Cooling Entire Data Centers Using Only Row Cooling

White Paper 139

Revision 1

by Jim VanGilder and Wendy Torell

> Executive summary

Row cooling is emerging as a practical total cooling solution for new data centers due to its inherent high efficiency and predictable performance. Yet some IT equipment in data centers appears incompatible with row cooling because it is not arranged in neat rows due to the nature of the equipment or room layout constraints, suggesting the ongoing need for traditional perimeter cooling to support these loads. This paper explains how a cooling system comprised only of row coolers, with no room cooling system, can cool an entire data center, including IT devices that are not in neat rows.

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Introduction

Row cooling has emerged as a best practice for efficiently cooling IT equipment in computer rooms and data centers. With this cooling approach, the cooling units are coupled to (and possibly integrated within) the rows of racks, providing much better predictability, higher density, higher efficiency, and a number of other benefits. A detailed discussion of the benefits and applications of row cooling can be found in White Paper 130, *The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers*.

Link to resource
White Paper 130
The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers.

For typical data centers, the majority of IT equipment consists of standard rack-mount servers, and other rack-mount equipment such as switches. These devices can be installed in racks that are configured in hot aisle / cold aisle layouts for optimized cooling. However, typically, there is also a small percentage of equipment that cannot go into these standard rows of racks, because:

- they are not rack-mount devices
- their form factor doesn't allow them to line up with racks
- their airflow is not front to back and would cause mixing of air in the hot & cold aisles
- the device needs to be strategically located (i.e. a central location for storage rather than multiple disk arrays)

The term "ancillary equipment" is used in this paper to mean any stand-alone equipment not arranged in standard alternating hot aisle / cold aisle rows. In typical data centers, this equipment includes devices such as switches, storage equipment, networking gear, and power distribution equipment. This equipment is generally lower in power density and accounts for approximately 5-10% of the IT load power for most data centers; however, depending on the business application, (e.g., a company whose primary application is data storage), this can be significantly higher.

> "Because of a lack of good science, data center designers tend to be very conservative in how they deal with cooling for these loads, and provision excess dedicated cooling in these ancillary areas."

Because of a lack of good science, data center designers tend to be very conservative in how they deal with cooling for these loads, and provision excess dedicated cooling in these ancillary areas. In the majority of cases, it is not necessary to provide additional cooling, as row cooling can effectively cool the entire data center, including the ancillary loads,

TradeOff Tool 12, *InRow Ancillary IT Equipment Cooling Calculator* (**Figure 1**), can help demonstrate to data center professionals how a pure row cooling strategy can effectively support their entire data center, without the need for additional cooling..

