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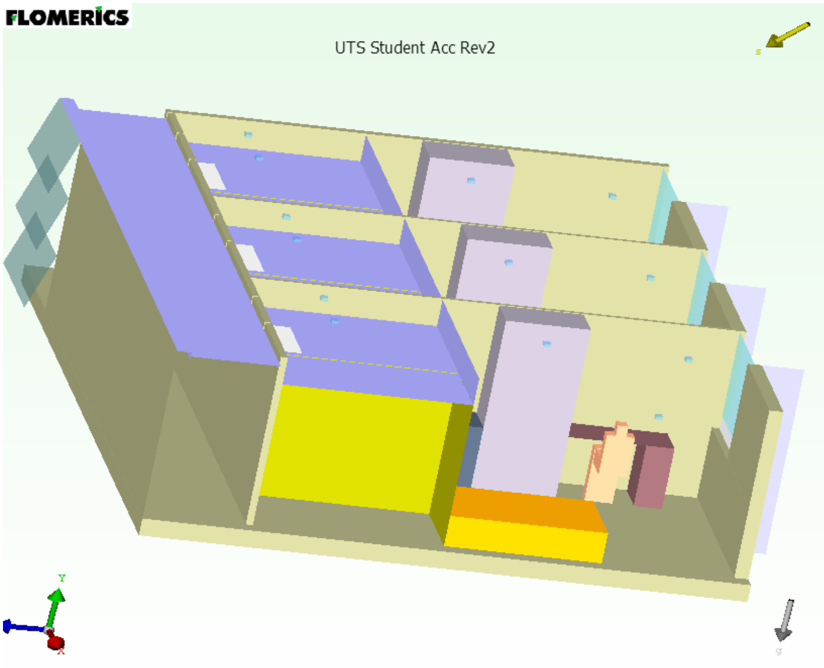
Computational Fluid Dynamics Study

University of Technology Sydney
Accommodation Studios



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Executive Summary

Computational Fluid Dynamics (CFD) simulations have been conducted to investigate cross flow ventilation in the proposed student accommodations at the University of Technology in Sydney.

Two studies were performed. In the first it was assumed that there are no ambient wind conditions and natural ventilation was purely driven by internal heatloads and solar radiation. In the second study it was assumed cross ventilation is driven by external wind conditions, neglecting the influence of internal buoyancy forces.

The outcome of the studies demonstrated that there appears to be significant air flow throughout the apartment under the modelled conditions.

1. Natural ventilation and Thermal Comfort

1.1 Ventilation Concept

The cross-flow ventilation concept is diagrammatically sketched in Figure 1. Each bedroom has an openable window combined with a wall louver on the western façade. The dropped ceiling bulkhead over the kitchen and bathroom has a ceiling vent and there is a wall mounted register above the door relieving air into the corridor. At one end of the corridor there is a full height openable window venting air to the outside.

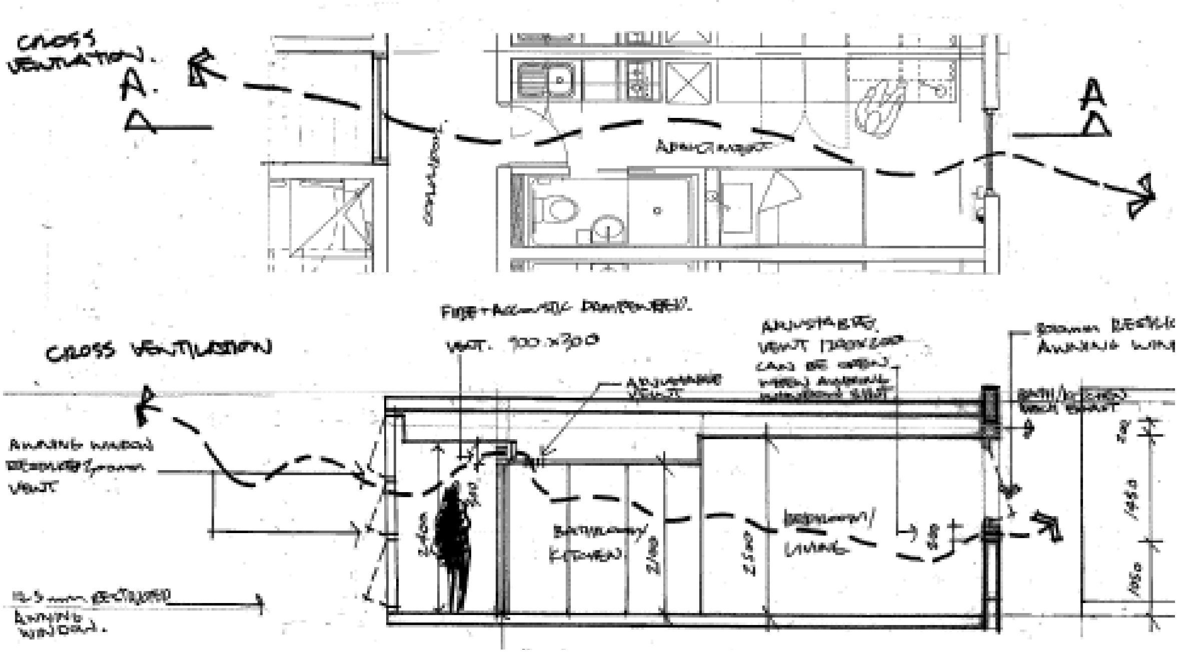


Figure 1 Sketch demonstrating the cross flow ventilation concept received from Hutchinson Builders 6/02/09 (louver under apartment window may be omitted)

1.2 CFD Methodology and Assumptions

It should be noted first, that this report has been compiled with the aid of information available to us and therefore, various assumptions have been made in the selection of heat loads, building parameters and scenarios to be modelled. The scenarios modelled were those agreed with Hutchinson as expected to be as a close representation of the intended use and application on under normal circumstances.

The computer modelling was performed using the commercial CFD code FLOVENT which is developed by Mentor Graphics Mechanical Analysis Division (formerly Flomerics).

A typical accommodation module consisting of 3 units, a common walkway and awning window were constructed to create a 3D model. The bedroom window louvers, ceiling vents and above door wall louvers were inserted. The 3D geometry of the building module is shown in Figure 2.

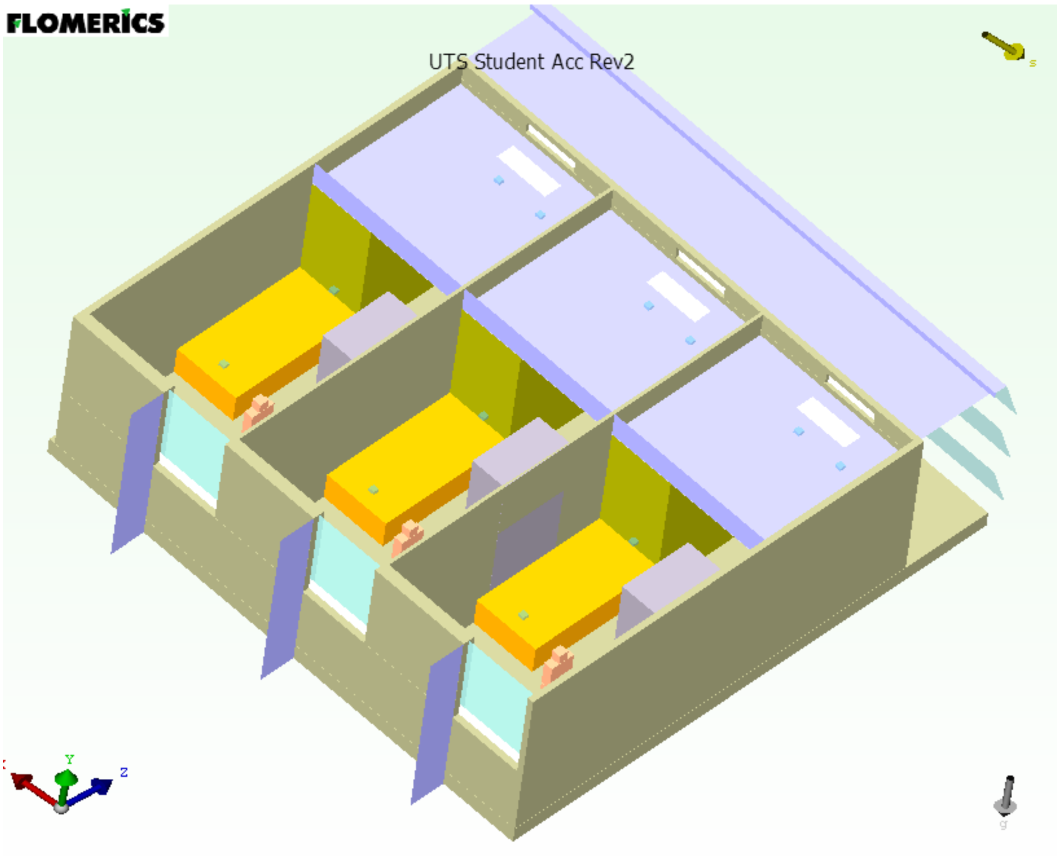


Figure 2: UTS Student accommodation 3D model

The following materials were assigned to the model components:

Floor and Roof	- Concrete
East and West Outer Walls	- Brickwork (Studies using concrete produced similar results)
Internal Walls and ceiling	- Plasterboard
Robe and desk	- Plywood
Windows	- Glass to correspond with a 5.7 W/m^2K U value and 0.61 Solar Heat Gain Coefficient

The following general assumptions were made:

- No external wind.
- 45 W lighting heat load.
- 80 W heat load for a person sitting at his desk.
- 85% Free Area Ratio louvers for the window, door and ceiling louvers.
- All louvers are open. The studio window is closed with the common walkway windows open.
- For solar radiation calculations a 3PM afternoon on 1 Jan is used, resulting in a $900W/m^2$ solar intensity.
- Where ceiling fans was used it was assumed that it circulates 400 L/s.
- For Predictive Mean Vote calculations a metabolic rate of $93W/m^2$ and clothing resistance 0.1 Km^2/W was used.

