A New Tool for Evaluating and Designing the Thermal Environment in Telecom Central Offices

Magnus K. Herrlin, Ph.D.
President
ANCIS Incorporated
17 Wood Street, Suite 201
San Francisco, CA
mherrlin@ancis.us
www.ancis.us

***Abstract* - Managing dense and diverse equipment environments is a challenge; out-of-bounds temperatures may not only harm electronic equipment but also interrupt critical services. Telecom central offices need a metric for evaluating and designing the thermal environment to ensure effective equipment cooling without excessive energy usage. This paper presents such a metric: The Rack Cooling Index (RCI).**

Although the equipment intake temperatures provide a picture of the environment, there is no yardstick for interpreting the data. The RCI has the capacity to change this situation; the Index is a metric of compliance with (industry) temperature specifications, where 100% means that the equipment is ideally cooled. More importantly, it allows standardized and unbiased comparisons between different thermal environments.

Ultimately, the cost of controlling the thermal conditions needs to be understood. Therefore, a cost metric for cooling the equipment room is reviewed. By incorporating the RCI and Cost Functions in the design process, it can be shown that a design not only improves the environment but also saves energy.

The RCI is currently used to evaluate various cooling solutions as well as develop telecom standards for optimal thermal design of equipment rooms. Other applications include real-time monitoring and design specifications. A certain level of thermal quality can now easily be specified, e.g., RCI > 98%.

The RCI is a practical metric that can readily be used in the design process. It also has the capacity to support non-technical decision makers since interpreting the Index does not require an in-depth understanding of its definition. A design with an RCI of 95% is obviously better than one with 85%.

I. Introduction

Managing dense and diverse equipment environments is a true challenge. The most important aspect of a telecom central office facility is to provide an environment that ensures reliable and uninterrupted operation of the electronic equipment. Over-temperatures or "hot-spots" may disrupt data processing equipment and cause downtime. Thermal management of equipment relies heavily on how well cool air is distributed in the equipment room. Telecom central offices need a tool for evaluating and designing the thermal environment to ensure effective equipment cooling without excessive energy usage.

Telcordia GR-3028-CORE "Thermal Management in Telecom Central Offices" (Telcordia, 2001) was developed to update historical environmental criteria in telecom facilities. While GR-63-CORE "NEBS Requirements: Physical Protection" (Telcordia, 2006) is broad in scope, GR-3028-CORE is dedicated to thermal management issues in telecom central offices. It introduced a common language and new concepts, requirements, and objectives for designing and operating equipment facilities.

Sharma, et al (2002) introduced two dimensionless parameters for evaluation of the thermal performance of data centers: The Supply Heat Index and the Return Heat Index. These indices provide a way of understanding the convective heat transfer in equipment rooms with raised floors. Energy efficiency can be impacted not only by inadequate cooling systems but also equipment room configurations that allow hot and cold air to mix.

"Thermal Guidelines for Data Processing Environments" produced by ASHRAE Technical Committee 9.9 (ASHRAE, 2004) adopted several of the ideas that were introduced in GR-3028-CORE. The document provides equipment manufacturers and facility operations personnel with a common set of guidelines for environmental conditions in data centers. The Telcordia documents are referenced when there is a comparison between data centers and telecom central offices.

The Rack Cooling Index (RCI) is a measure of how effectively equipment racks are cooled and maintained within industry temperature guidelines and standards (Herrlin 2005).

The Index is designed to help evaluate the equipment "comfort" for managing (monitoring) existing environments or designing new ones. It is also well suited as a design specification for new telecom centers. An example with under-floor vs. overhead cooling is included in the reference above to demonstrate the use of the Index.

The RCI has been used to evaluate various cooling solutions. Herrlin and Belady (2006) compared the RCI for contrasting cooling systems intended for equipment rooms: one under-floor system and two overhead systems. The results are pointing to some significant differences in cooling effectiveness when air is supplied from the top rather than from the bottom. Overhead cooling appears to have the upper hand, which should be comforting to the telecom community.

Besides a measure of the rack cooling effectiveness, another prerequisite is necessary to proceed with a design; namely, a measure of the associated costs. Cost Functions that assign the energy costs of improving the RCI were introduced by Herrlin and Khankari (2006). More advanced functions can be developed to take first costs into consideration or ultimately a life-cycle approach. The referenced paper highlights the potential of combining the RCI with Cost Functions to provide objective information for the telecom center owner and/or consultant.

II. CHALLENGE

High equipment heat dissipation and diversity contribute to challenges in providing an adequate thermal environment in telecom centers. Heat release from new networking devices and servers has increased sharply over the past years. Simultaneously, the energy usage to cool the equipment room has increased proportionally.

