The Significance of Radiation in a Central Office Chassis: A Case Study

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Abstract

A typical central office chassis (telecommunications) system was analyzed using FLOTHERM® to determine the significance of radiation heat transfer on specific computed solid and air temperatures and the overall partitioning of heat leaving the chassis by the various heat transfer modes. Various power levels and ambient temperatures were considered. All conditions were simulated both with "radiation on" and "radiation off" so the magnitude of error due to neglecting radiation could be assessed. Emphasis was on forced convection (i.e., with a fan tray present), however, one natural convection case (i.e., with no fan tray present) was analyzed for comparison.

Introduction

The effects of radiation are frequently ignored in FLOTHERM® analyses, even for passively cooled systems, based on the presumption that convection dominates and radiation is negligible. This work was performed to evaluate this presumption for a typical Central Office Chassis–an indoor, typically rack-mounted, piece of transmission and switching equipment.

In a mostly analytical work, VanGilder [1] determined the significance of radiation on the overall partitioning of heat flux from a rack of vertical PCB's. The PCB's were assumed to be at constant temperatures and to be (other than the presence of front and back bounding walls) in "free space" – no chassis or other geometry was considered. For the cases analyzed, radiation accounted for 19-48% and 7-23% of all heat removed from the PCB's under natural and forced convection situations respectively.

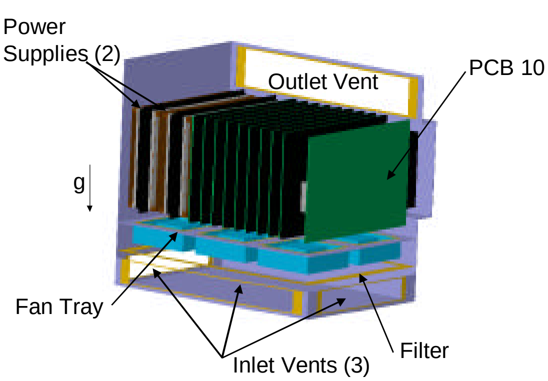

Figure 1 - Overall Chassis (3 Sides Hidden for Clarity)

The present effort is an extension of the work by VanGilder [1] to a specific, practical system. The primary emphasis is on specific computed solid and air temperatures and an assessment of the magnitude of error in computed temperatures when radiation is neglected.

The chassis design used for the analysis is generic, but fairly typical. Specifically, this chassis is the subject of the tutorial sequence associated with the "Modeling Telecommunication Systems" advanced FLOTHERM® training course.

Description of the Model

Figure 1 shows the overall chassis. The fan tray consists of 6 Papst 4212 fans that provide an airflow rate of approximately 190 cfm. Air enters the chassis through the three inlet vents near the bottom and exits through the one outlet vent near the top. The system consists of two 150 W brick-type power supplies with parallel fin heat sinks. (For modeling purposes, compact representations of the heat sinks, consisting of Non-Collapsed Sources and Resistances were used.) There are 10 vertically mounted PCB's. PCB's 1-9 dissipate 23 W each and consist of one solid component that spans one entire side of each PCB.

PCB 10, which is also shown in Figure 2, was modeled in more detail in the interest of obtaining (approximate) solid component temperatures. Each of the components of PCB 10 was modeled as a "lumped block" with uniform composition and heat dissipation.

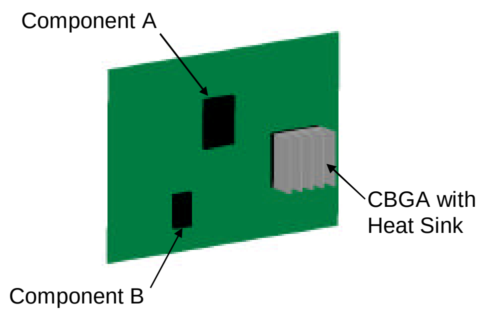

Figure 2 - PCB 10

The computational domain was taken coincident with the walls of the chassis and an estimated heat transfer coefficient of 6 W/(m^2 K) was assigned to all surfaces. The external radiant temperature was taken to be the same as the ambient temperature for each case.

