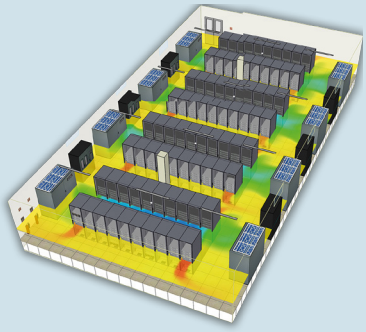
How Accurate Is 6SigmaDCX?

We know that our customers need **accurate results** that they can rely on to make critical decisions. We understand these challenges, and we've worked hard to ensure that 6SigmaDCX achieves this. Since the first release of the software, we've used the **expertise of our internal development and engineering teams** to develop room-scale models and their individual components. Furthermore, **independent audits** have been carried out by R&D establishments and educational bodies to validate the 6SigmaDCX software. The results of these audits, along with **positive messages from end users**, show that 6SigmaDCX provides the accuracy needed to make critical decisions about your facility's performance.

Introduction

Future Facilities is committed to ensuring that the 6SigmaDCX software suite operates as accurately as possible. Our highly experienced internal development team have an extensive knowledge of Computational Fluid Dynamics (CFD) and applying it to market-specific applications, while our engineering team - who specialize in data centers and electronics cooling - are constantly validating results for some of the most demanding clients in the industry. Together, they work to push modeling frontiers, consistently improving the accuracy of our software. Future Facilities also has a long history of working with educational and R&D bodies that audit and validate the 6SigmaDCX suite. All of this helps to ensure that we always maintain high levels of accuracy while we develop and improve software features, helping us to create world-leading CFD software that is second to none.



Figures 1, 2 and 3: The photographed exterior of a data center in real life (left), vs. the same exterior as modeled with rooftop details using DCX (middle), and the modeled interior of the data center (right). *The 6SigmaDCX software suite allows for very close and accurate representations of both the interiors and exteriors of physical facilities.*

Internal Development Team

Mark Bardsley - Principal Product Developer

Oliver Rosten - Senior Product Developer

Slava Semin - Director & Principal Solver Developer

Figure 4: CFD experts in the Future Facilities Development Team.

Three key members of our internal development team are widely regarded as CFD experts in the data center industry:

- **Mark Bardsley (Principal Product Developer)** - studied his undergraduate Bachelor's degree at the University of Cambridge, followed by a Master's degree at Princeton University - both in Mechanical Engineering. Importantly, he has 25 years of commercial CFD software development experience: with Ricardo Consulting Engineers; Flomerics; and, for the last 11 years, with Future Facilities as a principal product developer.

- **Oliver Rosten (Senior Product Developer)** - studied his undergraduate Physics degree (MPhys, 1st class) at Oxford University, and then went on to obtain a Ph.D. in Theoretical Physics at the University of Southampton. Following this, he completed postdoctoral research fellowships at Southampton, Dublin Institute for Advanced Studies and Sussex. With a deep understanding of modern C++, Oliver has an issue under active consideration for inclusion in the next C++ standard. He has worked at Future Facilities since 2011, and is currently a senior product developer.

- **Slava Semin (Director, Principal Solver Developer)** - studied his undergraduate Physics degree at the Moscow Institute of Physics and Technology (diploma with honours), followed by a Ph.D. in Physics and Mathematics, where the main focus of the research was designing CFD numerical algorithms to simulate flows. Slava has almost 30 years of experience working with CFD: as a senior scientist at a leading Russian rocket and spacecraft center, followed by roles as a solver developer at CHAM, Flomerics, and with an EU-funded grid computing project. He has been at Future Facilities since its beginnings in 2005 as a director and principal solver developer.

The experience and skillset of our development team adds a level of certainty, accuracy and precision to our simulation results that is yet to be matched by our competitors.