Designing or managing such equipment environments is far from trivial; over-temperatures may not only harm electronic equipment but also interrupt critical and revenue generating services. Energy efficiency measures may also impact the equipment environment, including those targeting the air-distribution system. At a minimum, the design criteria for telecom centers need to include the following:

- Design robust thermal environments
- Ensure adequately cooled equipment
- Avoid excessive energy usage

Although Computational Fluid Dynamics (CFD) modeling allows visualization of temperatures throughout the equipment room, to sort out the cooling effectiveness of different design options can be a formidable challenge. By using the same CFD technology, however, the rack intake temperatures can accurately be established. Although these temperatures (modeled or measured) provide a complete picture of the thermal environment, there is no common yardstick for interpreting the data. The RCI has the capacity to change this state of affairs.

The reminder of this section briefly reviews "room" temperature and temperature specifications in telecom central offices. This discussion provides the foundation for the subsequent section: Metric for Compliance with Temperature Specifications.

A. Room Temperature vs. Equipment Intake Temperature

The thermal environment for air-cooled electronic equipment is defined by the air temperature at the air intakes of the equipment, the temperature the electronics depends on for reliable cooling and operation. The temperature in the middle of the aisle, for example, has little to do with the rack cooling effectiveness. This also holds true for the "ambient" temperature specified by NEBS GR-63-CORE (Telcordia, 2006) of 1.5 meter above the floor and 0.4 meter in front of the equipment. In the present paper, consequently, only the intake air temperatures will be used.

For design purposes, CFD modeling can produce the necessary intake temperatures. Real-time monitoring is feasible by installing temperature sensors that mimics the intake conditions until the actual intake temperatures are probed by the electronic equipment. Indeed, most new equipment already has sensors installed to monitor adequate temperatures and control the speed of the cooling fans. However, these readings are generally not easily available outside the electronic equipment.

B. Temperature Specifications

Intake temperature specifications are depicted in Figure 1 along with a hypothetical intake temperature distribution, where the temperatures are arranged in order of increasing temperature. First, facilities should be designed and operated to target the "recommended" range. Second, electronic equipment should be designed to operate within the extremes of the "allowable" operating environment. Prolonged exposure to temperatures outside the recommended range can result in decreased equipment reliability and longevity; exposure to temperatures outside the allowable range may lead to catastrophic equipment failures.

The recommended range and the allowable range depend on the applied thermal guideline or standard. Generally, telecom equipment complying with the NEBS requirements tolerates wider extremes than equipment designed for traditional data centers. For the recommended range, NEBS (Telcordia, 2001) suggests 65°- 80°F (18°-27°C) whereas ASHRAE (ASHRAE, 2004) lists 68°- 77°F (20°-25°C) for "Class 1" data centers. NEBS (Telcordia, 2006) specifies an allowable range of 41°- 104°F (5°-40°C).

Over-temperature conditions exist when one or more intake temperatures exceed the maximum recommended temperature (under-cooled). Similarly, under-temperature conditions exist when one or more intake temperatures drop below the minimum recommended temperature (over-cooled). The significance of under-temperatures is the potential for harmful relative humidity (RH) levels—RH is strongly correlated to temperature—and that the equipment may not be qualified at low temperatures. Internal timing of data packages may be affected and thus contribute to data corruption.

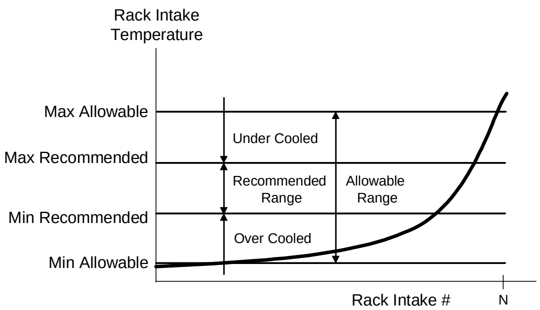

Figure 1. Operating Temperature Ranges and Hypothetical Temperature Distribution.

III. Metric For Compliance With Temperature Specifications

The Rack Cooling Index (RCI) was designed to be a measure of how effectively equipment racks are cooled and maintained within (industry) thermal guidelines or standards, where 100% mean that all racks are cooled within the recommended range. The RCI helps compare thermal environments based on the same criteria. In other words, the Index facilitates standardized and unbiased comparisons.

The RCI was developed to have the following key characteristics:

- Meaningful measure of rack cooling effectiveness
- Tied to leading thermal guidelines/standards
- Focus on over-temperatures and harmful conditions
- Over-cooling must not compensate for under-cooling
- Easily understood numerical scale (≤100%)
- Suited for computer modeling or measurements
- Portable between platforms (SI/IP) and non-dimensional

A. Definition of the RCI

The following is an overview of the RCI to provide an understanding of the definition and how to interpret the Index. For a complete discussion, the reader is referred to the original work by Herrlin (2005) as published by ASHRAE.

