

DATA Center Modeling Analysis & Validation



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Outline

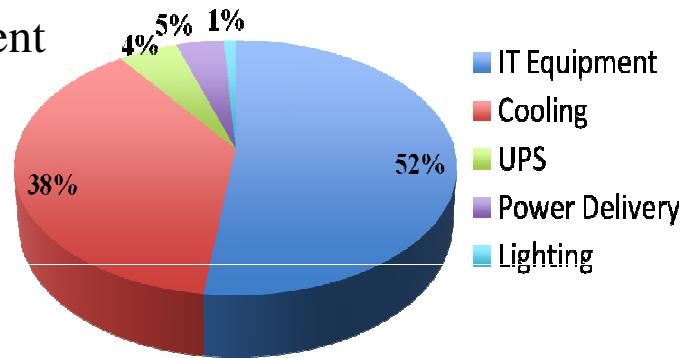
- Project introduction
- MACC Data Center Modeling Analysis
 - i. Space gradient
 - ii. Turbulence
 - iii. Work Allocation
- Dolfyn Validation
 - i. Models
 - ii. Auto tester
 - iii. Validation
- Conclusion
- Q&A



Introduction

Data center cooling cost

- 30,000 ft² data center: \$4-\$8 million annually [Moore 06]
- Energy prices still rising
- For every 10°C increase past 21°C, equipment lifetime decreases by 50% [Moore 06]



Maelstrom

- Real-Time Tracking of Data Center Thermal Topology
- Computational Fluid Dynamic (CFD) Software
- Save Energy\$\$\$
- Eliminate the hot spots

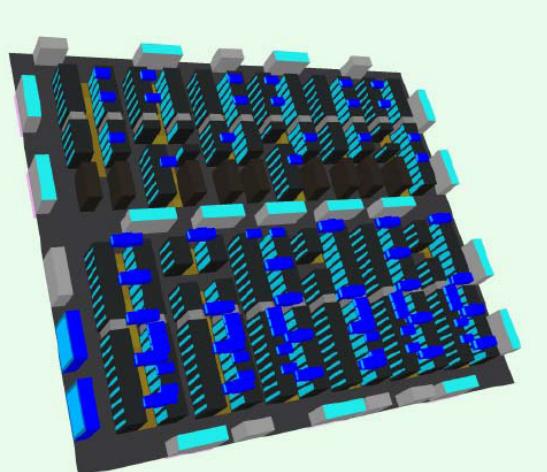


MACC Data Center Modeling Analysis



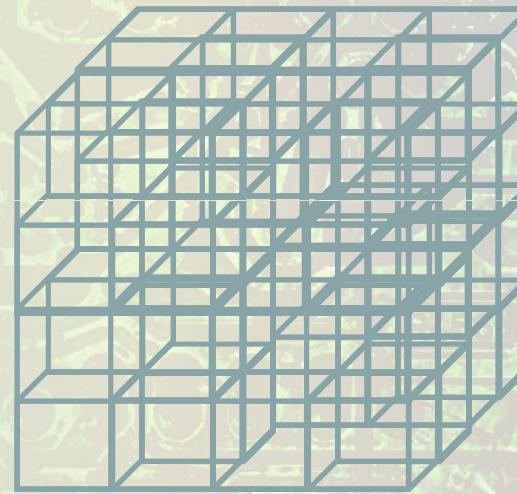
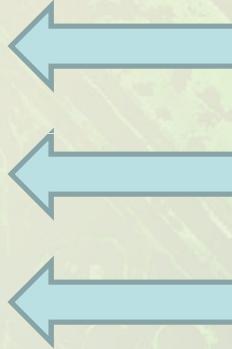
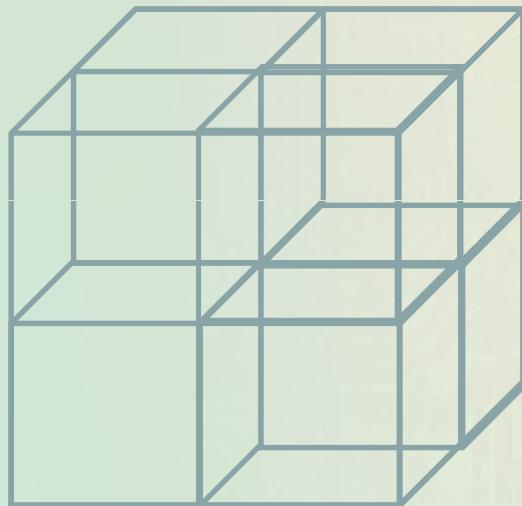
MACC Data Center Modeling

