MicroATX Small System Thermal/Acoustic Design Guide

November 2002

Revision 1.1

Revision History

Revision	Revision History	Date
1.0	Initial Release	April 2002
1.1	Updated for enhanced thermal capability	November 2002

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1 Introduction

1.1 Overview

The market for personal computer systems is continually growing and expanding into new applications and usage models. A recent focus area is that of small, quiet systems that better utilize and blend into environments such as a crowded office desktop or home living room. At the same time, users are demanding the highest performance components in these small systems, creating unique design and integration challenges.

To assist in the design of systems that meet these types of requirements, this document provides related background theory, design examples, test data, guidelines, and validation techniques to design a microATX system with the following design goals:

- Overall size in the range of 10 to 13 liters.
- Support for a 82 W processor Thermal Design Power (TDP) and enhanced capability to scale up to 100 W TDP.
- Acoustic sound power level at or below 4.0 BA, or sound pressure at or below 32 dBA at seated operator position.

This document is intended for those involved in the engineering design and/or integration of chassis platforms, power supplies, motherboards, and other system-level building blocks. It is intended as a follow-on to *MicroATX Thermal Design Suggestions* and *Performance MicroATX Thermal Design Suggestions*, which contain additional background information as well as design guidance for larger systems.

1.2 Recommendations Summary

The primary thermal/acoustic goals for any chassis design—and implementation recommendations for 10- to 13-liter chassis in particular—are summarized below and illustrated in Figure 1 and Figure 2.

- Minimize airflow impedance by maximizing the size and/or quantity of sheet metal and bezel vent openings, ducting cool air to critical areas, and avoiding airflow restrictions.
- Maximize airflow volume by providing a chassis front fan to supplement the power supply's airflow volume capability.
- Use fan speed control on all fans for reduced acoustic noise under normal operating conditions.
- Isolating the core inlet from the system provides an enhanced thermal environment for the core area of the motherboard.

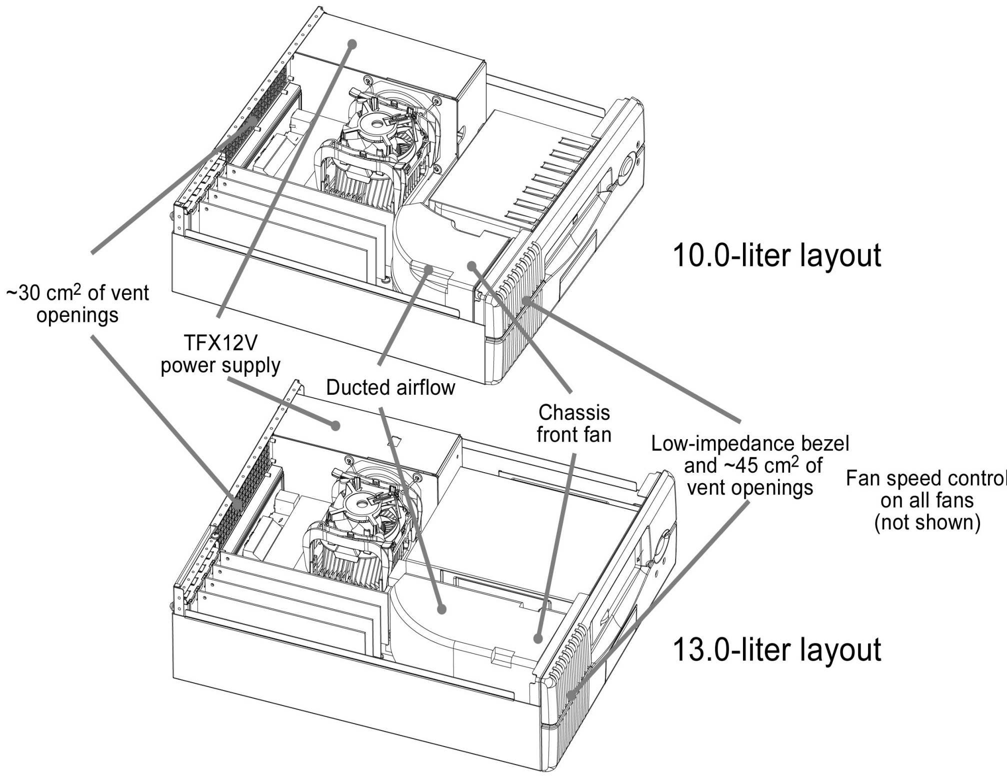

Figure 1: System Layout Recommendations, Front Duct 10 and 13 Liter

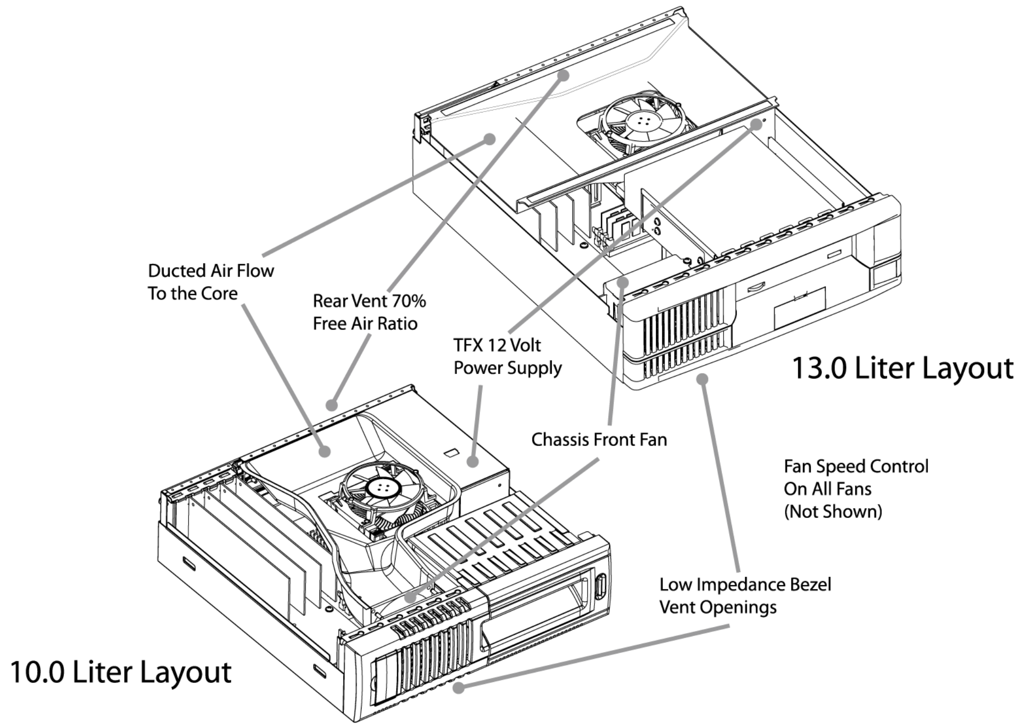

Figure 2: System Layout Recommendations, Core Duct 10 and 13 Liter

Table 1: Recommendation Summary

Solution Method	Airflow Solution	Processor T_A	TDP Target	Optical Drive	Motherboard Form Factor	Add-in Card Form Factor
10 Liter Fan Duct	Front fan duct	≤ 42 °C	82 W	Mobile	MicroATX	Low profile
13 Liter Fan Duct	Front fan duct	≤ 42 °C	82 W	Desktop	MicroATX	Low profile
10 Liter Core duct	Front inlet from external ambient direct to core	≤ 38 °C	100 W	Mobile	MicroATX	Low Profile
13 Liter Core duct	Side inlet from external ambient direct to core	≤ 38 °C	100 W	Desktop	MicroATX	Low Profile

To meet the design goals listed in Section 1.1, there are multiple design implementations possible. Table 1 summarizes the two methodologies addressed in this design guide. Two system sizes (10 and 13 liter) are addressed with for each methodology (Front duct and Core duct). Chapter 2 describes the design methodology for each of the system sizes and airflow approaches while Chapter 3 describes the design detail and analysis of one of the designs (13 liter core duct) that can be applied to the other configurations. Test and validation data for each of the reference systems is contained in the Appendix.

1.3 Related Documents

Table 2: Related Documents

Document	Location
Accelerated Graphics Port (AGP) Design Guide	http://developer.intel.com/technology/agp/
Acoustic Overview Design Guide	http://www.formfactors.org/technologies
Advanced Configuration and Power Interface (ACPI) Specification	http://www.acpi.info/
ISO 7779 –"Acoustics—Measurement of Airborne Noise Emitted by Information Technology and Telecommunications Equipment"	http://www.iso.ch/
Intel® Pentium® 4 Processor in the 478-pin Package Thermal Design Guidelines	http://developer.intel.com/design/pentium4/guides/249889.htm
MicroATX EMC Design Suggestions *MicroATX Motherboard Interface Specification* *MicroATX Thermal Design Suggestions* *Performance MicroATX Thermal Design Suggestions*	http://www.formfactors.org/developer/specs/microatx/microatxspecs.htm
PCI Local Bus Specification	http://www.pcisig.com/
TFX12V Power Supply Design Guide	http://www.formfactors.org/
Thermal Test Board	http://www.formfactors.org/validation/thermal.htm
U-seam Design Guide	http://www.formfactors.org/technologies
Wave Guide Design Guide	http://www.formfactors.org/technologies

2 Design Overview and Assumptions

2.1 Design Goals

This guide describes the thermal/acoustic design of small chassis that support a high-performance processor and leverages the standardization and infrastructure benefits of the microATX motherboard form factor. Two approaches are outlined in this guide. The first method uses a front duct system with high level targets outlined in Table 3. The second method uses a core duct system with high level targets outlined in Table 5.

2.2 Front Duct System

✏ **NOTE**

All target assumptions are provided only as examples. Actual values may vary for a particular product or market. The reader is responsible for determining the applicability of these assumptions to any planned product and making necessary adjustments. Any similarities to existing products are unintentional and should not be construed as approval or disapproval of a particular design.

Table 3: High-Level Chassis Design Targets

Parameter	Target		
Chassis size[1]	Total volume ≤ 10 liters Width ≤ 92 mm Depth ≤ 330 mm Height ≤ 328 mm	OR…	Total volume ≤ 13 liters Width ≤ 102 mm Depth ≤ 390 mm Height ≤ 328 mm
System orientation	Either vertical (tower) or horizontal (desktop)		
Motherboard component layout and feature set	Full-size microATX 1.1 form factor		
Processor support	Processor thermal design power (TDP) of 82 W[2]		
Peripheral drive support	One hard drive – standard 4.0” x 1.0” x ~5.7” One optical drive, mobile or standard (5.8” x 1.7” x ~8.2”) size		
System maximum operating temperature	System T_E ≤ 35 °C		
System acoustic noise limits	Measured acoustic sound power at 4.0 BA or pressure at seated operator position per ISO-7779 ≤ 32 dBA at idle, 23 °C, typical configuration (see Table 4)		

Notes: (1) Chassis dimensional measurements include all sheet metal and the optical disk drive bezel. They do not include the front system bezel or a supporting stand for vertical tower systems.

(2) The 82 W value was assumed for testing, and is not meant to necessarily imply the maximum capability of this solution

The text first addresses the assumptions, overall approach, and general considerations for a generic small system solution design. Specific design details and performance sensitivities are then presented, focusing on two differing implementations of thermal solutions. This document demonstrates the advantages of implementing small form factor solutions that result in a reduced temperature rise to the processor T_A of ≤ 3 °C from the external system ambient. The system integrator can assess that practical use of the solutions in their targeted platforms.

To keep pace with increasing processor TDP (and associated case temperatures T_C) values, new active heatsink technologies are continually being developed. It is not within the scope of this guide to suggest a processor thermal solution for a given timeframe or platform. Instead, the intent is to demonstrate *platform-level* chassis and power supply designs that provide the best possible operating environment for any such processor thermal solution.

2.2.1 Front Duct System Physical Layout

The 10-liter and 13-liter reference designs shown in Figure 3 and Figure 4 both use the same basic physical layout. In this layout, cool air enters through the chassis front fan, absorbs heat from the core area components, and exits at the rear through the power supply and rear vents.

