FlexATX Thermal Design Suggestions

Version 1.1

Version 1.1, May 2000

Revision History

Version		Date
1.0	First release; released on http://www.teleport.com/~ffsupprt/	04-20-00
1.1	Correct an error in width dimension, Figure 7, low-profile power supply #2	05-19-00

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1. Introduction

1.1 Abstract

The FlexATX motherboard specification requires mechanical designers to develop computer systems within a smaller system size. The implementation of standard personal computer (PC) building-block components and the newest technologies can pose thermal challenges to the system designer. As the market makes the transition to faster processors, special consideration is required to produce thermally and mechanically viable FlexATX platforms.

The goal of this document is to provide thermal design guidance to PC system designers, developers, and their customers. Assumptions, details, and recommendations are presented in the form of several design examples for FlexATX tower systems and low-profile desktop systems. These design examples are intended to typify the thermal design requirements and off-the-shelf hardware available to a system designer.

1.2 Recommendations Overview

Through the collection of empirical data, several conclusions and recommendations are made to aid in the development of chassis that will support most Intel® Pentium® III and Celeron™ processors into and possibly through the year 2001.

Table 1. Design Recommendations, Overview

Design recommendation	Suggested way to achieve this
Design for a 40 °C ambient temperature (T_{PROC_INLET}) at the active heat sink inlet or approach to the passive heat sink.	Deliver 12-16 CFM through the system (recommended ≥ 9.0 in^2, ≥ °0.45 Free Area Ratio (FAR) Alternative airflow capability (besides the power supply fan) should be added to the system to allow for the delivery of this internal ambient temperature.
Prepare to incorporate higher performance processor heat sinks.	To meet future power trends, select a heat sink capable of performing at ~1.0 °C/W or better. This value includes processor package, thermal interface material, and heat sink thermal efficiencies (assumes up to 40 W at 80 °C $T_{JUNCTION}$ specification and 40 °C T_{PROC_INLET}).
Design the internal chassis space to allow suitable performance from the active heat sink.	To support the performance of an active heat sink, system designers should provide 2.8 inches (recommended chassis keep-out) above the motherboard in Area A designated in the FlexATX specification. This clearance provides better active heat sink performance than the 2.3 inches (required chassis keep-out) presently specified.

1.3 Basic Design Concepts

To meet the recommendations listed in Table 1, system designers should consider three basic design concepts when developing FlexATX enclosures:

- **Maximize airflow capability** by incorporating provisions for additional system fan(s).
- **Minimize airflow restrictions** by increasing venting in appropriate areas.
- **Optimize airflow location** by directing air to where it is most needed with proper fan placement, ducting, or other features.

Compared to a traditional ATX or microATX system design, the smaller size of the FlexATX system limits the total number of heat-generating peripherals and add-in cards. This limitation inherently limits the power variability of the system thermal load, thus requiring less system thermal margin.

New innovative industrial designs also allow for layout and thermal design approaches that may not normally be considered in larger platforms. These changes, along with a reduced or legacy-free motherboard, allow for minimal overall system load besides that of the core components (which usually include the processor, chipset, memory, and graphics). The reduced system load allows cooler air to reach the core area, providing a better thermal environment.

1.4 Related Documents

Table 2. Related Documents

Document	Location
microATX Motherboard Interface Specification, Version 1.0	http://www.teleport.com/~ffsupprt/
FlexATX Addendum Version 1.0 to the microATX Motherboard Interface Specification Version 1.0	http://www.teleport.com/~ffsupprt/
microATX Thermal Design Suggestions, Version 1.0	http://www.teleport.com/~ffsupprt/
PC 99 and PC 2001 System Design Guides	http://www.pcguide.org/
EMC Design Suggestions	http://www.teleport.com/~ffsupprt/
PCI Local Bus Specification	http://www.pcisig.com/
Advanced Configuration and Power Interface (ACPI) Specification	http://www.teleport.com/~acpi/
ISO 7779 –“Acoustics—Measurement of Airborne Noise Emitted by Information Technology and Telecommunications Equipment”	http://www.iso.ch/

2. General Configuration

This section describes the general configuration, specific components, and testing approach and results for five FlexATX-based design examples. Table 3 summarizes typical desktop system-level specifications that are relevant to designing a thermal solution. (Section 3 describes the five design examples.)

This section describes the following:

- Peripheral types
- Processor heat sink types (four)
  - Two active heat sinks (one extruded aluminum; one skived aluminum)
  - Two passive heat sinks (one extruded aluminum; one skived aluminum)
- Power supply types (four)
  - SFX power supply
  - Low-profile power supply #1
  - Low-profile power supply #2
  - Custom power supply

NOTE

All specification targets are provided for example only and may vary considerably for a particular product or market. The similarity of any described components to actual products is purely coincidental and should not be construed as either an endorsement or disapproval of a particular design.

The maximum system operating temperature is +35 °C, which represents the worst-case environment for most thermal designs.

Table 3. System Environmental Specifications

System Specification	Target Value(s)	Thermal Solution Relevance
Temperature, operating	+10 °C to +35 °C	Highest operating temperature factors into worst-case environment.
Humidity, operating	To 95% relative humidity (noncondensing)	Air within a PC enclosure must remain above its dew point to avoid condensation.
Acoustic sound pressure (per ISO-7779) at idle, +22 °C, light load drives accessing +35 °C, heavy load	 ≤ 37 dB-A ≤ 45 dB-A	Cooling fans contribute to system noise with increasing size and RPM

In addition to the environmental system specifications, each system component has an ambient environment, package case, or junction temperature specification. For a typical configuration of a FlexATX system, the component description and specification would resemble those listed in Table 4.

Table 4. System Component Thermal Parameters

Location	Item	Power *	Temperature Target	Comments
Core	Processor	≤ 40 W	T_{PROC_INLET} = 40 °C	Current design goal
Core	Chipset/Graphics	3 W	T_{AMB} ≤ 55 °C	
Core	SDRAM memory	8 W	T_{AMB} ≤ 55 °C	Natural convection cooling
Core	Motherboard miscellaneous	5 W	T_{AMB} ≤ 55 °C	Natural convection cooling
Slot #5	PCI card	5 W	T_{AMB} ≤ 55 °C	½-length, low-profile resistive loads
Bay	Mobile CD-ROM or DVD	5 W	T_{AMB} ≤ 55 °C	
Bay	Hard Drive	8 W	T_{AMB} ≤ 55 °C	3.5”x1”, 7.2 k RPM, idling
Bay	Diskette Drive	0 W	T_{AMB} ≤ 55 °C	3.5”x1” optional
	Subtotal (DC)	≤ 74 W		
PS	Power supply	≤ 32 W	T_{AMB} ≤ 50 °C	Assumes 70% conversion efficiency
	Total (AC)	≤ 106 W		

* “Power” values represent continuous simultaneous power dissipations that might reasonably be expected during near-maximized system use. These values are not entirely conservative and do not reflect all possible device powers or system operating conditions.

2.1 Motherboard, Peripherals, and Add-in Cards

The FlexATX motherboard specification defines a 9.0 inches x 7.5 inches maximum motherboard footprint, a reduction from the 9.6 inches x 9.6 inches size specified in the microATX motherboard specification. For a complete specification on the FlexATX motherboard form factor, refer to the *FlexATX Addendum Version 1.0 to the microATX Motherboard Interface Specification Version 1.0* and the *microATX Motherboard Interface Specification,* Version 1.0 (for Web site URLs, see Table 2).

NOTE

System power dissipation varies widely depending on the specific system configuration. For example, a non-user–upgradable platform with a predefined hardware configuration may use an inexpensive point solution to cool the platform with minimal thermal margin. If a platform provides more expansion through additional drive bays and/or add-in card slots that could support uncharacterized components, then additional thermal design headroom is recommended to accommodate this expansion.

The FlexATX motherboard specification supports up to three expansion cards via the PCI bus. The number of memory slots and IDE interfaces depends on the specific motherboard layout and feature set. Other than the use of an Intel Pentium III processor, 810E Chipset, SDRAM, PCI slots, and standard or mobile IDE peripherals, the actual feature set of the FlexATX motherboards used to gather the data summarized in this document is considered inconsequential.

Peripheral components used during testing include a hard disk drive (HDD), CDROM, and sometimes a floppy disk drive (FDD). Although each chassis complied with the FlexATX motherboard specification, they did not all use the same components. All of the chassis tested have at least one HDD and CDROM. The desktop chassis designs allow an FDD. Peripheral placement plays an important role in the overall thermal performance of the system.

2.2 Package-level Cooling

The processor has the highest power density of any component listed in Table 4. To be cooled using practical air temperatures and velocities, the processor requires a heat sink to increase its convective surface area and heat-transfer efficiency. Typically an active fan heat sink is used because its application-independence makes it well-suited to the system integration market (see Figure 1 and Figure 2). As long as the system-level thermal solution maintains the appropriate temperature at the inlet of the fan heat sink, T_{PROC_INLET}, the fan heat sink provides sufficient cooling of the processor die.

Accordingly, T_{PROC_INLET} represents the threshold between the complementary package- and system-level thermal solutions. To decrease the required performance (and cost) of the system-level solution by raising T_{PROC_INLET} requires higher performance (and cost) at the package level. From an overall cost perspective, the goal is to balance the package- and system-level performance requirements to minimize the total cost.

NOTE

The power requirements of new high-performance components are causing the cost and complexity of package-level solutions to increase rapidly. To maintain the lowest overall cost balance, T_{PROC_INLET} of 40 °C is strongly recommended for future chassis designs. Chassis that do not maintain 40 °C at T_{PROC_INLET} may not be able to support future cost-effective package-level solutions.

Because the FlexATX specification is new and most of the chassis on the market today were not designed to the criterion described above, design improvements may be necessary to meet this goal. The following sections discuss different system designs and their solutions as well as their relative abilities to meet a T_{PROC_INLET} of 40 °C.

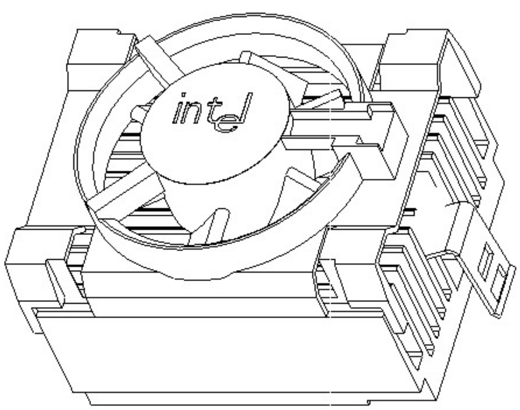
2.2.1 Heat Sink Options

This section defines several active and passive heat sinks that were used to test the projected performance of a Pentium III or Celeron processor in FlexATX systems.