- MACC : Michigan Academic Computing Center
- Flovent: Commercial CFD software that predicts 3D airflow, heat transfer, and contamination distribution in data center
- MACC data model in Flovent [Alan Lee]
 - Real power setting
 - Real static work distribution



Space Gradient

Finite Volume Method



Space Gradient

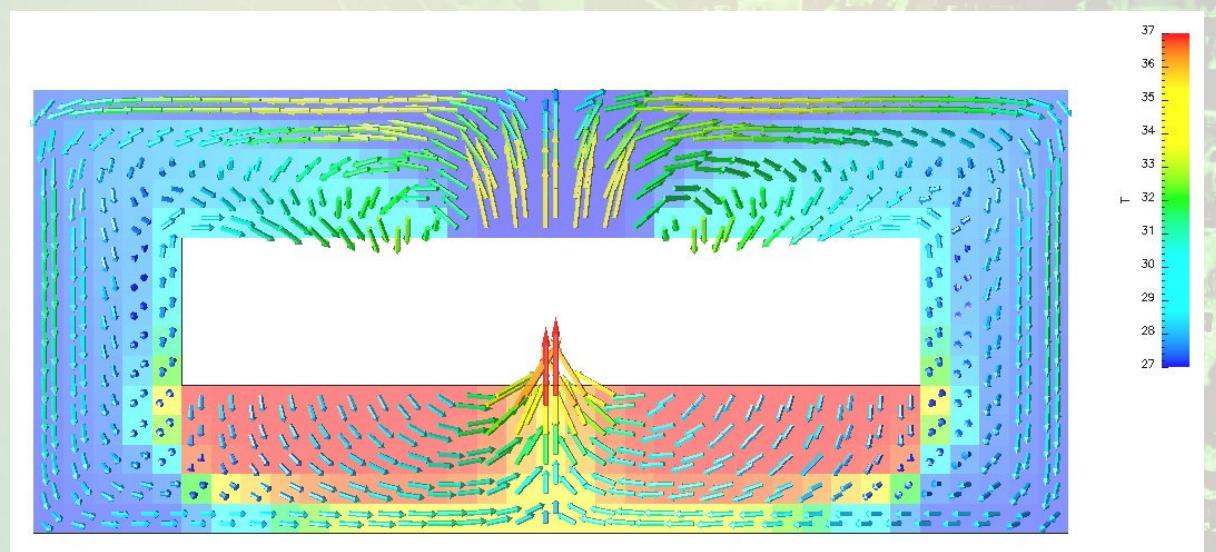
Temperature Comparison

Space gradient(m)	Run time	Max (°C)	Min (°C)	Max difference (°C)	Average difference (°C)
3×10^{-5}	1h14m48s	30.5638	16.1112	n/a	n/a
3×10^{-4}	1h14m54s	30.5638	16.1112	0	0
3×10^{-3}	1h14m16s	30.5638	16.1112	0	0
3×10^{-2}	59m42s	30.492	16.1113	4.9385	0.48153
3×10^{-1}	18m59s	30.492	16.1113	4.9385	0.48153

3×10^{-3} is the largest minimum space gradient with no error.