1.3 Results

For the purpose of this study several simulations were run to investigate the cross-flow ventilation concepts as well as the resulting thermal comfort levels (Predicted Mean Vote).

The following scenarios were simulated:

Scenario 1 – An ambient temperature of 32 °C, with 95% of the solar intensity blocked by internal blinds, resulting in a 45 W/m^2 solar intensity.

Scenario 2 – Same as Scenario 1, but with a 25 °C ambient temperature.

Scenario 3 – Same as Scenario 1, but with a 25 °C ambient temperature and Ceiling Fans

Scenario 4 – An ambient temperature of 32 °C, with no solar radiation and all internal surfaces assumed to be at 25 °C due to a night purge (heat removed in cooler ambient temperatures over the previous night, which is normally the case).

As part of the results, the Predicted Mean Vote (PMV) is calculated to give an indication of thermal comfort. The table below relates PMV values to different internal conditions.

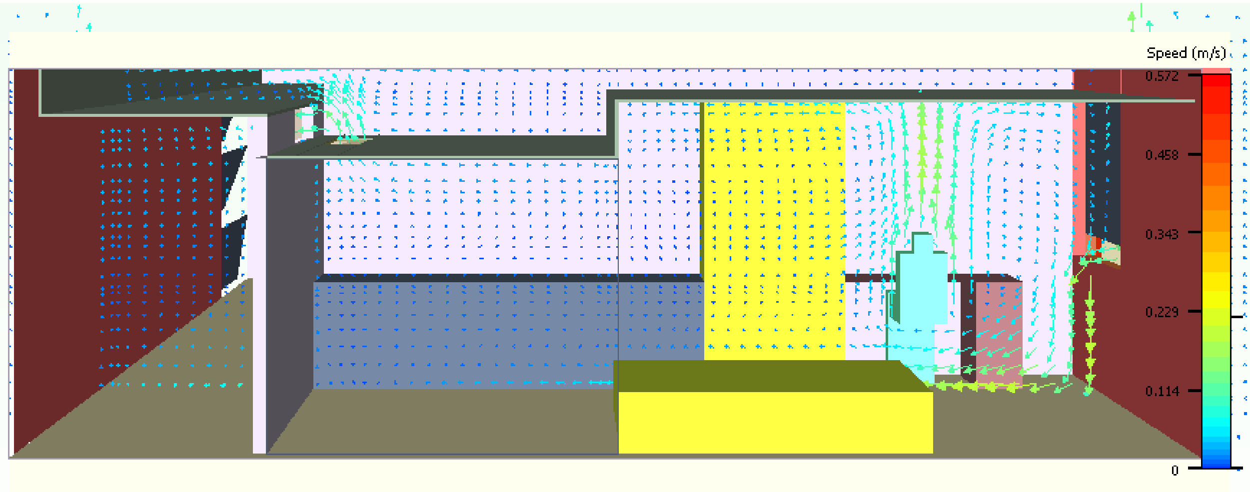
Predicted Mean Vote	Internal Conditions
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Scenario 1 – 32°C ambient, 95% Solar Radiation blocked, no Ceiling Fans

This scenario is performed with an ambient temperature of 32°C, with 95% of the solar radiation assumed blocked by the internal blinds and with no ceiling fans in operation. All the louvers are open, with the studio window closed.

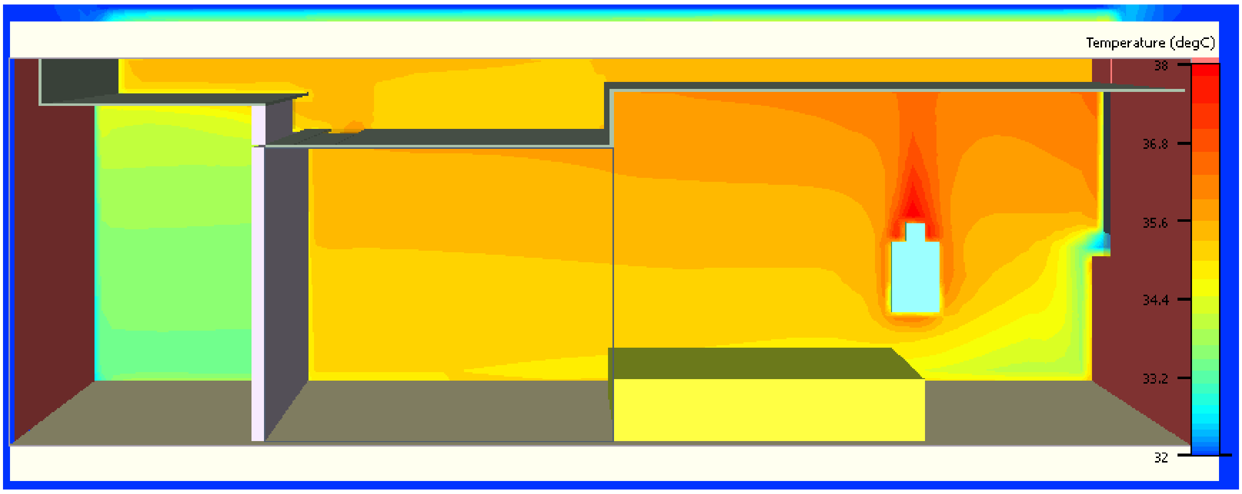
For this scenario the cross-ventilation concept works well as around 27 L/s air enters the louver below the window and exiting through the ceiling and door louvers.

The figure below shows the velocity vectors of a cut plane through the sitting student. On the right below the window, it can be seen how the air enters the room through the louver. Because this air is cooler than the internal temperatures it drops to the floor (cooler air is denser than warmer air). The heat generated by the student causes the air to rise. On the left, it can be seen how the air exits the ceiling louver and then through the door louver.



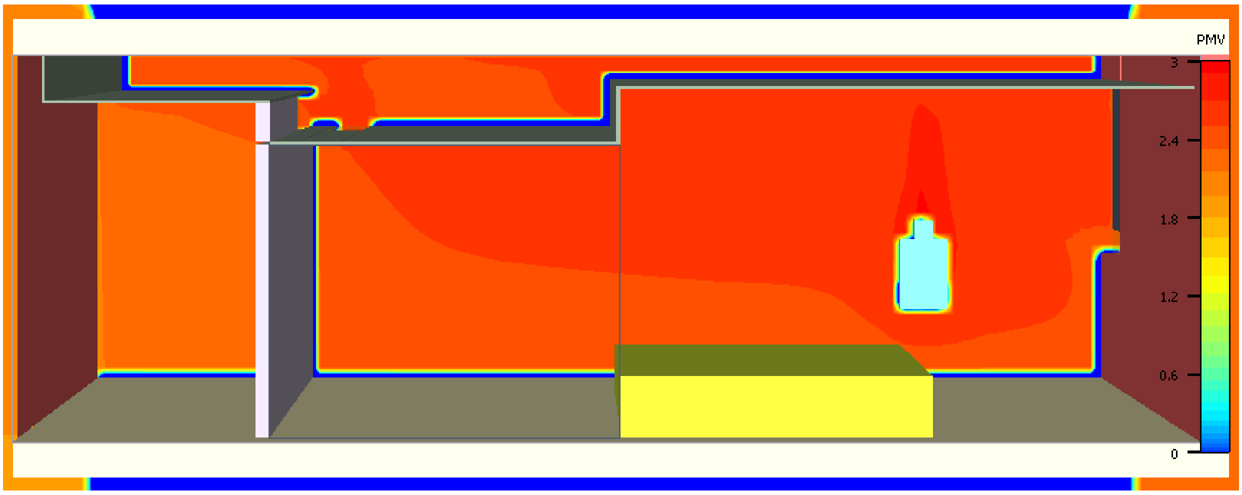
Scenario 1 – Velocity vectors

The temperature profiles can be seen below. The temperature in the vicinity of the sitting student is around 35 °C. It must however be noted that we've assumed a 32°C ambient temperature and that we have solar as well as lights and people heat loads. No credit is taken for i.e. colder inside surface temperatures due to night purging. It is also unlikely that the cross-ventilation system will be used in such hot ambient conditions, i.e. the louvres, windows and blinds etc. will be closed to block the hot air from entering.



Scenario 1 – Temperature

The Predicted Mean Vote shows conditions above +2, which means most people will experience warm internal conditions.