- Two active heat sink designs were used.
  - Extruded aluminum heat sink base (current approach)
  - Skived aluminum heat sink base (newer approach)
- Two passive heat sink designs were used.
  - Extruded aluminum heat sink base (traditional approach to passive or semipassive cooling)
  - Skived aluminum heat sink base (newer approach; similar to the active design but without the integrated fan and with a larger fin pitch)

See Figure 1 through Figure 4.

The active heat sink fans were powered at ~12.0 VDC during thermal testing. When possible, ducting was used with the passive heat sinks to focus airflow through the fin structures (semipassive cooling). Passive heat sinks with limited or no local airflow through their fin structures perform too poorly for consideration in this testing.

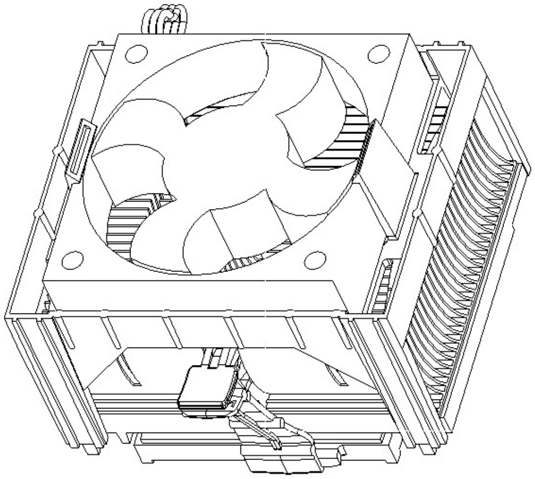


Active heat sink, #1.

Current approach. Extruded aluminum heat sink base/fin structure with 50-mm axial fan integrated within a plastic attachment feature.

Spring metal clip attaches heat sink assembly to the processor using the PGA370 socket tabs.

Figure 1. Extruded Aluminum Active Heat Sink, #1

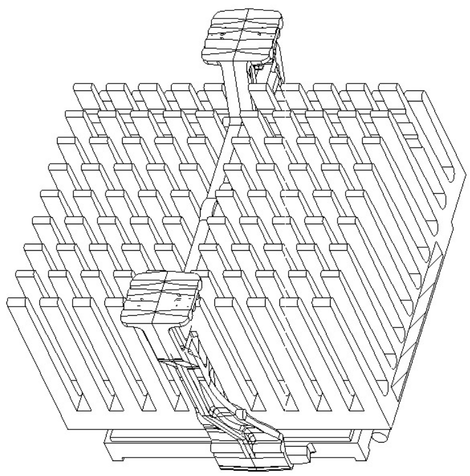


Active heat sink, #2.

Newer approach. Skived aluminum heat sink base/fin structure with 60-mm axial fan attached to the heat sink with a plastic bracket. Skived technology allows for a higher aspect fin ratio with continuous material (aluminum) between the base of the heat sink and the fins.

Plastic clip attaches heat sink assembly to the processor using the PGA370 socket tabs.

Figure 2. Skived Aluminum Active Heat Sink, #2

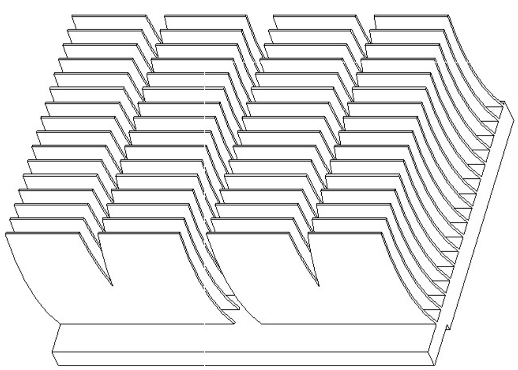


Passive (or semipassive) heat sink, #3.

Traditional approach. Extruded aluminum heat sink base/fin structure.

Plastic clip attaches heat sink to the processor using the PGA370 socket tabs.

Figure 3. Extruded Aluminum Passive Heat Sink, #3



(metal clip and socket not shown)

Passive (or semipassive) heat sink, #4.

Newer approach. Similar to #2 but without the integrated fan and with a larger fin pitch.

Spring metal clip attaches the heat sink assembly to the processor using the PGA370 socket tabs.

Figure 4. Skived Aluminum Passive Heat Sink, #4

2.3 Power Supply Options

Currently there are no specifications for FlexATX power supplies. This section defines four power supplies (Figure 5 through Figure 8) that were chosen to represent currently available supplies whose sizes and shapes can and often are considered for use in a FlexATX chassis.

SFX power supply.

Size: Standard 2.5” H x 4.0” W x 5.0” D (63.5 mm H x 100 mm W x 125 mm D).

60-mm axial fan evacuates the computer system by propelling air through the power supply.

Figure 5. SFX Power Supply

Low-profile power supply #1.

Size: 3.25” H x 2.5” W x 5.9” D (82.5 mm H x 63.5 mm W x 150 mm D).

80-mm axial fan evacuates the computer system by driving air from the side to the back of the power supply.

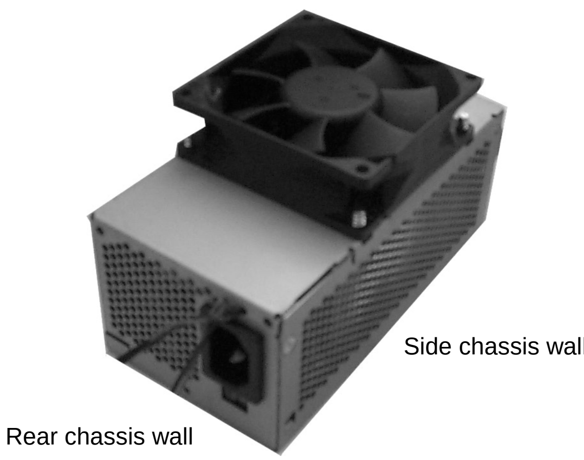
Figure 6. Low-profile Power Supply #1

Low-profile power supply #2.

Size: 3.25” H x 1.7” W x 7.5” D
(82.5 mm H x 43.2 mm W x 190.5 mm D).

40-mm axial fan withdraws air from the computer system by evacuating air from the back of the power supply.

Figure 7. Low-profile Power Supply #2



Custom.

This power supply’s dimensions are inconsequential considering that custom power supplies are developed to meet particular system mechanical, functional, and thermal needs.

Top-mounted 80-mm axial fan withdraws air from the computer system by pushing air from the top to the back and side of the power supply.

Figure 8. Custom Power Supply

2.4 System-level Cooling

2.4.1 Airflow Direction

Because of the dynamic nature of fluids, it can be difficult to show the exact airflow pattern inside a system. In traditional small form-factor-system designs, the power supply fan is the only fan oriented to exchange air between the system and the environment; therefore, the power supply fan is solely responsible for the overall airflow direction and volume **through** the chassis. Because of the smaller size of systems designed to use FlexATX motherboards, power supplies have become smaller, thus becoming unsuited to do more than cool themselves. Documentation for these smaller form-factor power supplies typically states that they are intended to cool **only** the power supply components and not the entire system. In most cases an additional chassis fan is needed to remove air from the system to meet a T_{PROC_INLET} of 40 °C.

The power supply fan in combination with a system fan exhaust interior air through the back or side of the chassis, slightly depressurizing the chassis interior with respect to the outside atmosphere. As a result, all other chassis openings become intakes. For each system tested, the airflow patterns are shown by various arrows in the figures for the design examples shown in Section 3. The size and direction of the arrows depict an approximate airflow pattern based on relative vent sizes, locations, and fan placement.

NOTE

The processor's active heat sink fan induces additional flow patterns within the chassis local to the processor area, but this usually does not significantly impact the volume of air passing through the chassis.

2.4.2 Estimating Airflow Volume

As air flows through a chassis, heat energy is transferred ("convected") from powered components to the air itself. This transfer cools the components but correspondingly raises the downstream temperature of the air. The amount of air temperature rise depends on the applied power and volume of airflow per the relationship in Equation 1 and Figure 9.

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/s, 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/s = 2119 ft^3/min (CFM)

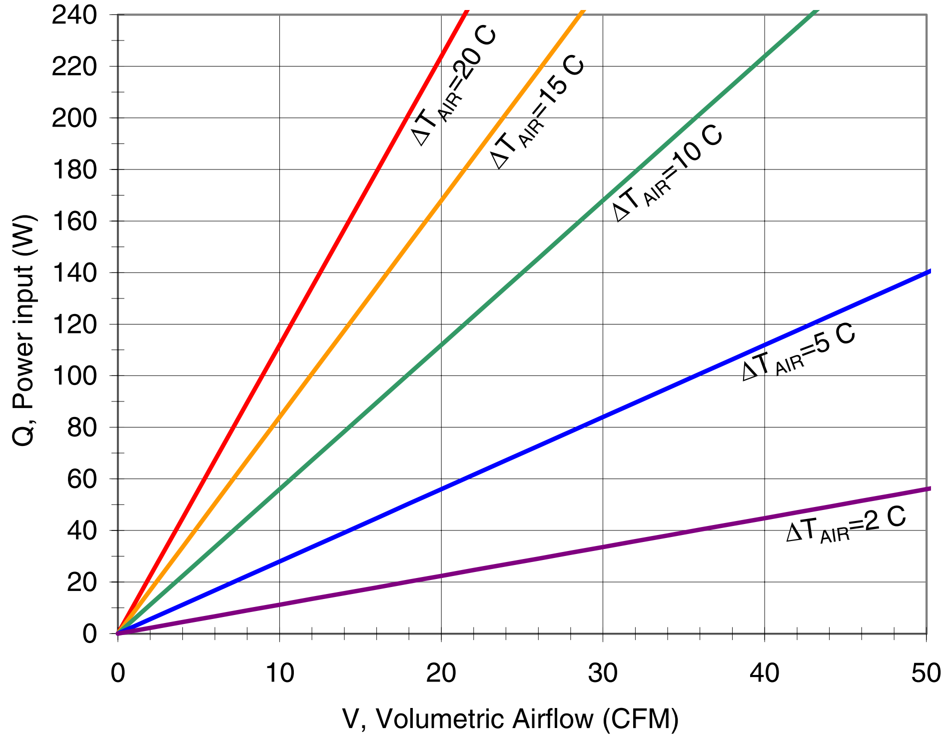


Figure 9. Airflow Heat Capacity

Figure 9 shows that increasing the applied power will increase the temperature rise of a given amount of airflow. Often in the case of a FlexATX system, the minimal power being dissipated by the small number of peripherals and board components creates a small amount of preheating to the airflow stream that approaches the core area. Empirical testing is necessary to insure proper ambient temperatures at any specified point in a FlexATX system.

