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Simulation of Buildings in the Environment

Some Particular Topics

David Glynn, CHAM

Topics

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- Wind (overview)
- Pedestrian Wind Comfort
  - Wind averaging
  - Lawson criteria
- Rain
- Greenery – Evapotranspirative Cooling
- *These features are available in FLAIR*

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Wind Overview

Wind modelling

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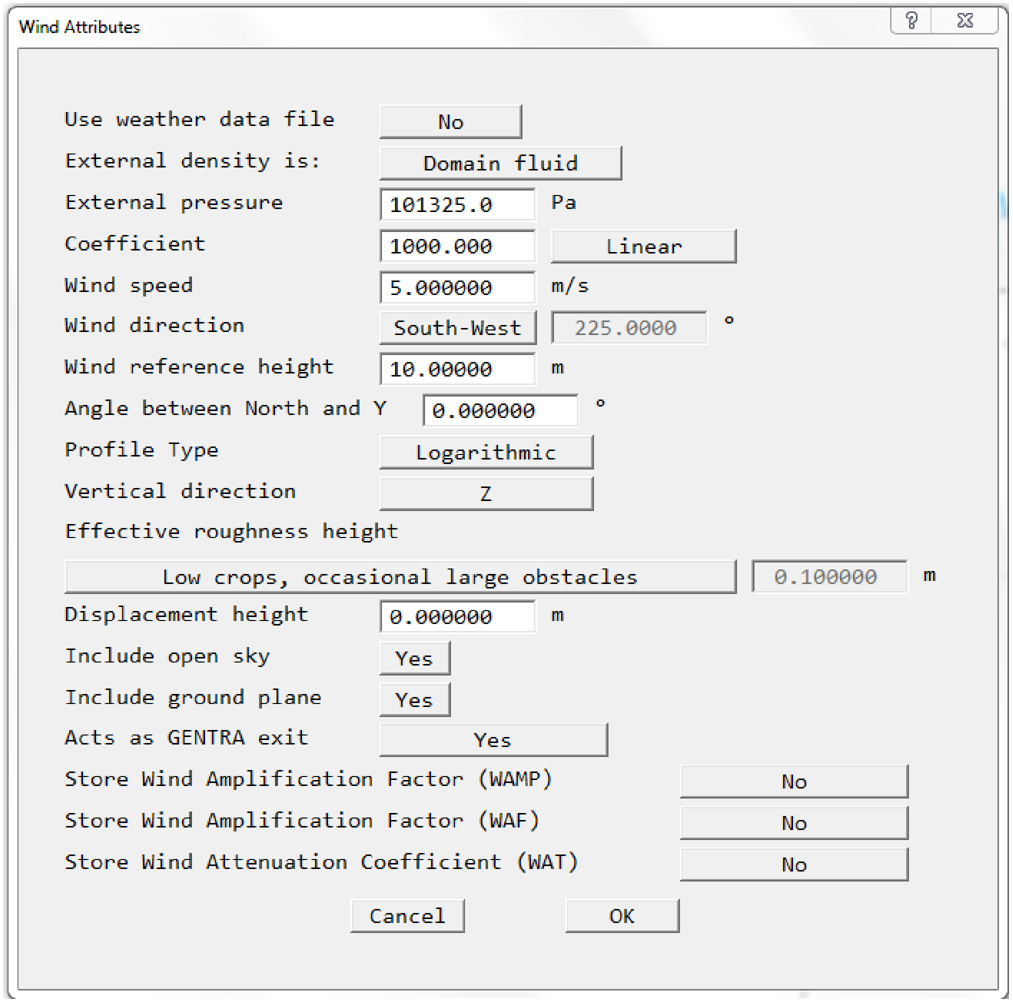
- Wind object sets up simulation for given set of wind conditions



Typical wind case

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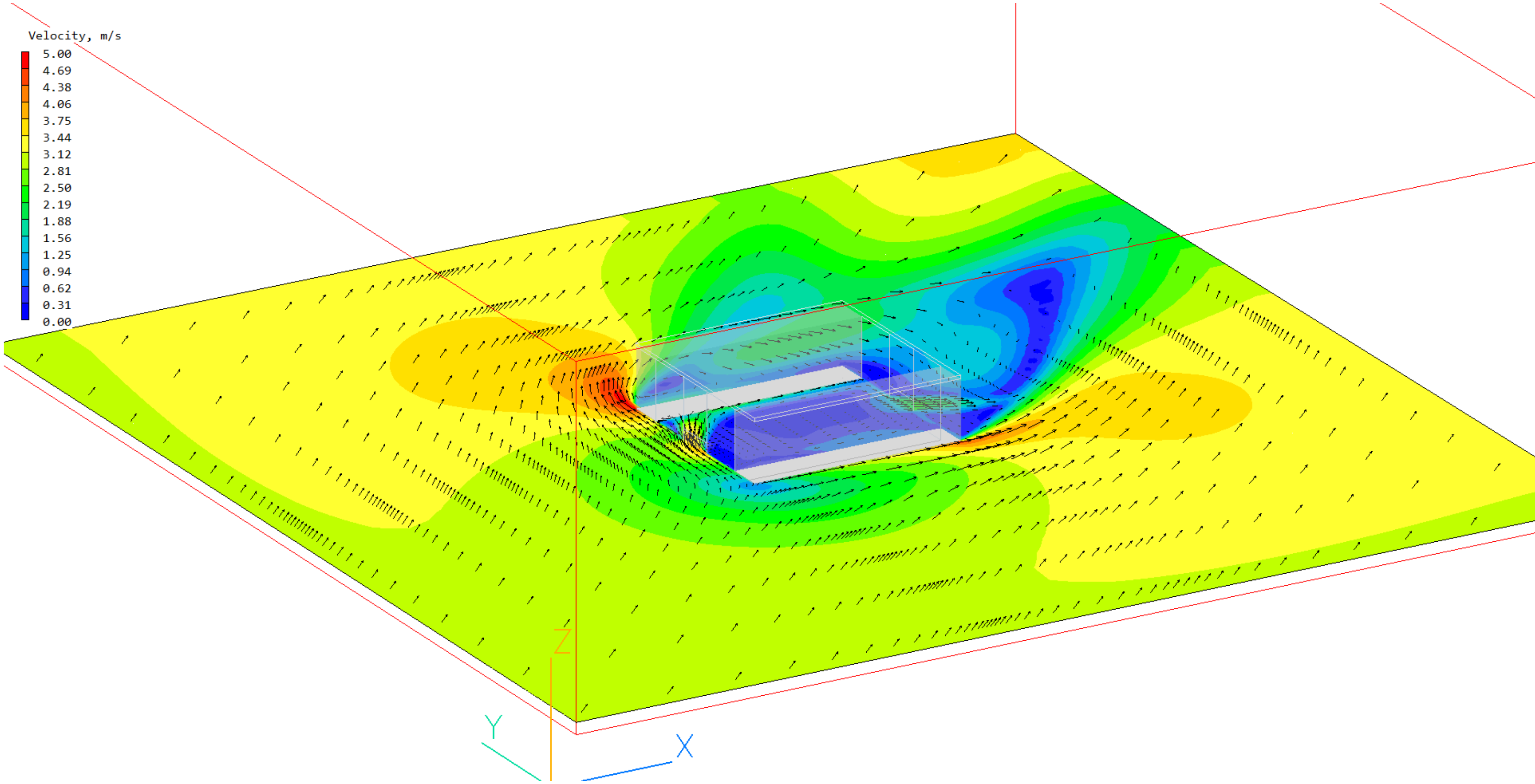

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Pedestrian Wind Comfort

Wind comfort - introduction

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- Suppose we ask questions like:
  - In my new office development, are the pedestrian walkways going to be excessively windy?
  - Where should I site my new outdoor café so that it will be most sheltered?
- Questions like this require information on wind conditions throughout the year
- CFD runs will be required for many wind directions
- Statistical averaging is required

Wind comfort - introduction

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- How to handle the statistical averaging in PHOENICS?
- This is the purpose of the new “wind comfort” facility
- In “Models”/”Comfort Indices” we find

“Show pedestrian wind comfort”

Show pedestrian wind comfort	ON	
Wind data format	PROBABILITY	
Wind data file	NOTSET	
Comfort index type	PROBABILITY	
Threshold velocity	6.000000	m/s
Store average velocity over all sectors	OFF	

Comfort index type:

- Probability of exceeding
- Dutch NEN8100
- Lawson Criteria

Wind statistical data

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- The wind statistical data is provided in a file of this form
- Rows are wind speeds, columns are wind directions
- One run for each direction – wind speed derived from this data

SiteName 01.01.02 - 31.12.02

65.1 59.9 50.0

12 1.00 0.00

	3.55	4.97	3.74	4.04	6.70	14.74	17.77	12.67	9.32	9.31	7.38	5.81
1.00	31.99	22.01	32.63	15.43	16.80	5.38	7.11	7.28	11.49	9.68	18.86	21.01
2.00	101.37	67.74	56.22	51.83	27.75	19.99	24.21	26.89	40.43	33.86	59.75	76.07
3.00	180.79	109.88	81.04	66.11	37.48	42.89	41.40	49.91	59.91	43.84	91.14	140.56
4.00	180.49	134.40	99.31	76.69	41.31	57.08	52.69	59.60	58.07	78.50	94.18	140.38
5.00	142.89	121.50	106.15	94.15	40.51	62.52	58.46	73.26	69.99	65.30	102.57	121.82
6.00	113.11	85.80	130.41	105.25	43.86	65.20	67.17	72.58	70.67	81.03	129.91	99.96
7.00	64.67	94.62	117.28	88.59	57.73	59.62	79.85	81.60	86.37	92.73	104.88	78.46
8.00	57.76	85.80	92.17	90.18	63.31	73.82	91.32	87.67	85.68	95.94	79.86	54.02
9.00	27.67	79.13	82.75	77.49	64.43	69.47	88.80	95.68	96.33	96.75	77.11	40.61
10.00	20.46	72.25	63.92	69.55	69.69	80.05	90.00	84.89	84.07	83.21	67.13	35.10
11.00	6.02	54.83	44.23	61.62	77.83	86.57	87.90	71.49	72.51	51.87	43.40	43.00
12.00	12.63	32.47	25.40	51.30	77.51	82.15	72.04	59.18	59.91	49.92	39.93	31.97
13.00	14.14	26.02	23.40	45.49	73.20	73.17	61.22	57.24	49.25	40.40	23.73	31.24
14.00	16.54	10.54	18.26	54.21	80.54	56.79	46.38	50.50	51.77	37.30	19.10	22.97
15.00	9.02	0.86	5.71	23.01	73.52	42.74	38.21	35.41	35.62	33.51	17.36	23.34
16.00	4.21	0.86	5.71	15.07	53.75	38.03	26.68	28.41	25.66	32.02	12.15	14.33
17.00	11.43	0.86	5.71	11.11	44.18	23.18	18.93	21.67	17.64	21.58	12.59	10.84
18.00	3.61	0.43	6.28	1.59	27.43	19.70	17.30	14.67	13.40	19.74	4.63	8.82
19.00	1.20	0.00	0.57	0.79	16.75	13.76	11.42	8.09	5.96	12.39	1.74	4.04
20.00	0.00	0.00	2.28	0.53	5.42	9.42	6.25	4.55	2.52	8.26	0.00	1.10
21.00	0.00	0.00	0.57	0.00	3.83	8.77	4.03	4.05	1.60	5.28	0.00	0.37
22.00	0.00	0.00	0.00	0.00	1.91	4.20	1.44	2.53	1.15	3.79	0.00	0.00
23.00	0.00	0.00	0.00	0.00	0.64	3.11	2.28	0.84	0.00	2.18	0.00	0.00
24.00	0.00	0.00	0.00	0.00	0.32	1.96	1.80	0.67	0.00	0.69	0.00	0.00
25.00	0.00	0.00	0.00	0.00	0.00	0.29	1.86	0.51	0.00	0.00	0.00	0.00
26.00	0.00	0.00	0.00	0.00	0.32	0.14	0.90	0.51	0.00	0.23	0.00	0.00
27.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.34	0.00	0.00	0.00	0.00
28.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Wind statistical data