Turbulence

- state of fluid motion which is characterized by apparently random and chaotic three-dimensional vorticity.
- Need much more time for calculation
- Not sure if it is necessary for data center



Turbulence

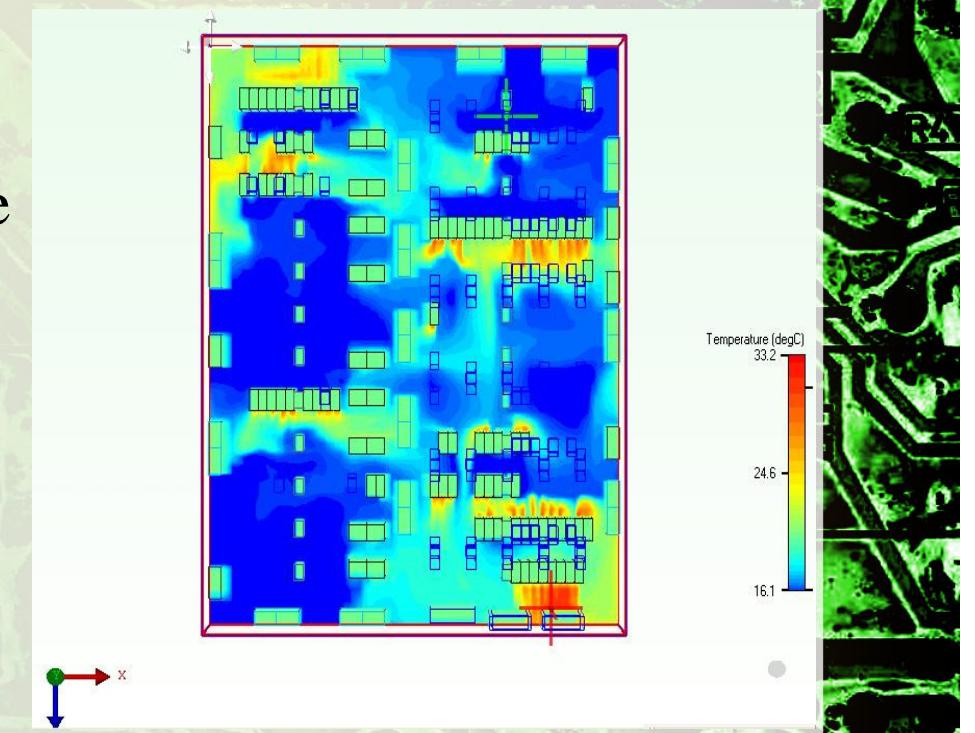
Temperature Comparison

Turbulence Mode	Space gradient(m)	Max (°C)	Min (°C)	Max difference(°C)	Average difference (°C)
On	3×10^{-5}	30.5638	16.1112	n/a	n/a
Off	3×10^{-5}	30.4927	16.1111	8.8862	0.5166
On	3×10^{-4}	30.5638	16.1112	n/a	n/a
Off	3×10^{-4}	30.4927	16.1111	8.8862	0.5166
On	3×10^{-3}	30.5638	16.1112	n/a	n/a
Off	3×10^{-3}	30.4927	16.1111	8.8862	0.5166