Again, the RCI is a gauge of the thermal equipment environment and—in turn—how effectively the equipment is cooled. Specifically, the RCI_{HI} is a measure of the absence of over-temperatures; 100% mean that no over-temperatures exist (i.e., ideal conditions). The lower the percentage, the greater probability (risk) that equipment will experience temperatures above the maximum allowable temperature. In other words, the RCI_{HI} is a measure of the equipment environment at the high (HI) end of the temperature range. Figure 2 provides a graphic representation of the RCI_{HI}, and the definition is as follows:

$$RCI_{HI} = \left[1 - \frac{\text{Total Over-Temp}}{\text{Max Allowable Over-Temp}}\right] 100\ \%$$

Note that the numerical value of the Index depends on the guideline or standard utilized for setting the four temperature limits in Figures 1 and 2. Consequently, the RCI is a gauge of compliance with a given temperature specification.

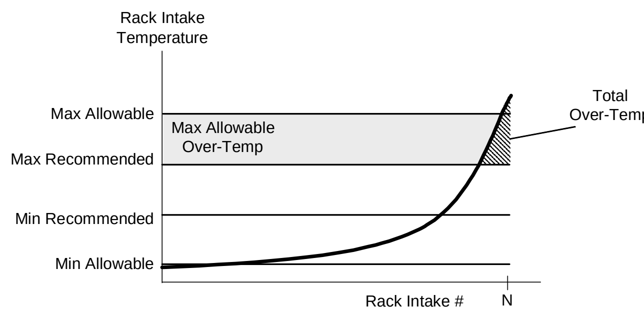

Figure 2. Graphic Representation of the RCI_{HI}.

A more practical expression of the RCI_{HI} is the following (Herrlin, 2005):

$$RCI_{HI} = \left[1 - \frac{\sum (T_x - T_{max\text{-}rec})_{T_x > T_{max\text{-}rec}}}{(T_{max\text{-}all} - T_{max\text{-}rec})\ n}\right] 100\ \%$$

where
- T_x Mean temperature at intake x [°F or °C]
- n Total number of intakes [−]
- $T_{max\text{-}rec}$ Max recommended temperature per some guideline or standard [°F or °C]
- $T_{max\text{-}all}$ Max allowable temperature per some guideline or standard [°F or °C]

Depending on the focal point, the RCI can be calculated using all intake temperatures or any subset, down to a single equipment intake. An analogous index is defined at the low (LO) end of the temperature range (Herrlin, 2005).

The RCI_{LO} complements the previously defined index especially when the supply air is below the minimum recommended temperature. If under-temperatures are of less concern, the focus should be on maximizing the RCI_{HI}.

$$RCI_{LO} = [1 - \frac{\sum (T_{min\text{-}rec} - T_x)_{T_x<T_{min\text{-}rec}}}{(T_{min\text{-}rec} - T_{min\text{-}all})\, n}]\ 100\ \%$$

where T_x Mean temperature at intake x [°F or °C]
n Total number of intakes [−]
$T_{min\text{-}rec}$ Min recommended temperature per some guideline or standard [°F or °C]
$T_{min\text{-}all}$ Min allowable temperature per some guideline or standard [°F or °C]

B. Interpretation of the RCI

Compliance with (industry) temperature specifications is the ultimate cooling performance metric, and the RCI is such a metric. 100% mean ideal conditions; no over- or under-temperatures. That is, all intake temperatures are within the recommended temperature range. 0% mean that at least one intake is outside the allowable range. Table 1 lists ratings based on a large number of studies.

TABLE 1
RELATIVE RCI RATINGS

Rating	RCI
Ideal	100%
Good	≥91%
Acceptable	81-90%
Poor	≤80%

Since this interpretation of the Index is straight forward, it does not require an in-depth understanding of the definition. It also has the capacity to provide support to non-technical decision makers. A cooling design providing RCI=95% is clearly better than one providing RCI=85%.

C. Calculation of the RCI

The process of evaluating the thermal performance of telecom centers can be automated. The RCI can be computed from modeled or measured temperature data by using specialized software. An example is given in the figure below (ANCIS, 2006). This software not only calculates the RCI values (lower-left corner of screen shot) but also provides a number of other statistics of the temperature data set.

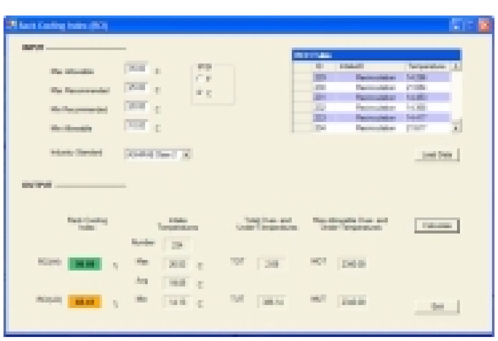

Figure 3. Screen Shot of RCI Software (ANCIS, 2006).