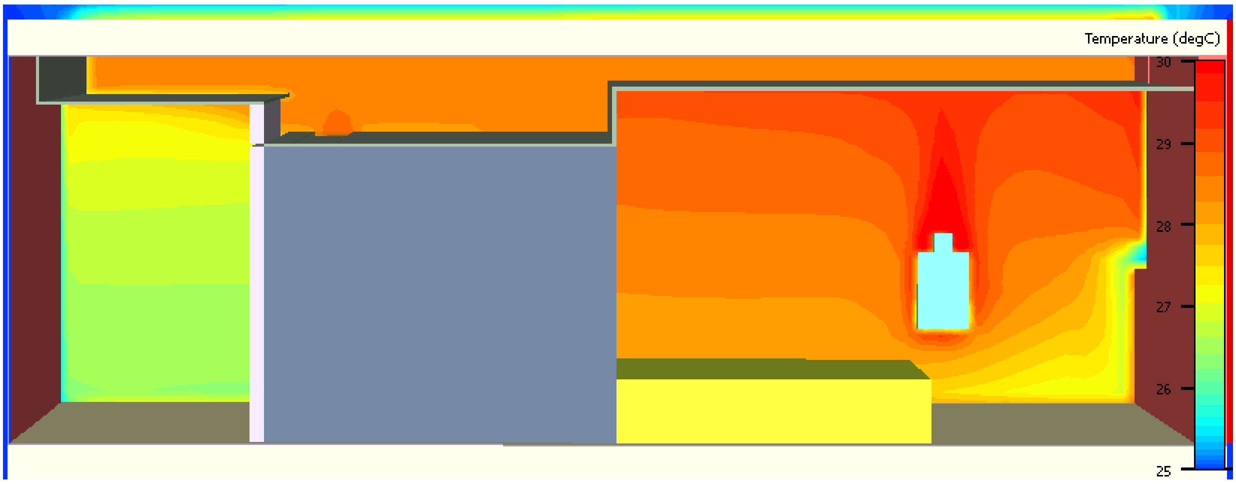
Scenario 1 – PMV

Scenario 2 – 25°C ambient, 95% Solar Radiation blocked, no Ceiling Fans

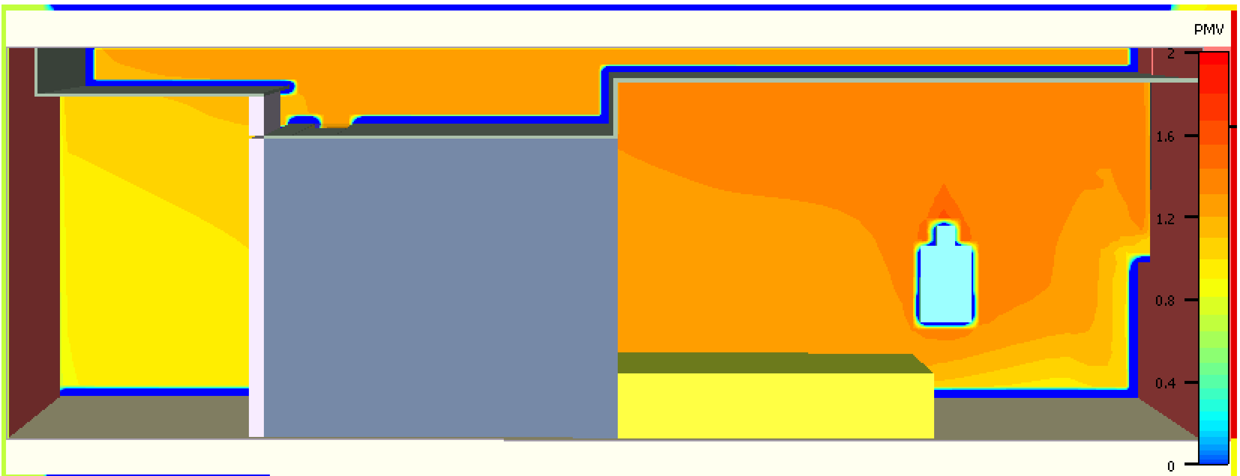
This scenario is performed with an ambient temperature of 25°C, with 95% of the solar radiation assumed blocked by the internal blinds and with no ceiling fans in operation. All the louvers are open, with the studio window closed.

The cross-ventilation concept works well and around 27 L/s air enters the louver below the window and exits through the ceiling and door louvers.

The temperature and PMV plots are shown below. The temperatures in the occupied zone is around 28°C and the PMV shows conditions around +1, i.e. slightly warm.



Scenario 2 – Temperature

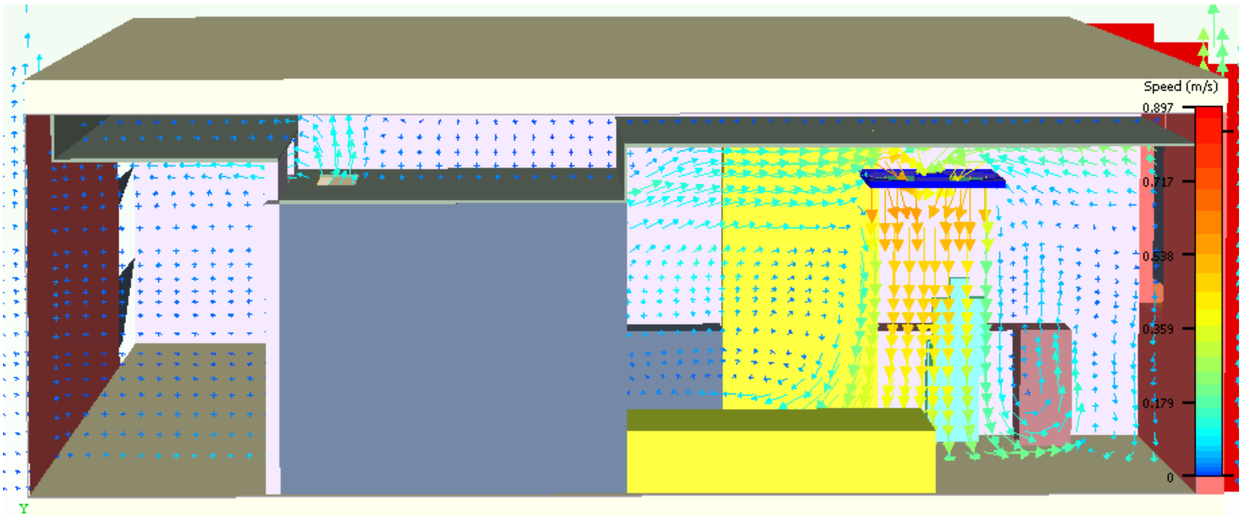


Scenario 2 – PMV

Scenario 3 – 25°C ambient, 95% Solar Radiation blocked, with Ceiling Fans

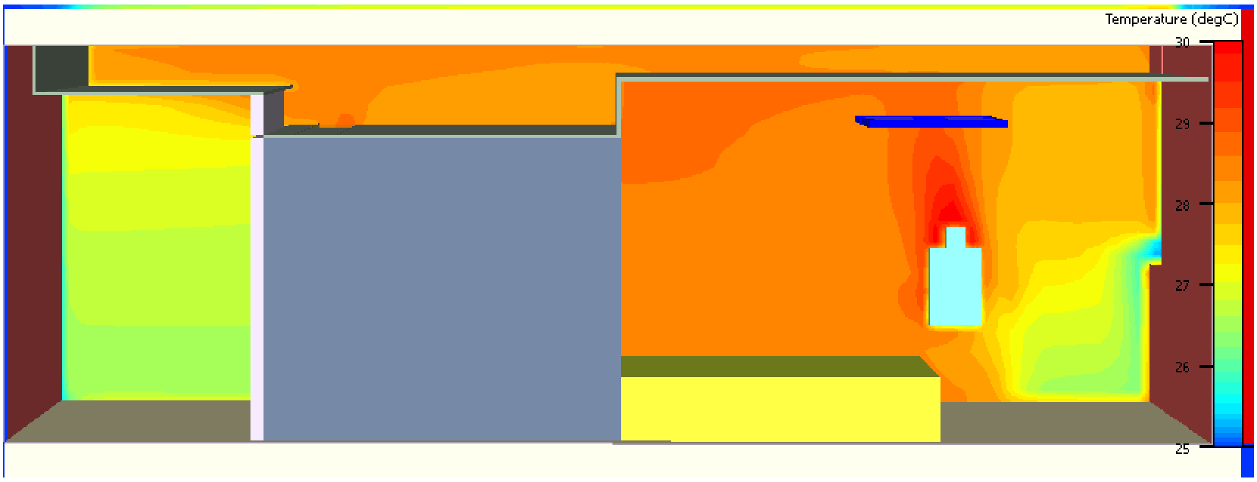
This scenario is similar to scenario 2 but with ceiling fans in operation.

The cross-ventilation concept works well and around 29 L/s air enters the louver below the window and exits through the ceiling and door louvers. The figure below shows the velocity vectors on a plane through the centre of the ceiling fan.