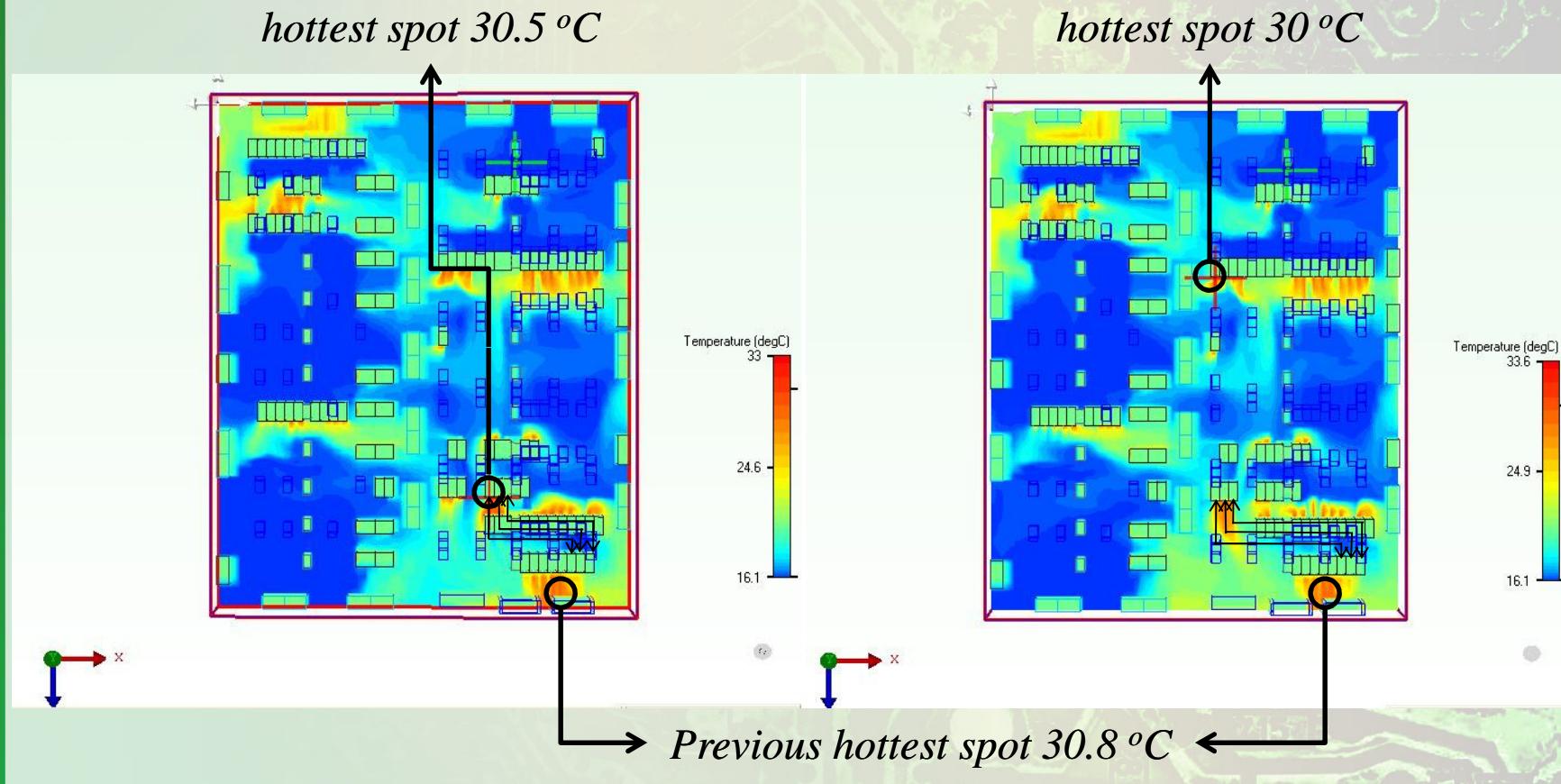
Turbulence is still in consideration due to the large maximum difference.

Work Allocation

- There are some hot spots in the current MACC work allocation
 - More energy cost, and shorter equipments' lifetime
-
- Switch servers' work load
 - Decrease hot spots temperature
 - Eliminate hot spots