The chassis walls and fan tray mounting plate were assigned the properties of carbon steel including an emissivity of 0.2. All components were assigned a thermal conductivity of 10 W/(m K) and an emissivity of 0.8. The CBGA heat sink was modeled in detail and assigned the properties of Duraluminum with a thermal conductivity of 164 W/(m K) and an emissivity of 0.038.

Computations

Initially, 18 forced-convection simulations were performed covering all combinations of the following conditions:

Ambient Temperatures, T_{amb}: 20, 35, 50 $^{\circ}$C
Radiation Model: On, Off
Power Levels: 1, 2, 3

When radiation was included, the default "Radiation On" mode was used with Single Radiating Surfaces everywhere. The power levels were selected in linearly increasing increments and are summarized in Table 1.

Table 1 – Component Power Dissipation

Case	Component Power (W)		
	A	B	CBGA
1	3.75	6	12
2	5.625	9	18
3	7.5	12	24

Finally, for comparison, two natural convection (with entire fan tray de-activated) simulations were performed. To maintain realistic operating conditions, only the lowest power level (Case 1) and ambient temperature (20°C) were considered.

Temperature results were extracted from the approximate centers of components in the Visualization Window. The one "air" temperature recorded was taken at an arbitrary, though consistent, location approximately in the center of the PCB channel, which contains the components of PCB 10. The CBGA heat sink temperature was taken at the approximate center of the heat sink base.

The overall breakdown of modes by which heat leaves the chassis (radiation from chassis walls, natural convection from chassis walls, and forced convection through the outlet vent) was determined from the summaries provided in the Tables Window.

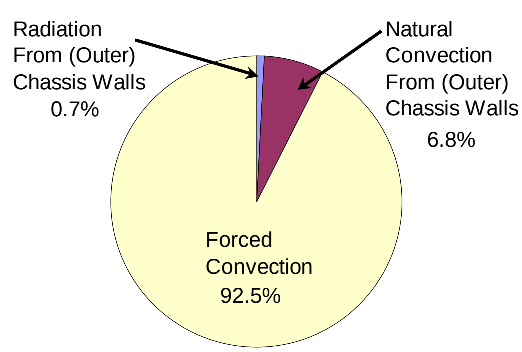

Figure 3 - Average Partitioning of Heat Flux From Chassis: Forced Convection Cases

Results

Figure 3 shows the average partitioning of heat flux from the chassis for all forced convection cases. (An average breakdown is presented because the breakdown of heat fluxes by the various modes varied only slightly over the cases considered.) Not surprisingly, most, 92.5%, of the heat dissipated in the system is removed by the (forced) airflow through the

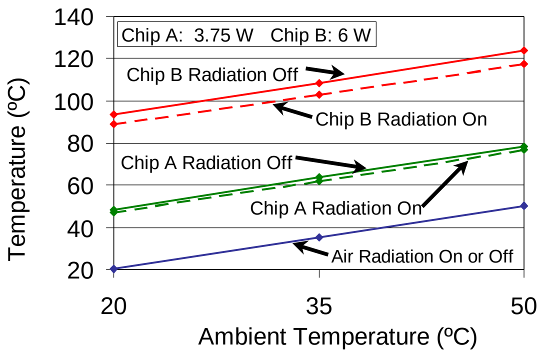

Figure 4 - Effect of Neglecting Radiation on Computed Temperatures: Forced Convection, Case 1

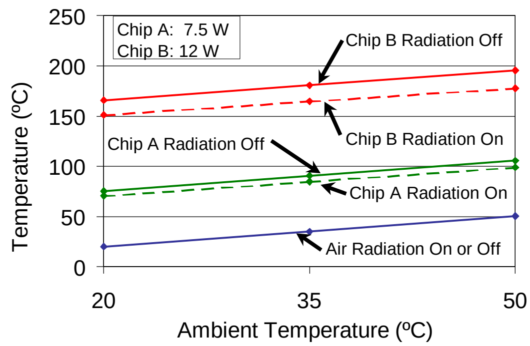

Figure 6 - Effect of Neglecting Radiation on Computed Temperatures: Forced Convection, Case 3