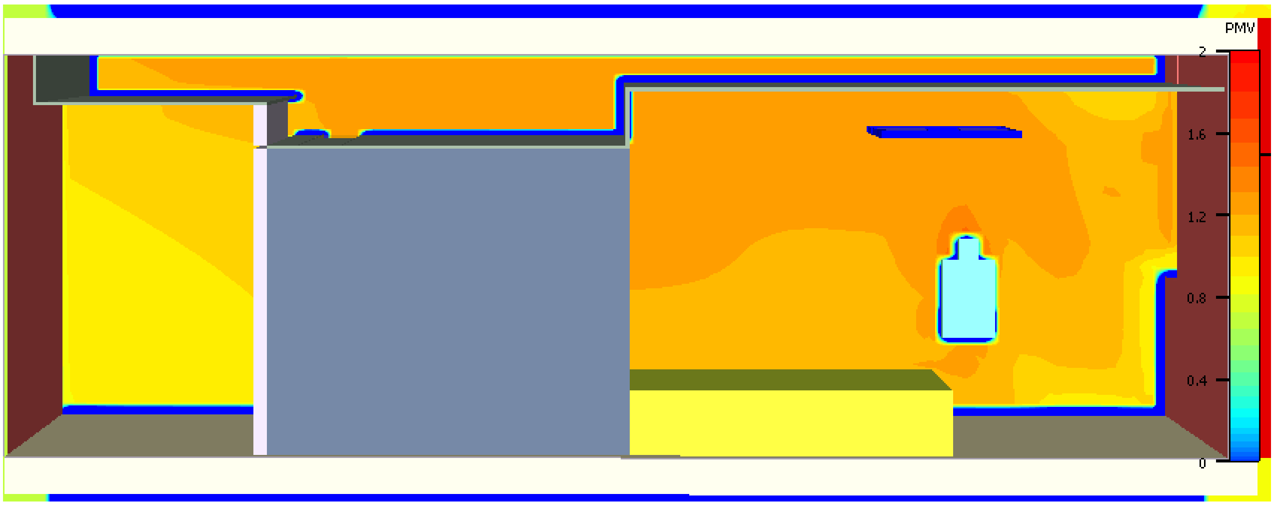


Scenario 3 – Temperature

The temperature and PMV plots are shown below. The temperatures seem slightly lower than that for scenario 2. The PMV also somewhat lower than scenario 2, probably because of the fan draught that increases the internal air velocities and adds to thermal comfort in warm conditions.



Scenario 3 – Temperature



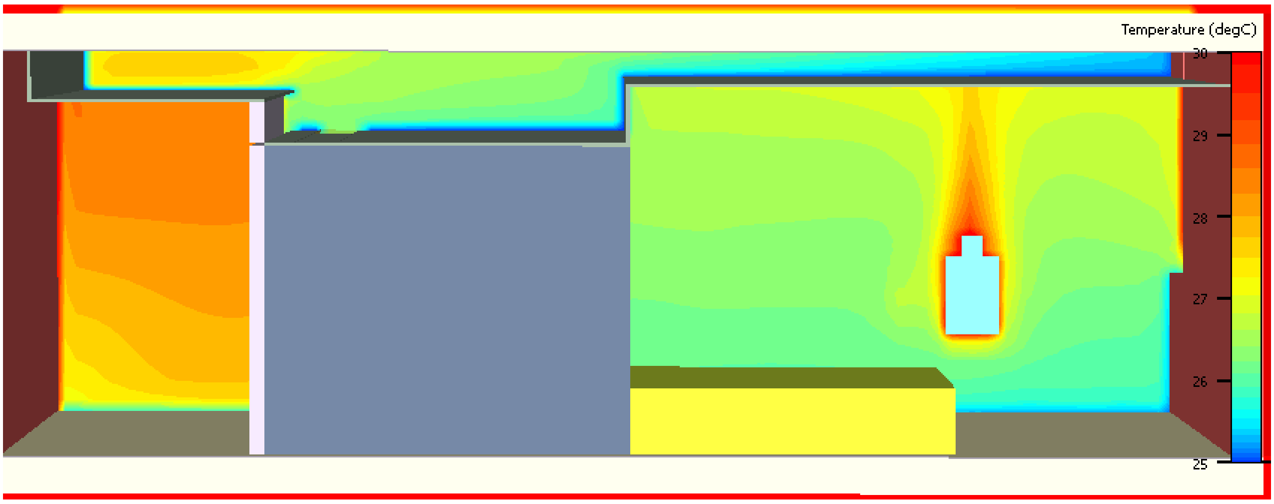
Scenario 3 – PMV

Scenario 4 – No Solar Radiation, 25°C Internal surface temperatures

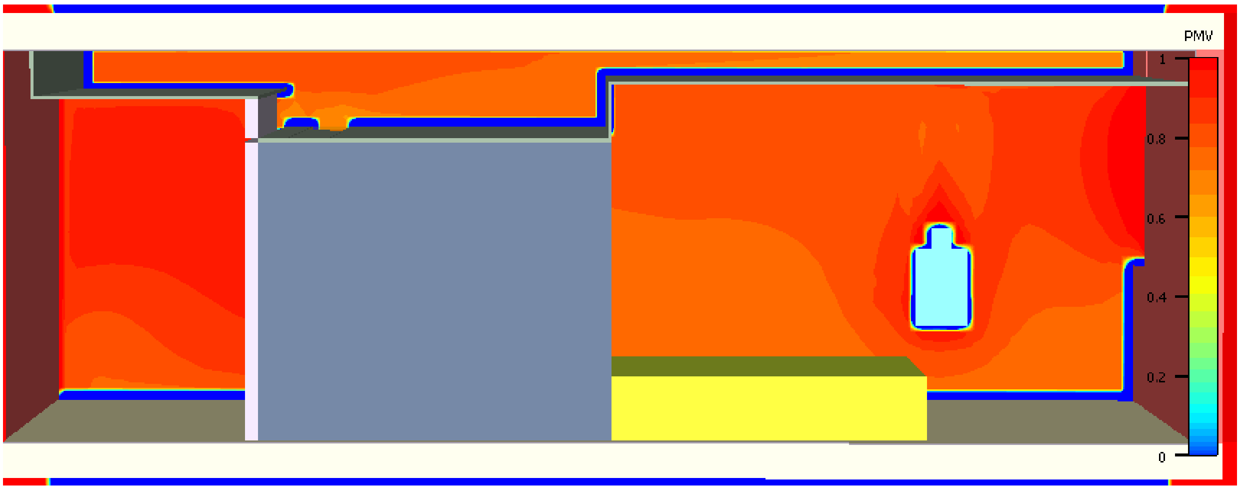
For this scenario the solar radiation was switched off. All the internal surfaces were assumed to be at 25°C due to thermal inertia because of e.g. a night purge.

The cross-ventilation concept is not working. However, the windows and louvers will probably be closed in high ambient temperature conditions.

The temperature is around 26 °C and PMV levels are below 1, which will be comfortable.



Scenario 4 – Temperature



Scenario 4 – PMV

1.4 Conclusions

The results presented shows that the cross-ventilation concept seems to work well for most of the investigated scenarios. It must however be noted that the windows and louvers will probably be closed during hot ambient conditions.

The results also shows that for e.g. a 25°C day with 95% of the solar radiation blocked by internal blinds a good fresh-air supply of around 27 L/s can be expected. The Predicted Mean Vote also shows reasonably comfortable conditions, with increased comfort when the ceiling fan is used.

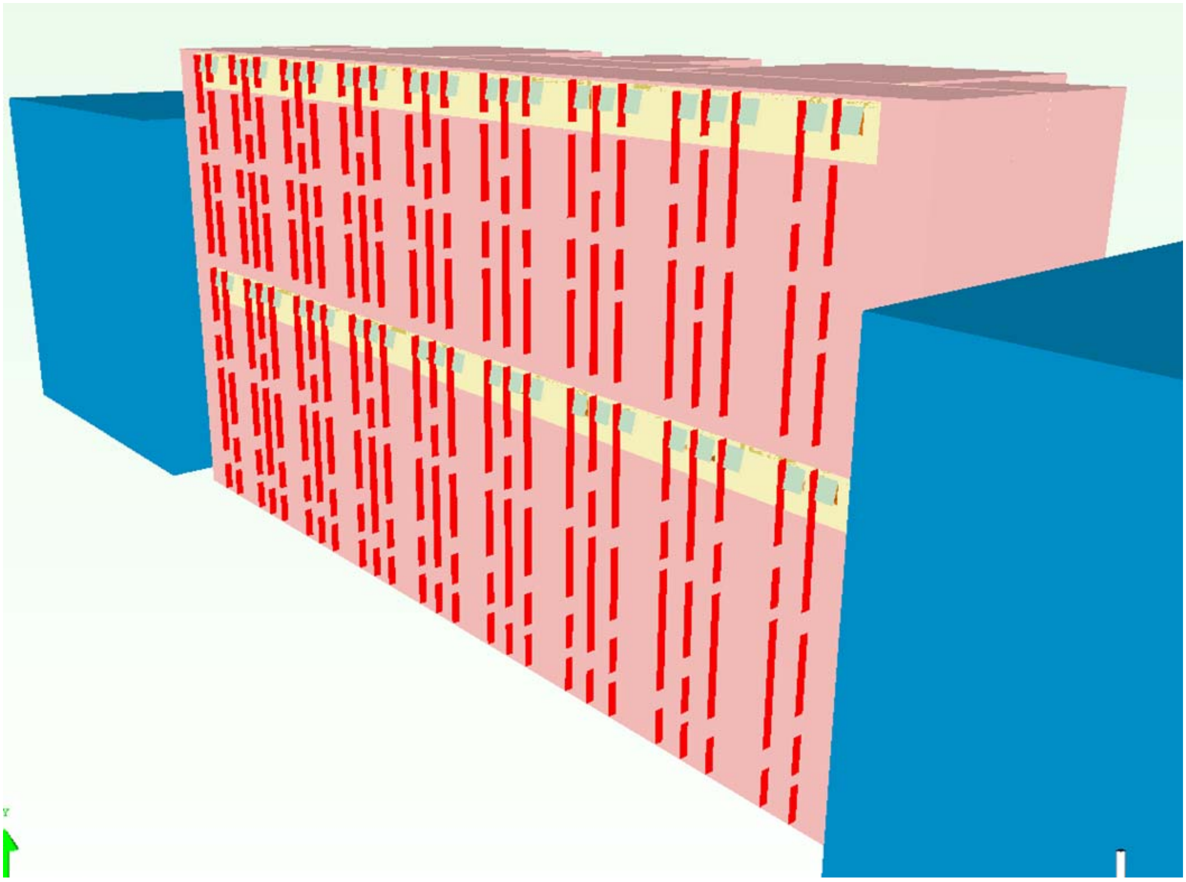
2. Cross-flow due to external wind conditions