D. Applications of the RCI

There are numerous practical applications of the RCI. The following are some of the more obvious.

- Design Equipment Environments. CFD modeling combined with the RCI provides a standardized and unbiased method for evaluating, analyzing, designing, and reporting environmental designs. The RCI is currently used to evaluate over-head cooling, under-floor cooling, and supplemental cooling solutions. The Index is also utilized to develop related telecom standards.

- Monitor Equipment Environments. Real-time monitoring of the thermal environment is feasible by installing temperature sensors that mimics the intake conditions (until intake temperatures are probed by the equipment itself). The RCI provides a reliable indication of the thermal equipment environment.

- Provide Design Specifications. Equipment owners and operators now have the opportunity to specify a certain level of thermal "quality" in an objective and standardized way. They can ensure an excellent equipment environment by specifying an RCI > 98%, for example.

- Help Product Development and Marketing: The RCI can effectively help demonstrate the benefits of cooling solutions and products. Quick standardized A-to-B comparisons can be made between product refinements. And, a product with an RCI at or near 100% should be marketed as such.

IV. METRIC FOR ENERGY EFFICIENCY

The rack cooling effectiveness and the cooling energy efficiency are often related. Since ultimately the costs associated with improving the RCI need to be known, the concept of energy Cost Functions was developed based on costs to cool the equipment room (Herrlin and Khankari, 2006). Figure 4 shows an example of a chiller Cost Function from this reference. The potential benefits of increasing the supply temperature were studied, and the graph shows the annual energy cost operating the chiller at different supply temperatures. More advanced Functions can be developed, taking first costs into consideration or deploying a life-cycle approach. Although difficult, costs can also be assigned to the risk of equipment failure.

By combining the RCI with Cost Functions, a practical and powerful tool is created for evaluating and designing telecom centers for optimal rack cooling effectiveness and cooling energy efficiency. Herrlin and Khankari (2006) demonstrate how the design process works. By incorporating Cost Functions, the telecom center owner and/or design consultant can assign a dollar amount on improving the thermal equipment environment as represented by the RCI.

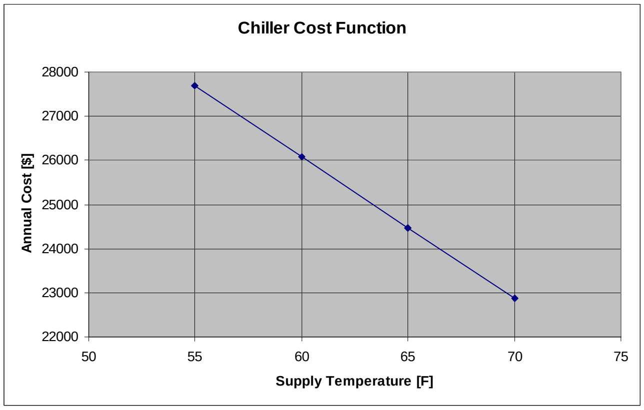

Figure 4. Example of Cost Function (Herrlin and Khankari, 2006).

V. SUMMARY

This paper outlines a new metric for evaluating and designing the thermal environment in telecom central offices: The Rack Cooling Index (RCI). By using results from Computational Fluid Dynamics (CFD) modeling or temperature measurements to compute the Index, various thermal environments can be evaluated, designed, and reported. The RCI is a rational gauge of how effectively electronic equipment is cooled and maintained within (industry) temperature specifications. The Index is not only easy to implement and automate, but it also condenses and highlights differences in the cooling effectiveness between equipment environments and/or cooling solutions.

Applications of the RCI include analyzing, designing, and monitoring equipment environments, supporting cooling product development and marketing efforts, and serving as an unambiguous design and report specification. The Index has the capacity to help manage existing environments or design new ones by facilitating standardized comparisons between various designs.

Since all necessary information is readily available, this new metric can immediately be incorporated into the design analysis. Specialized RCI software can assist the designer today, and when the algorithm has been incorporated into commercial CFD software, engineers will have yet another practical tool to evaluate and design telecom centers for adequate rack cooling effectiveness.

Because the costs associated with improving the RCI ultimately needs to be known, the concept of Cost Functions is introduced based on the costs to cool the central office. By incorporating CFD modeling, the RCI, and Cost Functions in the design process, it can be demonstrated that improving the thermal equipment environment and saving energy are not mutually exclusive. As such, this trio constitutes a powerful tool for making more informed design decisions.

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