Sensitivity Analysis of a Calibrated Data Center Model to Minimize the Site Survey Effort

Saurabh Singh[1], Kourosh Nemati[2], Vibin Simon[1], Ashwin Siddarth[1], Mark Seymour[3] and Dereje Agonafer[1]
[1]University of Texas at Arlington, Arlington, TX, US
[2]Future Facilities Ltd., New York, NY, US
[3]Future Facilities Ltd., London, UK
saurabh.singh6@mavs.uta.edu

Abstract

To reproduce a Digital Twin (DT) of a data center (DC), input data is required which is collected through site surveys. Data collection is an important step since accurate representation of a DC depends on capturing the necessary detail for various model fidelity levels of each DC component. However, guidance is lacking in this regard as to which components within the DC are crucial to achieve the level of accuracy desired for the computational model. And determining the input values of the component object parameters is an exercise in engineering judgement during site survey. Sensitivity analysis can be an effective methodology to determine how the level of simplification in component models can affect the model accuracy.

In this study, a calibrated raised-floor DC model is used to study the sensitivity of a DC component's representation to the DC model accuracy. Commercial CFD tool, 6SigmaDC Room is used for modeling and simulation. A total of 8 DC components are considered and eventually ranked on the basis of time and effort required to collect model input data. For parametrized component object, the object's full range of input parameter values are considered, and simulations run. The results are compared with the baseline calibrated model to understand the trade-off between survey effort/cost and model accuracy. For the calibrated DC model and of the 8 components considered, it was observed that the chilled water piping branches, data cables and the cable penetration seal (found within cabinets) have considerable influence on the tile flow rate prediction accuracy.

Keywords

Digital Twin, data center, calibration, sensitivity

Nomenclature

Data center – DC, Digital Twin- DT, ACU – Air Cooling Unit, PDU – Power Distribution Unit

1. Introduction

Data center thermal behavior can be reproduced by computer simulations using Computational Fluid Dynamics (CFD). Computer simulations or Digital Twin have become a widely used tool in many engineering applications [1]–[4]. CFD models can be employed to gain new insights into newly designed technology and to predict the thermal performance of DC at any operational changes [5]. Calibration, verification, and validation are three steps of producing an accurate model [6]A baseline model must be created and calibrated based on the current state of the facility.

In the computational modeling of data centers, the most representative models are achieved through site survey. Site survey allows the modeler access to a far greater amount of information than can conveniently be supplied by other data sources. Alongside gaining model input data, it also allows for the collection of measured performance data with which the model results may be compared. Building the Digital Twin requires you to create a model that is detailed in its level of information, but simple in its definition. Simplification of a DC component is achieved through geometry approximation and by the prudent selection of a component object model. Omitting details will always result in a model that is not an exact representation of the real facility, but modeling every nut and bolt is time consuming, unnecessary, and will generate an overly complex and slow model. One must always consider the time a task takes versus the relative benefit it brings. A lot of survey tasks are obvious, but as an example: it is not worth spending an hour detailing the metalwork inside a single rack containing one shelf with a powered-down 56K modem. A better use of that time is to capture the significant details for a rack design that appears many times in the facility.

In this paper, we conduct a sensitivity study of a calibrated DC model for factors which we believe can reduce amount of time and effort required for site surveys. The factors in this sensitivity study are the 8 DC components wherein the term 'factor' or component, as it will be referred to in this paper, is to be interpreted in a very broad sense. A factor is anything that can be changed in a model prior to its execution.

DC model used for sensitivity study:

Features	Units
Room Size	15,296 ft^2
Room height	>15 ft
Raised floor height	>3 ft
Number of ACU	17
Number of PDU	32
No. of Cabinets	254
Number of IT Equipment	1372
Number of Floor Grille/Tiles	262
Power density	37.9 W /sq.ft
Total cooling airflow	107,691 ft^3/min (cfm)

Table 1: Summary of the data center

The baseline model used for this study is a typical calibrated raised-floor data center provided by Future Facilities [7]. The model does not have a hot or cold aisle containment. Summary of DC is provided in Table 1. And Fig. 1 shows the isometric view of the DC model in 6Sigma Room.