Work Allocation



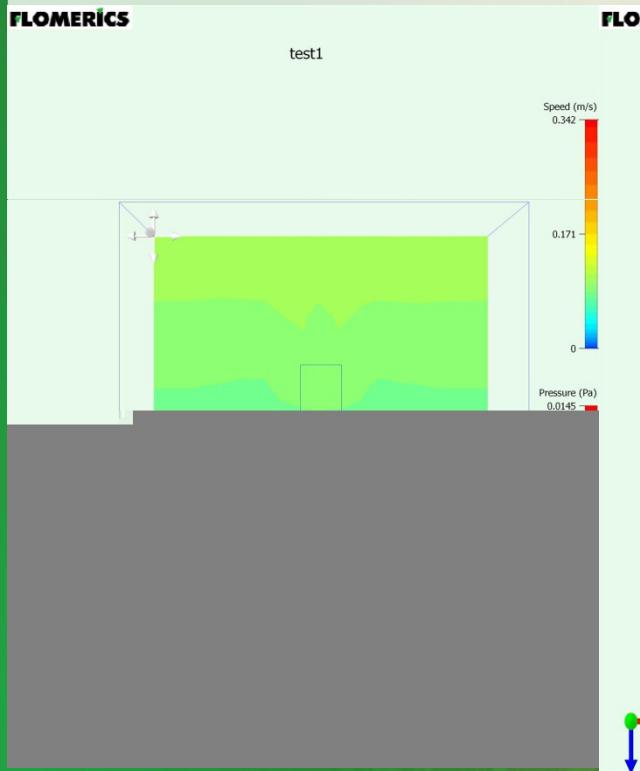
Dolfyn Validation



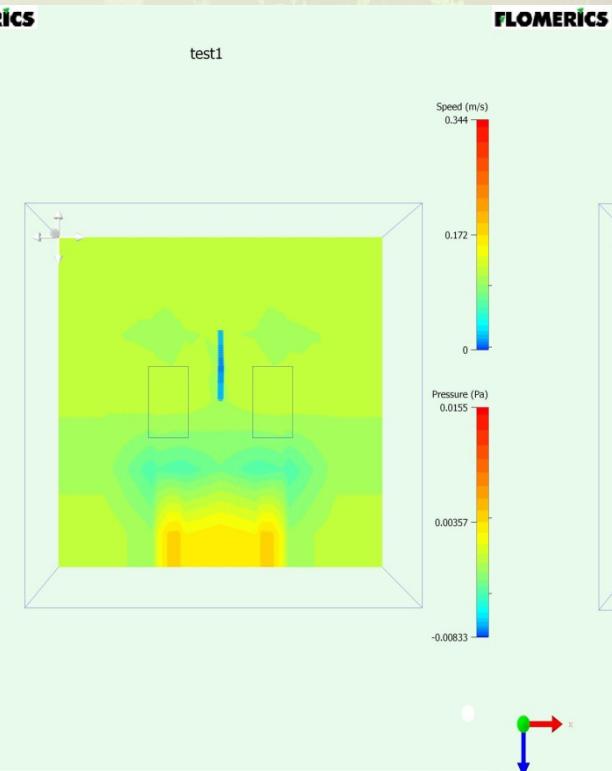
Models

Pressure

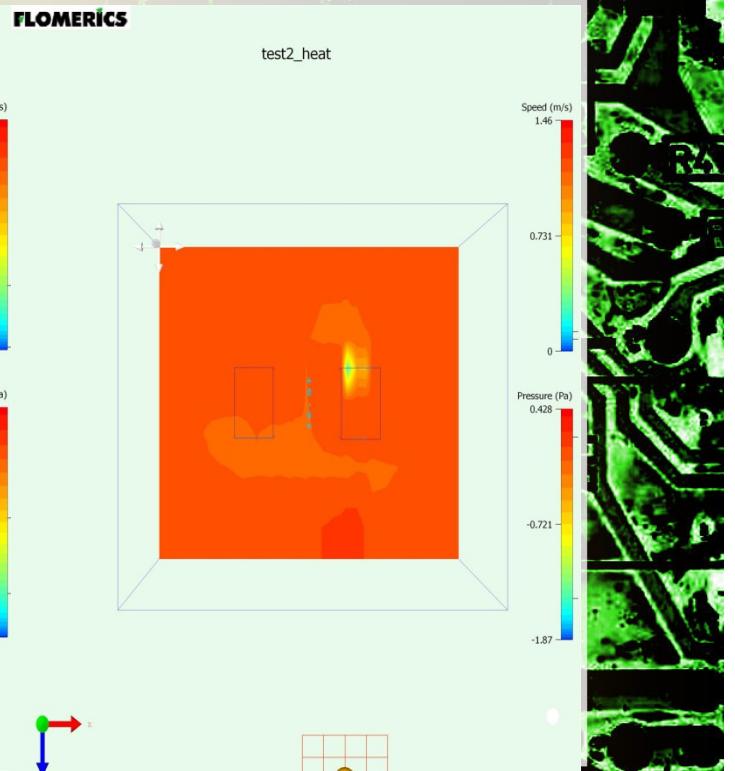
One server
without heat



Two servers
without heat



One server, one cooler
with heat



Auto Tester

Goal

Automatically compare the results from Flovent and Dolfyn

Comparison Method

- Arithmetic mean (default 2)