6SigmaDCX Library: The ACU

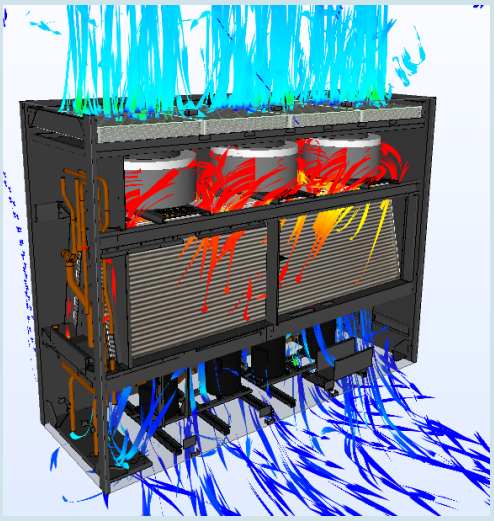


Figure 5: Smartcool detailed ACU. *This is one example of a wide range of library objects worked on by Future Facilities in partnership with Airedale (ACU manufacturers). These library objects enable users to improve the accuracy and precision of models.*

The 6SigmaDCX library contains a huge range of objects: the Design section consists of generic planning items, while the Vendor section contains over 4,000 objects representing real equipment from specific manufacturers. We work closely with manufacturers to create these, ensuring their performance in the software reflects reality. These objects – containing years of development work and expertise, along with accurate performance data – can simply be dragged and dropped straight into your model.

Our engineering team continuously works to improve our modeling accuracy through extensive testing and innovative object designs. They have continuously developed the Air Cooling Unit (ACU) object since the first release of the 6SigmaDCX software. In the beginning, the ACU was modeled as a simple box with uniform airflow. Today, the ACU is a complex object with master and independent control systems (see Figure 5). The timeline below shows how the ACU has developed over the years (see Figure 6).