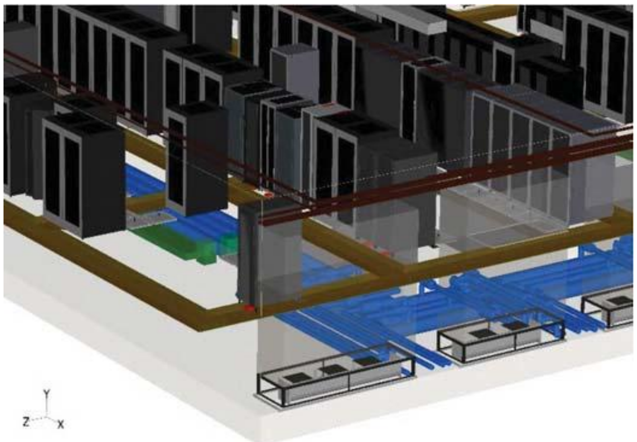

Fig. 1: Isometric view of a section of the data center model

2. List of Components

A total of 8 components were selected for the sensitivity study available in the model. Each component will be described briefly and for further information readers are referred to consult [8]. The components are listed below in Table 2.

Sr. No	Components
1	Cooling pipe branches
2	Underfloor data cables
3	Cabinet cable penetration seal
4	Unstructured cabling
5	Cables inside cabinet
6	Power conduit branches
7	Cabinet power strips
8	ACU support structure

Table 2: List of DC components considered

Cooling pipe branches: The main chilled-water cooling pipes offer significant obstruction to airflow; however, the smaller cooling pipe branches are often ignored. Ignoring an individual branch is warranted, however, depending on the size, the number of branches clustered together and what's in their vicinity they need to be included. For example, the branches meandering close to the ACUs can significantly affect the path and momentum of the ACU supply cooling jet. In the DC model considered, the main cooling pipes are installed within a trench that extends below the bottom side of the underfloor plenum. The smaller cooling pipe branches traverse across the underfloor plenum either towards the ACUs installed or are routed to a different floor. Capturing the branches in detail involves gaining access to the underfloor plenum and conducting a close inspection of the pipe sizes, bends, valves and fittings.

Underfloor data cables: These are data cables which are placed underfloor and are well stacked in cable trays or bundled together. The bottom of the tray can either be a wire-mesh sheet or a solid obstruction.

Fig. 2: Data cables in the underfloor plenum [9]

Cable penetration seal: The underfloor placed data cables penetrate through the raised floor to be connected to the cabinets or IT. To facilitate this, a hole is punched into the raised floor which needs to be sealed efficiently to prevent air leakage. The leakage sealing efficiency of cable penetration seal can vary based on the number of cables run through grommets and whether the cables are centered or pulled to a side [10].

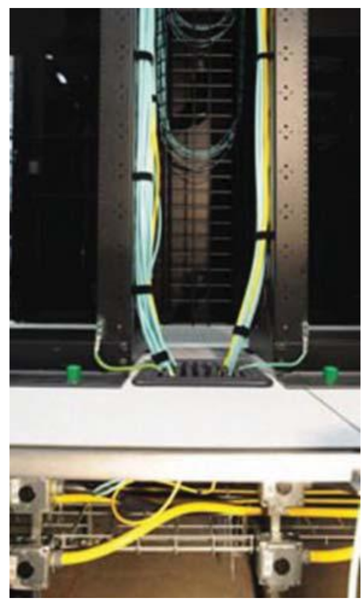

Fig. 3: A brush-type grommet to seal the cable penetration cut-out [11]

Unstructured data cable: These data cables are placed underfloor. They are not well ordered and stacked and hence are difficult to model. It is time-consuming to survey and record the details of unstructured cables. Moreover, the detailed representation increases the computational time with no viable improvement in prediction accuracy.

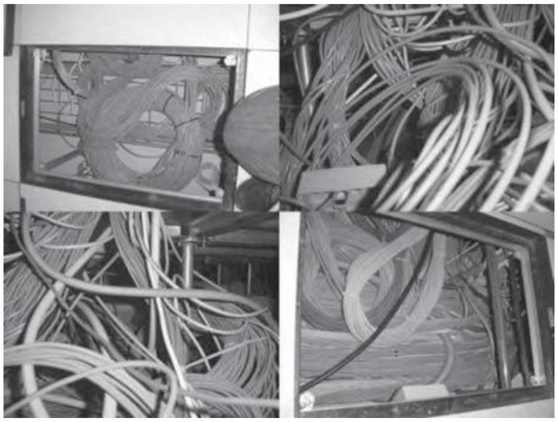

Fig. 4: Unstructured data cables in the underfloor [8]

Cables inside cabinets: Cabinets contain several IT equipment like server, switches etc. Cables are used to connect these IT which takes a form of a bundle inside the cabinet unit. A typical cabinet connected with cabling is shown in Fig.