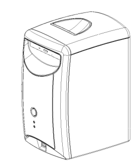
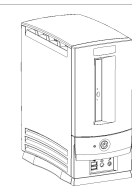
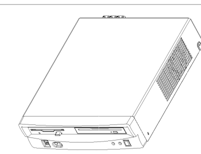
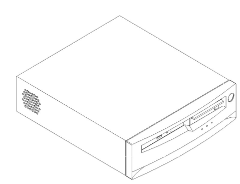
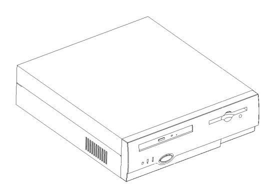
3. Design Examples

This section describes five design examples along with their thermal and airflow testing results and conclusions. All designs comply with the FlexATX addendum to the microATX motherboard specification. Two of the design examples use a tower chassis, and three use a low-profile desktop chassis design. The examples are intended to demonstrate the thermal capability of the designs and their ability to meet the needs of future technology. The section describes the specific components, power loading, and pass/fail criteria assumptions for the examples. Thermal, local airflow, and volumetric airflow testing was completed on each design example to determine the best possible thermal performance.

NOTE

All results are based on best possible performance (i.e., highest system fan speeds). Fan speed reduction or fan speed control is recommended to meet system acoustical goals or a reduced system power load.

Table 5. Five Design Examples (FlexATX motherboard-compliant)

Example	Configuration	Picture
Tower #1	Uses standard building block components while still maintaining a smaller size and a unique industrial design.	
Tower #2	Designed to minimize system size by using a strategically located custom power supply to provide all of the system's airflow. Unlike traditional tower designs that pull air in from the front of the chassis and evacuate it out the back, this system draws air in from the top and evacuates it out the bottom side and back of the chassis.	
Desktop #1	Low-profile desktop system designed to use standard building-block components while still maintaining a smaller size with upgradability through multiple low-profile PCI slots.	
Desktop #2	Low-profile desktop system with available low-profile PCI slots. Designed to minimize system size by using the low-profile power supply #2 located toward the back and right side of the system. An optional 60-mm fan mounting location is included at the left side of the chassis near the low-profile add-in card area.	
Desktop #3	Low-profile desktop system with available low-profile PCI slots. Designed to minimize system size by using the low-profile power supply #1 (Figure 6) located toward the back and right of the system. No optional system fans are located in the system.	

3.1 Tower #1 Configuration

The Tower Chassis #1 is designed to use standard building-block components while still maintaining a smaller size and a unique industrial design.

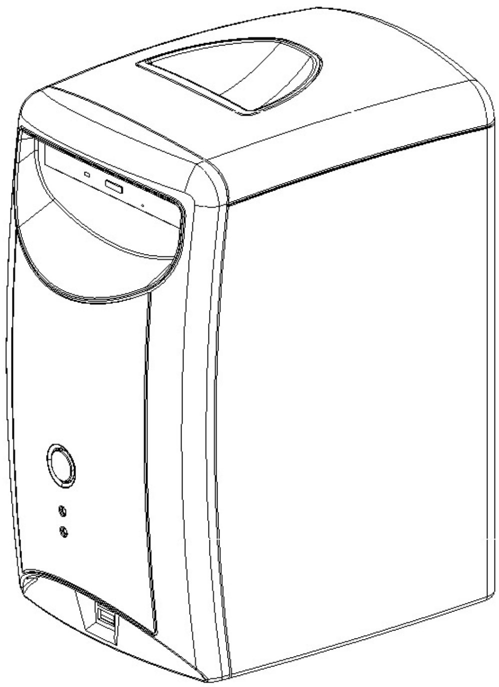


Figure 10. Tower #1 Configuration

Table 6. Tower #1 System Features

System Features	Component Description	Notes
Motherboard	FlexATX desktop board	
Processor	Intel Pentium III processor	Socketed FC-PGA package
Chipset	Intel® 810E Chipset	
Memory	64-MB SDRAM	One DIMM slot
Add-in card capability	2 PCI cards (slot 5 and 6)*	Half-length, full-height
Storage device(s)	Standard HDD	
	Mobile CD-ROM	Positioned horizontally
Power supply	SFX	Figure 5
System cooling component(s)	60-mm axial fan	25 mm deep, additional ducting for passive heat sink option
Other	Front USB	
	Carrying handle	

* Only slot 5 used during testing.

Figure 11 demonstrates the airflow pattern within the chassis. Tower #1 was tested with two configurations that accommodated either a passive or an active heat sink. In each case the system fan was a 60-mm high-speed fan.

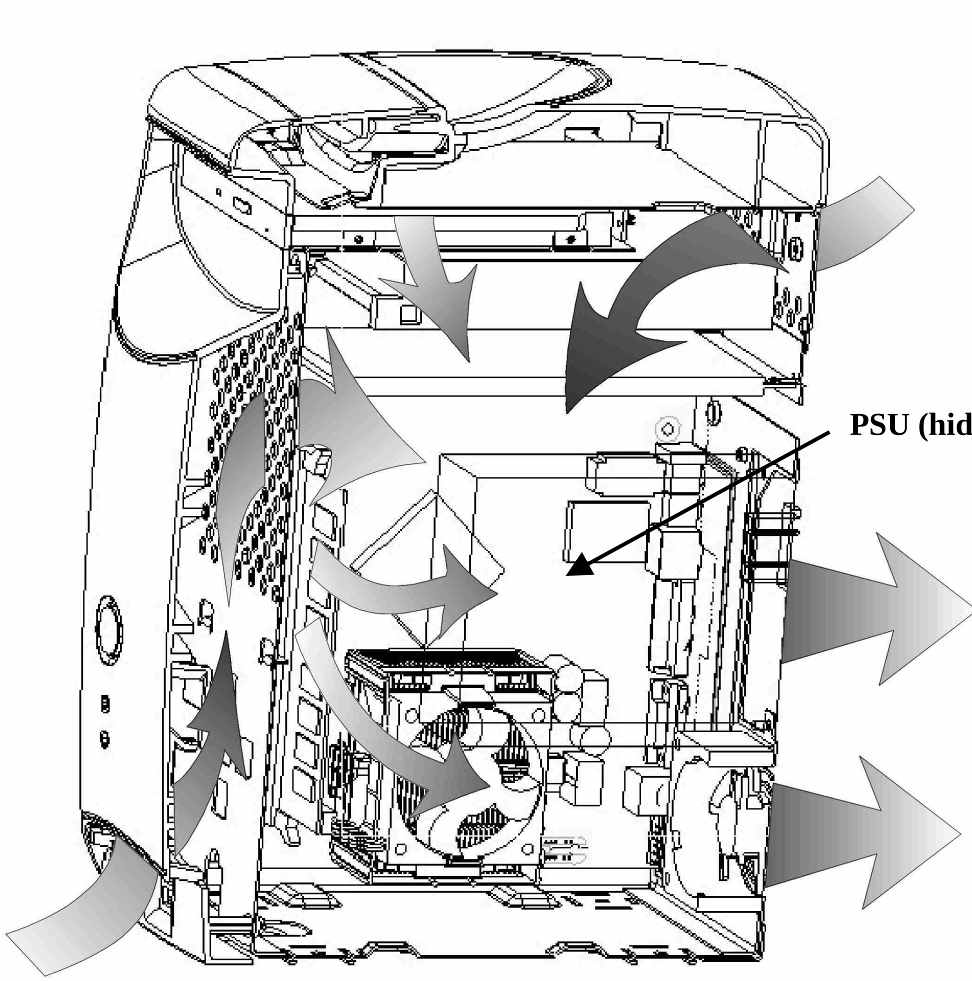


Figure 11. Tower #1 Airflow Pattern (cutaway view)

Venting Parameters:

Inlet sheet-metal venting

Total Area, in^2 [cm^2]: 7.85 [50.9]

Average Free Area Ratio (FAR): 0.45

With active heat sink: The PSU fan and a system fan evacuate the system without a duct.

With passive heat sink: The passive heat sink uses the PSU fan as well as the system fan and its duct. The duct is designed to draw air through the passive heat sink, thus improving its thermal performance.

3.1.1 Tower #1 Results

The results were obtained using each of the four processor heat sink options. Figure 12 details the results of system temperatures and local air velocities. Table 7 lists the performance of each of the four heat sinks used during testing.

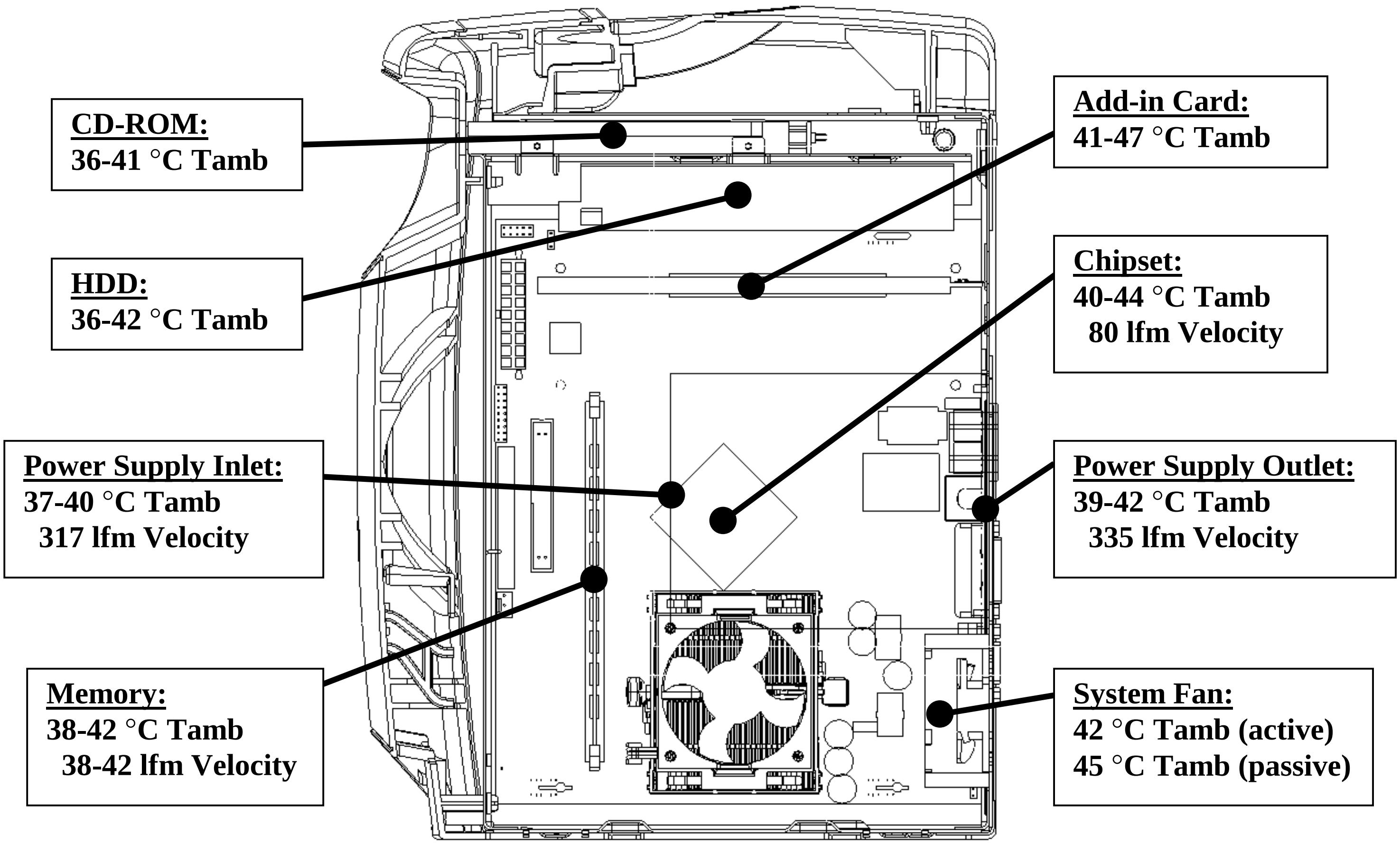


Figure 12. Tower #1 System Test Results (35 °C external temperature)

