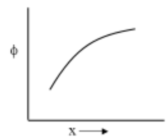
convection term coefficient incorporates velocity

How does CFD work?

The solution – a numerical approach

- The variation of the PDE dependent variable is continuous and may be visualised in the form of a curve

$$\frac{\partial}{\partial x_j}(\rho u_j \phi_i) = \frac{\partial}{\partial x_j}\left(\Gamma \frac{\partial \phi_i}{\partial x_j}\right) \quad \Rightarrow$$



- The continuous nature of these non-linear variations can be approximated by a number of linear relationships, i.e. the curve can be represented as a series of straight lines
- The idea behind this is that equations representing straight lines are easily solved

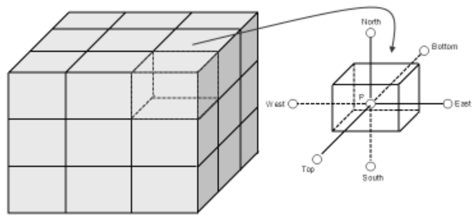
How does CFD work?

The solution – a numerical approach (cont'd)

- This process is known as "discretisation"
- To start the process, we divide the building space into a number of non-overlapping volumes or "control" volumes collectively known as the finite volume grid
- Each control volume surrounds a grid point at which the dependent variable is evaluated

How does CFD work?

The solution – a numerical approach (cont'd)



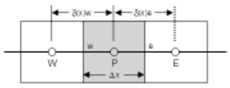
Finite Volume (FV) grid

FV grid control volume with neighbouring points

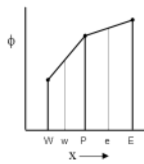
How does CFD work?

The solution – a numerical approach (cont'd)

- The PDEs can then be discretised across these control volumes using linear profiles to represent the variation of the dependent variables between the grid points and their neighbours



Finite volume grid in one dimension



Discretisation over control volume:

$$(\rho u\phi)_e - (\rho u\phi)_w = \left(\Gamma\frac{\partial\phi_i}{\partial x_j}\right)_e - \left(\Gamma\frac{\partial\phi_i}{\partial x_j}\right)_w$$

Re-write equation using linear profile shown at top right:

$$\tfrac{1}{2}(\rho u)_e(\phi_E+\phi_P) - \tfrac{1}{2}(\rho u)_w(\phi_P+\phi_W) = \frac{\Gamma_e(\phi_E-\phi_P)}{(\delta x)_e} - \frac{\Gamma_w(\phi_P-\phi_W)}{(\delta x)_w}$$

How does CFD work?

The solution – a numerical approach (cont'd)

- These discretised equations are then re-arranged to take the form of a set of simple algebraic equations that can be solved using basic numerical methods:

$$a_P\phi_P = a_E\phi_E + a_W\phi_W + a_N\phi_N + a_S\phi_S + a_T\phi_T + a_B\phi_B$$

$$a_P = a_E + a_W + a_N + a_S + a_T + a_B$$

where a_E, a_W, a_N, a_S, a_T and a_B are the combined diffusion-convection coefficients:

$$a_E = \frac{\Gamma_e}{\delta x} - \frac{\rho u_e}{2}$$

How does CFD work?

The iterative nature of the solution and convergence

- The numerical methods used to solve the equation set are iterative whereby the equations are repeatedly re-constructed and solved until there is no change in the dependent variables
- The algebraic equations are constructed in such a way that if the coefficients were constant, a converged solution would be guaranteed using the Gauss-Siedel method (simplest numerical method for solving simultaneous equations)
- The dependent variable coefficients contain the dependent variables themselves and are therefore not constant
- In practice, if the coefficients are of similar magnitude throughout and change gradually, a converged solution can normally be achieved

How does CFD work?

Outer and inner iterations

- Because the coefficients are changing, the iterative procedure uses an inner iterative procedure to solve the dependent variable equations within an outer iterative procedure to update the dependent variable coefficients
- At each outer iteration, only tentative values of the dependent variables are realised and consequently only a few inner iterations are required

How does CFD work?

Relaxation factors

- In order to prevent the equation coefficients from changing too quickly, the change in dependent variables from one outer iteration to another can be slowed by 'relaxing' them
- The traditional method of relaxation is the relaxation factor which combines a proportion of the dependent variable from the previous outer iteration with a proportion from the current iteration
- A relaxation value of 1.0 uses 100% of the current dependent variable value whereas a relaxation factor of 0.5 would combine 50% of the previous iteration value with 50% of the current value.

DesignBuilder Software

How does CFD work?

Dynamic solution and false time steps

- DesignBuilder CFD is steady-state, i.e. it calculates a 'snap-shot' in time
- In a dynamic CFD solution, the transient term acts as a very effective inertial relaxation factor
- The equation set in DesignBuilder CFD is actually constructed in a fully dynamic form
- The time steps in the transient terms are replaced with 'false time steps'
- False time steps are generally more effective than relaxation factors

DesignBuilder Software

How does CFD work?