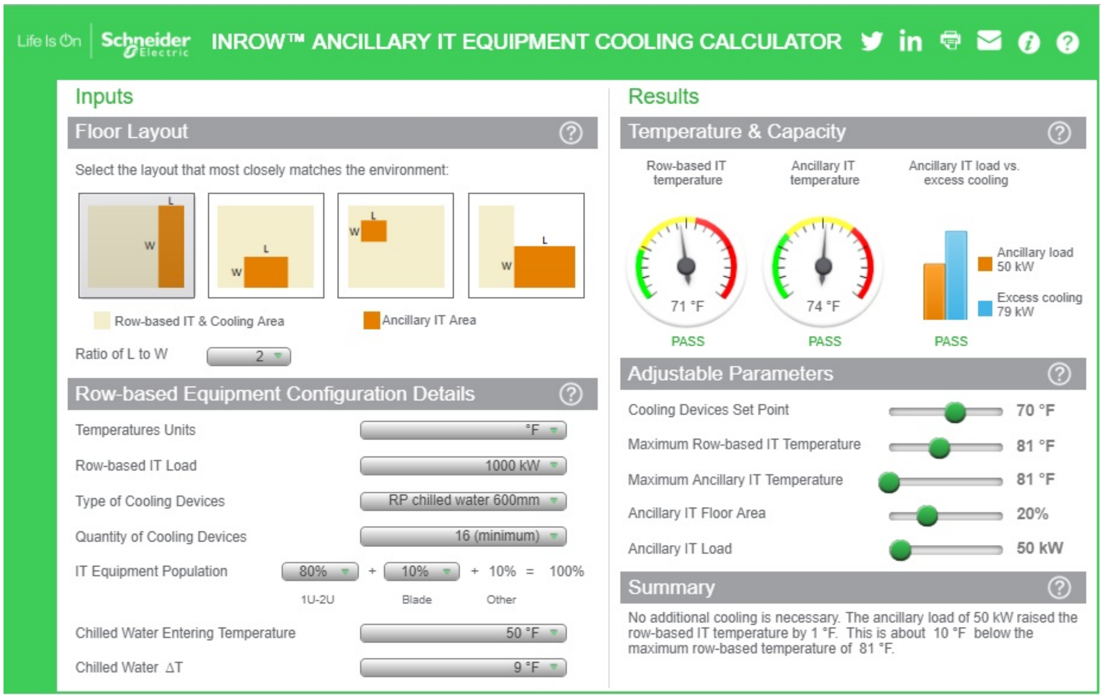


Figure 1

Screenshot of InRow Ancillary IT Equipment Cooling Calculator

(Click figure to link to live version of tool)

The advantages of cooling the entire room with only row coolers

A hybrid cooling architecture is a useful strategy when an existing data center with perimeter cooling has a requirement for supplemental row cooling. **However, when a new data center is being designed, and row cooling is being considered for the primary cooling means, there are significant benefits of going with *purely* row cooling vs. a hybrid approach.** The next section, *How row coolers can support more than just the row-based loads*, explains why perimeter cooing is not needed for base room cooling and/or to specifically target the non-row-based IT loads.

Cooling the entire room with only row coolers compared to a mix of row and perimeter coolers results in the following advantages:

- **Allows elimination of the raised floor** – Perimeter coolers generally distribute air to IT equipment via a raised floor plenum. The cost associated with installing and maintaining the raised floor can be eliminated when row coolers are used to cool the entire space.
- **No fighting between row and perimeter coolers** – Both temperature and humidity fighting can occur when two distinct cooling architectures are deployed in a room. This leads to ineffective operation and increased energy bills. When only row coolers are used, their operation is coordinated to avoid this.
- **Lower capital expense** – Over-conservative designing of a data center with row and perimeter coolers results in significant capital expense waste. Up to half of this expense can be eliminated by relying on the row coolers to cool the entire data center load.
- **Simpler redundancy** – If a data center has a redundancy requirement (i.e. N+1, N+2, or 2N), further capital expense could be avoided by eliminating the need for redundant coolers for the perimeter units.
- **Lower energy costs** – Over-provisioning of coolers results in added energy expense, especially if the unnecessary coolers have fixed-speed fans, which is common in perimeter units supplying a raised floor.

- **Lower maintenance costs** – Using only row coolers means no additional maintenance contracts for perimeter coolers, reducing the operating expenses in the data center.
- **Less vendor interactions** – Often times when hybrid designs are considered, designers look to multiple vendors to supply the different systems. Using additional vendors means additional complexity in maintaining the data center operation.

How row coolers can support more than just the row-based loads

Although not intuitive, a row-based cooling unit, located within a row of IT racks can cool IT equipment that is located outside of the row(s). Even row-based coolers in hot aisle containment systems can support these ancillary loads in many cases. **Figure 2** illustrates a sample floor layout of a data center utilizing row-based coolers with ancillary loads placed in one area of the room. The interactions of row-based coolers with the surrounding environment can be complex, and is often analyzed through computational fluid dynamics (CFD) modeling, but there are some basic laws of physics that explain how it is possible for these coolers to pick up the additional heat loads.