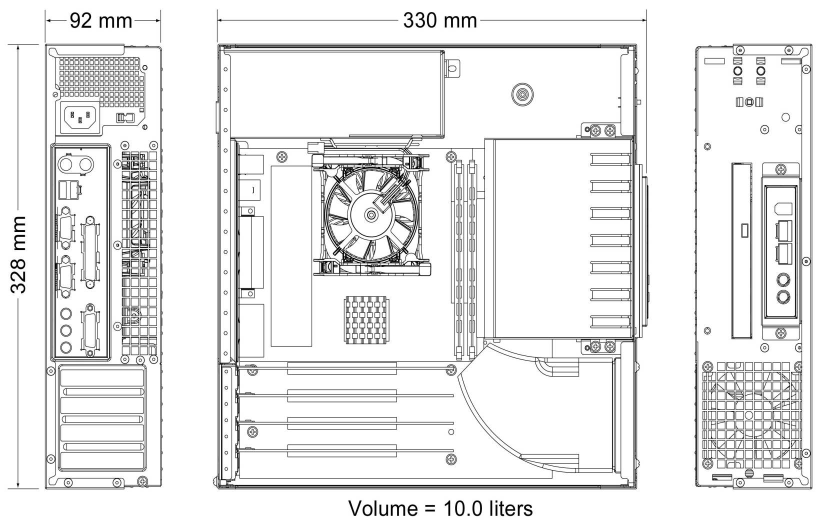

Figure 3: 10-Liter Reference Chassis Design Layout, Front Duct

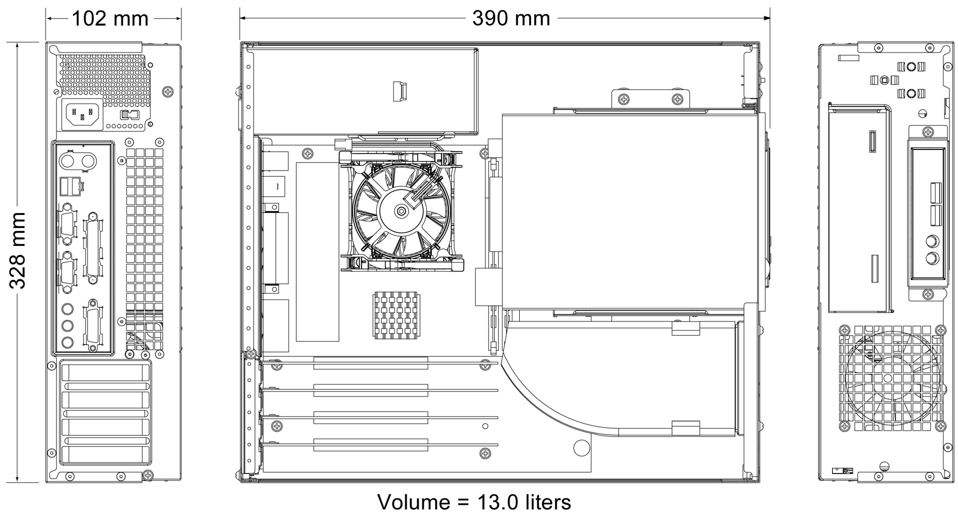

Figure 4: 13-Liter Reference Chassis Design Layout, Front Duct

2.2.2 System Power Load

The assumptions for power dissipation and location used for the 10 and 13 liters front duct reference chassis designs and validations are provided in Table 4 and Figure 5. The power values listed in the "Thermal Capacity Condition" column are used as the basis for designing the maximum system thermal capability at any external ambient temperature ("T_E") up to and including 35 °C. These values reflect the worst-case power load that, while not commonly observed by the average user, must be supported by the thermal solution. The power values listed in the "Acoustic Noise Condition" column are slightly lower and are those to which the system acoustic solution performance will be designed and tested at T_E = 23 °C. These values represent a more typical load expected from an average user running normal productivity applications. All values are provided as examples only and are not intended as actual product specifications.

Table 4: System Power Load Assumptions, Front Duct 10 and 13 Liters

Location	Item	System Power Load (1) Thermal Capacity Condition	Acoustic Noise Condition	Temperature Target	Comments
Core	Processor	82 W	52 W	$T_A \leq 42$ °C	
Core	Processor voltage regulator	18 W	13 W	$T_A \leq 55$ °C	~82% conversion efficiency
Core	Chipset (MCH)	6 W	6 W	$T_A \leq 55$ °C	
Core	SDRAM memory	3 W	3 W	$T_A \leq 55$ °C	Three DIMMs at 1 W each
Core	Motherboard misc.	7 W	7 W	$T_A \leq 55$ °C	Includes two fans
Slot #7	AGP graphics	12 W	12 W	$T_A \leq 55$ °C	Add-in cards are presumed to adhere to the LP-AGP/PCI MD2 specification max PCB size (6.600” x ~2.6”).
Slot #6	PCI card	5 W	3 W	$T_A \leq 55$ °C	
Slot #5	PCI card	5 W	3 W	$T_A \leq 55$ °C	
Slot #4	PCI card	5 W	3 W	$T_A \leq 55$ °C	
Bay #1	Optical drive	10 W (2)	1 W (2)	$T_A \leq 55$ °C	Idle mode
Bay #2	Hard drive	6W	6 W	$T_A \leq 55$ °C	3.5”, 7200 RPM, spinning but not accessing
	Subtotal (DC)	**159 W**	**109W**		
PS	Power supply	59 W	40 W	$T_A \leq 50$ °C	~73% conv. efficiency
	Total (AC)	**218 W**	**149 W**		

(1) Power values represent continuous simultaneous power dissipations that might reasonably be expected during typical system use. The values do not reflect all possible device powers or system operating conditions. See component specifications for actual values.

(2) 10-liter mobile optical drive used 1 W for both Thermal and Acoustic test condition

For this application, the motherboard represents the latest advances in processor, graphics, memory, power delivery, and associated logic technologies. These areas comprise the motherboard “core”, which provides most of the motherboard’s direct power dissipation. The 82 W value for processor power is based on a timeframe-dependent extrapolation of past desktop processor power trends. A processor voltage regulator operating at 82% conversion efficiency generates a corresponding power loss of $82\text{ W}\cdot\left(1/_{0.82}-1\right)=18\text{ W}$.

Actual power dissipation for internal peripherals and add-in cards may vary widely, depending on the range of possible system configurations. Variable power loads can affect the design of the thermal solution. For example, a non-upgradeable platform with a minimal, predefined hardware configuration can use a cooling solution with very little thermal design margin. However, if a platform contains extra bays and add-in card slots to support end-user expansion with uncharacterized components, then additional reserve thermal capability must be provided. The values in Table 4 attempt to quantify reasonable loading assumptions for small form factor desktop PC applications with a similar number of peripheral bays and add-in card slots.

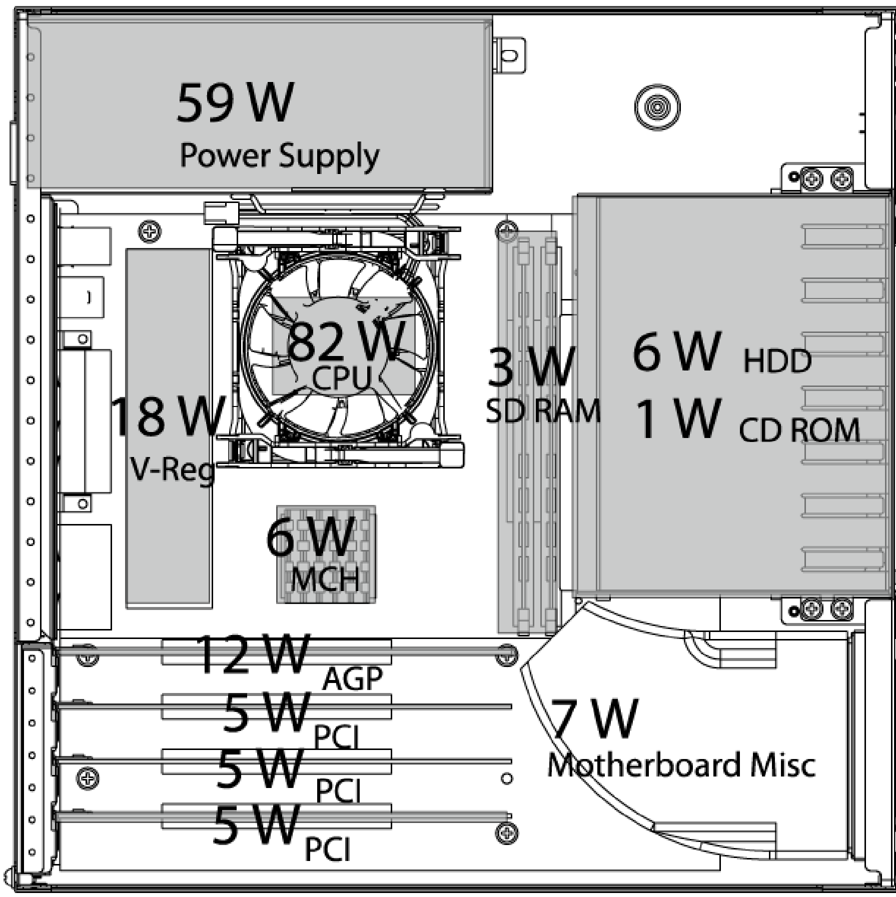

Figure 5: System Power Assumptions, Front Duct

✏ NOTE

The power supply wattage shown is an estimation of internal heat generated within the PSU itself. Since it is downstream from the system components, it has minimal impact to system thermal solution other than insuring that the PSU airflow is sufficient to cool its internal components.

2.2.3 System Airflow Direction

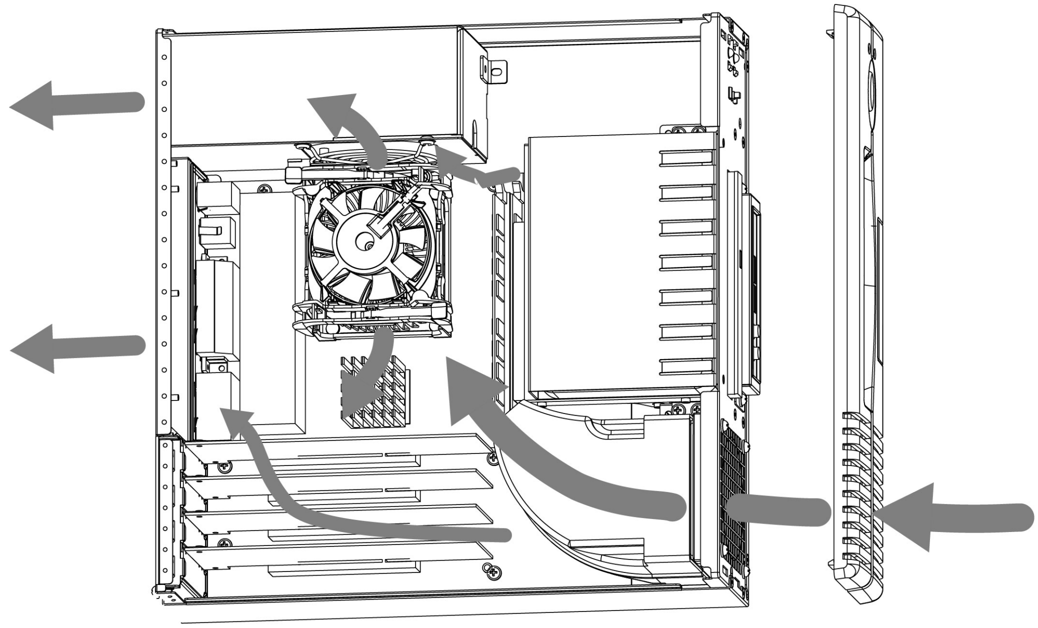

Figure 6: System Airflow Pattern, Front Duct

2.3 Core Duct System

Table 5: High-Level Chassis Design Targets

Parameter	Target
Chassis size[1]	Total volume ≤ 10 liters OR… Total volume ≤ 13 liters Width ≤ 92 mm Width ≤ 102 mm Depth ≤ 330 mm Depth ≤ 390 mm Height ≤ 328 mm Height ≤ 328 mm
System orientation	Either vertical (tower) or horizontal (desktop)
Motherboard component layout and feature set	Full-size microATX 1.1 form factor
Processor support	Processor thermal design power (TDP) 82 to 100W
Peripheral drive support	One hard drive – standard 4.0” x 1.0” x ~5.7” One optical drive, mobile or standard (5.8” x 1.7” x ~8.2”) size
System maximum operating temperature	System T_E ≤ 35 °C
System acoustic noise limits	Measured acoustic sound power at 4.0 BA or pressure at seated operator position per ISO-7779 ≤ 32 dBA at idle, 23 °C, typical configuration (see Table 6)

Notes:

(1) Chassis dimensional measurements include all sheet metal and the optical disk drive bezel. They do not include the front system bezel or a supporting stand for vertical tower systems.

(2) The 100 W value was assumed for testing is not meant to necessarily imply maximum capability for this solution.

2.3.1 Core Duct System Physical Layout

The differences between the 10-liter front duct system described in the previous section and the core duct system were driven by the core area ducting. The duct structure of the core duct system is significantly different than that of the front duct system. To achieve less than 3 °C rise to the core, the cross flow ducting shown in Figure 7 is necessary. Given the system height constraints (92 mm) left to right ducting was not possible. To ensure adequate airflow to the processor heatsink fan, the gap between the AGP graphics card and the ODD/HDD had to be maximized. This was achieved by shifting the optical and hard disc drive bracket to the right. The front panel I/O module was moved to the left of the system to improve access to the front panel connectors.