Convergence and termination residuals

- The solution may be considered converged when there is no perceptible change in the dependent variables from one outer iteration to another
- In cases where heavy under-relaxation or very small false time steps are employed, changes in dependent variables may not be obvious
- An attractive feature of the control volume formulation is that once convergence is achieved, integral conservation of quantities such as mass, momentum and energy is exactly satisfied for each cell, any group of cells and of course for the whole domain

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How does CFD work?

Convergence and termination residuals (cont'd)

- A more meaningful indication of convergence is to consider the degree to which conservation of mass, momentum and energy is satisfied for the calculation domain
- A residual may be calculated by considering the overall balance of a particular quantity using the algebraic equation for the appropriate dependent variable:

$$R = \Sigma a_{nb}\phi_{nb} + b - a_P\phi_P$$

- Maximum residuals for each dependent variable are calculated and compared with a supplied termination residual to determine whether or not convergence has been achieved

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How does CFD work?

Discretisation scheme – Upwind, Hybrid and Power-law

- The formulation of the combined convection-diffusion coefficient whereby the interface convection coefficient is determined from a simple average of the grid point velocity and the neighbouring grid point velocity is found to result in very unstable solutions
- As previously noted, the algebraic equations are constructed to comply with a set of rules that would guarantee convergence for an equation set involving constant coefficients
- One of the rules requires that coefficients must not become negative
- The simple average convection coefficient formulation can lead to a negative coefficient and consequently a non-convergent solution

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How does CFD work?

Discretisation scheme – the Upwind scheme

- A remedy for this difficulty is to ensure that the convected value of an interface property is equal to the value of the property on the upwind side of the face

$$a_E = \frac{\Gamma_e}{\delta x} - \frac{\rho u_e}{2}$$

$$\Downarrow$$

$$a_E = \frac{\Gamma_e}{\delta x} + \max\left(-\frac{\rho u_e}{2}, 0\right)$$

- The rationale behind this measure is that convection (unlike diffusion) may be considered a one-way process in that properties upstream of a point can affect properties downstream but not the other way round

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How does CFD work?

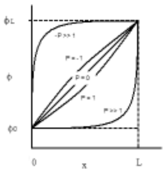
Discretisation scheme – Hybrid and Power-law schemes

- If we take our basic PDE, we can obtain an exact analytical solution by assuming that the convection and diffusion coefficients are constant

$$\frac{d}{dx_j}(\rho u_j \phi_i) = \frac{d}{dx_j}\left(\Gamma \frac{d\phi_i}{dx_j}\right)$$

$$\frac{\phi_P - \phi_P}{\phi_L - \phi_0} = \frac{\exp(P_x/L) - 1}{\exp(P) - 1}$$

$$\text{Peclet number, } P = \frac{\rho u L}{\Gamma}$$



How does CFD work?

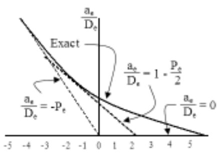
Discretisation scheme – Hybrid and Power-law schemes (cont'd)

- The ratio of the strengths of convection and diffusion may be measured using the Peclet number, P
- For high absolute values of P, the value of the dependent variable at the interface (i.e. x = L/2) can be seen to be nearly equal to the value at the upwind boundary which is the assumption made by the upwind scheme
- The dependent variable gradient at high absolute values of P is nearly zero at the interface (i.e. the line is horizontal)
- The upwind scheme always calculates diffusion assuming a linear relationship between the dependent variable and distance and therefore overestimates diffusion at large absolute values of P

How does CFD work?

Discretisation scheme – Hybrid scheme

- The hybrid scheme attempts to remedy this over-estimation of diffusion by representing the combined convection-diffusion coefficients with three straight line relationships for different ranges of Peclet number



For Pe < -2,

$$\frac{a_e}{D_e} = -P_e$$

For –2 =< Pe =< 2,

$$\frac{a_e}{D_e} = 1 - \frac{P_e}{2}$$

For Pe > 2

$$\frac{a_e}{D_e} = 0$$

Where

$$D = \frac{\Gamma_e}{\delta x}$$

How does CFD work?

Discretisation scheme – Hybrid scheme (cont'd)

- The simple average convection coefficient formulation can then be replaced with a formula combining the three straight lines:

$$a_E = \frac{\Gamma_e}{\delta x} - \frac{\rho u_e}{2}$$

$$a_E = \max\left(-\rho u_e\,,\ \frac{\Gamma_e}{\delta x} - \frac{\rho u_e}{2},\ 0\right)$$

How does CFD work?