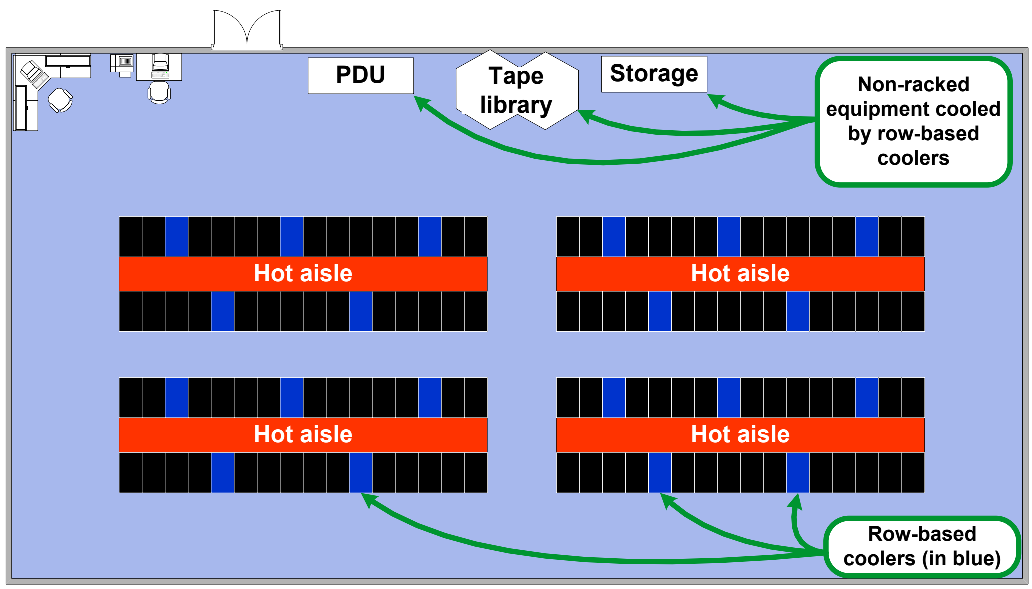


Figure 2

Sample data center layout with row cooling and ancillary IT equipment

So, how can row-based coolers, configured to support row-based IT equipment support these ancillary loads? First, it is important to understand that row coolers are variable capacity devices that are capable of over-supplying cold air to the cold aisle. Normally they operate in balance with the local IT equipment in the row, adjusting their capacity to the inlet temperature of the IT loads. When the system is in balance, the supply temperature from the cooler is equal to the IT inlet temperature. When an additional heat load is added outside of the rows, the temperature of the overall room environment increases due to air mixing. When this increase is sensed at the row by the row coolers, they will increase their air volume and cooling capacity in response. Since the increased airflow is greater than required by the IT equipment in the row, the excess begins to flow into the room space, cooling the room and any devices located in it. The horizontal

> **Heat removal equation**
>
> $Q = (CFM \times \Delta T)/3200$
>
> where,
>
> Q = sensible heat to be removed in kW
>
> CFM = cooler airflow (cubic feet per minute)
>
> Δ T = temperature difference (in Fahrenheit) between return and supply of cooler
>
> 3200 = constant used to account for the properties of air under standard conditions and unit conversions

airflow pattern of the row coolers, along with the airflow caused by the non-row IT equipment causes sufficient mixing to create effective room cooling. **Figure 3** illustrates the flow of what happens when ancillary loads are added in this case.

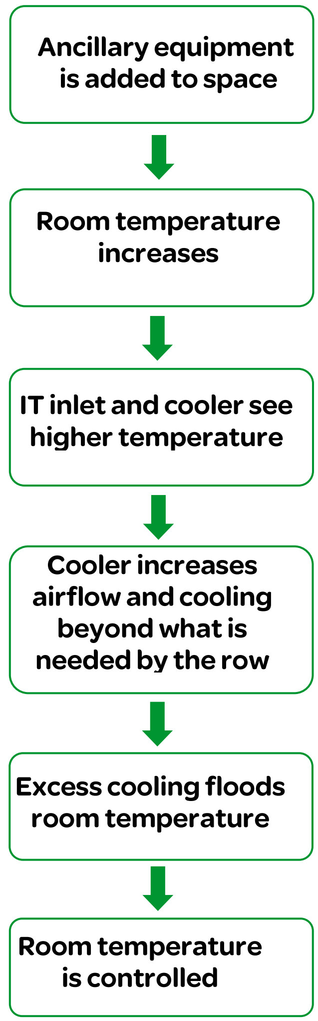


Figure 3

High-level flow of what happens when ancillary load is added

The steps describing how the row-based coolers “pick up the ancillary load” are the same even when containment is used. In this case, the row coolers still see the increase in room temperature caused by the non-row equipment and increase their airflow and capacity as a result. The contained row becomes a net generator of cool air from the room perspective, and that cool air causes mixing in the room that holds the hot spot temperature down.
In each case we do expect the non-row equipment to operate at slightly higher temperature than the row equipment, because it is not coupled as well to the row coolers. Should we be concerned about the temperature rise in the data center? Often times, the supply temperature of the row-based coolers (68˚F is common) is set well below what the IT equipment can tolerate (80.6˚F is ASHRAE’s recommended maximum). When this is the case, a small temperature rise of the non row-based equipment is acceptable and may be no worse than the temperature rise if a traditional raised floor system was installed.