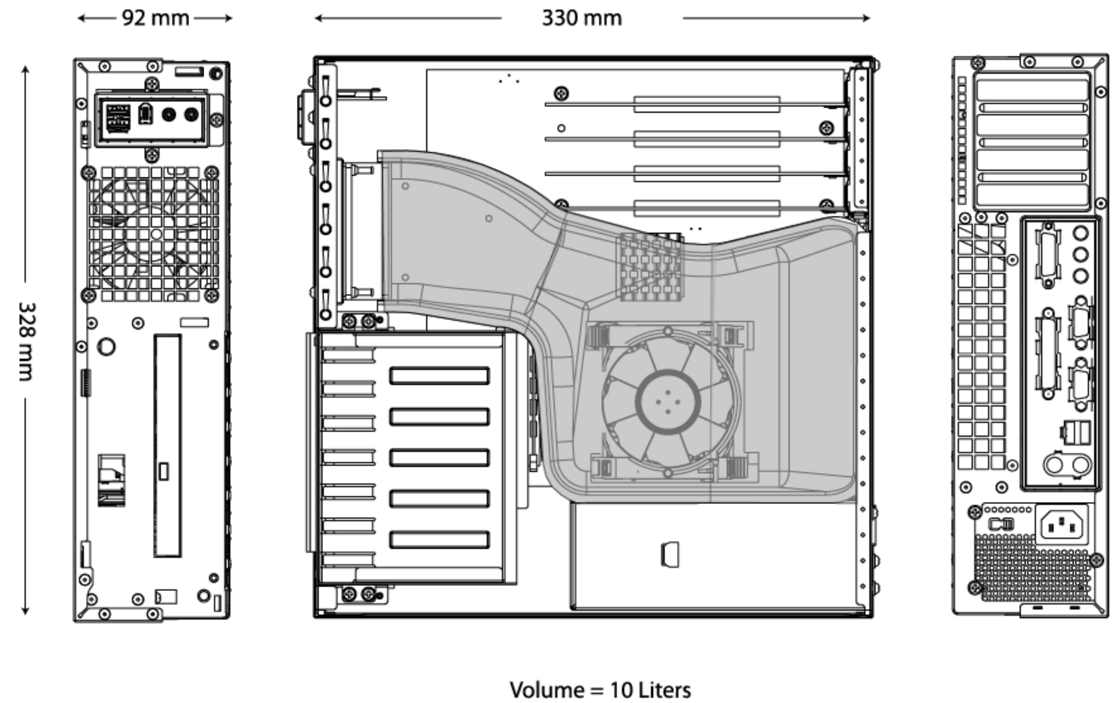

Figure 7: 10-Liter Reference Chassis Design Layout, Core Duct

The difference between the 13-liter core duct and front duct 13-liter system is the configuration of the duct. In the 13-liter core duct layout, cool air enters through both side vents of the chassis cover, absorbs heat from the core area components, and exits at the rear through the power supply and rear vents (as shown in Figure 8).

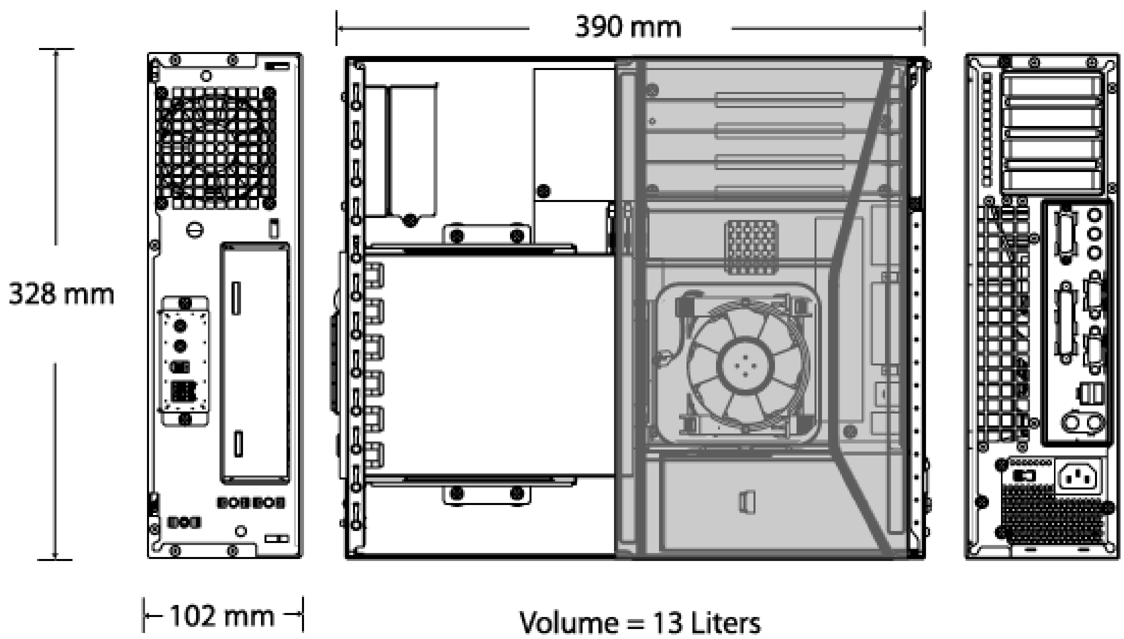

Figure 8: 13-Liter Reference Chassis Design Layout, Core Duct

2.3.2 System Power Load

Table 6: System Thermal Power Load Assumptions, Core Duct 10 and 13-Liter

Location	Item	System Power Load (1) Thermal Capacity Condition	System Power Load (1) Acoustic Noise Condition	Temperature Target	Comments
Core	Processor	82 W	49 W	$T_A \leq 38$ °C	
Core	Processor voltage regulator	18W	11 W	$T_A \leq 55$ °C	~82% conversion efficiency
Core	Chipset (MCH)	6 W	6 W	$T_A \leq 55$ °C	
Core	SDRAM memory	3 W	3 W	$T_A \leq 55$ °C	Three DIMMs at 1 W each
Core	Motherboard misc.	7 W	7 W	$T_A \leq 55$ °C	Includes two fans
Slot #7	AGP graphics	12 W	12 W	$T_A \leq 55$ °C	Add-in cards are presumed to adhere to the LP-AGP/PCI MD2 specification max PCB size (6.600” x ~2.6”).
Slot #6	PCI card	5 W	3 W	$T_A \leq 55$ °C	
Slot #5	PCI card	5 W	3 W	$T_A \leq 55$ °C	
Slot #4	PCI card	5 W	3 W	$T_A \leq 55$ °C	
Bay #1	Optical drive	10 W (2)	5 W (2)	$T_A \leq 55$ °C	Idle mode
Bay #2	Hard drive	10W	5 W	$T_A \leq 55$ °C	
	Subtotal (DC)	**163 W**	**107W**		
PS	Power supply	60 W	40 W	$T_A \leq 50$ °C	~73% conv. efficiency
	Total (AC)	**223 W**	**147 W**		

(1) Power values represent continuous simultaneous power dissipations that might reasonably be expected during typical system use. The values do not reflect all possible device powers or system operating conditions. See component specifications for actual values.

(2) 10-liter mobile optical drive 1 W for thermal and acoustic condition

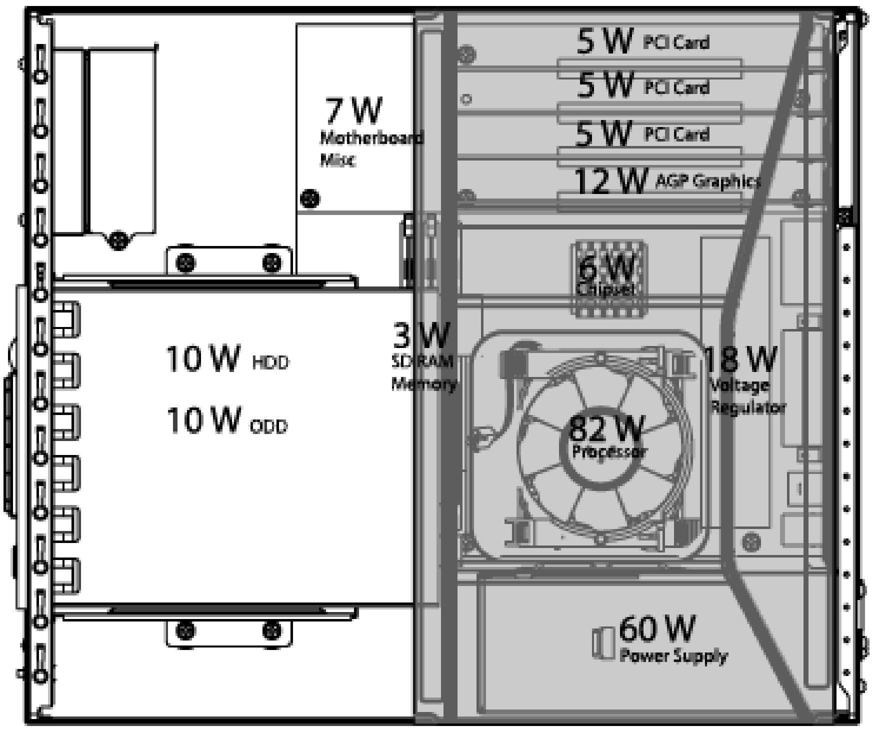

Figure 9: System Thermal Power Assumptions, Core Duct 13-Liter

2.3.3 System Airflow

In order to achieve less than 3°C temperature rise to the CPU inlet it is necessary to duct ambient air directly to the core. To ensure that the air temperature above the processor heatsink fan is relatively uniform the system must provide airflow from both the left and right hand sides of the system. This cross flow method is implemented on both the 10-liter and the 13-liter systems discussed in this document. While the implementation within each system is quite different the cross flow concept is the basis for each design. The 13-liter platform pulls air in from the sides whereas the 10-liter platform uses the front and back inlet scheme

The 10-liter system provides air from the front and rear of the system. Due to the height constraints of the system left to right ducting was not possible since there is not enough room above the power supply and add-in cards for a duct structure. The air impedance at the front of the system is much greater that that at the rear, due to the vent stack up of the front wall and the bezel. To ensure that sufficient air is provided to the processor heatsink fan, the chassis front fan is partially used to enhance the airflow through the front vents. The remainder of the airflow is drawn in through the vent on the top cover at the rear of the system, as shown in Figure 10.

The lower portion of the chassis front fan is used to provide cooling to the add-in cards, as well as the chipset. In addition to cooling the processor the heatsink also provides cooling to the memory, chipset, and voltage regulator.

Both the chassis front fan and the processor heatsink fan pressurize the system. The power supply is used to evacuate some of the heated air from the system. Additional venting at the rear of the system acts as an exhaust for the pressurized system.

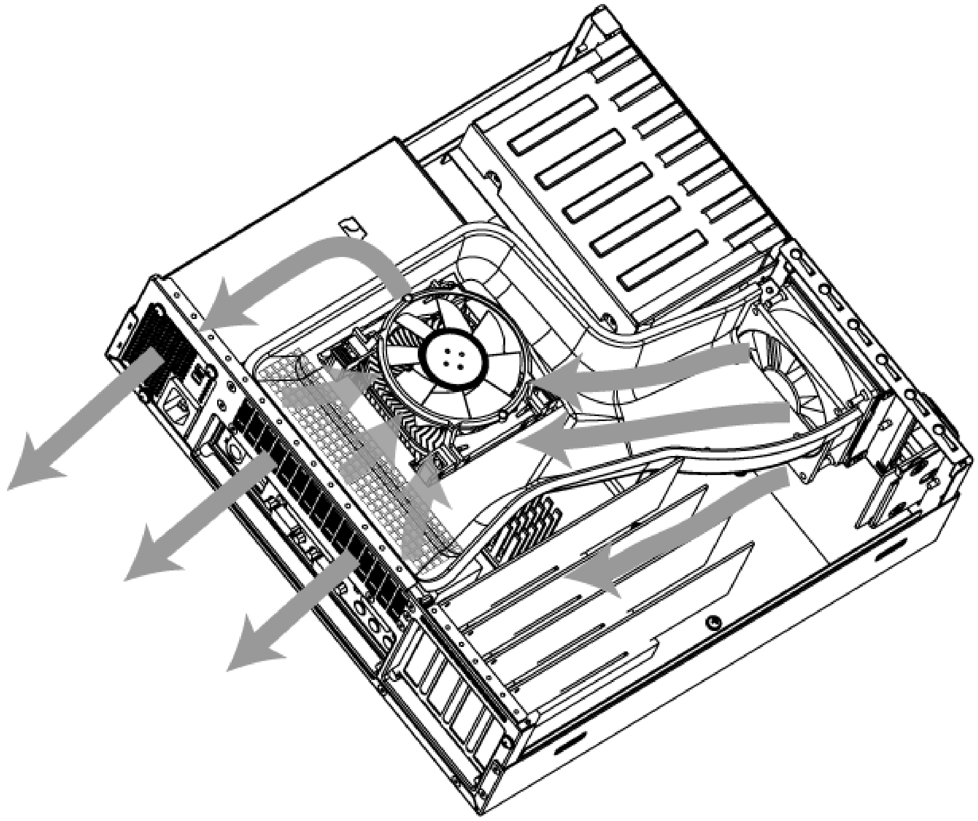

Figure 10: System Airflow Pattern, 10 Liter Core Duct

Figure 11 shows approximate airflow patterns through and within the 13-liter core duct system enclosure. In this layout, all three fans (processor heatsink, power supply, and chassis front fan) are oriented to exchange air between the system and the environment; they are responsible for overall airflow direction and flow volume through the chassis. The processor heatsink fan is responsible for inlet ambient to the heatsink and it maintains the processor within its operating temperature specification by transferring heat to the surrounding environment. The chassis front fan mainly provides cool air to the add-in card area as well as chipset and other components. Both the processor heatsink fan and the chassis front fan create positive air pressure (upstream), while the power supply fan creates a lower pressure region (downstream). The pressure differential between these two areas forces air through the chassis to the surrounding environment. They work together in series—or “push-pull”—arrangement.