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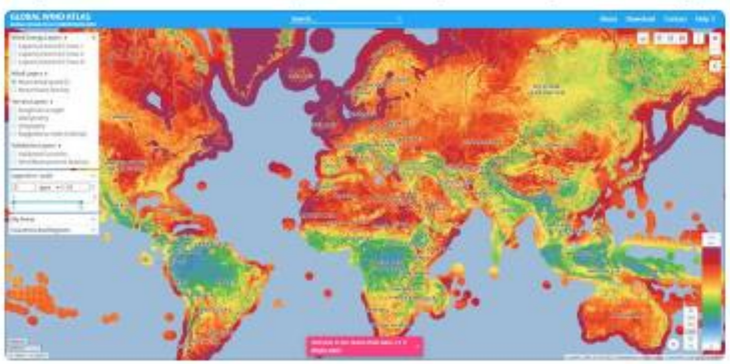
- Wind data can also be input in “Weibull” format.
- A good source of wind data is the “Global Wind Atlas” - https://www.globalwindatlas.info

globalwindatlas.info

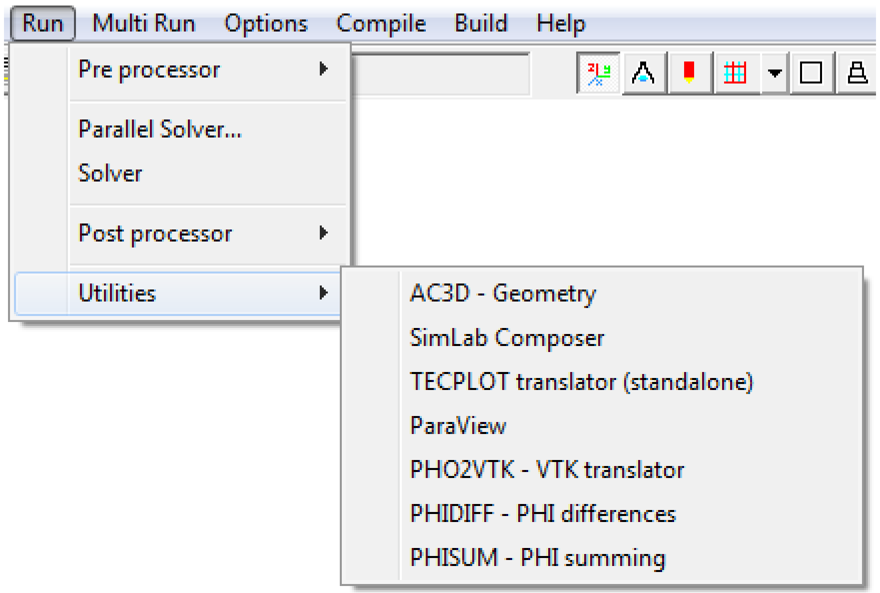
Global Wind Atlas

The Global Wind Atlas is a free, web-based application developed to help policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world, and then perform preliminary calculations. (297 kB)



Wind averaging

- (Absolute Velocity x Probability) for each run is written to phida file in variable VAV
- Utility "PHISUM" adds the VAVs for each run and outputs a new phida containing the average velocities at each cell in variable VAV



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“Probability of exceeding”

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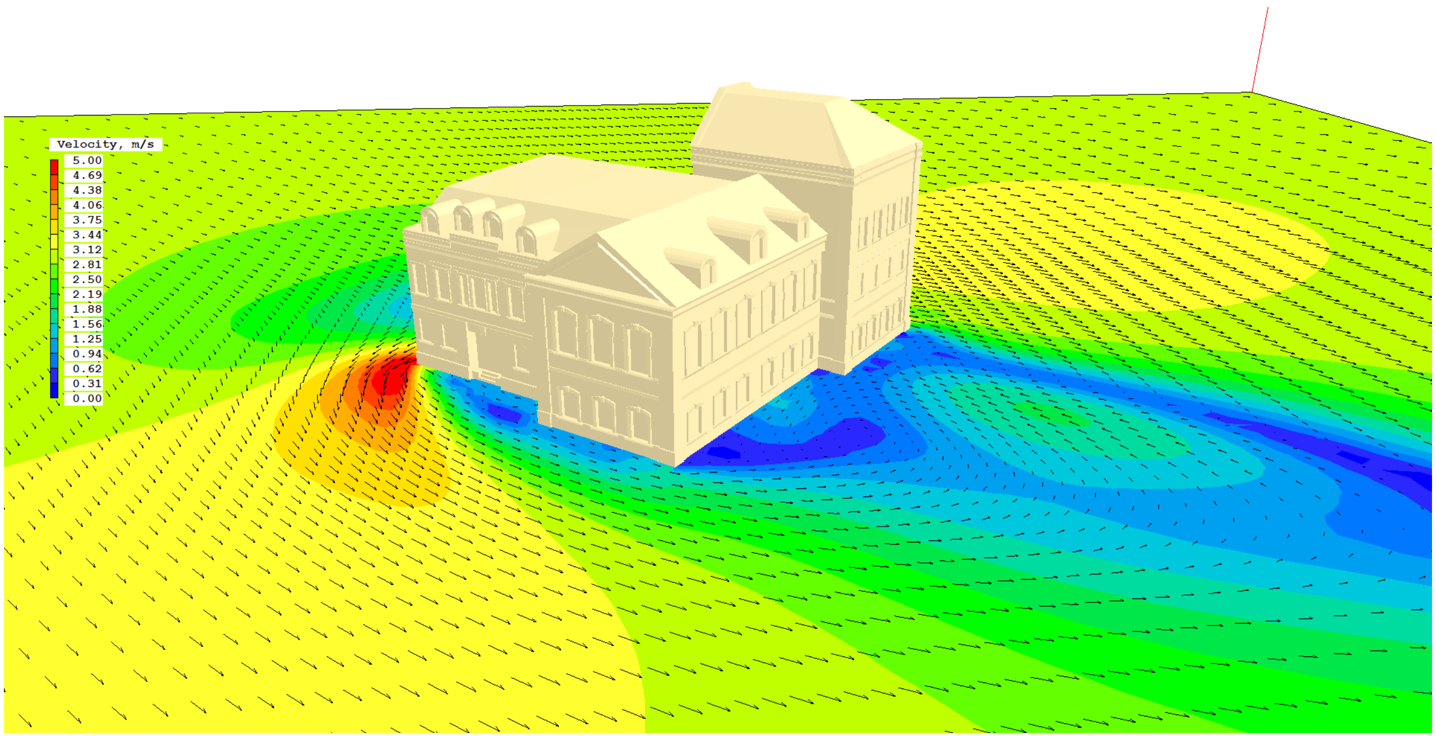
- The probability PRO of the wind velocity exceeding a given threshold can be plotted.
- Example – wind around a mansion – this is a typical velocity plot for a given wind direction



“Probability of exceeding”

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- We do such runs for <u>all</u> directions (usually 8 or 16)
- Then use PHISUM to sum velocity x probability
- Use this to determine the probability of the average velocity exceeding a given threshold

“Probability of exceeding”

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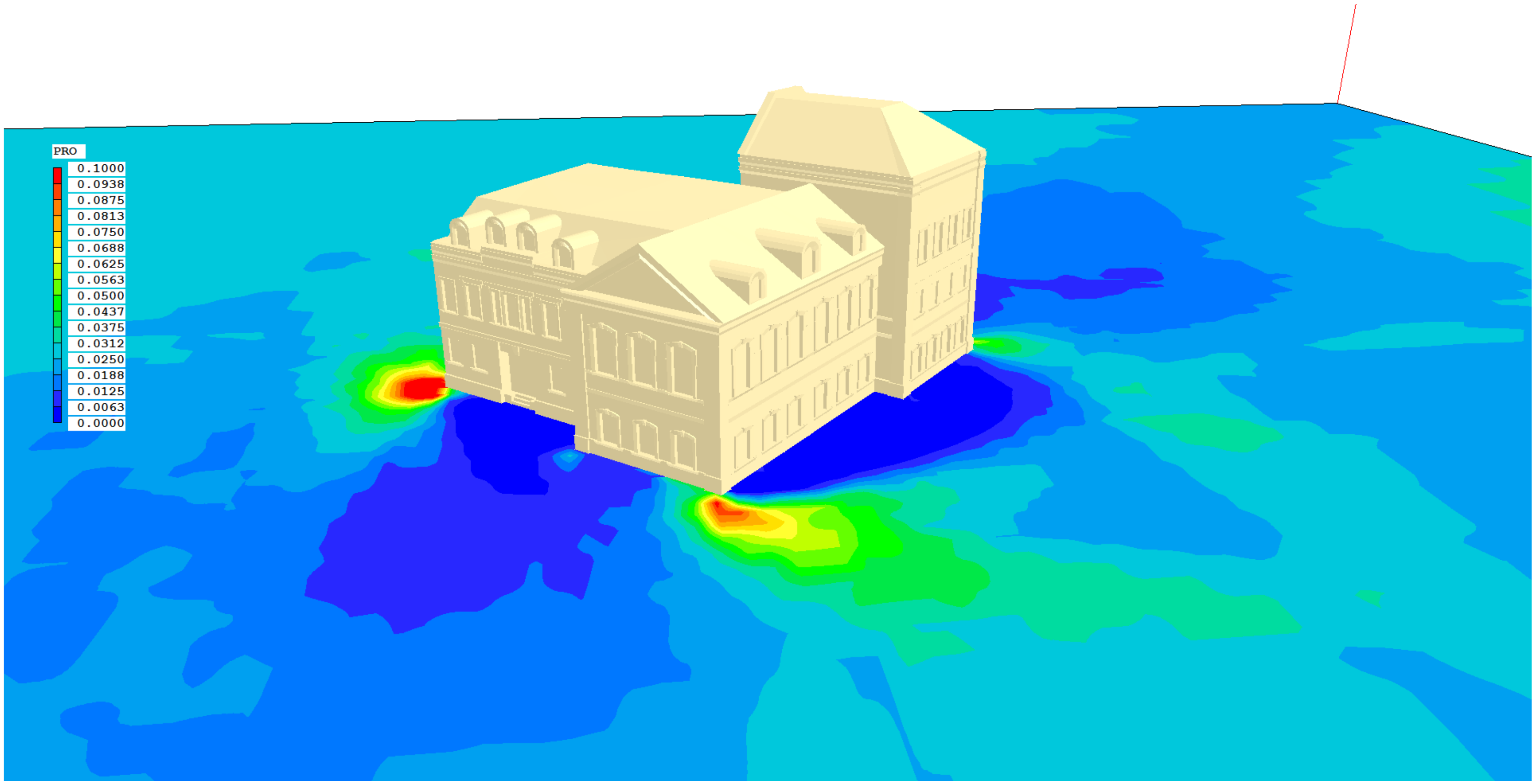
- Here is the probability of exceeding the threshold
- You would not site an outdoor cafe at the corners



Lawson Criteria

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- The Lawson Comfort Criteria specify a range of pedestrian activities - for each activity a wind speed and maximum frequency of exceedance is defined
- If the wind speed exceeds the threshold for the activity, the conditions are deemed unacceptable
- The default criteria are:

Activity	Band	Probability	Threshold Wind Speed
Roads and Car Parks	A -> 1	6%	10.95 m/s
Business walking	B ->2	2%	10.95 m/s
Pedestrian walk-through	C -> 3	4%	8.25 m/s
Pedestrian standing	D -> 4	6%	5.6 m/s
Sitting	E -> 5	1%	5.6 m/s

- Again Lawson requires runs for all (usually 8 or 16) wind directions

Lawson Criteria

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- The criteria can be modified by the user
- For example, for City of London guidelines:

Comfort Category	Threshold *	Description
Sitting	0-4 m/s	Light breezes desired for outdoor restaurants and seating areas where one can read a paper or sit for long periods.
Standing	4-6 m/s	Gentle breezes acceptable for main building entrances, pick-up/drop-off points and bus stops.
Strolling	6-8 m/s	Breezes that would be appropriate for window shopping and strolling along a city/town centre street, plaza or park.
Business Walking	8-10 m/s	High speeds that can be tolerated if one's only objective is to walk, run or cycle without lingering.
Uncomfortable	>10 m/s	Winds of this magnitude are considered a nuisance for most activities, and wind mitigation is required.

Safety Category	Threshold **	Description
Unsafe	>15 m/s	Winds above this threshold will pose safety risks, particularly for more vulnerable pedestrians (elderly, cyclists, etc.).

(*) Comfort threshold is set for the wind speed that is exceeded 5% of the time from all wind directions.

(**) Safety threshold is set for the wind speed exceeded once a year (0.022% of the time) from any wind direction.