A model for assessing cooling needs for stand-alone loads

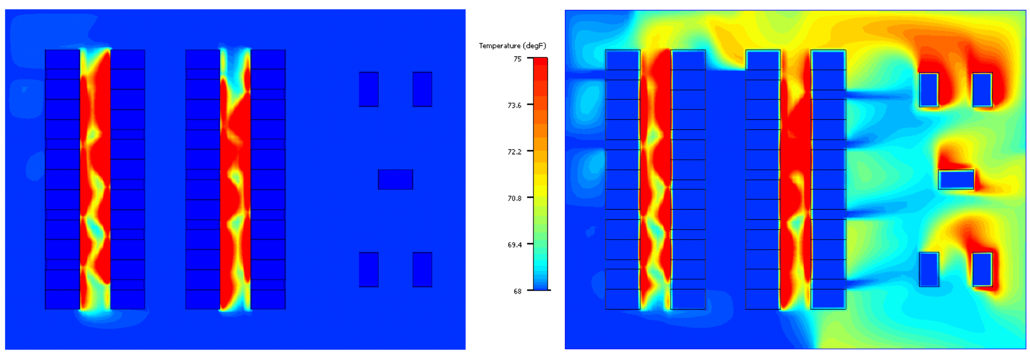
Computational fluid dynamics (CFD) modeling is a useful tool for understanding how air moves throughout a data center space. Over 200 CFD simulations were completed to analyze the effects of ancillary loads on airflow and temperature in the data center space.

When an ancillary load is placed in a data center, the area immediately around that equipment will get hotter than the rest of the data center. In essence, the equipment becomes an additional heat load which causes a "hot spot", and the temperature will generally rise quickly as the ancillary load is increased, as there is no cooling directly in this area of the room. This temperature rise can be estimated through the CFD studies and reduced to an empirical correlation based on the floor area and power associated with both the ancillary and row-based data center spaces plus a characterization of the shape and location of the ancillary space.

The remainder of the data center (in which the row-based equipment is located) also gets heated by this ancillary equipment, and it does so in a surprisingly uniform fashion. This temperature rise may be estimated based on a simple heat balance equation. The CFD images in **Figure 4** illustrate how the temperature in the row-based portion of the data center rises, but remains fairly uniform after the ancillary equipment is added. While there are the expected hot areas at the exhaust locations of the ancillary equipment, the intake air remains relatively cool as denoted by the light blue areas. The ancillary equipment is being effectively cooled by the row cooling units.

Figure 4

CFD images of data center with and without ancillary load. With ancillary load, temperatures are different but reasonably uniform over respective row-based and ancillary areas.



Without Ancillary Load

With Ancillary Load

Based on the CFD models and heat balance equations, a model was developed that identifies the parameters affecting the temperature rise in both the row-based and ancillary areas, in order to determine the practical limits of using row coolers to cool ancillary devices. The parameters that affect whether this approach will be effective fall under three categories:

- geometry of room
- IT equipment
- cooling configuration

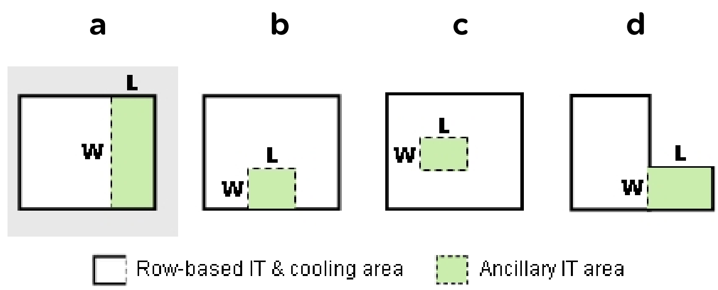
Geometry of room

The CFD analyses showed minimal correlation between where the ancillary equipment is placed in the room to how well the row-based coolers could pick up the additional heat load. Simulations were performed with the ancillary loads in several different places – next to the rows of coolers, off to the side, far away from the coolers, etc. In all cases, the additional heat increased the average room temperature fairly uniformly, distributing the ancillary load over essentially all coolers in the row-based area.