In addition to the intake and exhaust vents at these two corners, a chassis typically contains other vents or openings, either intentional or unavoidable that allow airflow between the chassis and the surrounding external environment. The most significant of these are the rear chassis vent adjacent to the motherboard rear I/O connector area and the add-in card vent. Since the processor heatsink fan and the chassis front fan provide more air than the power supply fan can exhaust, the rear vent and add-in card vent serve as an additional exhaust vents for the excess air pressure.

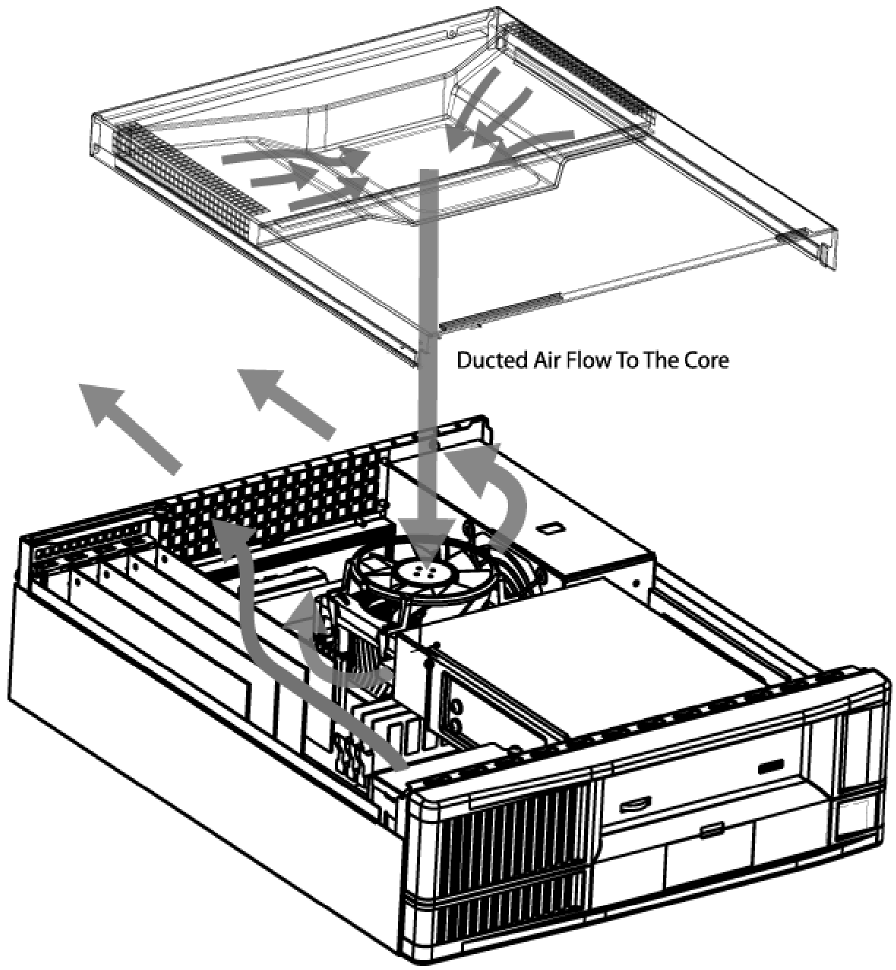

Figure 11: System Airflow Pattern, 13-Liter Core Duct

The amount of air entering or exiting at each vent can only be quantified with detailed analytical modeling or laboratory testing, as will be detailed in Section 3.1.1.

Since keeping the processor heatsink inlet ambient, T_A, below its maximum specified value is critical, two additional design features are incorporated. First, the processor heatsink fan uses a core duct to draw direct ambient air to the motherboard core. Second, the TFX12V power supply mechanical definition places its fan intake next to the processor thermal solution exhaust, allowing the two components to work together in removing processor heat through the power supply and reducing the hot air being recirculated back to processor heatsink ambient,T_A.

2.4 Processor Thermal Solution

To be cooled by reasonable air temperatures and velocities, a processor requires a package-level thermal solution to transfer heat energy from the processor to the surrounding air. An active fan heatsink such as that shown in Figure 12 is typically used, because its application-independence suits the system integration market. As long as the system-level thermal solution (i.e., fans, ducts, and vents) maintains the temperature at the inlet of the processor heatsink fan (“T_A”) below a specified maximum, the processor heatsink fan will provide sufficient cooling of the processor die.

Accordingly, the processor heatsink inlet, T_A, represents the threshold between the complementary package-level and system-level thermal solutions. To decrease the required performance (and cost) of the system-level solution by raising T_A requires higher performance (and cost) at the package level, and vice versa. Minimizing the *overall* solution cost requires finding the optimum balance between the package-level and system-level performance requirements.

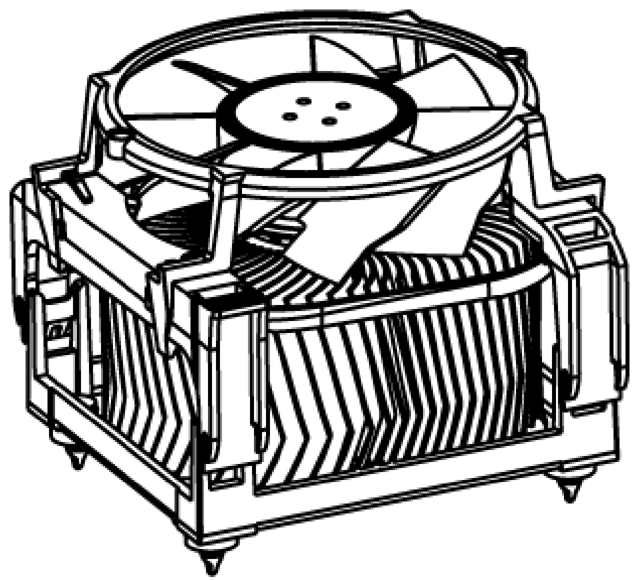

Figure 12: Example Processor Thermal Solution

Given the trend toward increasing processor power density, processor thermal solution designs are migrating from a previous processor heatsink inlet, T_A, of 42°C to an even more system-stringent 38°C. $T_A \leq 38°C$ will be assumed for the 10 and 13 liters core duct reference design examples. The processor heatsink inlet, $T_A \leq 38°C$ represents the critical path of the system thermal design. The design of the chassis with core duct and the selection of the power supply fan and chassis front fan are mainly motivated by their combined capability to maintain processor heatsink inlet ambient $T_A \leq 38°C$ under all conditions of power load and system inlet ambient, T_E. It will be shown that the resulting system airflow generated to meet this criterion is sufficient to keep all other components within their operating specifications with little additional design consideration.

3 Thermal/Acoustic Design Details

3.1 Core Duct System Level Airflow

3.1.1 Core Duct 13-Liter System Level Airflow

The processor heatsink fan and the chassis front fan provide the system level airflow, which pressurizes the chassis. The power supply fan is used to evacuate the system in addition to the rear vents.

To adequately cool the add-in cards, chipsets, and prevent recirculation the front fan should provide approximately 6.7 CFM (as measured) in the system.

To adequately cool the processor while maintaining a 38C T_A Inlet the processor heat sink fan must deliver 14.5 CFM (as measured with other fans not operating) in the system.

The power supply fan, in addition to cooling the power supply enclosure, should assist in evacuating the system with 10.5 CFM.

Figure 13 illustrates the airflow pattern described above.

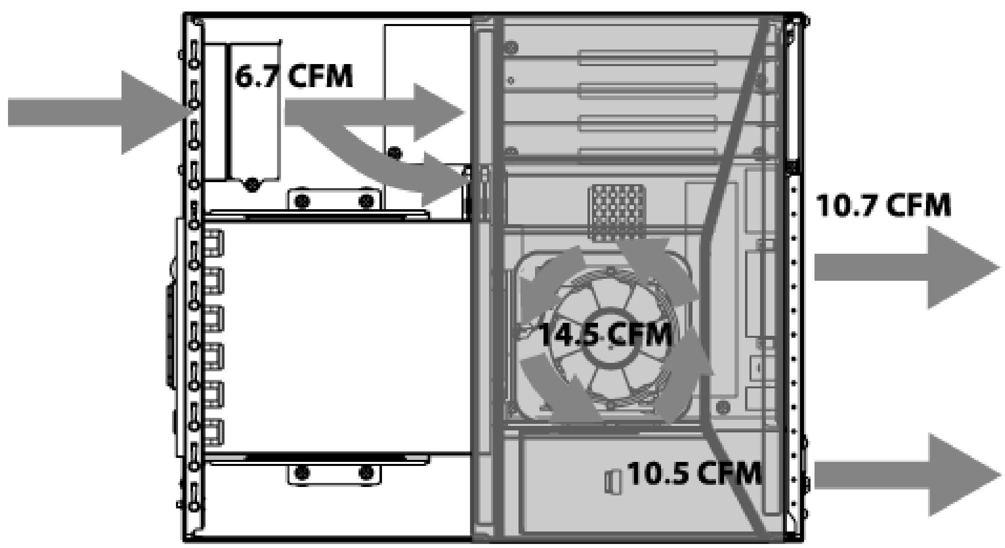

Figure 13: Simplified Airflow Representation Chassis Design

3.2 Chassis Design

3.2.1 Platform Impedance

To obtain the best possible airflow performance from the system fans, the platform must minimize unnecessary flow restrictions. In addition to the fan and component layout established in Figure 8 the sheet metal vents and the front bezel design are critical to creating a low impedance airflow path though the system. In general, more and larger openings yield lower chassis impedance, though the designer must avoid excessive airflow bypass of targeted components. Chassis airflow impedance curves can be quantified with either analytical modeling or laboratory testing using specialized airflow chamber equipment.

3.2.2 Core Duct Design

The design of the core duct is essential for directing ambient air to the processor heatsink. The duct allows for airflow from both sides of the cover venting, thus creating a more uniform processor heatsink inlet temperature, T_A that provides a < 3ºC rise from external ambient. The duct design allows some variance in processor placement as the processor heatsink opening is oversized. The proper size of the opening in the duct above the processor heatsink is critical in reducing recirculation of heatsink exhaust back to the fan inlet.

3.2.3 System Vents

The system vents should maximize the flow area but not adversely affect electromagnetic (EM) shielding effectiveness.[1]

To reduce airflow impedance, vent patterns were chosen to maximize free air ratio (FAR). Figure 14 shows the implemented system vents. The recommended FAR for the cover inlet vent is 50%. For the chassis used in the development of this design guide, a FAR of 64% was used.

[1] For more information about designing chassis vents for electromagnetic compatibility (EMC), see *MicroATX EMC Design Suggestions and Wave Guide Design Guide*.