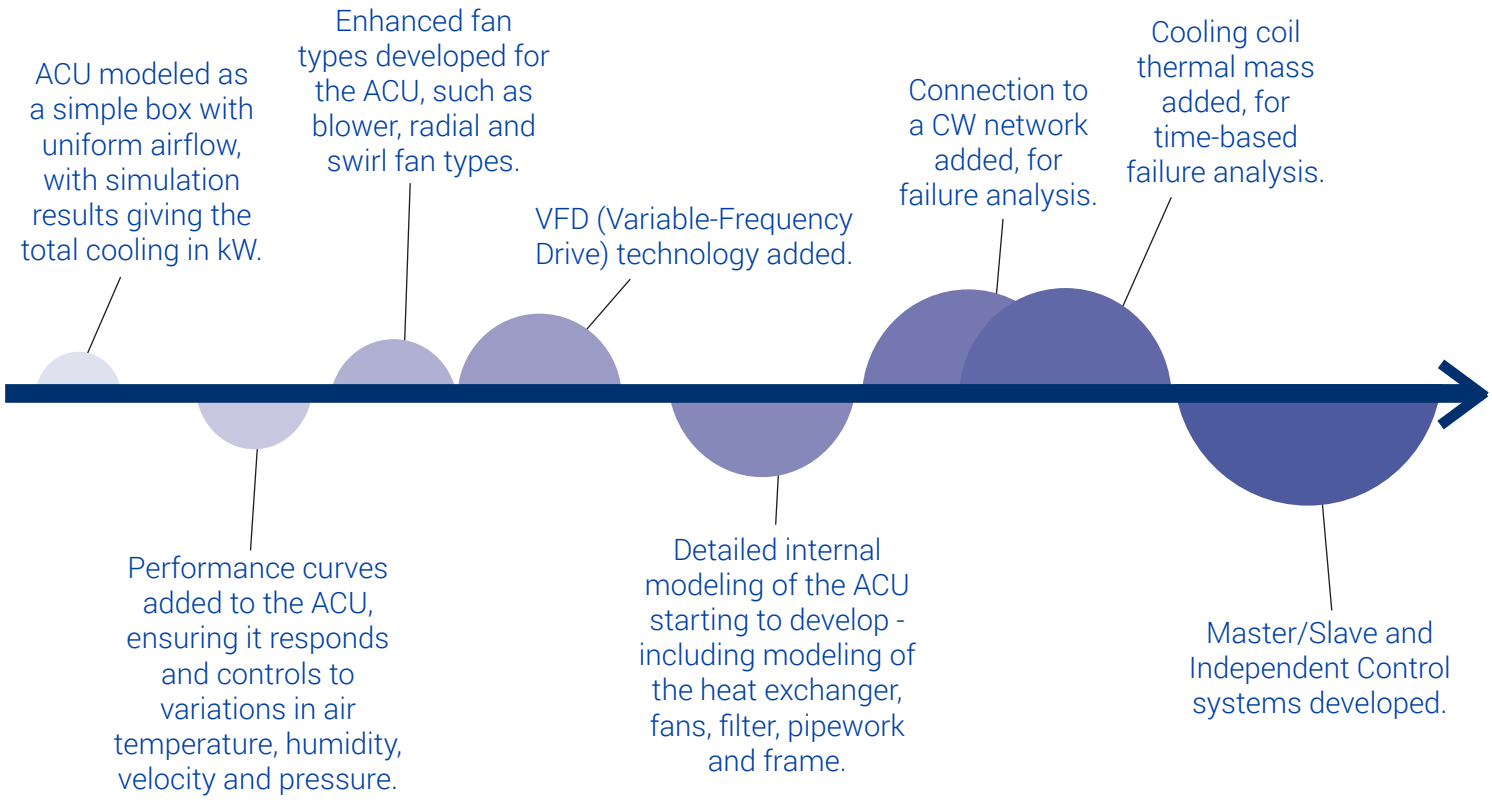


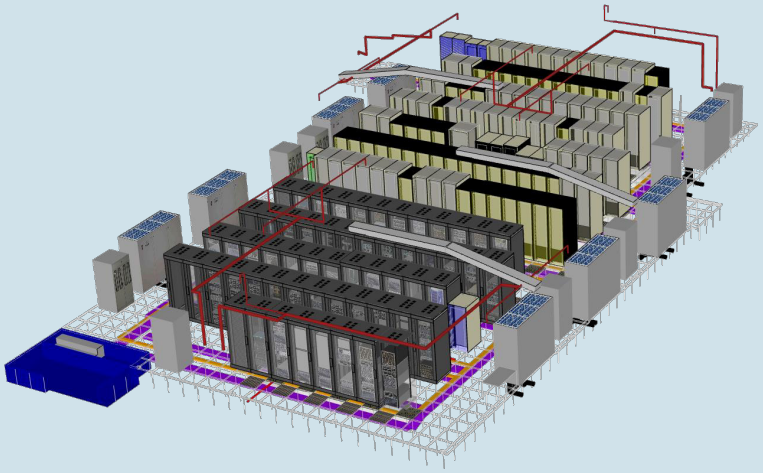
Figure 6: Timeline of evolution for the ACU object in the 6SigmaDCX software suite. *This timeline shows the new features added to the ACU to improve the accuracy of its simulation results.*