2.1 CFD Methodology and Assumptions

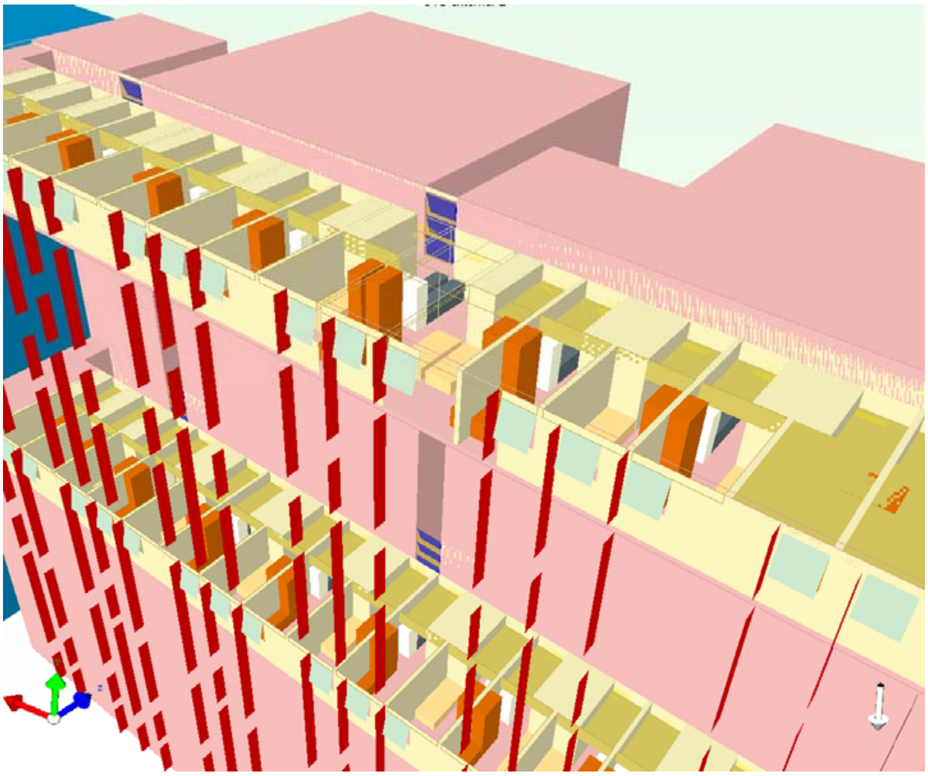
It should be noted first, that this report has been compiled with the aid of information available to us and therefore, various assumptions have been made in the selection of heat loads, building parameters and scenarios to be modelled. The scenarios modelled were those agreed with Hutchinson as expected to be as a close representation of the intended use and application on under normal circumstances.

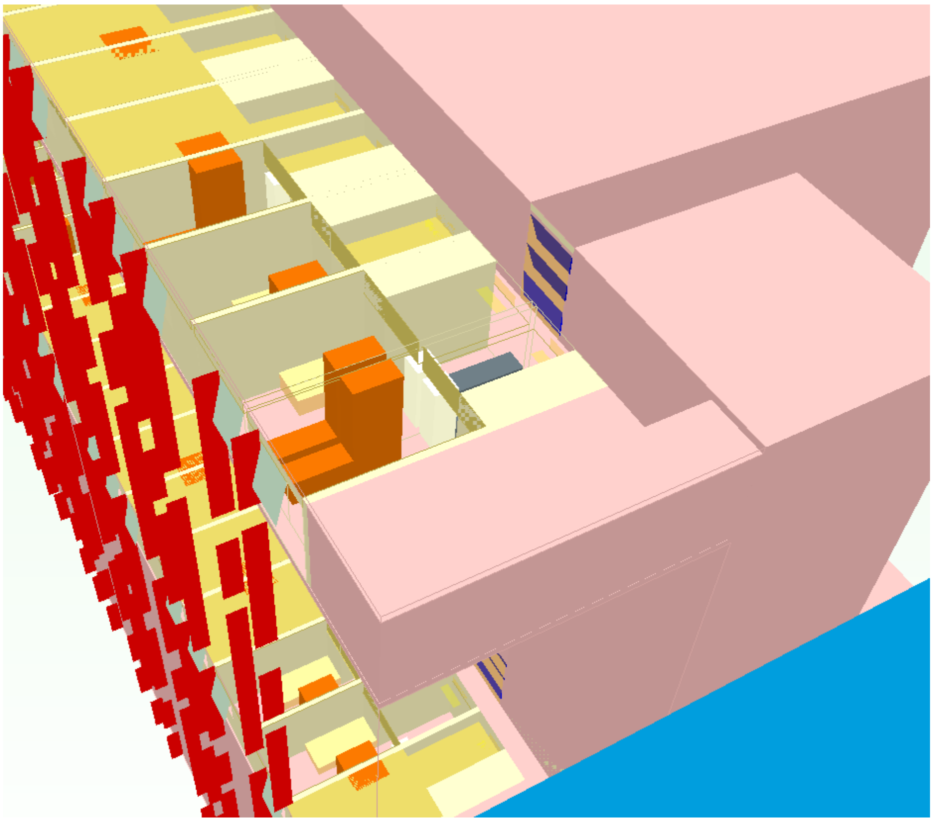
The computer modelling for the cross flow ventilation study was performed using the commercial CFD code FLOVENT.

The purpose of this study was to achieve an idea of typical cross flow ventilation flow rates that can be expected when ambient wind conditions are present. The figure below shows the CFD geometry used. Level 8 (35.8 m above ground level) and above were included in the model. The buildings on either side (North and East) were included.



Only the west rooms of Levels 14 and 20 were modelled in detail. The pictures below contain some hidden geometry to show the detail modelled. The rooms included all the applicable furniture, including the desk, robe, bed, kitchen bench and bathroom.





The following general assumptions were made:

- Only Level 8 and above were included in the model
- Only the adjacent buildings on the north and south sides were included
- The western studio windows were all assumed to be 150mm open. No louvers below the window
- 85% Free Area Ratio louvers for the window, door and ceiling louvers
- The 4 sets of awning windows on the eastern side are open. The top 2 windows are 300mm open with the bottom window 125mm open
- The studio door is closed. The path of air is thus through the studio window, into the studio, through the ceiling and door louver and out through the awning windows on the eastern side
- Only airflow is modelled, no heat loads

2.2 Results

4 different scenarios with varying ambient wind direction and velocity were modelled.

The following scenarios were simulated:

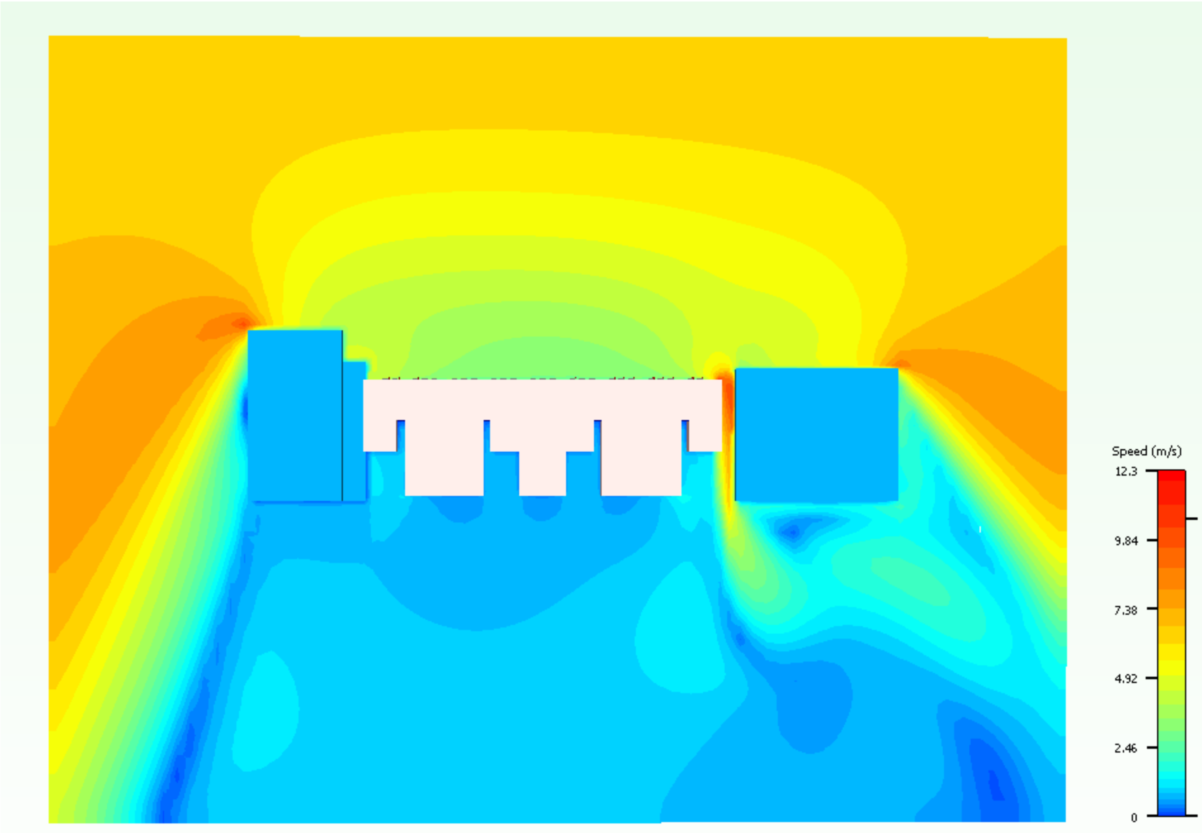
External Scenario 1 – A wind speed of 6.5 m/s blowing from a 90° angle towards the western façade.