Discretisation scheme – power-law scheme

- The departure of the hybrid scheme from the exact solution is quite marked when the absolute value of the Peclet number is equal to 2
- A better approximation to the exact curve is provided by the power-law scheme

For Pe < -10,

$$\frac{a_e}{D_e} = -P_e$$

For –10 =< Pe =< 0,

$$\frac{a_e}{D_e} = (1 + 0.1P_e)^5 - P_e$$

For 0 =< Pe =< 10,

$$\frac{a_e}{D_e} = (1 +- 0.1P_e)^5$$

For Pe > 10

$$\frac{a_e}{D_e} = 0$$

How does CFD work?

Discretisation scheme – power-law scheme

- The simple average convection coefficient formulation can then be replaced with a formula incorporating the power-law relationship:

$$a_E = \frac{\Gamma_e}{\delta x} - \frac{\rho u_e}{2}$$

$$a_E = D_e \max\left(0, \left(1 - \frac{0.1\,|F_e|}{D_e}\right)^5\right) + \max(0, -F_e)$$

$$\text{where,} \quad F = \frac{\rho u_e}{2} \quad D = \frac{\Gamma_e}{\delta x}$$

Geometric Considerations

Finite Volume Grid

- The space across which the calculations are to be conducted is first divided into a number of non-overlapping adjoining cells which are collectively known as the finite volume grid.
- The grid is automatically generated from key coordinates obtained from the model geometry along each major grid axes throughout the calculation domain.
- These key coordinates, extended from the X, Y and Z-axes across the width, depth and height of the domain respectively are called 'grid lines'.
- The distances between grid lines along each axis are called 'regions' and these regions are initially spaced using a supplied default grid spacing.

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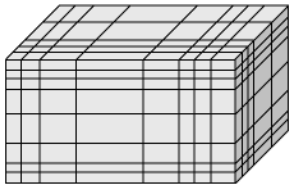
Geometric Considerations

Finite Volume Grid

- The grid used by DesignBuilder CFD is a non-uniform rectilinear Cartesian grid, which means that the grid lines are parallel with the major axes and the spacing between the grid lines enables non-uniformity.



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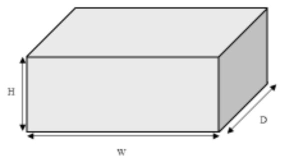
Geometric Considerations

Cell Aspect Ratio

- The cell aspect ratio is the ratio of the maximum cell dimension to the minimum cell dimension



$$\text{cell aspect ratio} = \frac{\max(H,W,D)}{\min(H,W,D)}$$

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Geometric Considerations

Cell Aspect Ratio (cont'd)

- If the cell aspect ratio is high, the equation coefficients can become widely different in magnitude which will result in large changes occurring in some variables but not in others which in turn can lead to an oscillating unstable solution

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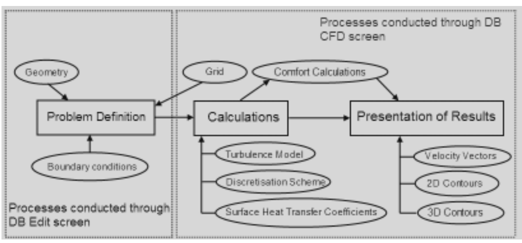
CFD Workflow



<u>Problem Definition</u>

- Define geometry using DesignBuilder geometric modeller

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CFD Workflow

<u>Problem Definition (cont'd)</u>

- Select required domain (building, building block or zone)
- Set default surface and window temperature boundary conditions (not required for external flows)
- Add surface boundary conditions including temperature patches, HVAC supplies, extracts, etc. (not required for external flows)
- Add CFD component blocks and/or assemblies representing occupants, radiators, fan-coil units, etc. (not required for external flows)
- Finite volume (FV) grid automatically generated from geometry during CFD project creation
- Edit FV grid as required

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CFD Workflow

Calculations

- Turbulence model:
  - Constant effective viscosity
  - k-ε
- Discretisation scheme:
  - Upwind
  - Hybrid
  - Power-law
- Outer iterations
- Isothermal

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CFD Workflow

Calculations (cont'd)

- Specification of surface heat transfer coefficients:
  - Calculated (wall functions)
  - User supplied
- Initial conditions
  - X-axis velocity component
  - Y-axis velocity component
  - Z-axis velocity component
  - Temperature
- Cell monitor
  - Cell location
  - Monitored variable

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CFD Workflow

Calculations (cont'd)

- Residual display
- Dependent variable control settings
  - Inner iterations
  - False time step
  - Relaxation factor
  - Termination residual

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CFD Workflow

Presentation of Results

- Velocity vectors
  - Scale factor
  - Maximum vector length
- Contours
  - Velocity
  - Pressure
  - Temperature
  - PMV
  - PPD

DesignBuilder Software

CFD Workflow

Presentation of Results (cont'd)

- Filled Contours
  - Velocity
  - Pressure
  - Temperature
  - PMV
  - PPD
- 3-D Contours
  - Velocity
  - Pressure
  - Temperature
  - PMV
  - PPD

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