Fig. 5: Cables inside a cabinet [12]

Power cables: These are cables which supply power to the cabinets from power distribution unit. These are in the form of conduits circular in shape and are run usually across the ceiling.

Cabinet power strips: Power strips are the sockets to which the IT equipment are connected to supply power. These power strips are mounted to the cabinets.

ACU support structure: ACU placement requires a support structure to bear its load. This support structure is part of what is commonly referred to as a floor stand. This is often accompanied with other components for seismic restraint and/or vibration isolation. An optional turning vane can be included to meet the airflow and acoustical requirements and are not to be ignored in the ACU model. The close proximity of fans, the height-adjustable frame and the survey effort involved due to poor access makes this a good candidate to study how it affects the air flow in the DC.

Fig. 6: ACU support structure with scoop [13]

Fig.7: Power conduits [14]

3. Sensitivity study of DC components:

3.1 Methodology:

The detailed DC model built in 6Sigma Room has been provided by Future Facilities [7]. The detailed model is calibrated with on-site measurements not limited to tile flow rates. Fig. 8 provides the minimum (min), maximum (max), mean (μ) and the standard deviation (σ) of tile flow rates for the baseline model and on-site measurements made with an airflow capture hood for every single tile.

The detailed model forms the baseline for comparison and is referred to as the baseline model in this paper. Simulations are run with a modification made for each component listed in Table 2. to obtain tile flow rate predictions for each simulation case.

The percentage change in the tile flow rate is calculated as shown by the equation below:

$$\%\ \text{Change} = \frac{(\text{Tile flow rate}_{B} - \text{Tile flow rate}_{S})}{(\text{Tile flow rate}_{B_{max}} - \text{Tile flow rate}_{B_{min}})} * 100$$

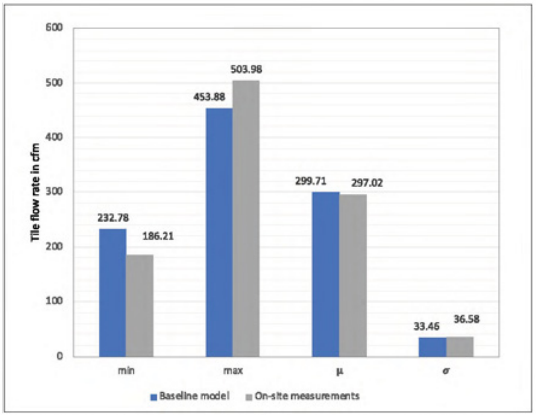

Fig. 8 Comparison of the baseline model with measured tile flow rates

B – Baseline model
S – Simulated model
B_{max} – Maximum value of tile flow rate in baseline model
B_{min} – Minimum value of tile flow rate in baseline model

Based on the % error and relative disagreement with the baseline model, the components are ranked from low to high sensitivity. The modification made for each simulation case is addressed in the next section.

3.2 Modification of DC components:

The level of detail necessary to model a component can either be the geometry or the parameters that constitute the component object model. In Table 3., the changes made to the component geometry or the model parameters are shown along with the corresponding values from the baseline model. As evident from Table 3, components pertaining to geometry definition are simplified either by ignoring or sacrificing details such as the sudden expansions found in cooling pipe branches as shown in Fig. 6. Fig. 7 shows the simplified geometry of the cooling pipe branches.

The components pertaining to cabling range from an individual loose cable to a bundle of data cables and to large power conduits. The volume obstruction effect of such cables can be accounted for by resistance coefficients or by model parameters that require visual inspection during survey [5]. To study the effect of underfloor data cables, changes were made in parameters used to define data cables. Data cables are defined using two parameters, cable density and fill percentage. For structured cables, the presence of a cable tray and the cable %fill and density allow for a simplified representation using a solid obstruction. To study the sensitivity of the data cables, they were first removed from the model completely and compared with the baseline case. Subsequently. The simulations were run for cable density in the increments of 25% and up to 100%. In the case of unstructured cabling, the degree of volume obstruction is difficult to estimate. Unstructured data cables are similar to the underfloor data cables in definition. To study its effect on tile flowrate, data cables were deleted. Cables within the cabinet and connecting IT are modeled using the cable density percentage. Again, the cables were deleted from the model to study how it affects the tile flow rates. Power conduit branches are defined in a similar way as the cooling pipe branches.