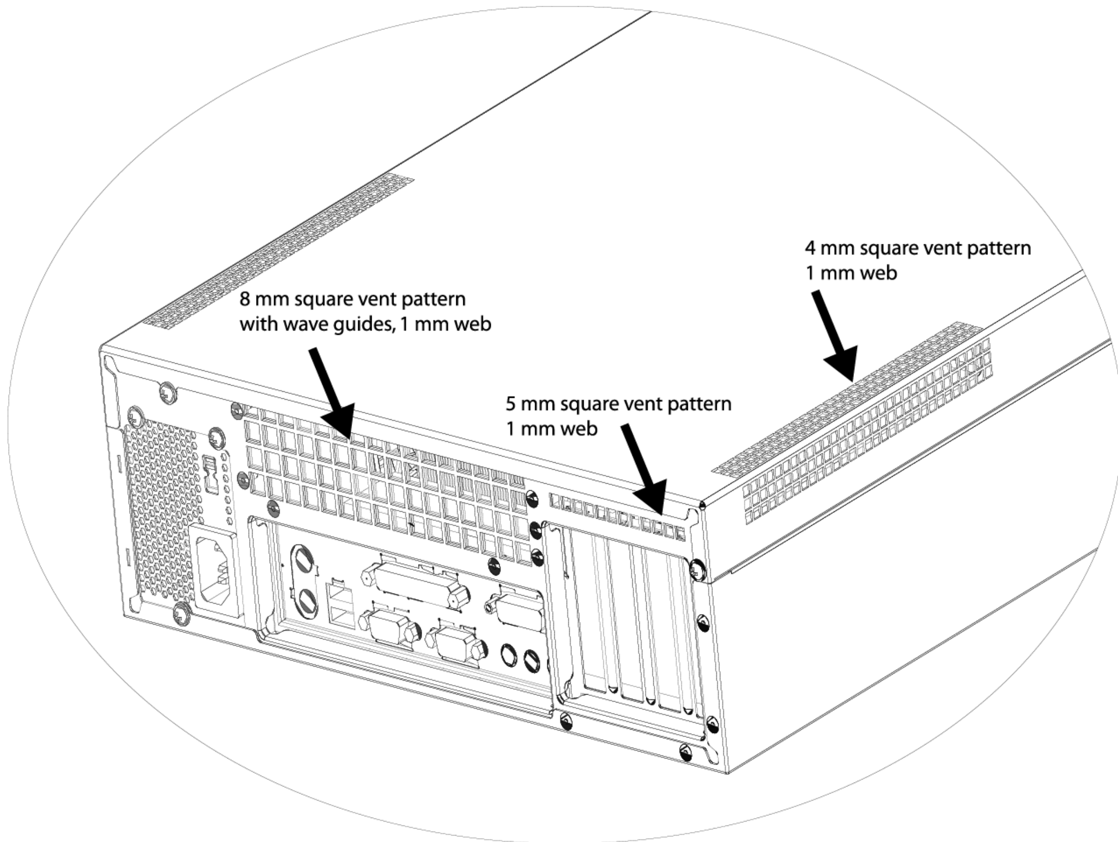

Figure 14: System Vents

The total area for the core duct inlet vents is approximately 55cm^2 of open vent area. As shown in Figure 14, the vent area is on both sides of the cover. Testing has shown that partial blocking of up to 25% of the vents still provides adequate airflow to the system. The total area available for the chassis front intake vent is dictated by the outline of the 80 mm chassis front fan. Applying the vent pattern above yields (80 mm)x(80 mm)x(0.694) = 44 cm^2 of open vent area. Similarly, the rear chassis vent is bounded within a 150-mm by 29-mm rectangle, which allows 41 cm^2 of open area, and the add-in card vent is 3 cm^2 of open vent area. The data throughout this document is based on a rear chassis vent pattern that yields 21 cm^2. The vent pattern shown in Figure 14 is optimized for reduced system impedance while maintaining electromagnetic (EM) shielding effectiveness.

3.2.4 Front Bezel

Even when front sheet metal vents are well designed, the front bezel design is often a significant airflow bottleneck. The bezel provides a cosmetic face to the front of the chassis that serves to conceal sheet metal and system components, yet it must allow for adequate airflow into the system. The designer must weigh the tradeoff between visual aesthetics and airflow impedance.

Figure 15 shows two example bezel designs. The vent pattern in Option 1 offers reasonably low airflow impedance and a generic industrial design. Option 2 has more open area and requires the airflow to make fewer sharp turns. As a result, it offers lower (better) airflow impedance than

Option 1. The drawback of Option 2 is a more visible line-of-sight to the chassis sheet metal in some system installations. The calculation of the exact airflow impedance for these options is beyond the scope of this text. Designers wishing to implement a bezel design with less open area than Option 1 ($\leq 33\ cm^2$) should carefully consider the potential impact to the chassis thermal/acoustic performance.

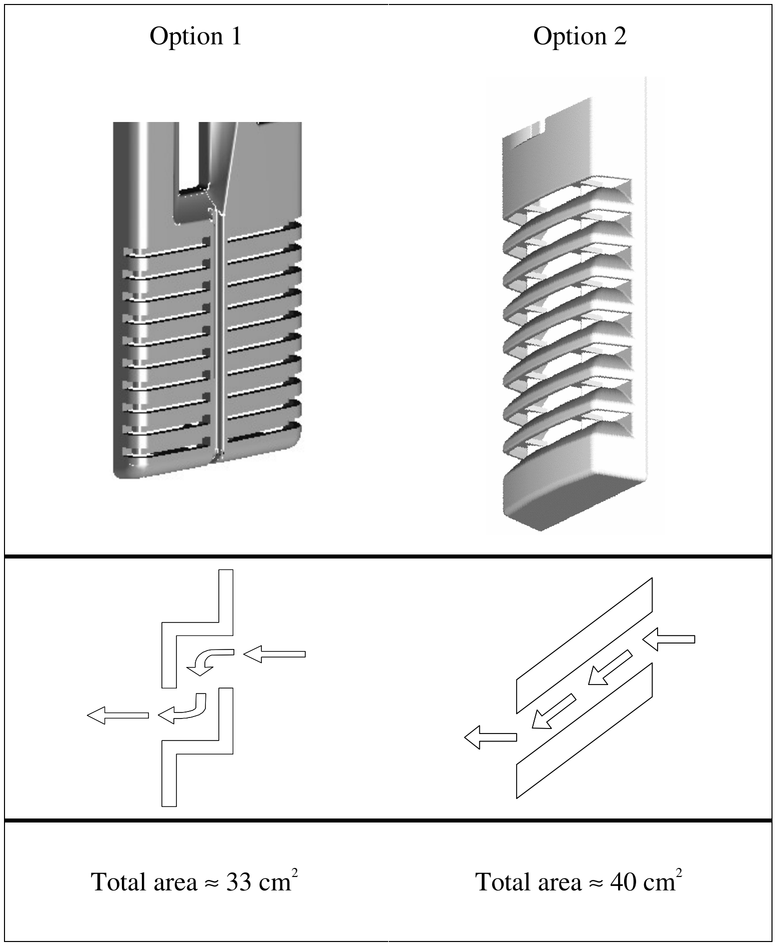

Figure 15: Bezel Design Examples, Front Duct

3.3 Fan Design

A good thermal/acoustic system design balances the airflow capacity needed at load and temperature extremes with acceptable acoustic performance under more common operating conditions. As the primary sources of both airflow and noise, the system fans are critical to overall system performance. The following subsections detail the specific considerations and steps involved in their design/selection:

- Size fan airflow capacities to meet worst-case thermal conditions
- Use fan speed control methods to reduce acoustic noise in typical use conditions

3.3.1 Processor Heatsink Fan

The processor thermal solution normally consists of a heatsink, an attached fan, and mechanical retention mechanisms that hold the assembly together during normal use and shipment. The processor thermal solution is responsible only for maintaining the processor within its operating temperature specification by transferring heat to the surrounding air. It generally does not evacuate that heat from the chassis, nor does it intentionally provide much airflow or thermal benefit to other components. This limited dependence on the surrounding platform design makes it relatively straightforward to apply to a range of system configurations, including the small form factor chassis.

The small chassis design examples assume the use of a processor heatsink fan that supports the particular processor up to the 82 W and higher TDP power limit listed in Table 3 so long as processor $T_A \leq 38$ °C. As mentioned previously and demonstrated by the test results in Appendix A, the processor thermal solution requirement for processor $T_A \leq 38$ °C is the critical path of the system thermal design, and it drives the selection of the remaining system fans.

Processor thermal solution providers design each of their products to support specific processor power and T_C requirements over a range of input (T_A) temperatures. For any given T_A temperature, there is a single corresponding Ψ_{CA}[2] requirement, and a single minimum fan RPM that supports that requirement. The best-case fan speed control curve is therefore pre-determined by the heatsink technology and fan design.

For the system designer, choosing an active processor thermal solution is a tradeoff between cost and performance. Heatsinks with better thermal/acoustic performance provide equal or better heat transfer at lower acoustic noise (i.e., lower fan RPM's). This is done by: (a) improving the fit of the product to the best-case curve, or (b) using advanced technologies to improve the curve itself. Either improvement generally increases the solution cost versus lower-performance alternatives. The rising cost of package-level thermal solutions with increased thermal/acoustic performance is the main reason for system-solution-focused design guides such as this one.

[2] For more information about processor thermal solution requirements, see Section 2.2.2.2 of *Intel Pentium 4 Processor in the 478-pin Package Thermal Design Guidelines.*

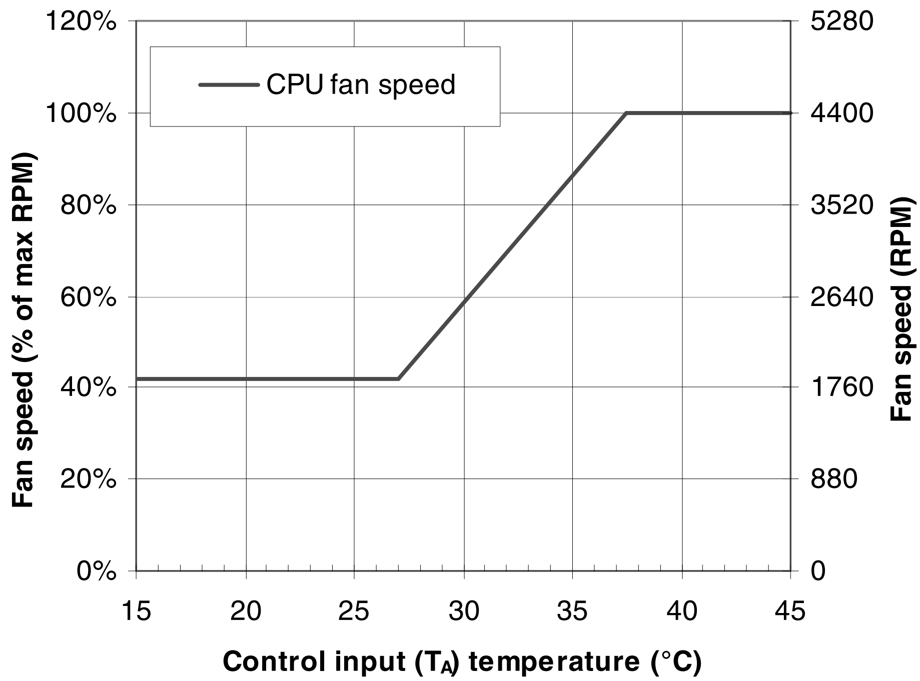

Figure 16: Example Processor Heatsink Fan Speed Control Curve

3.3.2 Chassis Front Fan

An 80-mm fan is the largest common size that can fit in the chassis front panel area and should yield the best acoustic performance at a given airflow. Obtaining the 6.7 CFM from the chassis front fan (as calculated in Section 3.1.1) requires a total free-air fan capacity well in excess of that amount (typically at least 100% more) to offset restrictions in the power supply and chassis. A fan with a free air capacity of 47 CFM at 12 V_{DC} was chosen as an initial starting point. Fan airflow impedance curves are available from vendor specifications or by experimental measurement.

To determine the final full-speed RPM, laboratory testing is used to find the solution that best balances the thermal and acoustic performance from all three fans.

Figure 17 shows the performance curve for this fan. When selecting a fan for a particular design, consider that most commonly available fans of similar geometry, blade design, and speed will have similar—although not identical—performance characteristics.

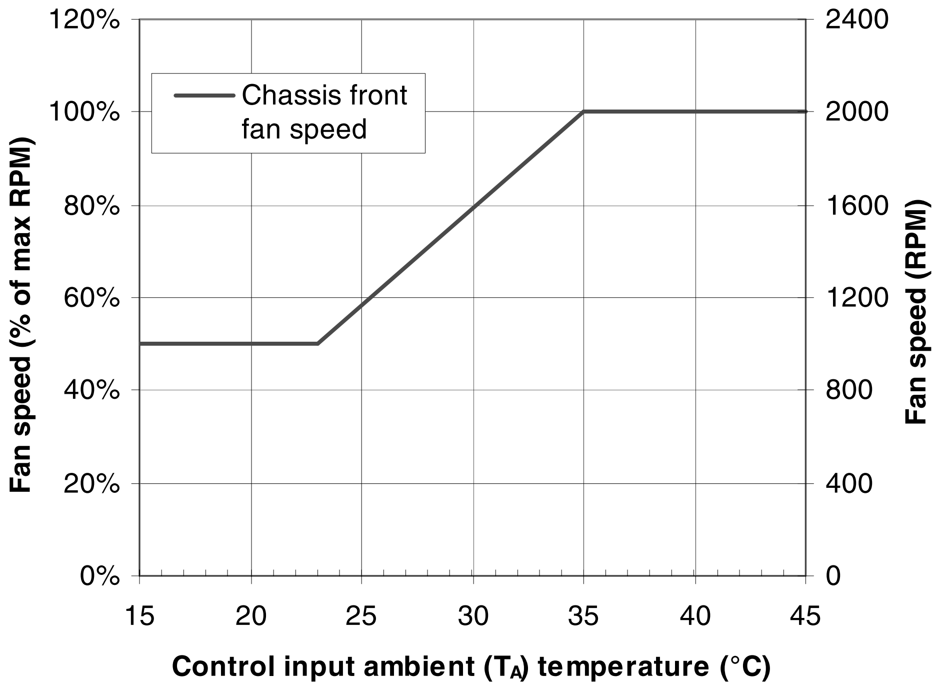

Figure 17: Chassis Front Fan Performance Curve

Although the chassis front fan is not the primary contributor to acoustic noise in the core duct system, it is still necessary to use fan speed control to attain acoustic goals. Using available fan speed technologies, the front fan can be slowed to optimum acoustic levels.