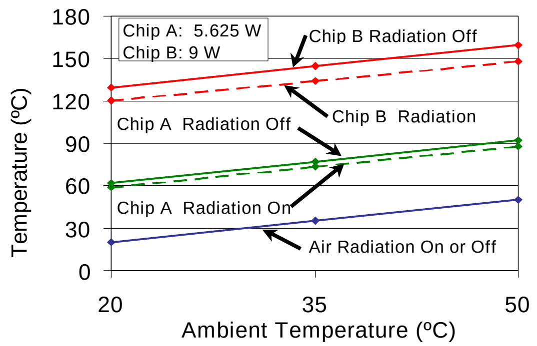

Figure 5 - Effect of Neglecting Radiation on Computed Temperatures: Forced Convection, Case 2

chassis. 6.8% of the heat travels via conduction through the chassis walls and is ultimately removed via natural convection on the outside of the chassis (consist with the prescribed heat transfer coefficient and ambient temperature). Only 0.7% of the overall heat dissipated in the system leaves via radiation from the outer walls.

Figures 4-6 show the effect of neglecting radiation on specific computed temperatures for the forced convection cases considered. 1.3-6.5°C

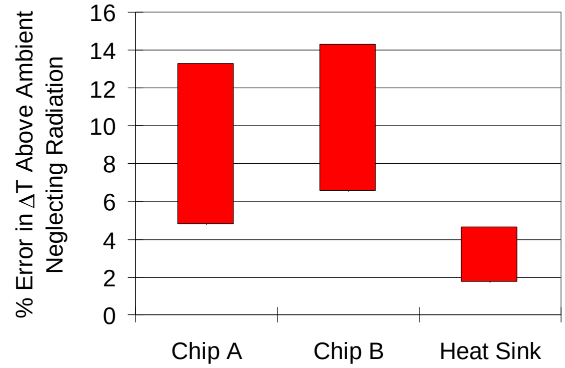

Figure 7 - Average % Error in Computed Temperatures: Forced Convection Cases

and 4.5-18.2°C errors are made in the computed temperatures of Components A and B, respectively, if radiation is neglected. The minimum error occurs at lowest power and ambient temperature conditions; the maximum error occurs at highest power and ambient temperature conditions.

Within a meaningful resolution of computed values, the air temperatures were the same for all corresponding "radiation on" and "radiation off" cases. The heat sink temperatures exhibited only marginal differences between corresponding cases and are not shown for clarity.

Figure 7 shows the average percentage error range in computed temperatures that can be expected (overall all cases analyzed) if radiation is neglected. 4.8-13.3%, 6.5-14.3%, and 1.7-4.6% errors are made in the computed temperatures of Components A and B and the heat sink, respectively, if radiation is neglected. Note that the percentage error is based on temperature rises above ambient to be consistent and

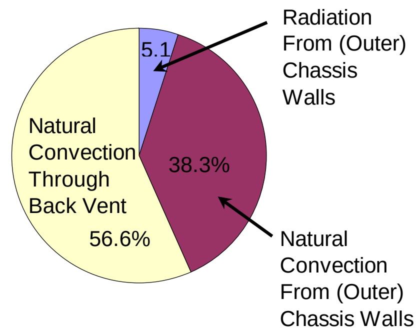

Figure 8 - Partitioning of Heat Flux From Chassis: Natural Convection Case

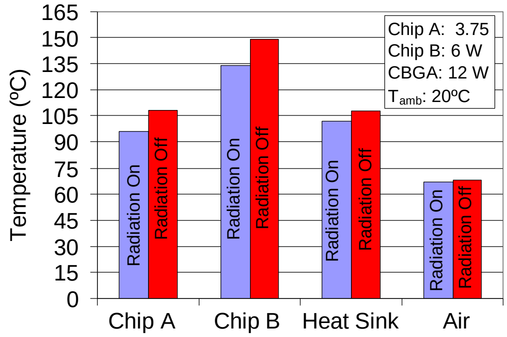

Figure 9 - Effect of Neglecting Radiation on Computed Temperatures: Natural Convection Case