Cable penetration seal is defined using the sealing efficiency which varies from 0 to 100 where zero means the floor cut-out is sealed perfectly. To observe the effect of cable penetration seal, the sealing percentage is set to zero for the comparison with the baseline model. Furthermore, simulations were run for the full range of % sealing efficiency and in increments of 25%. To study the effect of the power cables on tile flowrate, power cables were removed from the model for the simulations, similar action was taken for ACU support structure. Whereas to study the effect of power strips, they were added to the model. Power strips are used to supply power to ITs.

Components	Definition	Range	Baseline	Modification
Cooling pipes branches	Geometry		Included	Deleted sudden expansions
Underfloor data cables	Cable density	0 - 100 %	5 - 80%	Deleted
Cabinet cable penetration seal	Sealing efficiency	0 - 100 %	70%	Sealing efficiency set to zero
Unstructured data cables	Cable density	0 - 100 %	2 - 10%	Deleted
Cables inside cabinet	Cable density	0 -100 %	0.5 - 10%	Deleted
Power conduit branches	Geometry		1.25 - 2.25 inch	Deleted
Cabinet power strips	Geometry		Not included	Included
ACU support structure	Geometry		Included	Deleted

Table 3: Component definition and modifications to the baseline model

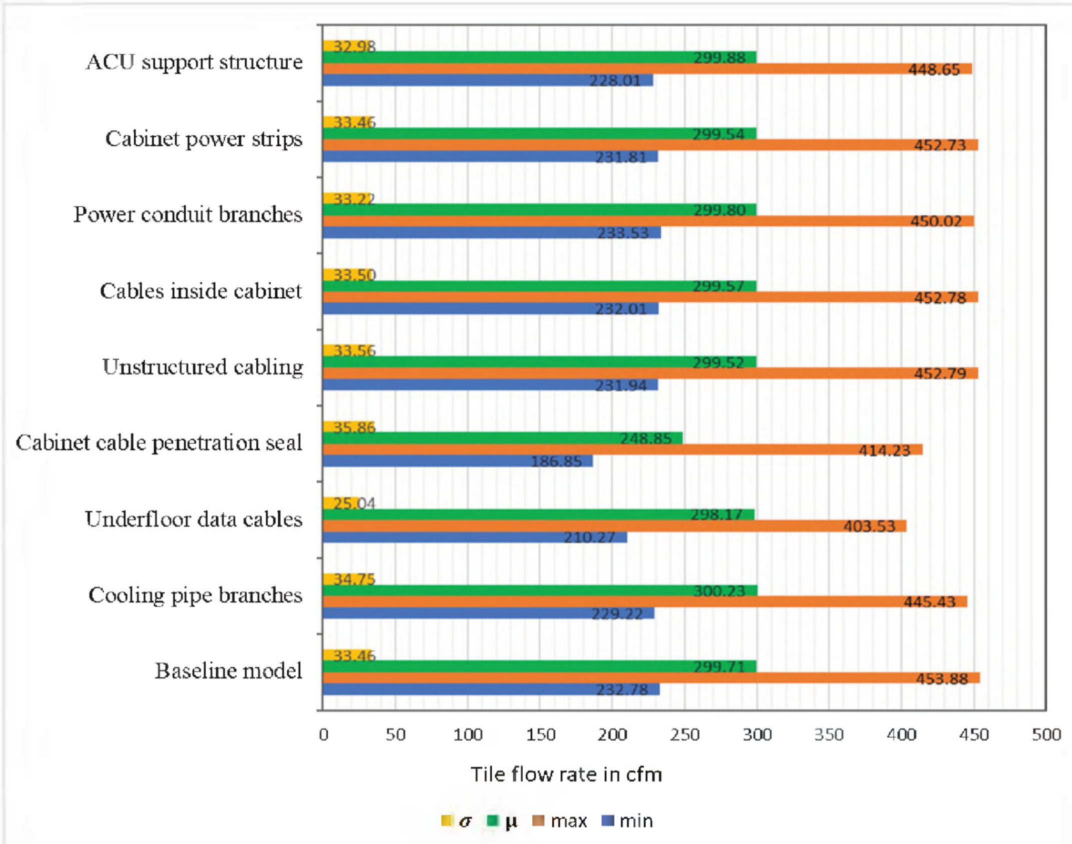

Fig. 9: Comparison of all the models with baseline model

4. Results:

The % error of the tile flow rates between the baseline model and simulated models are reported as minimum, maximum, mean, and standard deviation for each simulation case. The minimum and maximum tile flow rates could differ, however special attention should be given to mean and standard deviation values. Comparing the baseline with the various simulation results, if the values of the mean and standard deviation differ by small amount along with a small amount of difference in minimum and maximum values, we can conclude the component modification made for the simulation case is of low sensitivity. If the mean values are close but there is a considerable difference in standard deviation, or if the mean values itself have considerable difference, we can conclude that model has high level of disagreement. The results for individual components are shown next.

Cooling pipe branches: We observe from the Fig. 9 that minimum and maximum values have small difference in tile flow rate. The difference in average flow rate value and standard deviation value are in close range. From these observations we can say that level of disagreement is less in cooling pipe branches model and baseline model.