The placement of the ancillary loads does, however, have an impact on the temperature of the ancillary area. **Figure 5** illustrates four possible placements of the ancillary equipment within the data center. When the room is oriented like option “d”, the ancillary equipment is more isolated (in an alcove) from the main row-based area. In this case, the aspect ratio, or ratio of the width (W) to length (L) has a significant impact on the temperature in this area. For the other three layouts, the aspect ratio has negligible impact.

Figure 5

Placements of ancillary equipment in the data center



For fixed densities, the temperature in the ancillary area increases slowly with an increase in ancillary area or a decrease in row-based area since these scenarios lead to a greater fraction of un-cooled ancillary area in the data center. The temperature in the row-based area is less affected by the room geometry as the additional heat load is distributed fairly uniformly across the data center as discussed above.

IT equipment

The mix and power density of IT equipment in the data center also has an impact on the ability to remove the ancillary heat and the temperature rise because different types of IT equipment have different characteristic T’s across them. In this model, the assumed ΔT’s are shown in **Table 1**.

Table 1

ΔT by type of IT equipment

Type of IT	ΔT(˚F)	ΔT(˚C)
Blade servers	40	22
1U – 2U servers	30	17
Other	20	11

A cooler’s capacity to remove heat increases with return temperature. As the average ΔT of the IT devices increases or the row-based IT rack power density increases, the exhaust air becomes hotter, and the cooler’s return temperature increases. The increased capacity of the coolers means more capacity to pick up ancillary heat loads which decreases the ancillary area temperature. However, as the IT density (e.g. W/ft2) of the ancillary area increases, the temperature in the ancillary area also increases.

Cooling configuration

There are many attributes of the cooling configuration that impact the ability to remove the additional ancillary heat load. These include type and quantity of row-based cooler, chilled water entering temperature (chilled water supply temperature), and the chilled water ΔT. Based on these attributes, the capacity of the system can be determined. The control system of the coolers also impacts its capacity. In this model, it is (conservatively) assumed that cooling units are operating at maximum airflow.

TradeOff Tool, InRow Ancillary IT Equipment Cooling Calculator

Link to resource
TradeOff Tool 12
InRow Ancillary IT Equipment Cooling Calculator

Schneider Electric's Data Center Science Center created a web-based TradeOff Tool, InRow Ancillary IT Equipment Cooling Calculator to provide data center designers and operators with a means of determining if ancillary loads can be supported by their row-based coolers, given room geometry, IT equipment, and cooling configuration attributes discussed above.

The calculator allows the user to estimate the impact of several "adjustable parameters", including the cooler set point, maximum allowable temperatures for the IT equipment and ancillary loads, ancillary load, and the percentage of data center space taken up by the ancillary loads.

The calculator provides a summary stating one of three conditions:

- No additional cooling capacity is necessary. The cooling capacity is greater than the total load and the row-based IT and ancillary IT temperatures are within the defined thresholds.
- The cooling capacity is greater than the total load but the row-based IT and/or ancillary IT temperature(s) exceeded the defined threshold(s). In this case, either higher temperatures must be tolerated or additional cooling capacity must be added.
- In order to support the ancillary load, additional cooling capacity must be added to the ancillary area. This is because the ancillary load has exceeded the available cooling capacity and the cooling system is no longer able to effectively regulate the IT temperature.

Typical data centers, with ancillary loads on the order of 5-10% will not generally run into the third condition above, but for some data centers with a higher percentage of ancillary loads or with a room geometry in which ancillary loads are isolated in an alcove, the only alternative is to add additional cooling to the design in the ancillary area.

When additional cooling is required

When additional cooling is required to adequately cool the ancillary loads, it is often assumed that perimeter-based coolers are required. The reality is that row-based coolers can fulfill this need as well, by placing them next to the perimeter ancillary loads. From a TCO perspective (upfront cost, energy cost, maintenance cost), it makes much more sense to do this rather than installing perimeter coolers with supporting systems such as a raised floor. White Paper 130, *The Advantages of Row and Rack-Oriented Cooling Architectures for Data Centers*, discusses in greater detail the benefits of row-based cooling.