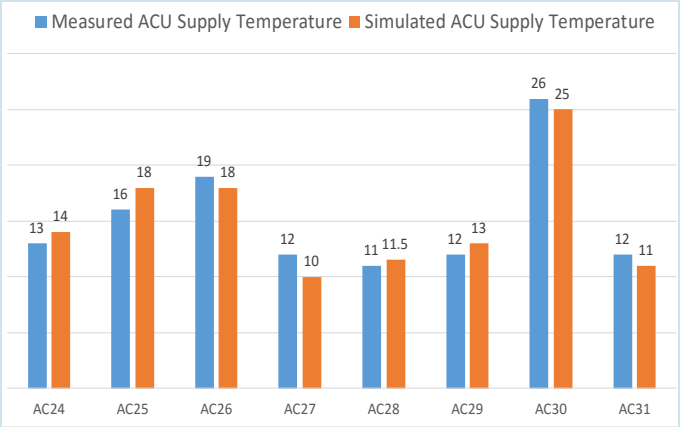
Calibration by Engineers

Future Facilities' engineering team are constantly performing their own in-house validation of our software results, as part of their consultancy work for data center clients. Our engineers work in a full range of data centers: new and old, large and small, neat and messy. As part of the quality assurance process for each project, they take measurements on site to compare against the output of the simulation - a process known as calibration.

Due to confidentiality agreements, we can't talk explicitly about the results that we have obtained during these calibrations. However, we *can* say that the matches between the software simulation results and the physical measurements have always satisfied our highly demanding clients - who use the results to make critical decisions about their business infrastructure.

Each calibration gives our team new knowledge about what's required to model data centers, which is passed onto the development team to improve the software. So, when you use 6SigmaDCX, you're benefitting from over a decade of engineering experience gained from modeling real data centers.





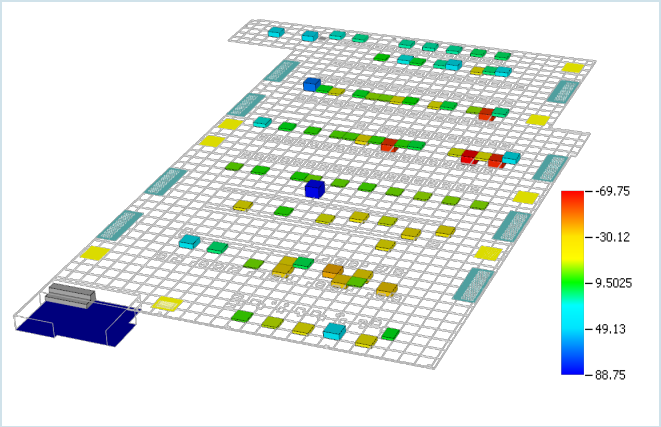


Figure 7 (top), 8 (bottom left), 9 (bottom right): Calibration by the engineering team. *The top image shows an example Virtual Facility model. All significant aspects of a data center facility are measured during a site survey to calibrate the Virtual Facility. As shown in the bottom left image, when there is agreement between real measurements from a real facility and measurements simulated in the Virtual Facility, this boosts confidence in both sets of data and proves that the modeling is accurate. More complex plots can be produced in the software to show the level of accuracy; for instance, the bottom right image shows a plot of the difference in simulated and measured flow rates from all of the floor grilles in the model.*

Independent Validation by End-Users

Independent validation often comes from our customers, who conduct their own systematic audits and validations of our software. Some have R&D facilities that validate our accuracy and functionality, while others validate in more critical environments.

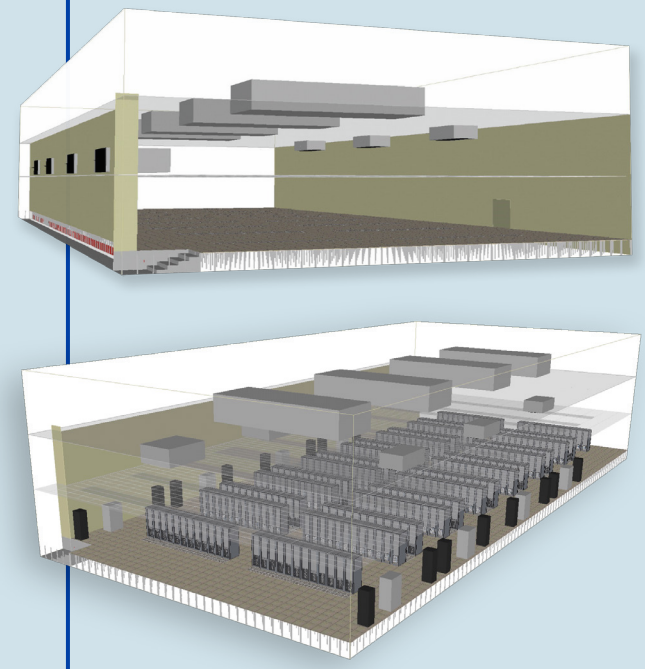
Compass Datacenters are one of several customers who have made their 6SigmaDCX validation results public (see Figures 11, 12 & 13). They concluded that:

"The results show a 1% error between measured and simulated values for grille flows, and 5% on AHU loads."