Underfloor data cables: The minimum and maximum tile flow rate values have considerable difference compared to baseline model. The average flow rate value is in close agreement, but we observe that there is considerable difference in the standard deviation value of model without data cables. As shown in Fig. 9, standard deviation value of this model is smaller as compared to baseline model which means tile flow rate is more evenly distributed in absence of underfloor data cables as compared to baseline model. From this observation we can conclude that underfloor data cables have significant impact on tile flowrate.

Further, when we increased the cable density from 0 to 100 % in steps of 25%, we observe from Fig. 12 that tile flow rate values fairly remained constant and close to baseline model values for cable density between 25 to 75%. This shows that reasonable accuracy can be obtained even after having 15 to 25% error in cable density calculation.

Cabinet cable penetration seal: From Fig. 9 we can see that there is considerable difference (decrease) in minimum and maximum tile flowrate. The average flow rate for cable penetration model decreases considerably (decrease by 50 cfm) which means that there is shift in tile flowrates. The difference in the standard deviation values between the models is small but considerable when compared to other component models. Following these observations, mainly the difference in the average values, it can be said that cable penetration seal has huge impact on tile flowrates. Further, Fig. 11 shows that as we improve the sealing efficiency from 0 to 100 the tile flow rate values increases which shows a strong relationship between sealing efficency and the tile flow rate.

Unstructured data cables: The results Fig. 9 shows that minimum and maximum flow rate is almost same to for the two models. The average tile flow rate value is almost same. Further, standard deviation values have a very small difference. From this observation we can say that unstructured data cables have very small level of disagreement between the two models.

Cables inside cabinet: The results Fig. 9 shows that minimum and maximum flow rate is almost same to for the two models. The average tile flow rate value is almost same. Further, standard deviation values have a very small difference. From this observation we can say that cables inside cabinet have very small level of disagreement between the two models.

Power conduit branches: The results Fig. 9 shows that minimum and maximum flow rate is almost same to for the two models. The average tile flow rate value is almost same. Further, standard deviation values have a very small difference. From this observation we can say that power conduit branches have very small level of disagreement between the two models.

Cabinet power strips: The results Fig.9 shows that minimum and maximum flow rate is almost same to for the two models. The average tile flow rate value is almost same. Further, standard deviation values have a very small difference. From this observation we can say that power strips have very small level of disagreement between the two models.