Consider the example of **Figure 6**. Three design alternatives are shown: an alcove with no additional cooling (6a), an alcove with additional cooling (6b), and no alcove (6c). Each alternative consists of the same row-based IT and ancillary IT equipment population – 140 kW and 12 kW respectively – representing a typical ratio for this equipment (8% of total IT load). Each alternative requires the same floor area and the maximum permissible temperature (in both the row & ancillary areas) is assumed to be 80.6°F, the upper limit of ASHRAE's recommended temperature range for IT systems.

Figure 6a illustrates the ancillary loads in the alcove result in temperatures well above the 80.6F design limit. The further into the alcove the loads are located, the more isolated they become from the row-based coolers and the hotter they get. In fact, in addition to the ancillary loads exceeding the allowable temperature, the IT racks closest to the alcove also experience relatively high temperatures as well.

Figure 6a

Example of data center with alcove and no additional cooling to ancillary area

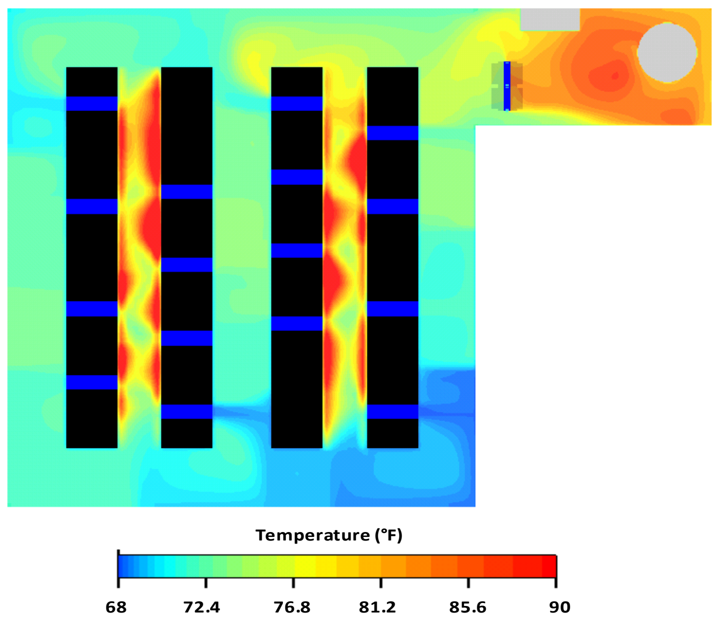


Figure 6b illustrates that adding two row-based coolers in the alcove area helps to cool the alcove to within the defined allowable temperatures, although, due to the geometry of the room, the temperature is still slightly warmer than the row-based-cooled area.

Obviously, if possible, a data center with a standard rectangular geometry should be designed, however when that is not possible – such as when an existing space is re-purposed as a data center – row-based cooling is still an effective cooling approach. When an alcove-type layout is employed, additional cooling can be added as shown. In this case, the two additional row-based coolers do, indeed, reduce operating temperatures to the acceptable limit and provide some measure of redundancy (though ancillary temperatures will rise in the event of a cooling failure). In this particular scenario, which is constrained by equipment clearances and access space, there are limited options regarding where to place the coolers. In general, row-based coolers can be placed essentially anywhere provided, front and rear clearances are respected, bolt-down brackets are used for stability when required, and power and cooling connections are available. As ancillary loads are often too diffuse to allow the coolers to effectively capture and neutralize warm air, it is often a practical choice simply to have the coolers blow directly on and around warm equipment in order to "mix" the warm air down to an acceptable temperature.