Lawson Criteria

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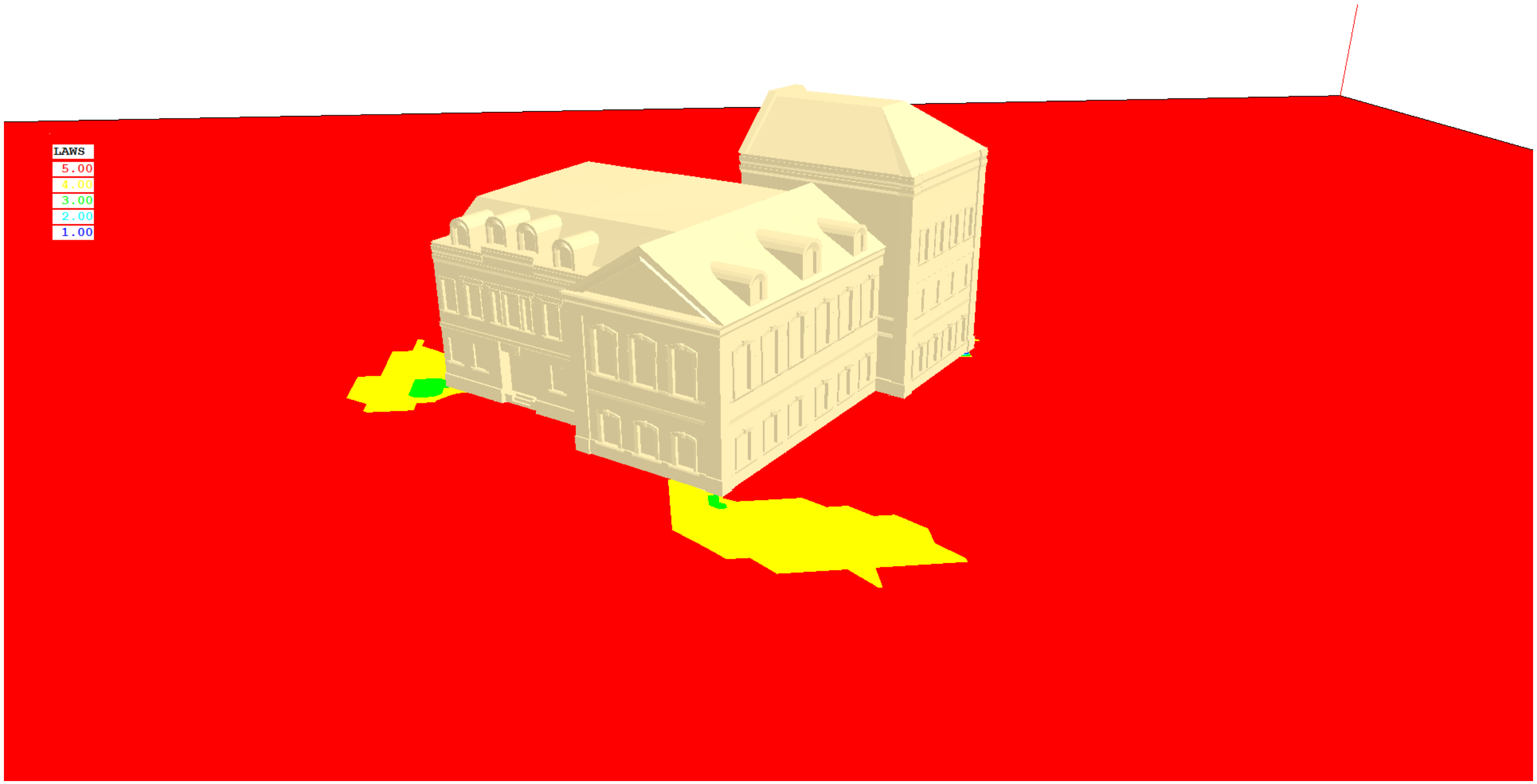
- Plot of Lawson regions for mansion case
- “Sitting” would not be comfortable at the corners!
- Note – plots benefit from a restricted colour palette



Rain Modelling

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Why Model Rain?

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- Why the interest in rain modelling?
- The Building and Construction Authority in Singapore issue a “Green Mark” code for non-residential buildings
- They encourage “Wind Driven Rain” simulation “to identify and reduce the severity of rain penetration into functional spaces of the development”

RAIN feature of FLAIR

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- The RAIN feature of FLAIR uses GENTRA, the Lagrangian particle-tracking module of PHOENICS, to track the paths of individual raindrops
- Helpful to think of rain tracks – each track carries a mass flux of water (kg/s)
- The “Rain” object starts the tracks on a rectangular array of points on a horizontal plane
- The total rain flow rate through the Rain object (mm/hr) is divided among the tracks
- The “RainGauge” object identifies which rain tracks impinge on the object, and notes the mass flux which these carry
- The rain drops do NOT affect the wind flow

RAIN feature of FLAIR

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- From each start location, tracks for up to 5 droplet diameters can be handled
- The drag coefficient Cd for the drops is a specified function of the Reynolds number
- At the start point of each track, the vertical drop velocity is set to the terminal velocity for drops of the relevant size
- Recommended to first run with wind case parallel <u>without rain</u>
- Then restart serial with rain, with relaxation 1.e-10 to “freeze” velocities

Important Considerations (1)

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- It is very important to give serious thought to the placement and size of the Rain object(s)
- Too near – the tracks need some distance to minimise the effect of uncertainty re the initial horizontal velocity
- Too far away – the tracks may miss the target!
- Too big – you may be wasting tracks, leading to excessive computation time
- You will not be able to afford to have tracks starting from the whole sky!

Important Considerations (2)

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- The precision with which you want to predict the extent of rain penetration will govern the spacing of the ports on the Rain object(s)
- Example – from the Singapore BCA Guidelines

	Industrial Building	Others	WDR Points
1. Very good (no noticeable penetration of WDR)	Depth of rain penetration ≤ 0.20 m	Depth of rain penetration ≤ 0.10 m	1.0 pt
2. Good (some but acceptable degree of penetration of WDR)	Depth of rain penetration ≤ 0.40 m	Depth of rain penetration ≤ 0.20 m	0.9 pt
3. Moderate (substantial penetration of WDR, barely acceptable)	Depth of rain penetration ≤ 0.75 m	Depth of rain penetration ≤ 0.30 m	0.8 pt

Rain - Example

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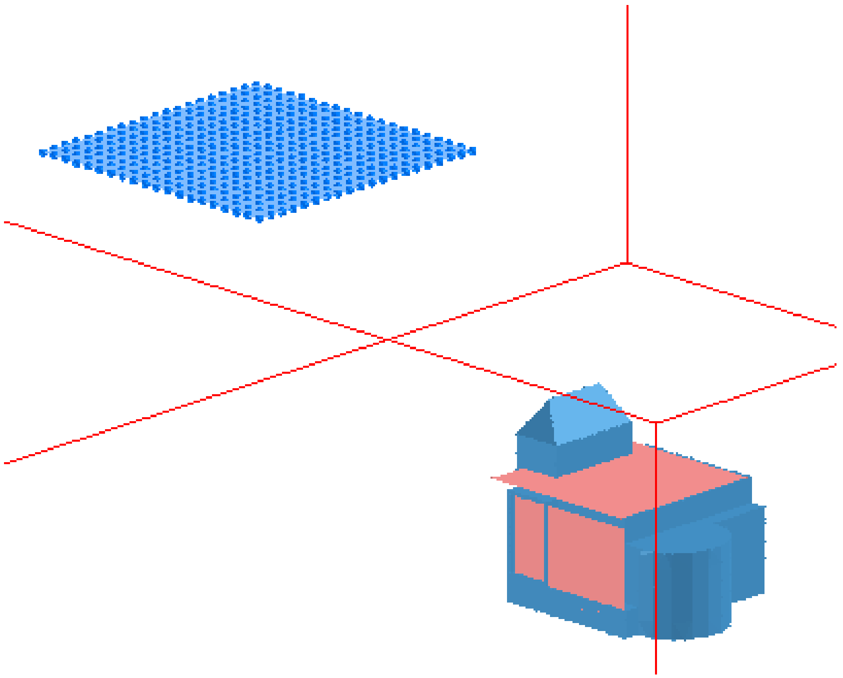
- Example - wind flow around a building
- Rain object with 20x20 ports, placed so that tracks go towards building
- RainGauge objects (pink) on wall and roof of building



Track Display (1)

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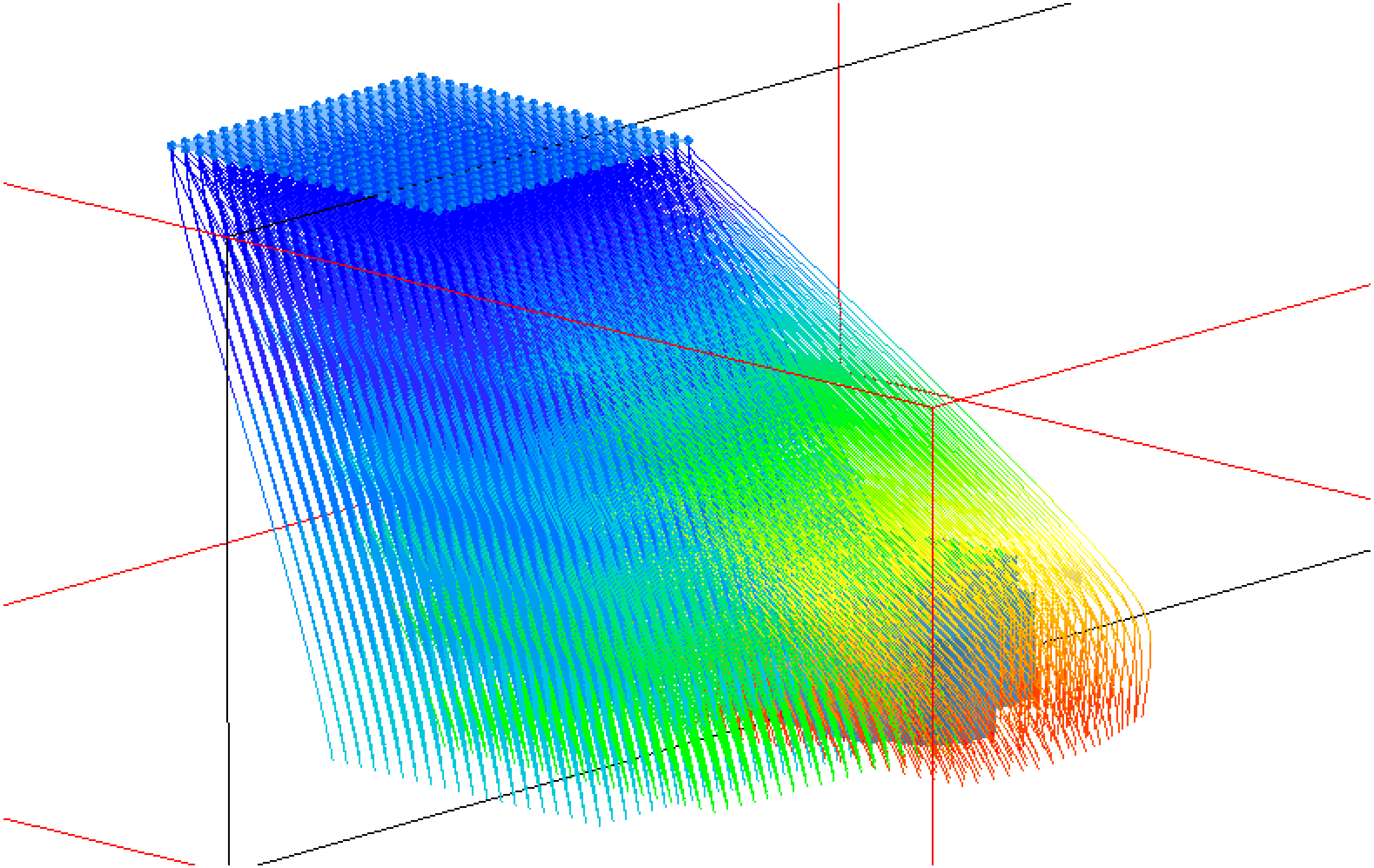
- All the rain tracks from the Rain object



Track Display (2)

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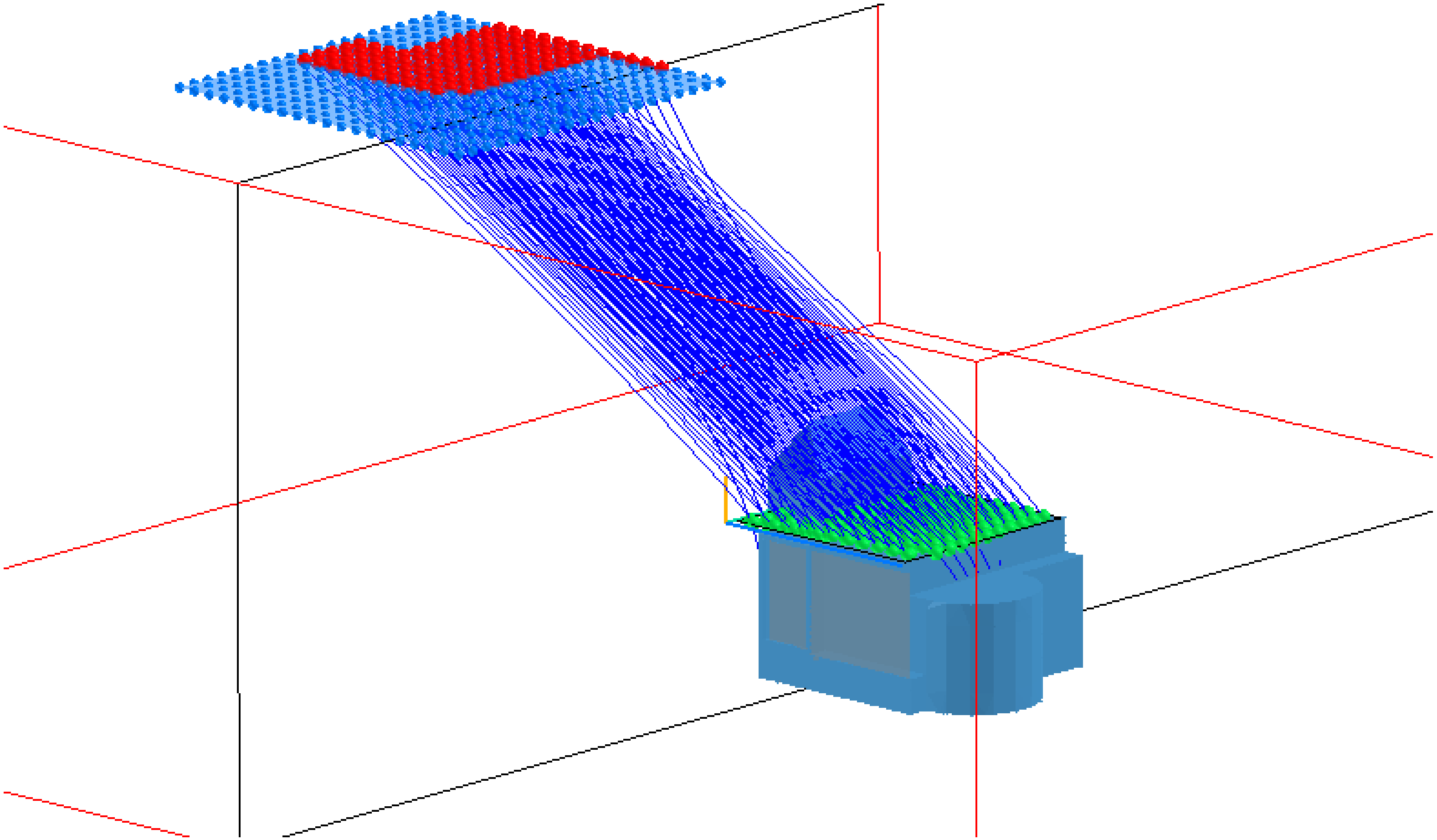
- The rain tracks that impinge on the roof RainGauge
- Green ball at end of each track, red ball at start