3.3.3 Power Supply Fan

The TFX12V power supply supports an 80 mm fan in the side facing the system processor.[3] The fan thickness can vary, depending on the power supply internal electronics layout. The reference design power supply uses a 20-mm-thick fan.

It is often difficult for system integrators to rely on off-the-shelf power supply designs to deliver large system-level airflows. Like the processor thermal solution, the power supply tends to be marketed as an independent design component, portable across many system platforms. Its thermal solution design is commonly focused on maintaining the operational temperatures of its internal components, with minimal acoustic liability (and therefore minimal thermal benefit) to the rest of the system. The amount of system-level airflow generated by a power supply varies depending on the wide range of system-level impedances and inlet temperatures into which the power supply is installed.

[3] For more information about the TFX12V power supply, see *TFX12V Power Supply Design Guide*.

To meet the acoustic condition it was determined that the targeted power supply operating point should be no greater than 1800 RPM. Remaining tasks include designing a reliable fan speed control method and verifying the power supply internal component temperatures at key operating conditions.

The power supply fan is often the most difficult fan for which to define a speed control method that meets specific system-level thermal/acoustic requirements. The power supply's downstream location means that an internal temperature sensor is influenced not only by changes in T_E but also by the internal power load and system-level airflow. To reliably control the power supply fan speed from low speed (here, 1800 RPM) at the acoustic noise test condition to high-speed (3650 RPM) at the thermal capacity test condition, the designer must identify a control input internal to the power supply that meets the requirements outline in Figure 9.

The thermal test results in Appendix A show the measured air temperature entering the power supply (T_A) at the thermal capacity test condition is ~43 °C. At the acoustic noise test condition, T_A is ~35.3 °C. If a fan-hub-mounted thermistor sensor measuring PSU temperature inlet, T_A, is used as the only control input, then the control circuit must ramp the fan speed by 1800 RPM (= 3650 – 1800) over a 7.7 °C difference in the control input per Figure 18.

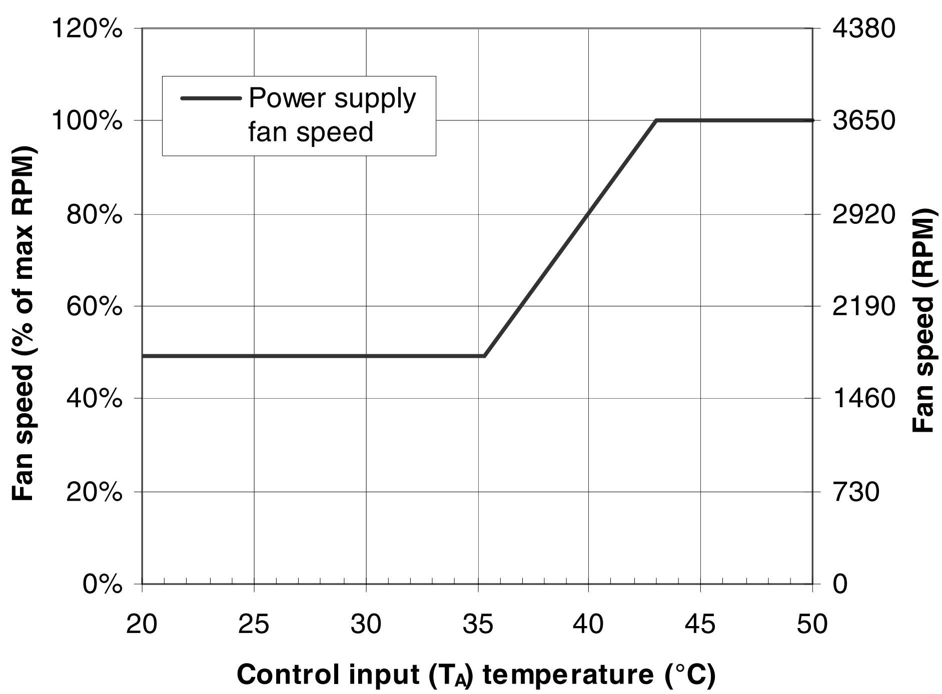

Figure 18: Example Power Supply Fan Speed Control Curve

In practice, the power supply designer would likely locate the control input sensor on an internal power supply component that becomes hotter with increasing system power load (such as on the heatsink for one of the output transistors). In that way, the load-dependent variation supplements the 7.7 °C PSU inlet temperature, T_A, variation for a wider, more stable control input signal span. It also couples the fan response to potentially limiting power supply component temperatures for a more robust power supply design. Unlike the chassis front fan or the processor heatsink fan, the power supply fan is difficult to control with a motherboard thermal ASIC because no standardized, widely adopted signal interface definition exists between the motherboard and the power supply.

The second task is to verify power supply internal component temperatures at various inlet temperatures and power loads. This task is beyond the scope of this document and should be performed by the power supply manufacturer. Only the manufacturer has the component operating temperature information needed to guarantee safe and reliable power supply operation. The small chassis reference designs used an off-the-shelf power supply and fan with a maximum T_A of 50 °C. After modifying the fan curve to match Figure 18, the design still met the thermal requirements of the power supply components.

3.4 Acoustic Considerations

In addition to fan speed control, the reference design uses several other techniques and components to obtain the best acoustic performance:

Avoidance of near-field fan obstructions. Locating anything very close to the fan blades—particularly the intake side of the fan blades—hinders airflow and can generate strong tonal acoustic emissions at harmonics of the blade passing frequency. To lessen this effect, the reference design provides a 0.4” air gap above the processor thermal solution fan intake. The chassis front fan is offset from the front grille on the sheet metal subpanel by approximately a 1” spacer bracket. Finally, the power supply utilizes a wire intake grille with a 3 mm gap to the intake blades. Flush-mounting fans to flat, stamped sheet metal grilles is a leading cause of unnecessary acoustic noise. Even a few millimeters of clearance near fan blades can greatly reduce acoustic emissions.

Hard drive selection. Hard drive manufacturers are constantly developing technologies (fluid bearings, isolating sleeves, control algorithms, etc.) that improve their products’ acoustic performance. The system integrator is responsible for selecting the level of hard drive acoustic performance (and cost) for the system design.

Well-fitting parts. Make sure plastic and metal parts fit together tightly enough that structural vibration does not cause them to rattle audibly. This is particularly important in systems with several fans or hard drives, where different rotational frequencies can cause structure-borne vibrations of considerable amplitude.

Chassis impedance. To minimize chassis impedance vent patterns with large FAR were used.

Fan Selection. To deliver the required airflow at the lowest possible acoustic noise the largest fans possible for this chassis were selected. This allowed for the lowest RPM setting for the required airflow.

For more details on these and other general acoustic design recommendations, see the *Acoustic Overview Design Guide*.

4 Related Considerations

Thermal/acoustic solution design requires knowledge of the inherent trade-offs with related performance criteria such as electromagnetic compatibility and dynamics. This section highlights some of those trade-offs and their significance.

4.1 Electromagnetic Compatibility (EMC)

An ideal chassis for EMC is a solid metal container with no openings. Unfortunately, real chassis require vent openings for airflow, and these vents provide opportunities for electromagnetic radiation to escape or permeate the system. As operating frequencies increase, so do both the thermal power and electromagnetic emissions, which create conflicting requirements for chassis openings.

The solution is to balance the size and pitch of vent holes to meet both thermal and EMC requirements. Although actual EMC requirements are difficult to quantify for a generic case, *MicroATX EMC Design Suggestions* provides basic rules for chassis holes as a function of the targeted operating frequencies. The document also discusses more advanced solutions (such as waveguides) for reducing flow impedance without compromising electromagnetic containment.

4.2 Dynamics

As package-level thermal solutions increase in size and weight, they become more difficult to secure during shipping and handling. Potential consequences include dislodged components, cracked PCB traces, increased packaging costs, and higher customer return rates. The costs associated with preventing shipping and handling damage represent another reason for the designer to balance the thermal solution requirements at the package and system levels.

5 Theory

5.1 Heat Transfer Theory

As air flows through a chassis, heat energy is transferred (convected) from hot powered components to the air itself. This transfer cools the components but raises the downstream temperature of the air. The amount of air temperature rise depends on the applied power load and volume of airflow per Equation 1.

Equation 1: $$\Delta T = \frac{\dot{Q}}{\rho C_P \dot{V}} \approx \frac{1.79\,\dot{Q}}{\dot{V}_{CFM}}$$

Where: $\dot{Q}$ = Power input (W)
ΔT = Temperature rise (°C)
$\dot{V}$ = Volume flow of air (m^3/min, or ft^3/min)
ρ = Density of air (≈ 1.18 kg/m^3 at std atmosphere)
C_P = Specific heat of air (≈ 1005 J / kg· °C at std atmosphere)
1 m^3/min = 35.31 ft^3/min (CFM)

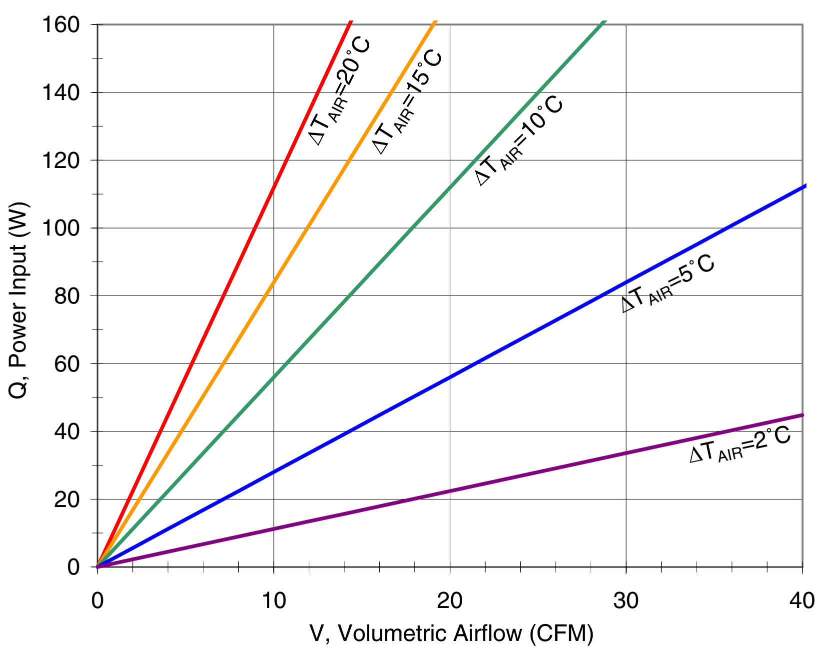

Figure 19: Airflow Heat Capacity

5.2 Airflow Capacity

Having selected an overall chassis layout per Section 2.3.1 and allowing for the best platform airflow impedance, the next step is to select the various fans. The fan airflow capacity requirements are driven by the local and overall airflow volumes needed to keep all components within their maximum temperature specs under the worst-case load and ambient temperature conditions (T_E = 35 °C). Analytical modeling and/or lab testing may be used to predict the fan capacities needed.

To obtain the best acoustic performance at a given airflow capacity, larger, slower fans are preferred over a smaller, faster fan. Figure 20 shows that both the airflow and acoustic noise generally increase with fan size and speed. For a given airflow, however, a larger fan spins at a slower speed and produces less noise at the same cost. Therefore, designers should use the largest possible common fan size that will fit in the application.