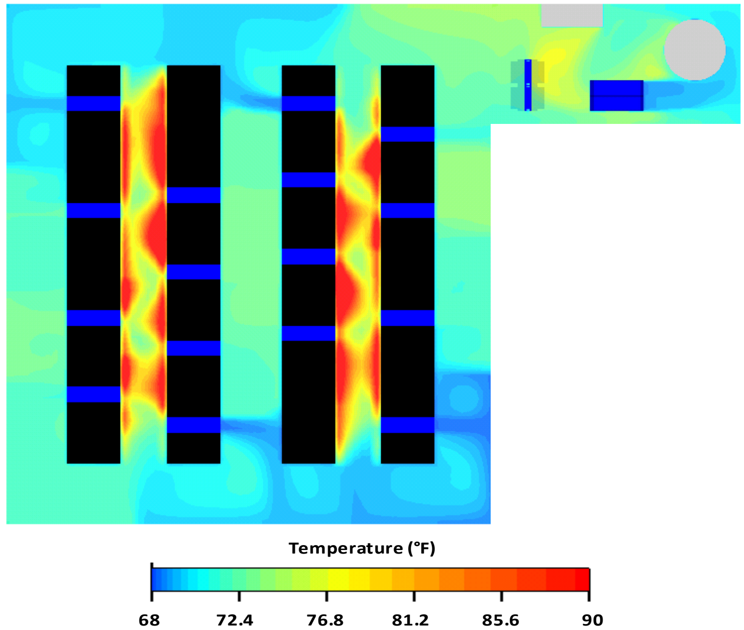


Figure 6b

Example data center with alcove and row-based cooling added to ancillary area

Figure 6c shows the scenario where no alcove exists. When a data center has standard room geometry like this example, additional cooling is often unnecessary. The row-based coolers in the 4 rows of racks are sufficient to cool not only the loads they were designed to handle, but also to pick up the additional heat load of the ancillary loads. Temperatures in the ancillary area, although warmer than the temperatures in the rows, are still below the design threshold.

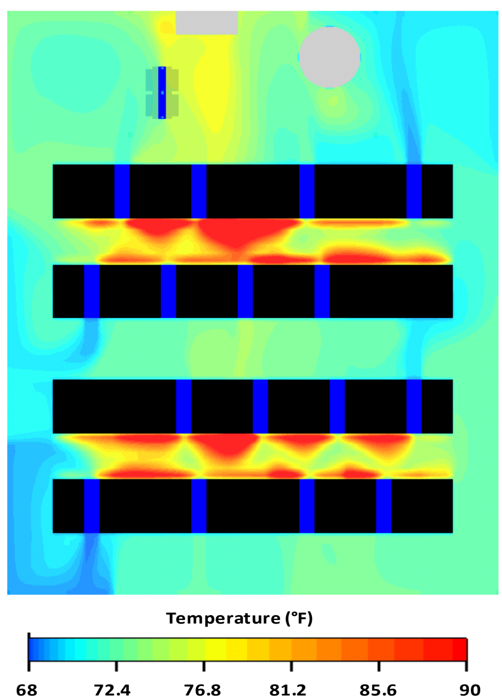


Figure 6c

Example data center with no alcove

Consistent with the CFD analysis shown for the three scenarios, the InRow Ancillary IT Equipment Cooling Calculator TradeOff Tool predicts that the layout with the alcove requires additional cooling while the layout without the alcove does not.

Conclusion

It is practical and effective to use a purely row based cooling architecture to cool a complete data center even when some of the loads are not located in neat rows. The row coolers effectively provide a source of generalized room cooling, in addition to cooling the rows they are placed in. This approach works when the non-row equipment is a small fraction of the total, which is a common situation.

The approach of using a pure row cooling architecture has a number of benefits when compared with a hybrid approach of room coolers and row coolers. Higher efficiency, lower cost, and the ability to eliminate the raised floor are some of these benefits.

Extensive CFD analysis validates the effectiveness of this approach. Tradeoff Tool 12, InRow Ancillary IT Equipment Cooling Calculator, assesses a data center's ability to cool these loads, given a floor layout, row-based cooling configuration, and IT load attributes and thresholds.

When additional cooling is necessary to support the ancillary loads (i.e., when ancillary loads represent a greater percent of the total load than typical data centers or when the loads are very isolated in an alcove), implementing additional row-based coolers is an effective cooling approach, since the infrastructure is already in place.

About the author

Jim VanGilder has been in the data center cooling and simulation business for over ten years. Prior to that, he specialized in the use of CFD for electronics-cooling applications. Presently, he directs the cooling-prediction R&D efforts for Schneider Electric's data center design and management software products. Jim has a master's degree in mechanical engineering from Duke University and is a registered professional engineer in the state of Massachusetts. He has authored or co-authored over 20 technical papers on data center cooling and has had several patents granted with many more pending in this area. Jim is the Vice Chair of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Technical Committee 4.10, Indoor Environmental Modeling.

Wendy Torell is a Senior Research Analyst at Schneider Electric's Data Center Science Center. She consults with clients on availability science approaches and design practices to optimize the availability of their data center environments. She received her Bachelors of Mechanical Engineering degree from Union College in Schenectady, NY and her MBA from University of Rhode Island. Wendy is an ASQ Certified Reliability Engineer.

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