External Scenario 2 – A wind speed of 3 m/s blowing from a 90° angle towards the western façade.

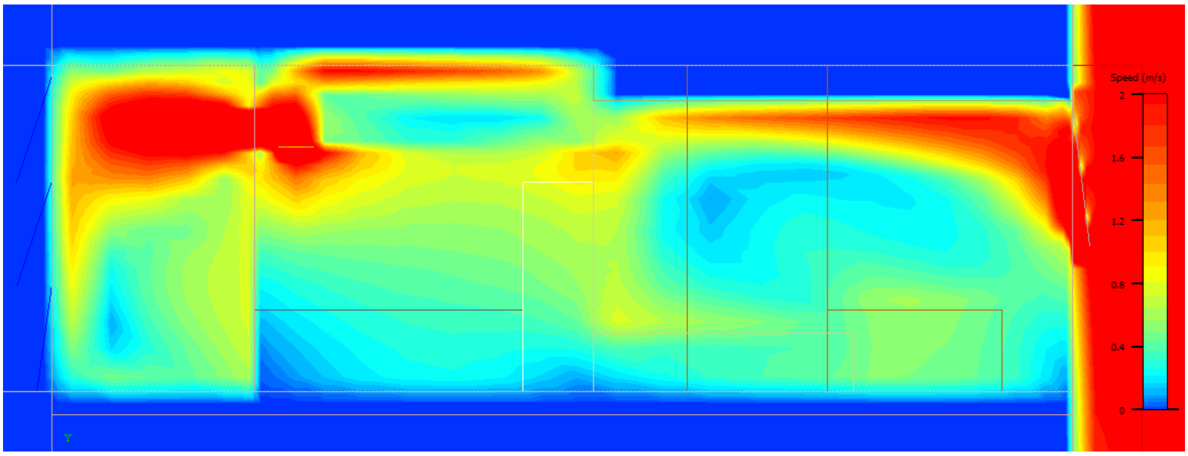
External Scenario 3 – A wind speed of 3 m/s blowing from a 45° angle towards the western façade. North/West wind.

External Scenario 4 – A wind speed of 3 m/s blowing from a 90° angle towards the Eastern façade.

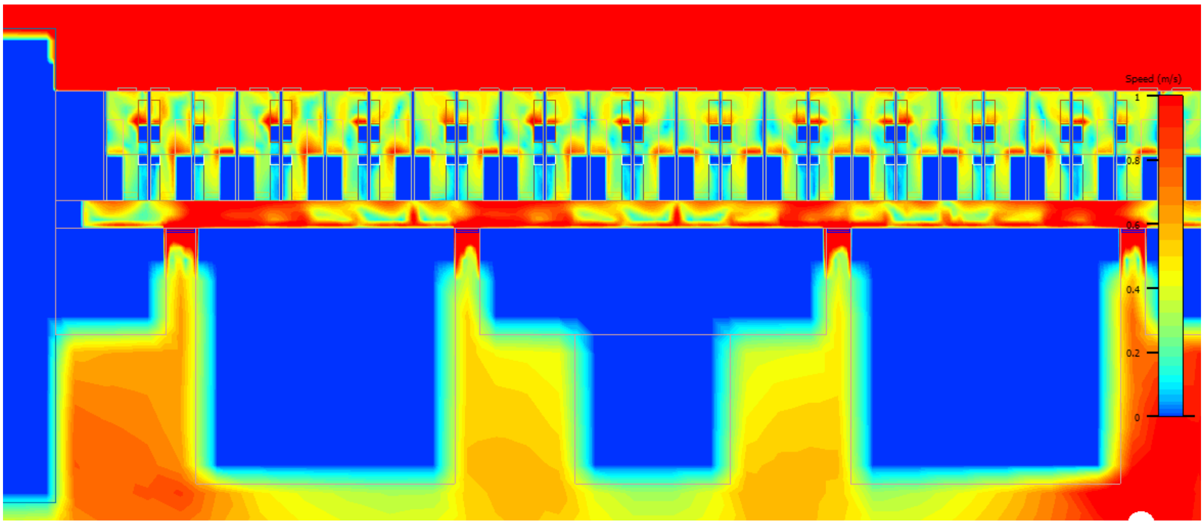
External Scenario 1 – A wind speed of 6.5 m/s blowing from a 90° angle towards the western façade



External Scenario 1 – External velocities at 60m height above ground

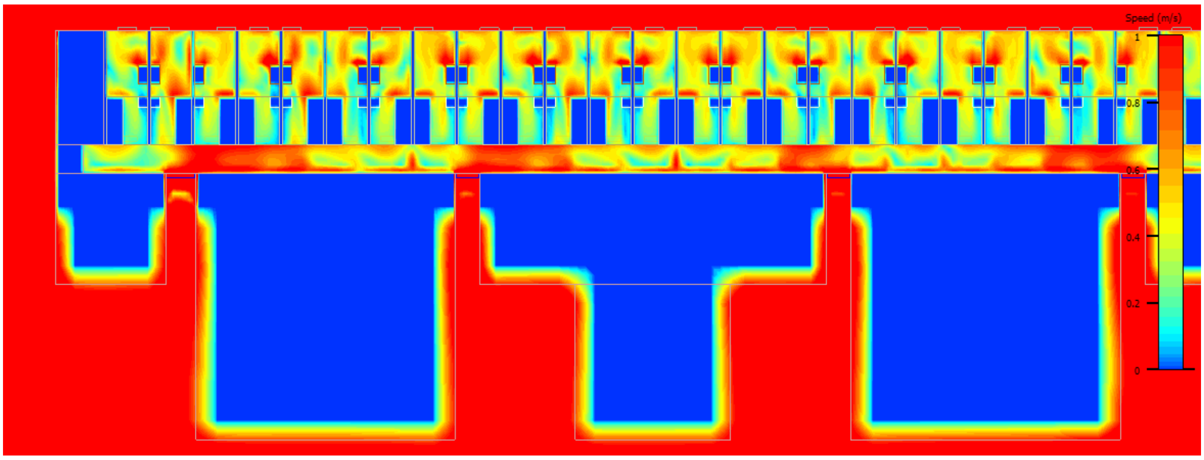


External Scenario 1 –Velocities through room on Level 14



External Scenario 1 –Velocities at 1m AFL Level 14

Room # 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25



External Scenario 1 –Velocities at 1m AFL Level 20

The table below gives the flow rate through the door louvers of each modelled room on levels 14 and 20. Looking at the picture above, Room 1 is the room on the left, with room 25 on the far right.

External Scenario 1 – Flow rate through dour louver (Litres/second)

Room #	Level 14	Level 20
1	972	739
2	995	836
3	1000	851
4	984	870
5	1010	883
6	1004	881
7	1013	894
8	1024	896
9	1021	902
10	1009	897
11	1031	909
12	1028	915
13	1027	912
14	1037	911
15	1036	921
16	1016	908
17	1020	902
18	1021	918
19	1006	899
20	1009	900
21	1019	920
22	986	895
23	987	886
24	1001	916
25	921	846

From the table it can be seen that the rooms on Level 14 all have similar flow rates. However, on Level 20, the top level, it can be seen that the rooms towards the ends (North and Eastern sides) have somewhat decreased flow rates. The explanation for this can be that Level 14 has adjacent buildings, thus allowing a pressure build-up, whereas for Level 20 the air can escape on the sides, thus less pressure build-up on the ends and thus lower flow rates on the ends.