Table 7. Tower #1 System/Processor Heat Sink Performance

Heat sink	Volumetric Airflow (CFM)	T_{PROC_INLET} (°C)	Meets Goal of 40 °C	Heat Sink Performance (°C/W)*	Maximum Processor Dissipation (W)**
Skived Active	17.6	38.1	Yes	1.00	**41.9**
Extruded Active	17.1	40.6	Yes	1.39	**28.3**
Skived Passive	16.6 ***	39.5	Yes	1.67	**24.3**
Extruded Passive	17.1 ***	40.4	Yes	1.58	**25.1**

* Includes the processor package, interface material, and heat sink. Performance and maximum dissipation values are determined from extrapolated data. Results may differ from those demonstrated.

** Maximum dissipation values are dependent on an assumption of a junction temperature of 80 °C.

*** With a duct.

3.2 Tower #2 Configuration

The Tower Chassis #2 is designed to minimize system size by using a strategically located custom power supply to provide all of the system's airflow. Unlike traditional tower designs that pull air in from the front of the chassis and evacuate it out the back, this system draws air in from the top and evacuates it out the bottom side and back of the chassis.

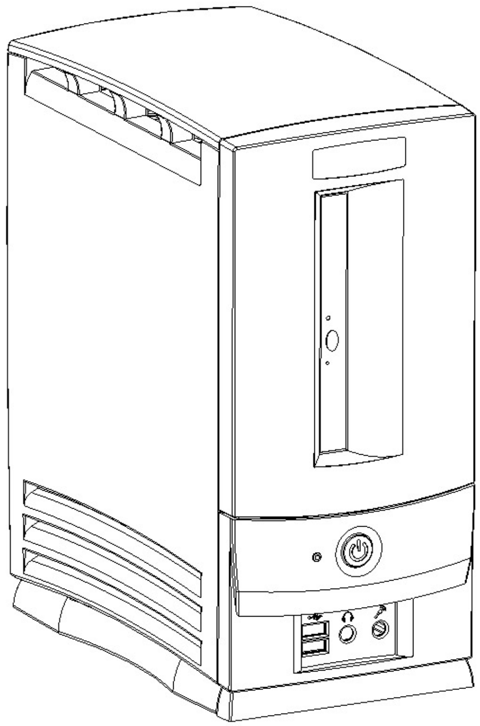


Figure 13. Tower #2 Configuration

Table 8. Tower #2 System Features

System Features	Component Description	Notes
Motherboard	FlexATX desktop board	
Processor	Intel Pentium III processor	Socketed FC-PGA type package
Chipset	Intel 810E Chipset	
Memory	Two 64-MB SDRAM	Two DIMM slots
Add-in card capability	1 mini-PCI card	8-mm connector
Storage device(s)	Standard HDD	
	Mobile CD-ROM	Positioned vertically
Power supply	Custom	Figure 8
System cooling component(s)	N/A	No optional system fans
Other	Front USB Front Audio	

Figure 14 demonstrates the airflow pattern within the chassis. Tower #2 was tested with two configurations that accommodated either a passive or an active heat sink.

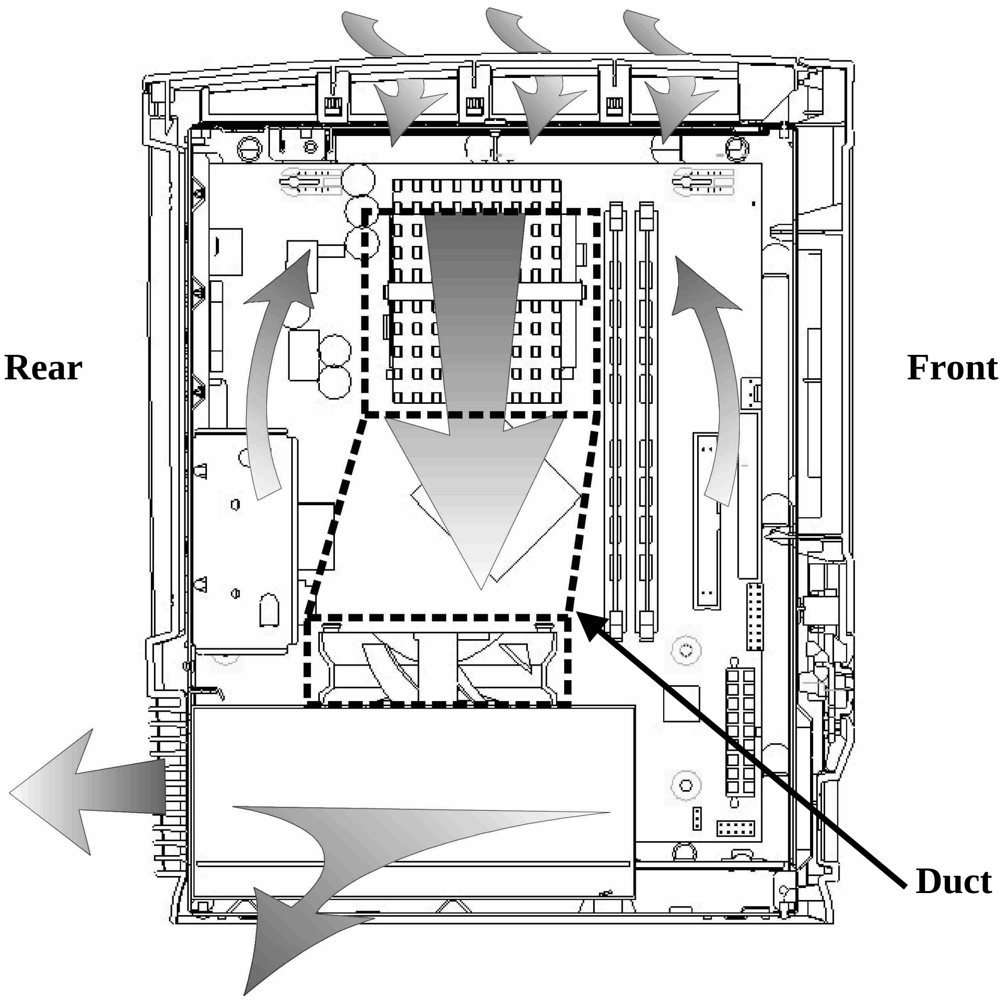


Figure 14. Tower #2 Airflow Pattern

Venting Parameters:

Inlet sheet-metal venting

Total Area, in^2 [cm^2]: 9.54 [61.5]

Average Free Area Ratio (FAR): 0.44

With active heat sink: The PSU fan evacuates the system without a duct.

With passive heat sink: The passive heat sink uses a duct to focus airflow through the heat sink, thus improving its thermal performance.

3.2.1 Tower #2 Results

The results were obtained using each of the four processor heat sink options. Figure 15 details the results of system temperatures and local air velocities. Table 9 lists the performance of each of the four heat sinks used during testing.

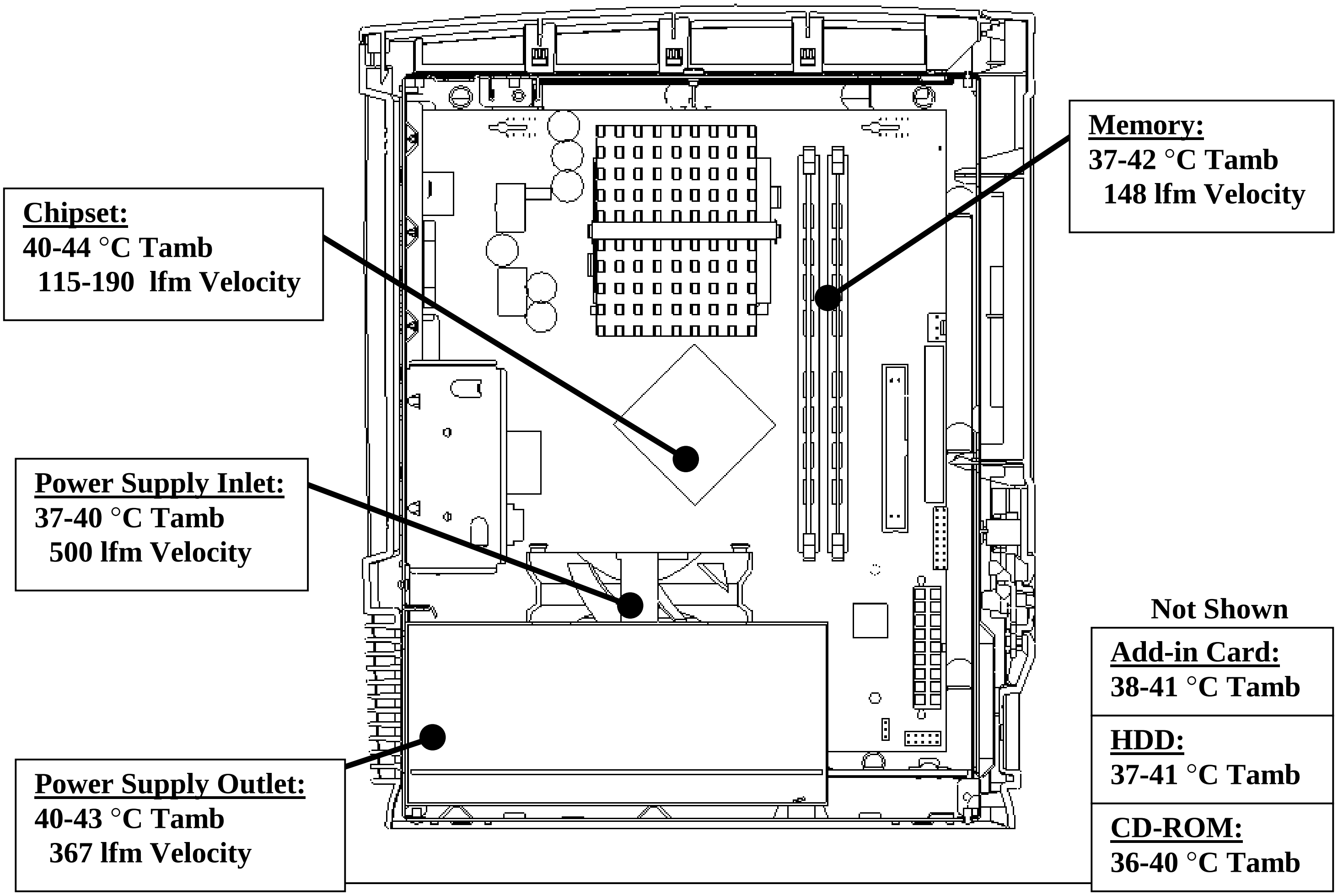


Figure 15. Tower #2 System Test Results (35 °C external temperature)

Table 9. Tower #2 System/Processor Heat Sink Performance

Heat sink	Volumetric Airflow (CFM)	T_{PROC_INLET} (°C)	Meets Goal of 40 °C	Heat Sink Performance (°C/W)*	Maximum Processor Dissipation (W)**
Skived Active	12.1	41.1	No	1.53	**25.4**
Extruded Active	12.3	36.4	Yes	1.76	**27.8**
Skived Passive	12.7	35.8	Yes	1.77	**25.0**
Extruded Passive	12.9	35.6	Yes	1.77	**25.1**

* Includes the processor package, interface material, and heat sink. Performance and maximum dissipation values are determined from extrapolated data. Results may differ from those demonstrated.