Track Display (3)

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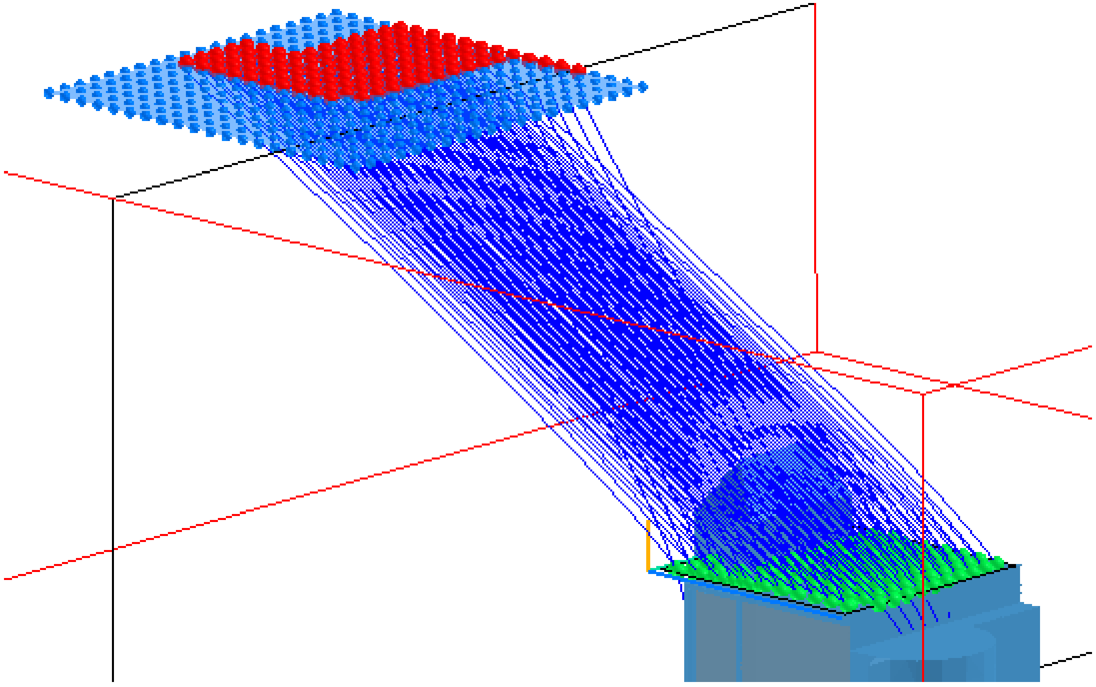
- IMPORTANT NOTE !
- The red and green balls have finite width in the plots, to make them visible. The tracks actually have zero thickness, and start and end at points.



Detailed Track Information

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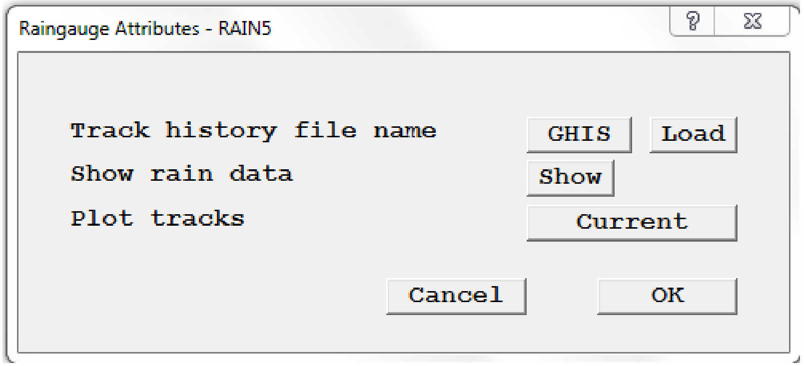
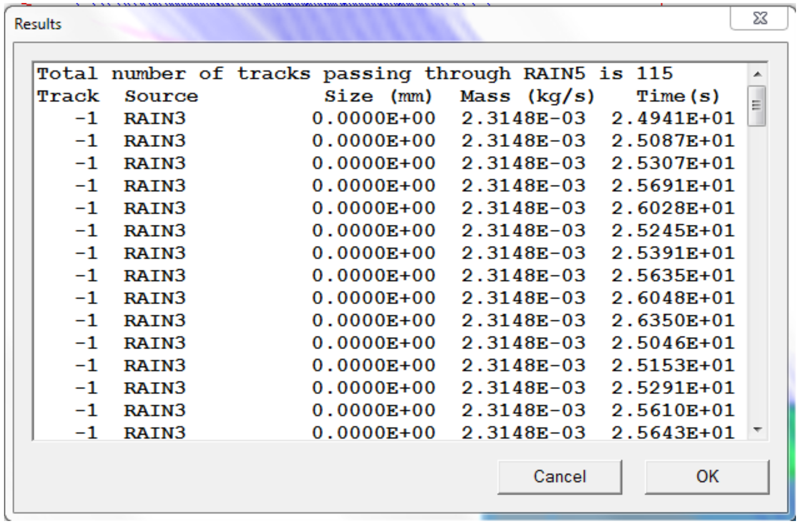
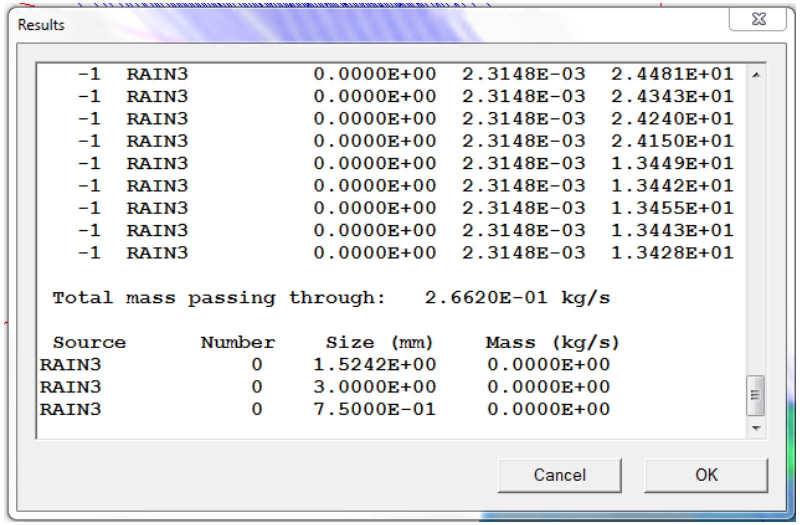
- Click “Show rain data” on RainGauge attributes to show mass flows







Rain – Other Controls

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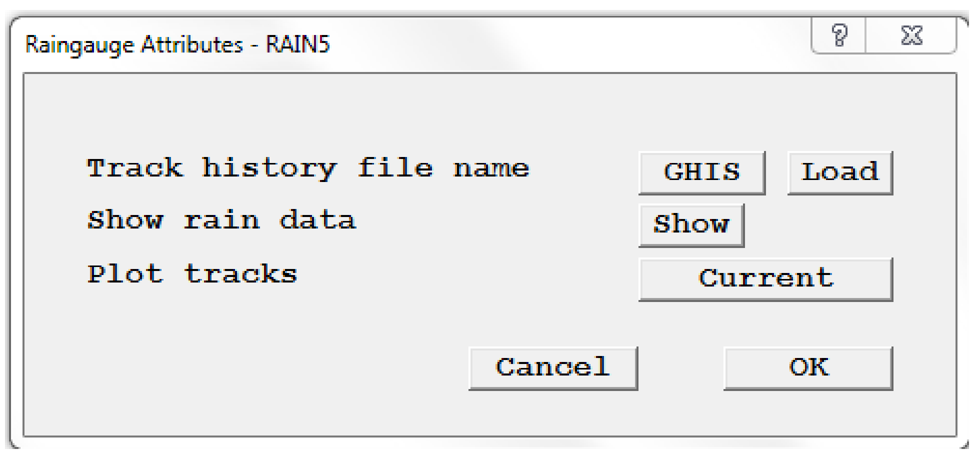
- Other buttons on the RainGauge attributes:
- “Load” – loads the Gentra tracks
- “Plot tracks” – toggles between:
  - “Hide all” - no tracks
  - “Show all” - all tracks visible
  - “Current” - only display the tracks impinging on the RainGauge



Rain Penetration Example

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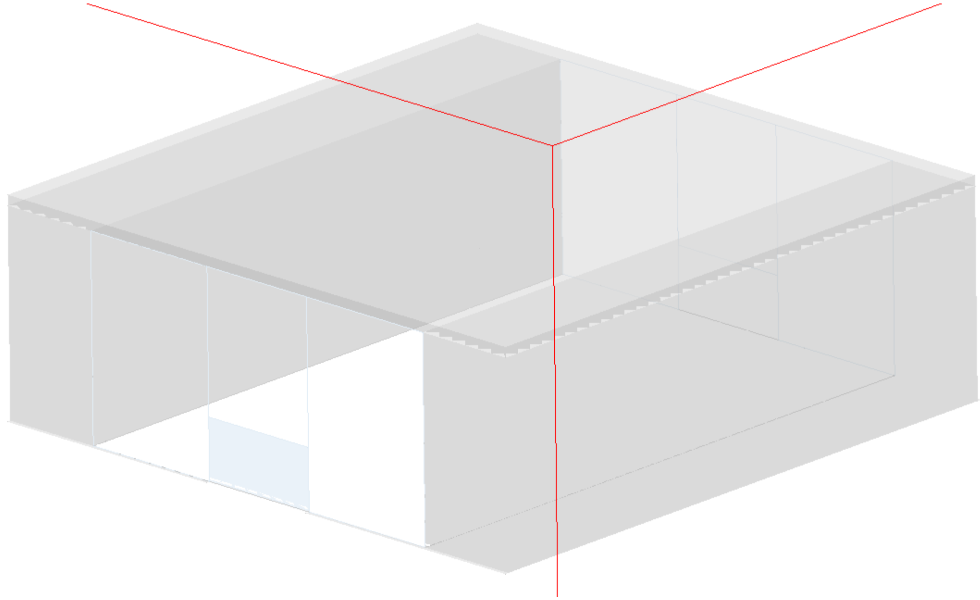
- Example – Rain penetration
- Building 30 x 30 x 10m
- Central full-height atrium with 5m deep offices either side
- Glazed screens with central doorways 6m wide x 3m high at both ends



Rain Penetration Example

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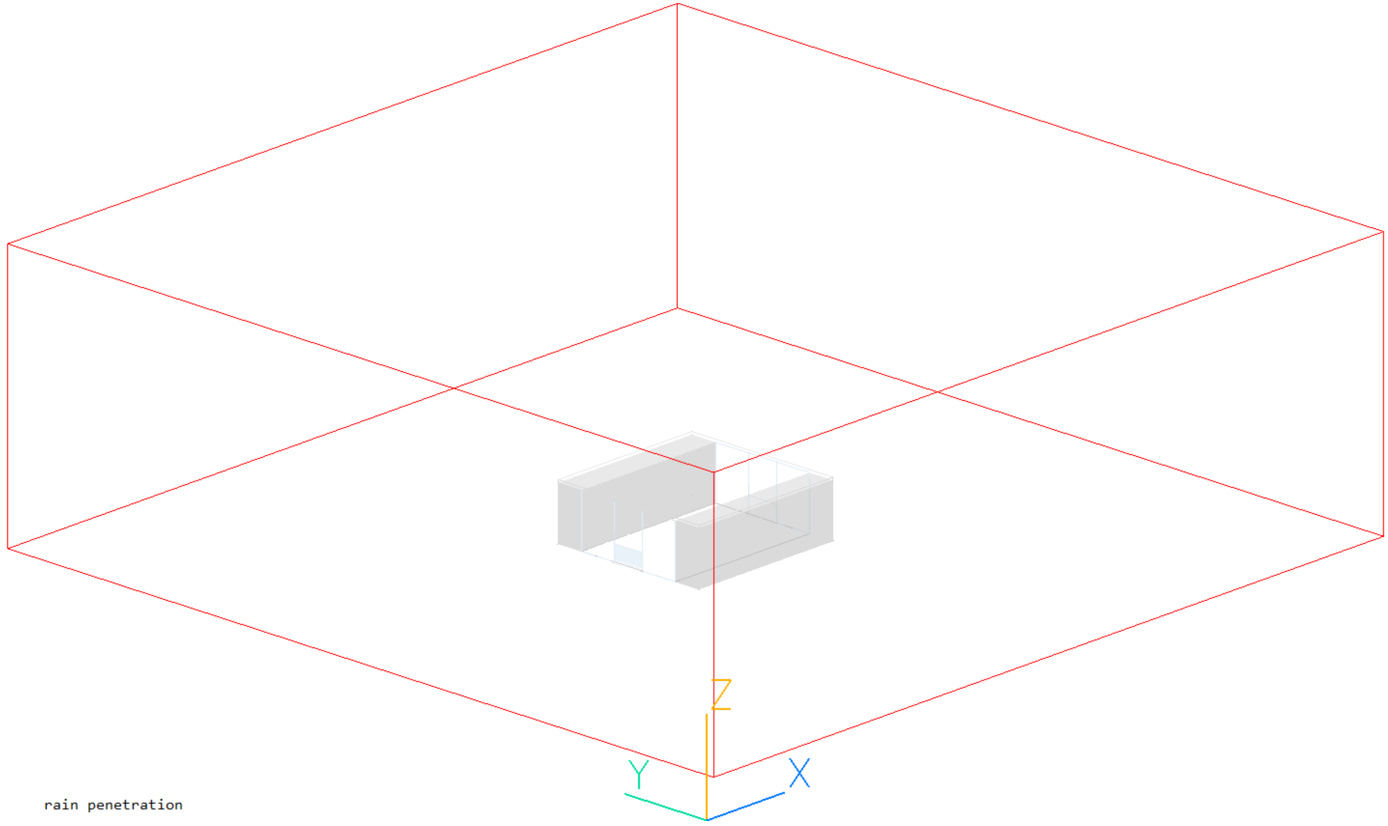
- Building at the centre of domain
- Domain size 150 x 150 x 50 m
- Wind 5 m/s from SW