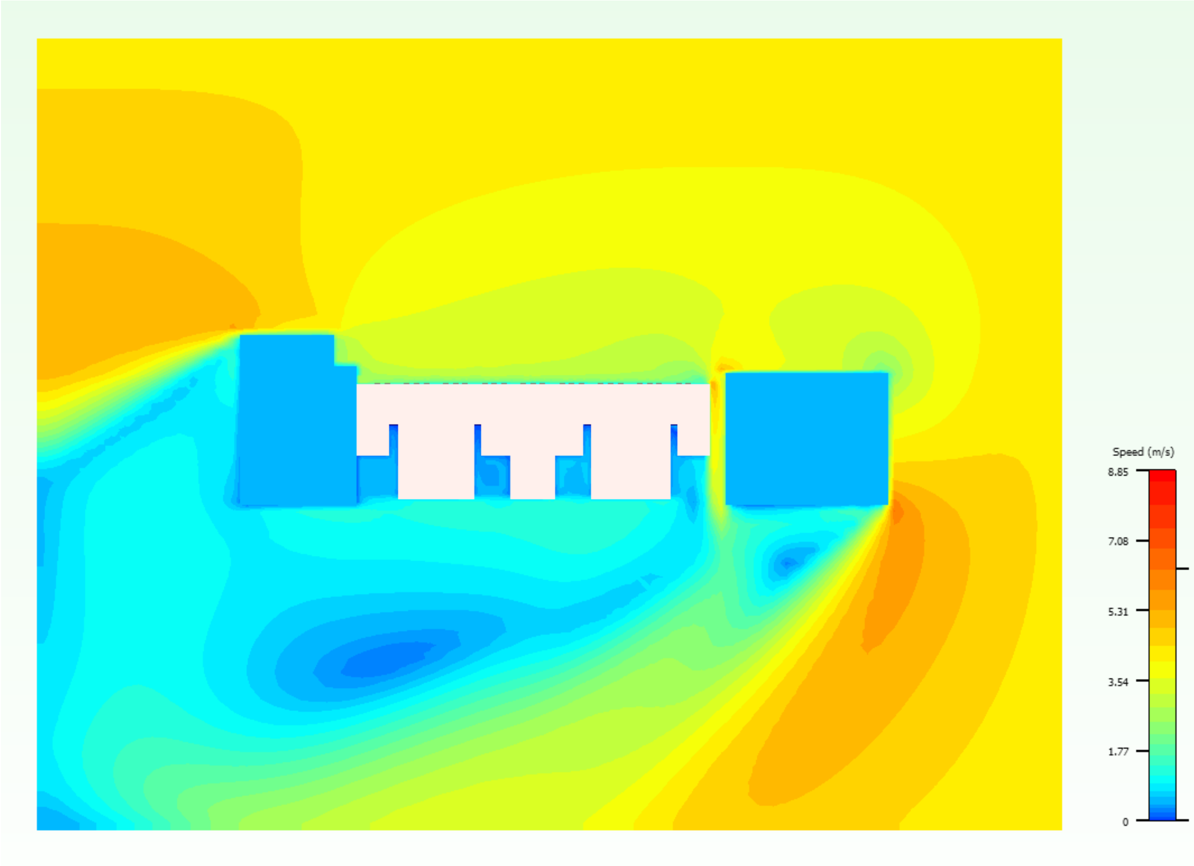
External Scenario 2 – A wind speed of 3 m/s blowing from a 90° angle towards the western façade.

The velocity profiles of this scenario looks similar to those of scenario 1, just lower velocity values corresponding to the smaller flow rates through the room, as can be seen in the table below.

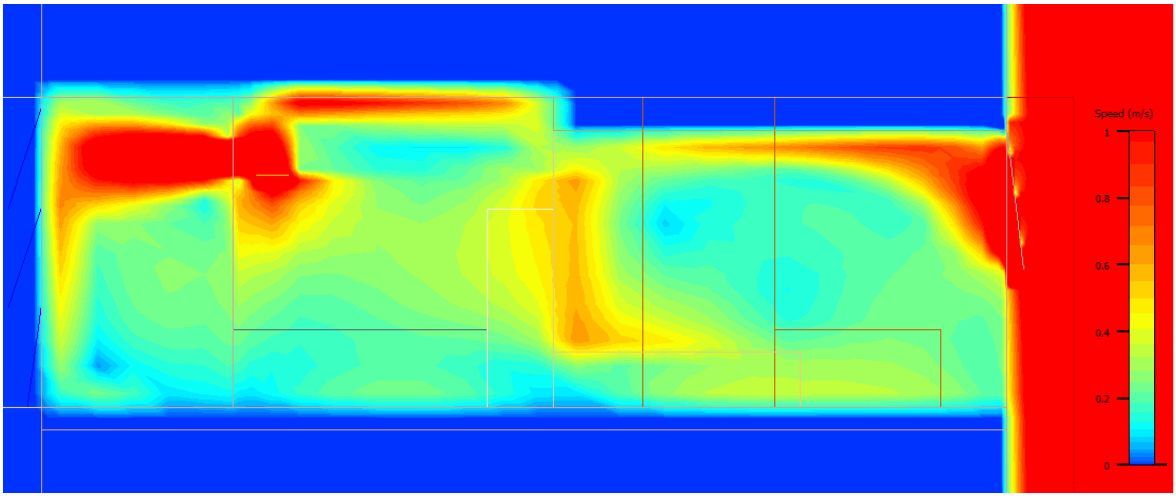
External Scenario 2 - Flowrate through dour louver (Litres/second)

Room #	Level 14	Level 20
1	449	340
2	459	385
3	462	392
4	454	400
5	466	407
6	462	405
7	467	412
8	473	412
9	471	416
10	465	413
11	476	418
12	474	421
13	473	420
14	479	420
15	477	424
16	469	418
17	470	415
18	471	422
19	464	414
20	468	414
21	472	424
22	454	411
23	456	408
24	462	422
25	425	389

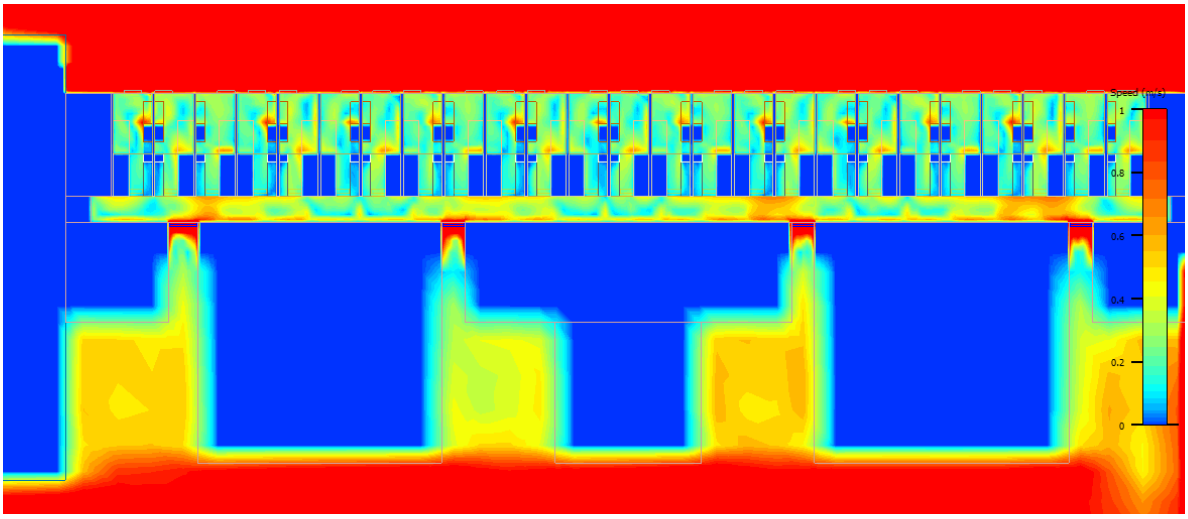
External Scenario 3 –A wind speed of 3 m/s blowing from a 45° angle towards the western façade. Northwest wind.



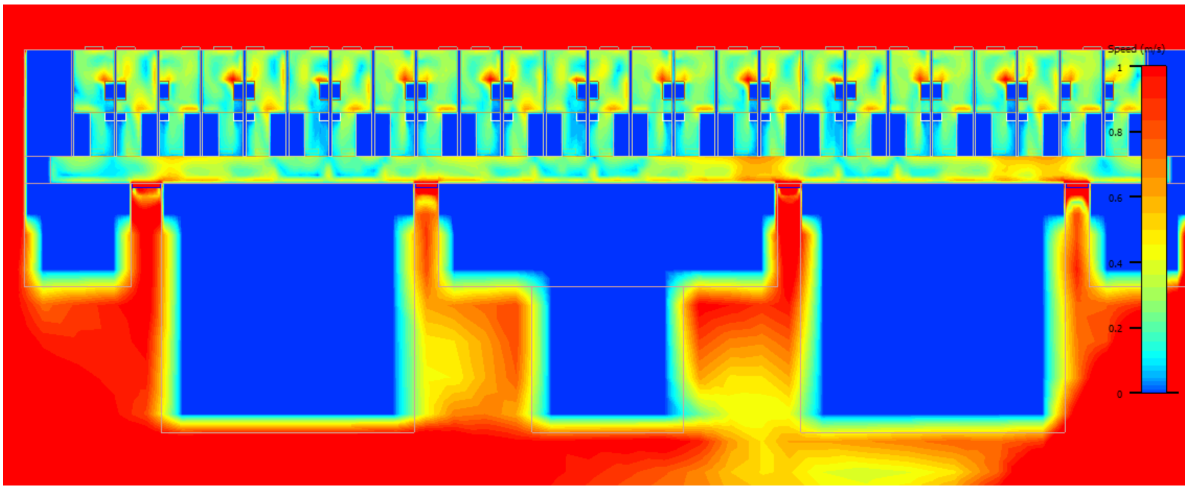
External Scenario 3 – External velocities at 60m height above ground