Today, this large colocation provider uses 6SigmaDCX to design its future data centers and operate its existing ones.

To learn more about the validation carried out by Compass Datacenters, visit:

https://journal.uptimeinstitute.com/the-calibrated-data-center-using-predictive-modeling



Figures 11 & 12: The Compass Datacenters' Shakopee facility as modeled with 6SigmaDCX, where the ACUs are on the rooftop. *Calibration testing showed measured values to correlate very closely with simulated results.*

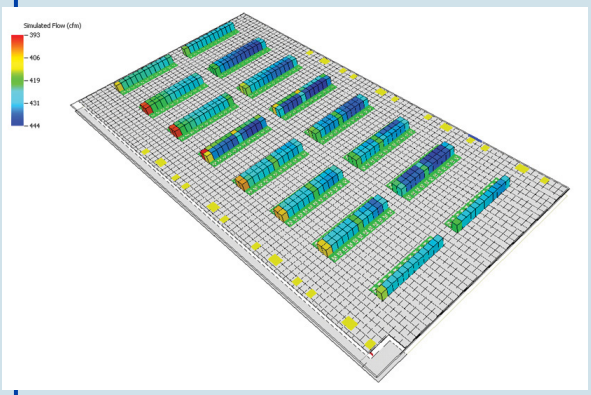


Figure 13: Simulated flow through the perforated tiles. *During the calibration process, all 336 perforated tiles in the Shakopee facility were measured. The total measured tile flow was found to differ by only 1% compared with the total simulated tile flow.*

Independent Validation by Binghamton University and ES2

Future Facilities has been a member of the National Science Foundation Center for Energy-Smart Electronic Systems (ES2) since 2012. ES2 develops ways to achieve optimal energy consumption for electronic systems - including data centers - by controlling resources and managing workloads. While it is largely a partnership between government, industry and academia, it remains staunchly independent of any commerical interest.

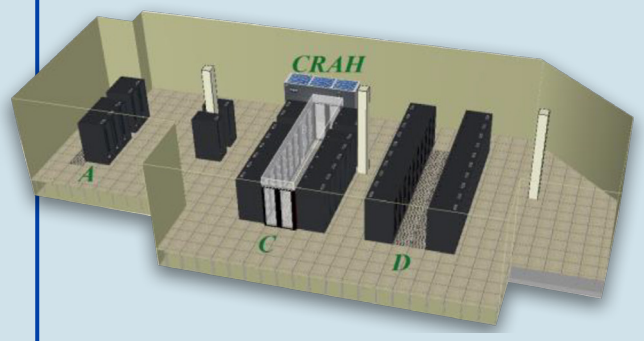
Binghamton University in New York is the lead university in ES2, and has been most prominent in performing validation and audits of CFD technologies. The university owns its own 'data center lab' (see Figures 14 & 15) that has been used to validate the 6SigmaDCX software suite. Binghamton's role has been crucial, because validation underpins a wide scope of ES2 research projects that rely on CFD capabilities to succeed. Therefore, it is imperative that an accurate CFD tool is employed.

Historically, the partner universities - and ES2 in particular - used general-purpose CFD code. However, the intelligence, automation and accuracy delivered by 6SigmaDCX gave ES2 reason to assess it as an alternative. Binghamton University invested a signficant amount of time validating 6SigmaDCX, focusing on the comparison between measured data and CFD simulation results (see Figure 16). They concluded resoundingly that the 6SigmaDCX models accurately represented the real facility, making it a tool of choice.