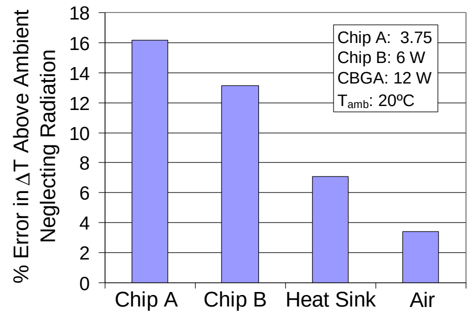

Figure 10 - % Error in Computed Temperatures: Natural Convection Case

meaningful regardless of what temperature scale is used.

Figure 8 shows the partitioning of heat flux from the chassis for the single natural convection case considered. The breakdown has shifted significantly from the forced convection cases: 56.6% by the (natural) airflow through the chassis, 38.3% by natural convection on the outside of the chassis walls, and 5.1% via radiation from the outer walls.

Figure 9 shows the effect of neglecting radiation on specific computed temperatures for the single natural convection case considered. 12.3°C, 15°C, 5.8°C, and 1.6°C errors are made in the computed temperatures of Components A and B, the heat sink, and the one air location, respectively, if radiation is neglected. With the natural convection case, we now have a meaningful difference in computed heat sink and air temperatures between "radiation on" and "radiation off" cases.

Figure 10 shows the percentage error in computed temperatures that can be expected if radiation is neglected for the single natural convection case considered. 16.2%, 13.2%, 7.1%, and 3.4% errors are made in the computed temperatures of Components A and B, the heat sink, and the one air location, respectively, if radiation is neglected. Note that again the percentage error is based on temperature rise above ambient.

Summary and Conclusions

Forced Convection

- Radiation plays a fairly insignificant role (0.7% of total heat flux on average) in removing heat from the system. Note that the carbon steel walls have an emissivity of only 0.2. A different material or surface finish (e.g., paint) with a higher emissivity would increase the proportion of radiant heat transfer from the outer chassis walls.
- Radiation is important if accurate solid-object temperatures are required. Up to an 18.2°C error was obtained for cases in which radiation was neglected. It is worth emphasizing that Components A and B were modeled simply as a "lumped block". The present results cannot be directly applied to the case of a detailed component model with the goal of obtaining a junction temperature.
- The inclusion or exclusion of radiation made virtually no difference in the computed heat sink base temperature. One contributing factor is the extremely low emissivity (0.038) of the heat sink. Like the outer chassis walls, increasing the emissivity of the heat sink would amplify the effect of radiation.
- Radiation has a negligible impact on air temperature. Since air is virtually transparent to thermal radiation, the only effect on air temperature is indirect; heat can be transferred from solid to solid via radiation and only then to the air by direct contact.

Natural Convection

- Radiation is a marginally significant (5.1%) mode by which heat is removed from the system. As with the forced convection case, increasing the emissivity of the chassis walls would further increase the importance of radiation.
- Radiation is very important if accurate solid temperatures are required. Up to a 15°C error in solid-component temperatures was

obtained when radiation was neglected for the single natural convection case analyzed. Recall that the one natural convection case considered was the case with lowest power and ambient temperature. Increasing component power dissipations and/or the ambient temperature would further increase the importance of radiation.

- Radiation has a negligible, although measurable (1.6°C difference between "radiation on" and "radiation off"), impact on air temperature.

Reference

[1] VanGilder, Jim, "Significance of Radiation in Telecommunication Racks", International Systems Packaging Symposium, San Diego, California, January 1999.