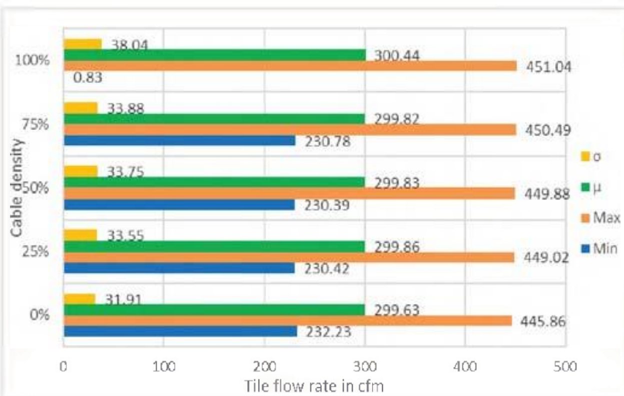

Fig. 10: Comparison of underfloor data cables with different cable density

ACU support structure:

The results Fig.11 shows that minimum and maximum flow rate is almost same for the two models. The average tile flow rate value is almost same. Further, standard deviation values have a very small difference. From this observation we can say that ACU support structure model has very small level of disagreement between the two models.

Comparing the above models using the minimum, maximum, mean and standard deviation gives us a good picture about the disagreement in tile flow rate compared to baseline model but lacks clarity in terms of relative level of disagreement with respect to each other. This is clear from the graphs as there is no scale which points toward the relative disagreement. To have better clarity in this context, we distributed percentage change in tile flow rate in bins of 3 percent from -25 to 35% and summed number of tiles in that range.

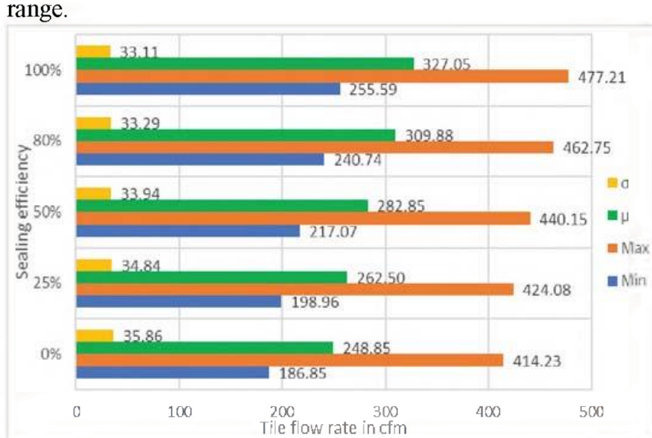

Fig 11: Comparison of cable penetration seal with different sealing efficiency

In Fig.12, x-axis is the percentage change in tile flow rate and y-axis is number of tiles. We observe that model without cable penetration seal has 83% of tiles in range of 20 to 26%. Similarly, model without data cables shows 57% of tiles in range of -7 to -1%, while the remaining 43% of tile is in range of 0 to 14%. The model with cooling pipe branches has 71% of tiles in range of -1 to 2%, while 28% of tiles in range of -7 to 5%. The models without Cables inside cabinet, Power strips Unstructured data cables have 98%, 97% and 95% of tiles respectively in range of -2 to 1%. The model without ACU support structure has 69% of tiles in range of -1 to 2% and remaining 31% tiles are in range of -4 to 5%. Table 5 shows detailed percentage of tiles for all the models.

5. Conclusions:

Data collected through simulations shows that cables inside cabinet, cabinet power strips, unstructured data cables and the ACU support structure have minimum effect on the tile flow rate. Cable penetration seal, Cooling pipes and Underfloor data cables have maximum effect on tile flowrate. Table 4 shows the components arranged in order having least to most effect on tile flowrate.

Rank	Components
1.	Cables inside cabinet
2.	Power strips
3.	Unstructured data cables
4.	Power conduit branches
5.	ACU support structure
6.	Cooling pipe branches
7.	Underfloor data cables
8.	Cabinet Cable penetration seal

Table 4: Components arranged in ascending order of their sensitivity to tile flow rate prediction