To learn more about Binghamton University's work with ES2, visit:

http://www.binghamton.edu/es2/

Figure 14: The virtual model of the data center lab, owned by Binghamton University. It consists of one main cooling unit, 46 perforated tiles and three cold aisles (labeled A, C and D).



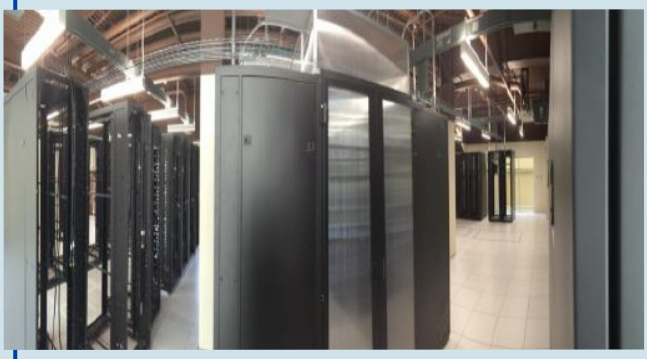


Figure 15: The layout of the data center lab. Practical measurements were made and checked against a CFD model. The highly accurate results led to ES2 and Binghamton adopting 6SigmaDCX for future DC operations.

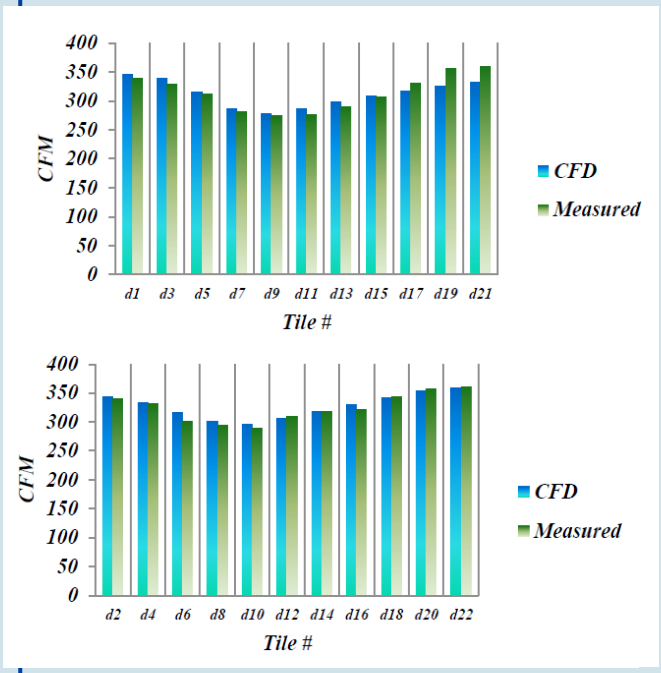


Figure 16: Comparisons between physical measurements and CFD simulation results. The results are for the aisle D left and right tile rows (top and bottom graphs respectively). The errors found were very small, generally under 5%.

Conclusion

With the ever-growing skills and expertise of our internal development and engineering teams, Future Facilities has been able to **refine model simulation results** to reach remarkable agreement with real life physical measurements. As a result of this, prominent R&D establishments and data centers - like **Binghamton, ES2 and Compass Data Centers** - are increasingly adopting 6SigmaDCX for projects that can benefit from CFD.

Through this continued relationship with Binghamton, ES2 and our customers, the 6SigmaDCX suite has benefitted from **substantial validation against cutting-edge measurements**. This has ensured that the software will continue to develop while maintaining the **accuracy and precision** required by DC professionals. While supporting these research projects, Future Facilities is helping to develop a deeper understanding of our data center space. More fundamentally, we are also helping to drive and develop **innovation and progression** for our industry and the people who work in it.

6Sigma DCX

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