** Maximum dissipation values are dependent on an assumption of a junction temperature of 80 °C.

3.3 Tower Conclusions

Both tower systems have many unique qualities. Tower #1 has a design incorporating standard building blocks but allows for a system fan to improve airflow and therefore improve internal ambient temperature. Tower #2 uses a custom power supply and a layout that allows cool, external ambient air to immediately cool the core area before being heated within the system. Even with the reduced system sizes seen in FlexATX systems, these features allow for many cooling benefits.

- **Tower #1 and Tower #2 both show a potential for delivering a T_{PROC_INLET} of 40 °C or better by creating between 12 and 17 CFM of airflow through the system (inlet vent area between 8.0-9.5 in^2 with 0.45 FAR).**
  Thermally, both FlexATX towers show relatively low internal ambient temperatures. These temperatures indicate the small amount of power dissipated by the legacy-reduced FlexATX platform relative to microATX or ATX platforms. Some internal ambient temperature increases may be seen as the active heat sink dissipates more power generated by future processors. These increases will be seen most likely around the core area and are not as likely to affect the peripheral areas. Passive heat sinks (with ducting) that evacuate the system will most likely not see such temperature increases because the increase in waste heat at the processor is immediately expelled from the system.
- **The thermal performance of the processor heat sink needs to reach 1.0 °C/W or better when it is necessary to dissipate 40 W of power. This assumes a T_{PROC_INLET} of less than or equal to 40 °C and a $T_{JUNCTION}$ specification of 80 °C.**
  This performance value includes processor package, thermal interface material, and heat sink thermal efficiencies. Tower #1 showed an ability to dissipate between 28.3 and 41.9 watts from the processor using the tested active heat sinks and between 24.3 and 25.1 watts from the processor using the tested passive heat sinks (with ducting). The skived active heat sink with a T_{PROC_INLET} less than or equal to 40 °C delivered the maximum power dissipation in all tested cases and met the goal of 40 W.
- **To insure maximum performance of an active heat sink in a FlexATX motherboard-compliant system, the chassis should be designed to at least 2.8 inches above the motherboard (the <u>recommended</u> chassis keep-out height in Area A).**
  Tower #2 showed an ability to dissipate between 25.0 and 27.8 watts using any of the tested heat sinks. This chassis has peripherals located up to the 2.3 inches required chassis keep-out zone detailed in the FlexATX motherboard specification (Area A). When active heat sinks used in this system are 2.1 inches high off the motherboard (the maximum component height allowed in Area A of the specification), there is only a ~0.2-inch clearance above the fan of the active heat sink. This small clearance reduces the performance of the active heat sink by restricting the air path to the fan and by introducing exhausted heated air back into the heat sink. Tower #1 active heat sink performance was superior to Tower #2 because Tower #1 had up to 3.5 inches above the heat sink.

3.4 Desktop #1 Configuration

The Desktop Chassis #1 is a low-profile desktop system designed to use standard building-block components while still maintaining a smaller size with upgradability through multiple low-profile PCI slots. This system uses low-profile power supply #2 that has an internal 40-mm fan (Figure 7). An 80-mm system fan is located on the side of the system near the core area to provide more system airflow and a source to duct airflow over passive heat sinks.

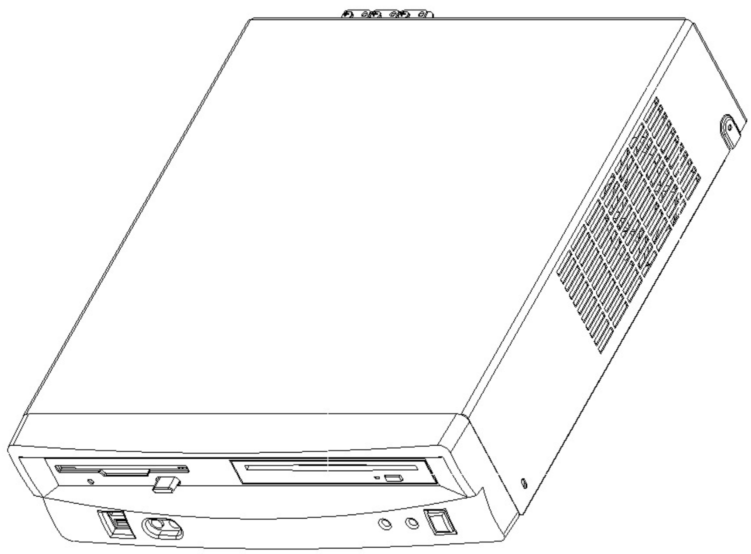


Figure 16. Desktop #1 Configuration

Table 10. Desktop #1 System Features

System Features	Component Description	Notes
Motherboard	FlexATX desktop board	
Processor	Intel Pentium III Processor	Socketed FC-PGA-type package
Chipset	Intel 810E Chipset	
Memory	64 MB SDRAM	One DIMM slot
Add-in card capability	3 PCI cards (slot 5, 6, and 7)*	Low-profile PCI card specification
Storage device(s)	Standard HDD	
	Slot-load CD-ROM	Positioned horizontally
	Standard FDD	
Power supply	Low profile; 40-mm axial fan	Low-profile #2 (Figure 7)
System cooling component(s)	80-mm axial fan	25 mm deep, additional ducting for passive heat sink use
Other	Front USB Front Audio	

* Only slot 5 used during testing.

Figure 17 demonstrates the airflow pattern within the chassis. Desktop #1 was tested with two basic configurations that accommodated either a passive or an active heat sink. In both cases the system fan is an 80-mm high-speed fan.

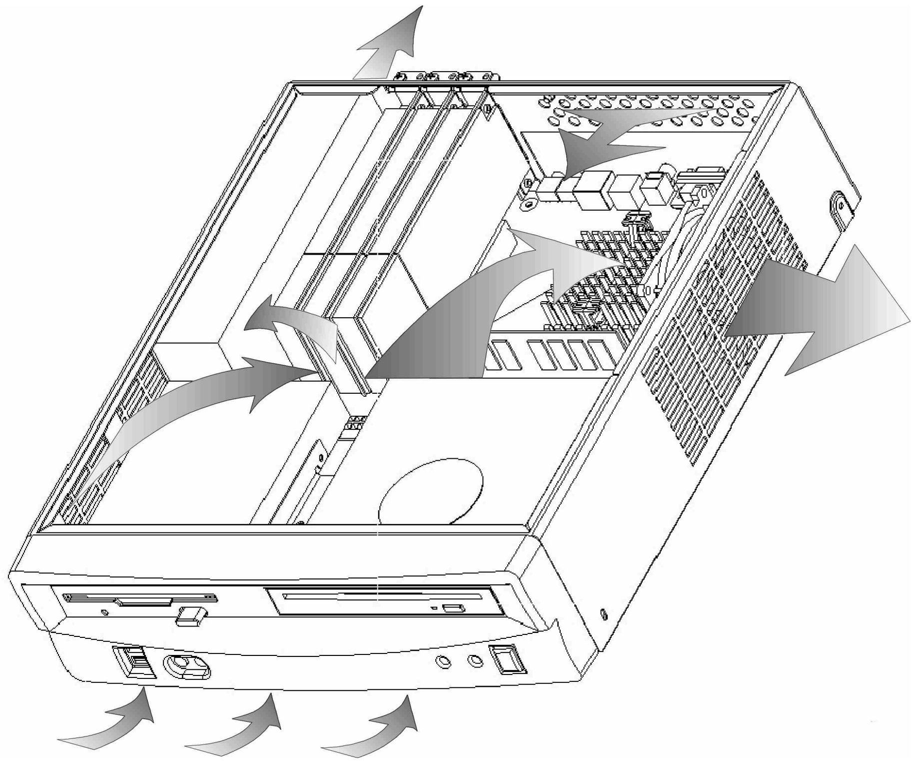


Figure 17. Desktop #1 Airflow Pattern

Venting Parameters:

Inlet sheet-metal venting

Total Area, in^2 [cm^2]: 13.0 [83.9]

Average Free Area Ratio (FAR): 0.45

With active heat sink: The PSU fan and a system fan evacuate the system without a duct.

With passive heat sink: The passive heat sink configurations use the same fan configuration as the active heat sink, but the system fan is ducted over the passive heat sink. The duct is designed to draw air through the passive heat sink, thus improving its thermal performance.

3.4.1 Desktop #1 Results

The results were obtained using each of the four processor heat sink options. Figure 18 details the results of system temperatures and local air velocities. Table 11 lists the performance of each of the four heat sinks used during testing.