Wind Solution

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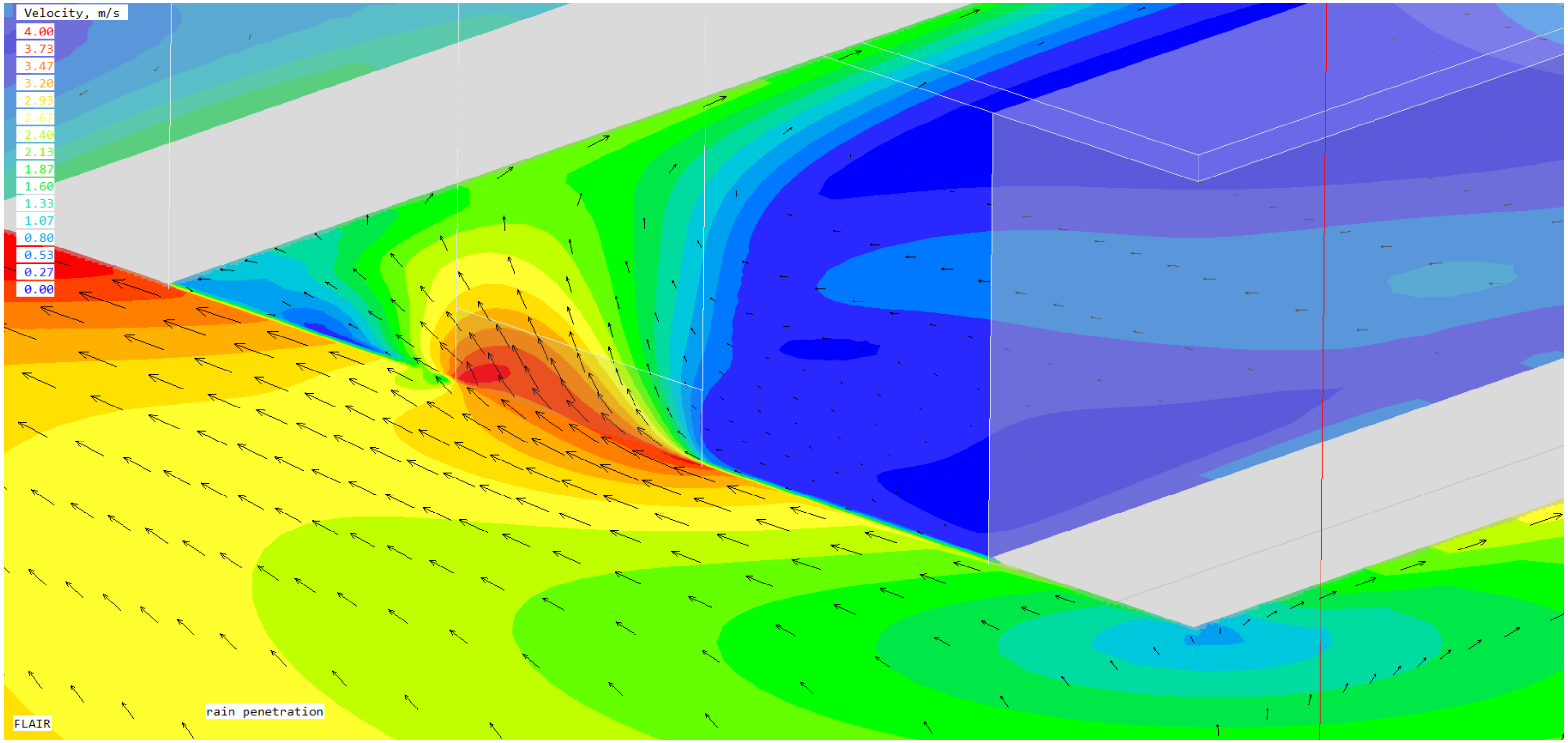
- Contours at door mid-height
- Note wind flows parallel to building side and then angles in through doorway



Wind Streamlines

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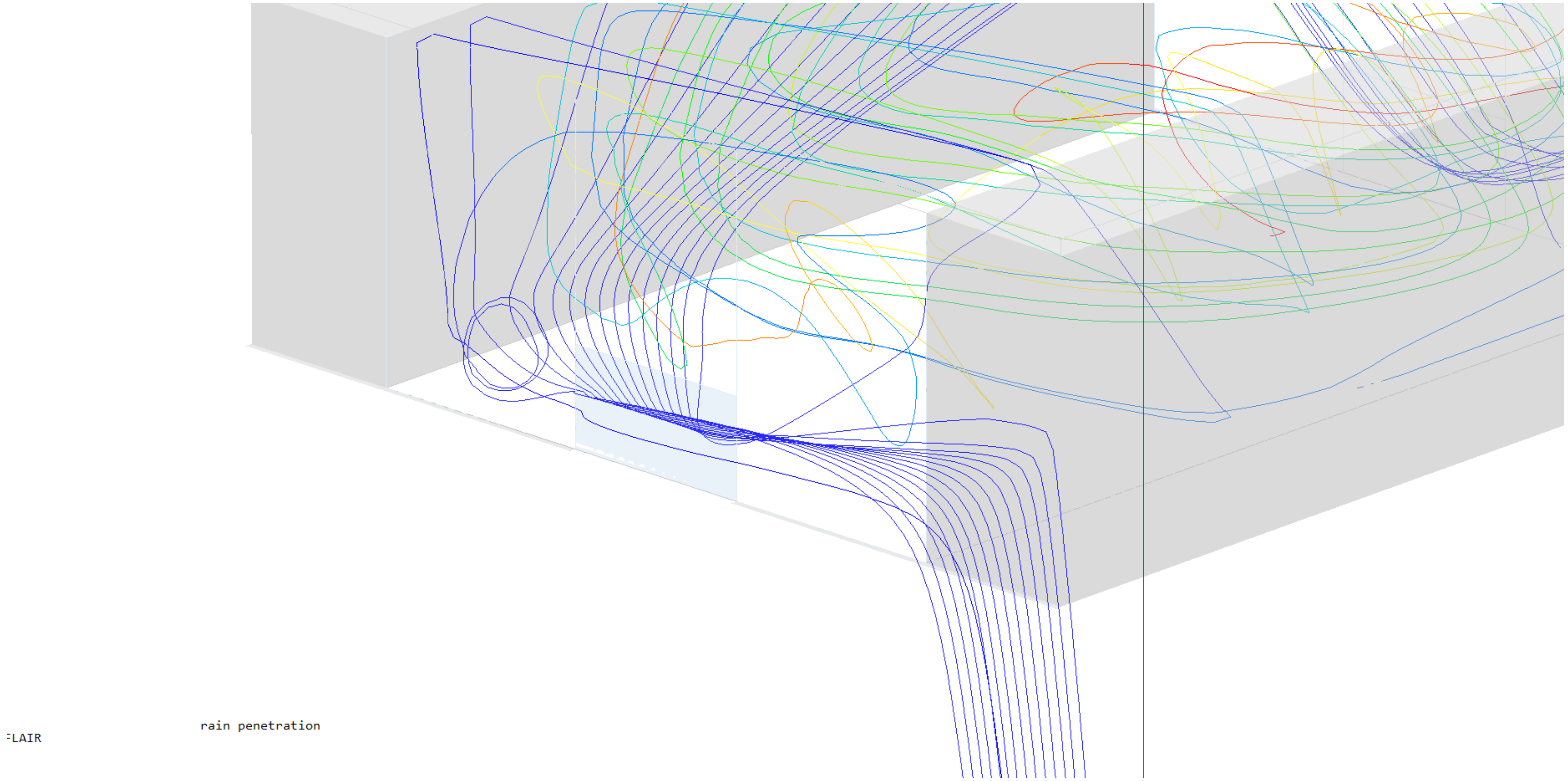
- Streamlines entering doorway at half height
- Note the abrupt turn inwards at the doorway
- And how the streamlines rise inside the building



Placing of Rain Object

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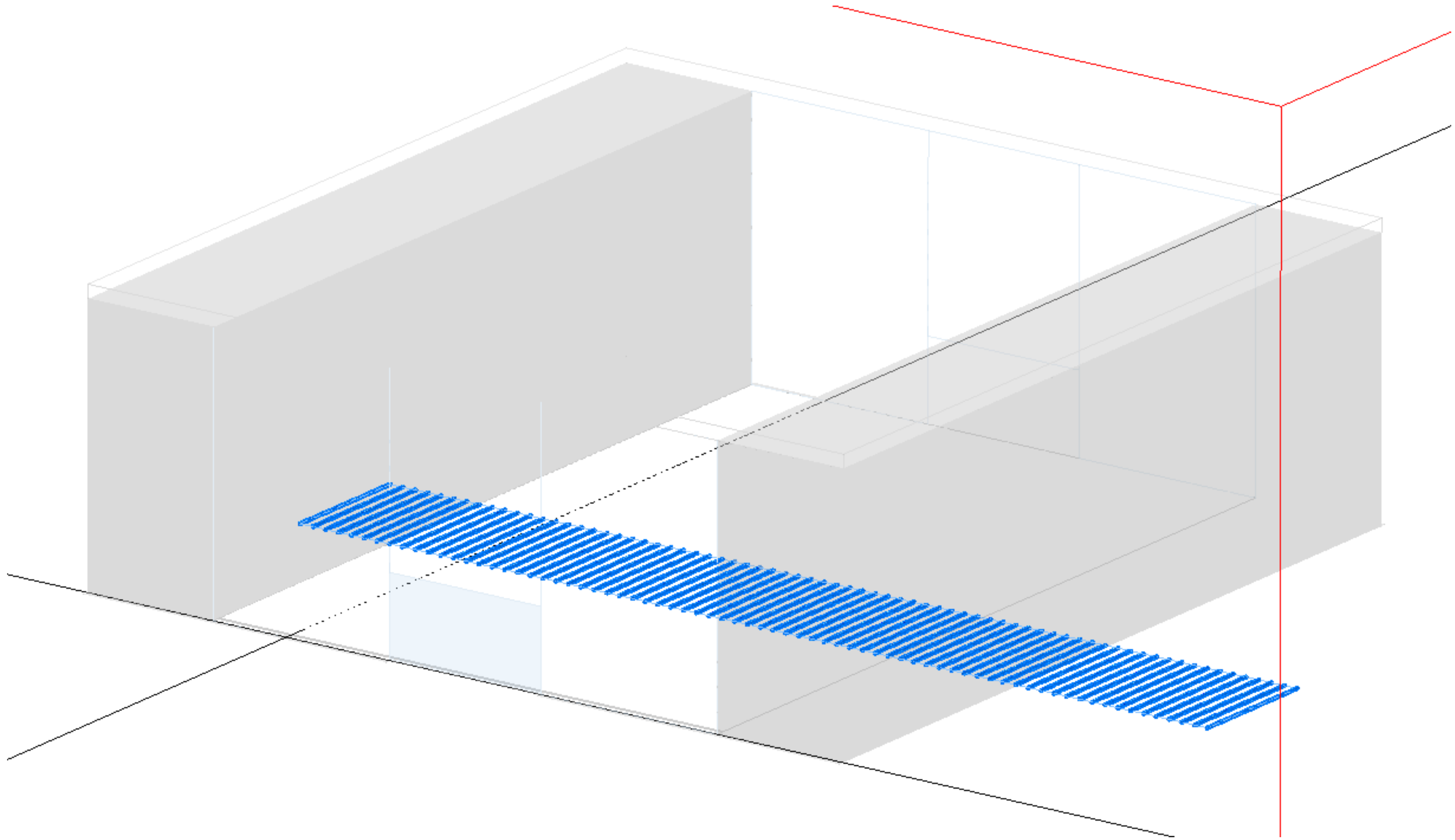
- 5 x 36 m, with 40 x 72 ports, 6m above ground
- Located above and upwind of door, touching glazing