External Scenario 3 –Velocities through room on Level 14



External Scenario 3 –Velocities at 1m AFL Level 14

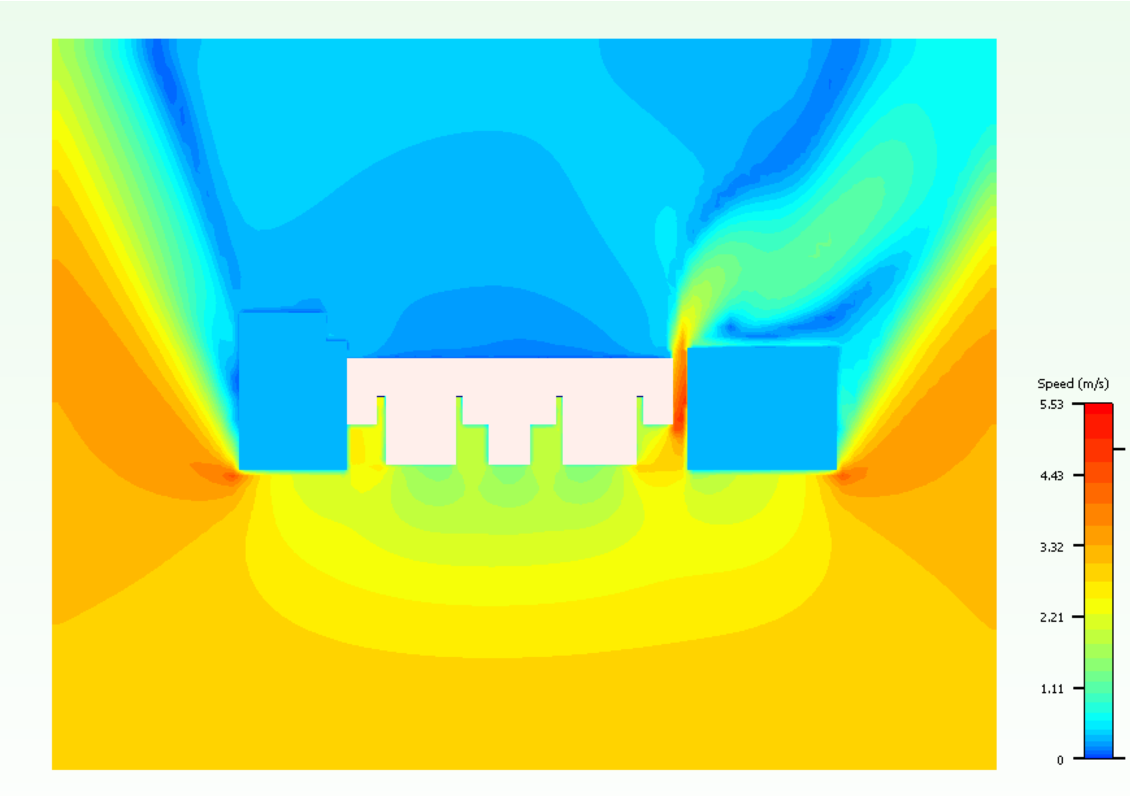


External Scenario 3 –Velocities at 1m AFL Level 20

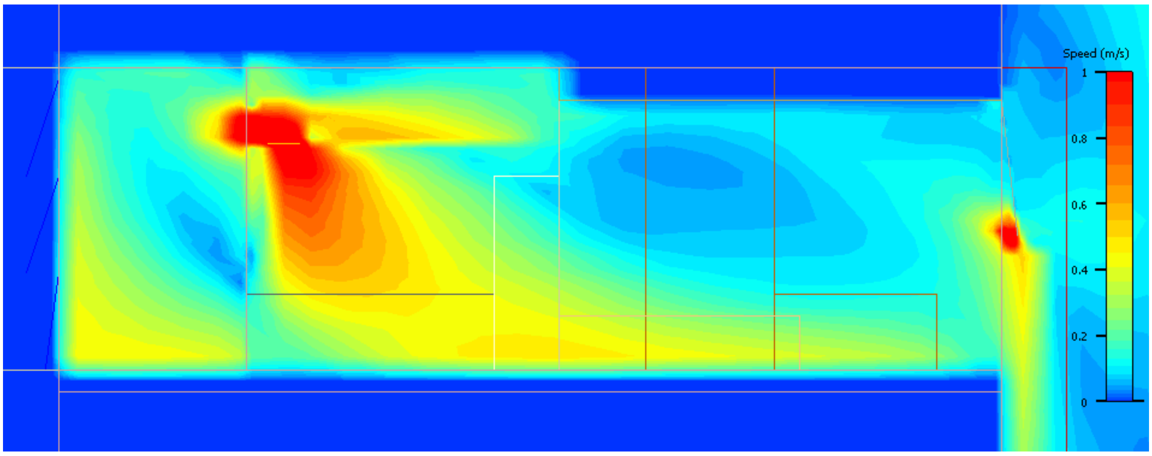
External Scenario 3 - Flowrate through dour louver (Litres/second)

Room #	Level 14	Level 20
1	602	404
2	599	462
3	582	456
4	565	477
5	574	483
6	544	462
7	558	488
8	554	487
9	542	474
10	539	487
11	556	493
12	537	471
13	548	497
14	550	495
15	545	480
16	553	500
17	558	496
18	545	477
19	563	488
20	563	486
21	560	467
22	578	490
23	592	491
24	591	481
25	630	517

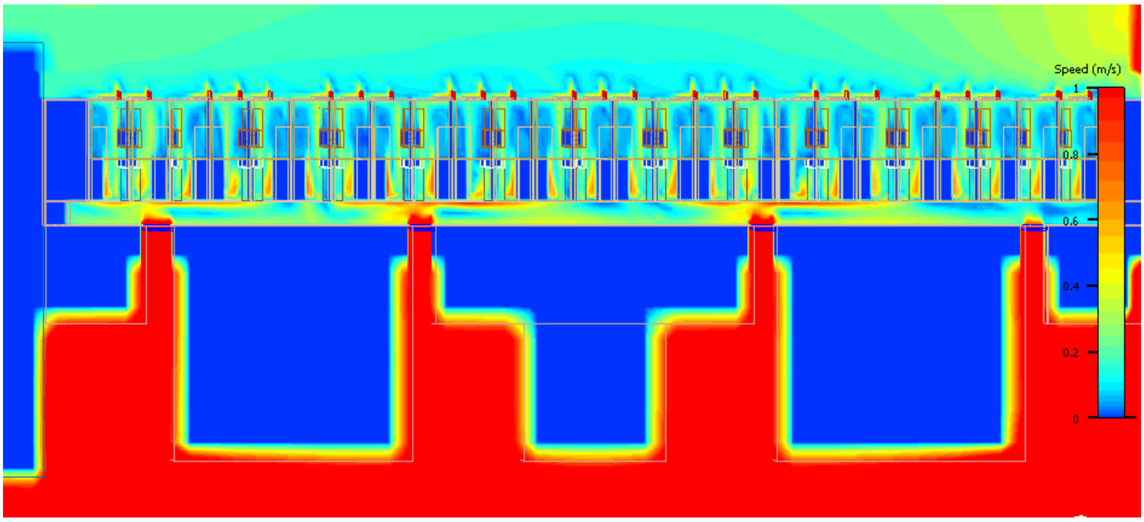
External Scenario 4 – A wind speed of 3 m/s blowing from a 90° angle towards the Eastern façade



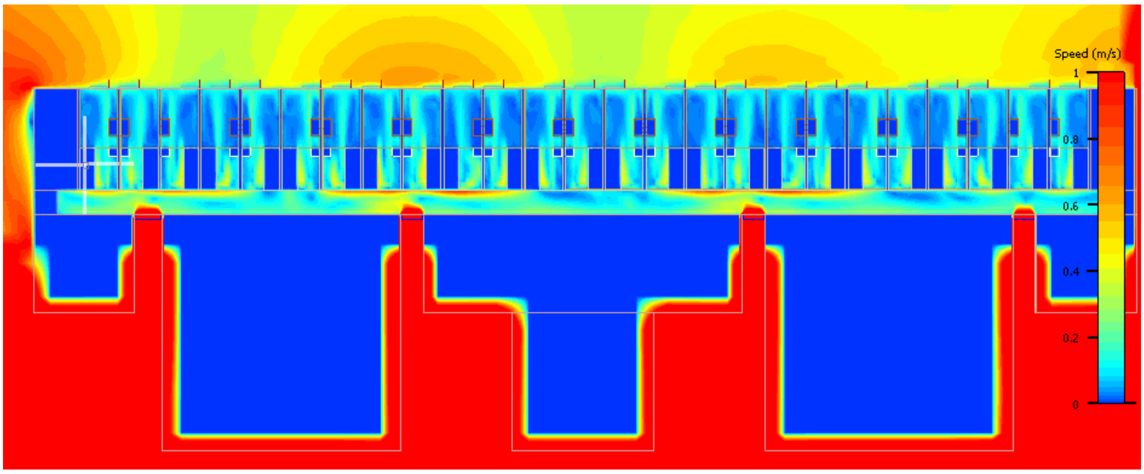
External Scenario 4 – External velocities at 60m height above ground



External Scenario 4 –Velocities through room on Level 14



External Scenario 4 –Velocities at 1m AFL Level 14



External Scenario 4 –Velocities at 1m AFL Level 20

External Scenario 4 - Flowrate through dour louver (Litres/second)

Room #	Level 14	Level 20
1	325	192
2	372	223
3	335	187
4	349	201
5	359	214
6	358	216
7	343	203
8	329	184
9	372	231
10	337	198
11	336	201
12	353	210
13	353	211
14	362	214
15	353	207
16	316	175
17	371	223
18	330	190
19	314	183
20	343	209
21	349	211
22	345	205
23	349	205
24	348	215
25	333	198

2.3 Conclusions

The results presented shows that the cross-ventilation concept seems to work well. Flow rates in excess of 300 Litres/second are obtained for all the rooms in scenarios 1 to 3 and above 180 Litres/second for Scenario 4. This would suggest that significant natural ventilation should be achieved under normal conditions at average expected ambient wind speed conditions and based on the assumptions made and options modelled.