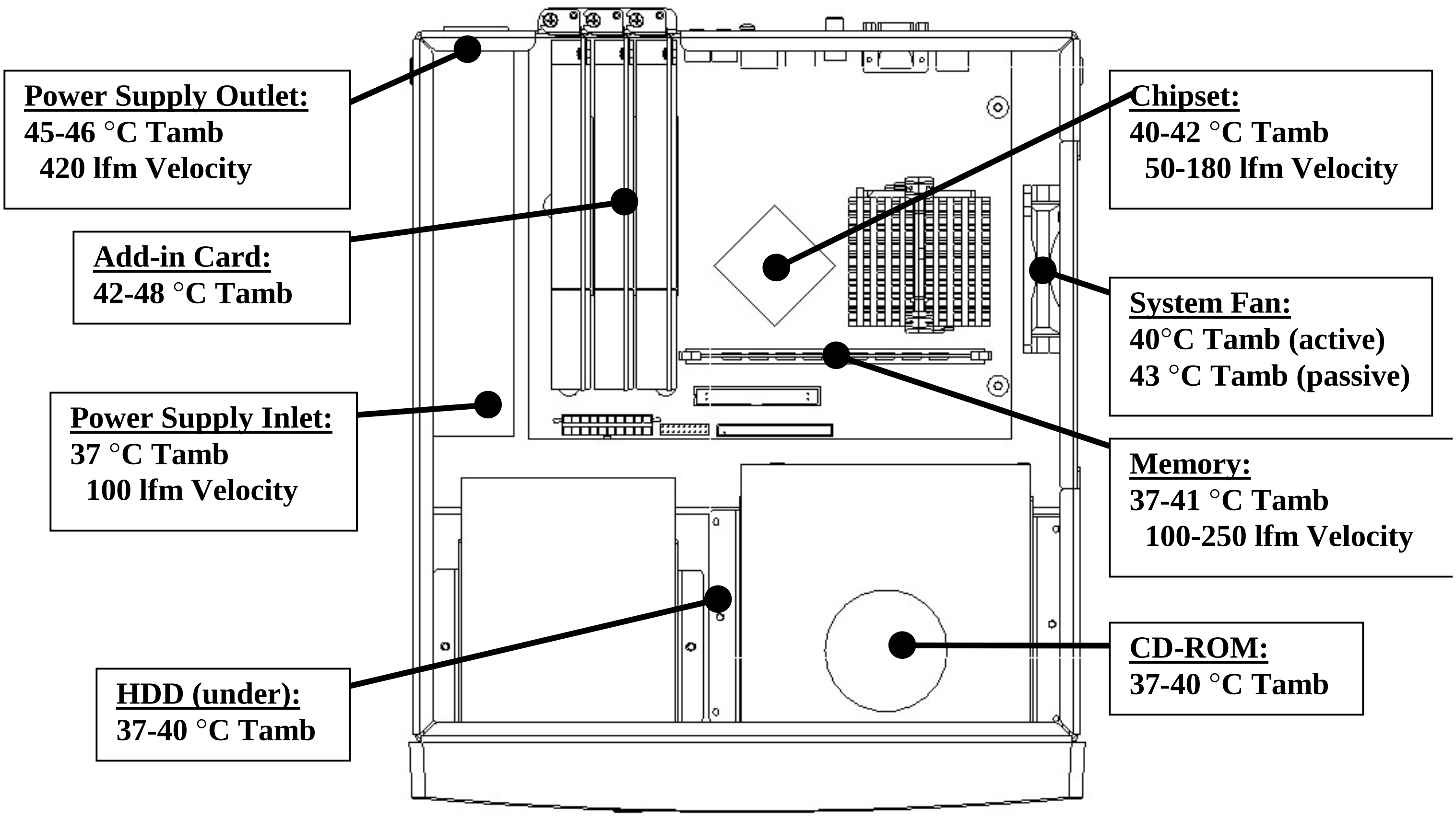


Figure 18. Desktop #1 System Test Results (35 °C external temperature)

Table 11. Desktop #1 System/Processor Heat Sink Performance

Heat sink	Volumetric Airflow (CFM)	T_{PROC_INLET} (°C)	Meets Goal of 40 °C	Heat Sink Performance (°C/W)*	Maximum Processor Dissipation (W)
Skived Active	18.3	39.7	Yes	1.01	**39.9**
Extruded Active	17.4	38.0	Yes	1.52	**27.6**
Skived Passive	13.6**	38.4	Yes	1.40	**29.7**
Extruded Passive	11.1**	39.3	Yes	1.46	**27.9**

* Includes the processor package, interface material, and heat sink. Performance and maximum dissipation values are determined from extrapolated data. Results may differ from those demonstrated.

** Airflow reduction because of tight ducting over heat sink.

3.5 Desktop #2 Configuration

The Desktop Chassis #2 is designed to minimize system size by using the low-profile power supply #2 (Figure 7) located toward the back and right side of the system. An optional 60-mm fan mounting location is included at the left side of the chassis near the low-profile add-in card area.

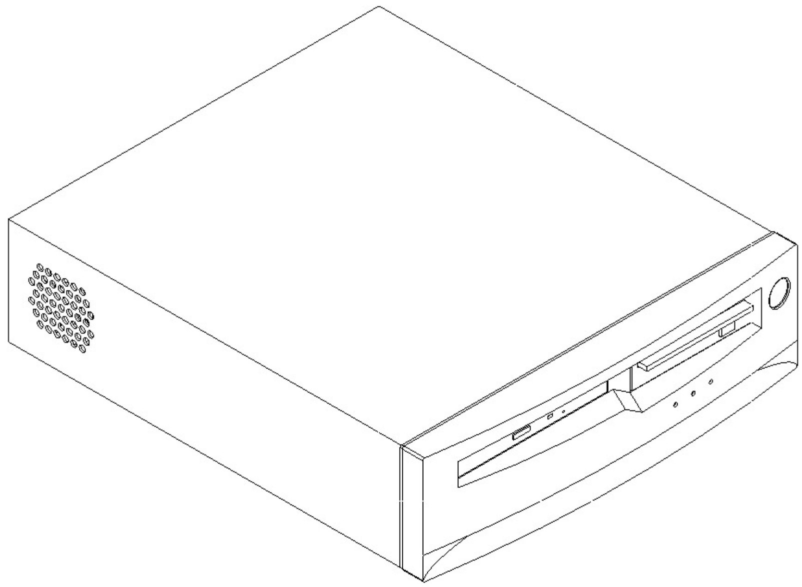


Figure 19. Desktop #2 Configuration

Table 12. Desktop #2 System Features

System Features	Component Description	Notes
Motherboard	FlexATX desktop board	
Processor	Intel Pentium III processor	Socketed FC-PGA-type package
Chipset	Intel 810E Chipset	
Memory	64 MB SDRAM	One DIMM slot
Add-in card capability	3 PCI cards (slot 5, 6, and 7)*	Low-profile PCI card specification
Storage device(s)	Standard HDD	
	Mobile CD-ROM	
	Standard FDD	
Power supply	Low profile; 40-mm axial fan	Low-profile #2 (Figure 7)
System cooling component(s)	60-mm axial fan	Located near add-in card area
Other		

* Only slot 5 used during testing.

Figure 20 demonstrates the airflow pattern that exists within the chassis. Desktop #2 was tested with only an active heat sink and with the optional system fan powered.

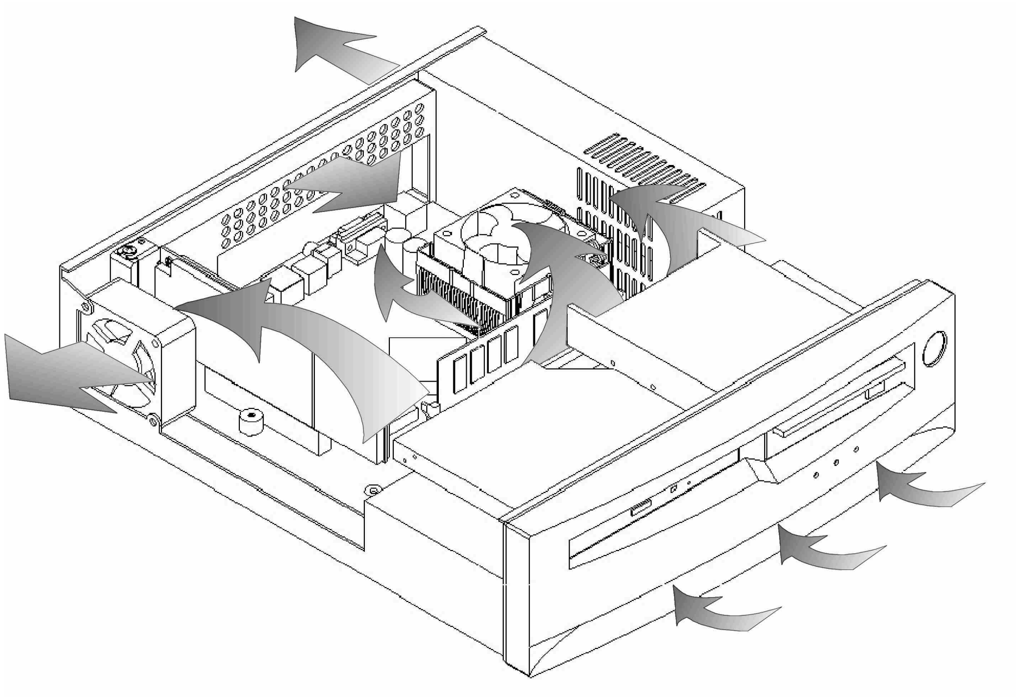


Figure 20. Desktop #2 Airflow Pattern

Venting Parameters:

Inlet sheet-metal venting

Total Area, in^2 [cm^2]: 6.27 [40.5]

Average Free Area Ratio (FAR): 0.30

With active heat sink: With the optional system fan powered.

With passive heat sink: Passive heat sinks proved ineffective because of the low airflow being pulled through the power supply's rather small fan.

3.5.1 Desktop #2 Results

The results were obtained using each of the two active processor heat sink options. Because of the location of the power supply and the low volumetric airflow near the core, passive heat sinks proved unable to meet performance expectations. Figure 21 details the results of system temperatures and local air velocities. Table 13 lists the performance of each of the active heat sinks used during testing.