$$\Delta\beta = \frac{\sum X_i}{n} - Y$$

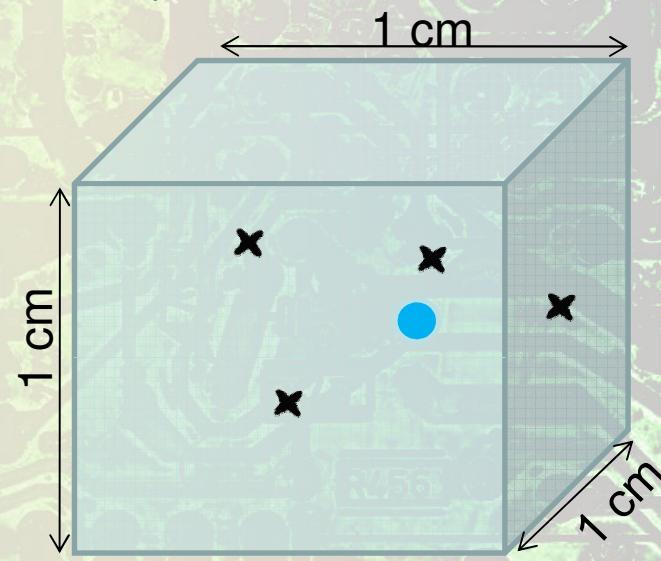
- Variance of the difference (default 0.25)

$$\Delta\alpha = \frac{\sum (X_i - Y)^2}{n}$$

- Arithmetic mean of square difference (default 1)

$$\Delta\varepsilon = \frac{\sum (\frac{\sum (X_i - Y)^2}{n})^2}{K}$$

K = number of Grids



✗ X_i : Flovent data point

● Y : Dolfyn data point

Auto tester

Execution

- autotest {Dolfyn output file} {Flovent output file}[-avr {maximum $\Delta\epsilon$ }]
[-diff {maximum $\Delta\beta$ } [-var {maximum $\Delta\alpha$ }]] [-size {maximum grid size}]
- autotest {Dolfyn output file} {Flovent output file} executes the auto-tester with default parameters.

Output

- Display “@ @@ @ Pass/Fail@ @@ @” on screen.
- Generate an overall output file contains $\Delta\beta$ for each grid.
- Generate a detail output file contains all the information.

```
@@@@@@@ Begin of a Cubic Point@@@ @@@@ @@@@  
Data from Flovent  
X = 2.241 Y = 3.518 Z = 0.4902 Value = 0.00095  
Data from Dolfyn  
No points from Dolfyn is within this cube.  
@@@@@@@ End of the Point@@@ @@@@ @@@@
```

```
@@@@@@@ Begin of a Cubic Point@@@ @@@@ @@@@  
Data from Flovent  
X = 2.5 Y = 1.503 Z = 0.4902 Value = 0.000508  
Data from Dolfyn  
X = 2.5 Y = 1.5 Z = 0.5 Value = 30.313
```

Statistical Information
Average of Difference is 35.1345 Variance of Difference is 1234.43
@@@@@@@ End of the Point@@@ @@@@ @@@@

Validation

In Progress


Conclusion

- MACC Data Center Model has been established in Flovent
- MACC Data Center Modeling Analysis
 - i. 3×10^{-3} is the largest minimum space gradient with no error.
 - ii. Turbulence is still in consideration due to the large maximum difference.
 - iii. Hot spots are unpredictable by simply switching workload allocation
- Dolfyn Validation
 - i. Three models have been set up in Flovent
 - ii. Auto tester has been implemented
 - iii. Validation is in progress

Questions and Answers