Behaviour of Rain Tracks

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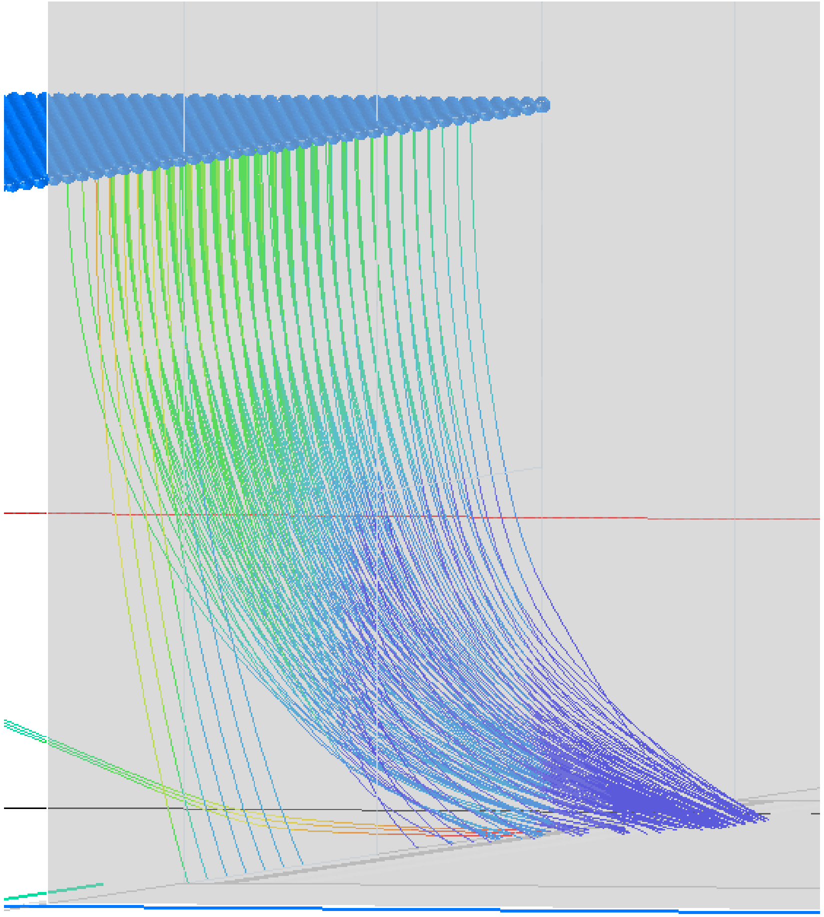
- Here we see how the rain tracks initially fall vertically before being caught by the wind
- This is why the Rain object must be a significant height above the doorway
- The Rain object position and size were arrived at from a process of experimentation



Other Model Features

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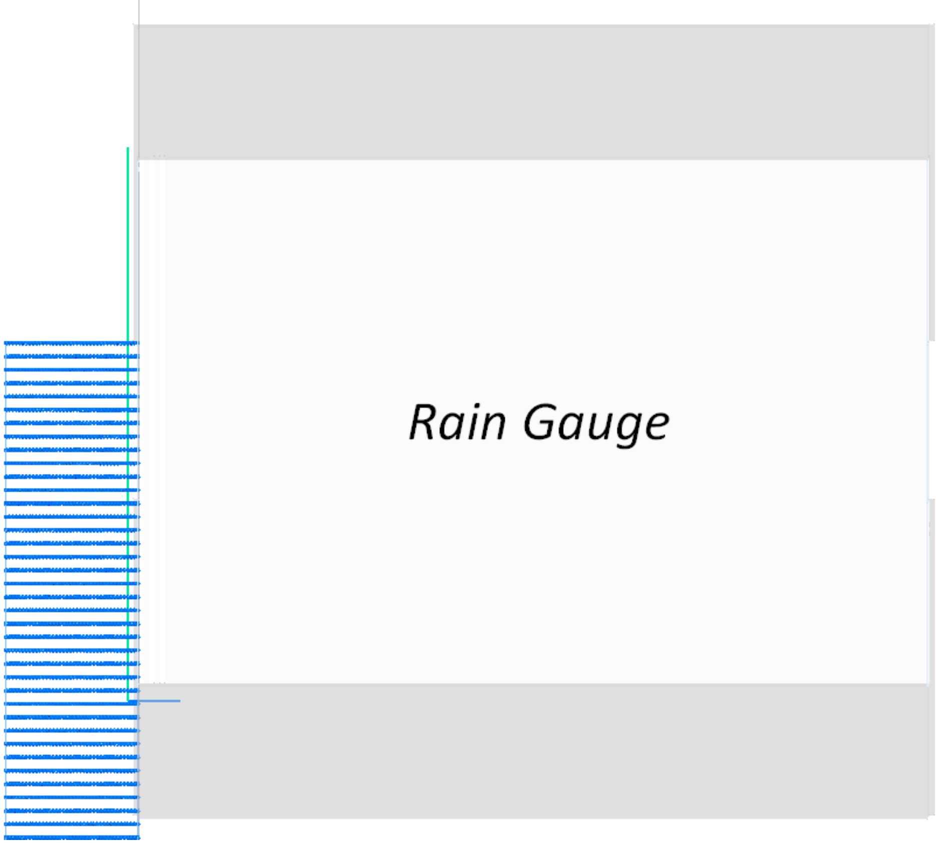
- Rain drop diameter 1.5 mm
- The RainGauge object covers the complete floor area within the building, here seen in plan view



Objective

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- The objective of this study is to determine the degree of rain penetration into the building
- In other words – how much of the floor will get wet?

Rain penetration for 1.5mm drops

- The grey rectangle is the open doorway
- Green balls indicate where rain tracks hit the floor
- Grey “stripes” 20cm wide – so penetration about 1.8m

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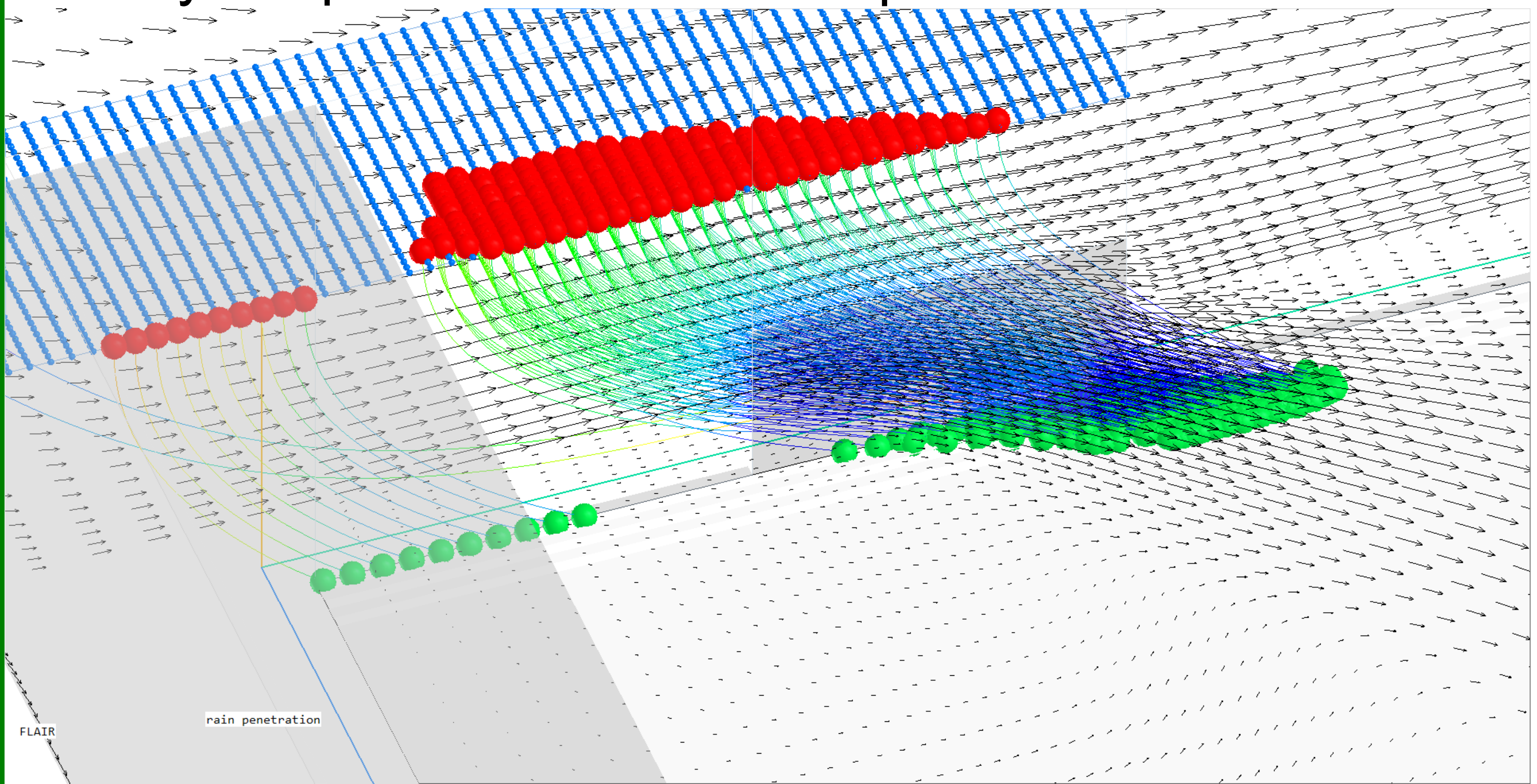
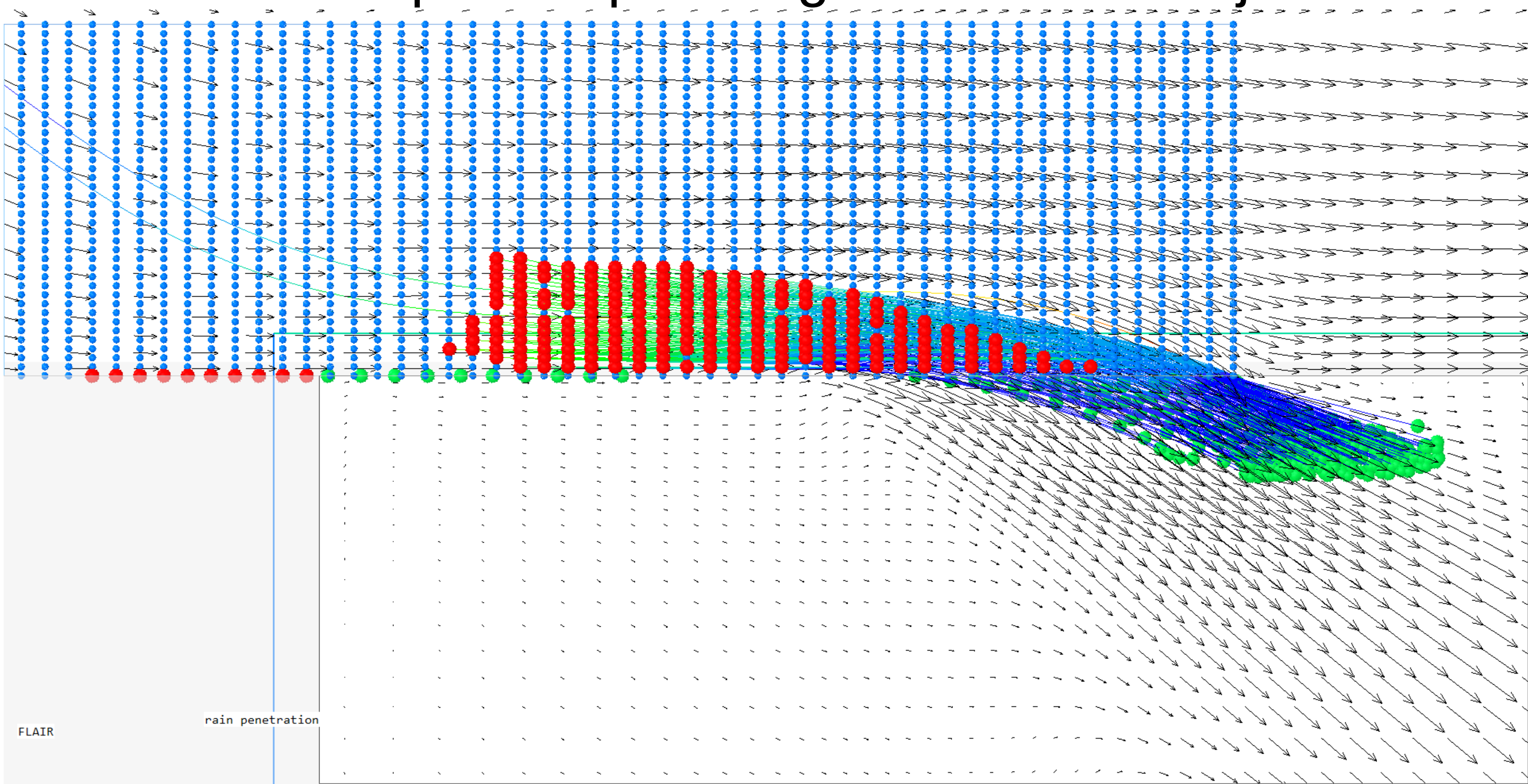