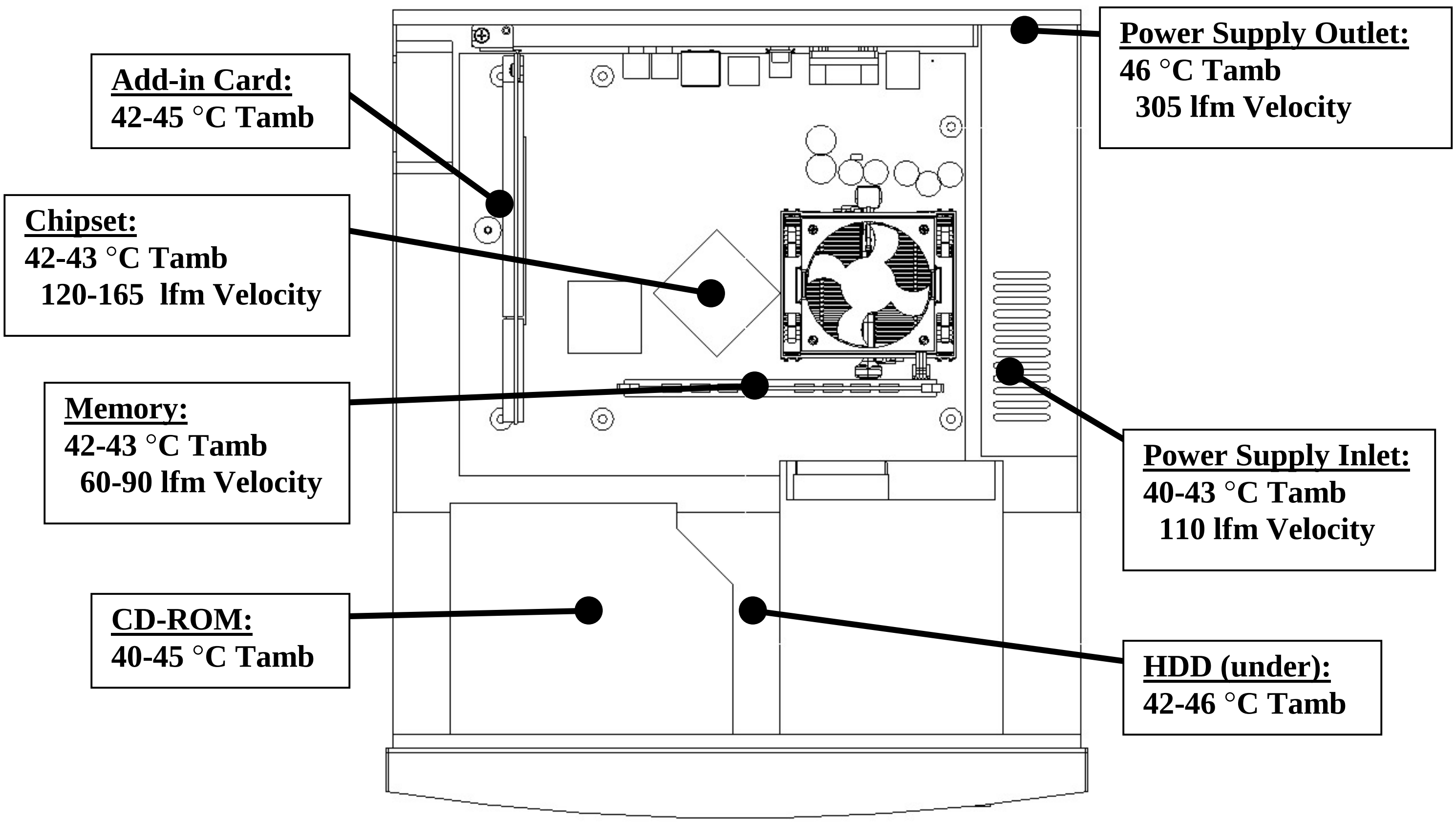


Figure 21. Desktop #2 System Test Results (35 °C external temperature)

Table 13. Desktop #2 System/Processor Heat Sink Performance

Heat sink	Volumetric Airflow (CFM)	T_{PROC_INLET} (°C)	Meets Goal of 40 °C	Heat Sink Performance (°C/W)*	Maximum Processor Dissipation (W)
Skived Active	9.3**	42.4	No	1.13	**33.3**
Extruded Active	8.9***	43.7	No	1.58	**23.0**

* Includes the processor package, interface material, and heat sink. Performance and maximum dissipation values are determined from extrapolated data. Results may differ from those demonstrated.

** 3.9 CFM without 60-mm system fan operating.

*** 3.7 CFM without 60-mm system fan operating.

3.6 Desktop #3 Configuration

The Desktop Chassis #3 is designed to minimize system size by using the low-profile power supply #1 (Figure 6) located toward the back and right of the system. No optional system fans are located in the system.

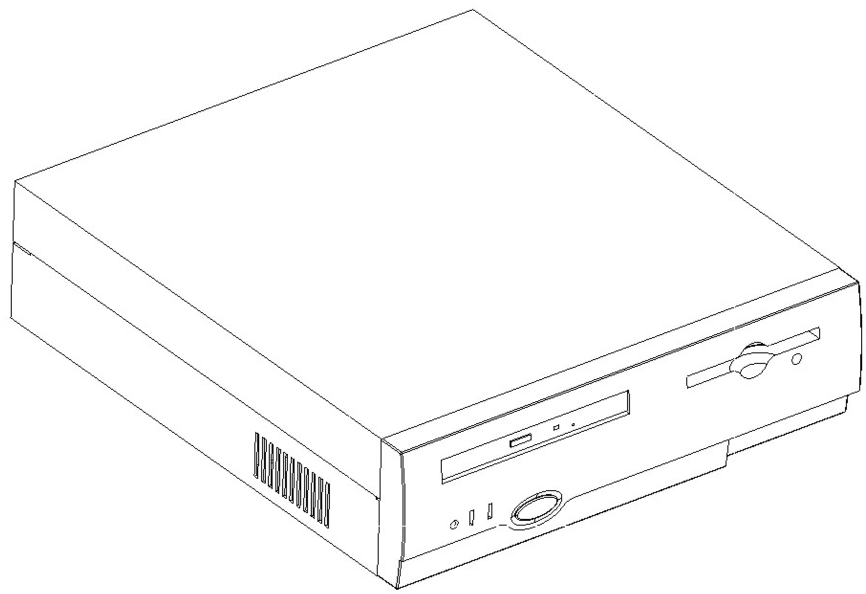


Figure 22. Desktop #3 Configuration

Table 14. Desktop #3 System Features

System Features	Component Description	Notes
Motherboard	FlexATX desktop board	
Processor	Intel Pentium III processor	Socketed FC-PGA-type package
Chipset	Intel 810E Chipset	
Memory	64 MB SDRAM	One DIMM slot
Add-in card capability	3 PCI cards (slot 5, 6, and 7)*	Low-profile PCI card specification
Storage device(s)	Standard HDD	
	Mobile CD-ROM	
	Standard FDD	
Power supply	Low profile; 80-mm axial fan	Low-profile #1 (Figure 6)
System cooling component(s)	None	
Other	Front Audio	

* Only slot 5 used during testing.

Figure 23 demonstrates the airflow pattern that exists within the chassis. Desktop #3 was tested with two basic configurations that accommodated either a passive or an active heat sink. Results were obtained for three of the four processor heat sink options (a skived passive heat sink was not tested).

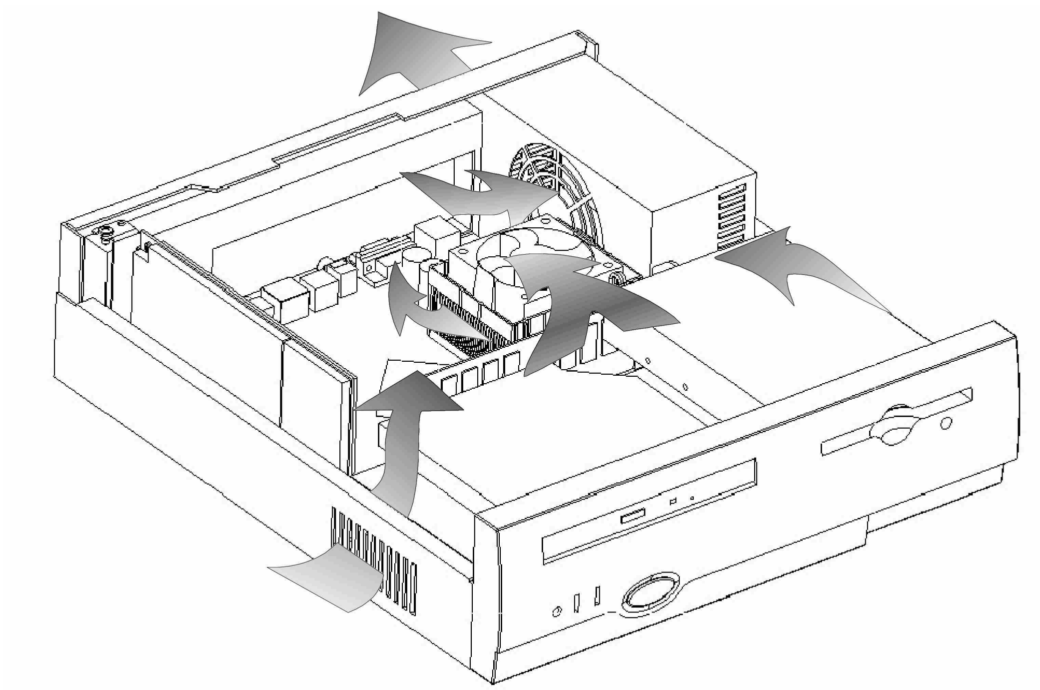


Figure 23. Desktop #3 Airflow Pattern

Venting Parameters:

Inlet sheet-metal venting

Total Area, in^2 [cm^2]: 4.46 [28.8]

Average Free Area Ratio (FAR): 0.33

With active heat sink: With the optional system fan powered.

With passive heat sink: Uses the PSU fan and a duct. The duct is designed to draw air through the passive heat sink, thus improving its thermal performance. (Skived passive heat sink was not tested.)

3.6.1 Desktop #3 Results

The following results were obtained using each of the two active processor heat sinks and the extruded aluminum passive heat sink. Figure 24 details the results of system temperatures and local air velocities. Table 15 lists the performance of each of the heat sinks used during testing.