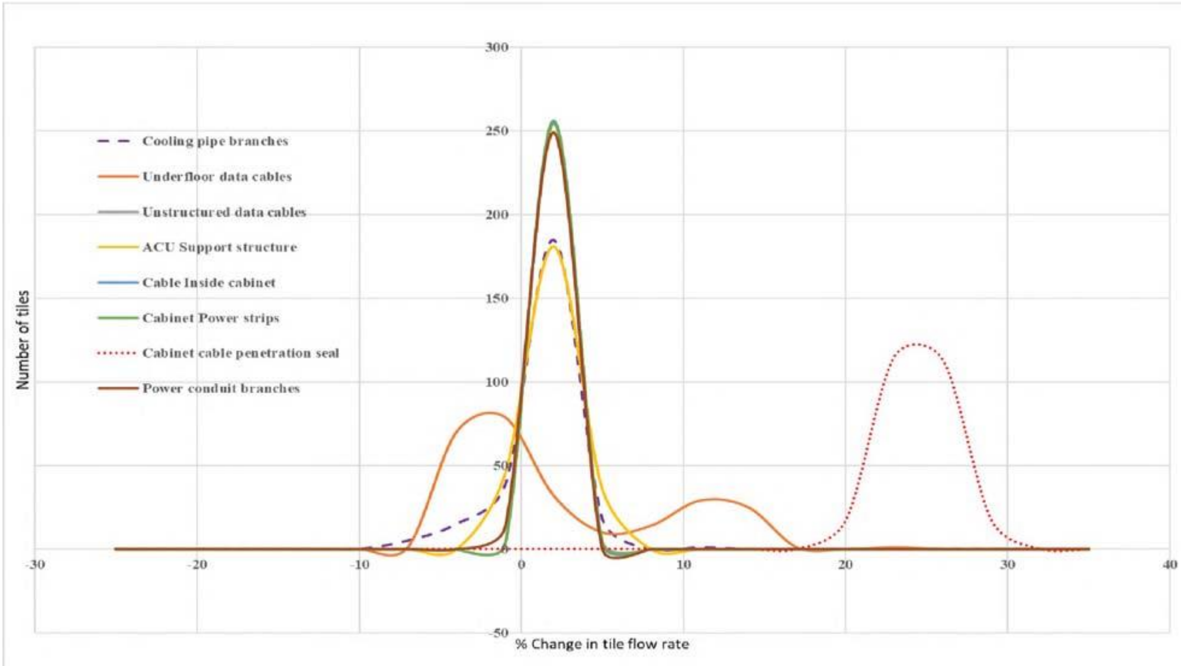

Fig 12: Comparing relative sensitivity of each model

The above table was prepared by simulating a raised floor data center model. Components were ranked to understand the relative sensitivity of the components. We believe that to develop more confident understanding of sensitivity of these components more data center models are needed to be studied to arrive at a concrete conclusion.

6. Discussions:

To demonstrate how the outcome of this sensitivity study helps in minimizing survey effort, consider Fig. 13. We see that cooling pipes branches in this case have sudden expansion of different diameter and lengths. To model these pipes, diameter, length as well as location of these expansions have to be measured which would be very tedious job and also time consuming. If accuracy obtained by ignoring those sudden expansions is acceptable, a large amount of time would be saved at survey sites. Similarly, we found that power conduits which are usually located near the ceiling have the least effect on tile flow rate. It takes lot of efforts to measure dimensions of the power conduit branches and also we have to account for the variation that may occur in vertical dimension.

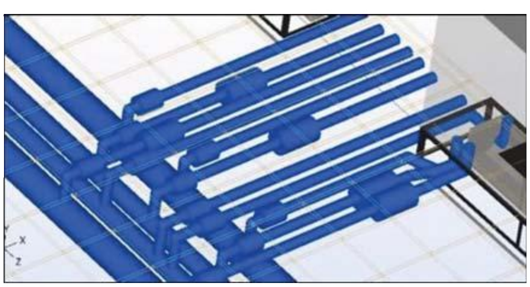

Fig. 13: Cooling Pipes in baseline model with sudden expansion

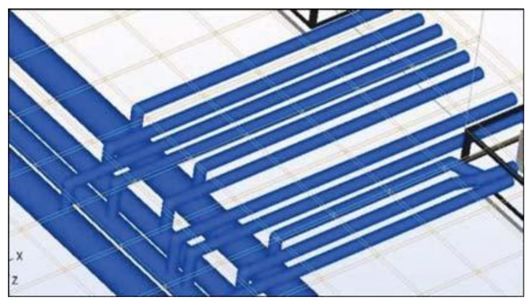

Fig. 14: Cooling Pipes simplified by deleting sudden expansion

As future work, 6 other calibrated DC models will be studied for the components considered here and several others found in a DC. Further, we plan to study how the changes in tile flow rate affects the other performance parameters like change in net flow rate across the IT, number of IT equipment that stay in compliance with ASHRAE standards, temperature difference across IT and effect on ACU supply and return air temperatures.