Rain penetration for 1.5mm drops

- The same in plan view
- Red balls show start points of tracks ending in green
- Red balls helpful for planning size of Rain object



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Rain penetration for 1.2mm drops

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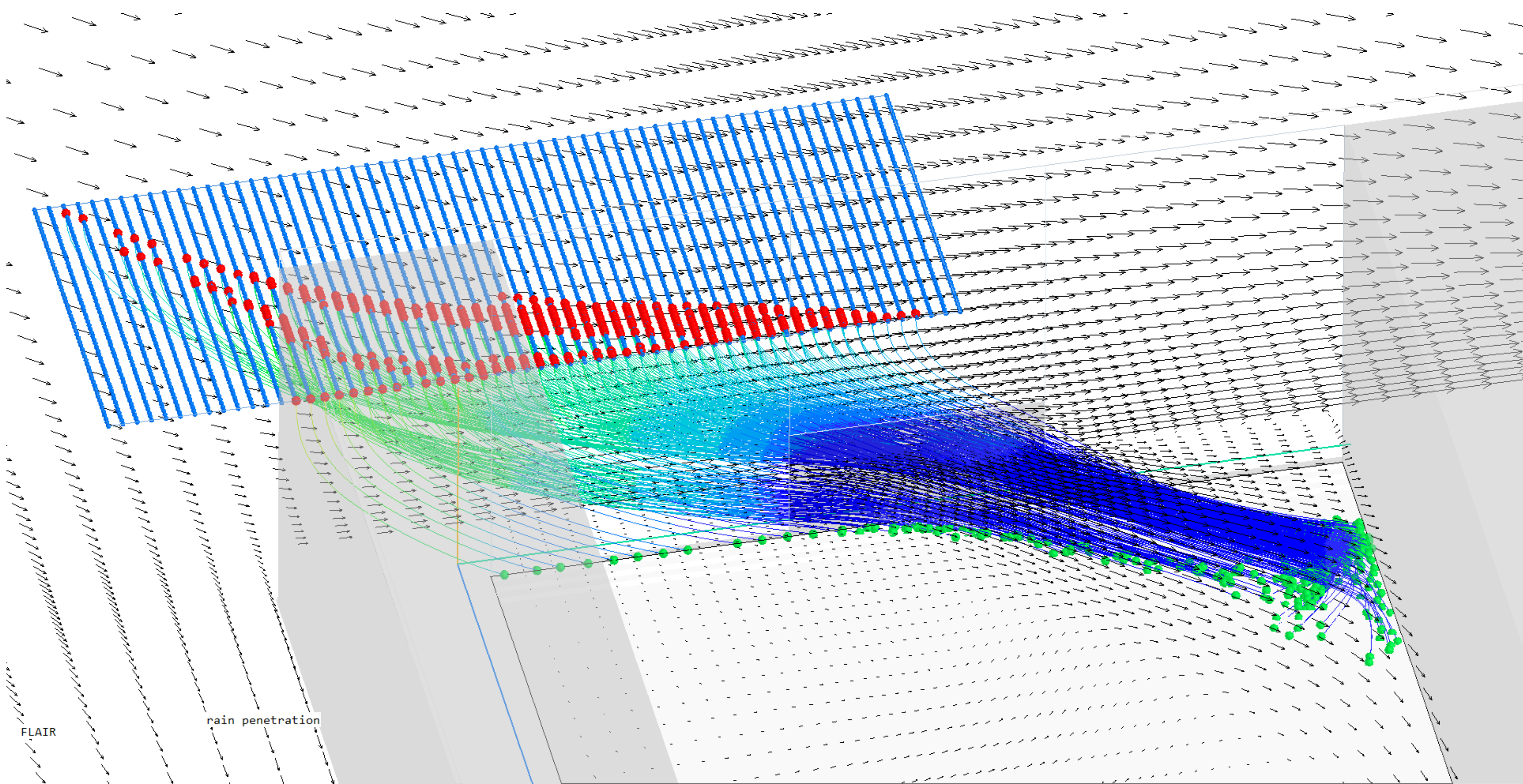
- Size of drops reduced to 1.2 mm
- Note greater penetration



Rain penetration for 1.2mm drops

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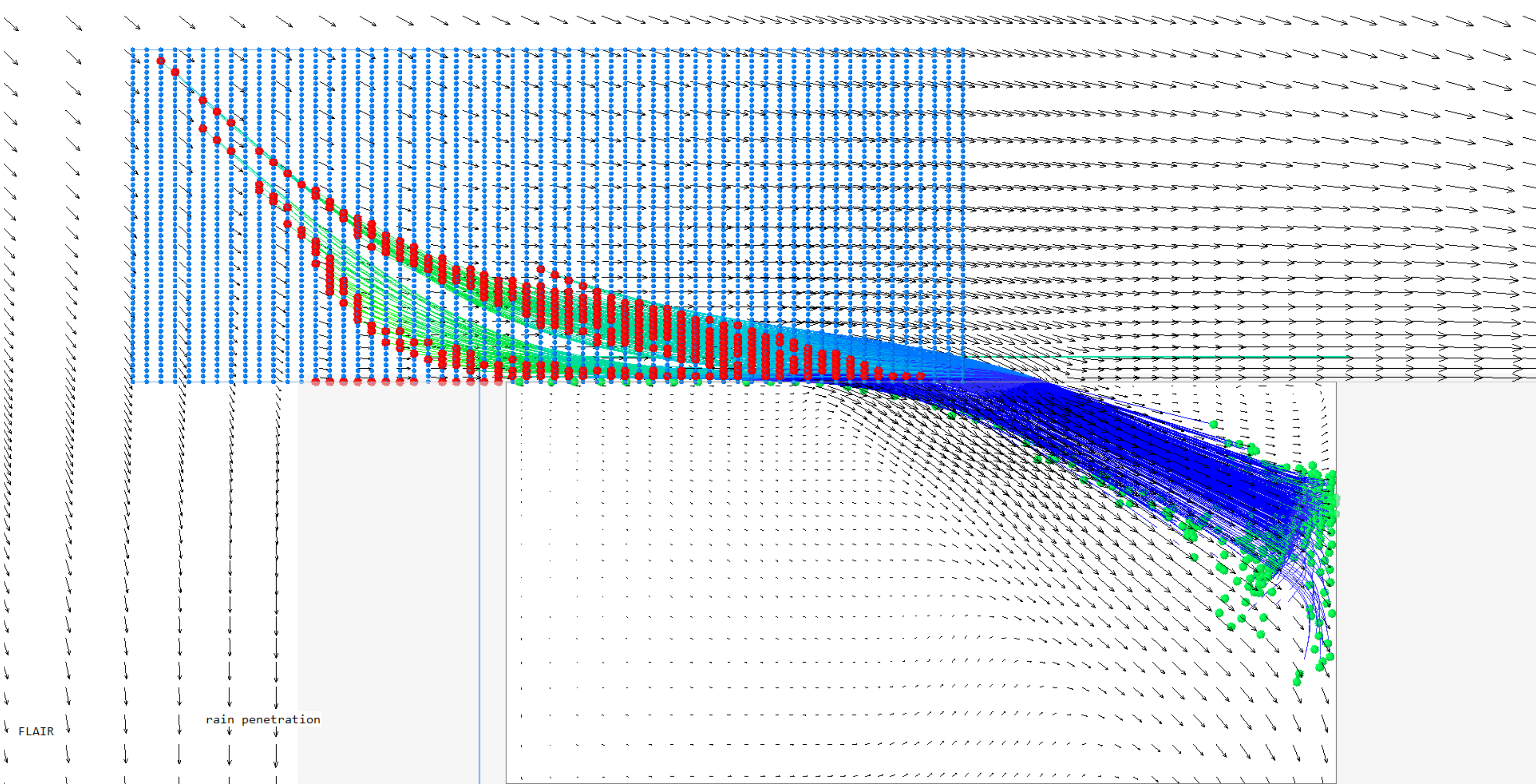
- The same in plan view
- *Where do the tracks "in the middle" go?*



Effect of door canopy

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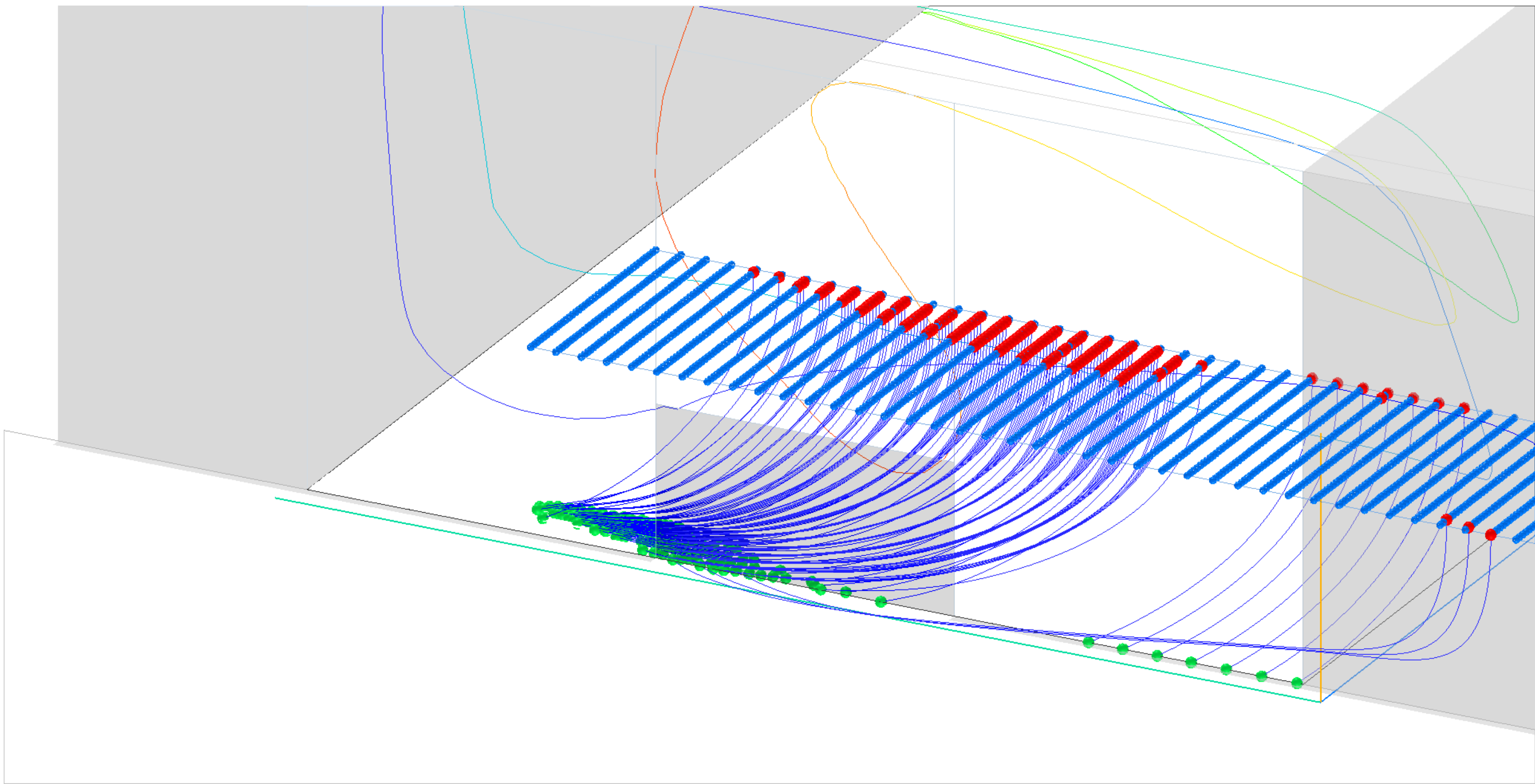
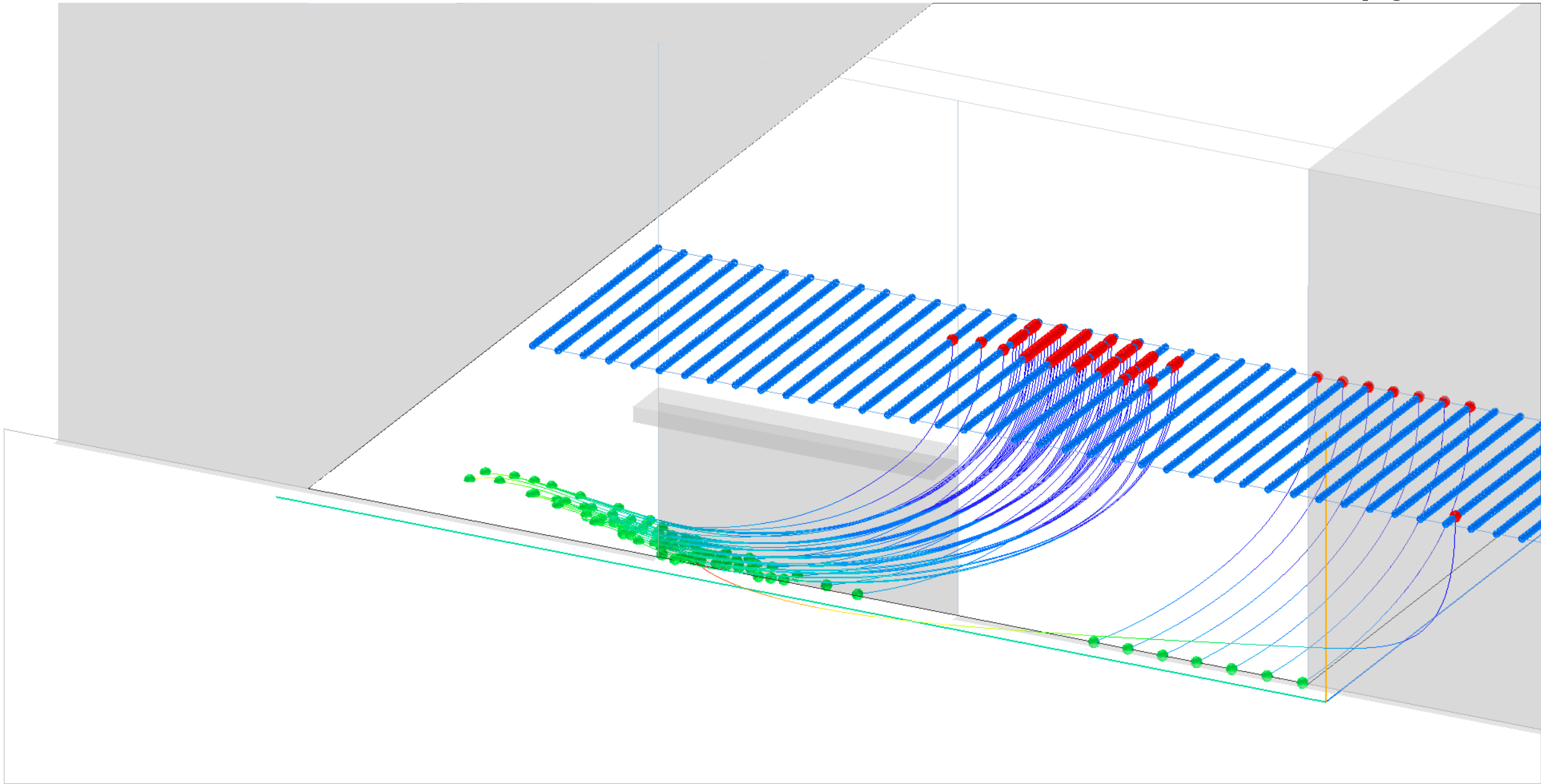
- Another view of the 1.5mm drops entering the doorway