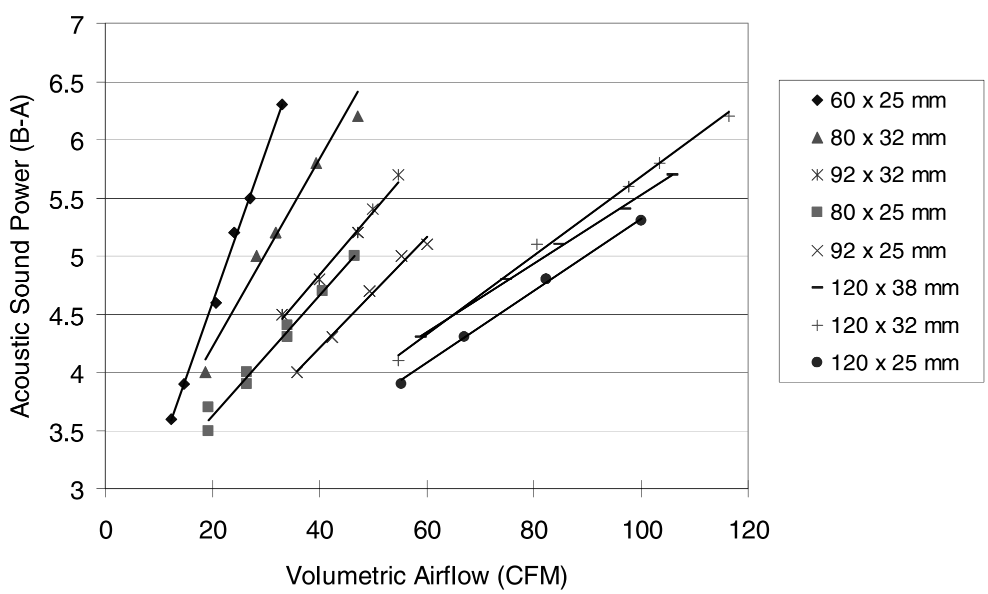

Figure 20: Fan Acoustic Noise vs. Airflow

In systems with multiple fans, different fan capacity combinations may exist that properly cool a given component(s). In such a case, the goal is to find the combination that cools all system components simultaneously at the lowest acoustic noise.

6 Conclusions

A well-designed chassis and power supply are key ingredients for any integrator focused on building desktop PCs using high-volume, low-cost components. As thermal loads increase, the system-level airflow supplied by the chassis and power supply critically affects overall costs by expanding or limiting the choice of off-the-shelf package-level cooling options.

This guide detailed the design of four small (10- and 13-liter) microATX-based platforms that provide a processor environment of T_A = 38 °C to 42 °C. Given an appropriate processor thermal solution, the designs support a ≥ 82 W TDP processor and quiet operation at ≤ 32.0 dBA sound pressure at the operator position or 4.0 BA sound power. The design of these or similar platforms requires a comprehensive and concurrent approach that carefully balances thermal and acoustic performance of and among the key ingredients throughout the process. The main considerations are summarized in Table 7.

Table 7: Chassis and Power Supply Airflow Recommendations

Goal	Recommendations
Minimum airflow impedance	• Maximize vent and bezel openings along desired airflow paths. Minimize other openings. • Use ducting to direct cool air to the processor with minimal impedance and temperature rise. • Avoid potential airflow “pinch points,” such as at the processor thermal solution intake or between the add-in cards and drives. • Provide an air gap of at least 3 mm around all fan blades, especially at the intake.
Maximum airflow volume	• Design system airflow to meet T_A requirements. The resulting solution will likely support most other system components in this layout. • For a given airflow volume, select the largest fans that will fit in the application.
Minimum acoustic noise	• Use fan speed control on all fans. • Balance the control curves among all system fans, so that throttling one fan down does not force a noisier one to speed up. • Ensure the power supply design throttles to a minimum fan speed at the system acoustic test condition.

Small chassis designs should consider these suggestions to support performance processors at the lowest system cost and acoustics. For updates and more information, please refer to: http://www.formfactors.org/

7 Glossary

Table 8: Terms

Term or Acronym	Description
acoustics	A branch of science dealing with the generation, transmission, and reception of sound. With respect to computer design, the goal is to minimize undesirable audible noise caused by fans, motors, and other components.
Airflow	Movement of air particles from a region of higher pressure to a region of lower pressure. When airflow occurs in the vicinity of a temperature differential, it provides a transport mechanism for heat energy.
airflow impedance	Resistance to airflow because of obstructions in the airflow path.
airflow impedance curve	A graph depicting the relationship between the volumetric airflow through a device and the corresponding pressure differential across the device.
dynamics	A branch of mechanics that deals with energy and forces and their relation to the motion of bodies. In computer design, the focus is on ensuring that system components do not incur damage when subjected to shock and vibration forces during product shipping and handling.
EMC (electromagnetic compatibility)	The ability of an electronic device to function properly in its intended electromagnetic environment (i.e., to neither cause undue interference to other devices nor be susceptible to interference from them). Electromagnetic compatibility is regulated by law for computer equipment in most countries.
motherboard core	The region of a motherboard layout containing the processor, chipset, memory, voltage regulator(s), and other primary logic components.
package-level thermal solution	A physical mechanism for transferring heat energy from an integrated circuit package to its surrounding environment. Heatsinks (passive or active) and heat pipes are common examples.
system-level thermal solution	A physical mechanism for transferring heat energy from within a chassis enclosure to its surrounding environment. Examples include fans, vents, and ducts.
TDP (thermal design power)	A power dissipation target based on worst-case applications. Thermal solutions should be designed to dissipate the thermal design power.
T_A	The temperature of air at the inlet to the processor package-level thermal solution (such as at the intake of a processor heatsink fan). Also referred to as T_A.
T_E	The temperature of external air at the inlet to the system-level thermal solution (such as at the chassis intake vents). Also referred to as T_E.
volumetric airflow	The volume rate of airflow measured in cubic feet per minute (CFM).

Appendix A

A.1 Introduction

This Appendix contains a high-level summary of thermal data collected from the 13-liter Core Duct, 10 Liter Core Duct and 10 Liter Front Duct reference designs. A single thermal test board (TTB)-based system was instrumented with RTD temperature sensors to monitor air temperatures at locations throughout the system. Temperature measurements were collected under various power load, fan speed, and hardware configurations to demonstrate the sensitivity of the design to such variations.

A.2 Sensor Locations

Table A1 lists the temperature sensor locations. Figure A1 shows the sensor locations referenced in Table A1.

Table A1: Temperature Sensor Locations

TC #	Location	Location	Z(1) (mm)
1a, 1b, 1c, 1d	T_A (front-left, back-left, back-right, front-right)	Centered on median fan blade radius. 6 mm above fan blade	
2	MCH ambient	Above center of MCH package	20 above MB
3a, 3b, 3c	Memory air (back, middle, front)	Between memory sticks	30 above MB
4a, 4b	PSU inlet (front, back)	At power supply fan intake centered on opposing sides of median fan radius	45
5a	PCI (slot #4)	Centered between PCI connectors	40 above MB
5b	PCI (slot #5)	Centered between PCI connectors	40 above MB
5c	PCI (slot #6)	Centered between PCI connectors	40 above MB
6	AGP (slot #7)	Centered between AGP connectors	40 above MB
7a, 7b	Processor voltage regulator ambient (left, right)	Approximate locations shown	30 above MB
8a, 8b	T_E (left, right)	12 mm	95
9a, 9b	Rear vent exhaust (left, right)	6 mm behind (external to) chassis rear vent	85
10	PSU exhaust	6 mm behind power (external to) supply rear vent	45
11	PCI & AGP vent exhaust	6 mm behind (external to) chassis PCI vent	95
12	Front fan inlet	12 mm in front of bezel	45
13	HDD ambient	Approximate location shown	40 above MB
14	ODD ambient	Approximate location shown	75 above MB

(1) [0,0,0] reference is bottom front left corner of chassis sheet metal, inside surface.

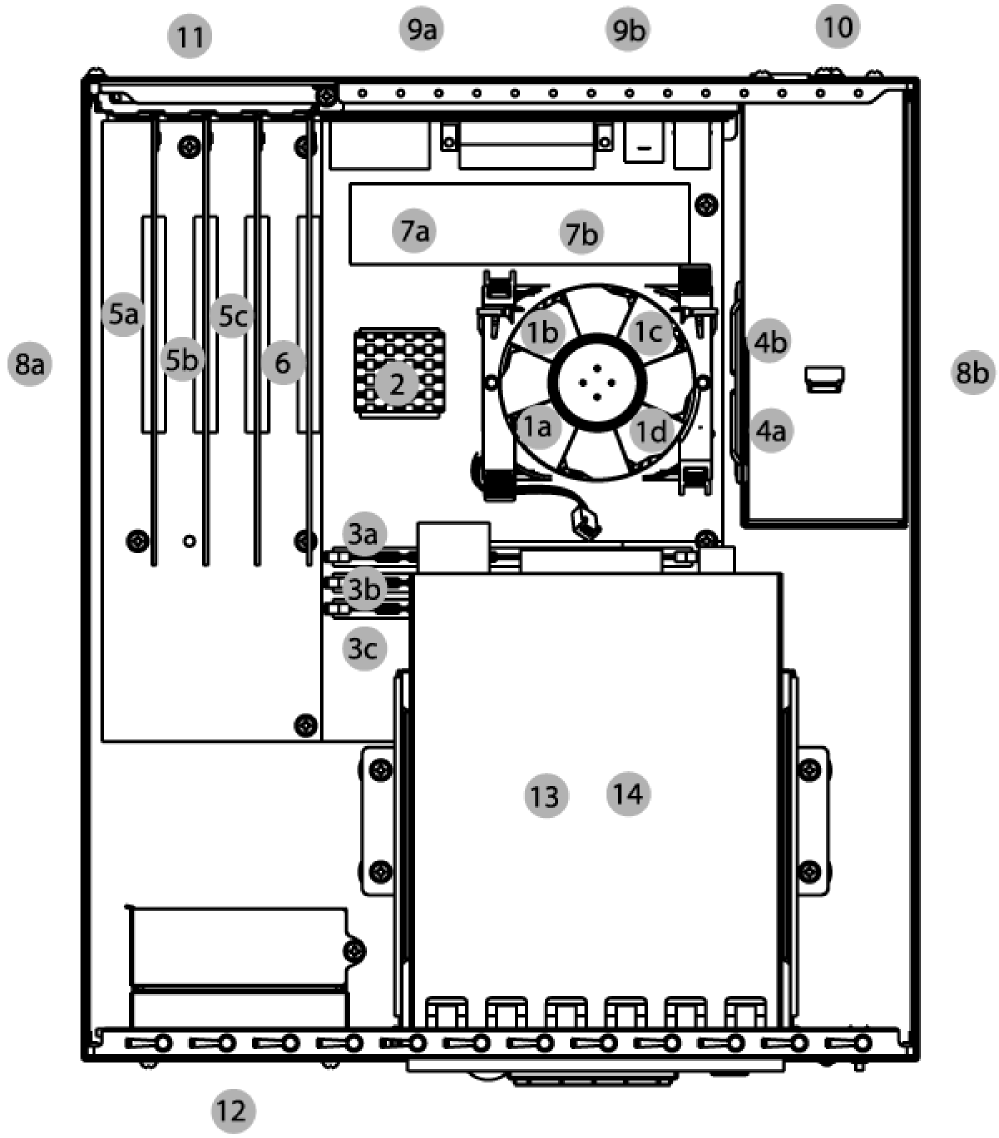

Figure A1: Temperature Sensor Locations Referenced in Table A1

A.3 Test Method

Data was collected every 20 seconds until all monitored temperatures indicated stable temperatures or for a maximum of 2 hours, whichever was longer. The last 10 data points were then averaged to yield the final value.

All testing was conducted on a laboratory bench at room temperature (20 °C-23 °C). Results were linearly scaled from the measured T_E for each run to the desired T_E (either 23 °C or 35 °C).