7. Acknowledgement:

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Percentage of Tiles								
Percentage Error (%)	Cooling pipe branches	Underfloor data cables	Unstructured data cables	ACU support structure	Cable inside cabinet	Power strips	Cabinet cable penetration seal	Power conduit branches
>= -13	0	0	0	0	0	0	0	0
-13 to -10	0	0	0	0	0	0	0	0
-10 to -7	2	0	0	0	0	0	0	0
-7 to -4	6	27	0	0	0	0	0	0
-4 to -1	15	30	1	17	1	1	0	5
-1 to 2	71	12	97	69	98	97	0	95
2 to 5	7	4	2	14	1	2	0	0
5 to 8	0	5	0	0	0	0	0	0
8 to 11	0	11	0	0	0	0	0	0
11 to 14	0	10	0	0	0	0	0	0
14 to 17	0	0	0	0	0	0	0	0
17 to 20	0	0	0	0	0	0	6	0
20 to 23	0	0	0	0	0	0	44	0
23 to 26	0	0	0	0	0	0	43	0
26 to 29	0	0	0	0	0	0	6	0
29 to 32	0	0	0	0	0	0	0	0

Table 5: Percentage of tiles in particular percentage error range for all models

References

[1] M. Grieves, "Origins of the Digital Twin Concept," 2016, doi: 10.13140/RG.2.2.26367.61609.

[2] F. Tao and M. Zhang, "Digital Twin Shop-Floor: A New Shop-Floor Paradigm Towards Smart Manufacturing," *IEEE Access*, vol. 5, pp. 20418–20427, 2017, doi: 10.1109/ACCESS.2017.2756069.

[3] B. Schleich, N. Anwer, L. Mathieu, and S. Wartzack, "Shaping the digital twin for design and production engineering," *CIRP Annals*, vol. 66, no. 1, pp. 141–144, Jan. 2017, doi: 10.1016/j.cirp.2017.04.040.

[4] A. Rasheed, O. San, and T. Kvamsdal, "Digital Twin: Values, Challenges and Enablers," *arXiv [eess.SP]*, Oct. 03, 2019.

[5] K. Nemati, A. Zabalegui, M. Bana, and M. J. Seymour, "Quantifying data center performance," in *2018 34th Thermal Measurement, Modeling & Management Symposium (SEMI-THERM)*, San Jose, CA, Mar. 2018, pp. 141–147, doi: 10.1109/SEMI-THERM.2018.8357365.

[6] C. J. Roy and W. L. Oberkampf, "A comprehensive framework for verification, validation, and uncertainty quantification in scientific computing," *Comput. Methods Appl. Mech. Eng.*, vol. 200, no. 25, pp. 2131–2144, Jun. 2011, doi: 10.1016/j.cma.2011.03.016.

[7] "6SigmaRoom CFD Software | Future Facilities." https://www.futurefacilities.com/products/6sigmaroom/ (accessed Feb. 08, 2021).

[8] M. Seymour, "Computational Fluid Dynamics Applications in Data Centers," in *Data Center Handbook*, Hoboken, NJ: John Wiley & Sons, Inc, 2014, pp. 313–341.

[9] E. Csanyi, "Underfloor cable systems explained in detail | EEP," *EEP - Electrical Engineering Portal*, Mar. 24, 2014. https://electrical-engineering-portal.com/underfloor-cable-systems (accessed Feb. 08, 2021).

[10] J. R. Fink, "Plenum-Leakage Bypass Airflow in Raised-Floor Data Centers," *ASHRAE Transactions*, vol. 121, pp. 422–429, 2015.

[11] American Tech Supply, "Raised Floor Grommets." https://www.americantechsupply.com/datacenterfloorgrommets.html (accessed Feb. 08, 2021).

[12] "5 Key Elements To Consider When Designing A Data Center," *DataStrait Networks.* http://www.datastrait.com/blog-news/5-key-elements-to-consider-when-designing-a-data-center (accessed Feb. 09, 2021).

[13] Kinetics Noise Control Inc., "Computer Room Floor Stand." https://kineticsnoise.com/hvac/computer_room_floor_stand.html (accessed Feb. 06, 2021).

[14] Digital Realty Trust, "Electrical conduit | Electrical conduit in a data center. Pho… | Flickr." https://www.flickr.com/photos/data-centers/4011192919 (accessed Feb. 08, 2021).