Effect of door canopy

- 1m deep canopy, same width as the doorway
- The rain ingress is changed but not really reduced
- Rain tracks sneak in around the side of the canopy



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Effect of door canopy

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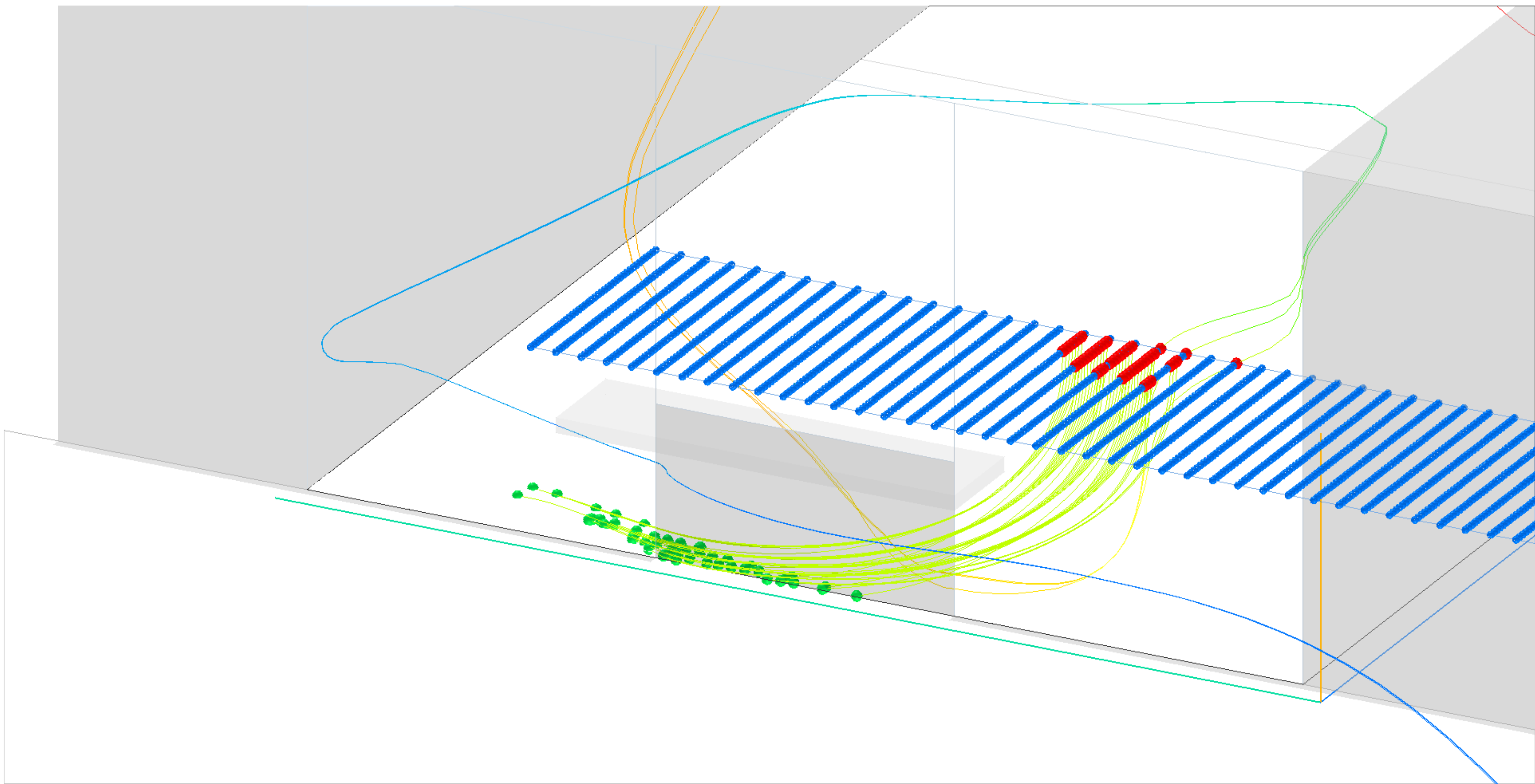
- Larger canopy – 2m deep, 1m wider each side
- Now the rain ingress is significantly reduced!



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Greenery
Evapotranspirative Cooling

Greenery Cooling

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- This is a topic of current research.
- Here we will discuss a few references – one by Blocken et al, and two by Ennos.
- Anyone seriously interested should do a proper literature search.

“Arnhem” paper

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- "CFD analysis of transpirational cooling by vegetation: Case study for specific meteorological conditions during a heat wave in Arnhem, Netherlands" by Gromke, Blocken et al.
- http://www.urbanphysics.net/2014_BAE_CG_BB_WJ_BM_TvH_HT_Arnhem__Preprint.pdf
- This focusses on the "volumetric cooling power P_c", i.e. the heat loss by transpiration of water from the foliage (W/m^3).
- This heat loss is specified over the region of the tree canopy.

"Arnhem" paper

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- The paper estimates a value of P_c, based on an Israeli study which involved measuring the cooling effect of trees in a courtyard.
- Based on this study, a value of P_c = 250 W/m^3 is estimated (per unit leaf area density).
- This value is supported by the work of Rahman et al [ref 86], which reports values of 284 and 335 W/m^3 for deciduous trees in Manchester UK during summer.
- The cooling power can be entered in the Foliage object attributes.
- Note the similarity of the above values - BUT Manchester is very different from the Israeli Negev !

Ennos 2011

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- "Quantifying the cooling benefits of urban trees" by R Ennos, “Trees People and the Built Environment”, Urban Trees Research Conference 13-14 April 2011, pp113-118.
- https://www.researchgate.net/publication/269632119
- Different approach.
- Postulates that “rate of transpiration is proportional to the photosynthetic rate and hence to growth rate”.
- Cooling rate therefore proportional to biomass growth, which can be measured.

Ennos 2011

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type	typical	peak rate / faster growing
short-rotation coppice	96 to 154	380 to 610
deciduous forest	19 to 31	75 to 125
urban trees - average stand	18 to 29	45 to 73

Table 1: Cooling rate of typical trees, W/m2 (Ennos)

- Note – this is W/m2 of ground area beneath canopy
- The data here is very scanty – and very imprecise
- Author emphasises: "These results, though promising and plausible, are only estimates"

Ennos 2014

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- “How Useful are Urban Trees? The Lessons of the Manchester Research Project”, “Trees People and the Built Environment II”, Urban Trees Research Conference 2-3 April 2014, pp62-70.
- https://www.researchgate.net/publication/274958579

Ennos 2014

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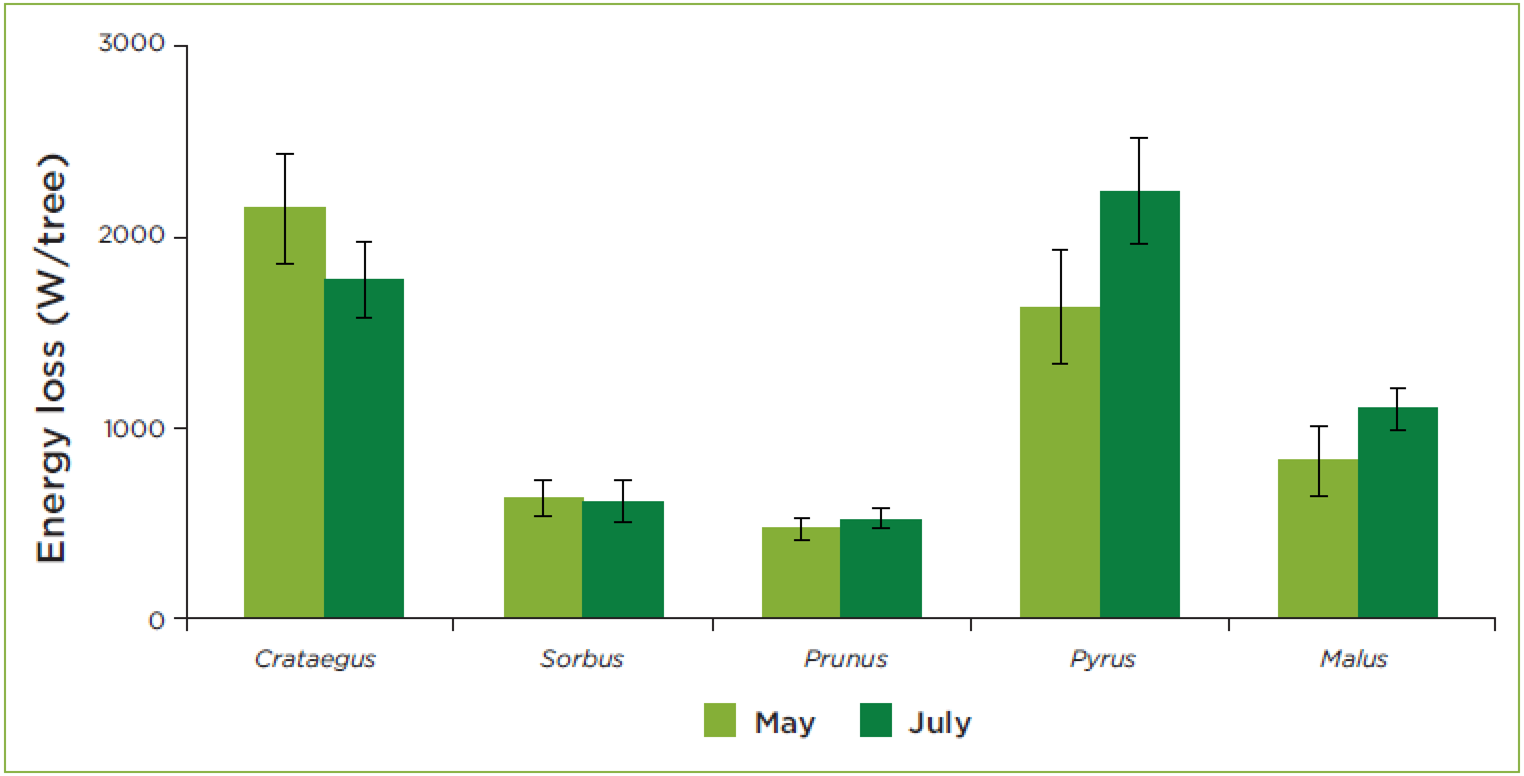
- Evapotranspirational cooling (energy loss per tree) calculated for five different species of street trees.
- Note these data are for individual (small) trees.



How to model in PHOENICS

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- A negative heat source can be defined in the Foliage object.
- Alternatively a Heat_Source object can be used.
- For the amount of the heat source, study the references above and perhaps search the literature.
- For individual trees, the Ennos 2014 data looks good. But bear in mind these are small street trees, not large oaks!
- For green walls or green roofs, again a literature search might reveal data. Alternatively, apply the data for trees – with great care and thought!

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THE END