A.4 Data

The system test configuration and temperature summary data are provided in the Tables below. Where Table A1 indicates the use of multiple sensors for a similar measurement, The Tables below list their average result. Suggested maximum temperature targets are listed in the "Max" columns

Table A2: 13 Liter Core Duct Sensitivity Studies

	Test #	Max	1	2	3	4	5	6	7	8	9	10	11
Configuration	Processor power (W)		82	**49**	82	82	82	82	82	82	82	82	82
	Front bezel vent		Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
	Rear chassis vent		Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	**50%**
	Core duct vent		100%	100%	**Left top vent closed**	**Left side vent closed**	**Right top vent closed**	**Right side vent closed**	**Left and right top vents closed**	**Left and right side vents closed**	**Left top and side vents closed**	**Right top and side vents closed**	100%
	Front fan RPM		2001	2006	2006	2007	2003	2007	2003	2009	2007	2004	2001
	Processor fan RPM		4205	4209	4206	4205	4202	4206	4208	4207	4206	4204	4205
	Pwr supply fan RPM		3651	3650	3651	3653	3654	3652	3652	3649	3652	3651	3655
Measured Temperatures (°C)	1 - T_A	38.0	37.5	36.9	38.1	38.4	37.2	37.1	38.0	38.5	42.8	38.0	37.6
	2 - T_E	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
	3 - MCH	55.0	49.0	46.3	49.7	49.5	49.5	49.7	49.7	49.8	54.2	50.2	51.2
	4a - Memory (Back)	55.0	44.8	41.3	45.7	45.7	45.2	45.2	46.4	46.6	53.6	48.0	45.4
	4b - Memory (Mid)	55.0	48.6	45.3	48.5	48.3	48.9	49.2	48.5	48.9	53.0	48.4	49.5
	4c - Memory (Front)	55.0	48.6	46.3	48.1	47.8	48.8	49.3	48.6	49.6	51.0	49.6	51.2
	5 - Pwr supply in	50.0	43.0	40.2	43.5	44.1	43.2	43.1	44.1	44.8	52.6	44.7	43.6
	6 – PCI (Average)	55.0	51.5	43.6	50.3	50.0	50.5	50.7	52.6	52.7	51.3	50.7	53.5
	7 - AGP	55.0	50.2	46.9	49.2	49.2	49.2	49.3	49.3	49.3	49.2	48.4	51.2
	8 - Voltage regulator	55.0	44.5	41.2	45.0	45.6	44.4	44.4	45.2	45.9	50.5	46.2	45.5
	9 - Rear vent out	N/Appl	45.1	41.8	45.5	45.7	45.4	45.5	45.6	46.1	47.7	45.5	45.8
	10 - PCI vent out	55.0	42.8	35.6	37.7	37.1	37.0	43.4	38.6	38.0	40.1	37.3	44.2
	11 - HDD	55.0	43.6	40.3	43.9	44.0	43.8	43.9	44.3	44.8	47.3	44.1	44.2
	12 - ODD	55.0	45.0	41.7	45.2	44.4	45.1	45.3	44.1	44.2	45.8	43.8	45.7

continued

Table A2: 13 Liter Core Duct Sensitivity Studies (continued)

	Test #	Max	12	13	14	15	16	17	18	19	20	21	22	23
Configuration	Processor power (W)		82	82	82	82	82	82	82	82	82	**49**	**49**	**100**
	Front bezel vent		**50%**	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
	Rear chassis vent		Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
	Core duct vent		100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Front fan RPM		2004	2004	**1804**	**1405**	2002	2009	2003	2003	2006	**1007**	**1007**	2009
	Processor fan RPM		4202	4208	4205	4208	**4003**	**3805**	**3605**	**3204**	**3004**	**1805**	**1804**	4206
	Pwr supply fan RPM		3652	**3005**	3652	3652	3651	3655	3655	3651	3651	**1808**	**1803**	3652
Measured Temperatures (°C)	1 - T_A	38.0	37.2	37.5	37.2	37.4	37.4	37.5	37.6	37.8	37.7	26.9	28.8	37.7
	2 - T_E	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	**23.0**	**23.0**	35
	3 - MCH	55.0	50.6	50.3	50.4	51.8	49.9	49.7	50.0	50.3	50.5	43.8	48.6	51.6
	4a - Memory (Back)	55.0	45.0	45.2	45.1	45.6	45.3	46.1	46.5	47.8	48.4	38.9	47.5	50.0
	4b - Memory (Mid)	55.0	49.5	49.6	50.1	52.2	48.8	48.6	48.6	47.7	47.4	45.4	49.8	50.2
	4c - Memory (Front)	55.0	49.3	49.6	50.2	52.1	48.9	48.6	48.7	47.2	46.8	43.8	50.4	47.4
	5 - Pwr supply in	50.0	42.7	42.6	42.7	42.8	43.2	43.8	44.3	45.5	47.5	35.3	42.0	43.0
	6 – PCI (Average)	55.0	53.1	53.7	55.0	59.9	50.5	52.0	51.8	51.2	51.0	37.9	49.9	53.2
	7 - AGP	55.0	50.1	48.9	49.5	54.1	48.8	48.8	48.8	48.6	48.6	45.9	47.5	49.1
	8 - Voltage regulator	55.0	44.5	44.3	44.4	44.9	44.5	44.6	44.9	45.8	46.2	37.3	44.4	45.7
	9 - Rear vent out	N/Appl	45.7	45.1	45.5	46.1	45.5	45.6	45.9	46.3	46.5	36.6	41.6	46.5
	10 - PCI vent out	55.0	43.1	37.9	37.5	38.4	41.6	37.8	38.1	37.9	37.9	26.4	28.0	37.6
	11 - HDD	55.0	43.7	44.0	43.9	44.5	43.7	43.9	44.1	44.4	44.5	34.4	39.6	44.8
	12 - ODD	55.0	45.1	45.1	45.2	45.9	45.2	44.7	43.8	43.5	43.9	34.5	38.9	46.8

Table A3: 10 Liter Core Duct Sensitivity Studies

	Max													
Test #		1	2	3	4	5	6	7	8	9	10	11	12	13
Processor Power		82 W	82 W	82 W	82 W	82 W	82 W	82 W	82 W	82 W	82 W	82 W	82 W	**100 W**
Front Bezel Vent		100%	100%	100%	100%	100%	100%	100%	**75%**	**50%**	100%	100%	100%	100%
Top Cover Vent		100%	**70%**	**40%**	**20%**	100%	100%	100%	100%	100%	100%	100%	100%	100%
Rear Chassis Vent		100%	100%	100%	100%	**75%**	**50%**	**25%**	100%	100%	100%	100%	100%	100%
Front Fan RPM		3000	3000	3000	3000	3000	3000	3000	3000	3000	**2800**	**2500**	**2200**	3000
CPU Fan RPM		4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200
PSU Fan RPM		3650	3650	3650	3650	3650	3650	3650	3650	3650	3650	3650	3650	3650
TA	38	37.2	37.13	37.9	38.15	36.7	37.13	37.98	37.78	38.93	37.48	37.83	38.4	37.68
TE	35	35	35	35	35	35	35	35	35	35	35	35	35	35
MCH	55	39.8	45.5	46.8	47.4	44.4	46.1	46.6	45.1	47	44.8	45.5	46.4	47.1
Memory (Back)	55	39.7	42	42.9	42.9	41.2	42.1	42	42.5	43	40.8	42.3	43.6	43.5
Memory (Mid)	55	38.5	38.3	38.2	38.5	37.2	38.9	39.5	39.4	41.5	37.6	39.9	42.3	38.4
Memory (Front)	55	36.7	35.8	35.7	36	35.5	37	37.1	36.8	38.3	35.8	36.5	38.1	36.6
Pwr supply in	50	39.7	39.5	39.9	40.6	38.9	40.6	40.7	39.9	40.6	39	39.2	39.6	41.1
PCI Average	55	44.9	46.2	45.7	46.6	47.6	49.6	53.3	44.7	53.2	46.4	48.6	52.3	41.1
AGP	55	45.7	44.8	48.2	49	43.7	47.7	55	43.6	54.5	47.3	53.1	54.1	43.9
Volatage Regulator	55	43.1	47.9	49.7	51.2	51.1	54	55.5	50.3	52.4	51.7	50.3	49.7	51.9
HDD	55	44.6	41	40.8	41.1	40.1	41.6	42.2	41.8	41.5	41.4	42.3	43.6	42
ODD	55	39.4	39.4	39.4	39.8	38.8	40.4	40.9	40.1	40.2	39.4	40.2	41.7	40.9

The system test configuration and temperature summary data for the 10 Liter front Duct system are provided in Table A4. Suggested maximum temperature targets are listed in the "Max" columns.

Test #1 represents the baseline 10-liter front duct design with all suggested hardware components at the "Thermal Capacity Condition" power loading and with all fans at 100% speed. **Bold** text denotes configuration differences between Test #1 and subsequent tests. Test #17 represents the optimized acoustic test result with throttled fans at the "Acoustic Noise Condition" power loading.

All tests for the 10 Liter Front Duct system were performed at 75 Watts and later validated at 82 Watts. The data shown below is not specific to the processor thermal solution and is intended to show system level sensitivities.

Table A4: Tidewater 10 Liter Front Duct Chassis Sensitivity Studies

	Test #	Max	1	2	3	4	5	6	7	8	9
Configuration	Processor power (W)		75	**52**[1]	75	75	75	75	75	75	75
	Front bezel vent		Std	Std	Std	Std	**50%**	**50%**	Std	Std	Std
	Rear chassis vent		Std	Std	Std	**50%**	Std	**50%**	Std	Std	Std
	Front fan duct		Duct	Duct	**None**	Duct	Duct	Duct	Duct	Duct	Duct
	Front fan RPM		3608	3609	3606	3606	3608	3606	3613	3613	3615
	Processor fan RPM		4007	4006	4018	4011	4006	4005	4004	4005	4005
	Pwr supply fan RPM		3012	3000	3006	3018	2986	2996	**3305**	**2258**	**1510**
Measured Temperatures (°C)	1 T_A	42.0	42.0	40.9	44.8	42.7	45.4	45.9	42.2	42.1	42.4
	2 - T_E	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
	3 - Front fan exh	N/Appl	36.2	36.4	36.2	36.0	36.2	36.1	36.2	36.1	36.1
	4 - HDD	55.0	41.7	41.1	39.8	42.7	43.3	43.8	41.6	42.3	42.0
	5a - Memory (B)	55.0	47.0	44.4	48.0	48.2	49.8	50.1	47.1	47.5	47.6
	5b - Memory (M)	55.0	38.2	38.2	42.5	38.4	40.0	40.2	38.1	38.1	38.1
	5c - Memory (F)	55.0	37.8	37.8	38.8	37.8	38.6	38.8	37.7	37.6	37.6
	6 - PCI	55.0	44.5	44.4	40.2	45.0	45.7	45.9	44.5	44.3	44.2
	7 - AGP	55.0	46.2	46.1	43.3	50.0	48.7	48.8	45.8	46.9	46.8
	8 - MCH	55.0	48.3	45.6	49.9	48.9	51.0	51.4	47.8	48.4	48.9
	9 - Voltage reg	55.0	46.9	44.6	49.5	48.6	49.9	50.8	47.3	46.9	46.8
	10 - Rear vent out	N/Appl	47.7	45.6	47.3	46.3	50.7	48.7	47.4	47.4	47.2
	11 - Pwr supply in	50.0	48.2	45.1	50.3	48.3	50.4	51.0	46.6	48.5	49.8

continued

Table A4: Tidewater 10 Liter Front Duct Chassis Sensitivity Studies (continued)

	Test #	Max	10	11	12	13	14	15	16	17	18	19
Configuration	Processor power (W)		75	75	75	75	75	75	**52**[(1)]	**52**[(1)]	75	**82**
	Front bezel vent		Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
	Rear chassis vent		Std	Std	Std	Std	Std	Std	Std	Std	Std	Std
	Front fan duct		Duct	Duct	Duct	Duct	Duct	Duct	Duct	Duct	Duct	Duct
	Front fan RPM		**4010**	**2702**	**1804**	**0**	3615	3612	**1803**	**1605**	**1604**	3600
	Processor fan RPM		4005	4003	4007	4006	**3003**	**2005**	**2804**	**2652**	**2656**	4000
	Pwr supply fan RPM		3018	2993	3015	3004	3015	3018	**2203**	**1504**	**1504**	3000
Measured Temperatures (°C)	1 - T_A	42.0	41.3	45.0	50.6	59.1	42.8	42.9	33.7	36.2	39.9	41.8
	2 - T_E	35.0	35.0	35.0	35.0	35.0	35.0	35.0	**23.0**	**23.0**	**23.0**	35.0
	3 - Front fan exh	N/Appl	36.0	36.0	36.3	36.2	36.1	36.2	23.8	24.1	24.3	N/A
	4 - HDD	55.0	41.4	43.7	47.3	49.8	42.5	43.1	32.2	34.5	36.5	40.6
	5a - Memory (B)	55.0	45.6	48.9	52.9	64.3	44.8	42.5	38.3	40.7	46.1	41.2 ave
	5b - Memory (M)	55.0	37.9	39.1	41.1	60.3	38.2	38.3	28.0	29.3	30.1	41.2 ave
	5c - Memory (F)	55.0	37.5	38.1	39.0	52.0	37.8	37.7	26.5	27.3	27.6	41.2 ave
	6 - PCI	55.0	43.8	46.7	54.8	89.3	45.3	45.3	37.2	39.2	39.6	40.7
	7 - AGP	55.0	44.8	46.5	48.4	88.4	42.9	42.1	36.4	42.1	45.1	43.6
	8 - MCH	55.0	47.4	49.7	53.4	68.6	49.2	45.7	38.1	41.5	46.8	47.3
	9 - Voltage reg	55.0	46.3	49.6	55.8	59.0	48.9	48.1	39.3	42.4	48.3	53.4
	10 - Rear vent out	N/Appl	45.8	51.1	52.6	38.6	46.7	45.1	41.1	42.9	48.0	48.7
	11 - Pwr supply in	50.0	46.4	50.2	57.3	62.1	48.3	52.3	40.7	42.7	49.6	47.9

Notes:
Bold text denotes configuration differences between Test #1 and subsequent tests.
(1) "Acoustic Noise Condition" power loading per Table 4. All other tests per "Thermal Capacity Condition."