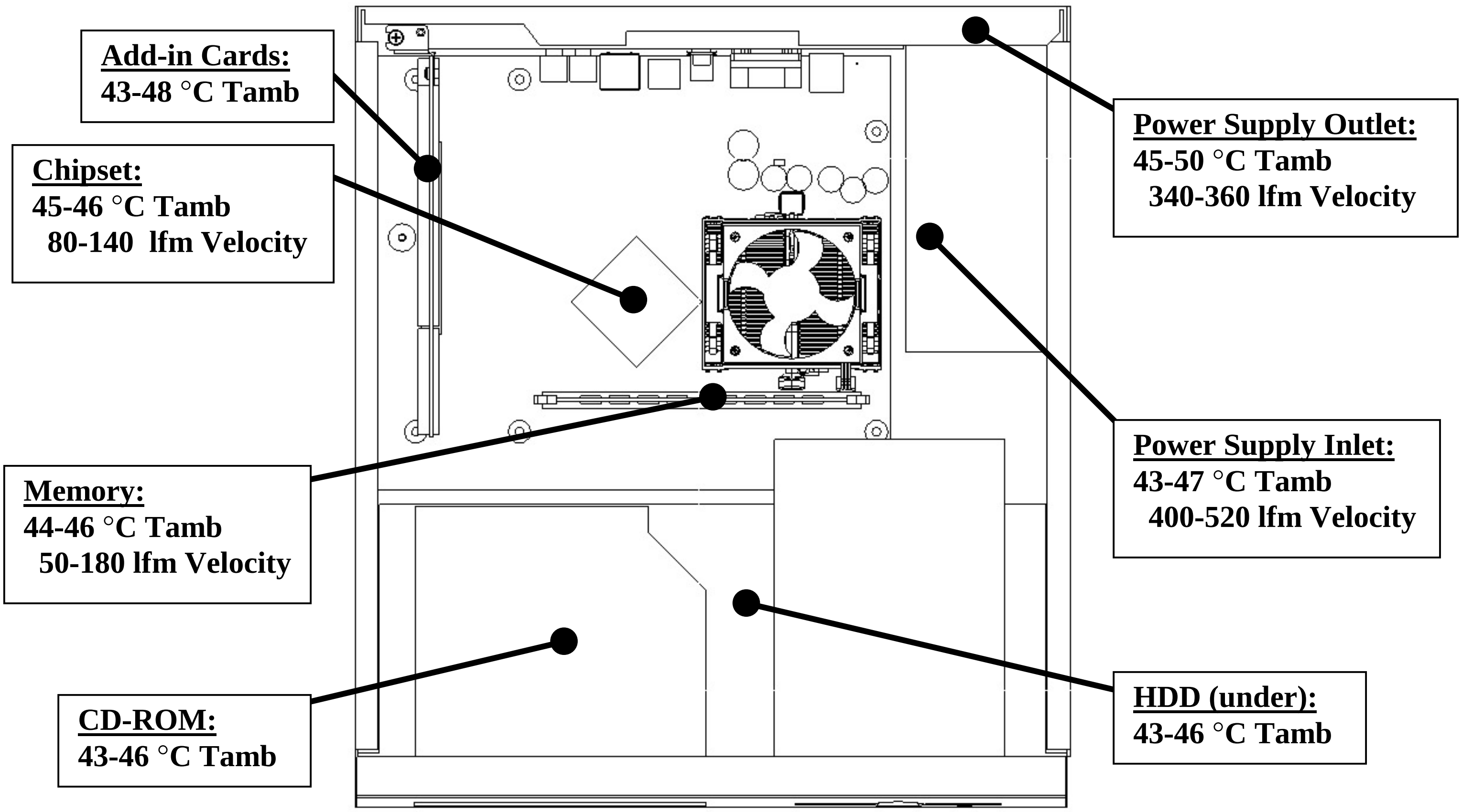


Figure 24. Desktop #3 System Test Results (35 °C external temperature)

Table 15. Desktop #3 System/Processor Heat Sink Performance

Heat sink	Volumetric Airflow (CFM)	T_{PROC_INLET} (°C)	Meets Goal of 40 °C	Heat Sink Performance (°C/W)*	Maximum Processor Dissipation (W)
Skived Active	7.4	42.2	No	1.00	**37.8**
Extruded Active	~7.4**	41.4	No	1.58	**24.4**
Extruded Passive	6.6	45.3	No	1.34	**26.7**

* Includes the processor package, interface material, and heat sink. Performance and maximum dissipation values are determined from extrapolated data. Results may differ from those demonstrated.

** Not tested, assumed to be similar to skived active.

3.7 Desktop Conclusions

Each of the low-profile desktop systems has many unique qualities both positive and negative. All of the low-profile desktop systems use the new low-profile PCI card specification to reduce system size.

- Desktop #1 has a design incorporating low-profile building blocks including a small power supply. The design also allows for a system fan near the core area to improve not only overall system volumetric airflow but also local airflow to the processor.
- Desktop #2 also uses a small power supply and a system fan, but the low-airflow power supply is located near the core, not providing enough airflow in this critical area.
- Desktop #3 uses a relatively small power supply with a larger integrated fan but allows for no secondary system fan. The power supply is located near the core, but the small inlet vent sizes, along with the low airflow through the power supply, may not allow for the necessary system airflow.

Even with the reduced system sizes created through low-profile PCI cards and power supplies seen in these FlexATX systems, there are thermal advantages to certain desktop layouts and cooling approaches:

- **FlexATX low-profile desktop systems show an ability to deliver a T_{PROC_INLET} of 40 °C or better by creating between 11 and 18 CFM of airflow through the system (inlet vent area equal to 13.0 in^2 with 0.45 FAR).**
  Thermally, all FlexATX desktops show relatively low internal ambient temperatures. These temperatures indicate the small amount of power dissipated by the legacy-reduced FlexATX platform relative to other microATX or ATX platforms. Desktop #1 showed the lowest overall internal ambient temperatures because of the constructive use and placement of the system fan near the core area. Desktops #2 and #3 were unable to hit the T_{PROC_INLET} goal of 40 °C because of the low volumetric airflow through these systems (between 6.6 and 9.3 CFM). This is because of the small inlet vent area, small FAR, and low-capacity power supply fans. Note that some internal ambient temperature increases may be seen as the active heat sink dissipates more power generated by future processors. Passive heat sinks with ducting that evacuates the system will most likely not see such temperature increases because increased waste heat is immediately expelled from the system.
- **The thermal performance of the processor heat sink needs to reach 1.0 °C/W or better when it is necessary to dissipate 40 W of power. This assumes a T_{PROC_INLET} of less than or equal to 40 °C and a $T_{JUNCTION}$ specification of 80 °C.**
  This performance value includes processor package, thermal interface material, and heat sink thermal efficiencies. These low-profile desktop systems demonstrated an ability to dissipate between 23.0 and 39.9 watts from the processor using the active heat sinks tested. Desktops #1 and #3 were able to dissipate between 26.7 and 29.7 watts from the processor using passive ducted heat sinks. The limiting factor of heat sink performance in these chassis was the higher value of T_{PROC_INLET} in chassis with insufficient volumetric airflow. The skived active heat sink with a T_{PROC_INLET} less than

or equal to 40 °C delivered the maximum power dissipation in all tested cases and met the goal of 40 W only in Desktop #1.

- **To insure maximum performance of an active heat sink in a FlexATX motherboard-compliant system, the chassis should be designed to the recommended chassis keep-out height of 2.8 inches above the motherboard.** The heat sink performance values remained comparable between these three desktop systems, especially for the active heat sinks. The limitation of future processor power dissipation was based on the T_{PROC_INLET} temperature value and not the heat sink performance or the height over the active heat sink. Because of the height of low-profile cards and power supplies, there is sufficient room over the core to allow the active heat sinks to perform properly.

4. Related Considerations

Thermal solution design requires knowledge of the inherent trade-offs with related performance criteria such as acoustic noise, electromagnetic compatibility, and dynamics. This section highlights some of those trade-offs and their relative significance. For more details, see *microATX Thermal Design Suggestions* (listed in Table 2)

4.1 Acoustics

System thermal and acoustic performance are inherently in contention, because the same fans that generate airflow also create much of the acoustic noise. As an example, running two identical fans at a given speed instead of just one fan typically incurs a +3 dB-A acoustic penalty. With any number of fans, a typical solution is to choose the correct-size/speed fans and incorporate a fan speed control mechanism that varies fan speed with temperature and/or load conditions. If done properly, such an approach can balance the acoustic requirements in benign environments with adequate thermal capability in harsh environments.

4.2 Electromagnetic Compatibility (EMC)

An ideal EMC chassis is a solid metal container with no apertures. 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 will both the thermal power and EM emissions, which in turn drive conflicting requirements for chassis apertures.

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

4.3 Dynamics

As package-level thermal solutions increase in size and weight, they become increasingly difficult to restrain during the vibration and shock rigors of shipping and handling. Potential consequences are dislodged components, cracked PCB traces, increased packaging costs, and dissatisfied customers. Thus, the area of dynamics represents another motivation to balance the thermal solution requirements at both the package <u>and</u> system levels.

5. Conclusions

A well-designed chassis and power supply are key ingredients for any integrator focused on building FlexATX PCs using high-volume, low-cost components. As thermal loads increase, the system-level airflow that the chassis and power supply provide and the manner in which they supply it will critically affect overall costs by either expanding or limiting the choice of off-the-shelf package-level cooling options. As the market makes the transition to faster speeds in smaller computer sizes, special considerations need to be made to produce thermally and mechanically viable FlexATX systems.

The following recommendations can be made to enable the development of FlexATX chassis that will support Intel Pentium III and Celeron processors into the year 2001.

- **A 40 °C ambient temperature (T_{PROC_INLET}) at the active heat sink inlet or approach to the passive heat sink is possible by means of approximately 12-16 CFM through the system under the described loading (recommended inlet vent area for tower chassis, ≥ 8.0 in2, with ≥ 0.45 FAR; recommended inlet vent area for desktop chassis, ≥ 13.0 in2 with ≥ 0.45 FAR)** (see Sections 3.3 and 3.7)**.** Alternative airflow capability (besides the power supply fan) should be added to the system to allow for the delivery of this internal ambient temperature. Chassis that do not provide this environment, risk incompatibility with future package-level solutions and will likely incur additional overall system costs to avoid premature component failures.
- **Heat sink thermal resistance from silicon to ambient needs to reach ~1.0 °C/W or better to meet future power trends** (assumes up to 40 W at 80 °C $T_{JUNCTION}$ specification and 40 °C T_{PROC_INLET}).
- **System designers should provide 2.8 inches (recommended chassis keep-out) above the motherboard in Area A specified in the FlexATX specification so as to not limit the performance of an active heat sink.** To allow for suitable performance from the active heat sink, chassis design must allow for more room above the motherboard than the 2.3 inches required chassis keep-out.

Table 16. System Results

System	T_{PROC_INLET} of 40 °C	Chassis is 2.8” above motherboard in Area A	Comments
Tower #1	✓	✓	Successful.
Tower #2	✓		Low height over active heat sink limits cooling performance.
Desktop #1	✓	✓	Successful.
Desktop #2		✓	Low volumetric airflow produced higher temperatures that limit cooling performance.
Desktop #3		✓	Low volumetric airflow produced higher temperatures that limit cooling performance.

It is thermally beneficial that a typical FlexATX system’s total power consumption (and dissipation) is much less than that of a microATX or ATX system. The power generated by a FlexATX system is also mostly localized to the core components, especially at the processor. Unfortunately, the system size is much smaller, not allowing much space for alternative cooling approaches or system enhancements. Proper system design must provide focused cool airflow to the core components in times of rigorous thermal loading. The combination of proper venting, fan selection and placement, and heat sink selection should allow the correct thermal environment in a system.

6. Glossary

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.
FAR (Free Area Ratio)	Ratio of open area to total area. Most commonly used in describing venting.
FC-PGA (flip chip—pin grid array)	Silicon integrated circuit packaging technique.
motherboard core	The region of a motherboard layout containing the processor, chipset, memory, voltage regulator(s), and other primary logic components.
$T_{JUNCTION}$	The temperature of the microprocessor silicon. Refer to thermal application notes provided at http://www.intel.com/ to determine proper data collection of this value.
T_{PROC_INLET}	The temperature of air at the inlet to the processor package-level thermal solution.
package-level thermal solution	A physical mechanism for transferring heat energy from an integrated circuit package to its surrounding environment. Heat sinks (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.
volumetric airflow	The volume rate of airflow measured in cubic feet per minute (CFM).